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Autor: Giger, Matthias / Hurford, Anthony J.

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Tertiary intrusives of the Central Alps: Their Tertiary uplift, erosion, redeposition and burial in the south-alpine foreland

By MATTHIAS GIGER[1]) and ANTHONY J. HURFORD[2])

Keywords: K/Ar dating, fission track dating, Tertiary plutonite boulders, southern Alpine foreland sedimentation, central Alpine uplift.

ABSTRACT

Tertiary plutonite boulders embedded in the Oligocene-Miocene Gonfolite Lombarda Group ("Molasse") of the southern Alpine foreland (Como-Varese region; Northern Italy) were sampled for K/Ar- and fission track dating. The data allow to reveal markedly different cooling patterns for two distinct textural types of tonalites ("serizzo"). Dating of boulders emplaced in younger conglomerates (Miocene) demonstrate the deceleration of uplift in the hinterland during the Miocene. Some conclusions about the origin of the boulders are possible when the uplift data are compared with uplift patterns of the Central Alpine hinterland (Bergell; Mera valley; Passo San Jorio).

ZUSAMMENFASSUNG

Gerölle tertiärer Plutonite aus der oligo-miozänen Gonfolite Lombarda Gruppe ("Molasse") des südalpinen Vorlandes (Region Como-Varese; Norditalien) wurden mit der K/Ar- und Spaltspurmethode datiert. Die Altersdaten zeigen deutlich verschiedene Abkühlgeschichten für zwei texturell unterscheidbare Tonalittypen ("serizzo"). Die Datierung von Geröllen aus dem miozänen Anteil der Gonfolite Lombarda Gruppe belegen die abnehmende Hebungsrate im zentralalpinen Hinterland während des Miozäns. Es lassen sich auch einige Schlüsse über die mögliche Herkunft der Gerölle ziehen, wenn ihre Abkühlraten mit jenen von tertiären Plutoniten des Hinterlandes (Bergell; Mera-Tal; Passo San Jorio) verglichen werden.

1. Introduction

In the Central Alps of Southern Switzerland the Insubric lineament separates two crustal blocks with different metamorphic evolution: the northern block, the so-called Lepontine gneiss region, with widespread Tertiary amphibolite-facies metamorphism and Tertiary mica cooling ages, and the southern block with a very low grade Alpine metamorphism and mainly Variscan mica ages – the Southern Alps. Both blocks are intruded by Tertiary intrusives, the Adamello plutonic complex in the Southern Alps, the Bergell pluton north of the Insubric Line. At its eastern margins the Bergell-intru-

[1]) Laboratory for Isotope Geology, University of Berne, Erlachstrasse 9a, CH–3012 Berne, Switzerland.
[2]) Fission Track Research Group, Dept. of Geological Sciences, University College, Gower St., London WC1 E 6BT, UK.

sion is accompanied by a contact aureole which overprints the greenschist-facies country rock (Fig. 1). In the west no contact phenomena are observed and it is assumed that a much deeper crustal level is exposed here. Evidence from U-Pb data (GULSON & KROGH 1973) indicates that magmatic activity of the main magmatic body, the Bergell granodiorite (ital. "ghiandone"), ceased at about 31 Ma B.P. The Bergell tonalites (ital. "serizzo") are older than these granodiorites from field evidence, whilst some smaller intrusions (e.g. the Novate granite and pegmatite dyke swarms) are younger than the granodiorite, although as yet dating is imprecise. Pioneering fission track work in the Bergell region and on boulders from the Oligo-Miocene Gonfolite Lombarda Group

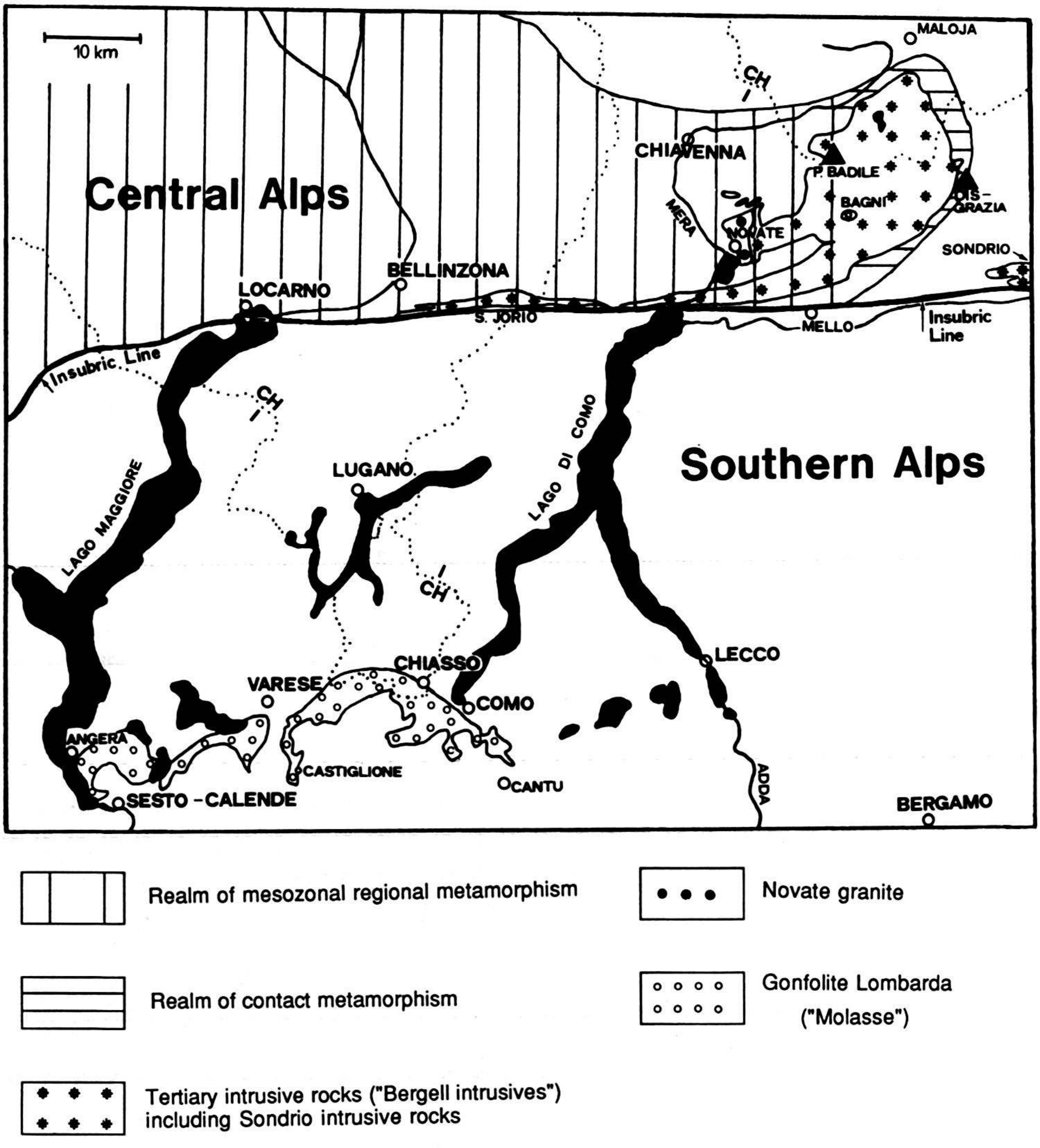

Fig. 1. Geological and topographical sketch map of the Gonfolite Lombarda Group and the hinterland (Central Alps and Southern Alps).

of the South-Alpine foreland (WAGNER et al. 1977; WAGNER et al. 1979) suggested a very rapid uplift in Oligocene times with cooling rates higher than 70 °C/Ma and low cooling rates of only 6 °C/Ma in the late Tertiary.

2. Stratigraphy and sample location

Boulders of the Bergell intrusives occur some 50 km to the south, mainly in the coarse-clastic Como and Lucino Formations (Fig. 1), which are part of the clastic foreland sediments of the Gonfolite Lombarda Group, the "South-Alpine Molasse" of earlier authors (cf. GUNZENHAUSER 1985). The coarse-clastic formations are void of fossils but the pelitic formations of the Gonfolite group occasionally contain planktonic microfaunas which were studied by GELATI et al. (in press). According to this study the marly Chiasso Formation below the coarse-clastic Como Formation has a Rupelian to Chattian (Oligocene) age. The marly Prestino Formation interfingers with and partly overlies the Como Formation and has a Chattian to Aquitanian age (Oligocene-Miocene-boundary), whereas the coarse-clastic Lucino Formation has marly intercalations of possible Burdigalian (Early Miocene) age. This latter age, however, is mainly based on the absence of certain planktonic forms and a Middle Miocene age, based on palynology, is possible (pers. communication D. BERNOULLI & B. MOHR).

Boulders of Tertiary intrusive rocks were sampled from coarse clastic formations at different stratigraphic levels (Fig. 2): KAW 3148 is a tonalite boulder from the Villa d'Olmo-Conglomerate which is intercalated in the oldest part of the marly Chiasso Formation (Rupelian according to GELATI et al. in press) near Como (Italy). The boulders KAW 2949 and 2950 were sampled from conglomerates at the base of the Como Formation which overlies the marls of the Chiasso Formation near Chiasso (Ticino; Switzerland). At the base of this huge conglomerate body, Tertiary plutonites are rare

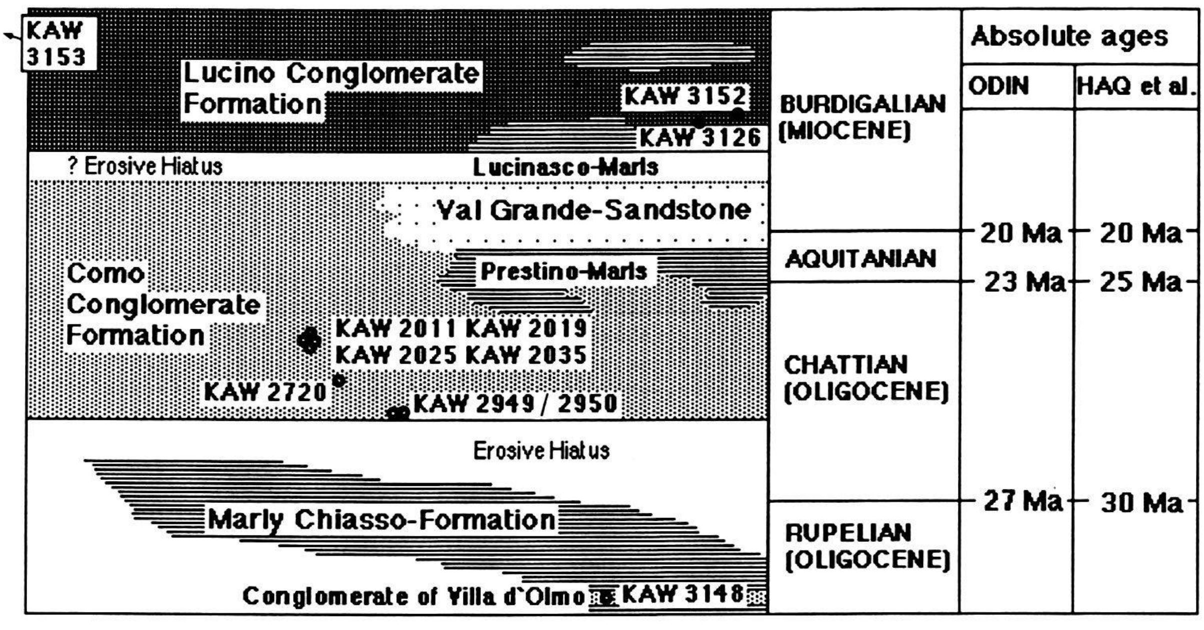

Fig. 2. Simplified stratigraphy of the Gonfolite Lombarda in the region of Como and Chiasso according to GELATI et al. (in press). The dated boulder localities are indicated on the schema.

and old basement (e.g. KAW 2950) as well as sedimentary rocks dominate the clastic assemblage. Tertiary plutonite pebbles from this low stratigraphic position show undisturbed magmatic textures under the microscope (e.g. KAW 2720, 2949 and 3148). In contrast the hornblendes of these rocks are in cases altered to chlorite and calcite suggesting a post-magmatic alteration in a shallow crustal level. The bulk of the samples were sampled near Pedrinate (Ticino, Switzerland) stratigraphically about 0.5 km above the base of the Como Conglomerate Formation. In this stratigraphic position up to 60% by volume of the components consist of Tertiary plutonites! Of the investigated Pedrinate samples only KAW 2011 resembles the rocks from shallow crustal levels described above whereas KAW 2020, 2025 and 2035 show deformed and partially recrystallized textures and the neoformation of medium-grained epidote at the expense of plagioclase. It is suggested that these rocks underwent a prolonged, post-magmatic episode of deformation in a crustal level deeper than 10 km (see below). The conglomerate of the Miocene Lucino Formation contains only few Tertiary plutonite components (e.g. KAW 3126 and 3152) but mainly polymetamorphic, old basement rocks (e.g. KAW 3153).

3. Methodology

13 biotite, 1 white mica and 5 hornblende samples were dated by the K/Ar-method using the techniques described by FLISCH (1986). Potassium was determined in duplicate by flame photometry, the reproducibility of measurements being better than ± 1% for the mica analyses, whilst for the low-K hornblendes reproducibility was only about ± 10%. Argon isotopic ratios were measured using a MM1200 mass spectrometer in static mode, employing an enriched ^{38}Ar spike (SCHUHMACHER 1975) calibrated against both known air volumes and standard minerals. All ages have been calculated using the constants recommended by IUGS (STEIGER & JÄGER 1977).

3 zircon and 3 apatite concentrates were dated by fission track analysis using the procedures described in HURFORD (1986). Apatites were dated using the population method whereas for the zircons the external detector approach was applied. Irradiations were performed in the HEROLD J1 facility, Aldermaston. The uranium glasses SRM 612, CN-1 and CN-2 were used as dosimeters. Ages have been calculated using the zeta approach (see HURFORD & GREEN 1983 for evaluation of zetas) and the errors were assessed with conventional statistics (GREEN 1981).

4. Results and discussion

K/Ar data and calculated ages are presented in Table 1 whilst Table 2 contains the analytical details and results of the fission track analyses.

A biotite from the sample KAW 3148 (*Tertiary tonalite from the Villa d'Olmo Conglomerate*) yields a K/Ar age of 31.7 ± 0.5 Ma. This age suggests a very rapid unroofing in the hinterland during Rupelian time exposing the hypabyssal Tertiary plutonites (Fig. 3). Further dating (fission track on apatite) and probably more detailed biostratigraphic investigations will be necessary to unravel the time scale problem in this lower part of the Southern Alpine Oligocene: The Rupelian – Chattian boundary has an absolute age of 30 Ma according to HAQ et al. (1987) or 27 Ma according to ODIN (1982).

KAW-No.	Lithology	Locality; Formation	Swiss coordinates	Mineral	Fraction mesh	% K	40 Ar rad ccm/g x 10 E-6	40 Ar rad %	Age Ma	1s-error Ma
2011	Diorite	Pedrinate TI, Como Formation	721.75 / 76.45	Biotit	80-100	7.61	9.18400	92.39	30.8	0.3
2011	Diorite	Pedrinate TI, do.	721.75 / 76.45	Hornblende	80-100	0.54	0.78010	74.56	37.1	3.5
2019	Tonalite	Pedrinate TI, do.	721.75 / 76.45	Biotit	60-80	7.71	8.08900	86.76	26.8	0.3
2019	Tonalite	Pedrinate TI, do.	721.75 / 76.45	Biotit	60-80	7.71	8.12470	87.01	26.9	0.4
2020	Tonalite	Pedrinate TI, do.	721.75 / 76.45	Biotit	40-60	7.37	8.25109	89.84	28.6	0.3
2020	Tonalite	Pedrinate TI, do.	721.75 / 76.45	Hornblende	80-100	0.80	1.07490	76.95	34.2	3.4
2025	Tonalite	Pedrinate TI, do.	721.75 / 75.45	Biotit	35-50	7.72	8.68890	89.37	28.7	0.4
2025	Tonalite	Pedrinate TI, do.	721.75 / 76.45	Hornblende	100-200	1.12	1.30379	22.79	29.7	2.7
2025	Tonalite	Pedrinate TI, do.	721.75 / 76.45	Hornblende	100-200	1.12	1.30083	85.59	29.6	2.7
2035	Diorite	Pedrinate TI, do.	721.75 / 76.45	Biotit	80-100	6.99	7.72925	89.46	28.2	0.3
2035	Diorite	Pedrinate TI, do.	721.75 / 76.45	Hornblende	80-100	0.79	1.00294	81.70	32.4	2.9
2720	Tonalite	Chiasso-Pedrinate TI, Como Fm.	723.20 / 76.40	Biotit	from > 35	6.86	8.43070	95.08	31.3	0.5
2949	Tonalite	Chiasso TI, do.	723.95 / 76.50	Biotit	60-90	7.11	8.95976	95.27	32.1	0.4
*3126	Granodiorite	Lucino I, Lucino Formation	724.20 / 71.03	Biotit	80-120	7.95	8.66111	95.82	27.8	0.5
*3126	Granodiorite	Lucino I, Lucino Formation	724.20 / 71.03	Biotit	80-120	7.97	8.62370	94.97	27.6	0.5
*3148	Tonalite	Como I, Villa d'Olmo conglomer.	726.25 / 75.15	Biotit	> 60	6.98	8.67468	90.26	31.7	0.5
*3148	Tonalite	Como I, Villa d'Olmo conglomer.	726.25 / 75.15	Biotit	> 60	6.96	8.72092	88.07	31.9	0.4
3152	Tonalite	Lucino I, Lucino Formation	724.60 / 71.15	Biotit	60-100	7.53	8.36070	85.76	28.3	0.4
2950	Gneissic Granite	Chiasso TI, basal Como Formation	723.95 / 76.50	Biotit	> 115	7.96	96.45760	98.47	287.6	3
3153	Granitic Gneiss	Castiglione-Olona I, Lucino Fm.	710.85 / 68.25	White mica	> 100	8.94	10.49050	90.68	29.9	0.7

*double determinations

Table 1: K/Ar data on and localities of boulders from the Gonfolite Lombarda Group.

Sample and Locality	Mineral and No. crystals	Spontaneous ρ_s	(N_s)	Induced ρ_i	(N_i)	ρ_s/ρ_i	Irrad. No.	Glass	Dosimeter ρ_d	(N_d)	Age Ma
KAW 2011 Pedrinate TI	apatite 100	2.434	(347)	1.987	(2125)	1.225	Be-14	612	6.207	(3687)	25.6±1.6
							Be-14	CN-1	1.830	(6521)	25.3±1.6
							Be-14	CN-2	1.710	(6094)	25.3±1.7
KAW 2020 Pedrinate TI	apatite 100	5.822	(830)	4.691	(2229)	1.241	Be-14	612	6.207	(3687)	26.0±1.2
							Be-14	CN-1	1.830	(6521)	25.6±1.2
							Be-14	CN-2	1.710	(6094)	25.6±1.3
KAW 2025 Pedrinate TI	apatite 100	4.756	(1695)	3.555	(2534)	1.338	Be-14	612	6.207	(3687)	28.0±1.1
							Be-14	CN-1	1.830	(6521)	27.6±1.1
							Be-14	CN-2	1.710	(6094)	27.6±1.3
KAW 2011 Pedrinate TI	zircon 10	39.709	(1217)	26.951	(826)	1.473	Be-27	612	1.144	(2500)	28.5±1.5
KAW 2020 Pedrinate TI	zircon 10	57.538	(1374)	40.285	(926)	1.428	Be-27	612	1.150	(2500)	27.8±1.4
KAW 2025 Pedrinate TI	zircon 10	52.388	(1338)	36.492	(932)	1.436	Be-27	612	1.132	(2500)	28.5±1.9

Notes:

(i). track densities (ρ) are as measured and ($x10^5$ tr cm^{-2});
(ii). all ages calculated with zeta-612 = 339 & zeta-CN-1 = 112;
(iii).the error of the ages is a 1-sigma error

Table 2: Fission track data on Tertiary plutonite boulders from the Gonfolite Lombarda Group.

Tertiary tonalite boulders from shallow crustal levels embedded in the late Oligocene (Chattian) *Como-Formation* yield relatively high K/Ar biotite ages of 30.8 ± 0.3 Ma (KAW 2011) to 32.1 ± 0.4 Ma (KAW 2949).

The K/Ar hornblende age for KAW 2011 (37 Ma ± 3.5 Ma) is comparable to a K/Ar hornblende age of 36.0 ± 0.9 Ma which was reported by WIEDENBECK & BAUR (1986) for a Tertiary tonalite in the eastern Bergell region (4 kms south-west of Mte. Disgrazia; Fig. 1). There the intrusion caused a contact metamorphism in the adjacent ophiolithes of Mte. Disgrazia (Malenco-unit; Fig. 1) and the above authors suggest that the hornblende could approximately date the tonalite magma emplacement, because the intrusives cooled very rapidly to the temperatures of the country rock (about 400 °C) in the eastern part of Bergell region (cf. REUSSER 1987). It must however be pointed to the susceptibility of the K/Ar system of hornblendes to incorporate excess ^{40}Ar. Thus these K/Ar hornblende ages only represent a possible *maximum* age for the magma emplacement.

The fission track ages for sample KAW 2011, a tonalite from a shallow crustal level, are 28.5 ± 1.5 Ma for zircon and 25.4 ± 1.6 Ma for apatite. An average cooling rate of 25 ° to 35 °C/Ma results for the boulder KAW 2011 if the K/Ar biotite and the fission track data is used for calculation (Fig. 3).

An old basement rock from the basal Como Formation (KAW 2950) has a late Variscan K/Ar biotite age of 287 Ma and certainly originates from a shallow crustal level of the Alpine orogen.

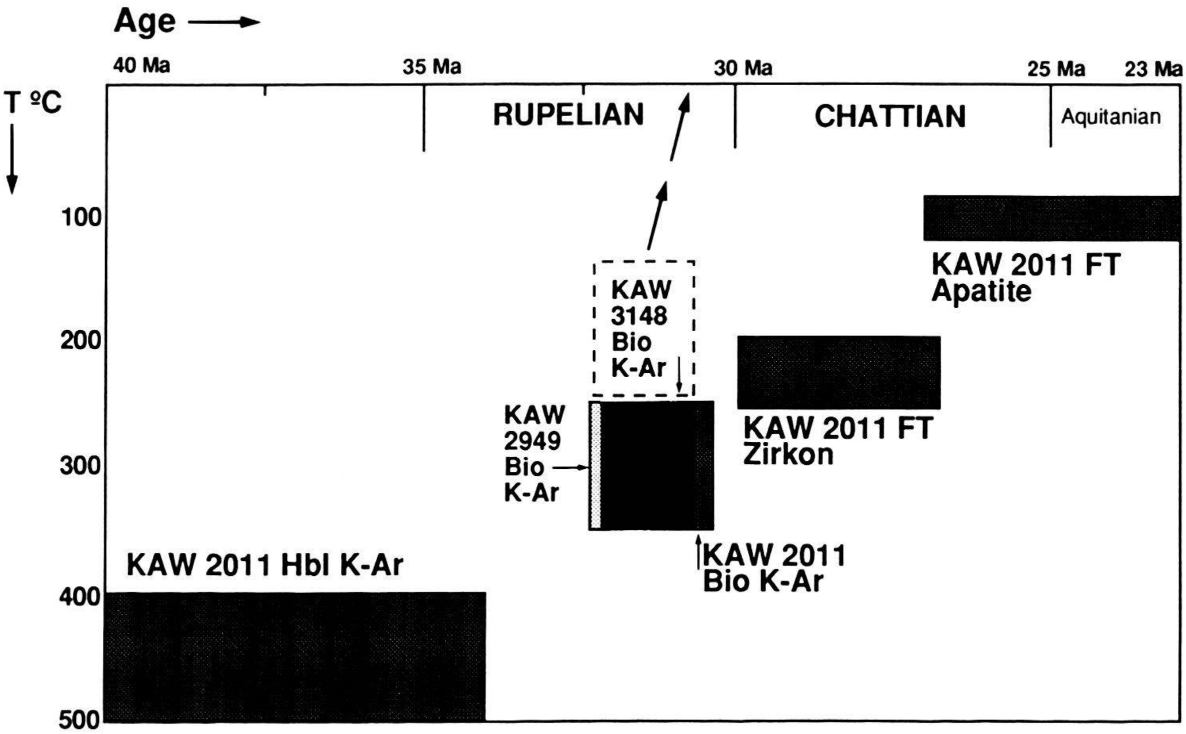

Fig. 3. Cooling history of Tertiary tonalite ("serizzo") boulders with undisturbed magmatic textures. These rocks cooled to ≈ 300 °C more than 31 Ma ago. KAW 3148 was emplaced in a Rupelian conglomerate body whereas KAW 2949 and 2011 originate from the Como Formation (Chattian). The fields represent the 1-sigma error of the ages and the uncertainties of the closure/annealing temperatures. Stratigraphic time scale according to Haq et al. (1987).

The *deformed and recrystallized Tertiary tonalite* boulders from *deeper crustal levels* (KAW 2019, 2020, 2025 and 2035) have younger K/Ar hornblende ages of 29.7 ± 2.7 Ma to 34.2 ± 3.4 Ma. These ages are comparable to K/Ar hornblende ages for Tertiary tonalites from Central Bergell (Bagni del Masino) to the Jorio-pass in the west reported by Wiedenbeck & Baur (1986): Five hornblende samples of the region from Mello (lower Valtellina-valley) to the west (Jorio-pass) have quite consistent K/Ar ages of 29 to 30 Ma and are suggested to date the cooling after the regional metamorphism. A hornblende from central Bergell (Bagni del Masino; cf. Deutsch & Steiger 1985 and Fig. 1) yielded a higher K/Ar age of 32.1 ± 1.0 Ma.

For all the above mentioned deformed and recrystallized tonalite boulders from deeper crustal levels the biotite K/Ar ages are less than 29 Ma and the difference between the biotite K/Ar ages and the fission track apatite ages is only in the range of 1 to 2 Ma suggesting a very high cooling rate of >100 °C/Ma for some cases! As an example boulder KAW 2025 was uplifted from a depth of about 15 km (closure of the K/Ar system for the hornblende at ca. 400–500 °C; cf. Onstott & Peacock 1987) to a depth of about 2 km (preservation of the fission tracks in apatite) in a very short time of only 2 Ma. Consequently an overlap of the age errors results for the boulder sample KAW 2025 (Fig. 4).

KAW 3126 (Fig. 4) and 3152, the *Tertiary plutonite boulders* from the *Miocene* (Burdigalian) Lucino Formation have K/Ar biotite ages of about 28 Ma. Assuming an absolute age of 16 to 20 Ma for the Burdigalian clastic sediments (Haq et al. 1987) an average cooling rate of 25° to 40 °C/Ma would result for these two boulders.

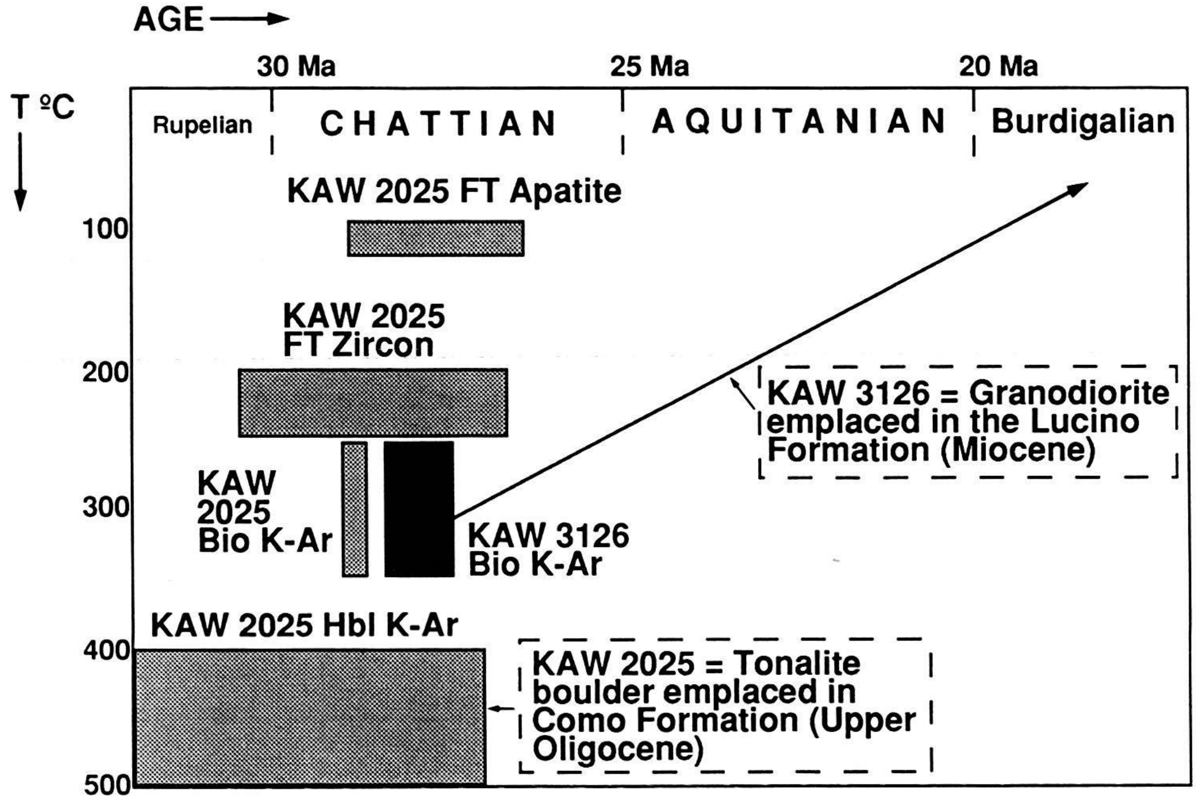

Fig. 4. Cooling history of Tertiary plutonites with partially recrystallized textures. These rocks were collected as boulders from the Como Formation (KAW 2025) and the Lucino Formation (KAW 3126) respectively. Stratigraphic time scale according to Haq et al. (1987).

A polymetamorphic, old basement boulder from the same formation (KAW 3153) has a K/Ar white mica age of 30 Ma. This means that the Burdigalian clastic sediments contain polymetamorphic old basement rocks that underwent an overprint by the Tertiary metamorphism followed by a substantial uplift of more than 10 km.

5. Conclusions

Two distinct *groups of tonalite* ("serizzo") boulders from the Gonfolite Lombarda Group could be distinguished on *textural and age* criteria: A first group with undisturbed magmatic textures originating from a shallow crustal level and a second group with partially recrystallized textures and a prolonged history of deformation in deeper crustal levels.

The tonalites originating from shallow crustal levels always have K/Ar biotite ages of about 31 Ma or more. This first textural type of tonalites already occurs in clastic sediments of Rupelian age (e.g. KAW 3148 from the Villa d'Olmo conglomerate) and is quite common in the basal parts of Como Formation. In the westernmost part of Como Formation near Sesto-Calende and Angera (Lago Maggiore) five out of six dated Tertiary tonalite boulders belong to the group originating from shallow crustal parts: The corresponding K/Ar biotite ages of these rocks are 31.8 to 32.5 Ma (Kapp 1986).

The relatively high K/Ar hornblende age of KAW 2011 (about 37 Ma) compares well to K/Ar hornblende ages in the easternmost part of the Bergell region (e.g. val Sissone).

As mentioned above a cooling rate of 25° to 35°C/Ma can be calculated from the K/Ar biotite and the fission track ages of the sample KAW 2011. A quite similar cooling rate can be deduced for the region of Mello: WIEDENBECK (1986) reports a K/Ar hornblende age of 29.8 Ma and a K/Ar biotite age of 23.6 Ma for this locality (cooling rate between 30 Ma and 24 Ma ca. 25°C/Ma). We therefore conclude that the boulder KAW 2011 could originate from a shallower crustal level eroded above the present Bergell region.

The *deformed and recrystallized Tertiary tonalite boulders* yield biotite K/Ar ages of less than 30 Ma. A very rapid uplift results for those samples which are embedded in the Como Formation (cooling rate >100°C/Ma in some cases). These deformed and recrystallized samples will probably originate from a region west of Mello possibly even west of the Mera valley where we tentatively locate the crustal block uplifted so rapidly in mid-Tertiary times.

A deformed and recrystallized tonalite sampled from the Miocene Lucino Formation (KAW 3152) has an average cooling rate of about 25° to 40°C/Ma: This rock cooled to 300°C about 28 Ma ago (K/Ar age of the biotite) and probably reached the surface at some time in early Miocene (16 to 20 Ma ago according to the time scales of ODIN 1982 and HAQ et al. 1987). These data suggest a deceleration of uplift in the hinterland during the Miocene, a fact already discussed by WAGNER et al. (1979) and WERNER (1986).

Newer studies (WAGNER 1988) suggest that a later partial annealing of the apatite fission tracks due the reburial of the boulders by post-Oligocene Molasse sedimentation could be of some importance for the lowest stratigraphic units as the estimated thickness of the overlying sediment-pile is 2 to 3 km. A partial annealing of the fission tracks could also explain why some of the apatite fission track ages almost coincide with the inferred stratigraphic age of the conglomerate (e.g. KAW 2011; Fig. 3). Track length studies are planned and could prove to be a useful tool to evaluate the burial history as well as the later thrusting and uplift of the Gonfolite Group (see BERNOULLI et al. 1987).

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