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Fission Track Record of the Wiesbachhorn Profile: The Highest Relief in the Eastern Alps

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With 3 figures and 2 tables

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Zusammenfassung: Spaltspurenanalysen vom Wiesbachhorn: Das höchste Relief der Ostalpen. – Das Profil des Wiesbachhorns im zentralen Tauernfenster weist das höchste topographische Relief der Ostalpen auf: Von seinem Gipfel auf 3565 m Seehöhe bis zum Zentrum von Bruck a.d. Glocknerstrasse im Salzachtal (auf 755 m Seehöhe) sind es 2810 Meter Höhenunterschied über nur 15 km Strecke. Davon fallen die ersten 2700 Höhenmetern innerhalb von 8 km vom Gipfel ab. Solch hohe Vertikalprofile sind nützlich im die Exhumations- und Hebungsraten von Gebirgen zu datieren. Dazu haben wir von 7 regelmäßig gestaffelten Proben von einem Profil zwischen Wiesbachhorngipfel und Kapruner Ache die Apatit Spaltspurenalter gemessen. Leider zeigen die Analysen, dass aufgrund der jungen Alter und der geringen Urangehalte der Apatite, die Fehlergrenzen wesentlich zu hoch sind, sodass praktische keine nützliche geologische Interpretation möglich ist. In diesen Artikel fassen wir unsere Ergebnisse zusammen, um eine Basis für weitere Versuche zu schaffen.

Summary: The Wiesbachhorn in the central Tauern window reflects the highest topographic relief in the Eastern Alps: From its summit at 3565 metres above sea level to Bruck a.d. Glocknerstrasse in the Salzachvalley (on 755 m.a.s.l.) there is 2810 metres of relief over a distance of 15 km. Of this drop, 2700 vertical metres are within 8 km of the summit. Such high vertical relief is extremely useful to determine exhumation and uplift rates of mountains. We have performed apatite fission track dating of 7 samples from this profile on regular intervals. However, because of the young age and low uranium contents of the samples, the obtained ages have enormous error bars, effectively precluding any useful interpretation in terms of a cooling history. In this paper we summarise our analyses in order to provide a database for further efforts.

1. Introduction

The Tauern window of the Eastern Alps contains not only the highest topography of the Eastern Alps, but also exposes the structurally deepest rocks of the orogen. It is mainly for this reason that its exhumation and uplift history has been of some interest and an abundance of studies have investigated its history of vertical motion (see summary by NEUBAUER & al. 1999). However, details of the final exhumation to the surface, valley incision and topography development are still sketchy (although see: FRISCH & al. 1998, 2000, KUHLEMANN & al. 2001). In order to resolve some details of this part of the evolution, we have sampled the highest relief in the eastern Alps for apatite fission track analysis – the almost 3000 vertical meter Wiesbachhorn profile near Zell am See. Although the analyses show that the samples are too young and the uranium contents of the apatites too low to allow any meaningful tectonic or geomorphological interpretation, we present here details of our analyses in order to provide future workers with some background information and sampling strategy.

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2. Geological and Geomorphological Setting

The Wiesbachhorn is located along the northern margin of the central Tauern window south of Zell am See (Fig. 1). The entire peak is made up of calcareous mica-schists that are part of the Bündnerschiefergroup of the Glockner nappe (geological and topographic maps 1:50,000, ÖK 153 Grossglockner and ÖK 123 Zell am See). The Glockner nappe is part of the Penninic series that cover Variscan gneiss domes inside the Tauern window. Two of these gneiss domes are located near the Wiesbachhorn: The Granatspitzkern to the west and the Hochalmkern to the east. The Penninic units experienced amphibolite facies metamorphism around 600° C and 7–8 kbar during the Alpine orogenic event at about 30 Ma (Droop 1985, Cliff & al. 1985). The high grade geological evolution of the region has been described in detail by Droop (1985), Cliff & al. (1985) and more recently summarised by Kurz & Neubauer (1996), Kurz & al. (1999) and many others. However, this part of the geological evolution is of minor relevance here.

Of more interest to our study is the cooling history during the exhumation of the Tauern window to the surface. This exhumation history is now reasonably well known (see summaries by Dunkl & al. 1998, Neubauer & al. 1999, Kuhlemann & al. 2001). A fast exhumation between 22 and 13 Ma is well documented by a series of geochro-

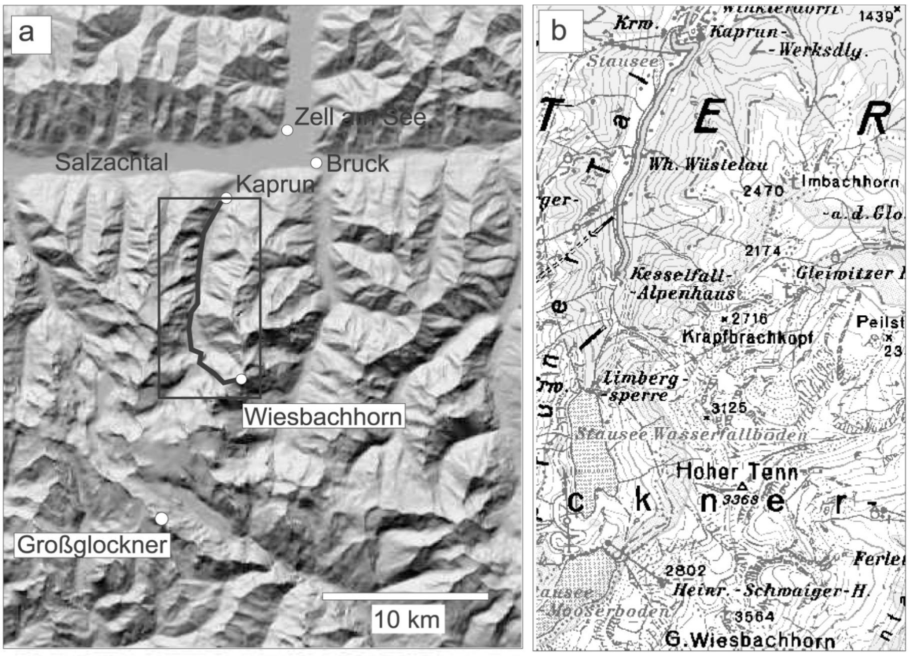

Fig. 1: Topographic maps of the Wiesbachhorn region. (a) Plot of the region from digital imaging of the SRTM30 digital elevation model. The box shows the enlargement shown in (b). The thick black line is the sampling line for which details of the sampled locations and elevations are shown in Table 1. (b) Detail from (a) plotted using the software AustroMap and the 1:200.000 maps. Note however that the scale of the section is not 1:200000 on this page.
Topographische Karte der Wiesbachhorn Region. (a) Darstellung des Gebietes mittels des SRTM30 digitalen Höhenmodels. Das Rechteck zeigt die Vergrößerung in (b). Die dicke schwarze Linie zeigt das Profil entlang dessen die Proben genommen wurden. Details dazu in Tabelle 1. (b) Detail von (a). Diese Abbildung wurde mit der Software AustroMap und dessen 1 : 200.000 Kartensatz produziert. Auf der vorliegenden Abbildung ist der Maßstab jedoch nicht 1 : 200.000.

nological methods (Cliff & al. 1985, Frank & al. 1987, Fügenschuh & al. 1997). This exhumation process has mostly been related to the process of the Miocene lateral extrusion (Ratschbacher & al. 1991). The final exhumation in the Tauern window has been documented with fission track ages by Grundman & Morteani (1985) and Stauffenberg (1987). It appears that the western margin of the Tauern window began cooling somewhat earlier than the eastern margin (Fügenschuh & al. 1997), but that cooling curves converge towards lower temperatures (see review of Kuhlemann & al. 2001). The cooling through the apatite fission track retention temperature around 110° C occurred in most regions of the Tauern window between 9 and 13 Ma with the central Tauern window probably cooling at 11 Ma. This is substantially later than exhumation of the Austroalpine outside the Tauern window, which occurred before about 50 Ma (Hejl 1997).

Morphologically the Wiesbachhorn 3565 m elevation above sea level – the 2nd highest peak of the Eastern Alps, over towered only by the Großglockner (3798 m), almost exactly 10 km to the southwest across the ice fields surrounding the Pasterze (Fig. 1). North of the Wiesbachhorn, one of the largest west – east lineaments of the Alps is located: the Salzachtal valley, which is part of the Salzachtal-Ennstal-Maria-Puchberg (SEMP) lineament (Wang & Neubauer 1998). The Salzachtal is one of 3 major knee-shaped drainages that drain the northern side of the Eastern Alps, also including the Inntal and the Ennstal. All three valleys are characterised by sharp knee-shaped bends at Wörgl (for the Inn), Bischofshofen (for the Salzach) and Hieflau (for the Enns), with these "escapes" of the rivers into the northern foreland occurring in all three cases at about 60 river kilometres from their source. The significance of this knee-shape has been discussed by Stüwe & Sandiford (1994) as well as Stüwe (2002) and may be related to river power. The Tauern window itself is drained by a series of north – south drainages that feed from the central ice fields into the Salzach. In the Wiesbachhorn region, these valleys include the valleys of the Fuscher Ache just east of the peak and the Kapruner Ache to the west. Both valleys are located at a mere 700 – 800 metres above sea level giving the Wiesbachhorn an astounding profile if seen from the north. The largest vertical change in the region is between the Wiesbachhorn summit on 3565 m and Bruck a.d. Glocknerstrassee at 755 m about 15 km from the summit. However substantially higher topographic gradients occur in the immediate vicinity of the peak: Towards to Kapruner Ache, there is 2700 m of relief within 8 km of the summit and towards to Fuscher Ache the drop to 1200 metres above sea level (2365 m of relief) occurs within 3.5 km of the summit, implying a mean slope of more than 35° over almost 2.5 vertical kilometres. It is this high relief and steep topographic gradients in the Wiesbachhorn region that has intrigued our interest to constrain the morphological history of valley incision and uplift in the region.

3. Apatite Fission Track Analysis

For our project we have sampled 19 rock samples between the summit of the Wiesbachhorn and the creek bed of the Kaprun at the Powerhouse near the Klamm entrance (Figs. 1, 2, Table 1). All samples are micaschists of mid-amphibolite facies metamorphic grade containing garnet, biotite, muscovite, some staurolite, aluminosilicate, plagioclase and quartz as major minerals. Each sample was about 1–2 kg in weight to ensure an abundance of accessory apatite. Samples were crushed, mounted and polished in the fission track laboratory at Melbourne university and irradiated by ANSTO (Lucas Heights) in Sydney. Counting was done in the facilities of Geotrack International Pty. Ltd. in Melbourne. Before discussing our results it seems worth explaining the significance of apatite fission track dating.

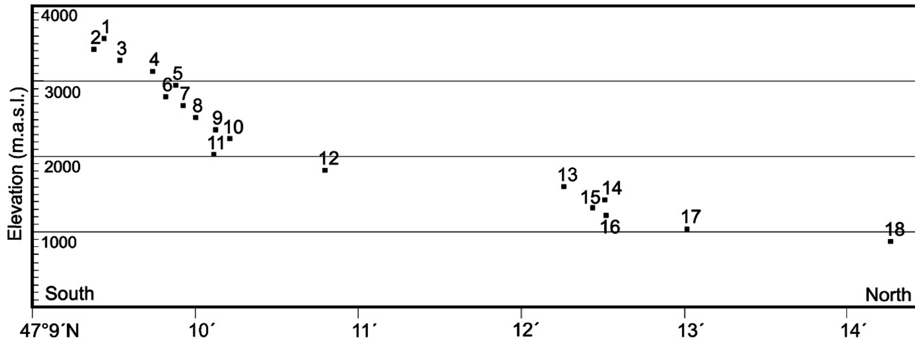

Fig. 2: Cross-section showing the elevations of apatite fission track samples collected near the Großes Wiesbachhorn of the Tauern Window, Eastern Austria. The sample locations have been projected to the plane12°44' East of Greenwich.
Probenahmeprofil mit Details der beprobten Seehöhen auf dem Großen Wiesbachhorn. Die Probenpunkte sind auf die Linie 12°44' East of Greenwich projiziert.

Tab. 1: Sample locations and elevations
Probenahmepunkte und deren Seehöhe.

#	Elevation (m) Map reading	Elevation (m) Altimeter record	Lat./Long.	
1	3564	3565	47°9'27"N	12°45'15"E
2	3420	3420	47°9'23"N	12°45'07"E
3	3270	3260	47°9'32"N	12°44'52"E
4	3125	3120	47°9'44"N	12°44'44"E
5	2950	2960	47°9'52"N	12°44'31"E
6	2805	2820	47°9'49"N	12°44'20"E
7	2660	2660	47°9'55"N	12°44'14"E
8	2520	2515	47°9'59"N	12°44'08"E
9	2355	2365	47°10'07"N	12°44'06"E
10	2225	2210	47°10'13"N	12°44'03"E
11	2020	2045	47°10'08"N	12°43'35"E
12	1805	1805	47°10'48"N	12°42'48"E
13	1620	1665	47°12'17"N	12°43'03"E
14	1420	1520	47°12'33"N	12°43'08"E
15	1310	1320	47°12'28"N	12°43'21"E
16	1230	1210	47°12'33"N	12°43'22"E
17	1020	1030	47°13'03"N	12°43'34"E
18	890	895	47°14'16"N	12°43'37"E
19	790	790 (Kaprun-creek	Powerhouse at Klamm Entr.)	

3.1 Methodology

Fission tracks are linear zones of damage in a crystal lattice and form by spontaneous fission of naturally occurring ^{238}U (Fleischer & al. 1975). In some minerals such fission tracks can be made visible by etching a polished crystal surface. Apatite has proved to be particularly useful for this as it is clear, abundant in most rock types and typically contains sufficient uranium to produce enough spontaneous tracks to be counted, but few enough tracks so that each of them is individually visibly separate from others (around 30–60 ppm uranium). When formed, new tracks have a consistent length of about 16 micron in an etched apatite crystal and they are produced continuously through time. However, fission tracks undergo track repair or "annealing" if the sample is exposed to temperatures above 60° C for times >1 million years (Green & al. 1986). Annealing has the systematic effect of shortening each fission track and therefore reducing the track density and hence the fission track age (Green 1988). The degree of annealing of fission tracks depends on temperature and to some extent on the chlorine contents of the apatite. If the sample is hotter than about 110° C, total annealing is practically instantaneous. No fission tracks can accumulate and the fission track age will be zero. Through time, the fission track age will remain zero until the temperature of the host sample falls below 110° C temperature at which point tracks will begin to accumulate. Shorter tracks from the earlier part of the cooling history are frozen in, while continued and constant production of new fission tracks adds longer lengths to the mix. Thus, the number of tracks and their length distribution will be a function of the cooling rate and sample age since cooling through the 110 °C isotherm. A number of methods have been developed that allow a detailed derivation of cooling histories from number and length distribution of fission tracks in apatite (Laslett & al. 1987, Galbraith 1990). Today fission track analysis is a well established tool for the derivation of low temperature cooling histories and finds important economic applications in the oil industry as the thermal history of rocks between 60° C and 110° C covers the oil maturation window.

3.2 Fission Track Analysis

Fission tracks were counted in between 4 and 51 apatites from each of seven of the 19 collected Wiesbachhorn samples. The results are summarised in Table 2 and details of the counting sheets are available from the authors. It may be seen on Table 2 that the uranium contents of most apatites are below 1 ppm. (Estimates of the apatite uranium contents are routine in fission track age determination, using the known flux of irradiation and the number of induced tracks in the external mica detector). Together with the young age of the samples (probably around 10 million years) this results in extremely low numbers of spontaneous fission tracks. After analysing 7 samples, it became apparent that the number of tracks is too small to justify any further analysis. The counting of further samples was then stopped and the remaining samples are stored at the university of Graz. The low number of spontaneous tracks results in large statistical errors on the derived fission track age. The errors given in Table 2 are 1σ, which equates to only ~67% of the confidence limit and a plot of the more standard 95% confidence limit (2σ) would result in even larger errors. Effectively, none of the samples contained any confined track lengths (only 1 confined track length in sample #15), because exposure of a confined fission track by chemical etching requires the fortuitous situation of a track being intersected either by a crack or another fission track which reaches the polished grain surface. No confined length measurements means that no thermal history modelling or derivation of a meaningful age is possible.

In a bid to solve statistical problems of fission track age to do with low U-apatites that have fairly young fission track ages, sample #1 was "extension counted". This sample contained a high yield of good quality grains so that it is possible to count more than the standard number of about 20 apatite grains. Track densities in a total of 51 single grains were counted. Interestingly, with more counting, the pooled age as well as the error decreased. This is probably because within the first 20 grains there was one strangely old, imprecise grain (current grain #19 "4, 5, 30"). The effect of this grain on the pooled age

Tab. 2: Apatite fission track results.
Apatit Spaltspuren Ergebnisse.

Sample number	Elevation (m)	ρ_D x10^6 (no. tracks)	ρ_s x10^6 (no. tracks)	ρ_i x10^6 (no. tracks)	Mean Uranium content (ppm)	$P(\chi^2)$ (%)	Age Dispersion (%)	Fission track age ±1σ (no. grains) (Ma)	Mean track length ±1σ (no. lengths) (µm)	Standard deviation (µm)
1	3565	1.676 (2927)	0.0292 (40)	0.1198 (164)	0.8	84.5	23.1	78.6±14.0 (51)	– (0)	–
2	3420	1.717 (2927)	0.01573 (3)	0.08391 (16)	0.6	4.496	2.58	62.0 ± 39.0 (9)	– (0)	–
12	1805	1.751 (2976)	0.0258 (2)	0.1034 (8)	0.7	43.9	1.27	84.1±66.6 (4)	– (0)	–
14	1420	1.831 (2976)	0.0147 (8)	0.1143 (62)	0.7	65.8	6.984	45.6±17.2 (18)	– (0)	–
15	1310	1.872 (2976)	0.0136 (5)	0.068 (25)	0.4	97.4	0.008	72.0±35.3 (14)	19.1 (1)	–
16	1230	1.912 (2976)	0.0073 (4)	0.0588 (32)	0.4	86.9	0.240	46.1±24.5 (13)	– (0)	–
17	1020	1.952 (2976)	0.0024 (1)	0.1714 (70)	1.0	100.0	2.221	5.4±5.4 (17)	– (0)	–

† Central age used in preference to the pooled age, where there is a significant spread in single grain ages indicated by the $P(\chi^2)$ test failing at the 5% confidence level. Calculation of the central age assumes that all single grain ages belong to a Normal distribution of ages, with a standard deviation (σ) known as the "age dispersion". An iterative algorithm is used to provide estimates of the central age with its associated error, and the age dispersion, which are quoted above. Note that this treatment replaces use of the "mean age", which was previously used by fission track workers for those samples in which $P(\chi^2) < 5\%$.

was diluted with more counting of zero-track grains. As a remedy for poor fission track age resolution, extension counting has worked modestly well. The age-error went from ± 27 Ma to ± 14 Ma, with 51 grains counted.

4. Discussion and Conclusion

In summary, the uranium content of the Wiesbachhorn apatites is too low to justify any meaningful tectonic interpretation, in particular thermal history modelling using length distributions. At best, it may be possible to infer the onset of exhumation from a break in slope of the age distribution on an elevation versus age plot in the style of Fitzgerald & Gleadow (1988) (Fig. 3). Whilst this is probably a valid technique for the Wiesbachhorn (because exhumation is known from independent evidence to be rapid), this would only be possible with more precise fission track age data and these cannot be achieved for the low uranium apatites obtained in this study, using the current available fission track analysis methods.

An interesting point is the low uranium content of the Wiesbachhorn apatites. Typical apatites from metapelites contain 30–60 ppm uranium, while they contain less than 1 ppm in the Wiesbachhorn samples. Such low uranium contents are extremely unusual for apatites from metapelites, but appear fairly common in the Tauern window (Dunkl pers. com. 2002). In our own experience we have only heard previously of such low uranium apatites from the Prince Charles Mountains, Antarctica (Arne, pers. comm. 2000). Although a tectonic interpretation of the analyses is not justified, it is worth discussion methodological questions on remedies to reduce the fission track age error in further studies performed on this profile.

Two remedies are possible: (a) "Extension counting" on the samples collected for this project is not possible because the collected sample sizes did not yield enough apatite. However, in principle this would be possible. Nevertheless, the error improvement will be modest, because there are large numbers of grains without any spontaneous fission tracks

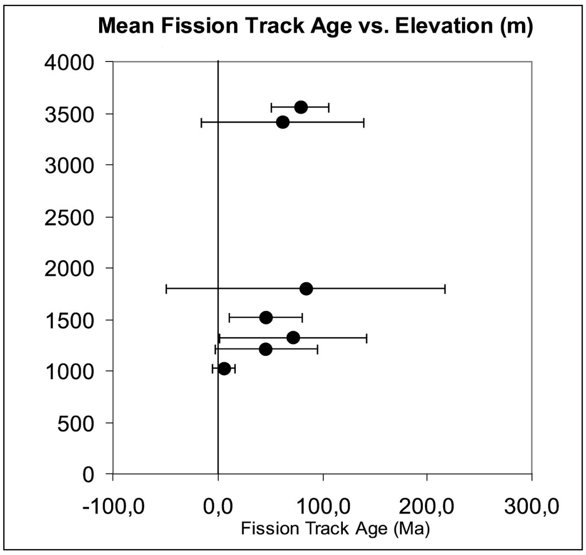

Fig. 3: Mean fission track age versus elevation.
Mittleres Spaltspurenaltern der gemessenen Proben gegen die Seehöhe aufgetragen.

in all samples and improvement can only be achieved by having more tracks. (b) One remedy that has been used for samples with low numbers of spontaneous fission tracks is by creating more confined tracks during the irradiation. However, low numbers of spontaneous tracks in apatite grains can never really create many confined fission track lengths that also happen to be horizontal and fully etched within the grain. Visibility of confined tracks rely on interception with a "crack" or another "track", so as to be etched from the surface via a conduit. Directional irradiation by Cf (Californian) method (as investigated previously by R. Donelick) can help by "bullet-holing" the sample, but if the number of spontaneous tracks is low (or zero), there are also going to be only a small number of horizontal confined tracks in existence. At best, only small gains could be made for the Wiesbachhorn samples (i.e. an improvement of 5 or 10 lengths per sample, where ideally 50 to 100 are required).

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