

## Isotopic and geochemical data of the Pingstaberg Mo-bearing granite in Bergslagen, South Central Sweden



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### Abstract

An isotopic and geochemical investigation of the Pingstaberg Mo-occurrence in the Bergslagen region, south-central Sweden, has been undertaken. The mineralization is of an intra-granitic type, and is situated within an undeformed granite of a minimum melt composition. In comparison with a 'normal granite', the mineralized part of the Pingstaberg granite is enriched in Y, Nb, Rb, U, Th and HREE, and depleted in Zn, Cu, Zr, Sr and Ba. Several of its characteristic isotopic and geochemical features are probably due to the Mo-mineralizing solutions, and these are likely also to have caused the strongly corroded structure of the analyzed zircons. As a result the U-Pb zircon and Rb-Sr whole-rock isotopic systems have been affected in various ways. The achieved U-Pb zircon age of  $1781 \pm 46$  Ma is, however, considered to be essentially undisturbed, and this age is considered to represent both the time of granite emplacement and the mineralization episode. The Rb-Sr whole rock age of 1.53 Ga, on the other hand, has been reset and is interpreted as reflecting a post-crystallization hydrothermal event. The results presented in this study suggest that the Pingstaberg granite was formed at a late-orogenic stage (1.80–1.75 Ga) of the Svecokarelian orogeny.

### Introduction

Mo-mineralizations are known from various Proterozoic areas in Sweden, occurring as molybdenite impregnations hosted by aplites and pegmatites or as contact-metasomatic skarn mineralizations (Hübner, 1971; Walser & Einarsson, 1982; Hellingwerf & Baker, 1985 and Öhlander, 1986). Mo-enrichments are often spatially associated with highly evolved granites and the generally accepted idea is that Mo and other incompatible elements have accumulated at the roof zone of rising granitic

cupolas (e.g. Westra & Keith, 1981; Öhlander & Nisca, 1985). The mineralization in the Pingstaberg granite is intra-granitic, using the terminology of Hellingwerf & Baker (1985), and one of the most important ones in Bergslagen.

In recent years several papers about the mineralogy, geochemistry and genetic relationships of Mo-mineralizations in western Bergslagen have been published (Hellingwerf & Baker, 1985; Baker et al., 1987; Baker & Hellingwerf (in press, a, b)). The traditional view, as first expressed by Magnusson (1940), is that the major Mo-occurrences in

Sweden are genetically linked to granites intruding at a late stage (ca 1.80–1.75 Ga ago) during the Svecokarelian orogenic cycle. However, this opinion is not unequivocal and arguments have been raised for a relation to the older generation of Svecokarelian granitoids (Lindroth, 1922; Hellingwerf & Baker, 1985; Öhlander, 1986). From a survey of skarn and granite/pegmatite related Mo-W occurrences in south-western Bergslagen, Hellingwerf & Baker (1985) suggested, on basis of field and petrological relationships, that these mineralizations are genetically related to early orogenic granites. Öhlander (1986) argued that Mo-deposits in northern Sweden are associated with early orogenic granites (between 1.89–1.85 Ga old) intruding in supracrustal formations.

However, no intrusions actually associated with major Mo-occurrences in Sweden have been dated and the most important problem to address in this study is unravelling the genetic relationship between the molybdenite mineralization of the Pingstabergr massif and the geological development of the area. Another question of interest is whether the mineralizing solutions have had any effect on the U-Pb and Rb-Sr isotopic systems of the granite or not. In order to provide basic data for a discussion, both isotopic and geochemical analyses have been undertaken. The isotopic part includes a U-Pb dating of zircons sampled from two localities in the massif and a Rb-Sr study of whole rock samples.

### Geological setting

The Pingstabergr granite is a small semi-circular body (1.0–1.5 km<sup>2</sup>), situated roughly three kilometers NW of lake Hörken in Bergslagen, south-central Sweden (Fig. 1). In a regional context, a volcano pile (ca 1.9 Ga old), metamorphosed in lower amphibolite facies, with meta-tuffs and meta-tuffites forms a steeply inclined fold structure which opens to the west (LKAB Prospektering AB, internal report 1976). Granites, presumably intruded during both an early and a late tectonic stage, occupy large areas. In addition, mafic dykes are common, cross-cutting the early orogenic intrusions

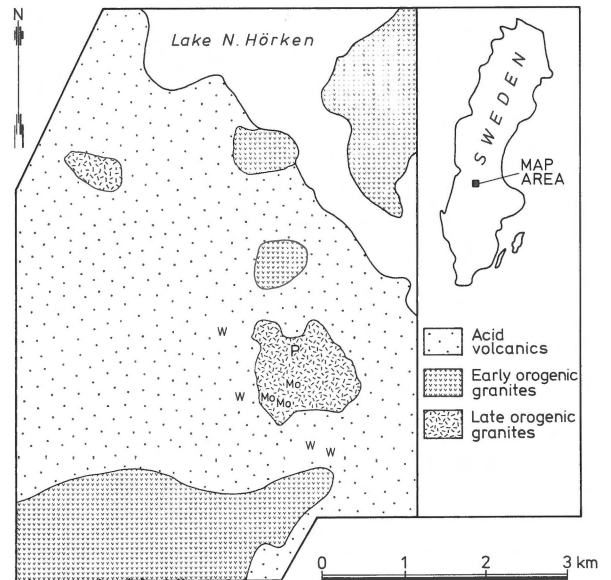


Fig. 1. Geological sketch-map of the area around the Pingstabergr intrusion (marked with P). Symbols W and Mo denote zones enriched in tungsten (W) and molybdenum (Mo) respectively.

but are themselves cut by the late orogenic intrusions.

The Pingstabergr granite is a massive, fine to medium-grained granite, which occasionally (along the northern contact) shows a weak foliation. It has a red colour grading into more greyish in the south-western mineralized part (ca 0.25 km<sup>2</sup>) of the intrusion. The texture is even-grained with a grain size between 0.1 and 3 mm. Occasionally towards the contact the rock becomes fine-grained, suggestive of a chilled margin. Xenoliths are rare. Apophyses of aplites and pegmatites can be found quite distant from the central intrusion. Dominant minerals of the granite are quartz, microcline, oligoclase and fine-grained biotite. The opaques include molybdenite, pyrrhothite, magnetite, and more rarely chalcopyrite. Epidote and chlorite sometimes appear as joint fillings. The biotite is often chloritized. Sericitization of feldspars is a very marked feature and ranges from a slight alteration to an almost complete sericitization. It is significant that there is no clear distinction, with regard to mineralogy (except for the presence of ore minerals) and alteration features, between the mineral-

ized and the non-mineralized part of the intrusion.

Locally, e.g. in the MoS<sub>2</sub> rich zones, fluorite and iron minerals (pyrite and magnetite) are abundant, and subordinate scheelite may also be present. The concentration of fluorite seems to increase with increasing metal grade. Mirolitic cavities and druses are common features in association with the mineralization. MoS<sub>2</sub>, present in erratically distributed mineralized zones, appears as blady aggregates, in the form of single grains or as joint fillings in feldspar and quartz. The tectonic control of the MoS<sub>2</sub> zones appears to be strong, and major faults occur mainly along two directions, N 60° E and

N65° W. Joint systems are frequently developed and the mineralized zones are concentrated into these systems and to pegmatitic zones. Molybdenite and scheelite mineralizations are also known to occur in nearby felsic supracrustals.

### Sample descriptions

Zircons have been separated from two different samples (77186 and 84618) taken from the southwestern mineralized part of the intrusion. One (84618) is a drill core sample (0–10 m below the

Table 1. Chemical analyses of the Pingstaberg granite.

Sample no.		84601	84602	84603	84618	86201
SiO <sub>2</sub>	wt. %	73.3	73.4	73.9	74.9	74.8
TiO <sub>2</sub>	wt. %	0.12	0.13	0.13	0.14	0.15
Al <sub>2</sub> O <sub>3</sub>	wt. %	13.3	13.1	14.0	14.0	13.4
Fe <sub>2</sub> O <sub>3</sub> -tot	wt. %	1.77	1.46	1.42	1.58	1.86
MnO	wt. %	0.03	0.02	0.02	0.02	0.03
MgO	wt. %	0.26	0.23	0.21	0.22	0.21
CaO	wt. %	0.74	0.69	0.93	0.79	0.97
Na <sub>2</sub> O	wt. %	3.32	3.19	3.40	3.49	3.38
K <sub>2</sub> O	wt. %	4.84	4.72	4.48	5.11	5.10
Ba	ppm	406	376	377	423	589
Rb	ppm	285	330	304	327	—
Sr	ppm	55	51	59	61	—
Cu	ppm	2	2	3	8	—
Zn	ppm	13	15	8	14	—
Pb	ppm	45	30	40	34	—
Zr	ppm	145	134	140	139	—
Y	ppm	145	145	111	69	—
Nb	ppm	29	30	35	31	—
Ga	ppm	18	18	19	19	—
Mo	ppm	<1	<1	16	13	—
Th	ppm	37	34	35	34	—
U	ppm	32	28	30	30	—
La	ppm	45.4	42.9	36.2	35.4	—
Ce	ppm	92.4	87.1	80.2	73.6	—
Nd	ppm	45.8	41.9	37.1	35.4	—
Sm	ppm	13.9	8.80	7.42	6.55	—
Eu	ppm	0.67	0.64	0.57	0.51	—
Gd	ppm	11.5	11.2	9.62	7.55	—
Dy	ppm	16.6	19.1	14.7	10.8	—
Ho	ppm	3.55	4.31	3.50	2.32	—
Er	ppm	12.9	14.2	11.9	7.72	—
Yb	ppm	14.2	14.2	13.1	9.27	—
Lu	ppm	1.97	2.74	2.42	1.28	—

— = Not analysed.

earth surface), the other (77186) is from a test trench on the surface. Chemical analyses for the drill core sample are given in Table 1. The zircons from these two samples, referred to as the outcrop and drill core sample respectively, have some features in common. The zircons are jointed and severely corroded, especially those of the drill core sample. Nevertheless a prismatic habitus is indicated. Most of the zircons are non-transparent, while in some grains a concentric zoning is evident. No cores are visible, although the low transparency obstructs the identification of possible cores. Most of the separated fractions (cf. Table 2) are found to be magnetic at 1.6 A (Franz magnetic separator, 5° tilt).

Zircons have been extracted using standard techniques and were digested according to the 'bomb technique' (Krogh, 1973). The uranium samples were run on an AVCO 901 A mass spectrometer while a Finnigan MAT 261 was used for the lead runs. The U-Pb zircon results, corrected for instrumental fractionation effects which were quantified after repeated runs of the NBS 981 Pb standard, are given in Table 2 and plotted in Fig. 4. The intercept ages presented, assuming an episodic lead loss model, were calculated according to Ludwig (1980) using the decay constants recommended in Steiger & Jäger (1977). Errors are given at the two-sigma level.

Samples for the Rb-Sr investigation were taken from outcrops within the mineralized part of the

Pingstaber intrusion. Eight whole rock samples were analysed with XRF for their Rb/Sr ratios and approximate Rb and Sr contents (Table 2). The Sr analytical work followed standard routines and the isotopic composition of Sr was measured on the AVCO 901 A spectrometer, and the obtained  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios were normalized to  $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ . The estimated standard deviations of the measured ratios is generally less than 0.6% and 0.05% for the  $^{87}\text{Rb}/^{86}\text{Sr}$  and the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios respectively. The age calculations followed the method of Williamson (1968) utilizing the decay constants in Steiger & Jäger (1977)

### Geochemistry

*Analytical methods.* In five whole rock samples from the mineralized area, the major elements, except for  $\text{K}_2\text{O}$ , and Ba were analysed at Luleå University by emission spectroscopy using an inductively coupled plasma (ICP) as the excitation source.  $\text{K}_2\text{O}$  was analysed at Luleå University using flame emission. Rb, Sr, Y, Nb, Ga, Cu, Zn, Pb, Mo, U and Th were analysed in four samples by energy dispersive XRF at the Open University, Milton Keynes, England. The REE were concentrated in these samples by a cation exchange procedure, and then analysed by ICP-spectroscopy (Thompson & Walsh, 1983) at Luleå University.

Table 2. U-Pb data for zircons from the Pingstaber granite intrusion.

No <sup>a</sup>	Fractions <sup>b</sup> in $\mu\text{m}$	Concentration (ppm)			U/Pb ratios <sup>c</sup>		U/Pb ages, in Ma		
		U	Pb <sub>rad</sub>	Pb <sub>comm</sub>	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$
1	45–74 m	1308	232	7	0.16967	2.3900	1010	1240	1664
2	>150 m + nm	1546	290	12	0.18456	2.5960	1092	1300	1661
3	74–106 m	1214	234	9	0.18692	2.6649	1105	1319	1686
4	75–105 m	1896	387	44	0.19656	2.7551	1157	1344	1655
5	>105 m + nm	1593	352	30	0.21495	3.1051	1255	1434	1711
6	<45 m + nm	1875	452	40	0.22779	3.2796	1322	1476	1705
7	75–105 nm	1498	358	30	0.23110	3.3376	1340	1490	1710
8	45–74 nm	1411	388	24	0.26139	3.8882	1497	1611	1764

<sup>a</sup> 1–3 = drill core sample (84618), 4–8 = outcrop sample (77186); <sup>b</sup> m = magnetic, nm = non-magnetic fraction at 1.6 A; <sup>c</sup> blank and common Pb corrected.

**Major elements.** The chemical analyses are shown in Table 1. The Pingstabergr granite is a SiO<sub>2</sub> rich granite, and has an average K<sub>2</sub>O/Na<sub>2</sub>O ratio of 1.45 (standard deviation 0.07). As it is a leucocratic granite the contents of Fe<sub>2</sub>O<sub>3</sub> (total Fe as Fe<sub>2</sub>O<sub>3</sub>), TiO<sub>2</sub>, MnO, MgO and CaO are low. Major elements are not useful to discriminate between mineralized and unmineralized granites in Bergslagen (Baker & Hellingwerf, in press, a). On the normative albite-orthoclase-quartz plot (Fig. 2), the samples lie within or close to the field where most granites concentrate (Tuttle & Bowen, 1958). They are slightly more potassic than the composition corresponding to the isobaric minima or ternary eutectic at various pressures. If the composition of the Pingstabergr granite is primary and represents the melt composition at the time of intrusion, this indicates that the melt was not saturated with water (Tuttle & Bowen, 1958).

The Pingstabergr granite analyses presented by Drake (1981) are included in Fig. 2. They confirm the character of the Pingstabergr granite, but scatter considerably. There is no obvious difference between the mineralized and unmineralized parts of the intrusion. Two samples show an extreme K-enrichment and contain 46 and 144 ppm Mo, respectively. In the two other samples from Pingstabergr, containing 3035 and 607 ppm Mo, an even more extreme K-enrichment (10.29 and 10.65 wt.% K<sub>2</sub>O, respectively) has been found (Baker & Hellingwerf, in press, a). Such compositions are not primary features of rocks crystallized from a melt, but are probably caused by hydrothermal activity in association with the Mo-mineralization.

**Trace elements.** In comparison with an 'average granite' (e.g. Vinogradov, 1962), the Pingstabergr granite (Table 1) has higher contents of Y, Nb, Rb, Pb, U and Th; and lower contents of Zr, Cu, Zn, Ba and Sr. This is in agreement with enrichment/depletion trends reported for a variety of granites associated with Mo- and W-occurrences in Bergslagen (Baker & Hellingwerf, in press, a). The content of Ga is approximately equal to the 'average granite' (20 ppm). The two samples with 13 and 16 ppm Mo probably contain minor amounts of molybdenite, but the non-mineralised samples

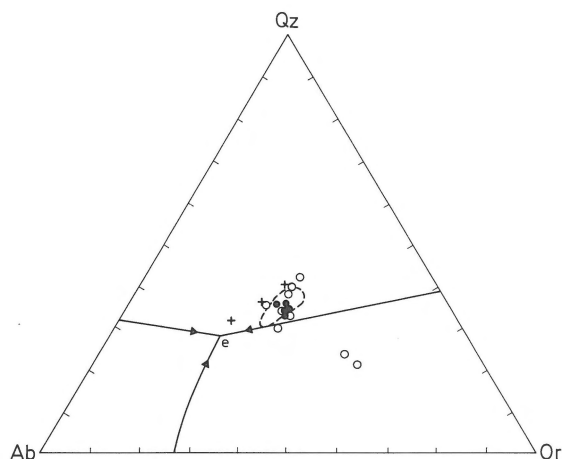


Fig. 2. Normative quartz (Qz) - Albite (Ab) - Orthoclase (Or) plot. Symbol e indicates the ternary eutectic point at a confining pressure of 5000 bar. Isobaric minima at pressures 3000, 1000 and 500 bar are indicated with crosses (After Tuttle & Bowen 1958). Over 90% of the more than 500 granites analysed in Tuttle & Bowen's study fell within the encircled area. Dots = the Pingstabergr samples analysed in this study. Open circles = the Pingstabergr samples analysed by Drake (1981).

have low contents of Mo (<1 ppm). Particularly the contents of U (8 to 9.1 times the content in the 'average granite' and Y (2.1 to 4.3 times the average content) are remarkably high. The high contents of Y and Nb clearly place the analysed samples in the 'within-plate' granite field of Pearce et al. (1984).

**Rare earth elements.** The chondrite normalized REE patterns are displayed in Fig. 3. As could be expected from the high Y abundances, the Pingstabergr granite has high contents of the HREE. Lu range from 40 to 85 times chondrite. The contents of LREE (La range between 114 and 146 times chondrite) are similar to those in unmineralized potassic granites (Cullers & Graf, 1984). The Pingstabergr samples, however, have anomalously large negative Eu-anomalies and are characterized by almost flat REE patterns, features considered to be characteristic of granites associated with Mo- and W-occurrences in Bergslagen (Baker et al., 1987; Baker & Hellingwerf, in press, b).

F<sup>-</sup> and/or CO<sub>3</sub><sup>2-</sup> complexes are often suggested to be important Mo-carriers in mineralizing fluids

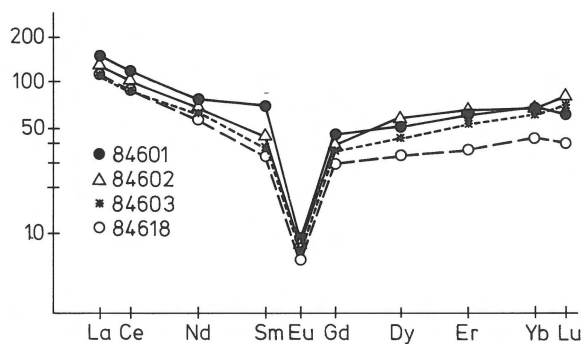


Fig. 3. Chondrite normalised REE patterns of the Pingstabergr granite. Normalising values are taken from Boynton (1984). Sample numbers correspond to those in Table 1.

associated with granites, and the stability of both REE-fluorine and REE-carbonate complexes increase from La to Lu (e.g. Taylor & Fryer, 1983). The Pingstabergr granite is rather fluorite-rich, and it appears probable that some of its chemical characteristics was caused by aqueous  $F^-$  and possibly  $CO_3^{2-}$  rich fluids developed in the apical parts of the highly evolved intrusion. This is supported by the occurrence of pegmatites, genetically associated with the Pingstabergr granite, in the vicinity of the intrusion. The Pingstabergr granite is U-rich, and transport and deposition of U in hydrothermal fluids is thought to be mainly due to carbonate complexing (Taylor & Fryer, 1983). Baker & Hellingwerf (in press, a) obtained similar REE patterns as those in this study for two Pingstabergr samples rich in  $K_2O$  and Mo as described above. Their samples, however, have lower contents of the LREE. These anomalously  $K_2O$ -rich samples deviate more from the typical granitic LREE enriched pattern than our Pingstabergr samples, which support the idea that the HREE enrichment was caused by a late-stage F-rich aqueous phase. Furthermore, the Yb content of fluorite from the Pingstabergr is as high as 47 ppm (Öhlander & Billström, unpublished results).

**Isotopic results.** Analytical U-Pb data for the zircons are summarized in Table 2 and Fig. 4. The two sample sets (drill core and outcrop data) define discrete groups in terms of uranium and lead contents and age discordance pattern. Zircons from

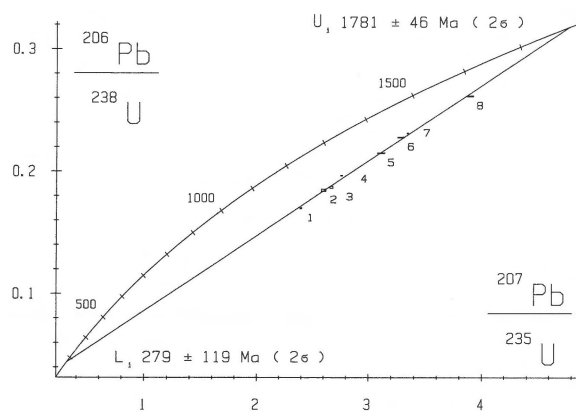


Fig. 4. U-Pb zircon data plotted in a concordia diagram. Note that the age 1781 Ma, given by a model 2 solution (see text), is preferred.

the outcrop sample have somewhat lower uranium and lead concentrations in comparison with the drill core sample, while the latter zircon fractions are more discordant. As a consequence of the significant scatter, probably of a geological nature, (note the high MSWD values) no perfect discordia line can be defined. If the two data sets are pooled together, using a model where all scatter is due to analytical errors (model 1), the resulting eight-point discordia yields intercept ages of ca  $1741 \pm 4$  and  $169 \pm 10$  Ma, respectively. On the other hand, for a model solution assuming equally weighted points with uncorrelated errors (model 2), a regression of the same fractions give an upper intercept age of around  $1781 \pm 46$  Ma, and a lower intersection at  $279 \pm 119$  Ma. Similar ages, between 1740

Table 3. Analytical Rb-Sr data for whole rock samples of the Pingstabergr granite.

Sample	Rb/Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
77186	360/75	13.999	1.05395
78148	365/75	14.237	1.05578
77188	355/65	15.833	1.09372
77190	355/60	17.923	1.13626
77189	375/65	17.960	1.15005
78149	410/50	25.831	1.28971
78150	315/25	37.556	1.59085
77187	355/25	43.121	1.68125

and 1800 Ma, will be achieved if the two data sets are regressed separately.

The Rb-Sr whole-rock samples are characterized by high  $^{87}\text{Rb}/^{86}\text{Sr}$  ratios, ranging from c. 14 to 43 (Table 3). When the data are plotted in an isochron diagram (Fig. 5), this results in an errorchron with a MSWD value of 47.5. A regression of all eight samples gives an age of  $1529 \pm 12$  Ma, with a high initial Sr isotope ratio of 0.7450. Added to Fig. 5 is a reference line corresponding to an age of 1755 Ma and an initial Sr isotope ratio of 0.706. This age and initial Sr isotope composition have been obtained for two late-orogenic granites of Malingsbo type (Fjällberg and Enkullen), situated ca 10 km further to northeast (Åberg & Bjurstedt, 1986).

## Discussion

### *U-Pb data*

An interpretation of the zircon data representing the mineralized zone at Pingstabergr requires some caution, considering the zircon habitus and the non-perfect fit to a discordia line. The nature of the zircons, corroded structure with frequent cracks, suggests that secondary disturbances may have affected the U-Pb system. The question therefore arises to what extent the obtained intercept ages are reliable. Recently, several new U-Pb zircon ages have been presented for rocks in south-central Sweden, which have changed the traditional picture of the geological evolution of the area. These age data suggest that granitoids formed essentially during two major periods of the Svecokarelian orogen, at c. 1.89–1.85 and 1.80–1.76 Ga respectively (Wilson et al., 1985; Gaal & Gorbatshev, 1987; Patchett et al., 1987; Jarl & Johansson, 1987).

The present distribution of zircon data points, which show a scatter in excess of the analytical error, is suggested to be due to a two-stage development. Following closely upon the granite emplacement was a period of epigenetic molybdenite mineralization. This opinion is based on the observations made in the Pingstabergr area (molybdenite occurring as fracture fillings and a clear tectonic control of the mineralization). Tectonic movements occurring at a late to post-magmatic stage

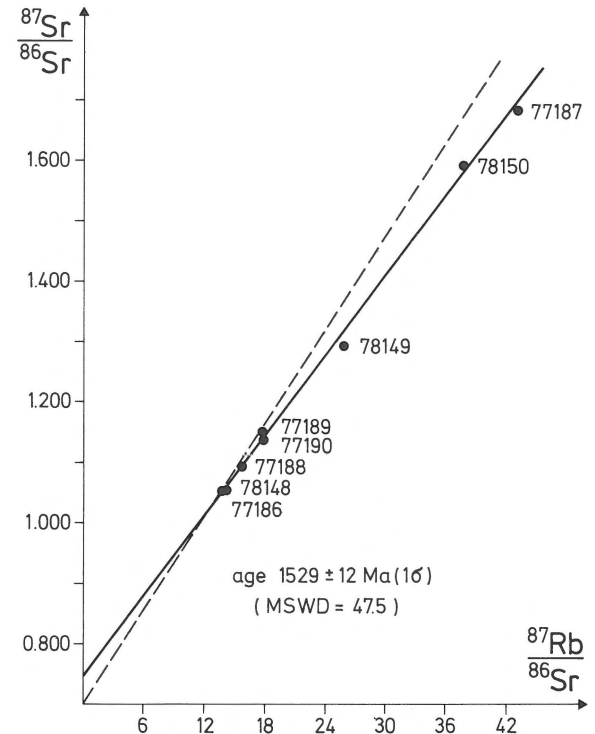


Fig. 5. Rb-Sr whole rock data shown for the Pingstabergr samples. Also given is a reference isochron (stippled line) corresponding to an age of 1755 Ma.

guided the paths for mineralizing solutions which probably were derived from the cooling Pingstabergr intrusion itself (cf. Stein & Hannah, 1985). These solutions, rich in volatiles, caused a complex history of dissolution and overgrowth processes affecting the zircons. Only the outer parts of the zircons were probably affected, and since only a short time had elapsed since intrusion the age given by the U-Pb system was not severely disturbed.

However, the first recrystallization episode may have paved the way for the second type of event, which is thought to be a more recent Pb-loss occurring in Phanerozoic time, when the rocks were exposed to weathering. The first recrystallization event, connected to cracking of zircon grains and the attack of etching fluorine-rich solutions already ca 1.78 Ga, would govern a more continuous Pb loss during a prolonged part of the Phanerozoic. This type of non-instantaneous Pb loss process, triggered by the fairly high uranium content of

zircon, is likely to be responsible for the major part of the analytical scatter observed. Possibly the enhanced uranium content of the granite and the zircon phase, as well as the high common Pb content of zircon, are likely to emanate from a final enrichment during a late stage of granite crystallization.

The non-perfect fit to the discordia line is, according to the preceding discussion, considered to be induced by geological processes. Since such type of non-analytical error is likely to differ in magnitude for individual zircon populations, the model 2 regression (and the age 1781 Ma) should be preferred. Probably, the 1781 Ma age approximates also the time of mineralization, even if this view cannot be constrained by isotopic data. Åberg & Bjurstedt (1986) reported a U-Pb zircon age of 1.75 Ga for two unmineralized granites in western Bergslagen, Fjällberg and Enkullen, of a type similar to the Pingstabergr granite. We therefore find it reasonable to conclude that the age of the Pingstabergr granite falls in the range typifying the late orogenic granites (1.80–1.76 Ga old). Since the Pingstabergr granite has not suffered any major metamorphic or deformative event, we can rule out the possibility that the linearity of the zircon data is due to a complete recrystallization event at 1.78 Ga.

#### *The significance of the Rb-Sr isotopic data*

The data for the Pingstabergr whole-rock samples, taken from the mineralized zone, result in an isochron and the age of c. 1529 Ma is clearly not a primary intrusion age. Several studies have shown that Rb-Sr ages, even for rocks in low metamorphosed terrains, often are lowered by as much as 10–20% in relation to an U-Pb zircon age (Van Schmus & Bickford, 1976; Welin, 1983; Åberg & Persson, 1984; Wilson et al., 1985). Possibly the age discrepancy results from a low temperature re-equilibration of the Rb-Sr isotopic system as an effect of chemical alteration of Rb-Sr bearing minerals (cf. Welin, 1983). It has been shown that secondary disturbances can cause a rotation of a Rb-Sr isochron, causing a lowered age and a raised initial Sr isotope ratio (Brooks, 1968; Page, 1978). The obtained 1529 Ma age for the Pingstabergr

granite, being ca 250 Ma lower than the corresponding zircon age and the high initial Sr isotope ratio of 0.7450 clearly suggest that secondary processes have disturbed the closed-system behaviour of the Rb-Sr whole-rock isotope system.

The Rb-Sr ages published for Svecokarelian granitoids (zircon dated to 1.75–1.89 Ga) scatter in an interval between 1.5–1.8 Ga. This age range indicates an open-system behaviour of the Rb-Sr isotopic system, which however does not appear to proceed in a completely random way with regard to the tendency for fitness to a Rb-Sr isochron. It has, however, not been possible to relate any Rb-Sr whole rock age to a specific geological event of known age. Possibly, a calculated Rb-Sr age is controlled by the degree and timing of the chemical alteration affecting a rock. In the case of the Pingstabergr granite, abundant fracture zones have been developed in the mineralized area and furthermore Rb-rich minerals (K-feldspar and biotite) are altered. This specific situation may have enabled a mobilization of radiogenic  $^{87}\text{Sr}$  within the fractured mineralized part of the intrusion, causing a resetting of the Rb-Sr isotopic system at approximately 1.53 Ga, in connection with a period of renewed hydrothermal activity. Epidote and chlorite, occurring along distinct joint planes, may be the visible products of this process.

#### *The provenance of the Pingstabergr granite*

Chemical characteristics of the Pingstabergr granite support an anatectic origin. Baker et al. (1987) arrived at the same conclusion for the V. Gråshöjden granite, which bears many similarities to the Pingstabergr granite. The zircon age data obtained for the Pingstabergr granite and the unmineralized analogues, Fjällberg and Enkullen (1.75 Ga; Åberg & Bjurstedt, 1986) strongly support a late orogenic origin, which points to a genetic relationship between intra-granitic Mo-occurrences and late orogenic granitoids. It is known that Mo occurs in different units of the supracrustal series in the Bergslagen region, and therefore one should expect a magma derived by melting of 'average' upper crust to be Mo-bearing. If we accept this mode of origin for the Pingstabergr granite, then a further concentration of Mo could take place when a late

F, Mo rich fluid phase moves from deeper levels up to more apical areas.

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