# Isotopic dating of adularia-bearing epigenetic mineralizations: I. Saar-Nahe region/Southwest Germany

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Abstract: Isotopic age determinations (40 Ar/39 Ar, Rb/Sr) on hydrothermally formed K-feldspars (adularia) from epigenetic vein mineralizations in the Saar-Nahe region (SW Germany) yielded age values of 224 Ma and 219 Ma. This places mineralizing activities in this region in the Upper Triassic. The geological significance of the isotopic data is assured by age concordances between a) the Rb/Sr and K/Ar systems, b) petrographically different adularia types and c) adularia from different locations. According to chemical and X-ray structural investigations, the adularia are pure K-feldspars with Or contents > 98 mol.% with a relatively high degree of Al,Si disorder. Due to the paragenetic position of the adularia within the sequence of the Saar-Nahe mineralizations as well as to the corresponding experimentally determined time marks, a considerable number of these mineralizations can be attributed to a syn- to post-Triassic age. A genetic relationship to the Permian magmatism of the Saar-Nahe region does not exist for these mineralizations in the sense of a post-magmatic sequence. This conclusion is supported by the 87Sr/86Sr variation of paragenetic calcites of 0.7103 ± 0.0006 which is significantly higher than the Sr initial ratios of the Permian magmatic rocks. The mineralizing events confirm an Upper Triassic super-regional hydrothermal phase whose existence has already been established for Western and Southern Europe and can now be extended to Central Europe.

**Key-words**: adularia, <sup>40</sup>Ar/<sup>39</sup>Ar dating, Rb/Sr dating, mineralization, Southwest Germany.

#### 1. Introduction

Adularia are hydrothermally formed K-feld-spars and are characterized morphologically – in contrast to other K-feldspar types – by the dominance of (110) and (101) faces (e.g. Franke and Ghobarkar, 1982). Munhá et al. (1980) determined, based on oxygen isotopic fractionation, crystallization temperatures of adularia in sea-floor rhyolites to be less than 140 °C. The crystallization temperatures of recent adularia in geothermal fields are below 265 °C (Steiner, 1968; 1970). Adularia are found in related geological environments in

parageneses of economically important mineralizations, e.g., in the inner zones of porphyry Cu deposits (e.g. Rose, 1970), in vein-like U deposits (e.g. Rich et al., 1977), in Au-bearing quartz veins (e.g. Silberman et al., 1972), in sub-volcanic Au-Ag vein deposits (e.g. Buchanan, 1981) or in baryte-fluorite vein mineralizations (e.g. Ziehr, 1967). Neogenic low-temperature K-feldspars are also known to exist in sedimentary (e.g. Kastner and Siever, 1979), magmatic and metamorphic environments (e.g. Mensing and Faure, 1983).

Particularly in hydrothermal mineralizations, adularia is of substantial interest with respect to the genesis of ores and gangues. As a K and Rb-bearing mineral, it may serve as a possible isotopic geochronometer for K/Ar and Rb/Sr

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dating. The paragenetic position of adularia in epigenetic deposits is often well definable within the polycyclic sequences of tectonics and mineralization (e.g. Badham, 1975; Mertz et al., 1989a). This permits the attribution of acquired isotopic age data to specific mineralizing events. Thus, it is possible to recognize causal mechanisms between the general geological evolution and the genesis of mineralizations. With the exception of a few minerals (e.g. Silberman and Ashley, 1970), other gangue and ore minerals are not suitable for isotopic K/Ar and Rb/Sr dating, as the radioactive nuclides <sup>40</sup>K and <sup>87</sup>Rb are not present in sufficient quantities.

The concordance of Rb/Sr (Lippolt et al., 1985), K/Ar (Brockamp and Zuther, 1985) and <sup>40</sup>Ar/<sup>39</sup>Ar ages (Mertz, 1987) of adularia of the same paragenesis from the Wölsendorf ore district (South Germany), indicates that hydrothermally formed K-feldspar may supply geologically significant age data. However, it is known that adularia are often susceptible to isotopic disturbance, which is evident in discordant K/Ar and Rb/Sr ages (Bass and Ferrara, 1969; Mertz et al., 1989a). These disturbances might be caused by Ar losses due to later hydrothermal (Kämpf and Pilot, 1981) or meta-

morphic (Bass and Ferrara, 1969) overprints or by changes of the structural state of the K-feldspars (Halliday and Mitchell, 1976). On the other hand, adularia are also known as reservoirs of excess argon (Joseph *et al.*, 1973; Purdy and Stalder, 1973; Hess, 1985). The results of the studies cited show that the application of adularia as isotopic chronometer in hydrothermal environment leaves a number of questions without a satisfying final answer.

Isotopic K/Ar or 40Ar/39Ar and Rb/Sr datings were carried out on adularia from epigenetic vein mineralizations in SW Germany (Saar-Nahe area. Odenwald, Pfälzerwald Schwarzwald). The main objectives of these investigations were 1) to work out the argon isotope systematics of adularia and 2) to explain geological aspects of the genesis of the mineralizations, in particular their temporal positions as well as causal correlations to the overall geotectonic evolution. The adularia analyzed in this study, which have been described by Müller (1975), are from mineralizations in the Saar-Nahe region.

## 2. Geological setting

The investigated mineralizations are located

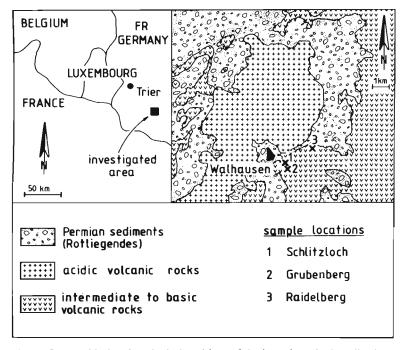


Fig. 1. Geographical and geological positions of the investigated mineralizations.

in the Saar-Nahe region (SW Germany) about 50 km SE of Trier, 1 to 2 km W of the village Walhausen (Fig. 1). The locations Schlitzloch, Grubenberg and Raidelberg represent the sampling points. The geological map of the "Saar-Nahe Bergland" 1:100000 (Dreyer et al., 1983) displays Permian intermediate to basic effusive rocks and acid magmatic rocks in the area of the mineralizations. This magma production is part of a phase of intensive volcanic activity which accompanied the formation of intramontanous basins in various parts of Europe after the Hercynian orogen. In the Saar-Nahe basin, tuffs and volcanic rocks were supplied during the Rotliegendes. Together with clastic-terrestrial sediments they form the so-called "Grenzlager", a lithological unit at the basis of the Upper Rotliegendes (e.g. Falke, 1959; Bambauer, 1960; Jung, 1970). K/Ar and 40Ar/ <sup>39</sup>Ar systematics yielded an age range of 295-300 Ma for biotites from rhyolites and tuffs of the "Grenzlager" (Lippolt and Hess, 1983). A Rb/Sr isochron (biotite and apatite, n = 27) gave an age of 291 ± 1 Ma (Lippolt et al., 1989).

## 3. Mineralization and parageneses

The mineralizations investigated are vein-like Pb-Cu mineralizations, related to tectonically fractured zones. The paragenetic succession is outlined in Fig. 2. Müller (1983; 1988) makes

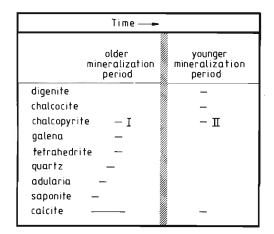


Fig. 2. Paragenetic succession of the Walhausen mineralizations (simplified after Müller, 1983). The hatching indicates a (non-defined) hiatus between an older and a younger mineralization period.

a distinction between an older Saxonian and a younger Saxonian mineralization period with an obvious hiatus. The succession of the older mineralization period, from old to young, is saponite, adularia and quartz, followed by the ores galena, tetrahedrite and chalcopyrite I. In the younger mineralization period, the ores digenite, chalcocite and chalcopyrite II were deposited. Calcite is ubiquitous. According to Müller (1983; 1988), this succession in principle may be attributed to a large-scale existing paragenetic succession, which is observed in various parts of the whole Saar-Nahe-Pfalz region. The isotopic dating of the adularia supplies an older time mark for the ores of the older and the younger mineralization periods due to its defined position within the paragenetic succession. The large-scale consistence of paragenetic relations makes this time mark not only of local importance for the Walhausen mineralization. It is also significant for the metallogenesis in the super-regional context.

## 4. Description of the dated adularia

## 4.1. Petrography

Thin-section investigations show that the host rocks of the mineralizations are tectonically overprinted andesitic rocks with alteration phenomena of various intensities. The tectonic stress is evident in numerous fractures of the plagioclase xenocrysts. Most of the fractures were healed by a probably syntectonic iron ore phase. Evident alterations are the replacement of mafics (probably hornblende) by ore and Mg,Fe sheet silicates, as well as the crystallization of authigenic K-feldspars which in turn may be affected by ore impregnations or light micatizations.

Principally, the authigenic K-feldspars occur in three different types: Type A is an idiomorphic to hypidiomorphic crystal with adularia habit in vesicular spaces (Fig. 3) and in joints. The K-feldspars are defined in the paragenetic sequence of the mineralization. Type B consists of xenomorphic poly-aggregates which replace dispersely the groundmass of the andesitic rocks (Fig. 4). Type C is a K-feldspar which replaces the plagioclase xenocrysts (Fig. 5). Type B and C of K-feldspars indicate that the andesitic host rock of the mineralizations has

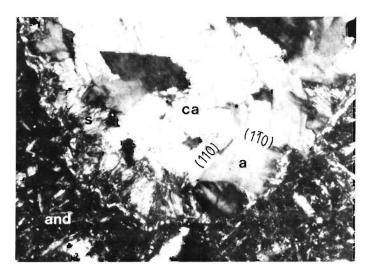


Fig. 3. Thin section (+N, width of photograph approx. 1.1 mm) of neogenic K-feldspar of type A: idiomorphic to hypidiomorphic crystals with adularia habit. The adularia (a) occur in vesicles in andesitic rocks (and), some of them have grown on fibrous sheet silicates (s). The marked adularia crystal shows a cut approx.  $\bot$  [001] with well-developped (110) and ( $1\overline{1}0$ ) faces.

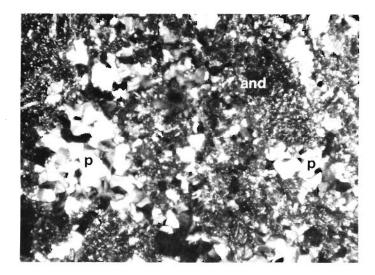


Fig. 4. Thin section (+N, width of photograph approx. 2.7 mm) of neogenic K-feldspar of type B: xenomorphic poly-aggregates (p) dispersely replace ground mass of andesitic rocks (and).

been affected by a K-metasomatosis. A correlation between the genesis of adularia and the K-metasomatic overprint of the wall rocks is assumed to be very likely. Similar phenomena of K-feldspar displacements are reported by Steiner (1970) on post-Miocene rhyolitic rocks within a recent geothermal field. Cathodoluminescence investigations on K-feldspars of type

A show that these adularia display a zoned structure (Fig. 6), documenting a quasi phase-like growth of adularia.

### 4.2. Measured samples

Conventional mineral-separation methods (crushing, sieving, magnetic separation, density

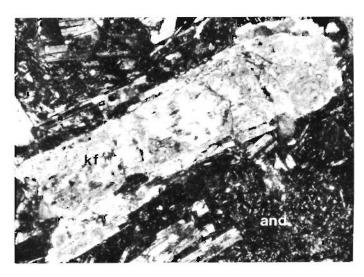


Fig. 5. This section (+N, width of photograph approx. 2.7 mm) of neogenic K-feldspar of type C: replacements of plagioclase xenocrysts in andesitic rocks (and) with typical spotty extinction of the K-feldspar.

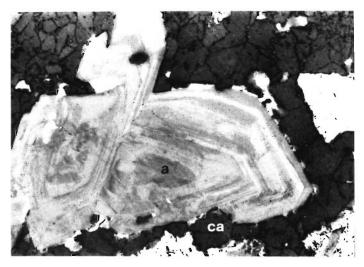


Fig. 6. Cathodoluminescence photograph (width of photograph about 0.4 mm) of neogenic K-feldspar of type A: the adularia crystals (a) show a clear zoned structure (original luminescence colour: dark-red). At the rims, a replacement of adularia by calcite (ca) (original luminescence colour: lilac) takes place.

separation, hand-picking) were performed. K-feldspar samples from the locations Schlitzloch, Grubenberg and Raidelberg for <sup>40</sup>Ar/<sup>39</sup>Ar and Rb/Sr measurements, as well as calcites from the locations Schlitzloch and Grubenberg for <sup>87</sup>Sr/<sup>86</sup>Sr measurements were prepared. The compositions of the K-feldspar separates were checked using grain thin-sections. Table 1 lists the petrographic characteristics of the samples.

The separates Grubenberg 01 and Raidelberg 01 are colourless-milky adularia, Grubenberg 02 represents colourless-clear adularia, Schlitzloch 01 are milky and clear adularia with slight sheet-silicate contamination. Sample Grubenberg 03 represents adularia overprinted by slight to intensive ore impregnations. All measured samples are exclusively K-feldspars of type A, comprised of different adularia

Sample		Relat	tive psition	Colour/transparency
Grubenberg	01*	>97%	Туре А	colourless-milky
Grubenberg	02*	>97%	Type A	colourless-clear
Grubenberg	03^^	≈90%	Type A	colourless to reddish
		≈10%	ore (weak	to intensive impregnation)
Raidelberg	01*	>97%	Type A	colourless-milky
Raidelberg	02*		Type A Type B	colourless to sligthly reddish very weak ore impregnation
Schlitzloch	01*		Type A sheet sil:	colourless, milky to clear
Schlitzloch	02 ^	≈70%	Type A	colourless-milky
		₹10%	Type B	to reddish
		≈20%	ore (weak	to intensive impregnation)

Table 1. Petrographic description of the measured K-feldspar separates.

populations (milky, colourless, etc.). Raidelberg 02 and Schlitzloch 02 are mixed separates which contain K-feldspars of type A and B and display ore impregnations of various intensities.

For the strontium isotopic measurements, calcites were extracted from small veins (Schlitzloch: WS ca 01-a to WS ca 01-c, Grubenberg: WG ca 01) and from vesicles (cf. Fig. 3) in andesitic host rocks (Schlitzloch: WS ca 02, Grubenberg: WG ca 02).

## 4.3. Chemical composition and X-ray structure

In order to characterize the adularia chemically and structurally and to recognize possible correlations between isotopic behavior and mineralogical state, microprobe and X-ray structural analyses were carried out on selected samples. Table 2 presents the chemical composition of the adularia Schlitzloch 01 and 02 together with reference data on adularia from two other Central European vein mineralizations. The adularia analyzed are K-feldspars of type A, whereas Schlitzloch 02, in contrast to separate 01, displays intensive iron-ore impregnations. Both samples show nearly the same composition (cf. Table 2). The  $SiO_2$ ,  $Al_2O_3$  and K<sub>2</sub>O contents are in good concordance with the reference data. The CaO and Na2O contents deviate. For the Schlitzloch adularia, the albite and anorthite components are below the litera-

Table 2. Chemical compositions of the adularia samples Schlitzloch 01 and Schlitzloch 02 (microprobe analyses) as well as reference analyses of adularia from other Central European vein deposits.

Saunple	:	Schlitz- loch 01	Schiitz- loch 02	Wölsen-1) dorf	Schmiede-	
Wt%	SiO2	64.36	64.18	64.07	64.63	
	T102	0.05	b.d.	n.d.	n.d.	
	A1203	18.76	18.41	18.80	18.62	
	FeŐ	0.01^	0.85*	0.47**	n.d.	
	MgO	n.d.	n.d.	0.20	n.d.	
	MnO	b.d.	þ.d.	n.d.	n.d.	
	CaO	0.01	b.d.	0.53	0.45	
	BaO	n.d.	n.d.	b.d.	n.d.	
	Na2O	0.04	0.11	0.34	1.11	
	K <sub>2</sub> Ō	16.29	15.88	15.43	15.39	
	Total	99.52	99.43	99.84	100.20	
Number:	s of ion	ns on the ba	sis of 32 O			
Number	s of ion	ns on the ba	sis of 32 O	11.827	11.979	
Number					11.979 4.046	
	si	11.899	11.951	11.827		
	Si Al	11.899	11.951	11.827	4.046	
	Si Al Z	11.899 4.153 16.052	11.951	11.827	4.046	
	Si Al Z	11.899 4.153 16.052 0.007	11.951 4.040 15.991	11.827 4.091 15.918	4.046	
	Si Al Z Ti Fe	11.899 4.153 16.052 0.007	11.951 4.040 15.991	11.827 4.091 15.918	4.046	
	Si Al Z Ti Fe Mg	11.899 4.153 16.052 0.007 0.001	11.951 4.040 15.991	11.827 4.091 15.918 0.064 0.055	15.963	
	Si Al Z Ti Fe Mg Ca	11.899 4.153 16.052 0.007 0.001	11.951 4.040 15.991 0.132	11.827 4.091 15.918 0.064 0.055 0.105	4.046 15.963 0.089	
Σ	Si Al Z Ti Fe Mg Ca Na	11.899 4.153 16.052 0.007 0.001 0.001 0.015	11.951 4.040 15.991 0.132	11.827 4.091 15.918 0.064 0.055 0.105 0.122	0.089 0.397	
Σ	Si Al Z Ti Fe Mg Ca Na K	11.899 4.153 16.052 0.007 0.001 0.001 0.015 3.903	11.951 4.040 15.991 0.132 0.040 3.771	11.827 4.091 15.918 0.064 0.055 0.105 0.122 3.634	0.089 0.397 3.620	
Σ	Si Al Z Ti Fe Mg Ca K	11.899 4.153 16.052 0.007 0.001 0.001 0.015 3.903 3.928	11.951 4.040 15.991 0.132 0.040 3.771 3.944	11.827 4.091 15.918 0.064 0.055 0.105 0.122 3.634 3.980	0.089 0.397 3.620 4.106	

b.d.: below detection limit
n.d.: not determined
1) Riederer (1966)
2) Hintze (1897)

separate for 40Ar/39Ar analysis \*\* separate for Rb/Sr analysis

<sup>\*</sup> total iron as FeO \*\* total iron as Fe<sub>2</sub>O<sub>3</sub>

ture values by approximate factors of 25 and 100, respectively. The relatively high FeO contents of about 0.9 wt.% of adularia Schlitzloch 02 may be assigned to the ore impregnations of the feldspar. Generally, the Schlitzloch adularia are very pure K-feldspars with Or contents > 98.9 mol.%. The reference adularia show significant lower Or contents of about 94 and 88 mol.%, respectively.

X-ray structure analyses of the adularia Raidelberg 01, Schlitzloch 01 and 02, a sanidine standard (Volkesfeld/Eifel, FRG) and of a microcline standard (Gundlebo/Sweden) were carried out using the Guinier technique. The data processing was done photometrically. The three adularia show analogous positions and intensities of diffraction maxima, which are similar to the diffraction pattern of the sanidine standard. A splitting into the line pairs  $(1\overline{3}0)$ and (130) (MacKenzie, 1954) or  $(1\overline{3}1)$  and (131) (Goldsmith and Laves, 1954a; 1954b), which is characteristic for the development of triclinic compounds, is not found in the adularia. However, the (130) and (131) diffraction maxima of the adularia are more widely spread compared to those of the sanidine standard. This is supposed to be due to a weak development of domains with Al, Si ordering tendencies. Taken as a whole, the adularia are to be regarded as radiographically monoclinic K-feldspars with a relatively high state of Al, Si disorder.

tion of 63 ppm and a  ${}^{87}\mathrm{Sr}/{}^{86}\mathrm{Sr}$  ratio of 0.8019 ± 0.0001 (Table 3). Sr ratios of the paragenetic calcites range from 0.7097 to 0.7109 (Table 4). Assuming this 87Sr/86Sr variation to be the initial value, a Rb/Sr age of 220.4 ± 4.8 Ma is calculated for the adularia ( $\lambda$  87Rb = 1.42 ·  $10^{-11}$  a<sup>-1</sup>). In order to demonstrate the significance of our data, accompanying concentration and isotope measurements on NBS standards potassium feldspar 607 and SrCO<sub>3</sub> 987 were performed. The results of our standard analyses agree with the certified values within analytical errors. Therefore the analytical data are considered to be significant. The exact data of our standard measurements have been discussed by Mertz (1987).

For <sup>40</sup>Ar/<sup>39</sup>Ar dating the adularia samples were wrapped in aluminium foil and irradiated (dose approx.  $1.5 \cdot 10^{17}$  and  $5 \cdot 10^{17}$ ) in cadmium-mantled evacuated quartz ampoules in a reactor of the Nuclear Research Centre Jülich (FRG). Each adularia sample was positioned between two standards. The irradiation gradients between two standards ranged from 1 to 8 %. Stepwise heating technique was applied. Ar extraction was done in an inductively heated molybdenum crucible or in a resistanceheated low blank vacuum apparatus modified after Staudacher et al. (1978). Ar blanks at 1h/  $1600^{\circ}$ C were approx.  $2 \cdot 10^{-8}$  or  $4 \cdot 10^{-9}$  cm<sup>3</sup> STP for the inductively heated crucible or the resistance-heated apparatus, respectively, and

Table 3. Rb and Sr concentration and isotope measurements on the adularia sample Grubenberg 03.

Rb [ppm]	Sr [ppm]	87 <sub>Rb/86</sub> sr	87 <sub>Sr/86</sub> <sub>Srt</sub>	87 <sub>Sr/86</sub> <sub>Sri</sub>	Age [Ma]
63.1	6.26	29.22	0.80188	0.7103	220.4
± 0.2	±0.02	± 0.09	±0.00008	±0.0006	± 4.8

The age of the adularia is  $220.4 \pm 4.8$  Ma, calculated with an initial Sr ratio of  $0.7103 \pm 0.0006$ , corresponding to the  $^{87}$ Sr/ $^{86}$ Sr spectrum of paragenetic calcites (Analytical errors :  $1-\sigma$ ).

# 5. Isotopic analyses and results

Rb/Sr and K/Ar dating methods were applied, the latter using the <sup>40</sup>Ar/<sup>39</sup>Ar technique. Rb and Sr concentrations and isotope compositions were determined using a Finnigan solid-source mass spectrometer MAT 261 with computerized data acquisition. The analysis of the adularia sample Grubenberg 03 yielded a Sr concentration of 6.3 ppm, a Rb concentra-

Table 4. 87Sr/86Sr ratios of various calcites from the Walhausen mineralizations Schlitzloch (WS) and Grubenberg (WG).

Sa	npl	e	87 <sub>Sr</sub> /86 <sub>Sr</sub>	±	1-σ
ca	WS	01-a	0.70989	±	0.00008
ca	WS	01-ь	0.70971	±	0.00002
ca	WS	01-c	0.70987	±	0.00003
ca	ws	02	0.70994	±	0.00002
ca	WG	01	0.71088	±	0.00002
сa	WG	02	0.71079	±	0.00005

better for lower temperatures. The isotopic compositions were measured on a Finnigan gas source mass spectrometer MAT-GD 150 in static mode. Muscovite of the Bärhalde Granite served as working standard ( $t_{integrated}$ : 326.2  $\pm$  2.0 Ma; Rittmann, 1984), which has been calibrated against the international hornblende standard MMhb-1 (Alexander et al., 1978). The age calculation is based on the constants recommended by Steiger and Jäger (1977). Table 5 lists the 40Ar/39Ar age results of the adularia. The Grubenberg samples 01 and 02 yield integrated ages of 225.0 ± 1.1 Ma and  $225.4 \pm 1.2$  Ma, the Raidelberg samples 01 and 02 yield 218.0  $\pm$  1.3 Ma and 211.9  $\pm$  1.4 Ma, whereas the Schlitzloch samples 01 and 02 yield 220.2  $\pm$  1.3 Ma and 214.1  $\pm$  1.2 Ma (Analytical errors of integrated ages and step age values do not contain monitor uncertainties). The plateau ages are  $226.3 \pm 3.0$  Ma and  $226.2 \pm 3.5$  Ma for the Grubenberg samples 01 and 02, 219.0  $\pm$  2.7 Ma and 218.9  $\pm$  2.8 Ma for the Raidelberg samples 01 and 02, as well as  $222.2 \pm 3.1$  Ma and  $214.7 \pm 2.4$  Ma for the Schlitzloch samples 01 and 02 (Analytical errors of plateau ages contain monitor uncertainties). Fig. 7 displays the degassing spectra.

# 6. Discussion of the analytical results

All adularia samples show relatively undisturbed <sup>40</sup>Ar/<sup>39</sup>Ar degassing spectra with plateau areas each > 70 % of the total <sup>39</sup>Ar degassing. The degassing steps in the low-temperature range each display apparent ages considerably younger than the plateau areas. This may be caused by slight Ar losses. Therefore, the plateau ages are considered to be of higher significance than the integrated ages.

For the location Grubenberg, concordant  $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$  plateau and Rb/Sr ages were obtained on different adularia populations. This concordance, both with independent isotopic systems and with petrographically different populations, indicates the geological significance of these isotopic ages. Considering the overlapping of the analytical errors of  $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$  and Rb/Sr ages, a hydrothermal event at 224 Ma is manifested, which is interpreted to be the crystallization age of the adularia of the location Grubenberg.

The adularia samples of the location Raidel-

berg display concordant 40Ar/39Ar plateau ages which are lower by about 4 Ma when compared with the Grubenberg data. This hiatus is not attributed to disturbances of the isotopic system by Ar losses of the Raidelberg adularia, but it is caused by the crystallization of two distinct adularia generations at the locations Grubenberg and Raidelberg. This is indicated by the following: a) The Raidelberg adularia has, like the Grubenberg adularia, a relatively undisturbed degassing spectrum with a clearly developed age plateau. b) The X-ray structure investigations show that the sample Raidelberg 01 is a radiographically monoclinic adularia with a relatively high degree of Al, Si disorder. Ar losses like those seen by Halliday and Mitchell (1976) due to the formation of triclinic compounds, therefore, have to be regarded as rather unlikely. c) Ar losses, caused by secondary overprints such as sericitization or ore impregnation, can be ruled out based on microscopic observations. d) Ar vacuum-diffusion analyses on the sample Raidelberg 01 yielded an activation energy for  $^{39}$ Ar of 134  $\pm$  7 kJ/mol (Mertz et al., 1989b). This value corresponds to the range of activation energies for volcanic high sanidines (personal communication Hess and Lippolt, 1989), which are to be regarded as excellent K/Ar chronometers (e.g. Hess and Lippolt, 1986). By analogy, this may also apply to the Raidelberg adularia. e) the samples Raidelberg 01 and 02 display different compositions of adularia types (cf. Table 1) with concordant K/Ar age data. The concordance of the isotopic ages of petrographically different samples suggests a very low probability of disturbance of the isotopic system. A crystallization age of 219 Ma is therefore assumed for the Raidelberg adularia.

The sample Schlitzloch 01 shows a <sup>40</sup>Ar/<sup>39</sup>Ar plateau age which, whithin analytical errors, agrees with the age of Grubenberg and Raidelberg adularia generations. Thus, this age range is confirmed by adularia from a third location. The plateau age of the sample Schlitzloch 02, however, is significantly lower, amounting to about 215 Ma. Since the samples Schlitzloch 01 and 02 are of very similar X-ray structure, the younger age of sample 02 probably cannot be attributed to Ar losses due to a higher degree of Al,Si ordering. Microscopic investigations show that part of the adularia Schlitzloch 02 are intensively impregnated by iron ore, either dispersely or in the shape of

Table 5. Results of  ${}^{40}\text{Ar}/{}^{39}\text{Ar}$  incremental heating measurements on adularia samples from the Walhausen mineralizations (Analytical errors :  $1-\sigma$ ).

Sample: Grubenberg 01   J = 4	Age [Ma]	40Arrad/39Ai	40Artotal	39Ar *10 <sup>-9</sup> cm <sup>3</sup> STP]	36Ar	erature Time [min]
170	4.290*10-3	.J =				
860 65 0.16110.001 131.4 10.3 4106 18 30.6610.10 9 2 920 65 0.1570.0017 119.5 10.2 3753 18 30.010.009 2 340 65 0.1992.0017 141.5 10.2 3753 18 31.0110.09 2 340 65 0.1992.0017 141.5 10.4 4456 111 31.0610.10 120 65 0.1410.0021 161.6 20.4 4456 111 31.0510.10 120 1100 65 0.04110.0021 161.6 20.4 4456 111 31.0510.10 120 1100 65 0.04110.0021 161.6 20.4 4456 111 31.0510.10 120 1100 65 0.04110.0021 161.6 20.4 4456 111 31.0510.10 120 1100 65 0.04110.0021 121.1 10.1 30033 1.7 31.3010.00 8 2 11100 65 0.04110.0021 121.1 10.1 30033 1.7 31.3010.00 11100 65 0.04110.0021 121.1 10.1 30033 1.7 31.3010.00 11100 65 0.04110.0021 121.1 10.1 30033 1.7 31.3010.00 11100 65 0.04110.0021 125.9 10.7 8116 142 31.7510.10 2 11100 65 0.19520.002 46.72 10.09 1292 12 26.8120.002 131.5 10.0 10.7 93551.003 25.81.0 8 30.6610.10 12 131.0 65 0.19520.002 46.72 10.09 1292 12 26.8120.002 131.5 10.0 10.0 12.0 12.0 12.0 12.0 12.0 12.0			1009 + 2	22 20 40		
920 65 0.15710.017 119.5 10.2 3733 18 31.0110.09 2 940 65 0.19920.027 141.6 10.4 4445 111 31.0610.19 2 940 65 0.19920.027 141.6 10.4 4445 111 31.0610.19 2 940 65 0.14110.023 164.6 10.4 3234 112 31.3510.11 2 1020 65 0.14110.023 164.6 10.4 3234 112 31.3510.11 2 1100 65 0.14510.038 1164.6 10.4 3234 112 31.3510.11 2 1100 65 0.14510.038 125.9 10.5 6735 131 30.9120.08 2 1130 65 0.13110.038 125.9 10.5 6735 131 30.9120.08 2 1130 65 0.13210.039 125.9 10.5 6735 131 30.9120.12 2 1210 65 0.28610.031 123.1 10.1 3875 110 31.1110.09 2 1220 65 0.28610.034 158.2 10.4 5081 111 31.5610.12 2 1330 65 0.13210.039 46.72 10.09 1292 1 2 2.6 810.08 1 1350 65 0.99510.014 7.99510.050 525.81 0.8 30.6610.58 2 1360 65 0.99510.014 7.99510.050 525.81 0.8 30.6610.58 2 18meje: Grubenberg 02  770 45 0.36410.030 46.42 10.05 1478 1 3 29.5010.08 1 980 65 0.1610.001 144.4 10.4 51144 112 32.2510.13 2 980 65 0.16010.087 212.0 10.5 6909 159 32 32.3510.29 2 980 65 0.16010.087 212.0 10.5 6909 159 32 32.3510.29 1 1140 65 0.21310.052 121.0 10.5 6909 159 32 32.3510.29 2 1140 65 0.21310.052 121.0 10.2 4005 111 32.8510.15 2 1140 65 0.21110.024 104.7 10.1 3513 17 32.9910.16 12 1130 65 0.24110.026 276.3 10.7 9016 147 32.5210.19 12 1130 65 0.24110.026 276.3 10.7 9016 147 32.5210.19 12 1130 65 0.24110.026 276.3 10.7 9016 147 32.5210.19 12 1150 60 0.08210.003 5.1020 11.3510.058 11.3 32.8510.19 12 1150 60 0.08210.003 5.1020 11.2510.17 1273 13 111.01.22 12.0 12.0 12.0 12.0 12.0 12.0	224.3± 0.7	30.86±0.10	4106 ± 8	131.4 ±0.3	0.161±0.001	65
960 65 0.19716.010 173.0 10.4 5468 ill 31.2610.11 2 1020 65 0.1410.023 10.4 6 20.4 5204 ill 31.31.2610.18 2 1100 65 0.1450.000 123.1 10.11 8875 ill 31.31.10.03 2 11100 65 0.1450.000 123.1 10.11 8875 ill 31.31.10.03 2 11190 65 0.45410.031 255.9 10.5 6735 ill 31.1110.09 2 11190 65 0.45410.031 255.9 10.7 6116 142 31.1710.19 2 1220 65 0.28510.04 7.93610.050 525.81 0.8 30.6610.18 2 1220 65 0.28510.014 7.93610.050 525.81 0.8 30.6610.18 2 1220 65 0.28510.014 7.93610.050 525.81 0.8 30.6610.18 2 1220 65 0.28510.014 7.93610.050 525.81 0.8 30.6610.18 2 1220 65 0.28610.024 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	225.3± 0.6 225.7± 0.9	31.01±0.09		119.5 ±0.2	0.157±0.017	
1060	227.0± 0.7	31.26±0.11	5468 ±11	173.0 ±0.4	0.197±0.010	65
1100	227.6± 0.8 227.3± 0.6	31.35±0.12	5204 ±12	164.6 ±0.4	0.141±0.023	
190	226.0± 0.6	31.11±0.09	3875 ±10	123.1 ±0.1	0.145±0.001	65
1220   65	225.1± 1.7 226.5± 1.3	30.97±0.26		215.9 ±0.5	0.151±0.038	
Integrated 3.437i0.075 1668 18 52654 172 30.95i0.16 2  Sample: Grubenberg 02	229.1± 0.8	31.56±0.12	5081 ±11	158.2 ±0.4	0.286±0.024	65
Sample: Grubenberg 02	196.4± 0.6 223.0± 4.0	26.81±0.08	1292 ± 2 525.8± 0.8	46.72 ±0.09 7.936±0.050	0.132±0.009	
Sample: Grubenberg 02  770	225.01 1.1					
170	4.095*10-3					
980 65 0.16010.087 212.0 10.5 6909 152 32.3510.29 2 1070 65 0.15110.055 146.8 10.4 4872 111 32.8810.16 2 1070 65 0.19210.018 77.76 10.10 2594 16 32.6110.11 2 1170 65 0.21310.052 121.0 10.2 4005 111 32.5710.16 2 1170 65 0.21310.052 121.0 10.2 4005 111 32.5710.16 2 1170 65 0.21310.022 10.07 10.2 4005 111 32.5710.16 2 1170 65 0.21310.024 10.07 10.2 4005 111 32.5710.16 2 1170 65 0.21310.024 10.07 10.2 4005 111 32.5710.16 2 1380 65 0.23110.036 26.27 10.15 9002 16 6 33.9010.09 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1550 65 0.39710.039 1381 17 45936 175 32.5020.18 2  Sample: Raidelberg 01  500 60 0.08210.002 1.19810.060 119 91 0.2 80.044 11 0.0 10.2 2 750 60 0.078810.04 5.79400.18 665.41 1.1 10.112.9 2 750 60 0.03510.019 9.65610.190 1077 1 1 1 1 10.112.9 2 850 60 0.05110.019 9.65610.190 1077 1 1 1 1 10.112.9 2 850 60 0.08210.002 10.61 10.21 119 1 1 1 11.322.2 2 850 60 0.08210.002 11.25 10.17 1273 1 3 111.001.7 2 950 60 0.09310.012 19.28 10.10 2269 1 3 113.100.6 2 1080 60 0.09310.012 19.28 10.10 2269 1 3 113.100.6 2 1080 60 0.09310.012 19.28 10.10 2269 2 3 113.100.1 2 1140 60 0.4110.055 42.98 10.09 3670 1 4 113.410.4 2 1140 60 0.4110.055 42.98 10.09 3670 1 4 113.410.4 2 1140 60 0.4110.055 42.98 10.09 3670 1 4 113.610.4 2 11500 60 0.1040.002 3.645 10.09 3670 1 4 1 113.610.4 2 1100 60 0.1040.002 3.008 20.008 20.008 20.008 20.008 20.009	205.8± 1.3	29.50±0.20	1478 ± 3	46.42 10.05	0.364±0.030	
980 65 0.1602.0.087 12.0 10.5 6909 152 32.35.0.29 2 1070 65 0.15110.055 146.8 10.4 4872 111 32.8810.16 2 1070 65 0.19210.018 77.76 10.10 2594 16 32.6110.11 2 1170 65 0.21310.052 121.0 10.2 4005 111 32.5740.16 2 1170 65 0.21310.052 121.0 10.2 4005 111 32.5740.16 2 1170 65 0.21310.052 121.0 10.2 4005 111 32.5740.16 2 1170 65 0.21310.024 10.77 10.7 3013 17.7 32.9410.10 2 11300 65 0.21310.036 276.7 10.7 3013 17.7 32.9410.10 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1380 65 0.33710.037 5.10210.036 252.21 0.6 29.9012.13 2 1550 65 0.92510.033 5.20610.040 455.01 1. 34.8311.92 2 1500 60 0.08210.032 1.19810.060 119 91 0.2 80.041 10.6 10.0 10.0 10.0 10.0 10.0 10.0 10.	223.8± 0.8 226.7± 0.7	32.25±0.13 32.70±0.11	5134 ±12 4771 ±10	156.9 ±0.4 144.4 ±0.4	0.248±0.034	
1070	224.5± 1.9	32.35±0.29	6909 ±52	212.0 ±0.5	0.160±0.087	65
1140 65 0.21310.052 121.0 10.2 4005 111 32.5740.16 22 11270 65 0.21310.024 104.7 10.1 3513 ± 7 32.9440.10 22 1230 65 0.24110.026 276.3 10.7 9061 ±47 32.5210.19 22 1300 65 0.24110.026 276.3 10.7 9061 ±47 32.5210.19 22 1300 65 0.24110.030 84.91 10.15 2902 ±6 33.1920.09 22 156 33.1920.09 21 1380 65 0.33780.037 5.10210.036 252.2±0.6 29.9021.13 21 1550 65 0.92520.033 5.20610.040 455.021.1 34.831.192 12 1550 65 0.92520.033 5.20610.040 455.021.1 34.831.192 12 1550 65 0.92520.039 5.20610.040 455.021.1 10.4 12.2 9 10.6 10.0 60 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0	227.9± 1.1 226.2± 0.7				0.151±0.055	
1170 65 0.24110.024 014.7 10.1 3919 7 32.9410.10 25 11300 65 0.24110.026 276.3 10.15 2902 147 32.520.19 2: 1300 65 0.28110.003 84.91 10.15 2902 147 32.520.19 2: 1300 65 0.28110.003 10.15 2902 147 32.520.19 2: 1550 65 0.28110.003 12.10.15 2902 147 32.520.19 2: 1550 65 0.28110.003 12.10.15 2902 147 32.520.09 2: 1550 65 0.28110.003 12.10.15 2902 147 32.520.09 2: 1550 65 0.28210.032 12.10.10.004 455.01.1 34.8311.92 2: 1550 65 0.28210.032 13.81 17 45936 175 32.5020.18 2: 1550 60 0.08210.032 13.81 17 45936 175 32.5020.18 2: 1550 60 0.04610.059 2: 63210.060 119 91 0.2 80.024.1 1: 1500.916.3 1: 1700 60 0.04610.059 2: 63210.078 279.32 0.6 100.916.3 1: 1700 60 0.27610.019 9: 79410.180 685.41 1.1 104.22.9 2: 1800 60 0.03510.020 10.6110.021 191 1 1.1 104.22.9 2: 1800 60 0.08210.002 11.25 10.17 1273 1: 3 111.01.7 2: 2 950 60 0.08210.002 11.25 10.17 1273 1: 3 111.01.7 2: 2 950 60 0.09310.012 19.28 10.10 2269 1: 3 113.10.6 2: 2 950 60 0.09310.012 19.28 10.10 2269 1: 3 113.10.6 2: 2 1000 60 0.0710.005 22.07 10.09 3671 1: 4 113.521.2 2: 1 1000 60 0.0710.005 22.07 10.09 3671 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3671 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3670 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3670 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3670 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3670 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3670 1: 4 113.610.4 2: 1 1200 60 0.10910.015 32.07 10.09 3670 1: 4 130.30 10.0 2: 1 1200 60 0.09310.012 19.28 10.09 3670 1: 8 130.30 10.6 2: 1 1200 60 0.09310.012 19.28 10.09 3670 1: 8 130.30 10.6 2: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.001 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60 0.09310.000 1: 1 1200 60	225.9± 1.1	32.57±0.16	4005 ±11	121.0 ±0.2	0.213±0.052	65
1300   65   0.28110.001   84.91 10.15   2902   2 6   33.1920.09   2 1300   65   0.39750.033   5.20610.040   455.01   1.1   34.8311.92   2 1   2   2   2   2   2   2   2   2	228.3± 0.7	32.94±0.10	3513 ± 7	104.7 ±0.1	0.211±0.024	
1380 65 0.33740.037 5.102t0.036 252.2t 0.6 29.9022.13 21  Integrated 3.483±0.139 1381 ±7 45936 ±75 32.50±0.18 2:  Sample: Raidelberg O1	225.6± 1.3 229.4± 0.6	33.19±0.09	2902 ± 6	84.91 ±0.15	0.281±0.001	65
Integrated 3.483±0.139   1381   ±7   45936   ±75   32.50±0.18   2.50±0.19   2.50±0.18   2.50±0.19   2.	208.4±14.0 240.6±12.4	29.90±2.13 34.83+1.92	252.2± 0.6 455.0+ 1.1	5.102±0.036	0.337±0.037	
Sample: Raidelberg 01  500 60 0.082±0.002 1.198±0.060 119 9± 0.2 80.0±4.1 11.600 60 0.046±0.059 2.633±0.078 279.3± 0.6 100.9±6.3 1.700 60 0.078±0.019 5.794±0.158 665.4± 1.1 104.152.9 2.2 850 60 0.051±0.019 9.655±0.190 1077 ± 4 109.9±2.3 2.850 60 0.051±0.019 9.655±0.190 1077 ± 4 11.09.1±2.9 2.2 850 60 0.082±0.002 10.6± 10.21 119± ±1 111.3±2.2 2.8 2.950 60 0.082±0.002 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.0±1.7 2.950 60 0.093±0.012 11.25±0.17 1273 ± 3 111.1±0.6 ± 2 1080 60 0.041±0.005 42.99±0.07 3455 ± 6 113.5±0.4 2.9 11.05±0.1 11.25±0.	225.4± 1.2					
Source   S	1.143*10-3	J =			<b>7</b> 01	
600 60 0.04610.059 2.632±0.078 279.3± 0.6 100.9±6.3 1.700 60 0.278±0.014 5.794±0.158 685.4± 1.1 104.1±2.9 12.750 60 0.051±0.019 9.656±0.190 1077 ±4 109.9±2.3 2.850 60 0.035±0.020 10.61 to.21 1191 ±1 111.3±2.2 2.850 60 0.082±0.002 11.25 ±0.17 1273 ±3 3 111.0±1.7 2.950 60 0.082±0.002 11.25 ±0.17 1273 ±3 3 111.0±1.7 2.950 60 0.082±0.002 11.25 ±0.17 1273 ±3 3 111.0±1.7 2.950 60 0.062±0.014 11.42 ±0.20 21.25 ±1 115.2±2.8 115.2±2.8 2.950 60 0.062±0.014 11.42 ±0.20 21.25 ±1 115.2±2.8 2.950 60 0.062±0.014 11.42 ±0.20 21.25 ±1 115.2±2.8 2.950 60 0.062±0.014 11.42 ±0.20 21.25 ±1 115.2±2.8 2.950 60 0.062±0.014 11.42 ±0.20 21.25 ±1 115.2±2.8 2.950 60 0.062±0.014 11.42 ±0.07 3671 ±4 11.3 ±0.6 ±2 1140 60 0.41±0.059 42.98 ±0.09 4964 ±6 112.7±0.5 ±2 1260 60 0.148±0.047 16.56 ±0.09 1911 ±3 112.7±0.5 ±2 1260 60 0.148±0.047 16.56 ±0.09 1911 ±3 112.7±1.0 ±2 1250 60 0.224±0.022 12.87 ±0.06 1516 ±2 112.7±0.5 ±2 1250 60 0.244±0.022 12.87 ±0.06 1516 ±2 112.7±0.5 ±1 12.5±0.01 12.5±0.00 60 0.146±0.020 1.848±0.068 243.7±0.5 108.5±5.1 ±2 11.0 ±0.05 ±	157.9± 7.7		119.9± 0 2	1.198±0.060		
The column   The	197.0±11.5	100.9±6.3	279.3± 0.6	2.632±0.078	0.046±0.059	60
800 60 0.03510.020 10.61 t0.21 1191 t 1 111.322.2 2 2 900 60 0.08210.002 11.25 t0.17 1273 t 3 111.021.7 2 900 60 0.08210.002 11.25 t0.17 1273 t 3 111.021.7 2 900 60 0.02910.014 11.42 t0.27 1325 t 1 115.212.8 2 955 60 0.09310.014 11.42 t0.27 1325 t 1 115.212.8 2 950 60 0.09310.012 19.28 t0.10 2269 t 3 111.021.7 2 1000 60 0.06710.008 29.89 t0.10 2269 t 3 113.110.61.4 2 1080 60 0.10910.015 32.07 t0.09 3671 t 4 113.410.4 2 1140 60 0.41110.059 42.98 t0.09 3671 t 4 113.410.4 2 1140 60 0.41110.059 42.98 t0.09 3671 t 4 113.410.4 2 1140 60 0.41110.059 42.98 t0.09 3671 t 4 113.410.8 2 1140 60 0.04110.059 42.98 t0.09 3671 t 4 113.220.8 2 1140 60 0.04110.059 42.98 t0.09 3671 t 4 113.200.8 2 1140 60 0.04110.059 42.98 t0.09 3671 t 4 113.200.8 2 1140 60 0.04110.047 16.56 t0.09 3671 t 4 113.200.8 2 1150 60 0.22410.022 12.84 t0.09 1811 t 2 1112.7 t0.5 2 1150 60 0.04140.047 16.56 t0.09 3671 t 4 113.200.8 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.09 3671 t 4 113.200.7 2 1150 60 0.04410.047 16.56 t0.048 10	202.9± 5.4 213.6± 4.2	104.1±2.9		5.794±0.158		
850 60 0.08210.002 11.25 ±0.17 1273 ±3 111.01.7 2 950 60 0.09210.012 11.25 ±0.17 1273 ±3 111.01.7 2 950 60 0.09210.012 11.28 ±0.17 1225 ±1 115.212.8 1 950 60 0.09210.012 11.28 ±0.10 2169 ±3 113.110.6 2 1000 60 0.06712.008 29.89 ±0.10 3675 ± 6 113.5±0.4 2 1080 60 0.10910.015 32.0 ±0.09 3675 ± 6 113.5±0.4 2 1080 60 0.10910.015 32.0 ±0.09 3675 ± 6 113.5±0.4 2 1260 60 0.10910.025 32.14 ±0.07 3671 ± 4 113.5±0.4 2 1260 60 0.148±0.047 16.56 ±0.09 1911 ± 3 112.7±1.0 2 1250 60 0.224±0.022 12.87 ±0.06 1516 ± 2 112.7±1.0 2 1350 60 0.224±0.022 12.87 ±0.06 1516 ± 2 112.7±1.0 2 1350 60 0.244±0.020 1.848±0.068 243.7± 0.5 108.5±5.1 2 11ntegrated 1.908±0.105 240.7 ±1.5 27612 ±13 112.3±0.7 2  Sample: Raidelberg 02  Sample: Raidelberg 02  Sample: Absolute 1.908±0.105 130.0±0.05 1491 ± 5 104.0±0.7 1 650 40 0.555±0.008 26.90±0.09 3670 ± 8 130.3±0.7 2 650 40 0.370±0.019 36.45 ±0.13 5189 138 139.4±1.2 2 650 40 0.370±0.019 36.45 ±0.13 5189 138 139.4±1.2 2 770 45 0.351±0.012 20.96 ±0.15 3057 ± 7 140.9±1.1 2 770 45 0.497±0.018 28.11 ±0.10 4663 ± 9 139.3±0.6 2 880 45 0.351±0.012 20.96 ±0.15 3057 ± 7 140.9±1.1 2 770 45 0.497±0.018 28.11 ±0.10 4063 ± 9 139.3±0.6 2 880 45 0.351±0.012 20.96 ±0.15 3057 ± 7 140.9±1.1 2 1400 45 0.361±0.01 11 18.47 ±0.15 2735 ± 7 140.9±1.1 2 1400 45 0.361±0.01 18.47 ±0.15 2735 ± 7 140.9±1.1 1 1500 50 1.445±0.02 0.06 26.0046 144.7±1.3 100.412.1±3.4 1 1900 45 0.495±0.01 0.050 2.068±0.046 144.7±1.3 100.9±1.0 1 11ntegrated 7.013±0.058 181.7 ±1.3 26682 ±43 135.5±1.0 2  Sample: Schlitzloch 01  770 45 0.469±0.011 6.782±0.056 280.7±1.0 0.91±0.53 1± 870 65 0.396±0.039 51.05.05 12.05 12.2 ±13 100.20 1.05 1.05 1.05 1.05 1.05 1.05 1.05 1.0	216.2 4.1	111.3±2.2	1191 ± 1	10.61 ±0.21	0.035±0.020	60
950 60 0.09310.012 19.28 ±0.10 2269 ±3 113.10.6 2 1080 60 0.06710.008 29.89 ±0.07 3415 ± 6 113.610.4 2 1080 60 0.10910.015 32.07 ±0.09 3671 ± 4 113.610.4 2 1140 60 0.41110.059 42.98 ±0.07 3415 ± 6 113.610.4 2 1200 60 0.10910.025 32.07 ±0.09 3671 ± 4 113.610.4 2 12100 60 0.10910.025 32.07 ±0.09 3671 ± 4 113.420.4 2 12100 60 0.10920.025 12.10 ±0.07 3671 ± 4 113.70.4 4 1210.100 60 0.10920.025 12.10 ±0.07 3671 ± 4 113.70.4 4 1210.100 60 0.10920.025 12.10 ±0.07 3671 ± 4 113.70.4 4 1210.100 60 0.10920.025 12.10 ±0.07 3671 ± 4 113.70.4 4 1210.100 60 0.10920.025 12.10 ±0.07 3671 ± 4 113.70.4 4 1210.100 60 0.10920.025 12.10 ±0.07 3671 ± 4 113.70.4 4 1210.100 60 0.14620.020 1.84820.068 1243.7± 0.5 108.5±5.1 2 1500 60 0.14620.020 1.84820.068 1243.7± 0.5 108.5±5.1 2 11ntegrated 1.908±0.105 240.7 ±1.5 27612 ±13 112.3±0.7 2  Sample: Raidelberg 02  330 45 0.471±0.015 130.0±0.05 1491 ± 5 104.0± 0.7 1 610 40 0.55±0.008 26.90±0.09 3670 ± 8 130.3±0.6 2 650 40 0.370±0.019 36.45 ±0.13 5189 ±18 139.4±1.2 2 650 40 0.370±0.019 36.45 ±0.13 5189 ±18 139.4±1.2 2 650 40 0.370±0.019 36.45 ±0.13 5189 ±18 139.4±1.2 2 650 40 0.38±0.011 18.47 ±0.15 2735 ± 7 140.9±1.1 2 770 45 0.35±0.012 20.96 ±0.15 3057 ± 7 140.9±1.1 2 780 45 0.35±0.012 20.96 ±0.15 3057 ± 7 140.9±1.1 2 780 45 0.35±0.012 18.47 ±0.15 2735 ± 7 140.9±1.1 2 1400 45 0.35±0.012 0.96 ±0.15 3057 ± 7 140.9±1.1 2 1400 45 0.36±0.017 0.650±0.058 178.1±0.4 105.9±12.4 11 920 45 0.49±0.018 28.11 ±0.10 4063 ± 9 139.3±0.6 2 880 45 0.36±0.017 0.650±0.058 178.1±0.4 105.9±12.4 11 920 45 0.49±0.019 0.650±0.048 402.4±1.0 142.1±3.4 4 1920 45 0.29±0.029 0.56±0.048 167.6±0.4 803.5±16.8 1 1500 50 1.445±0.021 0.85±0.048 402.4±1.0 142.1±3.4 4 1920 45 0.29±0.035 181.0 ±0.23 2303 ± 9 239.9±10.5 3 1100 65 0.29±0.035 181.0 ±0.23 2303 ± 9 239.9±10.5 3 1100 65 0.29±0.035 181.0 ±0.3 444.7 ±1.3 444.6±17.0 1 1100 65 0.29±0.035 190.035 181.0 ±0.3 4994 ±12 30.56±0.14 2 1100 65 0.29±0.035 190.035 181.0 ±0.3 4994 ±12 30.56±0.14 2 1100 65 0.29±0.035 190.035 180.0 ±0.5 4994 ±12 30.56±0.14 2 1100 65 0.29±0.035 180.0 ±0.5	215.6± 3.2 223.3± 5.1	111.0±1.7	1273 ± 3	11.25 ±0.17	0.082±0.002	
1080 60 0.10910.015 32.07 ±0.09 3671 ± 4 113.4±0.4 2 1140 60 0.411±0.059 42.98 ±0.09 4064 ± 6 112.7±0.5 2 1200 60 0.10910.025 32.14 ±0.07 3671 ± 4 113.2±0.4 2 1200 60 0.10910.025 32.14 ±0.07 3671 ± 4 113.2±0.4 2 1350 60 0.12910.025 32.14 ±0.07 3671 ± 4 113.2±0.4 2 1350 60 0.12910.025 32.14 ±0.07 3671 ± 4 113.2±0.4 2 1350 60 0.12910.020 1.88e0.068 2 13.2 1 12.7±1.0 8 2 1350 60 0.224±0.022 12.87 ±0.00 1516 ±2 112.7±0.8 2 1350 60 0.146±0.020 1.88e0.068 2 13.7±0.5 186.5±1.7 ±0.8 2 1300.105 240.7 ±1.5 27612 ±13 112.7±0.8 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.7 2 1300.105 1 1.80 ±0.00 1 12.3±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 1 1.80 ±0.00 ±0.00 1 1.80 ±0.00 ±	219.4± 1.1	113.1±0.6	2269 ± 3	19.28 ±0.10	0.093±0.012	
1140 60 0.41110.059 42.98 10.09 4964 1 6 112.710.5 2 1200 60 0.10910.025 32.14 10.07 3671 1 4 113.210.4 2 1260 60 0.14810.047 16.56 10.09 1911 2 3 112.711.0 2 1350 60 0.22410.022 12.87 10.06 1516 22 112.771.8 2 1500 60 0.14610.020 1.84810.068 243.72 0.5 108.515.1 2 11ntegrated 1.90820.105 240.7 11.5 27612 113 112.320.7 2  Sample: Raidelberg 02	220.3± 0.7 220.1± 0.7	113.6±0.4	3415 ± 6	29.89 ±0.07	0.067±0.008	
1200 60 0.10990.025 32.14 ±0.07 3671 1 4 113.2±0.4 2 1260 6C 0.14810.047 16.56 10.09 1911 ± 3 112.7±1.0 2 1350 60 0.22420.022 12.87 ±0.06 1516 ± 2 112.7±0.8 2 1500 60 0.146±0.025 12.87 ±0.06 1516 ± 2 112.7±0.8 2 1500 60 0.146±0.025 12.87 ±0.06 1516 ± 2 112.7±0.8 2 11.908±0.105 240.7 ±1.5 27612 ±13 112.3±0.7 2  Sample: Raidelberg 02  Sample: Raidelberg 02  J = 530 45 0.471±0.015 240.7 ±1.5 27612 ±13 112.3±0.7 2  530 45 0.471±0.015 26.90 ±0.09 3670 ±8 130.3±0.6 2 650 40 0.351±0.012 20.96 ±0.15 3189 ±18 130.3±0.6 2 650 40 0.351±0.012 20.96 ±0.15 3057 ±7 140.9±1.7 2 770 45 0.497±0.018 28.11 ±0.10 4063 ±9 139.4±1.2 2 770 45 0.497±0.018 28.11 ±0.15 2735 ±7 140.9±1.7 2 880 45 0.369±0.09 2.168±0.048 40.2±1.0 ±142.1± 3.4 2 880 45 0.369±0.017 0.650±0.048 40.2±1.0 ±142.1± 3.4 2 880 45 0.369±0.017 0.650±0.048 40.2±1.0 ±142.1± 3.4 2 880 45 0.369±0.017 0.650±0.048 40.2±1.0 ±142.1± 3.4 2 880 45 0.369±0.017 0.650±0.048 40.4±1.0 ±142.1± 3.4 2 880 45 0.369±0.017 0.650±0.048 40.4±1.0 ±142.1± 3.4 2 880 45 0.369±0.017 0.650±0.048 176.6±0.4 803.5±16.8 1 1400 45 1.228±0.021 0.820±0.046 44.7±1.3 44.6±17.0 1 11tegrated 7.013±0.058 181.7 ±1.3 26682 ±43 135.5±1.0 2  Sample: Schlitzloch 01	218.6± 0.9	112.7±0.5	4964 ± 6	42.98 ±0.09	0.411±0.059	
1350 60 0.22410.022 12.87 ±0.06 1516 ±2 112.720.8 2 108.55±1.0 108.55±1.0 2 112.3±0.7 2 115.00 60 0.146±0.020 1.848±0.068 243.7±0.5 108.55±0.7 2 112.3	219.6± 0.7 218.7± 1.9	113.2±0.4		32.14 ±0.07	0.109±0.025	
Integrated 1.908±0.105 240.7 ±1.5 27612 ±13 112.3±0.7 2  Sample: Raidelberg 02  Sample: Raidelberg 02  J =  \$530	218.7± 1.9 218.7± 1.4	112.710.8		10.56 ±0.09	0.14810.047	
Sample: Raidelberg 02  530	211.1± 9.4	108.5±5.1		1.848±0.068	0.146±0.020	
530	218.0± 1.3	112.3±0.7	27612 ±13	240.7 ±1.5	1.908±0.105	grated
610         40         0.55550.008         26.90 10.09         3670 1 8         130.31 0.6 2           650         40         0.37010.019         36.48 1.13         5189 138         139.41 1.2         2.6 2           690         40         0.61810.007         33.18 20.14         4839 138         139.41 1.2         2.7 2           720         45         0.35110.012         20.96 20.15         3057 1 7         140.92 1.1         2.7 2           740         45         0.38110.011         18.47 20.15         2735 2 7         141.92 1.2         2.2           770         45         0.38120.009         2.16820.048         402.42 1.0         142.12         3.9.32 0.6           880         45         0.36910.017         0.65020.058         18.12 0.4         105.9112.4         2.2           920         45         0.46820.029         0.56220.048         402.42 1.0         142.12 3.4         2           1500         50         1.44510.021         0.82020.052         1.62.91.1         1.0         91.1         100.911.0           1500         50         1.44510.021         0.82020.062         445.91.1         1.0         91.1         100.911.0           1500         50         1.44510.021 <td>9.20*10-4</td> <td>J =</td> <td></td> <td></td> <td>02</td> <td>le: Raidelberg</td>	9.20*10-4	J =			02	le: Raidelberg
690 40 0.61810.007 33.18 10.14 4839 111 140.91 1.1 2 720 45 0.35110.012 20.96 10.15 3057 1 7 140.91 1.2 2 740 45 0.38110.011 18.47 10.15 2735 1 7 141.92 1.2 2 740 45 0.38110.011 18.47 10.15 2735 1 7 141.92 1.2 2 830 45 0.31810.009 2.16820.048 402.41 1.0 142.11 3.4 2 830 45 0.36910.017 0.65010.058 18.11 1.0 10 4063 2 9 139.32 0.6 2 880 45 0.36910.017 0.65010.058 18.11 1.0 10 405.911.4 10.5 911.2 4 1000 45 1.22610.021 0.56220.048 167.62 0.4 83.516.8 1 1100 50 1.445510.021 0.82010.062 45.91 1.1 100.911.0 1 1100 50 1.445510.021 0.88820.046 444.72 1.3 44.6217.0 1100 110 110 110 110 110 110 110 110 1	164.9± 1.0	104.0 0.7	1491 ± 5	13.00 ±0.05	0.471±0.015	
690 40 0.61810.007 33.18 10.14 4839 111 140.91 1.1 2 720 45 0.35110.012 20.96 10.15 3057 1 7 140.91 1.2 2 740 45 0.38110.011 18.47 10.15 2735 1 7 141.92 1.2 2 740 45 0.38110.011 18.47 10.15 2735 1 7 141.92 1.2 2 830 45 0.31810.009 2.16820.048 402.41 1.0 142.11 3.4 2 830 45 0.36910.017 0.65010.058 18.11 1.0 10 4063 2 9 139.32 0.6 2 880 45 0.36910.017 0.65010.058 18.11 1.0 10 405.911.4 10.5 911.2 4 1000 45 1.22610.021 0.56220.048 167.62 0.4 83.516.8 1 1100 50 1.445510.021 0.82010.062 45.91 1.1 100.911.0 1 1100 50 1.445510.021 0.88820.046 444.72 1.3 44.6217.0 1100 110 110 110 110 110 110 110 110 1	204.3± 0.8 217.7± 1.7	139.4± 1.2	5189 ±38	36.45 ±0.13	0.370±0.019	
770	219.1 1.0	140.31 0.7	4839 ±11	33.18 ±0.14	0.618±0.007	
770	219.9± 1.6 221.5± 1.8	141.9 1.2	2735 ± 7	18.47 ±0.15	0.381±0.011	
880 45 0.36910.017 0.55020.058 178.12 0.4 105.9112.4 1 1 920 45 0.40820.029 0.55020.048 167.62 0.4 83.5116.8 1 1400 45 1.22810.021 0.82010.062 445.92 1.1 100.9111.0 1 1500 50 1.44510.021 0.88820.046 444.72 1.3 44.6217.0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	217.6± 0.9	139.3± 0.6	4063 + 9	28.11 ±0.10	0.497±0.018	45
920 45 0.40820.029 0.56220.048 167.62 0.4 83.516.8 1 1400 45 1.22810.021 0.82020.062 445.91 1.1 100.911.0 0 1500 50 1.44510.021 0.8820.046 444.72 1.3 44.617.0 1 1ntegrated 7.01310.058 181.7 11.3 26682 143 135.52 1.0 2  Sample: Schlitzloch 01	221.7± 5.1 167.8±18.7	192.11 3.9 105.9±12.4	178.1: 0.4	0.650±0.048	0.318±0.009	
1500 50 1.44510.021 0.38820.046 444.72 1.3 44.6217.0 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	133.6±26.0	83.5±16.8	167.6± 0.4	0.562±0.048	0.408±0.029	45
Integrated 7.013±0.058 181.7 ±1.3 26682 ±43 135.5± 1.0 2  Sample: Schlitzloch 01	160.1±16.6 72.5±27.1	100.9±11.0 44.6±17.0	445.9± 1.1 444.7± 1.3	0.820±0.062 0.388±0.046	1.228±0.021 1.445±0.021	
770	211.9± 1.4	135.5± 1.0	26682 143	181.7 ±1.3	7.013±0.058	grated
870 65 0.39610.039 57.89 ±0.33 1728 ±3 27.81±0.26 2.940 65 0.263±0.030 81.01 ±0.23 2503 ±9 29.93±0.18 2.960 65 0.308±0.041 143.3 ±0.4 4491 ±12 30.69±0.15 2.970 65 0.210±0.025 90.20 ±0.26 2856 ±7 30.69±0.15 2.1020 65 0.231±0.002 102.3 ±0.2 3201 ±8 30.61±0.10 2.1020 65 0.231±0.002 102.3 ±0.2 3201 ±8 30.61±0.10 2.1070 65 0.29±0.039 161.0 ±0.5 4994 ±12 30.65±0.10 2.1100 65 0.29±0.039 132.9 ±0.5 4185 ±14 30.83±0.18 2.1140 65 0.15±0.036 16.69±0.13 572.7±2.7 31.52±0.71 2.1280 65 0.080±0.001 5.84±2±0.058 ±17.2±0.4 33.10±0.33 ±1500 60 1.76±0.036 5.530±0.066 700.2±2.5 32.38±3.62 2.110±0.25 4.412±0.115 803.4 ±4.8 25729 ±26 30.39±0.19 2.2 32.2 32.2 32.2 32.2 32.2 32.2 32.2	4.272*10-3	J =			h 01	le: Schlitzloo
940 65 0.26310.030 81.01 10.23 2503 1 9 29.9310.18 2.960 65 0.30810.04 1 143.3 10.4 4491 112 30.6910.15 2.970 65 0.21010.025 90.20 10.26 2856 1 7 30.9610.14 2:1020 65 0.23110.002 102.3 10.2 3201 1 8 30.6110.10 2:1070 65 0.23110.002 102.3 10.2 3201 1 8 30.6110.10 2:1070 65 0.29910.035 161.0 10.5 4994 112 30.5610.14 2:1070 65 0.29910.035 161.0 10.5 4994 112 30.5610.14 2:1140 65 0.29610.039 132.9 10.5 4185 114 30.8320.18 2:1140 65 0.15610.036 16.69 10.13 572.72 2.7 31.5220.71 2:1280 65 0.08010.03 1 5.64220.058 217.21 0.4 33.1020.33 2:1500 60 1.76210.066 5.53020.066 700.21 2.5 32.3813.62 2:1140 4.41210.115 803.4 14.8 25729 126 30.3910.19 2:33810.18 2:34810	154.4: 3.7	20.91±0.53	280.7± 1.0	6.782±0.056	0.469±0.011	
960 65 0.30820.041 143.3 20.4 4491 112 30.6940.15 2: 970 65 0.21010.025 90.20 10.26 2856 17 3 0.9620.11 2: 1020 65 0.23110.002 102.3 10.2 3201 18 30.6120.10 2: 1070 65 0.23910.035 161.0 10.5 4994 112 30.5410.10 2: 1100 65 0.29610.039 132.9 10.5 4185 114 30.8320.18 2: 1140 65 0.15610.00 15.610.00 16.69 10.13 572.71 2.7 31.5210.71 2: 1280 65 0.08010.001 5.84220.058 217.21 0.4 33.1020.33 2: 1500 60 1.76210.066 5.53010.066 700.21 2.5 32.3813.62 2: 11tegrated 4.41210.115 803.4 14.8 25729 126 30.3910.19 2: 32.38110.001 32.381	202.5± 1.8 217.1± 1.2		1728 ± 3 2503 + 9	57.89 ±0.33 81.01 ±0.23	0.396±0.039 0.263±0.030	
1020 65 0.23110.002 102.3 10.2 3201 t 8 30.6110.10 2: 1070 65 0.23910.035 161.0 10.5 4994 t12 30.5610.11 2: 1100 65 0.29610.039 132.9 10.5 4185 114 30.8320.18 2: 1140 65 0.15610.036 16.69 10.13 572.71 2.7 31.5210.71 2: 1280 65 0.08010.001 5.84220.058 217.21 0.4 33.1020.33 2: 1500 60 1.76210.066 5.53010.066 700.21 2.5 32.3813.62 2: 11tegrated 4.41210.115 803.4 14.8 25729 126 30.3910.19 2: Sample: Schlitzloch 02	222.3± 1.0	30.69±0.15	4491 ±12	143.3 ±0.4	0.308±0.041	65
1070 65 0.299±0.035 161.0 10.5 4994 112 30.56±0.14 2: 1100 65 0.296±0.039 132.9 10.5 4185 114 30.83±0.18 2: 1140 65 0.156±0.036 16.69 ±0.13 572.7± 2.7 31.52±0.71 2: 1280 65 0.080±0.031 5.84±2.0.058 217.2± 0.4 31.0±2.0.7 2: 2.1 2.1 31.0±2.0.7 2: 2.1 2.1 31.0±2.0.7 2: 2.1 2.1 2.1 31.0±2.0.7 2: 2.1 2.1 2.1 2.1 2.1 2.1 2.1 2.1 2.1 2.1	224.1± 1.0 221.8± 0.6	30.96±0.14	2856 ± 7 3201 + 8	90.20 ±0.26	0.210±0.025 0.231±0.002	
1100 65 0.29610.039 132.9 10.5 4185 114 30.8320.18 2: 1140 65 0.15610.036 16.69 10.13 572.71 2.7 31.5210.71 2: 1280 65 0.080210.001 5.84220.058 217.21 0.4 33.1020.33 2: 1500 60 1.76210.066 5.53010.066 700.21 2.5 32.3813.62 2: 1140	221.4± 0.9	30.56±0.14	4994 ±12	161.0 ±0.5	0.239±0.035	65
1280 65 0.08010.001 5.84220.058 217.2: 0.4 33.1020.33 2: 1500 60 1.76210.066 5.53010.066 700.21 2.5 32.3813.62 2: 1114 2: 1.115 803.4 14.8 25729 126 30.3910.19 2: 2.116 2: 2.	223.2± 1.2	30.83±0.18	4185 ±14	132.9 +0.5	0.296±0.039	
Integrated 4.412±0.115 803.4 ±4.8 25729 ±26 30.39±0.19 23  Sample: Schlitzloch 02 J = 4.	238.6± 2.2	33.10±0.33	217.21 0.4	5.842±0.058	0.080±0.001	65
Sample: Schlitzloch 02 J = 4.	233.8±24.2 220.2± 1.3		700.2± 2.5	5.530±0.066	1.762±0.066	
			23129 120	0U3.4 14.8		•
	4.210*10 <sup>-3</sup>		571 O: 0 °	14 25 :0 01		
770 45 0.967±0.018 14.35 ±0.06 571.9± 2.0 19.92±0.41 14 870 65 0.701±0.022 115.7 ±0.3 3550 ± 7 28.87±0.12 20	145.3± 2.9 206.9± 0.8	28.87±0.12	3550 ± 7	14.35 ±0.06 115.7 ±0.3	0.967±0.018 0.701±0.022	65
940 65 0.404±0.015 139.8 ±0.6 4326 ±10 30.08±0.15 21	215.1± 1.0	30.08±0.15	4326 ±10	139.8 ±0.6	0.404±0.015	65
960 65 0.407±0.023 173.5 ±0.5 5355 ±11 30.16±0.11 21 970 65 0.241±0.017 94.24 ±0.16 2926 ± 6 30.28±0.10 21	215.6± 0.7 216.4± 0.7	30.16±0.11	2926 ± 6	1/3.5 ±0.5 94.24 ±0.16	0.40710.023	65 65
1020 65 0.316±0.014 173.7 ±0.5 5321 ± 9 30.07±0.10 21	215.0± 0.7	30.07±0.10	5321 ± 9	173.7 ±0.5	0.316±0.014	65
1070 65 0.609±0.009 287,2 ±0.6 8780 ±45 29.93±0.17 21	214.1± 1.1 218.4± 0.8	29.93±0.17	8780 ±45	287,2 ±0.6	0.609±0.009	65
1140 65 0.035±0.032 26.61 ±0.10 852.4± 2.1 31,64±0.38 22	225.6± 2.6	31.64±0.38	852.4± 2.1	26.61 ±0.10	0. <b>035±</b> 0.032	65
1220 75 0.673±0.039 16.86 ±0.07 716.5± 2.3 30.69±0.70 21	219.2± 4 7 227.1± 7.2			16.86 ±0.07 6.006±0.054	0.673±0.039 1.636±0.019	75 80
	214.1± 1.2					
Antogracoa 0.73710.071 1100 17 57300 131 27.77110.10 21			0.400 131		0.73710.0/1	,

The corresponding irradiation parameters (J-values) are listed in the headings.

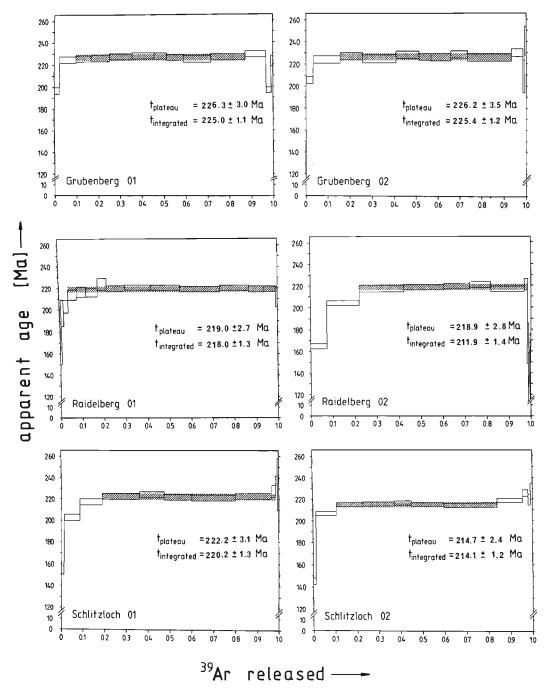


Fig. 7. <sup>40</sup>Ar/<sup>39</sup>Ar degassing spectra of neogenic K-feldspars (adularia) from the Walhausen mineralizations. The hatchings within the spectra indicate the plateau areas.

micro veins. This overprint may account for a disturbance of the isotopic system. Thus, a slight lowering of the crystallization age from

about 219-225 Ma, corresponding to the age of sample Schlitzloch 01, to about 215 Ma, may be assumed for sample Schlitzloch 02. The dis-

turbance postulated cannot be recognized by a significant difference in the shape of the <sup>40</sup>Ar/<sup>39</sup>Ar degassing spectrum compared with that of the undisturbed adularia systems. The slightly younger Rb/Sr age of the sample Grubenberg 03, in contrast to the <sup>40</sup>Ar/<sup>39</sup>Ar ages of the samples Grubenberg 01 and 02 also may possibly be due to disturbances by ore impregnations of the K-feldspars in the Rb/Sr separate.

On the whole, two hydrothermal events at about 224 Ma and about 219 Ma could be established by the adularia measurements for the mineralizations of the Walhausen area. The geological significance of the isotopic data is evidenced by age concordances of the Rb/Sr and K/Ar systems, petrographically different types of adularia, and geographically different locations.

## 7. Geological discussion

The dated events of hydrothermal activity correspond to the ages Carnian to Norian (Keuper), i.e., Upper Triassic (Odin and Létolle, 1982). Mineralizing events in the Saar-Nahe region during the Upper Triassic also have been confirmed by 40Ar/39Ar measurements on hydrothermally formed celadonite from the vein mineralization "Louise", which are in concordance with U+Th/He ages of haematite from this mineralization (Bähr et al., 1987). There is a hiatus of approximately 70 Ma between the intrusion of the host rocks at about 290 Ma and the hydrothermal activities at Walhausen. Therefore, a derivation of the ore-forming solutions from the volcanic rocks in the sense of a post-magmatic hydrothermal succession is unlikely. This is also supported by the 87Sr/86Sr ratios on calcites of the mineralizations with a variation of  $0.7103 \pm 0.0006$ . In case of a primary magmatic source, the Sr ratios of the gangues should about agree approximately with the initial value of the magmatic rock. However, the initial Sr values of the "Grenzlager" magmatic rocks are 0.706, measured on apatites from rhyolites and tuffs (Lippolt and Raczek, 1979) and on clinopyroxene from basalt (Göpel and Zindler, 1980), which is significantly lower than the Sr ratios of the calcites. The Sr values of the location Schlitzloch vary in a distinct range from about 0.7097 to 0.7100. The Sr ratios of the location Grubenberg are significantly higher, ranging

from 0.7107 and 0.7109. This indicates differentiations of the hydrothermal solutions on a local scale, which is also supported by the age difference between the adularia from the locations Grubenberg and Raidelberg. Similar conclusions for other hydrothermal vein deposits were made by Norman and Landis (1983) and Mertz (1987) based on systematic investigations of Sr isotopic characteristics of paragenetic successions.

In previous studies (e.g. Schneiderhöhn, 1941; Geis, 1959) it was assumed that the mineralizations in the Saar-Nahe region are post-magmatic formations derived from the Permian volcanism in this area. As the experimental data indicate, however, this may not be applied to the Walhausen mineralizations. According to the paragenetic sequence worked out by Müller (1983; 1988) for the Saar-Nahe region, and the time mark for this sequence supplied by the adularia data, the majority of the mineralizations from this region are not temporally related to the intrusion of the Permian magmatic rocks. Most likely, there is a subordinate hydrothermal phase derived from the volcanic rocks. 40Ar/39Ar measurements on hydrothermal celadonite from the Saar-Nahe region (Kastel mineralization) yielded an integrated age of about 270 Ma (Mertz, 1987) which may be evidence for such a phase.

Sample Raidelberg 02 contains, besides adularia of type A, about 40 % metasomatically formed K-feldspar of type B. There is no age difference between it and sample Raidelberg 01 which is composed exclusively of adularia of type A. Such a result indicates that both the K-feldspar types A and B were formed at the same time and in the same genetic context. Petrography and isotopic data suggest K-metasomatism initiated by a hydrothermal phase. This event obviously provided a favorable environment for processes of mobilization, enrichment and deposition of metal.

The experimental proof of two distinct mineralizing events with a hiatus of about 5 Ma indicates multi-stage hydrothermal activities on a local scale during geological periods of times. The multi-stage characteristic of solution-transport processes is also clearly reflected in the zoned structure of the adularia (cf. Fig. 6). The results of U/Pb datings on U ores of the vein deposit Höhenstein/Oberpfalz, FRG (Carl et al., 1985), on adularia from mineralizations of the Lizard District/SW England (Halliday and

Mitchell, 1976) or on authigenic illites and sericites of the Clara vein mineralization/ Schwarzwald, FRG (Bonhomme et al., 1983; Lippolt et al., 1986) tendentiously confirm this assertion.

Halliday and Mitchell (1984) compiled isotopic age data measured on hydrothermal K-feldspars and clay minerals from mineralizations from Southern and Western Europe. As a result, a pronounced peak of mineralizing activity at 220 Ma was identified, which is in very good agreement with the adularia ages presented here. Halliday and Mitchell (1984) proposed that this 220 Ma event "was related to an initial rapid fracturing of the crust associated with the break up of Pangaea, which was related with an increase in the geothermal gradient and penetration of the crust by surface waters which returned via fissure systems". Such a model, applied to the Walhausen veins, plausibly provides a super-regional geotectonic framework for these mineralizations. Sufficient indication of deep-going syn-Triassic tectonic activities are found in the area of the so-called Eifeler North-South zone (e.g. Echle and Gusonne, 1985), a geotectonic unit, that contains the Walhausen mineralizations in its southern part.

#### 8. Conclusions

Within the mineralizations investigated, adularia (Or contents > 98 mol.%, relatively high degree of Al,Si disorder) are found as co-genetic compounds in the hydrothermal succession.

The age concordances of independant isotopic clocks, petrographically differing adularia types and geographically different mineralizations confirm the undisturbed condition of the isotopic system of the K-feldspars.

Deteriorations of the Ar retention of adularia may be caused by syn- or post-genetic hydrothermal overprinting (e.g. ore impregnations).

Hydrothermal activities associated with K-metasomatic processes took place in the area of the Walhausen mineralizations at about 224 Ma and 219 Ma (Upper Triassic).

The hiatus of 5 Ma between both hydrothermal events indicates multi-stage mineralizing activities on a local scale during geological periods of time.

The majority of the epigenetic mineralizations in the Saar-Nahe region have been deposited in the syn- or post-Upper Triassic. The genesis of these mineralizations is not related to the Permian magmatism of this area.

This is also supported by the  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$  variation of  $0.7103 \pm 0.0006$  on paragenetic calcites, which is markedly higher than the initial values of the magmatic host rocks.

The established mineralizing events confirm the existence of a super-regional hydrothermal phase in Europe during the Upper Triassic.

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