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ACTUAL AND ANCIENT UPLIFT RATE IN THE GOTTHARD REGION, SWISS ALPS: A COMPARISON BETWEEN PRECISE LEVELLING AND FISSION-TRACK APATITE AGE

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ABSTRACT

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Along the St. Gotthard road, crossing the central part of the Swiss Alps, precision levellings have revealed evidence of uplifts which are expressed by a general and symmetrical bulging with a local average rate of up to 1 mm/year. The fission-track dating of twenty samples of apatites taken in the granitico-gneiss rocks of the Aar and Gotthard Massifs permits the determination of the deformation undergone by the paleoisotherms (approximately 120°C) of different ages. As determined by this method, the average rate of uplift (0.3—0.6 mm/year) 6—10 m.y. ago, is similar to that of the present day.

INTRODUCTION

The comparison of precision levelling measurements at various points along the Basel—Chiasso line corroborates the existence of recent movements (Jeanrichard, 1972). These data were examined within the framework of the past and recent geological history of the region (Schaer and Jeanrichard, 1974). The results of this research show that in the sector which traverses the Alps, the present-day rate of deformation causes a symmetrical doming, the crest of which, lying well south of the water-shed, rises at the rate of 1 mm/year.

When comparing these deformations with the geological history of the region, it appears from the assembled data, that the same rhythm of deformation could have been maintained over a period of 15 million years. At the St. Gotthard level, the registered rates of elevation of both past and recent movements are very similar. The data did not, however, permit a too positive affirmation inasmuch as the reasoning employed was founded on arguments which could be considered as being somewhat weak.

To prove that the present-day deformations, particularly of the northern slope of the Alps, are the expression of the same tendency and the same orogenic factors as those which took place over the past 10—15 m.y., it is necessary to take into consideration a certain number of problems, the principal ones of which are as follows:

(1) It is necessary to be certain that the present-day deformations are orogenic in type and owe nothing to the residue of isostatic deformation which could have followed the retreat of the Quaternary Alpine glaciers. This is hardly probable (Schaer and Jeanrichard, 1974) but can not be totally excluded.

(2) When attempting, through the use of geological arguments, to establish the rate of past deformations, it is rare that access is available at one and the same time to a position (altitude in our particular case) and a rather accurate age.

(3) It is rash to compare deformations recorded over a period of 50 years with those recorded for nearly 10 m.y. It would be wiser to have intermediate observations.

(4) Change in the altitude of a given point is of little significance, however, through the use of several points along a given line it is possible to plot the deformation along a profile, but the volume should always be the primary consideration.

This study is an attempted approach to some of these problems. Applying the fission-track method, we propose to compare the present-day levellings with the fission-track ages which give the time of cooling to a fixed temperature and which, thanks to certain models, could be transformed into a positioning within the earth's crust.

APATITE FISSION-TRACK CLOCK

The apatite fission-track clock, like most radiometric clocks, is reset by elevated temperatures. The temperature at which the resetting occurs is called the "blocking temperature". In order to determine the blocking temperature of the apatite fission-track clock, the thermal stability of tracks in apatite must be known. Through annealing experiments it was found that fission-tracks are relatively unstable in apatite (see summary by Wagner, 1972). For example, 400° C are sufficient to anneal all tracks in apatite within one hour. This temperature lowers with increasing duration of annealing. For geological conditions such as in the Swiss Alps, where temperatures prevail for much longer than in laboratory experiments, the critical temperature for track fading in apatite must be extrapolated.

An effective blocking temperature of 120° C ± 20° C was calculated (Wagner and Reimer, 1972). Consequently, the pre-existing fission-track memory has been extinguished in all rocks which were heated sufficiently during the Alpine metamorphism. During the ensuing uplift, as the rock temperature dropped below 120° C, the apatite fission-track clock started again. The resulting age represents the time which elapsed since the rock crossed the 120° C-isotherm. Such data are very useful for unraveling the uplift history (Wagner and Reimer, 1972). They allow calculation of ancient uplift rates for various regions.

THERMAL MODELS

The use of the apatite fission-track ages leads to an estimate of the uplift rate, if it is deemed possible to make reasonable proposals concerning the position of the isotherms in a rock mass such as the Alps.

The different thermal models proposed by Rybach (1973) show that at a depth of 5 km in the forepart of the Alps, the temperatures are 131 ± 11° C and that they could be as much as 140° C in the central massifs. At such shallow depths, the question can be posed as to whether certain exterior factors have not contributed noticeably to the modification of the isotherm pattern. We have examined the effect of three possible types of disturbances, namely the relief, the anisotropy of the thermal production, and the heterogeneity of the thermal conductibility (Kiraly and Schaer, in preparation). None of these factors seem to disturb the isotherms at the level of 120°. They remain almost flat and horizontal especially in the crystalline basement and where the sedimentary cover is thin, and it is from this level that we have taken our samples. We have not taken into account the thermal disturbances which can be introduced through the circulation of water because: (1) we have very little information on the influence of this factor at a depth of approximately 5 km lower than the valley; and (2) for an efficient heating or cooling of the rocks, large volumes of water must circulate in relatively porous zones which probably do not exist at depth in the crystalline part of the Hercynian Massif under study. This fact is corroborated by the relatively undisturbed thermal profile that was encountered during the drilling of the Gotthard tunnel (Stapff, 1880).

RESEARCH IN THE EXTERNAL CRYSTALLINE MASSIFS

The research undertaken was meant to fulfill two objectives. On the one hand we wanted to test the apatite fission-track method of dating by obtaining a sufficient number of samples taken from a limited, relatively homogeneous sector, and on the other hand see if it were possible through this method, to analyze the recent deformations in a sector of the Alps which is still active and which seems to have been so for quite a long time.

In the Swiss Alps, at the level of the external crystalline massifs (Aar and Gotthard Massifs) repeated precision levellings along the Brunnen—Airolo route disclosed evidence of present-day deformations which are expressed in a slope tilting northward 0.0147 mm/km/year. Along this route, between Erstfeld and Airolo, the rocks, other than those of the deformed Andermatt

Mesozoic syncline, are gneiss and granites of Hercynian age, all containing apatites lending themselves favorably to fission-track analysis. Over a route of 30 km (see Fig. 1), 19 samples were taken with an attempt made to obtain material which often came from quarries, from artificial outcrops, or

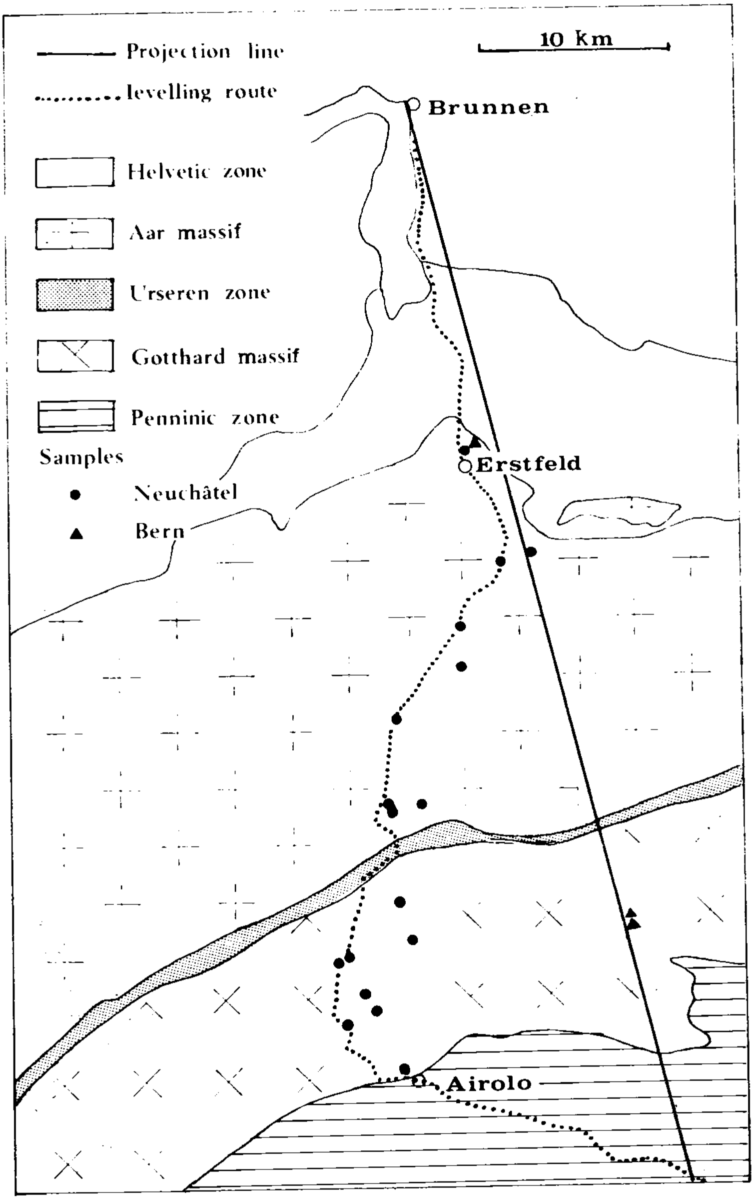

Fig. 1. General geological situation and position of sampling sites. Location of the projection plane and the precision-levelling itinerary.

TABLE I

Apatite fission-track ages* along the Gotthard-road traverse

Sample No.	Location of sample	Coordinate	(m)	Age (m.y.)
Samples Neuchâtel				
A1	Gurtnellen	691.82/177.20	705	6.2
A2	Waldiberg	695.75/181.28	1200	7.9
A3	Wiger	692.35/187.2	480	7.2
A4	Amsteg	693.95/181.0	510	6.5
A6	Wassen	688.5 /172.75	945	6.7
A7	Gotthard-Tunnel	688.07/168.00	1085	6.7
A8	Gemsstock	689.75/162.05	2960	10.2
A9	Gurschenalp	688.82/163.7	2212	8.7
A10	Mätteli	686.3 /161.1	1210	6.5
A11	Mätteli	686.00/160.7	1795	7.9
A12	Stöckli	690.55/168.4	2480	9.4
A13	Chlauserli	688.85/168.0	1895	8.3
A14	Monte Prosa	687.6 /157.4	2736	9.8
A15	Gotthardpass	686.55/156.75	2092	7.9
A16	Gotthard-Tunnel	158.34/687.00	1160	6.2
A17	Gotthard-Tunnel	157.25/687.37	1155	6.2
A18	Gotthard-Tunnel	157.15/688.70	1150	6.2
A19	Taghorn	691.8 /175.15	2065	9.0
Samples Bern				
KAW 87	Erstfeld-Bocki	690.75/187.82	760	8.0
KAW 394	Val Nalps	700.30/161.95	2250	8.8
KAW 395	Val Nalps	700.30/161.75	2300	9.4
KAW 397	Val Nalps	701.59/166.12	1860	8.1

* The precision of these ages is better than 10% and for the most ages about 5%.

from fresh outcrops. Some of the samples were taken at the bottom of the valley, some on the flanks, and others at the summit. Thanks to the irregularity of the relief it was possible to take samples which, on the same vertical line, are separated by a difference of nearly 2000 m. Four samples from the University of Bern have been added in Table I (Wagner et al., 1974a), but these have not been taken into consideration in the construction of Fig. 2.

The apatite crystals were separated from the rock samples by using standard techniques. Any heating which could result in partial track fading was carefully avoided. The dating procedure was essentially the same as described by Wagner and Reimer (1972). The fission-tracks were counted independently by two persons. The apatites were irradiated with a thermal neutron dose of $6.99 \cdot 10^{14}$ neutron/cm^2 in the reactor FR2 (Karlsruhe). The fission-track ages were calculated with the decay constant $\lambda_f = 8.46 \cdot 10^{-17}$ year^{-1} (Galliker et al., 1970; Wagner et al., 1974b).

RESULTS

The results were used for the graphic presentation of Fig. 2. Each sample was projected on a plane whose track is shown on Fig. 1. (The plane was already used in the analysis of recent movements.) Here the projection is made by using the structural directions which are appreciably perpendicular to the projection plane. The apatite ages present two general tendencies. First, they increase with increasing topographic altitudes of the sampling sites; second, they decrease generally northward. The systematic vertical and horizontal changes of the apatite fission-track age allow construction of isochrones within this profile by interpolating the ages. For this interpolation and to draw the isochrone, a three-dimensional quadratic-regression surface was constructed with the age (dependent variable), the altitude, and the horizontal distance. The multiple-correlation coefficient of 99.5% and the quadratic-regression surface accounts for 98.9% of the total variance in apatite age. The analysis of variance confirms that the regression is highly significant. All localities which lie on the same isochrone must have simultaneously passed the 120°C-isotherm. Assuming that these paleoisotherms were horizontal (p. 295) and in a fixed position for the past 10 m.y., each isochrone represents the actual position of rocks which were once at the same depth (i.e. 6, 7, 8, 9, 10, m.y. ago, respectively). The shape of the isochrones reveals the differential uplift and the age of the isochrones gives the deviation of the uplift. In other words, the isochrones in Fig. 2 show the evolution of the uplift along the Erstfeld—Airolo traverse over the past 10 m.y. From this illustration, uplift rates can be directly calculated as shown in Table II.

The present-day uplift rates shown in Table II were obtained through

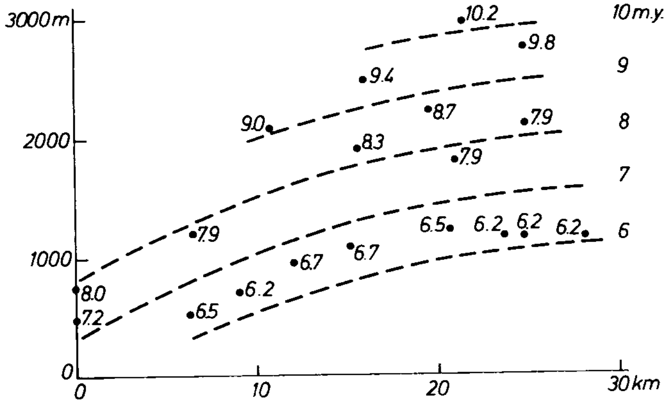

Fig. 2. Projection of the samples on the reference plane indicated in Fig. 1. The age obtained through apatite fission-track dating (cooling age) is shown near each sample. In abscissa, the horizontal distances originating at the level of the northernmost measurements (near Erstfeld); in ordinate, the altitude of the sampling site. The isochrones were drawn by ordinator.

TABLE II

Actual and paleo uplift and tilting rates derived from precise levelling and apatite fission-track ages (average rates)

	Actual	Last 7 m.y.	Between 7 and 8 m.y.
Uplift rates along the Gotthard road			
Erstfeld, km 0	0.44 mm/year	0.38 mm/year	0.4 mm/year
Goeschenen, km 15	0.52	0.50	0.46
St. Gotthard, km 25	0.76	0.54	0.47
Apparent tilting rates along the projection plane			
Erstfeld	0.014 mm/km/year	—	—
Between Erstfeld and St. Gotthard	0.014	0.006	—

comparison of precision levellings at 50-year intervals (Jeanrichard, 1972; Schaer and Jeanrichard, 1974). The calculations of uplift rates between 7 and 8 m.y. ago, are based on isochrones 7 and 8 of Fig. 2 and it was taken for granted that during this period the thermal regime was not modified in the region under consideration. Use of these simplifications leads us to envisage in the whole sector under study from Erstfeld to the Gotthard, a uniform lifting of the basement which occurred at an average rate of approximately 0.45 mm/year between 7 and 8 m.y. ago. Between 8 and 10 m.y. ago, at the level of the Gotthard Pass, comparable rates must also be admitted in our model. Taking into account the density of the sampling in this sector it is possible to repose a certain amount of confidence in these values. For the localities situated more to the north, and particularly for the region of Erstfeld, the calculations of the rates still display some uncertainty due to the fact that the number of samples are insufficient and all are from comparable altitudes. It is possible that the isochrones would come closer together if more and better place-samples were available. In Table II, we have also endeavored to show the average rate of uplift over the course of the past 7 m.y. Figure 2 shows that the paleoisotherms have a marked curvature (which, at the level of the 7-m.y. isochrone, corresponds to a difference in altitude of 1,200 m for 25 km). Under a thermically stable regime with homogeneous heat flow, one is led to state that the curvature of the paleoisochrone results principally from the differences in the rate of uplift between N and S. The calculation was made on the basis that, 7 m.y. ago, the 120° C-isotherm was horizontal, 4,300 m deep, and that the average altitude of the Alpine landscape was, at that time, approximately 2,000 m in the whole sector under consideration.

Applying this model it can be seen that the northward tilting along the projection plane would have been on the average of 0.006 mm/km/year during the last 7 m.y., which corresponds to a total tilting of nearly 3° for the period under consideration. For the study of the tilting between 10 m.y.

and 7 m.y. ago the number of sampling locations for fission-track dating is still insufficient.

To create Fig. 2 we were obliged to project on our reference plane, data which sometimes came from regions lying 15 km westward. The projection of these points was made without taking into account the differential uplift which could have existed transverse to our profile. The data from samples KAW 394, KAW 395, and KAW 357 of the University of Bern, suggest that in this direction, the gradient of uplift is small (between 0.002 and 0.001 mm/km/year), dipping to the east as does the general structure. We believe, therefore, that our presentation is not very much affected by this method.

CONCLUSIONS AND COMMENT

Dating of apatites from the Aar and Gotthard Massifs is an excellent means of analyzing paleoisotherms which permit a good approach to the calculation of ancient uplift rates (Wagner and Reimer, 1972). Our conclusions, based on some twenty points over a distance of approximately 25 km, confirm that average present and recent past (6—10 m.y.) uplift rates in the central Alps have been of the same order of magnitude (0.4—1 mm/year).

The data given here still do not permit us to say whether a part of the uplift registered by precision levellings has its origin in the isostatic readjustment which followed the melting of the Quaternary glaciers.

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