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U–Pb zircon dating of the Central Aar Granite (Aar Massif, Central Alps)

by *U. Schaltegger*[1] *and A. von Quadt*[2]

Abstract

U–Pb age analyses of zircons of the Central Aar Granite yield upper intercept ages of 296 ± 3 Ma (Reuss valley granites) and 298 ± 6 Ma (Grimsel Granodiorite). These ages are interpreted to represent the time of emplacement of the entire Central Aar Granite body; no age differences within this granite have been detected up to now. A dioritic enclave within a granodiorite of the Reuss valley (the so-called Schöllenen "syenite") has an upper intercept age of 316 ± 27 Ma. This rock may belong to an earlier intrusion, but its upper intercept age overlaps with the age of the Central Aar Granite within its error limits.

The precision of the U–Pb determinations is restricted by high amounts of common lead that are incorporated in white opaque zircon overgrowths as well as in inclusions of acicular apatite. During Alpine metamorphism the zircons suffered variable lead loss, depending on their structural state.

Keywords: Aar Granite, Aar Massif, Central Alps, Switzerland, U–Pb age determination.

1. Introduction

The Central Aar Granite is an Upper Carboniferous granodioritic to granitic intrusion, situated in the central part of the Aar Massif, Switzerland (Fig. 1). Its emplacement postdates the peak of Hercynian metamorphism and deformation; a Carboniferous to Permian intrusion age was postulated by former authors (SIGRIST, 1947; WÜTHRICH, 1965). The granite shows no Hercynian, but only Alpine metamorphic overprint that caused a cataclastic fabric in most of the investigated rock types. K–Ar and Rb–Sr mineral ages have been partially or completely reset by this metamorphic overprint (WÜTHRICH, 1965; JÄGER et al., 1967; DEMPSTER, 1986).

The first attempt to date the Central Aar Granite was made by PASTEELS (1964), using the U–Pb zircon system. His results confirmed a late Carboniferous age around 300 Ma ($^{207}Pb/^{206}Pb$ ages between 285 and 315 Ma). Rb–Sr analyses of whole-rocks by WÜTHRICH (1965) yielded a slightly younger isochron age of 287 ± 30 Ma (approximative error, recalculated with new decay constants). More recent Rb–Sr investigations revealed the existence of a post-magmatic low-temperature alteration event that disturbed the Rb–Sr whole-rock systems in the western part of the studied area (SCHALTEGGER, 1989 and SCHALTEGGER, 1990b), see Fig. 1.

The aim of this investigation was to establish the intrusion ages for the different rock types that belong to the Central Aar Granite body and to detect possible age differences within that granite. The results will reveal the significance of the different Rb–Sr whole-rock ages ranging from 230 to 297 Ma (SCHALTEGGER, 1989 and SCHALTEGGER, 1990b). They should also allow to quantify the influence of Alpine metamorphic overprint on the U–Pb systems of the zircons.

2. Petrogenesis of the Central Aar Granite

The Central Aar Granite forms a lense-shaped body that is surrounded by high-grade basement rocks (the so-called "Altkristallin") of mainly pre-

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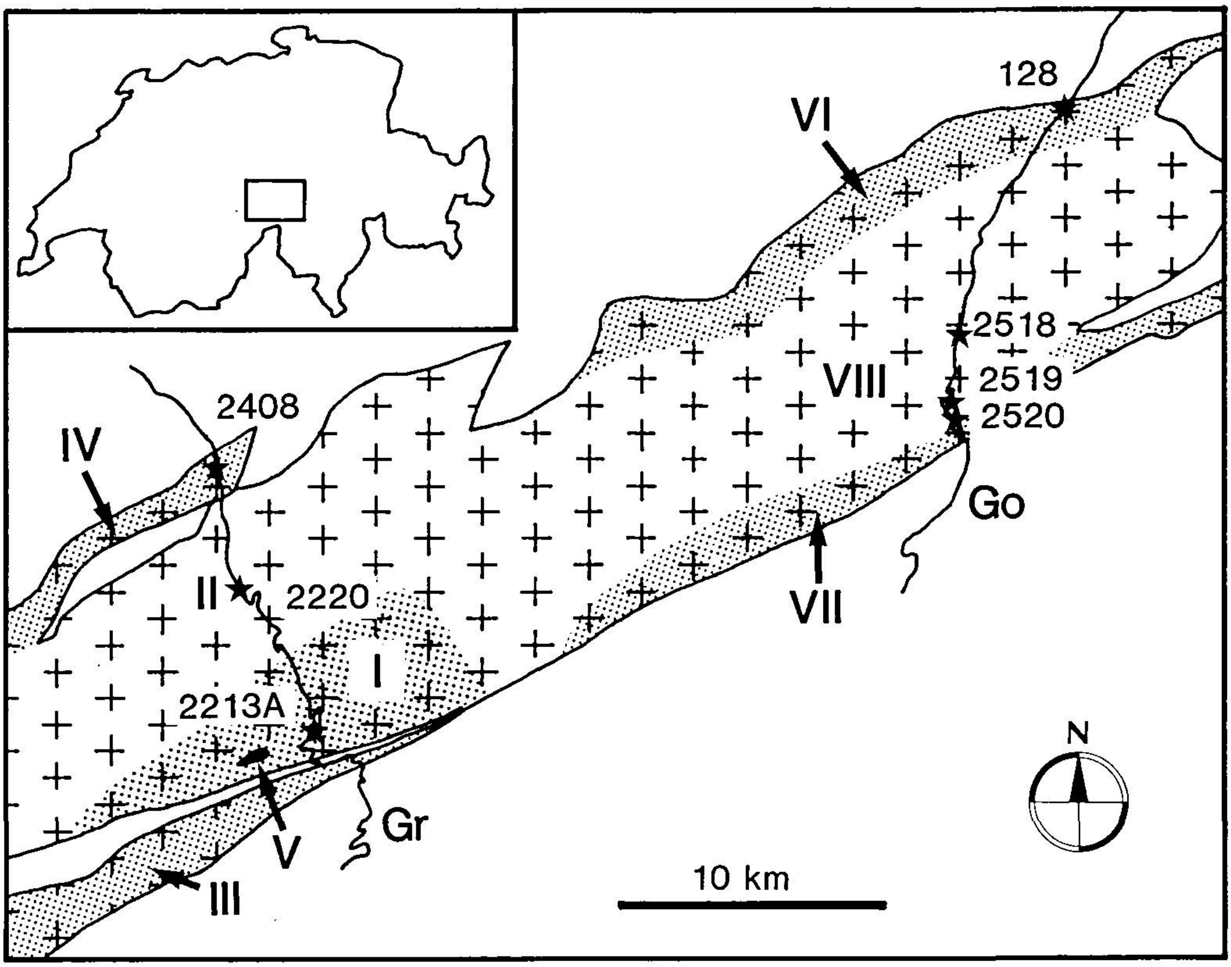

Fig. 1 Geological sketch map of the central section of the Aar Massif, after LABHART (1977), showing the two investigated profiles. Rock samples are marked with KAW numbers. Symbols – I: Grimsel Granodiorite: II: Central Aar Granite s.str.; III: Southern Aar Granite; IV: Mittagflue Granite; V: Kessiturm Aplite (all western profile); VI: Northern Border Facies; VII: Southern Border Facies; VIII: central zone (all eastern profile); aplitic dykes and small leucogranitic stocks are not shown. Gr: road over the Grimsel pass, western profile; Go: Reuss valley, Gotthard pass road, eastern profile.

Hercynian age. It probably consists of Paleozoic to Proterozoic rocks and has an inherited detrital component of Archean age, similar to the nearby Gotthard Massif (GRAUERT and ARNOLD, 1968; GULSON and RUTISHAUSER, 1976; GEBAUER et al., 1988). The granite body itself consists of a variety of rock types that all have different local names (see Fig. 1 and Tab. 1). The spatial relationship in the field suggest that some of these granite subtypes have the same age and coexisted as melts without considerably mingling or mixing, e.g. the Central Aar Granite s.str. and the Grimsel Granodiorite, both of the western profile. The granites and granodiorites of the Reuss valley (eastern profile) do not show clearly defined lithological boundaries; these rocks were thus emplaced within a very short time span. For other granite types a slightly younger intrusion age cannot be excluded, e.g. the Mittagflue Granite of the western profile.

The granites form a calc-alkaline differentiation suite that mainly evolved by fractional crystallization processes, leading to the extreme depletion of compatible elements, such as Sr and Ba, and to the enrichment of Rb, Th, U, Nb, Y and heavy rare earth elements (SCHALTEGGER, 1990a; SCHALTEGGER and KRÄHENBÜHL, 1990) in the leucogranites, i.e. granites with less than 5% mafic constituents. The granites are considered to represent I-type melts with a subordinate sedimentary component, free of Proterozoic or Archean inheritance. This is indicated by low initial Sr ratios around 0.705 (SCHALTEGGER, 1989 and 1990b) and zircon morphology (PUPIN, 1976 and 1980). They intruded the basement rocks after the peak of metamorphism and tectonic movements at the end of the Variscan orogeny (SCHALTEGGER, 1990a).

Thus the granites are only deformed by the compressional deformation of Alpine age (MAR-

Tab. 1 Short petrographic description of the analyzed samples of the Central Aar Granite and Schöllenen "syenite". Abbreviations – qtz: quartz; kfs: k-feldspar; plag: plagioclase; bio: biotite; all: allanite; sph: sphene; zir: zircon; ap: apatite; op: opaques; gar: garnet; cc: calcite; fluo: fluorite.

sample number	rock name	mesoscopic description	mineralogical composition
KAW 128	Northern Border Facies, Gurtnellen (Reuss valley)	leucocrate, massive, coarse-grained granite,	38% qtz, 35% kfs, 25% plag, 2% bio; ap, op, all, zir, gar, sph, ep, stilp, chl;
KAW 2213A	Grimsel Granodiorite, Grimsel lake (Grimsel)	dark, coarse-grained granite to granodiorite, strongly foliated in most cases, augen texture; abundant dark enclaves	25% qtz, 25% kfs, 38% plag, 12% bio; ap, op, sph, all, zir, chl, ep, ser, leuk, cc; plag-cumulates
KAW 2220	Central Aar Granite s. str., leucocrate facies, Hangholz (Grimsel)	medium-grained granite, slightly foliated, occurring as stocks and schlieren within the main facies of the Central Aar Granite s. str.	34% qtz, 32% kfs, 28% plag, 6% bio; ap, op, zir, all, gar, chl, leuk, ser, ep
KAW 2408	Mittagflue Granite, Tschingel bridge (Grimsel)	leucocrate, massive, coarse-grained granite, analogous to the Northern Border Facies of the Reuss valley	35% qtz, 35% kfs, 28% plag, 2% bio; ap, zir, gar, all, chl, ep, stilp
KAW 2518	Central Aar Granite s.l., Göschenen (Reuss valley)	coarse-grained granite, slightly foliated; corresponding to the main facies of the Central Aar Granite s.str. in the Grimsel cross section	32% qtz, 31% kfs, 29% plag, 8% bio; all, op, sph, ap, gar, ep, chl, leuk
KAW 2519	Central Aar Granite s. l., Schöllenen (Reuss valley)	dark, coarse-grained granodiorite with moderate foliation, augen texture	27% qtz, 35% plag, 28% kfs, 10% bio, all, zir, op, ap, sph, ep, leuk, chl
KAW 2520	"Schöllenen Syenite", dioritic enclave within the C.A. Gr. s.l., Schöllenen (Reuss valley)	dark massive rock, no preferential orientation, medium-grained, dioritic in composition with interstitial k-feldspar	10% qtz, 20% plag, 13% kfs, 15% bio, 40% hbl, 2% acc: ap, op (py), sph, zir, leuk; bio secondary after hbl

QUER, 1987; CHOUKROUNE and GAPAIS, 1983). The Alpine metamorphism reached lower greenschist facies conditions, leading to the formation of stilpnomelane and the recrystallization and isotopic rejuvenation of biotite (DEMPSTER, 1986). The temperatures did not exceed 450 °C for the southernmost samples of this study.

3. Investigated material and methods

Seven samples were taken along two cross-sections through the Aar Massif (Fig. 1): a western profile along the Grimsel Pass road (samples KAW 2408: Mittagflue Granite; 2220: Central Aar Granite s. str., main facies; 2213A: Grimsel Granodiorite) and an eastern one situated in the Reuss valley (samples KAW 128: Northern Border Facies; 2518: granite of the central zone; 2519: granodiorite of the Schöllenen gorge; 2520: Schöllenen "syenite", a dioritic enclave in the latter). The sample size is around 30 kg, except for KAW 128 (100 kg).

The zircons were separated from a size fraction of < 160 μm using a Wilfley Table, heavy liquids (tribrommethane and diiodomethane) and a Frantz magnetic separator. All analyzed fractions were hand-picked under a binocular microscope. Prior to dissolution all zircons were washed in warm 2% nitric acid and triple distilled water. For analysis 2 to 10 mg of zircon material were taken; dissolution was performed in steel-jacketed Teflon-vessels (KROGH, 1973, slightly modified) for two weeks. The chemical separation of U and Pb was done using a HCl–HBr chemistry, slightly modified after MANHES et al. (1984). For the chemical treatment double distilled acids and triple distilled water were used. Blanks were in the range of 1–2 pg Pb/ml for water and 10–25 pg Pb/ml for HCl, HF, HBr and HNO_3. Total lead blank was about 400 pg at the beginning of the investigations, 50 to 100 pg for the last determinations. The blank contribution was determined and corrected for each set of samples individually.

The measurements were done on Finnigan MAT 261 and VG Sector mass spectrometers. Pb was loaded with H_3PO_4 and Silica-gel on single Re-filaments, U as nitrate on double or triple filaments. A mass discrimination correction of 0.1% was applied to the U results. The analytical reproducibility of the two mass spectrometers was controlled measuring the NBS 982 standard. Calculations were done using the algorithms of RODDICK (1987) and YORK (1969).

4. Results

4.1. ZIRCON MORPHOLOGY

The zircons of the studied granites and granodiorites are mostly transparent and pink in colour. They may contain abundant inclusions of acicular apatite, e.g. in samples 2213A, 2220, 2518 and 2519 (Fig. 2), of opaque Th-U-silicates and fluid inclusions. Thorite and polycrase were reported by BAJO et al. (1983) as inclusions in zircons of the Mittagflue Granite (western profile). In the more evolved granites and leucogranites (i.e. in samples 128, 2220 and 2408) the zircons are partly or com-

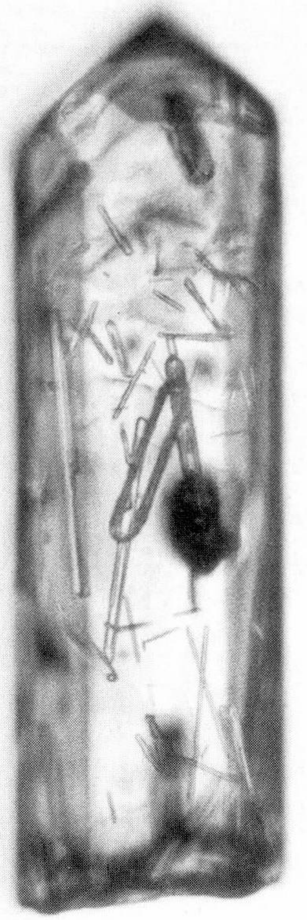

Fig. 2 Photomicrograph of analyzed sample KAW 2518, 75–112 n.m. (KAW 2518/2), in transmitted light (magnification: 63×). The zircons have abundant inclusions of acicular apatite, which are partly responsible for high common lead contents.

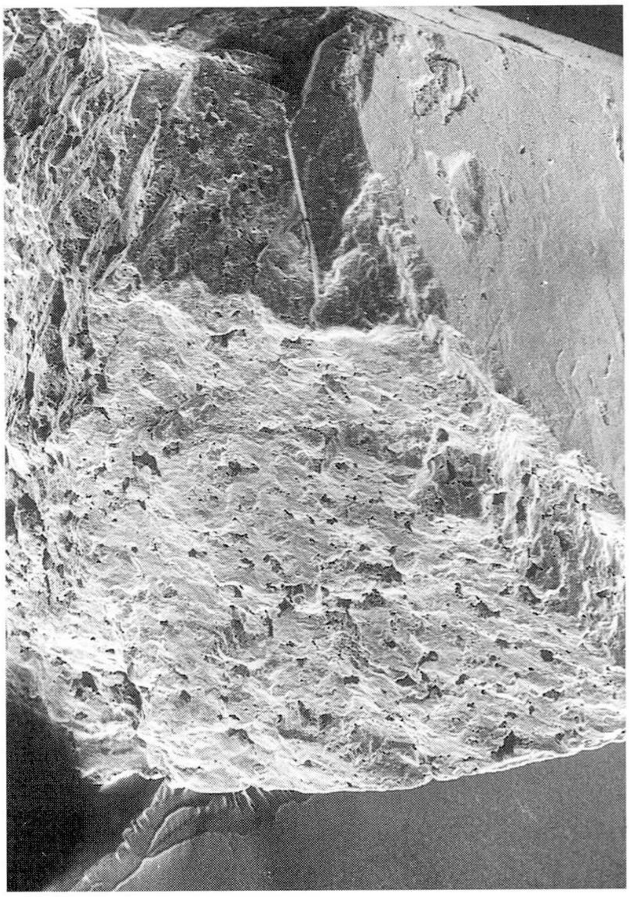

Fig. 3 Electron microscope image of a fragment of white milky zircon material, showing extensive porosity (sample KAW 128); magnification 360×.

pletely overgrown by white opaque zircon material. This zircon material is porous and certainly has an imperfect crystal structure (Fig. 3); it may contain up to 1.1% of U and is metamict but not completely amorphous for x-rays. It appears as partial or complete overgrowths and is volumetrically dominant over the transparent cores in most cases. The same zircon material has already been mentioned by PASTEELS (1964) and PUPIN (1976) from identical rock samples as brown-opaque zircons. The colour was probably caused by Fe^{3+} and was removed by the acid washing procedure in this investigation. Similar white overgrowths have already been reported from other granitic rocks in the Alps (GRÜNENFELDER, 1963; GRÜNENFELDER and HAFNER, 1962).

Zircon morphology has been analyzed by PUPIN (1976) showing that the growth of the white zircon material is coupled to increasing alkalinity and decreasing temperature of the melt. The morphological trend runs from S19–S25, P5–P4 to P2, P1 and G-type morphologies; the white zircon material is progressively recorded in this morphological evolution with a maximum for P1 and P2 types. P3, P2 and P1 are mostly present in felsic granites (leucogranites) with more than 74% SiO_2. G-type zircons are rarely found in the same rocks.

The Schöllenen "syenite" (KAW 2520) has a zircon population that consists of two different morphological types. Brown zircons form stubby prisms or nearly isometric grains with subordinate prism faces; they are often turbid or only slightly translucent. The U contents of these zircons may exceed 1%. The other type is formed by red transparent grains, mainly with G-type morphology (PUPIN, 1980), rarely forming penetration twins. The U content of a hand-picked fraction of red zircons was found to be 0.38%.

4.2. ISOTOPIC ANALYSES

The analytical results are presented in Tab. 2. All quoted errors refer to the 95% confidence level. Some analyses were performed independently at

Tab. 2 Analytical data of zircons of the Central Aar Granite and Schöllenen "syenite". All quoted errors refer to 95% confidence levels. Double analyses of the same material are marked with I and II. The correction of common lead was performed using the model of Stacey and Kramers (1975): according to an age of 300 Ma. Some of the double analyses do not overlap within error; the bad reproducibility may be due to sample inhomogeneity. Sample KAW 2520, 75–112 n.m.(l), was leached in warm nitric acid after being coarsely ground.

KAW	description	U	Pb rad	Pb nonrad	206/204	208/206	atomic ratios			apparent ages						error corr.
number		ppm	ppm	ppm	measured	blank corr.	206/238	207/235	207/206	206/238	% error	207/235	% error	207/206	% error	rho
128 /1	>110 n. m.	1033	39.54	24.02	117.32±0.30	0.4617	0.03666	0.2621	0.05186	232.2	1.5	236.5	2.3	279.4	1.7	0.70
/2	75-110 n. m.	1211	44.85	13.72	214.84±1.69	0.3214	0.03557	0.2553	0.05205	225.4	1.3	230.9	1.9	287.6	1.4	0.85
/3	75-112 white	3104	69.25	11.33	359.64±4.11	0.3373	0.02001	0.1418	0.05138	127.8	1.6	134.7	1.9	257.9	0.9	0.94
/4	<75 n.m.	1557	59.69	6.51	570.56±0.22	0.2183	0.03691	0.2652	0.05210	233.4	0.26	238.6	0.42	289.9	0.32	0.94
2213A /1	125-155 n. m.	1040	45.86	7.67	390.86±0.74	0.2133	0.04377	0.3154	0.05227	275.9	0.54	278.1	0.73	297.0	0.48	0.92
/2	75-100 n. m.	1079	42.32	9.30	288.81±1.72	0.2600	0.03832	0.2755	0.05214	242.5	1.2	247.2	1.7	291.3	1.2	0.88
/3	<42 mag.	1395	61.30	9.48	411.48±0.99	0.2230	0.04249	0.3057	0.05217	268.0	0.93	270.6	1.0	292.8	0.48	0.92
2220 /1	>112 n. m.	2061	68.80	42.01	122.27±0.07	0.3970	0.03375	0.2399	0.05155	213.8	0.56	218.1	1.7	265.5	1.5	0.78
/2	75-112 n.m.	1466	54.19	26.50	147.81±0.03	0.3484	0.03726	0.2657	0.05171	235.6	0.41	239.0	1.4	272.6	1.2	0.78
/3	<53 mag.	3879	104.07	23.43	305.20±0.13	0.2013	0.02756	0.1964	0.05169	175.1	0.26	181.9	0.74	271.6	0.66	0.52
2408 /1	>112 transp.	772	24.54	21.04	86.73±0.47	0.5622	0.03062	0.2173	0.05147	194.5	1.3	199.7	2.6	261.7	3.1	0.68
/2	75-112 transp	748	27.78	34.68	64.89±0.14	0.7296	0.03456	0.2440	0.05122	219.1	1.2	221.8	3.4	250.6	3.4	0.71
/3	75-112 white	12378	115.55	15.13	497.40±7.21	0.1565	0.009573	0.06711	0.05085	61.4	6.4	66.0	6.2	233.9	0.93	0.99
/4	<75 transp.	1240	34.41	21.44	116.73±0.03	0.4431	0.02715	0.1922	0.05134	172.5	0.27	178.3	1.7	255.9	1.6	0.75
2518 /1	>125 n. m.	1211	50.25	8.29	381.04±2.82	0.2135	0.04117	0.2968	0.05229	260.2	1.2	264.0	1.8	298.0	1.2	0.80
/2	75-112 n. m. I	1573	68.17	8.92	492.30±0.64	0.1998	0.04276	0.3075	0.05215	269.6	0.80	272.0	1.2	292.0	0.67	0.93
/3	75-112 n. m. II	1552	68.02	8.83	498.50±0.48	0.2002	0.04318	0.3112	0.05226	272.5	0.70	275.1	2.9	296.9	2.6	0.97
/4	<42 mag. I	2115	84.95	14.76	369.54±0.34	0.2295	0.03932	0.2869	0.05291	248.7	0.60	256.2	1.9	325.0	0.89	0.91
/5	<42 mag. II	2514	98.78	33.09	202.96±0.50	0.3086	0.03857	0.2758	0.05185	244.0		247.3		279.0		
2519 /1	>125 n. m. I	1209	55.45	6.26	562.04±0.96	0.2012	0.04487	0.3231	0.05223	282.7	0.44	284.1	0.56	295.5	0.34	0.94
/2	>125 n. m. II	1171	54.89	5.59	621.65±0.54	0.2021	0.04576	0.3300	0.05230	288.4	0.50	289.5	0.80	298.4	0.5	0.82
/3	75-112 n. m. I	1362	62.92	7.53	582.66±0.74	0.2126	0.04489	0.3230	0.05218	282.8	0.46	283.9	0.59	293.2	0.35	0.89
/4	75-112 n. m. II	1319	58.75	5.89	630.84±0.84	0.2131	0.04335	0.3133	0.05242	273.6	0.70	276.7	2.5	303.7	2.1	0.96
/5	42-53 mag.	1495	65.03	19.21	220.56±0.28	0.3307	0.04135	0.2972	0.05213	260.9	0.56	264.0	1.2	291.2	1.0	0.83
2520 /1	>125 red	3762	139.53	27.10	319.85±1.52	0.3042	0.03456	0.2493	0.05231	218.8	2.0	225.8	2.2	299.0	0.9	0.92
/2	>125 brown	9741	309.02	59.56	290.02±0.73	0.4549	0.02640	0.1891	0.05195	167.8	1.0	175.7	1.3	283.2	0.67	0.96
/3	75-112 n. m.	4599	162.80	46.91	217.73±0.20	0.3775	0.03233	0.2330	0.05226	204.9	0.91	212.4	1.2	296.6	0.83	0.88
/4	75-112 n.m.(l)	4542	179.35	25.82	425.88±0.62	0.3782	0.03706	0.2679	0.05243	234.6	1.10	241.0	2.4	304.1	1.8	0.89
/5	75-112 mag.	7577	258.81	91.81	172.57±0.07	0.4761	0.02971	0.2130	0.05200	188.5	1.0	195.9	1.5	285.3	1.0	0.86
/6	42-53 mag. I	5988	199.00	84.83	151.31±0.04	0.4630	0.02995	0.2147	0.05200	190.0	2.5	197.3	2.8	285.4	1.2	0.91
/7	42-53 mag. II	5668	184.20	81.03	147.14±0.04	0.4690	0.02928	0.2098	0.05196	185.8	2.0	193.2	2.4	283.6	1.2	0.91

the two laboratories in Bern and Zürich; these results are labelled as I and II in Tab. 2. Part of these results differ up to 2%, significantly more than the internal errors of the respective data sets. The reason for this phenomenon may be sample heterogeneities.

The results reveal high U concentrations for most of the analyzed zircon fractions, especially samples 2220 and 2520 and the white zircons of 128 and 2408; the resulting metamictization of the zircon lattice leads to an enhanced susceptibility to episodic lead loss during a later overprint. High concentrations of non-radiogenic, i.e. common lead, that cannot be attributed to a blank contribution are a striking feature; they may reach values up to 92 ppm (KAW 2520; see Tab. 2). This common lead component is thought to be mainly incorporated in the white milky zircon material. Common lead concentrations are indeed directly related to the amount of white zircon material in the analyzed concentrate. The common lead concentrations in transparent grains, e.g. of samples 2213A, 2518 and 2519, range usually between 5 and 10 ppm, which may be caused by apatite inclusions (Fig. 2).

The high common lead concentrations lead to $^{206}Pb/^{204}Pb$ ratios beyond values of 100. The accuracy of the analytical data presented here is thus heavily restricted by the uncertainty of the common lead correction, using the model of STACEY and KRAMERS (1975) for an age of 300 Ma. The age result of the presented data depends strongly on the Pb isotope ratios used for this correction; therefore another set of Pb isotopic ratios – feldspar and galena results of GRÜNENFELDER and HAFNER (1962), GRAESER (1971) and SCHALTEGGER (1989) – was taken for correction. These minerals are weakly enriched in radiogenic isotopes (206/204: 18.6–19.5; 207/204: 15.6–15.9; 208/204: 38.3–39.4). Using these ratios the upper intercept ages are slightly lowered, but still within the error envelopes of the presented discordias, thus the STACEY and KRAMERS (1975) values were taken for this study.

The $^{208}Pb/^{206}Pb$ ratios in Tab. 2 give a qualitative information about the Th/U ratio in the zircons; the Th/U ratio of the transparent zircons is definitely coupled with Th whole-rock concentrations (for whole-rock data see LABHART and RYBACH, 1980, and SCHALTEGGER, 1989), being highest in the Mittagflue Granite (KAW 2408, western profile) and the Northern Border Facies (KAW 128, eastern profile). The white opaque zircons have lower Th concentrations than transparent ones, which is indicated by the $^{208}Pb/^{206}Pb$ ratios of KAW 2408 (Tab. 2).

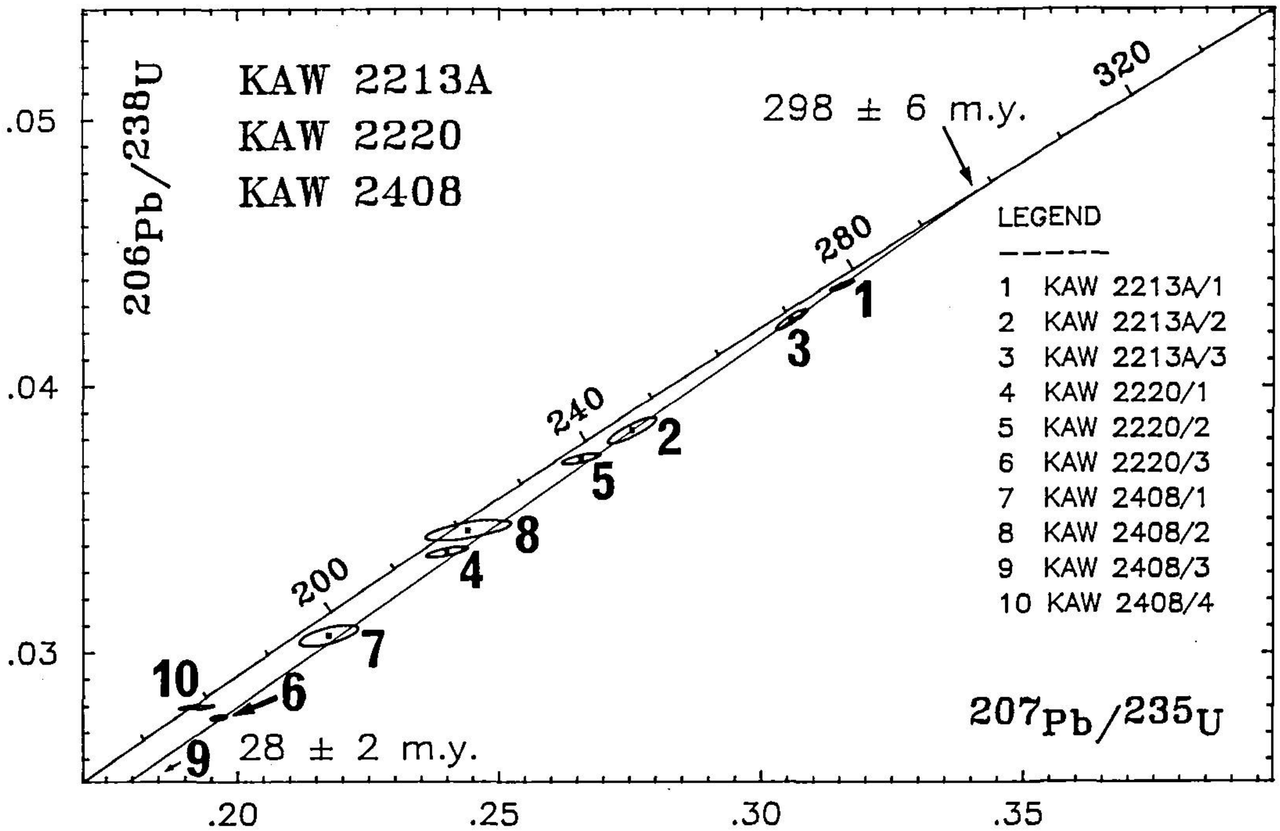

Fig. 4 $^{206}Pb/^{238}U$ vs. $^{207}Pb/^{235}U$ diagram for zircons from sample KAW 2213A, 2220 and 2408 (all western profile).

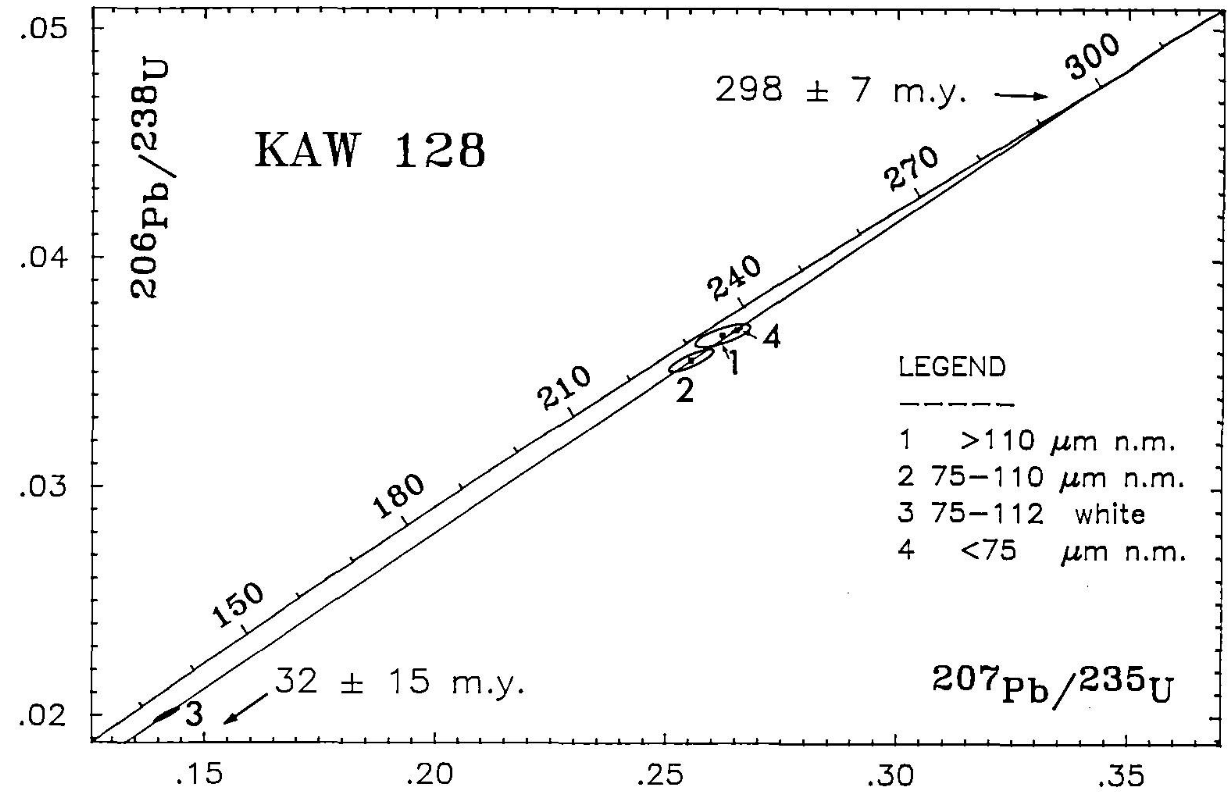

Fig. 5 $^{206}Pb/^{238}U$ vs. $^{207}Pb/^{235}U$ diagram for zircons of sample KAW 128 (Northern Border Facies, eastern profile).

Grimsel Granodiorite and Central Aar Granite s.str. (western profile, KAW 2213A and 2220):

These two rock types are discussed together because a similar intrusion age can be derived from field criteria. The zircons of the Grimsel Granodiorite are mostly transparent and show no overgrowth of white zircon material. They are slightly discordant, the $^{207}Pb/^{206}Pb$ ages being in the range of 291–297 Ma. The intermediate U concentrations show a clear relationship with grain size. An upper intercept age of 298 ± 6 Ma can be calculated with the three data points (Fig. 4). The discordancy is due to Alpine metamorphism, as indicated by the lower intercept age of 28 ± 2 Ma. The same age was found by DEMPSTER (1986) with Rb-Sr ages of white micas. The analyzed grain fractions do not show any sign of Pb inheritance from an older crustal source.

The three data points of KAW 2220 (leucocratic facies of the Central Aar Granite s.str.) plot above the discordia of KAW 2213A; their respective error ellipses however intersect the line. The lowered $^{238}U/^{206}Pb$, $^{235}U/^{207}Pb$ and $^{207}Pb/^{206}Pb$ ages (the latter around 270 Ma) indicate partial lead loss after the emplacement of this granite. The disturbance was more efficient in the white milky grains than in the transparent ones, e.g. of sample 2213A. The white zircons may carry high amounts of common lead (23–42 ppm) and U (Tab. 2). The U concentration of the studied zircon fractions depends on the amount of white material and not on grain size.

Mittagflue Granite (KAW 2408, western profile):

The zircon concentrates of this granite consist of large amounts of white zircons and only few transparent ones. The U concentration reaches a value of 1.2% in a hand-picked white zircon concentrate, but shows the lowest analyzed values (around 750 ppm) in two transparent concentrates (Tab. 2). As the white zircons are strongly porous (see Fig. 3) and the lattice strongly disordered, they were very susceptible to lead loss. The analyzed fraction KAW 2408/3 is strongly discordant due to an episodic and also recent lead loss. The $^{207}Pb/^{206}Pb$ ages are 250–262 Ma; the four analyzed fractions of KAW 2408 plot above the discordia of the Grimsel Granodiorite, but their error ellipses still intersect the discordia line with the exception of 2408/4. Its significant deviation from the line may be caused by analytical difficulties.

Granites and granodiorites of the eastern profile (samples KAW 128, 2518 and 2519):

The analyzed zircon grains of these granite types are transparent in most cases, or show only minor overgrowth by an opaque white zircon phase, especially in sample 128. The U concentration show a clear negative correlation with grain size, except for KAW 128/4, which contains considerable amounts of white zircon material.

With the four fractions of KAW 128 a regression line may be calculated separately, which intersects with the concordia at ages of 298 ± 7 Ma and 32 ± 15 Ma (Fig. 5). The $^{238}U/^{206}Pb$ and $^{235}U/^{207}Pb$ ratios of 8 zircon fractions of a granite (KAW 2518) and a granodiorite (KAW 2519) of the eastern profile spread over a small range, thus no useful regression line can be calculated. The analysis of KAW 2518/4 yielded a $^{207}Pb/^{206}Pb$ age higher than 300 Ma (Tab. 2), which is unique for all studied zircons. This result is considered to be an analytical artefact; a duplicate analysis of the same powdered zircon concentrate (KAW 2518/5) gave a lower $^{207}Pb/^{206}Pb$ age of 279 Ma (Tab. 2). These data are thus excluded from regression. A discordia based on all other data of samples 128, 2518 and 2519 intersects at 296 ± 4 Ma and 29 ± 12 Ma (Fig. 6).

Schöllenen "syenite" (KAW 2520, eastern profile):

The so-called Schöllenen "syenite" is a complex of mainly dioritic enclaves, reaching probably km^3-size. It is embedded in a granodioritic rock of the Schöllenen gorge in the southern part of the Reuss valley (eastern profile). The sample was taken along the road at the location "Brüggwald". The intrusion of its protolith must predate the emplacement of the Central Aar Granite.

The analyzed zircon fractions are highly discordant and show high U contents of 3000 to 10000 ppm, but the $^{207}Pb/^{206}Pb$ ages are in the same range than those of the Central Aar Granite (Tab. 2 and Fig. 7). Measuring coarsely ground unleached and leached aliquots of the fraction KAW 2520, 75–112 n.m. (KAW 2520/3 and /4) yielded a higher $^{206}Pb/^{204}Pb$ ratio and $^{207}Pb/^{206}Pb$ age for the latter (Tab. 2), suggesting an older intrusion age than that of the granites. The difference may be caused either by the leaching of common Pb from the zircon lattice or by leaching or dissolution of lead-containing inclusions. The extensive partial lead loss of these highly radiation-damaged, U-rich zircons may have blurred the primary isotopic systematics. Small degrees of recent lead loss or lead inheritance would result in upper intercept ages that are meaningless. The calculated upper intercept age of this rock is 316 ± 27 Ma, higher than the age of the granites, but identical within the error limits (Fig. 7). Taking 28 ± 5 Ma as age of *metamorphism* for the lower intercept, an upper intercept age of 306 ± 8 Ma is obtained.

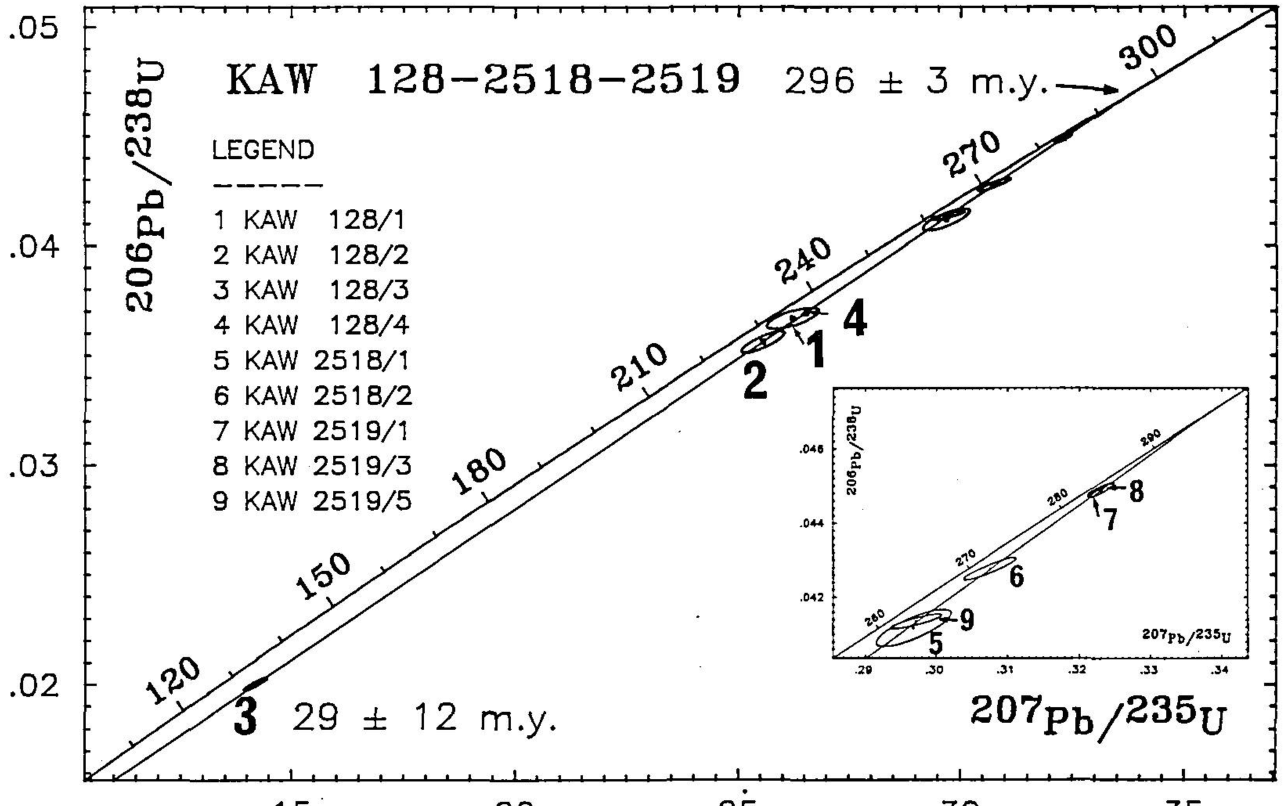

Fig. 6 $^{206}Pb/^{238}U$ vs. $^{207}Pb/^{235}U$ diagram for zircons of samples KAW 128, 2518 and 2519 (all eastern profile); the inset is a enlarged portion of the area near the upper intercept of the discordia.

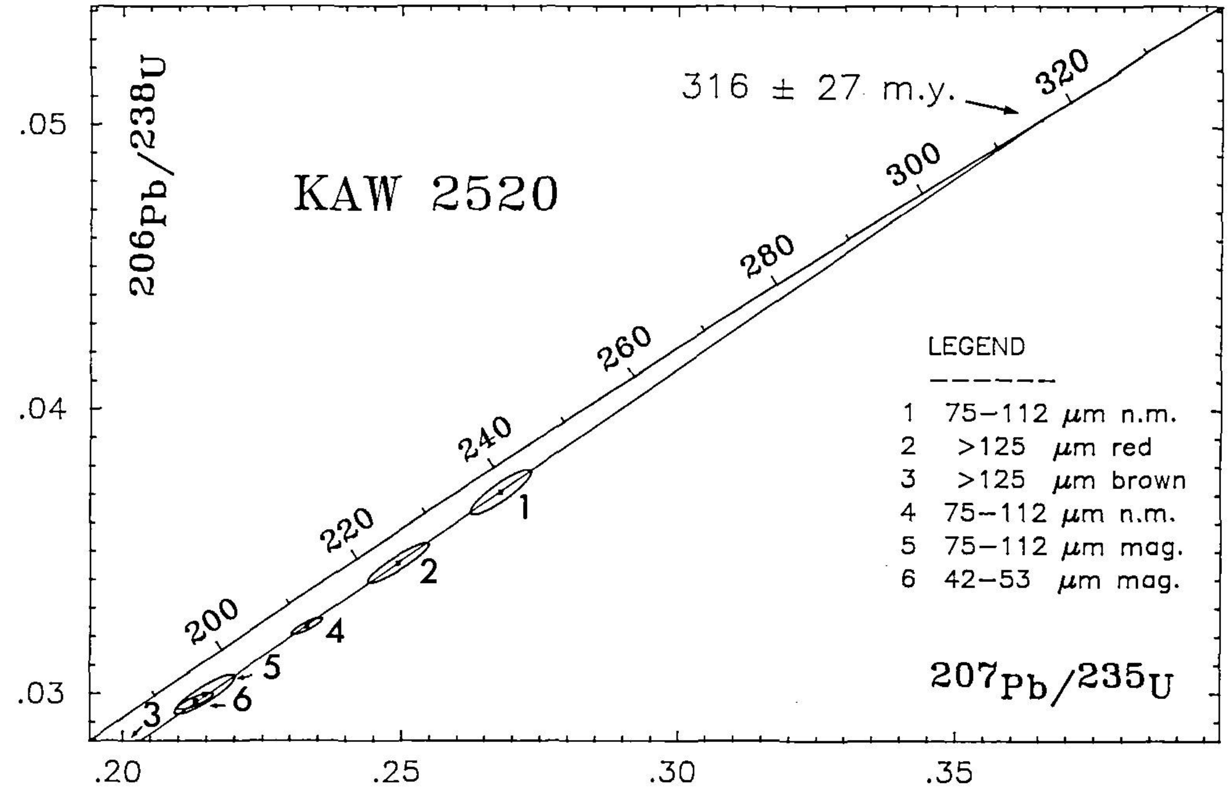

Fig. 7 $^{206}Pb/^{238}U$ vs. $^{207}Pb/^{235}U$ diagram for zircons of sample KAW 2520 (Schöllenen Syenite, eastern profile).

5. Discussion

Milky white opaque zircons, possibly coloured by trivalent iron, seem to be typical for felsic, highly differentiated granites. They grow in a late-magmatic melt that is enriched in incompatible elements (U, Th, Y, REE) and water (Pupin, 1976). Th is incorporated in contemporaneously crystallizing idiomorphic thorite. The morphology of these zircons suggest a formation in a late magmatic stage. Pupin (1976) reports typological evolutionary trends that are consistent for different rock types (granodiorite to leucogranites). Increasing A and decreasing T indices (Pupin, 1976 and 1980) are clearly related with increasing amounts of white zircon material in the case of leucogranites, whereas the Grimsel Granodiorite shows the same trend, but is nearly free of this white zircon generation. Therefore an Alpine formation of these zircons, under different conditions than the late magmatic ones, can be excluded. Later thermal overprints would cause major lead loss, because these zircons are highly metamict and disordered. An interconnected system of pores allows fluids to penetrate through the grains (see Fig. 3). A fluid-dominated, low-temperature metamorphic overprint would thus cause a larger lead loss than a medium-grade metamorphism would do, the latter possibly causing recrystallization of the lattice.

The upper intercept ages of 298 ± 6 Ma (Grimsel Granodiorite), 298 ± 7 Ma (Northern Border Facies) and 296 ± 4 Ma (all Reuss valley granites) are interpreted as intrusion ages. They are in agreement with results of Rb–Sr whole-rock investigations; a Rb–Sr whole-rock isochron of the Reuss valley granites (17 samples) yields an age of 292 ± 2 Ma (Schaltegger, 1989 and 1990b), the age difference being within the error limits of both methods. No Rb–Sr result exists for the Grimsel Granodiorite (KAW 2213A, western profile), but the whole-rock age of the main facies of the Central Aar Granite s.str. was found to be 297 ± 15 Ma (Schaltegger, op. cit.). The intrusion age of the Mittagflue Granite remains a matter of debate; a Rb–Sr whole-rock isochron age of 230 ± 8 Ma (Sr_i = 0.745) was interpreted as reset age during a Triassic/Liassic hydrothermal alteration (Schaltegger, op. cit.). The U–Pb systems of the Mittagflue Granite zircons seem rather strongly affected by either a Mesozoic or Alpine overprint; the highest $^{207}Pb/^{206}Pb$ age is 262 ± 8 Ma (Tab. 2). This age must be considered as a minimum estimate for the intrusion; it is thus highly unrealistic that the 230 Ma Rb–Sr whole-rock age reflects the magmatic emplacement of this granite.

The lower intercept ages around 28 Ma reflect the overprint by Alpine metamorphism. Lead loss during the Trias/Lias hydrothermal event remains a hypothesis. The milky white zircons also suffered recent lead loss.

The studied samples do not show any sign of inheritance from a crustal material older than 300 Ma. The calculated zircon saturation temperatures (WATSON and HARRISON, 1983) lie in the range of 778 to 793 °C for the Reuss valley samples, between 730 to 803 °C for the Grimsel samples. Geochemical data suggest that the melt was saturated in Zr through the whole differentiation history (SCHALTEGGER, 1990a). An inherited lead component could only be incorporated during the formation of these melts and would most probably include an Archean component. Trace element geochemistry does not favour a model of partial or batch melting for the generation of these rocks, but only shows evidence for fractional crystallization (SCHALTEGGER, 1990a).

The age of the Schöllenen "syenite", a dioritic enclave in a granodiorite of the eastern profile, is not yet well determined. The upper intercept age of 306 ± 8 Ma (with a fixed lower intercept age of 28 ± 5 Ma) does not clearly indicate an earlier formation than the granites.

6. Conclusions

U–Pb determinations of zircons of the Central Aar Granite reveal the contemporaneity of all studied granitic and granodioritic rock types of the whole intrusive body, its age being 296 ± 3 Ma (Fig. 6). For the Mittagflue Granite (western profile) and the Schöllenen "syenite" (eastern profile), no exact intrusion ages can be given; the former may be slightly younger than the Central Aar Granite. The latter is thought to be older, but the large age uncertainties (316 ± 27 Ma) cause an overlap with the age of the granites.

The investigation was complicated by a late-magmatic, white zircon phase that is enriched in U and common lead. Due to its bad lattice organization, it was subjected to severe lead loss during one or more post-magmatic alteration events. The common Pb concentrations are possibly further enlarged by inclusions of acicular apatite. The Alpine metamorphism, causing variable lead loss in all studied zircons, was dated around 28 Ma.

The intrusion of the Central Aar Granite 296 Ma ago, took place after the peak of Hercynian metamorphism and deformation. Regional metamorphism reached the 300 °C isograd at 312 ± 12 Ma (WÜTHRICH, 1965; SCHALTEGGER, 1986). The geochemical as well as the Sr isotopic compositions are typical for highly evolved, mantle-derived I-type magmas with little crustal contamination (SCHALTEGGER, 1990a). The absence of a detected inherited crustal lead component older than 300 Ma is in agreement with this conclusion.

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