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APATITE FISSION-TRACK EVIDENCE FOR A MESOZOIC UPLIFT OF THE BRABANT MASSIF : PRELIMINARY RESULTS

by

P. VAN DEN HAUTE and C. VERCOUTERE

(4 figures and 2 tables)

ABSTRACT.- Apatite samples from the Upper Ordovician igneous rocks outcropping at the southern border of the Brabant massif (Fauquez and Bierghes), were analyzed in detail with the fission-track method, including age determinations and track length measurements. The apatites yielded ages of 182 ± 13 Ma and 173 ± 7 Ma for the Fauquez and Bierghes site respectively. For both samples the length measurements revealed a rather limited thermal shortening of the spontaneous tracks indicating that the low temperature history (120-60°C) of the investigated rocks was governed by a steady and relatively rapid cooling. This cooling is interpreted to result from an important uplift and concomitant erosion of the Brabant Massif, related to the Cimmerian tectonism which affected large parts of Northwestern Europe during the Jurassic. The apatite FT-ages are thought to reflect approximately the onset of this movement.

As the presently outcropping Ordovician-Silurian basement of the Brabant Massif was residing at temperatures of 100°C or higher prior to the uplift, it must have been covered by a considerable overburden of sediments of 3000m or more till the Middle Jurassic. These sediments are supposed to date mainly from the Late Carboniferous considering the geology of the investigated area. These results confirm the geologic history of the Brabant Massif outlined by Patijn more than 25 years ago.

RESUME.- Des échantillons d'apatite provenant des roches éruptives de l'Ordovicien supérieur du massif de Brabant, à Bierghes et à Fauquez ont été datées par la méthode des traces de fission. Un âge de respectivement 182 ± 13 Ma et 173 ± 7 Ma a été établi pour les apatites de ces deux localités. Une analyse des longueurs indique que les traces spontanées n'ont subi qu'une légère influence thermique qui signifie que les âges enregistrés représentent des âges de refroidissement lequel s'est déroulé assez vite dans l'intervalle 120-60°C. Ce refroidissement est interprété comme resultant d'une phase importante de soulèvement et d'érosion du massif de Brabant liée à la phase tectonique cimérienne qui a affecté une grande partie du Nord-Ouest de l'Europe pendant le Jurassique. Les âges TF des apatites datent approximativement le début de ce soulèvement.

Comme les roches siluriennes présentes actuellement à la surface du massif de Brabant se trouvaient à une température de 100°C ou plus avant le commencement du soulèvement ceci implique qu'elles étaient recouvertes de 3 km ou plus de sédiments jusqu'au Jurassique moyen. Pour sa majeure partie cette couverture sédimentaire date probablement du Carbonifère supérieur. Ainsi nos résultats semblent confirmer l'opinion de Patijn sur l'histoire géologique du massif de Brabant formulé il y a plus de 25 ans.

Laboratorium voor Aardkunde, R.U.G. - Krijgslaan, 281, 9000 - Gent.

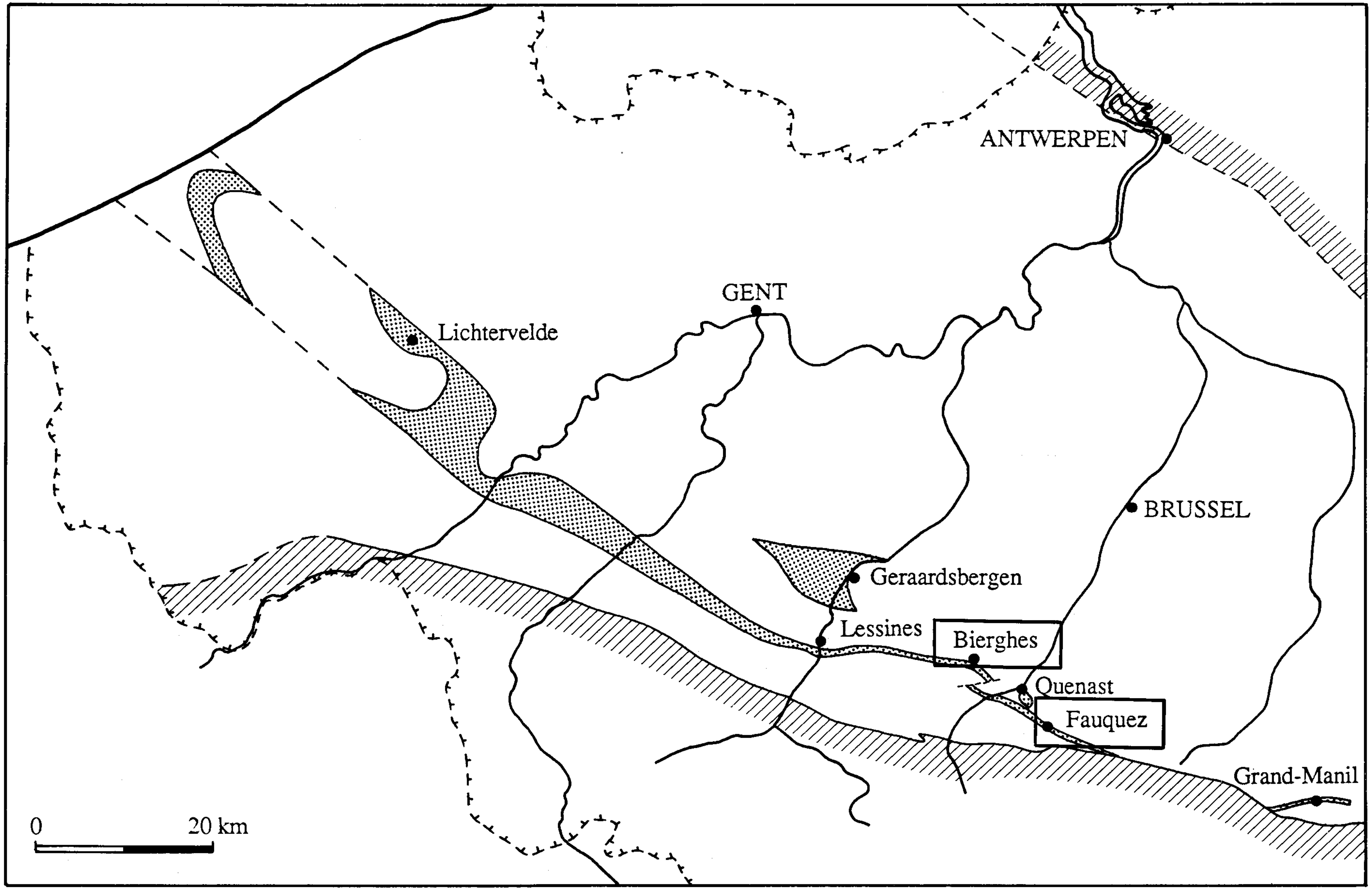

Fig. 1.- Outline of the western and central part of the Late Ordovician-Early Silurian igneous belt at the southern border of the Brabant Massif (after Legrand, 1968) showing the sampled localities (framed).

INTRODUCTION : THE APATITE FISSION-TRACK GEOCHRONOMETER

Based on the microscopic observation and counting of natural ^{238}U fission damage tracks in minerals, the Fission-Track (FT) dating method is becoming more and more widely used for the reconstruction of the thermal history of rocks. This application depends on the observation that fission tracks are thermally unstable and anneal in function of time and temperature. The principles of the dating method have been outlined in several review publications (Wagner, 1972; Fleischer *et al.*, 1975; Naeser, 1979; Faure, 1986) and have also been treated in the Belgian literature (Van den haute, 1977 and 1983); they will not be discussed here.

When applied to apatite, the method becomes particularly informative if one is interested in the low temperature history of a rock body. Indeed, laboratory experiments (Naeser and Faul, 1969; Wagner and Reimer, 1972) and drill core studies (Gleadow and Duddy, 1981; Gleadow *et al.*, 1983) clearly show that fission tracks in apatite are very unstable. They already start to fade at about 60°C and disappear completely at about 120°C for «geological» heating times in the order of 1 Ma. Hence, apatite FT dating can be employed to reconstruct the low-temperature cooling history of rock bodies which very often is connected to crustal uplift and erosion (Wagner and Reimer, 1972; Wagner *et al.*, 1977).

During the last years much attention also has been focussed on track length in apatite as a function of annealing (Green *et al.*, 1985; Green *et al.*, 1986; Laslett *et al.*, 1987) and it has been demonstrated that more specific information about the cooling history can be retrieved from track length studies (Gleadow *et al.*, 1983; Gleadow *et al.*, 1986).

In the present paper the first results are communicated of a more comprehensive fission-track study being carried out on the Brabant Massif. The purpose of this study is to obtain a better insight in the post-orogenic cooling history of this Caledonian massif.

GEOLOGICAL SETTING AND INVESTIGATED SAMPLES

It is well known that the igneous rocks of the Brabant Massif are mainly confined to a concave belt of volcanics and high level intrusives running E-W along its southern border and turning to a NW-SE direction towards the west (Corin, 1965; Legrand, 1968) (Fig. 1). In its western part the belt remains covered under tabular Meso-Cenozoic sediments, but starting from Lessines towards the east, regular outcrops occur some of which are the site of quarries still active at present times. The volcanic rocks occur intercalated between Late Ordovician (Caradoc-Ashgill) to Early Silurian (Llandovery) shales which are relatively rich in graptolites and chitinozoans and leave little doubt about the age of the volcanic activity (Denaeyer and Mortelmans, 1954; Verniers, 1983). The age of the economically more important intrusive rocks in the central part of the belt and their relation to the Caledonian orogeny has long been debated. Recent evidence brought up by trace element and U-Pb and Rb-Sr isotopic studies, show that they are comagmatic with and essentialy of the same age as their extrusive counterparts (André and Deutsch, 1984).

The apatites that were investigated in this study have been recovered from rock specimens sampled at two classical localities in the central part of the eruptive belt: Bierghes and Fauquez (Fig. 1).

At Bierghes, a sill of fine grained, porphyritic metaquartzdiorite is exposed in a large quarry, still in operation in its north-eastern part. In the middle of the quarry, a NW-SE trending fault zone caused an intense granulation and mylonitisation of the rocks during the Late Givetian according to André and Deutsch (1985). The sample investigated here was taken at the most southerly wall of the abandoned part of the quarry where a massive, unfoliated porphyry occurs. It is composed of phenocrysts of plagioclase, embayed quartz and chlorite pseudomorphs (after the original mafics), embedded in a micro-felsitic to micro-spherulitic groundmass. The composition of the original plagioclase is lost due to large scale replacement by epidote and minute grains of white mica.

The Fauquez sample was taken in the «Bois des Rocs» where lava's, breccia's and other volcanoclastics are exposed along the valley slopes of a small brook (Ruisseau du Bois de Fauquez) feeding the Sennette river. The sample comes from the western part of the exposures where the more massive, unfoliated rocks occur. It was a lava fragment similar in composition (meta-andesite-dacite) to the Bierghes sample with the exception that calcite occurs as a major secondary mineral, epidote only being present as a minor accessory. Also the occasionally well developed trachytic texture of the groundmass composed of albitized plagioclase microlites gives the rock a different aspect in thin section.

Apatite occurs in both rocks as slender prisms ranging up to 150 μm in size, mainly associated with the chlorite pseudomorphs and occasionally also in the groundmass.

ANALYTICAL METHODS

After crushing, grinding and sieving of the rocks, the apatites were recovered with standard separation techniques, using heavy liquids and a Frantz magnetic separator. Tedious handpicking at the end of the separation work was however necessary to obtain an amount of about 500 grains, considered to be minimal for an analysis with the population technique.

According to this technique, each apatite population was split into two parts: the first part was retained for the analysis of the spontaneous tracks while the second was used for the analysis of the induced tracks after it had been heated at 450°C for 16h. Induced tracks were created by irradiation of the apatite samples in Channel 8 (CR_{Au} = 11) of the THETIS nuclear reactor (INW, Ghent University). The thermal neutron fluence was determined with γ-spectrometry of Au and Co monitors (0.1% and 2.0% Al-Au and Al-Co alloys) according to the procedure outlined in Van den haute *et al.,* 1988 which was tested against recommended age standards (Fish Canyon tuff and Durango apatite) and recently used for an international interlaboratory comparison of fission-track age determinations (Van den haute and Chambaudet, in press). In addition, Cu monitors were used for a precise determination of the flux gradient.

The apatites containing the natural and the induced tracks of each sample were embedded separately in epoxy resin, polished and etched in 2.5% HNO_3 (0.4N) for 60 sec at 25°C. Track counting was done under transmitted light using 100X immersion oil objectives on Reichert biovar and Olympus BH-2 microscopes yielding a total magnification of 1075X and 1225X respectively. Both projected lengths of surface tracks and full lengths of horizontal confined tracks were measured using a drawing tube attachment to the Olympus microscope and a digitizing tablet connected to a microprocessor and personal computer allowing automatic treatment of the data. Projected tracks were measured with the immersion oil objective while for the confined tracks a 100X dry objective was used.

RESULTS

The fission-track counting data are summarized in table 1. The Fauquez sample was counted three times and the Bierghes sample twice. The track density distribution in the Fauquez apatites was quite homogeneous while that of the Bierghes apatites was more heterogeneous and displayed a narrow tail towards higher values (fig. 2). This tail was more explicitely present in the induced track density distribution than in the natural one, suggesting an unequal sampling of both track populations. As was already pointed out earlier (Van den haute, 1984) an insight in the homogeneity of the track density distributions is provided by their coefficients of variation (C-values in table 1). For the Fauquez apatites the experimental values of C are close to the ideal value of a Poisson distribution while for the Bierghes sample C is distinctly larger for both the natural and induced tracks. Moreover, although the mean densities of natural and induced tracks are nearly equal, the coefficients of variation are significantly different, which must be ascribed to the unequal tails of high track densities in both track density distributions.

It is normal to utilize the arithmetic mean of the track density distributions for calculating the ρ_s/ρ_i ratio in the fission-track age equation. However, as the arithmetic mean is rather sensitive to extreme values the calculated age can be biassed if an unequal sampling of such extremes is suspected in the induced and natural track density distributions. In this case it can be more efficient to use a less sensitive parameter such as the geometric mean. In table 1 the ages have been calculated using both the arithmetic and the geometric mean. For the Fauquez sample this practice essentially leads to the same result, the average age of the three counting efforts being 182 ± 12 Ma and 183 ± 8 Ma respectively. The first date is retained as the age of these apatites. For the Bierghes sample the average ages are significantly different: 145 ± 12 Ma and 173 ± 7 Ma respectively and this time it is the last value based on the geometric mean, which was retained for the reasons outlined above. The final dates fall in the Middle-Jurassic, in the time span covered by the Bathonian-Aalenian (169-188 Ma) according to Harland *et al.,* 1982.

The results of the track length measurements are summarized in table 2. It should be mentioned here that these measurements were carried out with the same etching conditions as for track counting. This is the common procedure for measuring projected lengths but not for measuring confined tracks which are normally observed after stronger etching (Gleadow *et al.,* 1986). Not the etching conditions but a right selection of fully etched tracks is however of major importance for this type of measurements and proper care was taken with this respect. An analysis of Fish Canyon tuff apatite with the same etching conditions is relevant in this context and shows that although the absolute lengths of the natural and induced tracks (table 2) are somewhat shorter than the average values of respectively 15.3 μm and 16.2

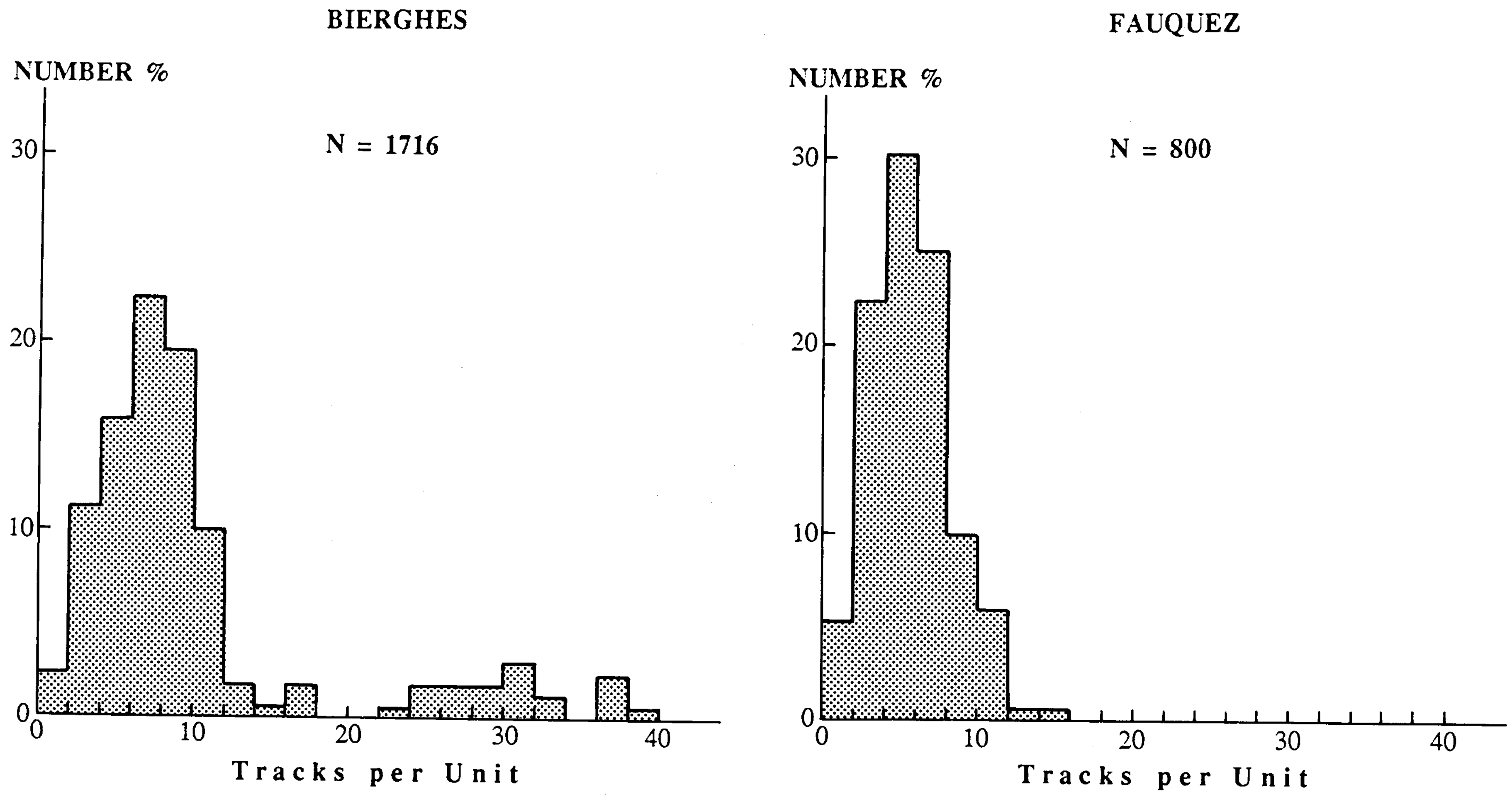

Fig. 2.- Frequency distributions of the induced track densities in the Fauquez and Bierghes apatites (N=total number of tracks counted).

Table 1.- Fission-track counting data of Fauquez and Bierghes apatite

	Spontaneous tracks						Induced tracks							
	n_s	N_s	ρ_{sa} $10^5 cm^{-2}$	ρ_{sg} $10^5 cm^{-2}$	C_s	Cp_s	n_i	N_i	ρ_{ia} $10^5 cm^{-2}$	ρ_{ig} $10^5 cm^{-2}$	C_i	Cp_i	Age_a (Ma)	Age_g (Ma)
(A) Fauquez apatite														
FAU1(1)	150	801	2.476	2.305	0.38	0.31	152	800	2.440	2.270	0.37	0.31	184±12	184±7
FAU2(2)	200	610	2.296	2.159	0.35	0.40	210	638	2.287	2.073	0.41	0.41	182±11	189±8
FAU3(2)	204	640	2.362	2.061	0.49	0.40	214	675	2.374	2.130	0.44	0.40	180±12	175±9
											Mean Age		182±12	183±8
(B) Bierghes apatite														
BIE1(2)	216	1798	6.266	5.307	0.60	0.35	170	1716	7.598	5.654	0.87	0.31	147±12	167±7
BIE2(1)	200	2052	6.343	5.693	0.47	0.31	199	2543	7.900	5.640	0.95	0.28	143±11	180±7
											Mean Age		145±12	173±7

n = number of grains counted ; N = number of tracks counted ; ρ_a = arithmetic mean track density ; ρ_g = geometric mean track density ;

C = experimental coefficient of variation of the track density distribution ; Cp = coefficient of variation of a Poisson distribution.

Age calculation is based on the following parameters : I = $7.253\ 10^{-3}$; $\lambda_d = 1.551\ 10^{-10} a^{-1}$; $\lambda_f = 8.46\ 10^{-17} a^{-1}$; $\sigma = 580.2\ 10^{-24} cm^2$;

$\phi = 3.690\ 10^{15}$ and $3.626\ 10^{15}$ n cm^{-2} for Fauquez and Bierghes apatite, respectively.

Age_a is based on arithmetic, Age_g on geometric mean track densities.

The error on the individual ages includes the error on the track density ratios ρ_s/ρ_i and an error of 2.5 % on the thermal neutron fluence.

(1) Reichert Biovar miscroscope.

(2) Olympus BH2 microscope.

Table 2.- Length measurements on Fauquez, Bierghes and Fish Canyon Tuff apatite.

	Spontaneous			Induced			
	N_s	$\bar{l}_s$ (µm)	s.d. (µm)	N_i	$\bar{l}_i$ (µm)	s.d. (µm)	$\bar{l}_s/\bar{l}_i$
(A) Horizontal confined tracks							
FAU	67	13.55	1.03	40	15.80	0.74	0.86±0.02
BIE	57	13.33	1.44	38	15.90	0.80	0.84±0.02
FCT	68	14.60	0.52	70	15.72	0.76	0.93±0.02
(B) Projected lengths of surface tracks							
FAU	605	4.74	2.19	728	5.07	2.46	0.93±0.04
BIE	451	4.62	2.39	609	4.98	2.21	0.93±0.06
FCT	663	4.69	2.51	618	5.15	2.72	0.91±0.06

N = number of tracks measured ; $\bar{l}$ = mean track length ;
s.d. = standard deviation.

µm calculated from the data of Gleadow *et al.*, 1986, the $\bar{l}_s/\bar{l}_i$ ratio of 0.93 found here is within the range 0.93-0.96 found in the same publication. Hence, the interpretation scheme of the above authors can be safely applied if the length ratio is used as the source of information instead of absolute lengths. Like the mean lengths, also the standard deviations of the confined track length distributions are rather small. The reason for these observations are thought to be related to the care taken when selecting tracks or to a smaller variation introduced by bulk etching compared to the strong etching of Gleadow and coworkers.

For both samples a rather small degree of shortening of the spontaneous tracks has been registered (7% only for the projected lengths and ≃ 15% for the confined tracks). Fig 3 displays the

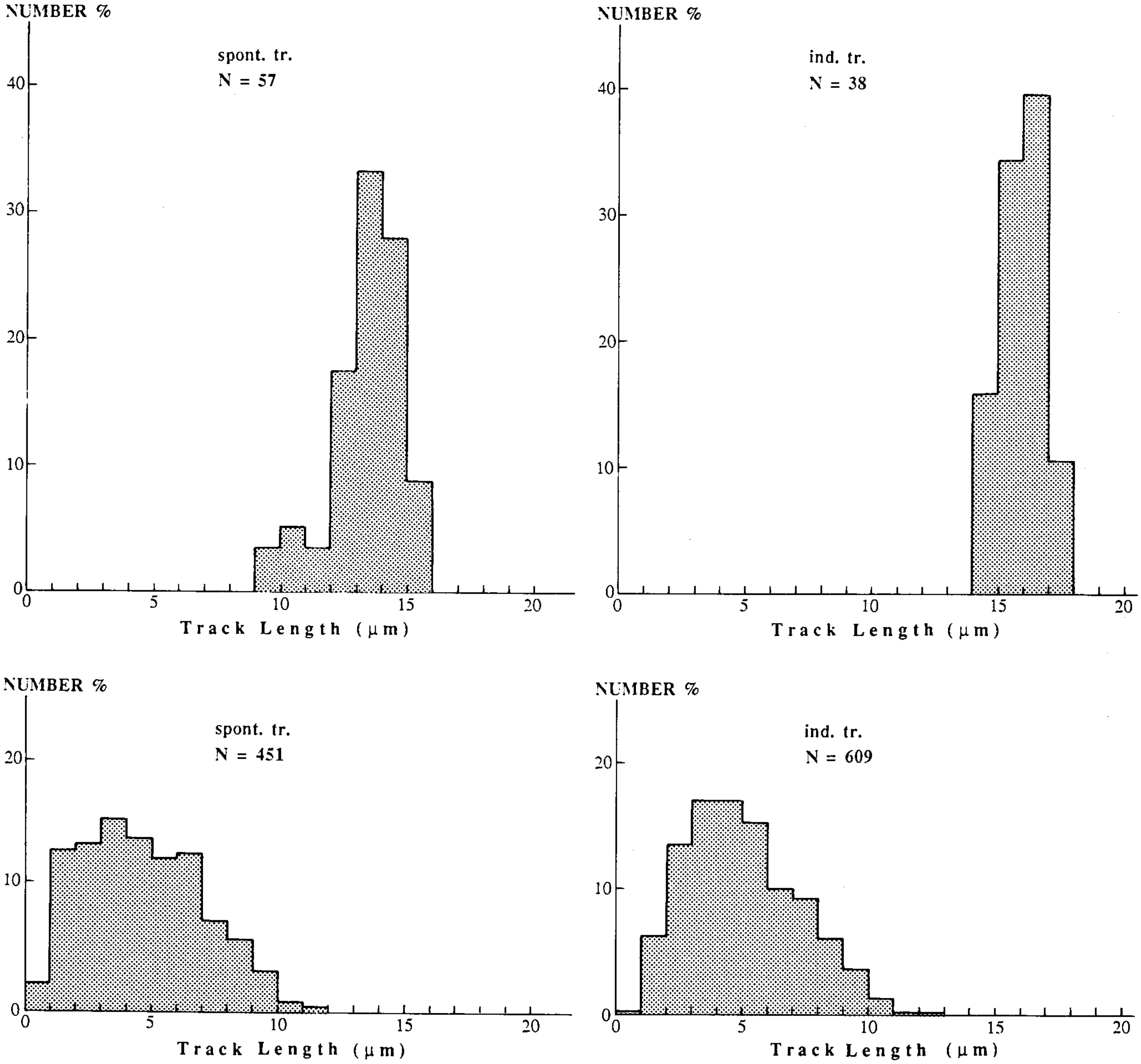

Fig. 3.- Length distributions of confined (top) and projected crystal surface tracks (bottom) in Bierghes apatite (N = total number of tracks measured).

track length distributions in the Bierghes apatites. As has already been pointed out earlier (Laslett *et al.,* 1982; Van den haute, 1984) the general assymetric shape of the projected length distributions is not very informative. However, it can be noticed that the distribution of the spontaneous tracks contains a relatively higher amount of very short tracks ($< 3 \mu m$). The length distribution of the spontaneous confined tracks is slightly shifted and skewed towards smaller lengths compared to the distribution of the induced tracks.

DISCUSSION

When interpreting apatite FT-ages the major step is to decide whether the registered dates are the result of a complex thermal history including one or more heating episodes or of a simple monotonous cooling through the temperature interval 60° - 120°C. In the first case the FT-dates generally represent hybrid or mixed ages with no specific geologic meaning; in the second case the dates effectively yield information about the time when the cooling took place and as a consequence also about the geological event that was responsible for it. The dates obtained on the Brabant Massif essentially can be interpreted as simple cooling ages. This is indicated by the spontaneous track lengths which only bear a small thermal influence. The reduction of the mean projected length is similar to the one found in the FCT-apatite standard, which originates from a rapidly cooled welded tuff and yields FT-ages very close (Van den haute *et al.,* 1988) to the 27.8 Ma formation age recommended by Hurford and Hammerschmidt (1985). The confined tracks exhibit a stronger length reduction than the FCT standard but still similar to samples originating from relatively rapidly cooled basement rocks (Gleadow *et al.,* 1986). Hence, it seems clear that the FT-ages date a phase of relatively rapid cooling of the presently outcropping Ordovician-Silurian rocks from temperatures higher than 100°C down to possibly surface temperatures. The only obvious geological event which can be accounted for to explain this cooling is a major uplift of the Brabant Massif and a concomittant erosion of several thousands of meters of sedimentary cover which must have been overlying the Ordovician-Silurian till the beginning of the Middle-Jurassic.

Using the FT-ages and the results of the confined track length measurements, tentative model curves for the cooling and uplift history of the Brabant basement rocks of the Bierghes-Fauquez area are presented in Fig 4. The curves are calculated using the approach of Gleadow and coworkers, assuming a geothermal gradient of 30°C/km and an average surface temperature of 15°C. As an additional constraint some premises have been made concerning the end of the uplift movement, taking into account the regional geology. If the end of the uplift is set approximately at the Aptian-Albian (115 Ma), corresponding with the first invasion of marine sediments in the Mons-basin the uplift curve flattens rather suddenly. A more gradual decrease in uplift rate is achieved if the movement is accepted to last till the Senonian (90 Ma), corresponding with the onset of a more general invasion of the Brabant Massif by Cretaceous sediments. The investigated rocks undoubtedly were lying near to the surface at Paleocene times.

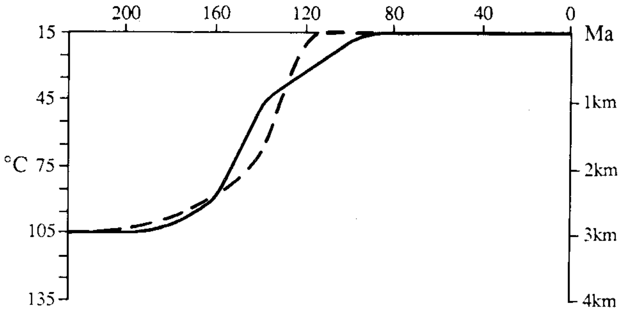

Fig. 4.- Cooling and uplift model curves for the southern part of the Brabant Massif:

- if the uplift ends around 90 Ma (solid line)
- if the uplift ends around 115 Ma (dashed line).

On both model curves the apatite FT-ages appear to date the initiation of the uplift movement rather than its paroxismal phase which seems to occur around 140 - 150 Ma. Also, the rocks were apparently not situated under, but slightly above the bottom of the partial annealing zone (120°C) before the beginning of the uplift. This is due to the presence of a not insignificant amount of thermally shortened spontaneous tracks. However, it should be emphasized that such a detailed interpretation is rather hazardous at present, considering the limited amount of analyzed samples. Additional samples from other parts of the Brabant Massif will probably yield a more definite picture.

As stated above, our results indicate that before the Middle-Jurassic the investigated area of the Brabant Massif was covered by a considerable sedimentary burden having a thickness of about 3000 m. Regarding the age of these sediments it seems the most obvious to attribute them mainly to the Upper-Carboniferous (Namurian-Westfalian). Indeed, already in 1954 Delmer and Ancion suggested the presence of Upper-Carboniferous sediments on the Brabant Massif and this view was advocated and elaborated by Patijn (1963) who estimated the thickness of the Upper-Carboniferous cover to about 3400 m in the eastern part of the massif. Nevertheless, a limited contribution of Early-Carboniferous and/or Triassic sediments (Antun, 1954) is also likely.

The Mesozoic uplift of the Brabant Massif registered by the apatite fission-track geochronometer is not an unique feature but incorporates well in the Cimmerian tectonic phase which affected large parts of Northwestern Europe (Ziegler, 1980). It forms a positive counterpart of the subsiding West-Netherlands trough to the north of the massif. Important deformations occuring in the Mesozoic and Paleozoic sediments underlying the Campine basin also have been attributed to Cimmerian tectonics and are seen in relation with an uplifted Brabant Massif (Dusar, 1982; Bouckaert an Dusar, 1987). Finally, the uplift movement has already been postulated by Patijn in 1963, who in this way debated the position of the Brabant Massif as structural high prior to the Variscan deformation. This opinion now is supported by our preliminary fission-track data yielding evidence recorded within the massif itself. As already stated above, a study including more samples and from a larger area is however required to obtain more detailed information.

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