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# K-Ar Ages of Fissure Minerals from the Swiss Alps

By *J. W. Purdy* (Bern)*) and *H. A. Stalder* (Bern)**)

With 2 figures and 1 table in the texte and 1 plate

## Zusammenfassung

Die Arbeit enthält K-Ar-Alter der Kluftmineralien Muskovit, Adular und Biotit aus den Schweizeralpen. Die Proben stammen aus dem Aar- und Gotthardmassiv und aus dem penninischen Deckengebiet.

Die Beziehungen zwischen den verschiedenen Kluftmineralien und den gesteinsbildenden Glimmern sind nicht überall gleichartig. Im *Penninikum* ergeben die Kluftglimmer und Adulare gleiche (oder niedrigere) Alterswerte als die Gesteinsglimmer. Es scheint sich, gleich wie bei den Gesteinsglimmern, um Abkühlungsalter zu handeln. Die Alter einiger Kluftmuskovite, die niedriger sind als die entsprechenden Werte der Gesteinsglimmer, werden als Kristallisationsalter interpretiert.

Im *Gotthardmassiv* ergeben die Kluftmuskovite Kristallisations- und/oder Abkühlungsalter, während die Biotite und Adulare einen Überschuss an Argon enthalten.

Im *Aarmassiv* streut das Alter für die Adulare von 11 bis 65 Mill. Jahre; dies zeigt, dass einige Kalifeldspäte einen Überschuss an Argon besitzen (bis zu $2 \cdot 10^{-5}$ cm$^3$/g STP).

Der Grund für diese *Divergenz* liegt in den Abhängigkeitsbeziehungen der Altersdaten von kritischen Schliessungstemperaturen für die Diffusion radiogenen Argons in den verschiedenen Mineralien, von der Temperatur des Nebengesteins beim Einfliessen der Kluftlösungen und von der Abkühlungsgeschwindigkeit der Kluftmineralien nach ihrer Bildung.

Im Aarmassiv ist eine Beziehung zwischen dem *$CO_2$-Gehalt* der fluiden Einschlüsse in den Adularen (oder den koexistierenden Quarzen) und dem K-Ar-Alter festzustellen: $CO_2$ ist bei den «niedrigeren Altern» vorhanden und bei den «höheren Altern» der Adulare abwesend. Trotzdem ist eine klare Unterscheidung zwischen den bedeutungsvollen Kristallisationsaltern und den hohen Altern, welche von einem Argonüberschuss herrühren, durch die Daten der vorliegenden Untersuchung nicht möglich.

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## Abstract

K-Ar ages of the fissure minerals muscovite, adularia, and biotite from the Swiss Alps are presented. The samples have been selected from the Aar and Gotthard massives and the Pennine nappes.

The relationship among the various fissure minerals and rock micas is not everywhere identical. In the Pennines, fissure micas and adularia are equal to or less than the rock mica ages and show cooling age patterns similar to the rock mica age patterns. Some of the fissure muscovites, younger than the rock micas from the same region, are interpreted as crystallization ages. In the Gotthard, fissure muscovites give crystallization and/or cooling ages while the biotites and adularia contain excess argon. In the Aarmassive the adularia ages range from 11–65 m. y. indicating that some have excess argon (up to $2 \cdot 10^{-5}$ cm$^3$/g STP). The divergence in age relationships can be understood from a consideration of the critical closure temperatures for the diffusion of radiogenic argon from the various minerals; the temperature of the country rock when the mineral solutions entered the fissure and the cooling rate of the country rock after the fissure minerals formed.

In the Aar massive there is a relationship between the $CO_2$ content of the fluid inclusions in the adularia or coexisting quartz and the K-Ar age; $CO_2$ being present in the "younger ages" and absent in the adularia of "older age". Nonetheless, a clear distinction between meaningful crystallization ages and high ages due to excess argon is not possible from the data of the present investigation.

## INTRODUCTION

An investigation of the K-Ar ages of the Alpine fissure minerals muscovite, adularia and biotite was undertaken in an effort to establish the age relationship of these minerals to the Alpine tectonics and metamorphism. Further, it was hoped that the fissure mineral ages may give an indication of their crystallization age, over what period of time they formed in the Alps and, over what time interval minerals crystallized within a given fissure.

The two fissure minerals adularia and muscovite sometimes coexist. In this case, the crystallization sequence is adularia first, then muscovite although exceptions to this do occur. More often, the occurrence of adularia excludes muscovite, especially in the Aar massive. The rarity of fissure muscovite occurrences in the Aar massive is probably due to the low $CO_2$ content of the fissure solutions, the $CO_2$ content controlling the $K^+/H^+$ equilibrium and hence kind of mineral that crystallizes (Poty, 1969). In several fissures in the Gotthard massive with an excess of $CO_2$ in the fluid inclusions, adularia is lacking (Mühlebach, Campo Blenio) while muscovite is abundant.

Fissure biotites are rare in the Alps and of the biotites investigated only those from the eastern part of the Gotthard massive are real fissure biotites (Arnold, 1972). In other regions of the Swiss Alps, fissure biotites usually occur only as inclusions in the oldest parts of the quartz crystals. Biotite is a mineral species that disappears in the neighbourhood of an alpine mineral fissure during the formation of the fissure minerals. The biotites from the Simplon railway tunnel are in part envelopments of other minerals which form massive nodules (KAW 350 and KAW 349). In one case (KAW 348), a large biotite sheet originating from the Antigorio gneiss was investigated. This sheet surely did not form in a normal alpine mineral fissure but unfortunately it was not possible to reconstruct the true type of formation. These biotites from the Simplon tunnel crystallized during the Alpine orogeny, but presumably before the mineral fissures appeared.

For a comprehensive discussion of the occurrence, types of mineral assemblages and their successions, etc., of fissure minerals the reader is referred to STALDER et al. (1973).

The minerals for investigation have been selected from fissures which occur in the Penninic nappes, the Aar and Gotthard massives. From these tectonic units we have a large amount of metamorphic petrology (E. NIGGLI and C. NIGGLI (1965), E. WENK (1962)) and Rb-Sr and K-Ar ages of micaceous minerals. For a full account of the metamorphic petrology and Rb-Sr dates from this region the reader is referred to JÄGER, NIGGLI, and WENK (1967). For the present discussion the following K-Ar rock mica results are pertinent (ARMSTRONG et al. (1966), PURDY and JÄGER (in preparation)).

In the Penninic nappes within the staurolite isograd only young Tertiary biotite, muscovite and phengite ages are found. These are all less than 38 ± 2 m. y. the age of the climax of the last phase of Alpine metamorphism (HUNZIKER, 1970). Like the Rb-Sr biotite ages, the K-Ar biotite and muscovite ages show a regional areal distribution of ages decreasing gradually from 25 m. y. in the Bergell region, to a low of 11 m. y. (biotite) and 14 m. y. (muscovite) in the Simplon region. These have been interpreted as cooling ages, that is, the ages represent the time since the rock passed through the critical closure temperature for the diffusion of radiogenic argon from the minerals, muscovite closing at a higher temperature than biotite. Arguments have been given for the closure temperatures for biotite being around 300°C (JÄGER et al. 1967) and for muscovite between 350–400°C (PURDY and JÄGER, in preparation). In addition, the difference in age between coexisting muscovite and biotite changes gradually from 0 m. y. to 3 m. y. as one moves westward from the Bergell region to the Simplon. This age difference pattern has been interpreted as reflecting different uplift rates as the rocks passed through the temperature interval between the critical closure temperature for argon diffusion from muscovite and biotite.

In the Gotthard massive which lies mostly between the chloritoid and staurolite isograds apart from a small portion in the south central region which lies in the staurolite zone, the micas separated from acidic rocks give young Alpine ages less than 38 ± 2 m. y. For micas separated from basic rocks, the pre-Alpine K-Ar age is preserved or partially preserved (ARMSTRONG et al.

1966, PURDY and JÄGER, in preparation). In the Aar massive, which lies partially in the transition region between Alpine chloritoid and stilpnomelane and in the stilpnomelane zone we find the transition from Alpine to Hercynian K-Ar mica ages (ARMSTRONG et al. 1966, JÄGER and FAUL 1959).

As will be seen later the interpretation of K-Ar ages of the various kinds of fissure minerals is closely related to the tectonic position, degree of Alpine metamorphism, and the K-Ar age of the rock biotites and muscovites.

## ANALYTICAL TECHNIQUES

Both the potassium and argon measurements were determined in the manner more extensively described by PURDY and JÄGER (in preparation).

Two different $Ar^{38}$ spikes were used, one for samples analysed in Zürich on a Reynolds type mass spectrometer, the other for those analysed in Bern on a Varian Mat GD 150 (PURDY, 1972). The spike for the Bern measured samples was calibrated against known volumes of air. This spike yielded values of 27.79 and $28.08 \times 10^{-6}$ $cm^3/g$ STP for U.S.G.S. P 207 and $6.31 \pm 0.03$ $(1\ \sigma) \times 10^{-6}$ $cm^3/g$ STP for the Bern muscovite 4 M. The spike for the Zürich measured samples was calibrated with the Bern muscovite 4 M using the value $6.31 \times 10^{-6}$ $cm^3/g$ STP. Argon concentrations measured in Zürich and Bern on the adularia Steinbruchgraben 6500 give a mean value of 5.56 $cm^3/g$ STP with a spread of $\pm 2.7\%$. For samples analysed on the same instrument, duplicate argon determinations on the same mineral separate agree with the mean value to about 2%.

All of the potassium concentrations were measured at least in duplicate and the values agree to better than 1%. WEIBEL and MEYER (1957) have shown from chemical analyses of thirty-three adularia from the Alps that the average potassium content is 11.4% with a range of 11.0–12.3%. With the exception of the two adularia samples from Steinbruchgraben, the average potassium content of our remaining eighteen adularias is 12.7% with a range of 11.9–13.5%. The samples from Steinbruchgraben with potassium contents of 10.5% and 8.8% are probably impure adularia separates.

The analytical data are given in table I. Errors quoted in the K-Ar age are $(1\ \sigma)$ and have been calculated from a statistical assessment of errors with a 1% error in the potassium content; 0.5% error in the spike concentration for samples measured in Bern; 1% error in the spike concentration for samples measured in Zürich; and errors incurred in measuring the ion beam intensities (0.2–0.5% for $Ar^{40}$, $Ar^{38}$ and 0.5–4% for $Ar^{36}$). Included in table I is the FG (Fundortgruppe) number after STALDER et al. (1973), this number giving an indication of the sample locality and paragenesis, and also in table I is given an indication of the presence or absence of $CO_2$ in the inclusions of the adularia or quartz. A description of the sample localities, mineral parageneses, etc. is to be found in the Appendix.

## RESULTS AND DISCUSSION

Table 1 gives the analytical data and fig. 1 a plot of the K-Ar ages of the fissure minerals. The tectonics and metamorphic isograds on figure 1 are after E. Niggli and C. R. Niggli (1965), Wenk (1962).

There is a relationship between the K-Ar age of the various kinds of fissure minerals and the degree of Alpine metamorphism undergone by the host rock during the last phase of the metamorphism. For fissure muscovite and adularia in the Pennines within or near the staurolite isograd the ages are all Alpine and less than 38 ± 2 m. y., the age of the climax of the last phase of Alpine metamorphism (Hunziker 1970). Although the data are limited, there is a pattern of fissure muscovite and adularia ages within or near the staurolite isograd similar to the rock mica age patterns, namely the ages increase systematically as one moves eastward from the Simplon region. In the Gotthard massive which lies mostly within the chloritoid zone, the south central portion within staurolite isograd, the fissure biotite and muscovite ages are again less than 38 m. y. Adularia from the Pennines give young Tertiary K-Ar ages; from the Gotthard both ages less than 38 ± 2 m. y. and ages slightly older than 38 m. y.; from the more southern portions of the Aar massive near the chloritoid isograd the ages range from 10.6–22.5 m. y., in the more northern portions of the Aar massive in the stilpnomelane-chloritoid and stilpnomelane zones the ages range from 25.1 to 63.6 m. y. The local age relationship among the various fissure minerals and rock micas in different tectonic units is summarized below.

| | | |
|---|---|---|
| *Pennines* | $\mathrm{MR} > \mathrm{BR} > \mathrm{MF} > \mathrm{A}$ | West |
| | $\mathrm{MR} \geqq \mathrm{BR} > \mathrm{MF}$ | East |
| | $\mathrm{MR} \approx \mathrm{BR} \approx \mathrm{MF} \approx \mathrm{A}$ | |
| *Gotthard massive* | $\mathrm{A} > \mathrm{MR} > \mathrm{BR} > \mathrm{MF}$ | |
| | $\mathrm{A} > \mathrm{BF} > \mathrm{MF}$ | |
| *Aar massive* | $\mathrm{A} \lessgtr 38$ m. y. | |

where (A ≡ adularia, BR ≡ rock biotite, BF ≡ fissure biotite, MR ≡ rock muscovite, MF ≡ fissure muscovite).

We suggest that the reason for the above divergence in age relationships is essentially a function of three things: firstly, the critical closure temperatures for the diffusion of radiogenic argon from the various minerals, secondly, the country rock temperature when the solutions entered the fissures; and thirdly, the cooling rate of the country rock after the fissure minerals formed.

If we assume that fissure micas close to radiogenic argon diffusion at the same temperatures as the corresponding rock micas; fissure muscovite does not incorporate argon on crystallization but fissure biotite and adularia might under special conditions; the critical closure temperature for the diffusion of argon from adularia is less than for biotite, then we can account for the various age relationships mentioned above with reference to the curves labelled 1 and 2 in figure 1.

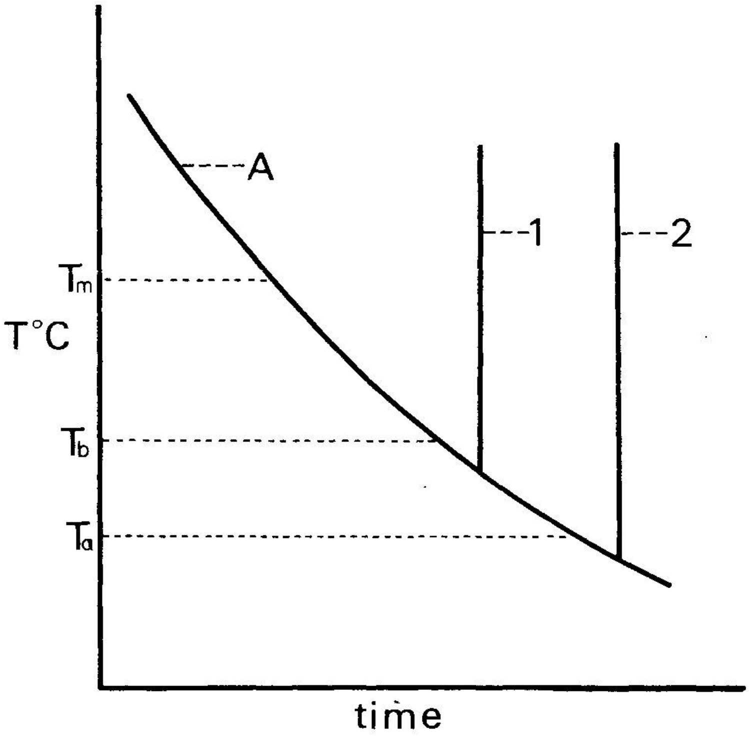

Fig. 1. For explanation see text.

In figure 1, $T_m$ ≡ closure temperature for the diffusion of radiogenic argon from muscovite; $T_b$ ≡ closure temperature for biotite; $T_a$ ≡ closure temperature for adularia. Curve "A" is the cooling curve for the country rock. We know that the temperature interval (Tm-Tb) has time intervals from 0–1 m. y. to 3.0 m. y. as one moves westwardly from the Bergell to Simplon region (PURDY and JÄGER, in preparation). When a hot solution comes into a fissure its cooling curve will be essentially vertical until it intersects the rock cooling curve whereafter it will follow the same cooling curve as the country rock. The type of local age pattern exhibited among the fissure minerals and rock micas will depend upon the country rock temperature and its cooling rate when the hot solutions came into the fissure.

*Curve 1*

This would explain the Simplon tunnel results where we have the rock micas (musc. 14 m. y., biotite 11 m. y., PURDY and JÄGER, in preparation) older than the fissure muscovite older than the adularia if the solutions forming the adularia and muscovite came into the rocks at the same time when the country rock was below 300° C. The biotite ages could be explained by having formed together with the nodules at an earlier time when the country rock was above 300° C. In this case the biotite and adularia give cooling ages whereas the fissure muscovite is a crystallization age. Curve 1 may also explain the results of other fissure muscovites and adularia younger than the rock biotites from the same region (Mühlebach, Foppiano, Binnatal, Pizzo Barone). These muscovites (Mühlebach, Foppiano) must be crystallization ages but whether the adularia are cooling or crystallization ages depends on the intersection of curve 1 and curve "A" which we do not know for Binnatal or Pizzo Barone. For most of the samples east of Val Antigorio the country rock curve is too steep to permit any age fine structure to be seen, that is, one finds the rock and fissure mineral ages locally agreeing within experimental error (Helgenhorn, Alpe di Crozlina, Val di Chironico, Valle dell'Isorno, Cavagnöö, Lago Scuro). In this case we cannot say whether these muscovites came into the rock when the rock temperature was above or below $T_m$.

*Curve 2*

In this case adularia and biotite may contain excess argon because these minerals cooled too quickly below their critical closure temperatures to allow all the argon present in fluid inclusions, etc. to diffuse away. Curve 2 could explain the results of Gotthard Fibbia where we have $A > MR > BR > MF$, the adularia and muscovite being in one case in the same fissure. In this case the fissure muscovite is interpreted as a crystallization age.

We have analysed five fissure minerals from Val Casatscha by the K-Ar method. Arnold (1972) has recently reported an extensive Rb-Sr study of fissure minerals from this region. He has given three precise fissure mineral (biotite, adularia, muscovite) – country rock (whole rock plus mica separates) isochrons, the country rock having been collected within ten meters of the respective fissure. In addition, he has given one precise adularia-fissure biotite isochron. All the isochrons give ages of 15–16 m. y. but there is a variety of ($Sr^{87}/Sr^{86}$) intercepts (0.720–0.736). Since the rock biotites from this region give cooling ages, Arnold interprets the fissure mineral ages (which lie on the same isochron as the rock biotite ages) as minimum crystallization ages. The variety of ($Sr^{87}/Sr^{86}$) intercepts and the colinearity of the rock and fissure biotites with the other minerals and whole rock points from each individual fissure – country rock pair reflects the variable Rb-Sr whole rock systems and the fact that the "common strontium" of both the fissure minerals and rock minerals was derived from the nearby country rock 15–16 m. y. ago. Further, Arnold states from the fissure biotite – rock biotite age equality that the minimum formation temperature of the fissure minerals is 300° C.

Of the 13 fissure minerals analysed by ARNOLD, we have dated 5 by the K-Ar method; namely, the fissure biotites KAW 528, KAW 537, the fissure muscovite KAW 536, and the fissure adularias KAW 535, KAW 529. The Rb-Sr fissure biotite ages ($15.7 \pm 0.7$, $16.0 \pm 0.9$ m. y.) are not in agreement with our K-Ar ages on the same biotites ($18.6 \pm 0.5$, $19.5 \pm 0.6$ m. y.) but the Rb-Sr biotite ages do agree with our K-Ar fissure muscovite (KAW 536) age of $16.0 \pm 0.5$ m. y. and with two other fissure muscovite ages from the same region (Campo Blenio, $15.1 \pm 0.3$ m. y. and Piz Rondadura, $16.2 \pm 3$ m. y.). The Rb-Sr ages of the adularia and fissure and rock muscovite are imprecise because of the large common strontium contents. However, within experimental error, ARNOLD found that these minerals lie on the 15–16 m. y. isochrons.

Summarizing the precisely dated minerals from Val Casatscha, we have

$$A(\text{K-Ar}) > BF(\text{K-Ar}) > BF(\text{Rb-Sr}) = BR(\text{Rb-Sr}) = MF(\text{K-Ar})$$

where A, BF, BR, MF are as defined above.

If we interpret the K-Ar fissure muscovite, Rb-Sr fissure and rock biotite ages as cooling ages then it is difficult to account for the adularia and fissure biotite K-Ar ages. We suggest that the above age relationship can be explained with Curve 2 of figure 1. In this case both the adularias and fissure biotites contain excess argon. The K-Ar fissure muscovite age is a formation age and by implication the Rb-Sr fissure biotite ages are formation ages. ARNOLD has interpreted the Rb-Sr fissure biotite ages as minimum formation ages and, further, that the minimum formation temperature of the fissure minerals was 300° C. We do not disagree with this but we suggest in addition that the country rock was below 300° C when the fissure solutions came into the rock and that the Rb-Sr fissure biotite ages are crystallization ages. South of Val Casatscha the uplift and cooling has been relatively rapid; the rock cooling from $T_m$ to $T_b$ in 0–1 m. y. If the rocks in Val Casatscha cooled this quickly as well, then the time interval between $T_b$ and the temperature of the rock when the fissure solutions came in is probably not measurable. Hence the equality of the rock and fissure biotite ages even though one is a cooling age and the other a formation age.

The biotite KAW 175 (K-Ar age = $34.0 \pm 0.8$ m. y.; Rb-Sr age = $15.1 \pm 1.6$ m. y.) may be explained with Curve 2, the biotite taking up excess argon but not any radiogenic $Sr^{87}$. The biotite from Massaboden (K-Ar age = $15.4 \pm 0.3$ m. y.; Rb-Sr age = $9.9 \pm 1.3$ m. y.) may be due to a similar phenomenon as KAW 175 but the biotite from the Massaboden (KAW 314) agrees more closely with the K-Ar age of the rock biotite KAW 359 ($14.1 \pm 0.2$ m. y.) from the same region. In any case KAW 175 and KAW 314 are not normal fissure biotites.

All of the adularia ages from the Aar massive greater than 38 m. y. could be explained by curve 2 of figure 1. It is possible that some of the adularia in the Aar massive less than 38 m. y. are genuine crystallization or cooling ages whence the cooling curve would intersect the rock cooling curve above $T_a$. Without some additional isotopic evidence (for example, age of coexisting muscovite) it is difficult to say whether or not the adularia ages below 38 m. y. are genuine crystallization ages. The random distribution of adularia ages less than 38 m. y. old in theAar massive precludes all of them being interpreted as cooling ages.

There exists several pieces of evidence which suggests that some (perhaps all) of the adularia from the Aar and Gotthard massive contain excess argon. Firstly, two separate mineral fractions each measured in duplicate from the same fissure (Münstigertal) yield significantly different amounts of radiogenic argon, although the potassium contents (12.17, 12.51) agree within experimental error. The argon values were (7.55, 7.67) and (6.55, 6.51) $\times 10^{-6}$ cm$^3$/g STP. This could mean that one separate has a larger fraction of adularia containing an excess argon component. Secondly, in the early phase of the investigation, before the samples were ground to $(-20+40)$ mesh, small chips (200 mg) of the adularia KAW 529 were analysed. The spread of the argon concentration values (15.17, 13.30) $\times 10^{-6}$ cm$^3$/g STP was in excess of that expected from normal analytical precision. Although no K values were measured on the chips it was thought that sample inhomogeneity was the cause of the spread of argon values and subsequently all adularia samples were ground to $(-20+40)$ mesh. This led to duplicate determinations for KAW 529 of (11.07, 10.96) $\times 10^{-6}$ cm$^3$/g STP a spread attributable to analytical error alone. In retrospect, it seems possible that the spread in argon concentration values on the adularia chips KAW 529 may have been due to different fractions containing different amounts of excess argon rather than just due to sample inhomogeneity (in both K and radiogenic Ar). Grinding to $(-20+40)$ mesh only homogenized the mineral separate. Thirdly, and perhaps most convincing, the age difference between coexisting muscovite and adularia of 22.1 m. y. for the fissure from Freilaufstollen and 27.8 m. y. for the fissure Fibbia is much greater than could be due to some effect like cooling. Besides there adularia are older than the coexisting muscovite, a result different from adularia in the Pennines which were interpreted as cooling ages. Fourthly, the adularia from the fissures Freilaufstollen are different in age by 16.5 m. y. although they are only 1 km distant from one another.

In an effort to find some other difference between possible genuine crystallization ages and ages due to the presence of excess argon, the $CO_2$ content of the inclusions in the adularia or coexisting quartz was examined. Figure 2 is a histogram plot of the adularia ages from the Aar massive with an indication of the presence, trace of, or absence of $CO_2$ in the inclusions. There is a correlation between age and $CO_2$ content of the inclusions; the youngest having the highest $CO_2$ and the oldest having no $CO_2$. It might be that the presence of

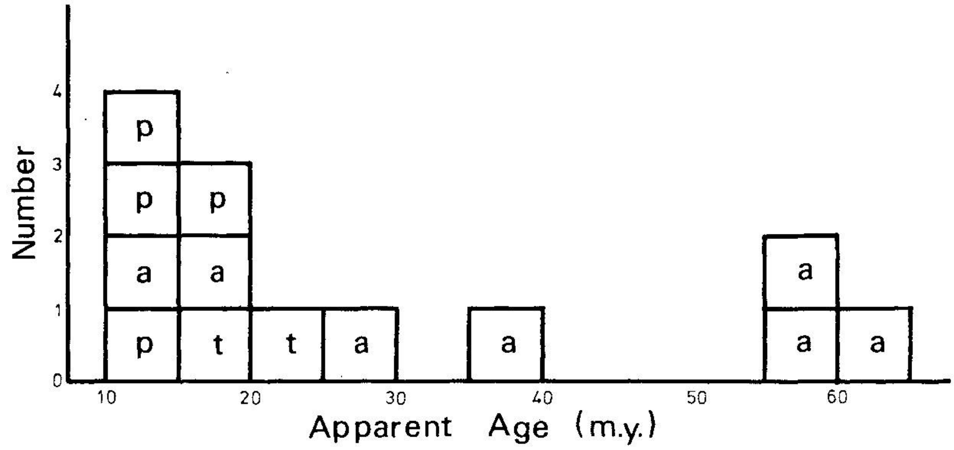

Fig. 2. Histogram of adularia apparent ages from the Aar massive. Letters p, a, t within the boxes indicate the presence of, trace of, or absence of $CO_2$ in the inclusions of the adularia or coexisting quartz.

$CO_2$ in the fissure forming solutions (and hence pH) may in some way allow most or all of the excess argon (if present) to diffuse out of the crystal at the time of crystallization. A second possibility for this correlation of age with $CO_2$ content is that the $CO_2$ bearing solutions originated from sediments with a low potassium and hence radiogenic argon content while the more pure water solutions originated from granite and gneisses with higher potassium and hence radiogenic argon centents. The data from Gletsch would suggest that the presence of $CO_2$ does not guarantee the absence of excess argon. The absence of $CO_2$ in the inclusions then, indicates the possibility of excess argon in adularia.

## CONCLUSIONS

The following are the conclusions from the present investigation.

1. Fissure muscovite and adularia from the Pennines give young Tertiary ages. Both muscovite and adularia give cooling age patterns similar to the rock mica Rb-Sr and K-Ar age patterns. Some of the fissure muscovite ages are younger than the rock biotite ages and are interpreted as crystallization ages, these ages also give the time when the solutions came into the fissure after the country rock had cooled below 300° C.
2. Three fissure muscovites from the Gotthard massive are interpreted as crystallization ages, the others from Campo Blenio, Piz Rondadura may be crystallization or cooling ages. Fissure biotites from the Gotthard appear to contain excess argon, the adularia do contain excess argon.
3. Adularia from the Aar massive do not show a regional cooling age pattern. Some, in the more lower grade Alpine metamorphic zones are greater than 38 m. y. and must contain excess argon. Others between 11 and 38 m. y.

Table 1

| Sample | FG after STALDER et al. 1973 | Fluid inclusions in quartz (or other minerals). Number of phases | Min. | % K | | $^{40}Ar^{*1)}$ $\times 10^{-6}$ cm³/g STP | % $^{40}Ar^*$ | K-Ar age in m. y. | Rb-Sr age in m. y. (JÄGER et al. 1967)²) |
|---|---|---|---|---|---|---|---|---|---|
| *Aar massive* | | | | | | | | | |
| Val Gronda da Cavrein, Val Russein | 1a | 2 no $CO_2$ | Ad | 13.40 | 13.34 | 34.46 | 94.1 | 63.6 ± 0.8 | |
| Bändertal, Maderanertal | 1a | 2 no $CO_2$ | Ad | 13.11 | 13.18 | 30.73 | 93.8 | 57.7 ± 0.7 | |
| Stollen Mittagfluh-Trift, bei Guttannen A 7580 | 2a | 2 no $CO_2$ | Ad | 13.20 | 13.24 | 29.99 | 93.9 | 56.1 ± 0.7 | |
| Im Jeizel bei Goppenstein 6414 | 2a | 2 no $CO_2$ | Ad | 13.09 | 13.13 | 13.19 | 91.4 | 25.1 ± 0.3 | |
| Hälsital im Etzlital | 3a | 2 no $CO_2$ (in Adularia) | Ad | 13.48 | 13.49 | 19.95 | 92.8 | 36.7 ± 0.5 | |
| Tiefengletscher 186 | 4a | 2 trace of $CO_2$ | Ad | 12.73 | 12.72 | 8.68 | 76.7 | 17.0 ± 0.3 | |
| Furka, Belvedere JA 592/1 | 4a | 2 with $CO_2$ under pressure (in Adularia) | Ad | 12.20 | 12.27 | 6.47 | 93.9 | 13.2 ± 0.2 | |
| Gletsch, Sondier-Stollen 48/25 and 50/4 | 5d | 2 trace of $CO_2$ | Ad | 11.91 | | 10.13 | 84.6 | 21.2 ± 0.3 | |
| | | | | 11.93 | | 10.75 | 59.5 | 22.5 ± 0.4 | |
| Hinterbru im Münstigertal A 5800 | 5d | 2 no $CO_2$ | Ad | 12.12 | 12.21 | 7.55 | 90.8 | 15.5 ± 0.2 | |
| | | | | | | 7.67 | 50.1 | 15.7 ± 0.3 | |
| | | | Ad | 12.36 | 12.50 | 6.55 | 96.0 | 13.1 ± 0.2 | |
| | | | | 12.54 | 12.63 | 6.51 | 57.2 | 13.0 ± 0.2 | |
| Massaboden bei Brig KAW 314 | 5 | | Bi | 8.19 | 8.21 | 5.04 | 84.6 | 15.4 ± 0.3 | 9.9 ± 1.3³) |
| Massakin bei Brig JA 106 | 5d | 2 with $CO_2$ under pressure (in adularia) | Ad | 12.33 | 12.29 | 8.19 | 90.4 | 16.6 ± 0.2 | |
| Steinbruchgraben 6500 | 5e | 2 with $CO_2$ under pressure (in adularia) | Ad | 10.43 | 10.51 | 5.72 | 88.1 | 13.6 ± 0.2 | |
| | | | | | | 5.41 | 81.2 | 12.9 ± 0.3 | |
| Steinbruchgraben 6378 | 5e | 2 with $CO_2$ under pressure (in adularia) | Ad | 8.76 | | 3.79 | 88.7 | 10.8 ± 0.3 | |
| | | | | 8.79 | | 3.72 | 78.7 | 10.6 ± 0.2 | |

Table 1 (cont.)

| Sample | FG after STALDER et al. 1973 | Fluid inclusions in quartz (or other minerals). Number of phases | | Min. | % K | | $^{40}$Ar*[1]) $\times 10^{-6}$ cm$^3$/g STP | % $^{40}$Ar* | K-Ar age in m. y. | Rb-Sr age in m. y. (JÄGER et al. 1967)[2]) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Gotthard massive* | | | | | | | | | | |
| Freilaufstollen, Val Casatscha-Sta. Maria Meter 1677, KAW 528, KAW 529 | 7e | 2 | trace of $CO_2$ | Bi | 7.94 | 7.97 | 5.93 | 87.8 | 18.6±0.5 | 15.7±0.7[4]) |
| | | | | Ad | 12.33 | 12.27 | 10.96 | 89.0 | 22.2±0.5 | |
| | | | | | | | 11.07 | 91.0 | 22.4±0.5 | |
| Freilaufstollen, Val Casatscha, Sta. Maria Meter 2790, KAW 535, KAW 536, KAW 537 | 7e | 2 | trace of $CO_2$ | Ad | 12.64 | 12.63 | 19.40 | 96.5 | 38.1±0.7 | |
| | | | | Mu | 8.92 | 8.93 | 5.71 | 37.8 | 16.0±0.5 | 30.6±20.0[4]) |
| | | | | Bi | 8.22 | 8.24 | 6.45 | 34.5 | 19.5±0.8 | 15.4±0.4[4]) |
| Stollen Oberalp Val Val Meter 863, KAW 175 | 6 | | | Bi | 6.32 | 6.33 | 8.65 | 64.0 | 34.0±0.6 | 15.1±1.6[3]) |
| Fibbia, St. Gotthard A 2882 | 7d | 2 | with $CO_2$ under pressure and | Ad | 12.95 | 12.94 | 21.90 | 85.9 | 41.9±0.6 | |
| | | 3 | with some liquid $CO_2$ | Mu | 8.97 | 9.01 | 5.06 | 76.7 | 14.1±0.3 | |
| Fibbia | 7d | | with $CO_2$ under pressure | Ad | 12.61 | | 12.79 | 89.7 | 25.2±0.4 | |
| | | | | | 12.64 | | 13.64 | 83.3 | 27.0±0.5 | |
| Mühlebach bei Fiesch A 3553 | 5b | 3 | with liquid $CO_2$ | Mu | 8.60 | 8.72 | 3.15 | 58.8 | 9.1±0.7 | |
| Piz Rondadura | 7d | 2 | with much $CO_2$ under pressure | Mu | 9.18 | 9.26 | 5.97 | 59.4 | 16.2±0.3 | |
| Campo Blenio | 10d | 3 | with liquid $CO_2$ | Mu | 7.97 | 7.99 | 4.82 | 66.3 | 15.1±0.3 | |
| *Pennines* | | | | | | | | | | |
| Alpe di Crozlina | 10h | 3 | with liquid $CO_2$ | Mu | 7.28 | 7.26 | 4.90 | 66.1 | 16.8±0.9 | |
| Pizzo Barone | 10h | 2 | with liquid $CO_2$ | Ad | 13.15 | 13.09 | 7.52 | 66.1 | 14.3±0.3 | |
| Val di Chironico, JA 836 | 10h | 3 | with liquid $CO_2$ | Mu | 7.58 | 7.62 | 5.11 | 71.7 | 16.8±0.5 | |
| Lago Scuro, A. Campo la Torba, KAW 387 | 10 | | | Mu | 9.42 | 9.43 | 4.91 | 73.6 | 13.0±0.5 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cavagnöö, Val Barona | 10h | 3 | with liquid $CO_2$ | Ad<br>Mu | 12.16<br>9.08 | 12.09<br>9.11 | 6.58<br>5.01 | 94.8<br>57.1 | 13.6±0.2<br>13.7±0.4 | |
| Valle dell'Isorno, Italy, B 6 | — | | | Mu | 8.88 | 8.83 | 5.08 | 43.4 | 14.3±0.7 | 20±14[3]) |
| Steinbruch Foppiano Italy, B 25 | — | | | Mu | 9.03 | 9.00 | 3.90 | 49.2 | 10.8±0.6 | |
| Helgenhorn HA/180 | 5b | | | Mu | 7.07<br>7.01 | 6.99 | 4.39 | 64.8 | 15.6±0.6 | |
| Albrunpass, Binnatal SG 657 | 11b | | | Ad | 12.73 | 12.79 | 5.68 | 89.7 | 11.1±0.2 | |
| Lengenbach, Binnatal | 11b | 3 | partly 4+5 with salt and sulphur | Hy | 8.65 | 8.69 | 3.96 | 87.2 | 11.4±0.3 | |
| Simplon tunnel Meter 4600 SP KAW 348 | — | | | Bi | 8.16 | 8.17 | 4.45<br>4.25 | 52.8<br>26.5 | 13.6±0.6<br>13.0±2.0 | 14.3±2.7[3]) |
| Simplon tunnel Meter 5528/32 NP | 11f | 2 | with $CO_2$ under pressure (in adularia) | Ad | 12.70 | 12.63 | 4.32 | 86.8 | 8.5±0.1 | |
| Simplon tunnel Meter 6100 NP, KAW 350 | 11f | | | Bi | 7.94 | 7.97 | 3.46 | 71.2 | 10.9±0.5 | 10.2±1.8[3]) |
| Simplon tunnel Meter 7225/72 NP | 11f | 2 | with $CO_2$ under pressure (in albite, anhydrite) | Mu | 8.98 | 8.95 | 3.51 | 52.4 | 9.8±0.3 | |
| Simplon tunnel Meter 7294–7898 NP KAW 349 | 11f | | | Bi | 8.23 | 8.27 | 3.88 | 62.5 | 11.7±0.4 | 12.8±0.9[3]) |
| Simplon tunnel Meter 7294–7898 NP KAW 352 | 11f | | | Bi | 7.92 | 7.94 | 3.85 | 71.9 | 12.1±0.8 | 12.7±2.4[3]) |
| Simplon tunnel Meter 9483 NP | 11f | 3 | with liquid $CO_2$ (in adularia) | Ad | 12.87 | 12.92 | 4.23 | 84.7 | 8.2±0.1 | |
| Simplon tunnel Meter 9951–9957 NP | 11f | | | Mu | 9.18 | 9.12 | 3.72 | 69.6 | 10.2±0.4 | |

$\lambda = 5.30 \times 10^{-11}\ \mathrm{yr}^{-1}$ $\lambda_e = 0.585 \times 10^{-11}\ \mathrm{yr}^{-1}$
$K^{40}/K = 1.19 \times 10^{-4}$ (atom ratio)

1) $^{40}Ar^{*}$ = radiogenic argon
2) Rb-Sr ages from Jäger et al. (1967) followed by 3)
Rb-Sr ages from Arnold (1972) followed by 4)

may or may not be genuine crystallization ages. If we assume a minimum age of 38 m. y. for adularia in the Aar massive, excess argon contents as high as $2.10^{-5}$ $cm^3/g$ STP are indicated. The biotite from Massaboden may contain excess argon.

4. Fissure minerals formed in the Pennines and Gotthard massive over a period of at least 7 m. y. but the present data does not permit anything to be said about the formation time of various minerals within a given fissure.

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## APPENDIX

### Location and Description of Analysed Fissure Minerals

*Aar massive*

Val Gronda da Cavrein, Val Russein, GR (P. Indergand).
Country rock: Northern crystalline schists of the Aar massive.
Paragenesis: Quartz, *Adularia* (Maderaner habit), Chlorite ... FG 1a.
Two phase inclusions in quartz without $CO_2$.

Bändertal im Maderanertal, UR (X. Gnos).
Country rock: Sericite gneiss of the northern crystalline schists of the Aar massive.
Paragenesis: Quartz, *Adularia* (Maderaner habit), Chlorite ... FG 1a.
Two phase inclusions in quartz without $CO_2$.

A 7580 Stollen Mittagfluh-Trift by Guttannen, BE (Natural History Museum of Bern).
Country rock: Sericite gneiss of the northern crystalline schists of the Aar massive.
Paragenesis: Quartz, *Adularia* (Maderaner habit), Chlorite ... FG 2a.
Two phase inclusions in quartz without $CO_2$.

6414 Im Jeizel near Goppenstein, VS, Coordinates 625.2/133.5 (Natural History Museum of Bern).
Country rock: Amphibolite from the northern crystalline schists of the Aar massive.
Paragenesis: Quartz, *Adularia* (Maderaner habit), Chlorite, Asbestos ... FG 2a.
Two phase inclusions in quartz without $CO_2$.
Literature: Ed. von Fellenberg (1893).

Hälsital im Etzlital, UR (X. Gnos).
Country rock: Giuv-Syenite.
Paragenesis: Asbestos, Chlorite, *Adularia* (Maderaner habit), Sphene . . . FG 3a.
The adularia is streaked here and there with fine asbestos fibers.
Two phase inclusions in adularia without $CO_2$.

Tiefengletscher, Furka, UR, Coordinates 675/163 (P. Indergand).
Country rock: Central Aar granite.
Paragenesis: Quartz, Chlorite, *Adularia* (Maderaner habit) . . . FG 4a.
Some $CO_2$ escaped from the two phase inclusions in quartz from a neighbouring fissure in a crushing microscope stage.

Ja 592/1 Furka, above Hotel Belvedere, VS (Jos. Arnoth).
Country rock: Central Aar granite.
Paragenesis: *Adularia* (Maderaner habit), Quartz, Apatite, Milarite . . . FG 5d.
The adularia contains two phase inclusions; much $CO_2$ escapes in a crushing miscroscope stage.

48/25 Gletsch, Sondierstollen, VS, Coordinates 670.78/157.00 (Natural History Museum of Bern).
Country rock: Amphibolite from the main migmatite zone of Gletsch, southern gneiss of the Aar massive.
Paragenesis: Quartz, Chlorite, *Adularia* (Maderaner habit), Sphene, Calcite, Epidote. FG 5d.
Some $CO_2$ escapes from the two phase inclusions in quartz in a crushing microscope stage.
Literature: S. GRAESER et al. (1963).

A 5800 Hinterbru im Münstigertal, VS, Coordinates: 660.5/150.8 (Natural History Museum of Bern).
Country rock: Southern gneiss of the Aar massive.
Paragenesis: Quartz, *Adularia* (Fibbia habit), Chlorite, Stilbite, Apatite . . . FG 5d.
Two phase inclusions in quartz without $CO_2$.

KAW 314 Massaboden, Main entrance tunnel of the Central, 328 meters from the South entrance, VS, Coordinates 643.67/131.83 (T. Labhart).
Country rock: Biotite-Plagioclase gneiss from the southern gneiss of the Aar massive.
Paragenesis: *Biotite* from small fissures completely filled with biotite only.
Literature: E. JÄGER et al. (1967), p. 19 and 58.

JA 106 Massakin near Brig, VS (Jos. Arnoth). Umleitungsstollen from the Electra Massa.
Country rock: Southern gneiss of the Aar massive.
Paragenesis: Quartz, *Adularia* (Fibbia habit), Chlorite, Anatase, Brookite, Pyrite, Chabazite . . . FG 5d.
The adularia contains two phase inclusions. Much $CO_2$ escapes in the crushing microscope stage.

6378 Steinbruchgraben im Baltschiedertal, VS, Coordinates ca. 633.5/130.7 (Natural History Museum of Bern).

Country rock: Dolomite and massive limestone from a sedimentary wedge in the southern part of the Aar massive.
Paragenesis: Quartz, *Adularia* (Maderaner habit), Dolomite, Anatase, Muscovite, Calcite . . . FG 5e.
The adularia is here and there intensively streaked with dolomite and some muscovite, and contains two phase fluid inclusions from which $CO_2$ escapes in the crushing microscope stage.
Literature: Ed. von Fellenberg (1893).

6500 Steinbruchgraben im Baltschiedertal, VS, Coordinates ca. 633.5/130.7 (Natural History Museum of Bern).
Country rock: Dolomite from a sedimentary wedge in the southern part of the Aar massive.
Paragenesis: Quartz, Adularia (Maderaner habit), etc.
The adularia contains various solid inclusions, and two phase fluid inclusions, from which some $CO_2$ escapes in the crushing microscope stage.
Literature: Ed. von Fellenberg (1893).

### *Gotthard massive* (including the Tavetsch massive)

KAW 528 Freilaufstollen Val Casatscha-Sta. Maria der KW Vorderrhein, 1660 meters
KAW 529 from Sta. Maria, GR, Coordinates: 706.25/160.16 (A. Arnold). Fissure B after Arnold 1972.
Country rock: Crystallina-granodiorite.
Paragenesis: Quartz, Calcite, *Adularia* (Fibbia habit), Chlorite, Sphene, *Biotite*.
These are closed fissures and/or nodules with small druses; they have been moved tectonically after their formation. The biotite is located around the edges of the large nodules.
Literature: A. Arnold (1972).

KAW 555 Freilaufstollen Val Casatscha-Sta. Maria, 2790 meters from Sta. Maria, GR,
KAW 536 Coordinates 707.37/160.22 (A. Arnold).
KAW 537 Country rock: Quartz, *Adularia* (Maderaner habit), Chlorite, *Biotite*, *Muscovite*.
Fissure D after Arnold 1972. Two phase inclusions in quartz with some $CO_2$ under pressure.
Literature: A. Arnold (1972).

KAW 175 Stollen Oberalp-Val Val, Meter 863, GR, Coordinates 695.41/168.40 (A. Arnold).
Country rock: Amphibolite from the Tavetsch massive.
Paragenesis: Quartz, Calcite, Chlorite, *Biotite*. Closed fissure.
Literature: A. Arnold et al. (1965), E. Jäger et al. (1967).

A 2882 Fibbia, St. Gotthard, TI, Coordinates 686.37/156.10 (Natural History Museum of Bern).
Country rock: Fibbia granite gneiss.
Paragenesis: Quartz, *Adularia* (Fibbia-habit), Chlorite, *Muscovite*, Rutile, Sphene, Stilbite, Hematite, FG 7d.
Two phase inclusions in quartz with $CO_2$ under pressure and three phase inclusions with liquid $CO_2$ (homogenized to gaseous $CO_2$ at 29.5° C).
Literature: B. Poty and H. A. Stalder (1970).

Fibbia, North-east flank of Fibbia, Gotthard, TI (G. Peterposten).
Country rock; Fibbia granite gneiss.
Paragenesis: Quartz, *Adularia* (Fibbia-habit), Hematite, Muscovite, Chlorite. FG 7d.
Two phase inclusions with $CO_2$ under pressure.

A 3553 Mühlebach near Fiesch, VS, coordinates 654.75/139.70 (Natural History Museum of Bern).
Country rock: Phyllite from the northern crystalline schists of the Gotthard massive.
Paragenesis: Quartz, Ankerite, Breunnerite, green *Muscovite* (with considerable chromium content), Rutile, Calcite. FG 5b.
Three phase inclusions in quartz with liquid $CO_2$ (homogenized to liquid $CO_2$ at 24.5° C).

Piz Rondadura, North-east flank, Val Medel, GR (G. Venzin).
Country rock: Porphyritic orthogneiss.
Paragenesis: Quartz, Adularia (Fibbia-habit), Hematite, *Muscovite*, Chlorite.
Two phase inclusions in quartz with much $CO_2$ under pressure.

Campo Blenio, slope to the south of the village near point 1193 (A. Wagner).
Country rock: Bündnerschiefer from the paraautocthonous sedimentary cover of the Gotthard massive.
Paragenesis: Quartz, Albite, *Muscovite*, Chlorite, Calcite, Rutile, Pyrite.
Three phase inclusions in quartz with liquid $CO_2$.
Literature: A. WAGNER et al. (1972).

### *Pennines*

Alpe di Crozlina, Val Piumogna, Coordinates 700.80/143.80 (J. Hunziker).
Country rock: Block from the Campo Tencia.
Paragenesis: *Muscovite*, Pericline, Chlorite, Quartz. Adularia (Maderaner habit) . . . FG 10h.
Three phase inclusions in the quartz with liquid $CO_2$.

Pizzo Barone, south of the top, TI (E. Wenk).
Country rock: Biotite-Muscovite-schist.
Paragenesis: Quartz, Chlorite, Muscovite, *Adularia* (Maderaner habit), FG 10h.
Three phase inclusions in quartz with liquid $CO_2$.

JA 836 Val di Chironico, TI, Coordinates 703.0/140.5 (Jos. Arnoth).
Country rock: Biotite gneiss (Augengneise der Verzasca).
Paragenesis: Quartz, Adularia (Maderaner habit), Chlorite, *Muscovite*, Sphene, Pyrite. FG 10h.
Three phase inclusions in quartz with liquid $CO_2$.

KAW 387 Lago Scuro, Alpe Campo la Torba, TI.
Coordinates 687.9/148.15 (A. Günthert).
Country rock: Aplitic gneiss.
Paragenesis: *Muscovite* . . .

| | |
|---|---|
| A 5551 | Cavagnöö, below the dam, Val Bavona, TI, Coordinates: about 682.2/145.3 (Natural History Museum of Bern).<br>Country rock: Psammite gneiss of the Lebendun nappe.<br>Paragenesis: Quartz, Calcite, *Adularia* (Fibbia habit), *Muscovite*, Chlorite, Hematite, Sphene ... FG 10h.<br>Three phase inclusions in quartz with liquid $CO_2$. |
| B 6 | Valle dell'Isorno, Italy. Coordinates: 669.65/112.15 (H. Wieland, Wi 462/464).<br>Country rock: two mica gneiss with a platy texture Monte-Leone-gneiss.<br>Paragenesis: *Muscovite*, Chlorite, Quartz, Adularia, Calcite.<br>Literature: H. WIELAND (1966). |
| B 25 | Quarry from Foppiano, Valle Antigorio, Italy. Coordinates: 674.70/131.80 (J. Hunziker, Hu 1239).<br>Country rock: Aplite in the Biotite-Flatschengneiss of the Antigorio unit.<br>Paragenesis: Quartz, *Muscovite*.<br>Literature: J. HUNZIKER (1966). |
| Ha 180 | Helgenhorn (syn. Punta Elgio), VS (J. W. Hansen).<br>Country rock: Bündnerschiefer.<br>Paragenesis: *Muscovite* ...<br>Literature: J. W. HANSEN (1972). |
| SG 657 | Albrunpass, Binnatal, VS, Coordinates 666.30/136.13 (S. Graeser).<br>Country rock: Sugar-grained dolomite (Trias).<br>Paragenesis: Dolomite, *Adularia* (Fibbia habit), Rutile, Tourmaline ... FG 11b.<br>Literature: S. GRAESER (1965). |
| SG | Lengenbach, Binnatal, VS, Coordinates: 660.15/135.15 (S. Graeser).<br>Country rock: Sugar-grained dolomite (Trias).<br>Paragenesis: Dolomite, *Hyalophane*, many various kinds of Sulfosalts etc. ... FG 11b.<br>Various fluid inclusions in quartz, in part with liquid $CO_2$, with rocksalt and with sulfur.<br>Literature: S. GRAESER (1965). |
| KAW 348 | Simplontunnel, 4600 meters from the south entrance.<br>Country rock: Antigorio gneiss.<br>Paragenesis: *Biotite* (isolated biotite sheet with a diameter of about 20 cm), Hematite.<br>Literature: E. JÄGER et al. (1967). |
| | Simplontunnel, 5528–5532 meters from the north entrance.<br>Country rock: Berisal gneiss.<br>Paragenesis: *Adularia* (Maderaner habit), Muscovite, Rutile, Pyrite ... FG 11f.<br>Two phase inclusions in adularia. Much $CO_2$ under pressure escapes in a crushing microscope stage. |
| KAW 350 | Simplontunnel, 6100 meters from the north entrance.<br>Country rock: Berisal gneiss. Nodules of anhydrite mantled by *biotite*/chlorite.<br>Literature: E. JÄGER et al. (1967). |

Simplontunnel, 7225–7232 meters from the north entrance.
Country rock: Berisal gneiss.
Paragenesis: *Muscovite*, Pericline, Chlorite, Sphene, Anhydrite. FG 11f.
In albite and anhydrite only two phase fluid inclusions.
In a crushing microscope stage some $CO_2$ escapes.

KAW 349 Simplontunnel, 7294–7898 meters from the north portal.
KAW 352 Country rock: Bündnerschiefer.
Nodules of quartz, sericite and calcite mantled by *biotite* (349) and anhydrite mantled by *biotite* (352).
Literature: E. Jäger et al. (1967).

Simplontunnel, 9483 meters from the north entrance.
Country rock: Bündnerschiefer of the Veglia-syncline.
Paragenesis: *Adularia* (Maderaner habit), Muscovite, Rutile. FG 11f.
Three phase inclusions with liquid $CO_2$ in Adularia.

Simplontunnel, 9951–9957 meters from the north entrance.
Country rock: Bündnerschiefer of the Veglia-syncline.
Paragenesis: *Muscovite*. FG 11f.

## BIBLIOGRAPHY

SMPM = Schweiz. Min. Petr. Mitt.

Armstrong, R. L., Jäger, E., and Eberhardt, P. (1966): A comparison of K-Ar and Rb-Sr ages on Alpine biotites. Earth and Planetary Sci. Letters, *1*, 13–19.

Arnold, A., and Jäger, E. (1965): Rb-Sr Altersbestimmungen an Glimmern im Grenzbereich zwischen voralpinen Alterswerten und alpiner Verjüngung der Biotite. Eclogae geol. Helv. *58*, 369–390.

Arnold, A. (1972): Rb-Sr-Altersbestimmungen an Mineralien alpiner Zerrklüfte und deren Nebengestein im Cristallinagranodiorit (Lukmanier, östliches Gotthardmassiv). SMPM, *52*, 537–551.

von Fellenberg, Edm. (1893): Geologische Beschreibung des westlichen Theils des Aarmassivs, enthalten auf dem nördlich der Rhone gelegenen Theile des Blattes XVIII der Dufour-Karte. Beitr. geol. Karte Schweiz, Liefg. 21.

Graeser, S., Niggli, E., Stalder, H. A. (1963): Morphologische Studien an einem grösseren Titanit-Fund südlich Gletsch. SMPM, *43/1*, 367–384.

Graeser, S. (1965): Die Mineralfunde im Dolomit des Binnatales. SMPM, *45*, 597–795.

Hansen, J. W. (1972): Zur Geologie, Petrographie und Geochemie der Bündnerschiefer-Serien zwischen Nufenenpass (Schweiz) und Cascata Toce (Italia). SMPM, *52*, 109–153.

Hunziker, J. (1966): Zur Geologie und Geochemie des Gebietes zwischen Valle Antigorio (Prov. di Novara) und Valle di Campo (Kt. Tessin). SMPM, *46*, 473–552.

Hunziker, J. C. (1970): Polymetamorphism in the Monte Rosa, Western Alps. Eclogae geol. Helv. *63*/1, 151–161.

Jäger, E., and Faul, H. (1959): Age measurements on some granites and gneisses from the Alps. Bull. geol. Soc. Amer. *70*, 1553–1558.

Jäger, E., Niggli, E., and Wenk, E. (1967): Rb-Sr-Altersbestimmungen an Glimmern der Zentralalpen. Beitr. geol. Karte Schweiz, N.F. 134.

NIGGLI, E., and NIGGLI, C. R. (1965): Karten der Verbreitung einiger Mineralien der alpidischen Metamorphose in den Schweizer Alpen (Stilpnomelan, Alkali-Amphibol, Chloritoid, Staurolith, Disthen, Sillimanit). Eclogae geol. Helv. *58/1*, 335–368.

NIGGLI, E. (1972): Alpine Metamorphose und alpine Gebirgsbildung. Fortschr. Miner. *47*/1, 16–26.

POTY, B., and STALDER, H. A. (1970): Kryometrische Bestimmungen der Salz- und Gasgehalte eingeschlossener Lösungen in Quarzkristallen aus Zerrklüften der Schweizer Alpen. SMPM, *50*/1, 141–154.

PURDY, J. W. (1972): The Varian Mat GD 150 for Argon Analysis in connection with K-Ar Dating. Eclogae geol. Helv. *65*/2, 317–320.

STALDER, H. A., DE QUERVAIN, F., NIGGLI, E., und GRAESER, ST. (1973): Die Mineralfunde der Schweiz. Neubearbeitung von R. L. Parker: Die Mineralfunde der Schweizer Alpen. Verlag Wepf, Basel.

WAGNER, A., FREY, M., QUADRIO, F., SCHWARTZKOPFF, J., and STALDER, H. A. (1972): Die Mineralfundstellen von Camperio und Campo Blenio, Kanton Tessin, Jb. Naturhist. Museum Bern, 1969–1971, 277–360.

WEIBEL, M., and MEYER, F. (1957): Zum Chemismus der alpinen Adulare (I). SMPM *37*, 153–158.

WIELAND, H. (1966): Zur Geologie und Petrographie der Valle Isorno (Novara, Italia). SMPM *46*, 189–303.

WENK, E. (1962): Plagioklas als Indexmineral in den Zentralalpen. Die Paragenese Calcit-Plagioklas. SMPM *42/1*, 139–152.

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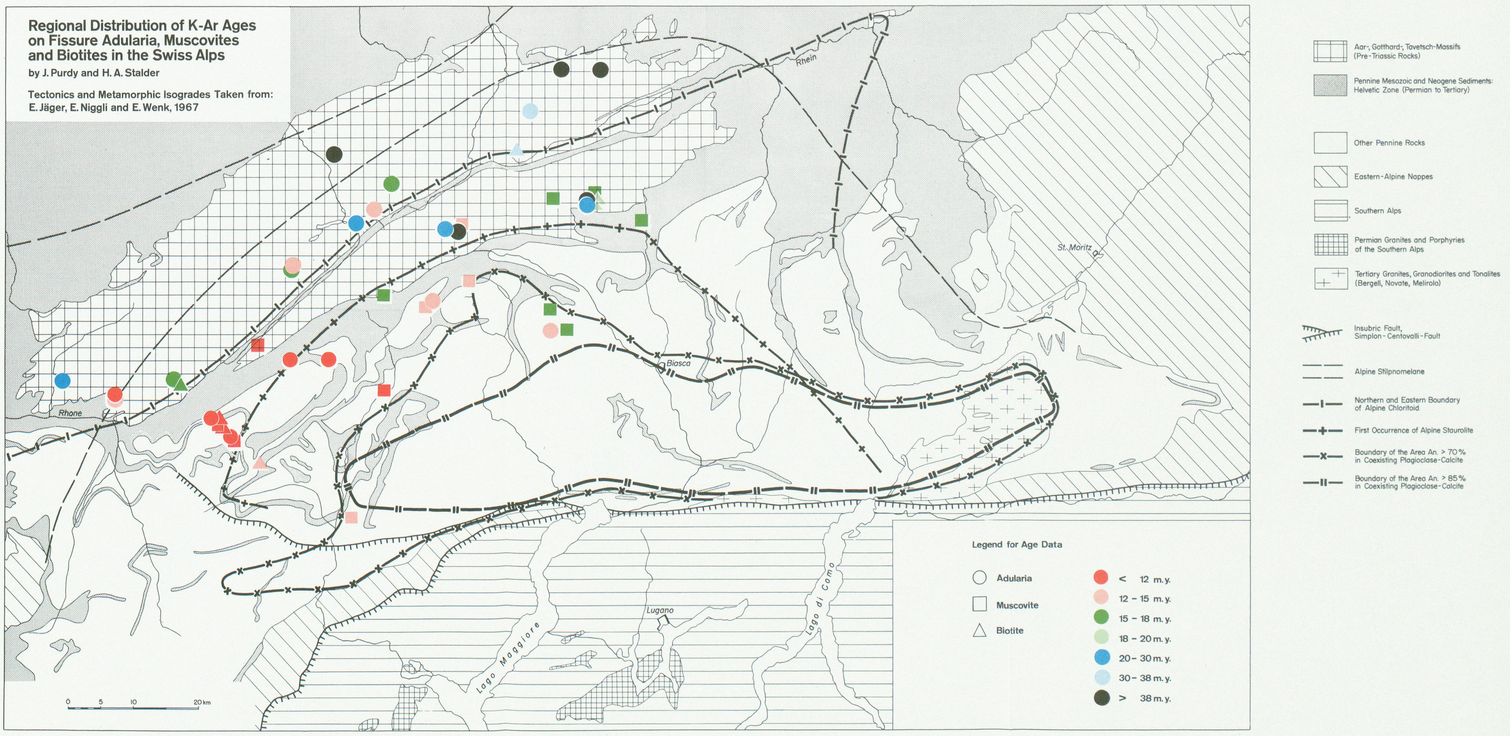
PLATE I

J. W. PURDY and H. A. STALDER: K-Ar Ages of Fissure Minerals from the Swiss Alps



## Regional Distribution of K-Ar Ages on Fissure Adularia, Muscovites and Biotites in the Swiss Alps

by J. Purdy and H. A. Stalder

Tectonics and Metamorphic Isogrades Taken from:
E. Jäger, E. Niggli and E. Wenk, 1967