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Rb-Sr mica ages in the Alpine shear zones of the Truzzo granite: Timing of the Tertiary alpine P-T-deformations in the Tambo nappe (Central Alps, Switzerland)

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Key words: Granites, mylonites, shear zones, Rb-Sr dating, mica ages, Tertiary tectonics, Central Alps, Switzerland

ABSTRACT

The Truzzo granite, located in the southern part of the Tambo nappe, has recorded the Tertiary history of Alpine deformation. Rb-Sr whole rock dating method of this late Variscan complex leads to an age of intrusion around 280 Ma. During the Tertiary deformation, the Truzzo granite has undergone a finite heterogeneous strain at all scales. The study of Rb-Sr ages on micas from shear zones of the granite yields ages between 25 Ma–32 Ma for white micas and between 18 Ma–22 Ma for biotites. In this part of the Alps, these Rb-Sr ages are interpreted as cooling ages. These new results, associated with a compilation of previously published studies in the Tambo and Suretta nappes, allow to propose a tectono- metamorphic evolution for these Briançonnais units: (i) a high pressure event combined with a top to the NNW shearing during the stacking of these Pennine nappes is proposed between 55–35 Ma. (Valais subduction) (ii) a strong decompression, associated with a slight decrease of temperature in the upper Pennine units between 35–30 Ma occurred during the progressive activity of the Frontal Pennine Thrust (continental collision). (iii) This onset of the collision is followed by a typical Barrovian metamorphism, contemporaneous with the uplift of this part of the Alps and of the activity of the External Crystalline Massifs Thrust between 30–20 Ma.

RESUME

Le granite du Truzzo, situé dans la partie sud de la nappe de Tambo, a enregistré l'histoire tertiaire de la déformation alpine. L'âge de l'intrusion est évalué à 280 Ma par la méthode Rb-Sr roche totale. Pendant la déformation tertiaire, le granite du Truzzo a subi une déformation hétérogène à toutes les échelles. L'étude Rb-Sr des micas provenant des zones de cisaillement du granite fournit des âges compris entre 25 Ma–32 Ma pour les phengites et entre 18 Ma–22 Ma pour les biotites. Dans cette partie des Alpes, ces âges sont interprétés en termes de refroidissement. Ces nouveaux résultats, associés à un inventaire des études publiées dans les nappes de Tambo et de Suretta, permettent de proposer une évolution tectono-métamorphique de ces unités briançonnaises: (i) la subduction valaisanne correspond à l'empilement de ces nappes Penniques autour de 55–35 Ma. (ii) La collision continentale, contemporaine de l'avancée progressive du chevauchement pennique, est responsable d'une forte décompression de ces unités penniques supérieures entre 35 et 30 Ma. (iii) Ce premier stade de collision est suivi par un métamorphisme barrovien, contemporain de l'activité du chevauchement des massifs cristallins externes entre 30 et 20 Ma.

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Introduction

East of the Lepontine dome of the Central Alps, the Adula, Tambo and Suretta nappe pile results of a crustal stacking (Gansser 1937, Zurflüh 1961, Blanc 1965, Strobach 1965, Weber 1966). This nappe pile belongs to the upper Penninic zone (Trümpy 1980). A narrow suture, the so-called Misox zone, separates the southern European margin, the Adula nappe, from Briançonnais units formed by the Tambo and Suretta nappes (for a paleogeographical reconstruction, see Figure 10 in Schmid et al. 1990). The Misox zone constitutes the southern extremity of the Bündnerschiefer which have been deposited in the north Penninic Valais trough. The Truzzo granite, a late Variscan intrusive complex, is located in the southern part of the Tambo nappe (Weber 1966, Gulson 1973) (dashed area on Figure 1).

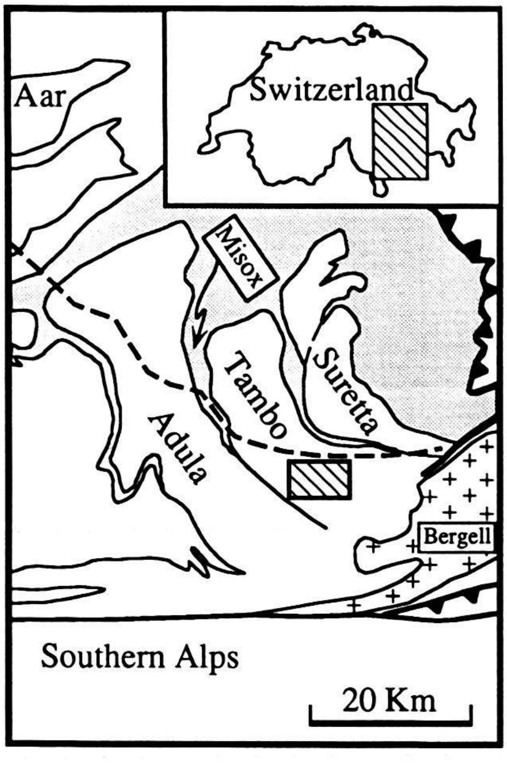

Fig. 1. Localisation of the studied area: The cross-hatched area reveals the position of the Truzzo granite in the southern part of the Tambo nappe. The stipped domain represents the Pennine Mesozoic cover. The dashed line corresponds to the staurolite isograd, after Frey et al. 1980.

According to recent geological investigations (Schmid et al. 1990, Baudin et al. 1993) and to new deep reflection seismic surveys (Frei et al. 1989, Pfiffner et al. 1988, 1990 a, b), the Tambo nappe forms a 3.5 to 4 km thick crystalline sliver overlain by its Mesozoic cover, the Splügen zone. Numerous structural and metamorphic studies have been conducted recently in the Adula, Tambo and Suretta nappes (Heinrich 1982, Löw 1987, Mayerat 1989, Schmid et al. 1990, Marquer 1991, Ring 1992, Meyre & Puschnig 1993, Baudin et al. 1993, Schreurs 1993). Different tectono-metamorphic models have been proposed (compare Ring 1992, Schreurs 1993 and Baudin et al. 1993). Based on analogue modelling of the deep structures of mountain belts (Merle & Guiller 1989), a new tectonic model was proposed for the evolution of the Tambo and Suretta nappes and their covers by Schmid et al. (1990).

Although numerous geochronological data exist in the various rocks and minerals of the Suretta nappe (see review in Hurford et al. 1989), only few analyses exist for the Tambo nappe (Hanson et al. 1966, Jäger et al. 1967, Jäger et al. 1969, Gulson 1973). The southern part of the Tambo nappe has experienced amphibolite facies conditions during the main Tertiary deformation phase while the Suretta nappe was deformed under greenschist facies conditions (Frey et al. 1974, 1980). Rb-Sr phengite ages of the Suretta nappe (with a clustering of ages around 37 Ma) were interpreted as formation ages by Steinitz & Jäger (1981) because these minerals crystallised below the blocking temperature of white micas (500 ± 50 °C according to Jäger et al. 1967). These minerals crystallised during the Ferrera phase (Milnes & Schmutz 1978, Schreurs 1993) which corresponds to D1 of this study. Following this interpretation the phengite data from the southern part of the Tambo nappe were used to estimate the cooling ages of white micas and biotites. In this area the temperature was above 500 °C during the main ductile deformation phases D1 and D2 (see below).

This paper presents Rb-Sr whole rocks analyses of the Truzzo granite and of the D1 and D2 shear zones to point out (i) the age of the intrusion and (ii) the behaviour of the Rb-Sr whole-rock system in the shear zones of the granite. Published data from the Suretta nappe together with new Rb-Sr phengite and Rb-Sr biotite ages from shear zones of the Truzzo granite lead to a pressure-temperature time diagram and a new model of the kinematic timing of the Tambo nappe.

Tectonic and strucutral evolution

During Alpine deformation, the Truzzo granite has undergone a finite heterogeneous strain (Weber 1966, Marquer 1991). The geometry of the deformation is characterised by ductile shear zones surrounding lenses of weakly deformed granite. The shear zone patterns in the Truzzo granite reveal the kinematics of the main ductile deformation phases D1 and D2 on the large scale. Four distinct deformation events have been recognised in the Truzzo granite (Marquer 1991). On the basis of the principal directions of finite strain, metamorphic paragenesis, the analysis of shear zone patterns and the observation of superposed structures, the following Alpine deformation history has been proposed by Marquer (1991) and Baudin et al. (1993):

D1 was caused by the burying due to subduction of a thinned continental lithosphere. This ductile heterogeneous deformation is associated with a strong SSE-NNW stretching lineation and a top to the NNW shearing. Estimations of P-T conditions based on the phengitic substitution (Massonne & Schreyer 1987) in D1 mylonitic foliations systematically show HP-LT (i.e. 1.2 GPa and 550 °C at the bottom of the nappe, Fig 2).

D2 is a ductile and heterogeneous deformation linked with an W-E stretching lineation. Most of the D2 mylonitic zones cross-cut prior contacts and indicate a top to the East shearing. Between these subhorizontal D2 shear planes the D1 foliation and the pre-alpine foliations previously steeply dipping towards the SE suffered strong SE vergent folding (D2). The angles between the fold axes and the stretching lineations are very weak. The phengitic substitution values measured in D2 mylonites and shear bands indicate the pressure to decrease sharply with time but the temperature to decrease only slightly (1.1 GPa to 0.5 GPa and 550 °C to 500 °C at the bottom of the nappe (Fig. 2)). Hence, D2 deformation is interpreted to result in a strong ductile vertical shortening and

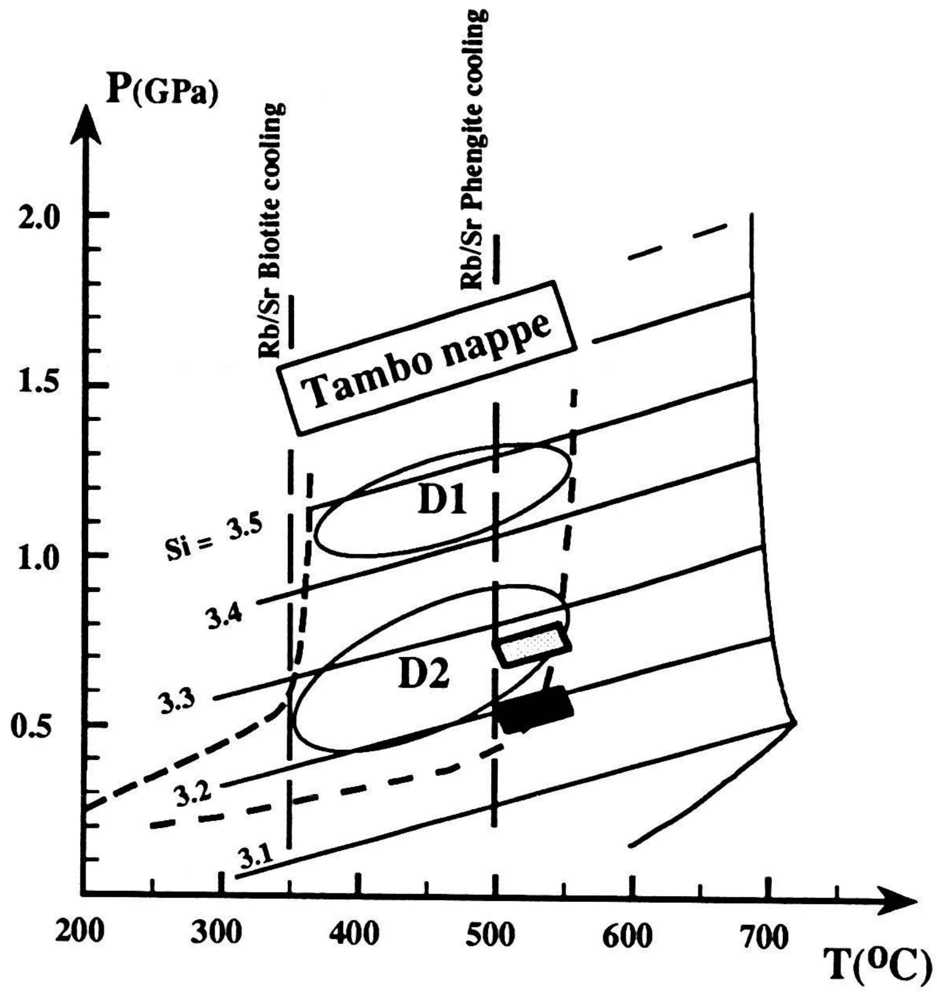

Fig. 2. Pressure-Temperature diagram based on Si content in the phengite according to Massonne & Schreyer 1987. D1 and D2 areas indicate the PT conditions for deformation phases D1 and D2 in the Tambo nappe: the left dashed line for the northern part of the nappe and the right dashed line for the southern part (Baudin & Marquer 1993). the black and grey boxes show the compositions of phengites in the sample TC4a and TC4g respectively (Tab. 1). The vertical lines corresponding to the Sr closure temperatures of the phengites and the biotites according to Jäger et al. (1967) and Amstrong et al. (1966) respectively.

a preferentially top to the East shearing, which occurred simultaneously with a substantial decompression. It is obvious that ductile deformation cannot entirely be responsible for the whole decompression. Another tectonic process, e.g. tectonic denudation by extension in the upper unit (Platt 1987), could be invoked to explain a substantial part of the decrease of pressure during D2.

The youngest deformation phases D3 and D4 occurred under greenschist facies conditions and indicate a more superficial crustal environment. The deformations gradually became much more localised. D3 is expressed by large and rhythmic folds at the nappe scale. In these areas, the structures are vertical and the D3 folds form a "stair-case" geometry: the fold hinges trend E-W with 10 °E dip and axial planes are subvertical. During D3, the contact between the Adula and Tambo nappes was slightly reactivated. D4 consists in several NNW-SSE trending brittle-ductile normal faults which dip steeply

Sample	TC4a	TC4g
SiO_2	48.52	46.87
Al_2O_3	31.50	31.27
TiO_2	0.88	0.86
MgO	1.16	1.17
FeO	2.34	2.37
MnO	0.03	0.03
CaO	0.03	0.02
Na_2O	0.27	0.30
K_2O	10.19	10.88
Total	94.91	93.77
Si	3.24	3.19
Al iv	0.76	0.80
Al vi	1.73	1.71
Ti	0.04	0.04
Mg	0.12	0.12
Fe	0.13	0.14
Mn	0.00	0.00
Ca	0.00	0.00
Na	0.04	0.04
K	0.87	0.95

Tab. 1. Phengite analysis in deformed samples from D2 shear zones in the Truzzo granite. TC4a: weakly deformed granite, average of 11 analysis; TC4g: mylonite, average of 14 analysis. The anhydrous structural formula are calculated on the basis of 11 oxygens.

to the ENE. Along each fault the eastern side is lowered by several hundreds of meters (for details see Marquer 1991, Baudin et al. 1993).

During D1 and D2 the pressure conditions were similar in the entire nappe but the thermal conditions increased from 400 °C in the north up to 500 °C in the south (Baudin & Marquer 1993). In the southern part of the Tambo nappe, the PT path during D1 and D2 cross-cuts the line of blocking temperature of phengite (Jäger et al. 1967) after D2. The phengites analysed from ductile D2 shear zones in the Truzzo granite and associated with E-W stretching lineations (Tab. 1), yield an estimation of pressure between 0.8–0.5 GPa for temperatures above 500 °C (rectangles on Fig. 2). Some of theses shear zones were analysed for their Rb-Sr whole rock compositions to examine the behaviour of the Rb-Sr system in ductile shear zones. Phengites and biotites in weakly deformed granite and mylonites were studied to define the Rb-Sr mineral cooling ages of the D2 shear zones.

Mineralogy of the shear zones

Shear zones which developed under amphibolite facies conditions have been sampled in the Truzzo granite near the Liro valley (coordinates of the Swiss topographic map: 748.9–132.9) and the Truzzo lake (coordinates of the Swiss topographic map:

744.7–136.1), north of Chiavenna (Italy). These high temperature shear zones developed during the main D2 event (Marquer 1991). The Truzzo intrusion is composed of a two-mica-granite with centimetre-sized phenocrysts of K-feldspar. In the shear zones, strain induced a progressive ductile grain-size reduction for plagioclase and K-feldspar. In the orthogneisses, the microstructures of ductile deformation in plagioclase, typical of strain partitioning at high temperature as described by Bell & Johnson (1989) as well as the occurrence of myrmekitic textures in K-feldspar indicate temperatures above 500 °C during D1 and D2 (Fig. 2). These conditions are also reflected by the metamorphic paragenesis: recrystallised oligoclase, K-feldspar, biotite, white mica and quartz. In contrast to the newly formed inclusion-free oligoclase, magmatic oligoclase within the weakly deformed rocks shows abundant sericite inclusions. Recrystallised biotite has the same brown colour as the initial magmatic biotite. The occurrence of recrystallised oligoclase is taken as an indicator of amphibolite facies conditions during mylonitisation (Yardley 1989).

Only results from metagranite shear zones generated during D2 are presented, because these deformation zones have not suffered strong reactivation during late stages of Alpine tectonism (D3 and D4), and because the phengite of weakly deformed rocks and mylonites crystallised above the blocking temperature for the Rb-Sr white mica system (Jäger et al. 1967) during both D1 and D2 ductile deformation in this southern part of the Tambo nappe (Baudin & Marquer 1993). In that case, the results of Rb-Sr phengite ages can be interpreted as cooling ages after D2 deformation.

The Rb-Sr system in the Shear zones

The age of intrusion of the Truzzo granite still raises some controversy (see in Gulson 1973): 339 ± 70 Ma (U-Pb zircon: Grünenfelder 1966), 294 ± 13 Ma with an initial isotopic ratio of 0.714 ± 0.0018 (recalculated with the 1.42×10^{-11}yr constant and 2σ with the whole rock Rb-Sr data of Fig. 2 in Gulson 1973) or about 305 Ma (whole rock Rb-Sr: Jäger et al. 1969). For a better definition of the intrusion age, some isotopic data of weakly deformed samples of the Truzzo granite published by Gulson 1973 were added with our own isotopic data (Tab. 2). Assuming that the Gulson's samples are weakly deformed, only those from the same area are selected (see table 6 in Gulson 1973). All the data of weakly deformed rocks (black dots and open circles on figure 3; Tab. 2) define an isochron relationship which can be interpreted in terms of the following intrusion age: 284 ± 21 Ma. This range of age confirms the previous estimate of Gulson 1973. The initial isotopic ratio is 0.7133 ± 0.0019 which implies a significant crustal contribution (cf. Gulson 1973, p. 297). The estimate of the Mean Standard Weighted Deviation (MSWD) on weakly deformed rocks (York 1969; Brooks et al. 1972) yields a large value of 29. Although the MSWD estimated on weakly deformed rocks produces a significant error for the calculated isochron, it must be pointed out that this deviation is lower than that calculated with the mylonites, orthogneisses and weakly deformed rocks together (Fig. 3). The high MSWD values reflect the effects of Alpine metamorphism and deformation recorded by these granites.

During Alpine deformation, the formation of the amphibolite facies shear zones produces a very low decrease of Rb/Sr and 87Sr/86Sr ratios in the mylonites. The mylonite samples are slightly offset to the left side of the initial isochron (Fig. 3). In general, the deviation of analyses of deformed rocks is rather small and leaves these data close to the

No Samples	Rb ppm	Sr ppm	87Rb/86Sr	87Sr/86Sr
Undeformed rocks: Truzzo granite (Gulson 1973)				
G.73.791	255	131	5.46	0.73650
G.73.105/4	305	89.5	9.72	0.75200
G.73.105/7	315	91.1	9.86	0.75340
G.73.789	207	51.8	11.51	0.76270
G.73.789/1	208	51.2	11.59	0.75970
G.73.790	266	56.6	13.98	0.77060
G.73.790/1	266	56.4	14.19	0.77070
Granite shear zones: Truzzo granite				
Undeformed rocks				
TC1a	152	60.2	7.32	0.74256
TC4a	226	99.8	6.57	0.73775
TC5a	192	139	4.02	0.72940
TC6a	254	114	6.46	0.73625
HTC2	196	143	3.97	0.73070
HTC4	185	135	3.90	0.72928
Orthogneiss				
TC1f	139	70.8	5.70	0.73555
TC4e	199	111	5.18	0.73080
TC4i	187	120	4.74	0.73007
TC5g	152	129	3.40	0.72543
TC5h	152	141	3.12	0.72545
Mylonites				
TC1g	104	84.7	3.57	0.73218
TC1h	124	79.9	4.49	0.73348
TC4g	181	128	4.09	0.72966
TC4h	186	125	4.31	0.73026
TC5i	135	164	2.38	0.72373
TC5j	109	237	1.33	0.72029

Tab. 2. Rb-Sr whole rock analysis in the shear zones of the Truzzo granite. The weight of the samples are around 4–8 kg. Shear zones TC1, TC4 and TC5 have a width of 3, 6 and 10 meters respectively. Samples G. 73.XXX are from Gulson (1973). TC1, TC5, TC6 and HTC samples were collected around the Truzzo lake, while TC4 samples come from the Liro valley.

initial isochron (Fig. 3). In these shear zones it is not possible to calculate isochron ages from deformed samples because of the small shift observed in the Rb-Sr system. The use of mylonitised whole rocks in order to estimate the timing of deformation seems not to be suitable for the Truzzo granite.

Rb-Sr mineral ages

In order to focus our analysis on a shear zone of the Truzzo granite (Liro Valley), the micas were isolated from one weakly deformed sample and from two mylonites. Biotite and phengite were separated using a high density sodium polytungstate liquid and a magnetic

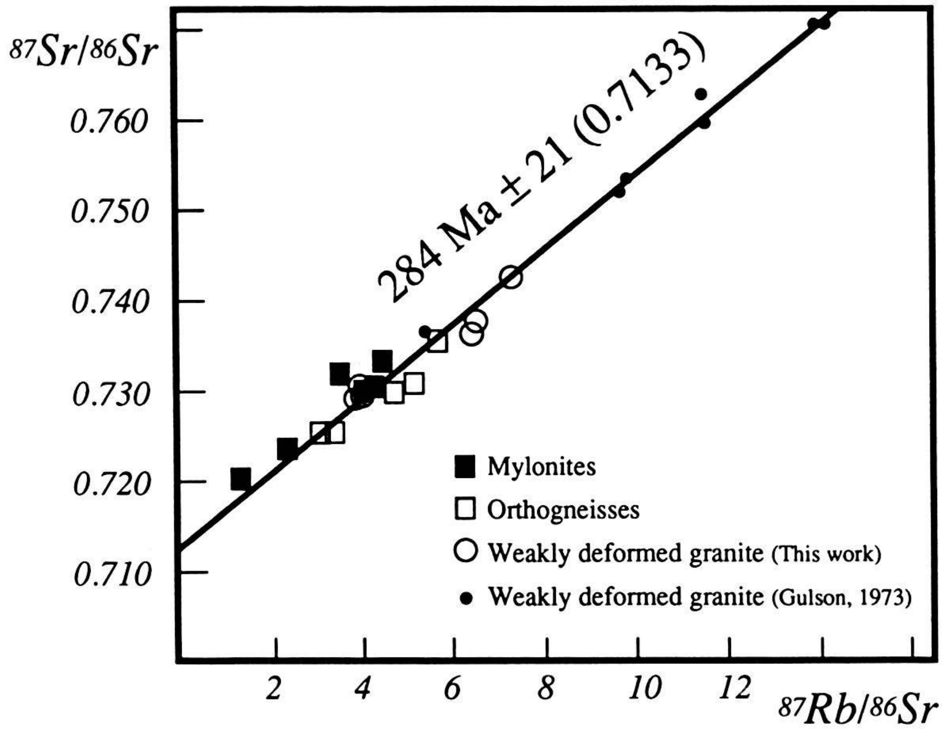

Fig. 3. Rb-Sr diagram for samples from shear zones in the Truzzo granite (see Tab. 2). See text for explanations.

Frantz separator. The high and unmixed concentrations of micas were controlled using an X-ray diffractometer. The estimation of ages of the minerals leads to the following results: for phengite 24.8 ± 0.5 Ma to 31.8 ± 0.6 Ma and for biotite 18.2 ± 0.4 Ma to 22.3 ± 0.4 Ma (Tab. 3). Comparison of the results obtained in the mylonites with those obtained in the weakly deformed rocks reveals no strain-dependence.

The Suretta nappe never reached temperatures above 450 °C but underwent the same, tectonic evolution as the Tambo nappe (Baudin et al. 1993, Schreurs 1993). Compiling the published ages of the Suretta nappe leads to the dashed curve in the Temperature-time diagram (Fig. 4). The K-Ar and Rb-Sr phengite ages (Purdy & Jäger 1976, Steinitz & Jäger 1981, Baltzer 1989, Schreurs 1993) are interpreted as formation ages of the white micas during D1 (Hurford et al. 1989, Schreurs 1993). The maximum age of the stacking of these tectonic units is the age of the Arblatsch Flysch (middle Eocene) which is involved in the nappe pile. In addition, Flisch & Sonsuk (quoted in Hurford et al. 1989) announced one K-Ar age of blue amphiboles (52 ± 3 Ma but unfortunately, no data from this study is available) in a sample which shows the structural direction of D1 and was collected at the top of the Suretta nappe. The cooling of the northern part of the Suretta unit is defined by fission tracks on zircon (250–200 °C, 20–21 MA) and apatite (120–60 °C, 16–9 MA; Hurford et al. 1989). Hurford et al. (1989) also published fission track data on zircons of the Tambo nappe. With this compilation of geochronological and geological data, it is possible to describe the Temperature-time evolution of the northern and central part of the Suretta nappe (dashed line on Fig. 4) and to conjecture that of the northern and central part of the Tambo nappe (solid line on Fig. 4).

Samples	Rb ppm	Sr ppm	87Rb/86Sr	87Sr/86Sr	Age Ma	Errors
Undeformed rock						
TC4a WR						
Biotite	1095	2.42	1367	1.16871	22.3	±0.4
Phengite	557	8.36	195	0.81763	29.9	±0.6
Mylonites						
TC4g WR						
Biotite1	1204	2.42	1494	1.11571	18.2	±0.4
Biotite2	1029	2.44	1268	1.10578	21.0	±0.4
Phengite1	438	8.08	158	0.78534	25.5	±0.5
Phengite2	483	9.68	145	0.77942	24.8	±0.5
TC4h WR						
Biotite	938	3.94	705	0.95125	22.2	±0.4
Phengite1	389	12.9	87.7	0.76388	28.4	±0.6
Phengite2	478	15.8	88.1	0.76815	31.8	±0.6

Tab. 3. Rb-Sr analysis of micas in weakly deformed rocks TC4a and two mylonites TC4g and TC4h. The analyses were performed on minerals with a size between 64 and 112 μm. Some duplicate of two aliquots of the same size fraction of micas were performed (quoted as 1 and 2). Errors indicated are the range of ages calculated from errors of each whole rocks and micas couples. The TC 4 samples were collected in the Liro valley.

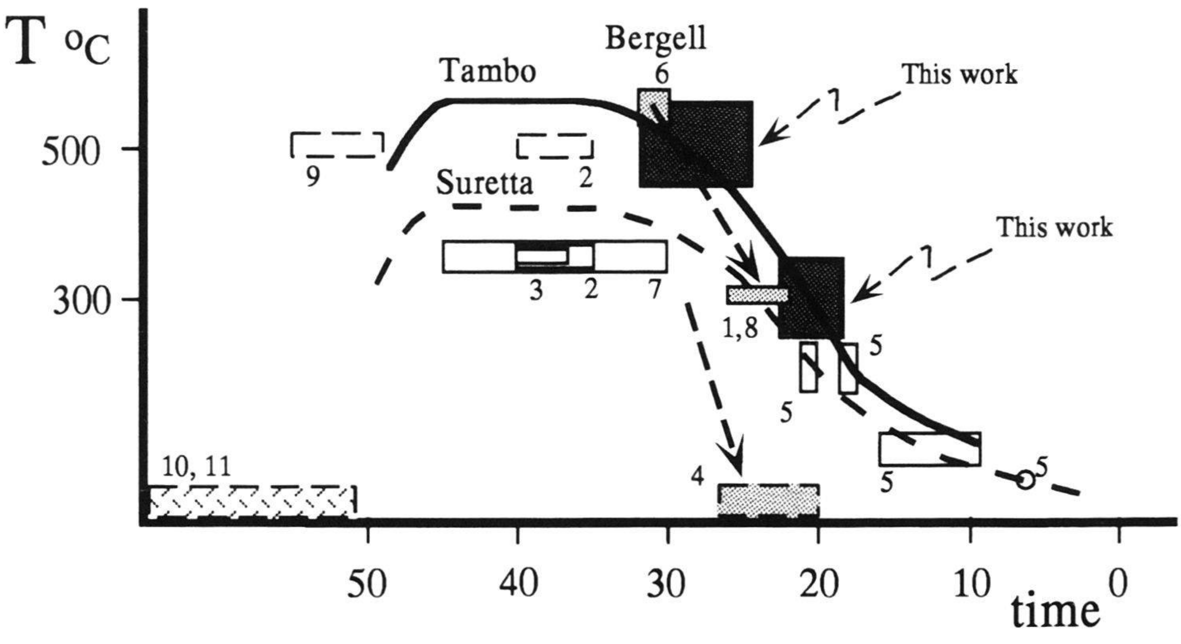

Fig. 4. Temperature-time diagram: the dashed line describes the evolution of the northern and central part of the Suretta nappe and the solid line, the evolution of the central part of the Tambo nappe (Truzzo granite). The dashed arrows describe the temperature-time evolution of the Bergell unit further in the south. See text for explanations. The numbers near the boxes correspond to the data from different authors: (1) K-Ar and Rb-Sr biotite ages, Jäger et al. 1967; (2) K-Ar and Rb-Sr phengite ages, Purdy & Jäger 1976, Steinitz & Jäger 1981; (3) K-Ar phengite ages, Baltzer 1989; (4) Bergell boulders, Giger & Hurford 1989; (5) Zircon and apatite fission tracks, Hurford et al. 1989; (6) U-Pb monazite and zircons, von Blanckenburg 1990; (7) K-Ar phengite ages, Schreurs 1993; (8) K-Ar and Rb-Sr biotite ages, Giger 1991; (9) K-Ar amphibole ages, Flisch & Sonsuk in Hurford et al. 1989; (10) Arblatsch flysch deposits, Ziegler 1956 and (11) Eiermann 1988.

While the first part of the curve (Fig. 4) of the Tambo nappe can be clearly related to D1, several geological arguments reveal that the part between 30 and 20 Ma corresponding to the new Rb-Sr phengite and Rb-Sr biotite ages in the Truzzo granite represent cooling temperatures contemporaneous to D3. D2 which is associated with a strong decompression with nearly constant temperature (Fig. 2) starts before the granodiorite intrusion in the eastern Bergell: the granodiorite intrusion cross-cuts the Turba mylonite (interpreted as contemporaneous with our D2) further in the East (Liniger 1992). Based on the ages of the Bergell intrusion 30–32 Ma (Gulson 1973, von Blanckenburg 1990), of Bergell cooling (K-Ar and Rb-Sr biotite ages: 26–22 Ma, Jäger et al. 1967, Giger 1991) and occurrences of Bergell boulders in the Gompholite Lombarda (Como conglomerates: Aquitanian, c. 24–20 Ma) in the Southern Alps (Giger & Hurford 1989), the timing of rapid cooling, strong uplift and denudation in this southern part of the central Alps was effective between 30–24Ma.

Pressure-Temperature-time evolution

The Pressure-Temperature-time diagram for the Tambo nappe north of Chiavenna (Fig. 5) is constructed using Temperature-time (Fig. 4) and Pressure-Temperature (Fig. 2) diagrams: the solid line corresponds to the temperature curve of the figure 4. The pressure curve (dashed line on the Fig. 5) is constructed using pressure-temperature estimates for D1 and D2 deformation on the figure 2. As no data of pressure are available during the late deformation phases, D3 and D4, the last part of the pressure curve was just fitted to the temperature curve (Fig. 5). Hence, the pressure and the temperature values in this late part of the curve are conjectured for a mean geothermal gradient of 30 °C/km. This geothermal gradient corresponds to the conditions of the Barrovian P-T-path occurring after the deformation D2 (see the area between the small dashed lines on Fig. 2).

The age of the increase of pressure between 55–35 Ma (Fig. 5) is constrained by the time of the sedimentation of Arblatsch Flysch and by amphibole and phengite ages in the Suretta nappe, as a same tectono-metamorphic story is assumed for both Tambo and Suretta nappes (cf. Fig. 4). This part of the curve is interpreted as the Valais subduction (Fig. 5). After the high pressure event in the Tambo nappe the pressure decreases strongly while the temperature is nearly constant during the first stage of the continental collision (D2) (Fig. 5). The change in slope of the decompressional curve approximately during Bergell emplacement (32–30 Ma) is purely hypothetical and introduced in order to separate D2 and D3. After these tectonic events with fast cooling rates (average of 30 °C/Ma), the cooling rates decrease towards values about 10 °C/Ma during D4 (Fig. 5).

At the scale of the Central Alps, the early history of the tectonic evolution of the Tambo nappe reflects the underplating of thinned crustal slices in a tertiary crustal wedge, during the closure of the Valais trough: the Valais subduction (Fig. 6a). This stage lasted till the two continental crusts (European and Apulian) overlapped, pinching the Penninic crustal wedge. D1 is linked to the progressive Eocene stacking of the Adula, Tambo and Suretta nappes towards NNW. During the Eocene (Flysch formations), the Valais trough was subducted below the northern Briançonnais border (Tambo nappe, dashed area on the Fig. 6a).

The following stage, the continental collision, is characterised by thinning of the upper Penninic zone, coeval with the activity of the frontal Pennine thrust (FPT) further

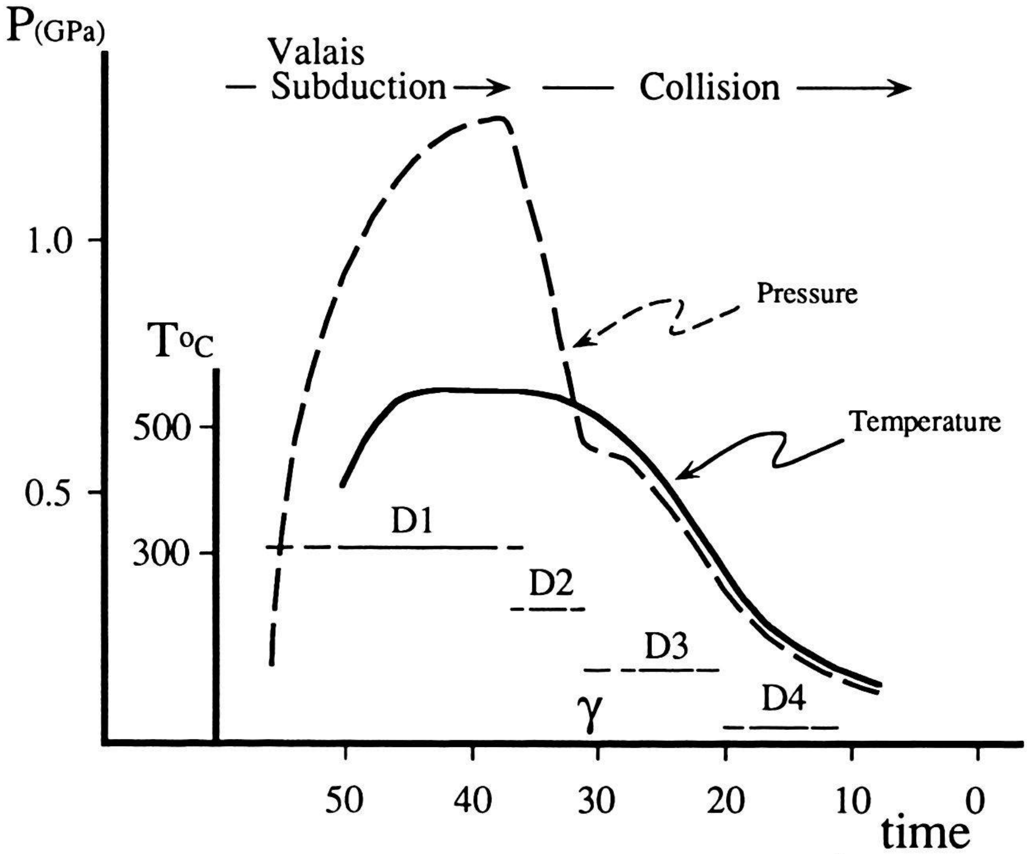

Fig. 5. Pressure-Temperature-time diagram for the Tambo nappe: the four Tertiary deformation phases are approximately situated on the diagram. The dashed line represents the evolution of the pressure in time. The solid line represents the evolution of the temperature in time. γ corresponds to the age of the Bergell intrusion which cross-cuts mylonites of D2 age.

north: this progressive D2 deformation (Oligocene) led to a crustal thinning parallel to the Alpine chain and a huge post-nappe refolding (Schmid et al. 1990). It is important to notice that D2 W-E thinning began while the more external frontal penninic thrust was still transporting the whole nappe pile towards the NNW (Fig. 6b). Moreover the D2 thinning, associated with the substantial decompression (Fig. 2), could also explain a part of the exhumation of the eastern domain of the high grade Ticino zone (Bradbury & Nolen-Hoeksema 1985). At a large scale, even if the rigid tilting of the eastern Pennine domain occurred preferentially during D3 and D4, these Tertiary longitudinal (W-E) extensional tectonics could be responsible of a part of the regional eastern plunge of the Penninic units.

D3 and D4 are due to late tectonic events during retrograde metamorphism. These deformation phases could be related to late vertical movements and strike slip displacements along the Insubric and Engadine lines during the late Oligocene and the Miocene (Heitzmann 1987, Schmid & Frotzheim 1993). The staircase geometry of D3 folding suggests a differential uplift of the southern part of the nappe. This north vergent D3 folding is possibly linked to the uplift along the Insubric line.

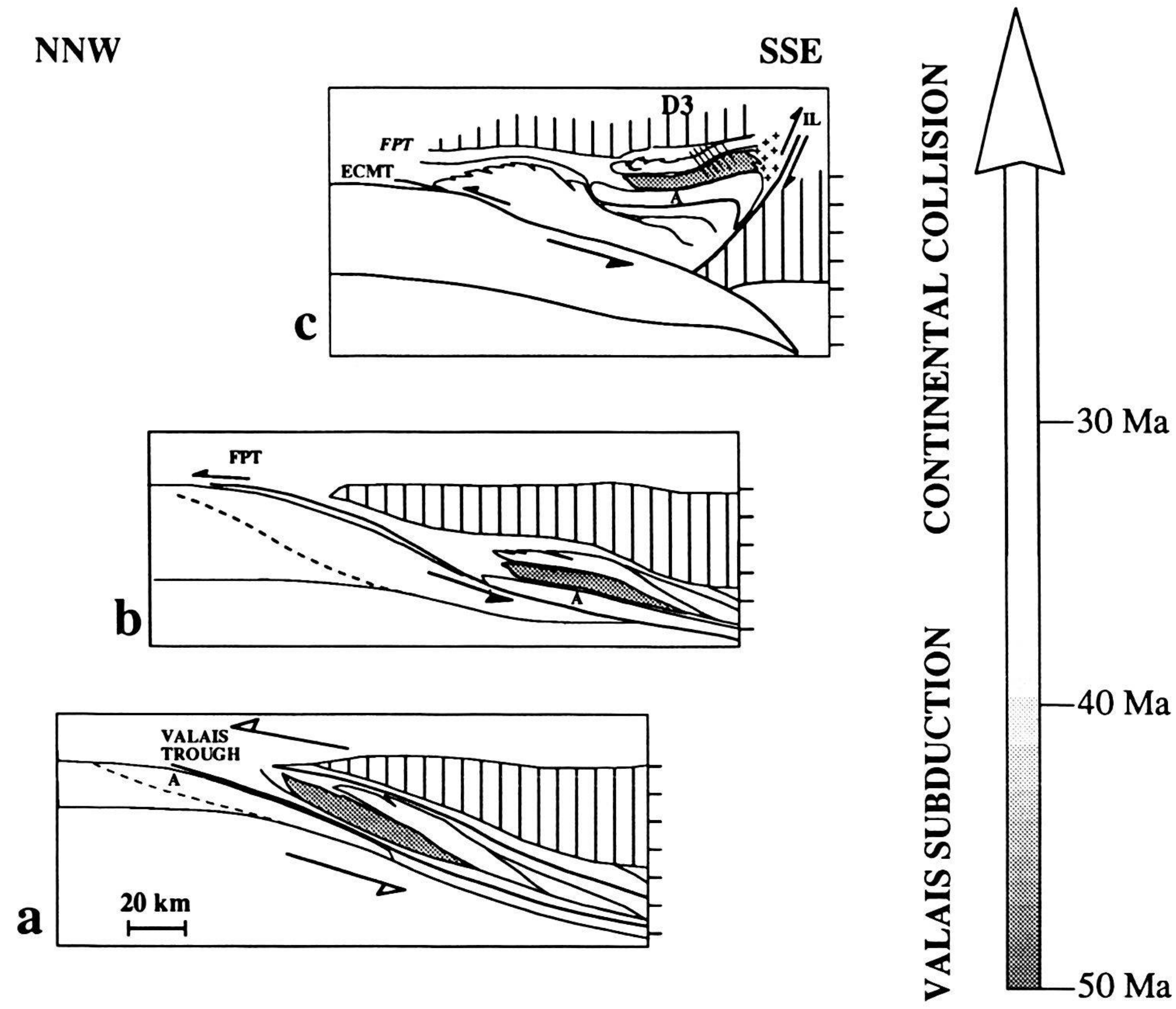

Fig. 6. Sketch of the tectonic evolution of the Tambo nappe (dashed area). a) Valais subduction: D1 deformation; b) Continental collision: The Frontal Penninic Thrust (FPT) is active below Adula nappe (A) and D2 deformation affects the Tambo nappe c) Continental collision to actual geometry: the External Crystalline Massif Thrust (ECMT) and the Insubric line (IL) act, contemporaneously with the D3 deformation in the Tambo nappe.

The Insubric back-thrusting is dated late Oligocene – early Miocene by isotope cooling ages of different minerals (Hurford 1986, Heitzmann 1987). Consequently, the differential uplift D3 of this domain might be contemporaneous with the thrusting of the External Crystalline massifs in the North (Marquer 1990; ECMT = External Crystalline Massifs Thrust on Fig. 6c). The late D4 extensional deformation phase seems to be a symmetrical structure coeval with the last Simplon normal faulting (Mancktelow 1985) and could also be linked to late transpression of the Apulian plate along the Alpine arc.

In this proposed pressure-temperature-time evolution, no tectonic event is related to the Cretaceous age. The Eoalpine Rb-Sr whole-rock isochron age (Steinitz & Jäger 1981) obtained in the frontal part of the Suretta nappe is not supported by other data (see also Hurford et al. 1989). Hence, this isochron yielding an age of 118 ± 7.8 Ma could also be considered as fictitious isochron related to chemical mass transfer and partial rejuvenation of the Rb-Sr whole rock system (Marquer 1987).

Conclusions

These results emphasise that the Rb-Sr dating methods (whole-rock and minerals) are not well suited to conjecture directly the age of heterogeneous deformation in granitic rocks which have suffered amphibolite metamorphism conditions. Two essential reasons can be pointed out: first, the difficulty to acquire a bulk isotopic homogeneity of the whole system which is explained by the presence of shear bands and preserved domains at a smaller scale than the samples. Second, isotopic homogenisation postulated in high grade metamorphic models is controlled by diffusion processes. The diffusion mechanism is thermally enhanced and at the scale of the shear zones of the Truzzo granite a bulk isotopic homogenisation is, with no doubt, never reached.

Minerals isolated in well-defined Alpine shear zones lead to propose a pressure-temperature-time evolution of the Tambo nappe. Rb-Sr phengite and Rb-Sr biotite analyses are interpreted as cooling ages in the Truzzo granite. These new data combined with structural and metamorphic results allow to propose two main distinct tectonic events during the Tertiary: (i) The Valais subduction between 55–35 Ma and (ii) the continental collision responsible for two major thrusts, the Frontal Pennine Trust and the External Crystalline Massifs Thrust, acting separately and progressively in time, after 35 Ma, towards the external part of the Alpine belt.

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Appendix:
Analytical procedures

Rb and Sr contents of micas were determined by the isotope dilution method at Géosciences Rennes. The Rb and Sr contents of whole rocks were analysed by XRF method in the laboratory of H.R. Pfeiffer (Lausanne). Isotope analyses were performed at Rennes using Cameca THN 206 and Finnigan Mat 262 mass spectrometers. NBS 987 yields homogeneous values of 0.71020 ± 5. Uncertainties for 87Rb/86Sr ratios were 2%. Isochrons were calculated according to the method of York (1969). The probable errors of the isochrons are quoted as $2\sigma \times \sqrt{MSWD}$, where MSWD>1. Total error on the 87Sr/86 Sr used in calculation is 0.02%. The errors on the run from Cameca MS is $3–8 \cdot 10^{-5}$ and $1–2 \cdot 10^{-5}$ from Finnigan Mat.

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