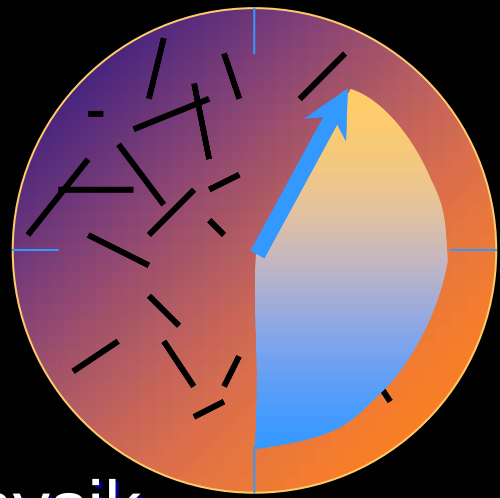
Ganz spontan - die Kern-spaltung als geologische Uhr



Ursula Weber

Max-Planck-Institut für Kernphysik
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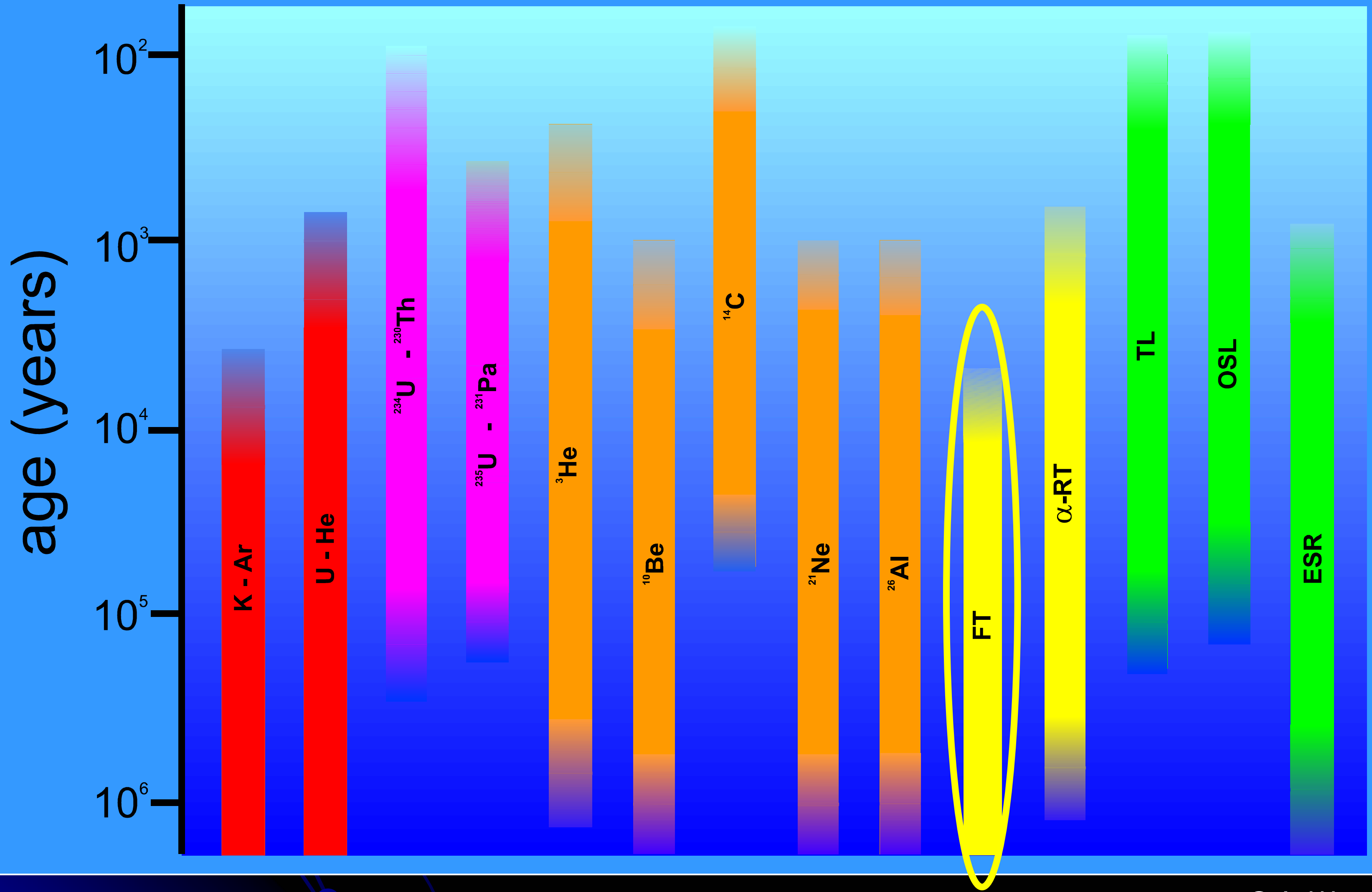
Warum machen wir das?

- Wir wollen herausfinden
  - Wie alt ist dieses Gestein?
  - Wann waren bestimmte Temperaturen erreicht?
  - Wann fanden archäologische Ereignisse statt?
- Dazu gibt es viele verschiedene Datierungsmethoden

Basaltsäulen

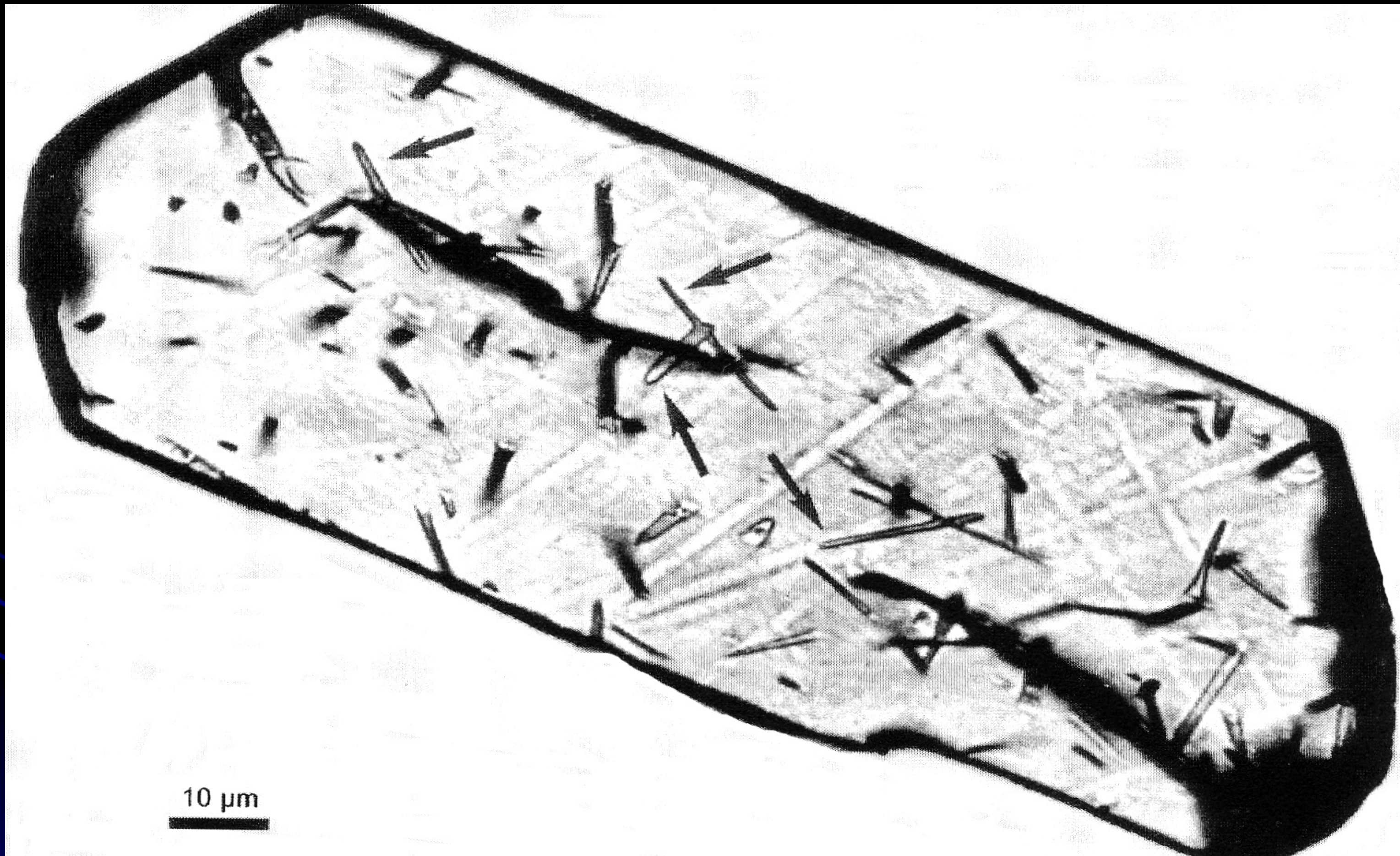
Foto: W.J.Pilsak

Radiometric dating methods in archaeology



G.A. Wagner

Was sind Spaltspuren?

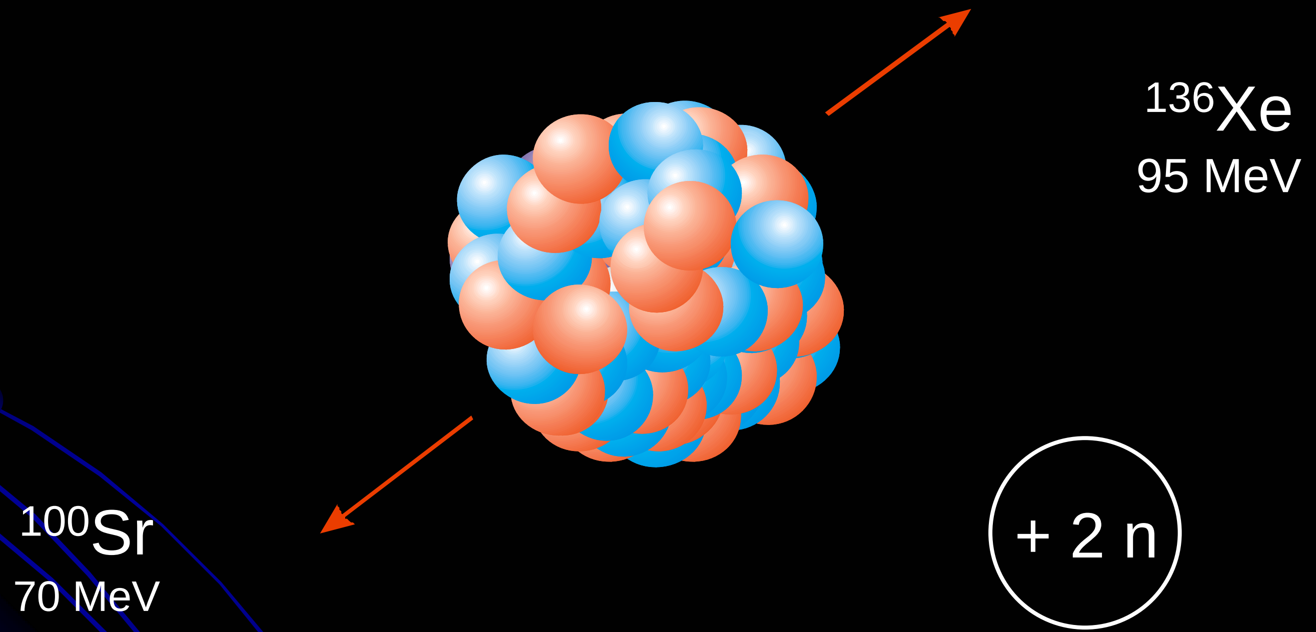


Spaltspuren im Apatitkristall

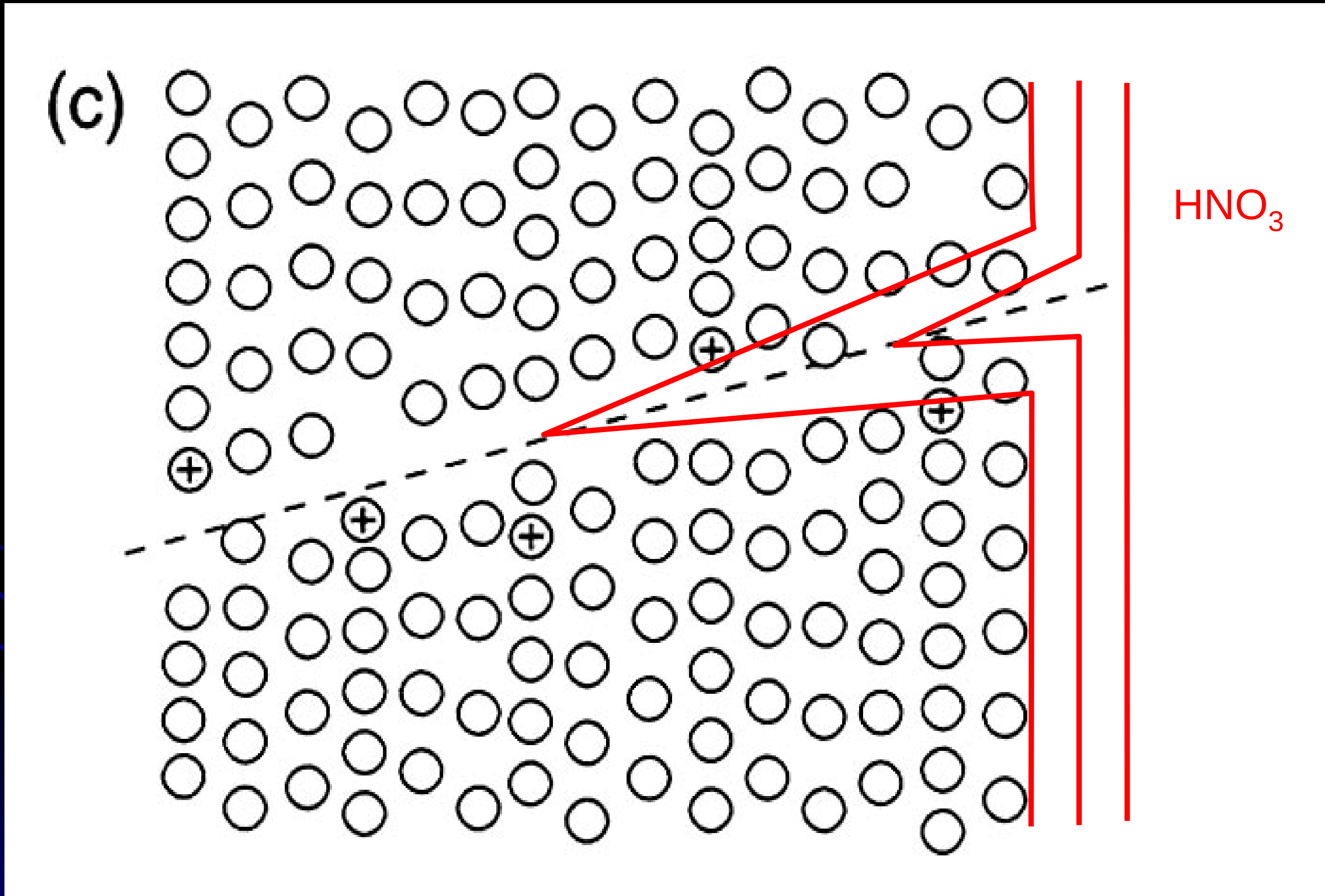
Gleadow et al., 2002

Wie entstehen Spaltspuren?

Spontane Kernspaltung von ^{238}U

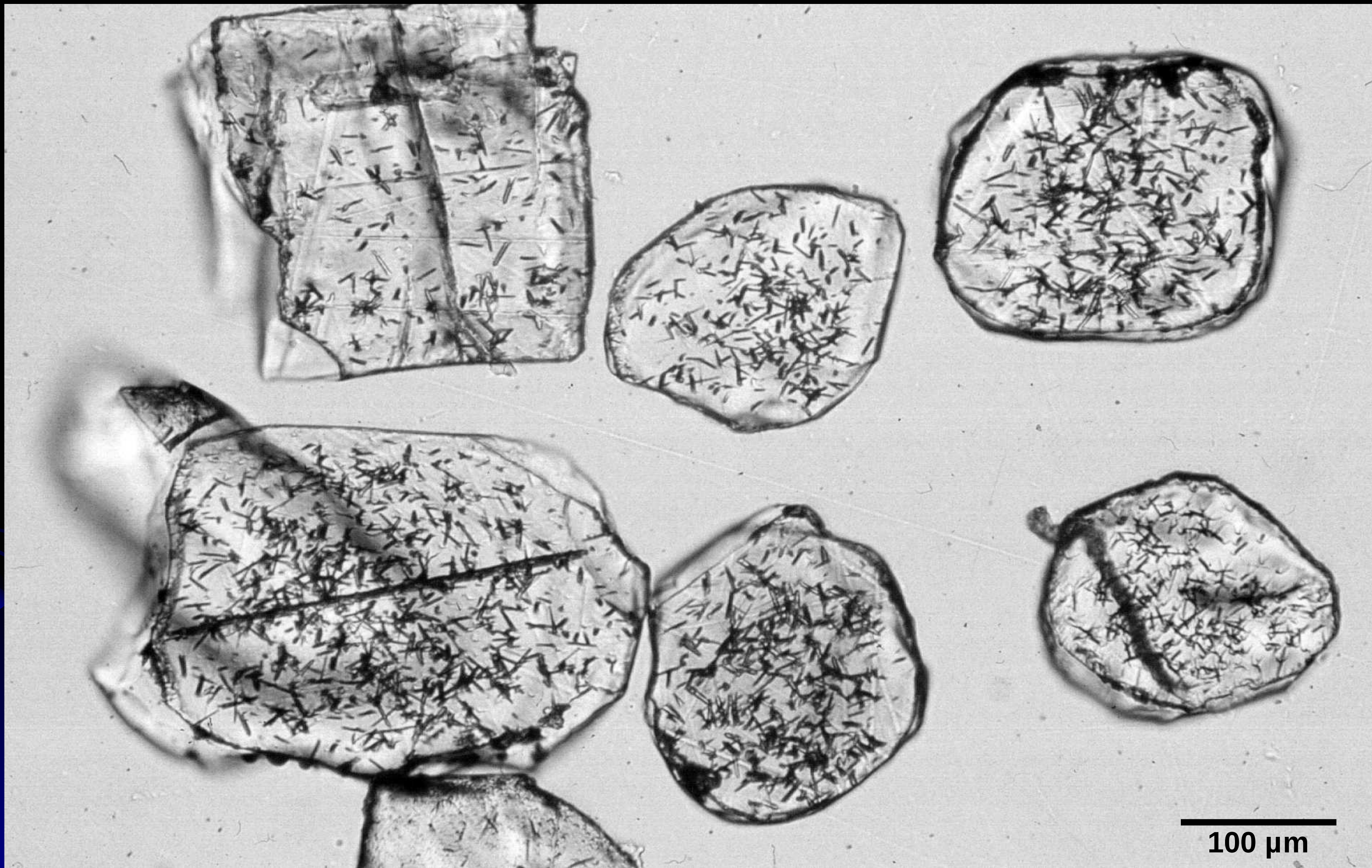


Was passiert im Kristallgitter?



Gleadow et al., 2002

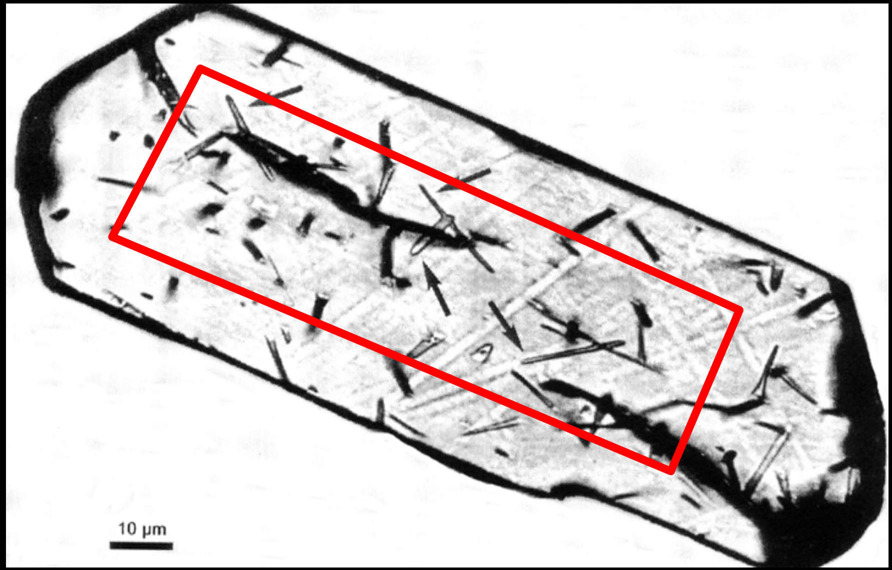
Apatite mit angeätzten Spaltspuren



G.A. Wagner

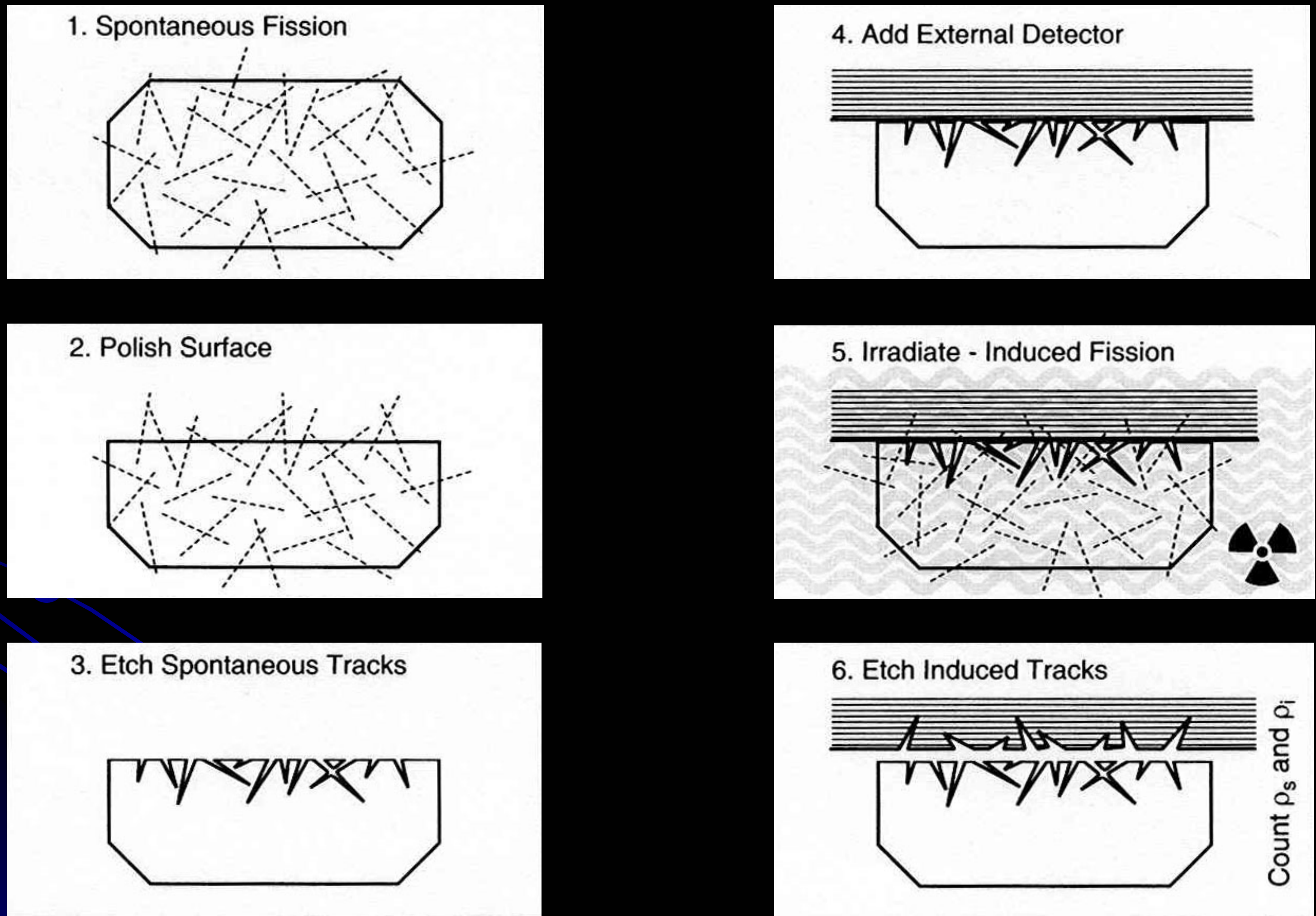
Methode

- Wir wissen die Halbwertszeit der spontanen Kernspaltung von ^{238}U.
- Wir können die Spaltspuren zählen und somit herausfinden, wieviel ^{238}U zerfallen ist.



- Wir können ein Alter errechnen, wenn wir herausfinden, wie hoch die Konzentration von ^{238}U im Kristall ist.

Methode

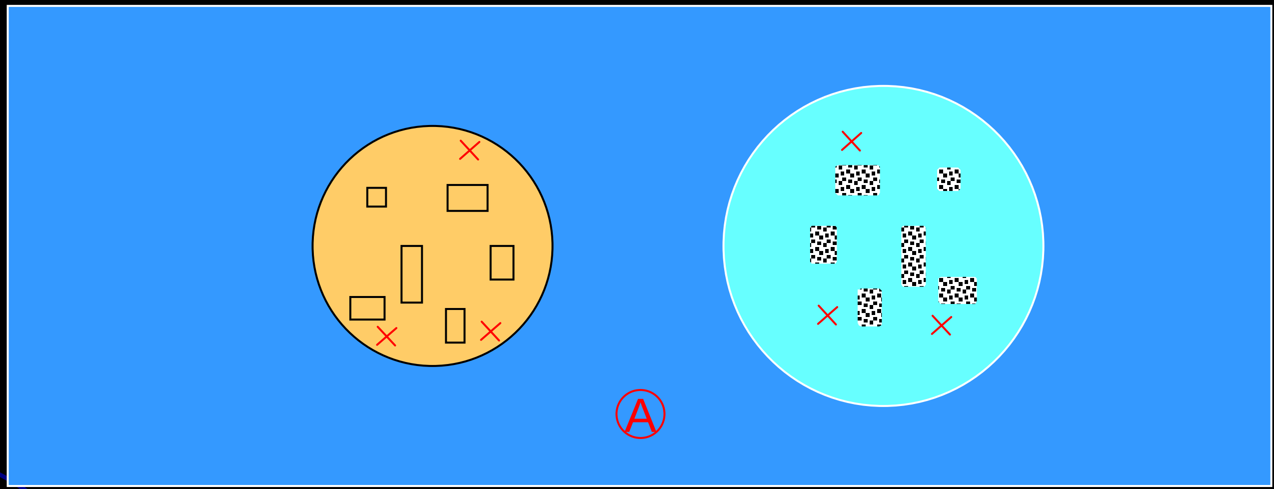


Gleadow et al., 2002

Apatit - Spaltspurenprobe

Apatitkörner in
Epoxyharz gegossen

Detektor Glimmer



Glasträger

Spaltspurenanalytik - Labor

Spaltspurenalter - Zerfallsgleichung

$$\frac{D^*}{N} = \left(e^{\lambda t} - 1\right)$$

*D** = Anzahl der zerfallenen Atome (Spaltspuren)

N = Anzahl der “Elternatome” ^{238}U

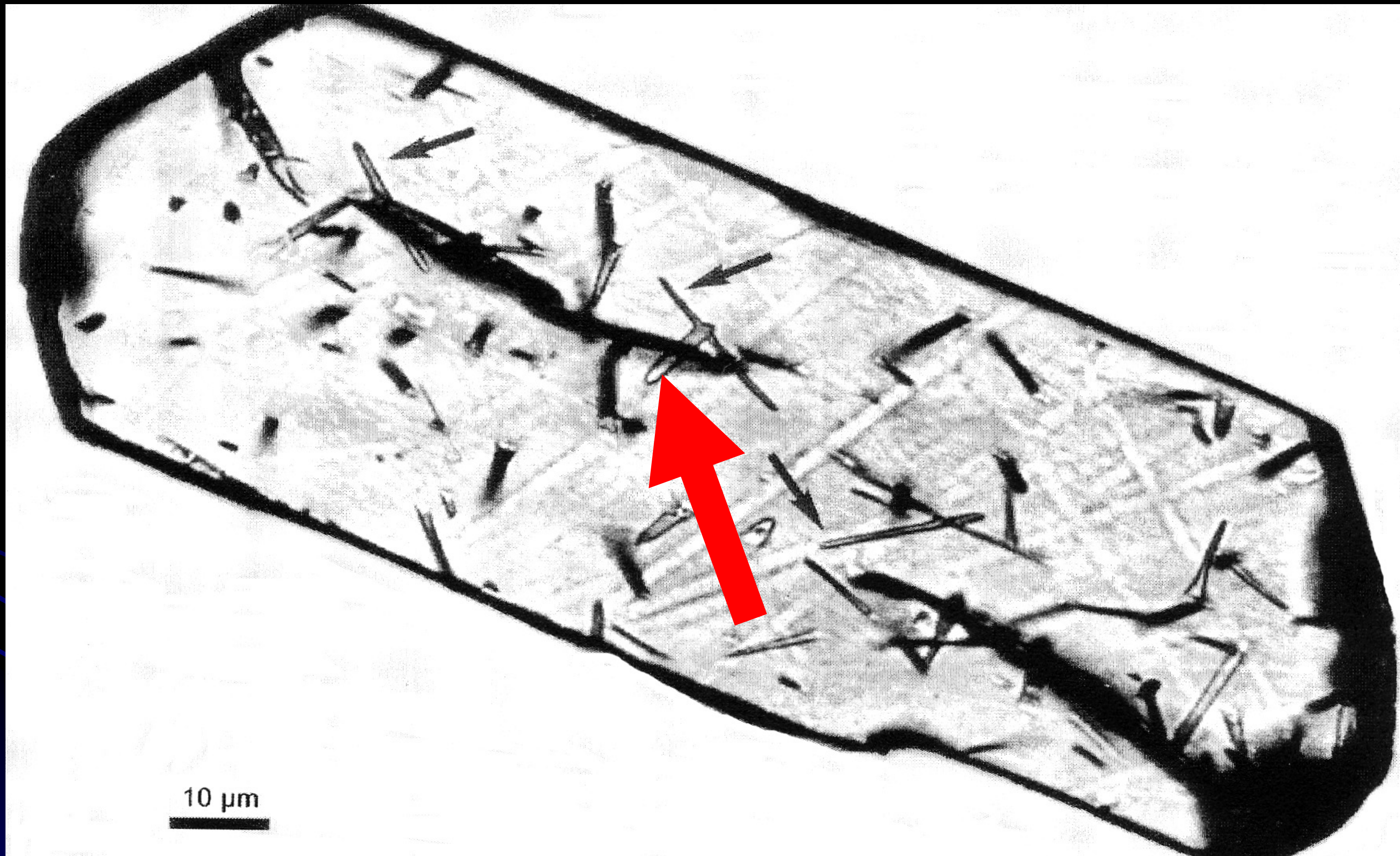
t = Zeit

λ = Zerfallsrate des ^{238}U

Stabilität der Spaltspuren

- Spaltspuren kommen nur unterhalb einer mineralspezifischen Temperatur vor, in Apatit unterhalb von ~110° C.
- Bei höherer Temperatur verkürzen sich die Spuren – über längere Zeiträume verschwinden die Spuren ganz. Dabei verheilt das Kristallgitter und die Atome nehmen ihre Ausgangsposition im Kristallgitter wieder ein.
- Unterhalb von 60° C in Apatit sind die Spuren stabil – zwischen 60°-110° C werden die Spuren mit der Zeit in diesem Temperaturbereich verkürzt.

Längenmessung der Spaltspuren

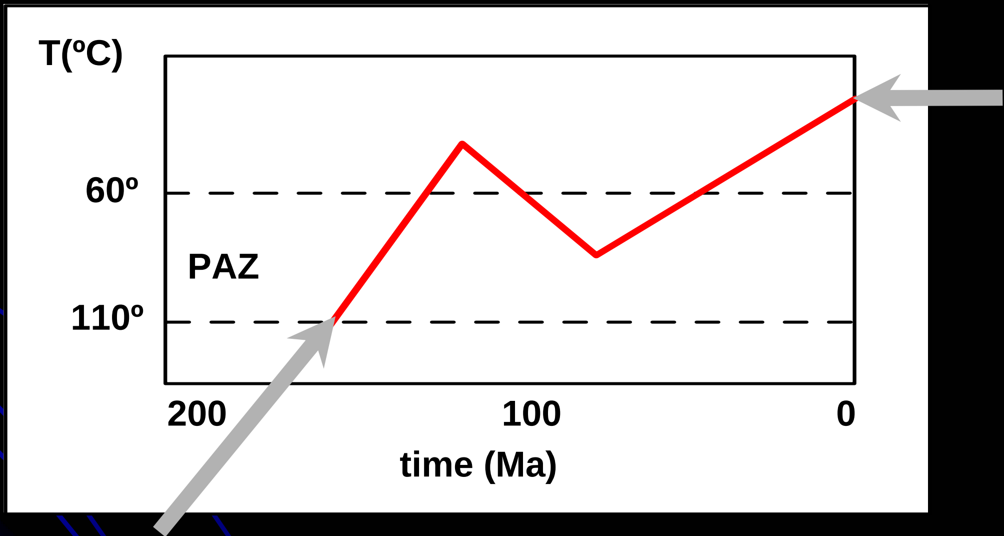


Spaltspuren im Apatitkristall

Gleadow et al., 2002

Anwendungsbeispiele - Geologie

- Abhängigkeit der Spaltspuren von Zeit und Temperatur ist von großem Nutzen in der Geologie
- Modellierung der thermischen Geschichte eines Gesteins mit Spaltspurendaten



Gestein an der Erdoberfläche - heute

Gestein in ca. 5 km Tiefe in der Erdkruste - vor 150 Millionen Jahren

Anwendungsbeispiele - Geologie

- Bergell Massiv
  Apatit Spaltspuren

  Hebungsraten:
  0,3 mm/Jahr

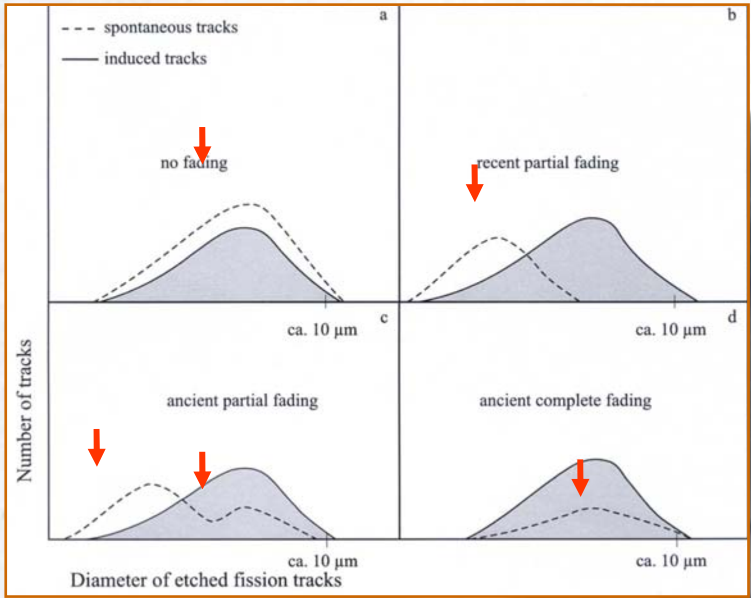
G.A. Wagner

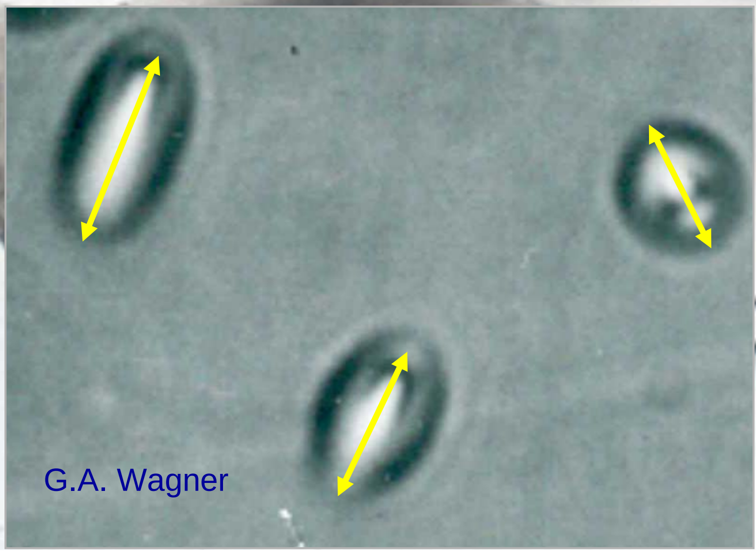
Anwendungsbeispiele - Geologie

- Ausnahme: wenn Gestein sehr schnell abkühlt – wie bei einem Vulkanausbruch – ist das Spaltspurenalter auch ein direktes Entstehungsalter

Anwendungsbeispiele - Archäologie

geological FT-age: 2.0 ± 0.2 Ma
archaeological FT-age: 3.5 ± 0.35 ka





G.A. Wagner

Obsidian, Cerro la Tefa / Kolumbien

Anwendungsbeispiele - Archäologie

BELEG-EXEMPLAR

77/034

(Reprinted from *Nature*, Vol. 267, No. 5612, p. 649, June 16, 1977)

Fission-track dating of pumice from the KBS Tuff, East Rudolf, Kenya

HURFORD, Gleadow and Naeser[1] claim to have fission-track dating results supporting the controversial 2.61-Myr value for the age of the KBS Tuff in East Rudolph, Kenya as determined by K–Ar dating[2–4]. The fission-track age does not, however, contribute substantially to solving this controversy, particularly since the authors[1] have not drawn attention to two important points, namely the error limits of the age and the current uncertainty about the spontaneous fission constant of uranium-238.

First, the quoted error of about 3% seems unrealistically small and probably represents only precision. The authors should give also the age accuracy which is necessary for comparing different radiometric ages. Second, many fission-track specialists no longer use the 6.85×10^{-17} yr^{-1} value, but now use as the decay constant 8.46×10^{-17} yr^{-1}; there are good reasons for this preference[5]. If this higher value for the decay constant is used, the fission-track age of the pumice in the KBS tuff recalculates to 1.98 Myr, which would lend support to the K–Ar age measured by Curtis *et al.*[3]. For stratigraphic use of fission-track ages one has to be critically aware of, and draw attention to, the present uncertainty of the spontaneous fission constant of uranium-238.

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1 Hurford, A. J., Gleadow, A. J. W. & Naeser, C. W., *Nature* 263, 738–740 (1976).
2 Fitch, F. J., Findlater, J. C., Watkins, R. T. & Miller, J. A. *Nature* 251, 213–215 (1974).
3 Curtis, G. H., Drake, R. F., Cerling, T. E., Cerling, B. L. & Hampel, J. H. *Nature* 258, 395–398 (1975).
4 Fitch, F. J., Hooker, P. J. & Miller, J. A., *Nature* 263, 740–744 (1976).
5 Wagner, G. A. *et al. Geochim. cosmochim. Acta* 39, 1279 (1975).

NAESER, HURFORD AND GLEADOW REPLY—We feel that the age we reported is a reasonable estimate for the age of the zircons separated from the pumice lumps in the KBS Tuff[1]. If our age is wrong, it is wrong for reasons other than our choice of the decay constant[2] for the spontaneous fission of ^{238}U. Two possible sources of error in this age are geologic in origin:

(1) The samples were collected in a sedimentary sequence. In this type of occurrence, contamination by detrital zircons is always possible and, in fact, is quite common. One advantage of the fission-track dating method is that the age of single crystals can be determined. A detrital zircon having an age greater than 10 Myr can easily be excluded from the population being dated. The problem occurs when the contaminating zircons are only a little older than the zircons being dated. The statistics of individual grains are such that a zircon having an age of 6 Myr would be included in the data because it cannot be reasonably separated from the rest of the population. In this case, however, five different determinations were made by three different individuals, and it seems highly unlikely that all three would choose the same relative numbers of contaminating grains. For this to happen, the detrital and pyrogenic zircons would have to be present in equal proportions, and the age of the detrital zircons could not be much greater than about 3 Myr.
(2) These zircons contained many small needle-like inclusions. Some of these could possibly have been counted as tracks, and this would result in an older age. As was true for the first source of error, this type of counting error would have to have been made by all three laboratories to the same extent.

Wagner[2] has questioned our choice of a decay constant, $\lambda_F=6.85\times10^{-17}$ yr^{-1} (ref. 3). When it is used in conjunction with the fission track glass standards of the U.S. National Bureau of Standards[4], we get the best agreement with the K–Ar ages of co-existing minerals and we use it for this reason. This agreement has been found for minerals such as zircon, apatite, and sphene, as well as natural glasses that have not suffered track annealing. Figure 1 shows the results of 34 zircon fisison-track ages plotted against the average K–Ar age of one or more minerals from the same rock. These ages are all from volcanic or subvolcanic rocks in which annealing should be absent or minimal. Alternatively we could have chosen an empirical method[5] to calculate the ages of the KBS Tuff zircons. This method is independent of λ_F and neutron-dose calibration, simply requiring a number of samples from well-dated rocks. Had we chosen this method, our results on

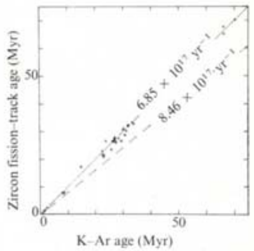

Fig. 1 Zircon fission-track ages and the average K–Ar ages of minerals from volcanic and subvolcanic rocks. λ_F values 6.85×10^{-17} yr^{-1} (solid line) and 8.46×10^{-17} yr^{-1} (broken line).

the zircons from the KBS Tuff would have been the same.

Wagner has also questioned our statistics[2]. The precision of a single fission-track age determination is not equal to that of a K–Ar age, and probably never will be, but five separate determinations can produce a mean that has a reasonably small error associated with it. The accuracy of any age can only be guessed at, in that we do not know the true age of any geologic sample. We can only strive for the best agreement with K–Ar and the other dating methods.

We therefore think that our age of 2.4 Myr is a reasonable estimate of the age of zircons separated from the pumice lumps present in the KBS Tuff. If Wagner feels that we must use $\lambda_F=8.4\times10^{-17}$ yr^{-1}, then he must show us where we have a corresponding 20% error in our method that compensates for our choice of decay constant and that will account for our close agreement with K–Ar ages.

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1 Hurford, A. J., Gleadow, A. J. W. & Naeser, C. W. *Nature* 263, 738–740 (1976).
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3 Fleischer, R. L. & Price, P. B. *Phys. Rev.* 133, 1363 (1964).:
4 Carpenter, B. S. & Reimer, G. M., NBS Sp. Pub. 260–49 (1974).
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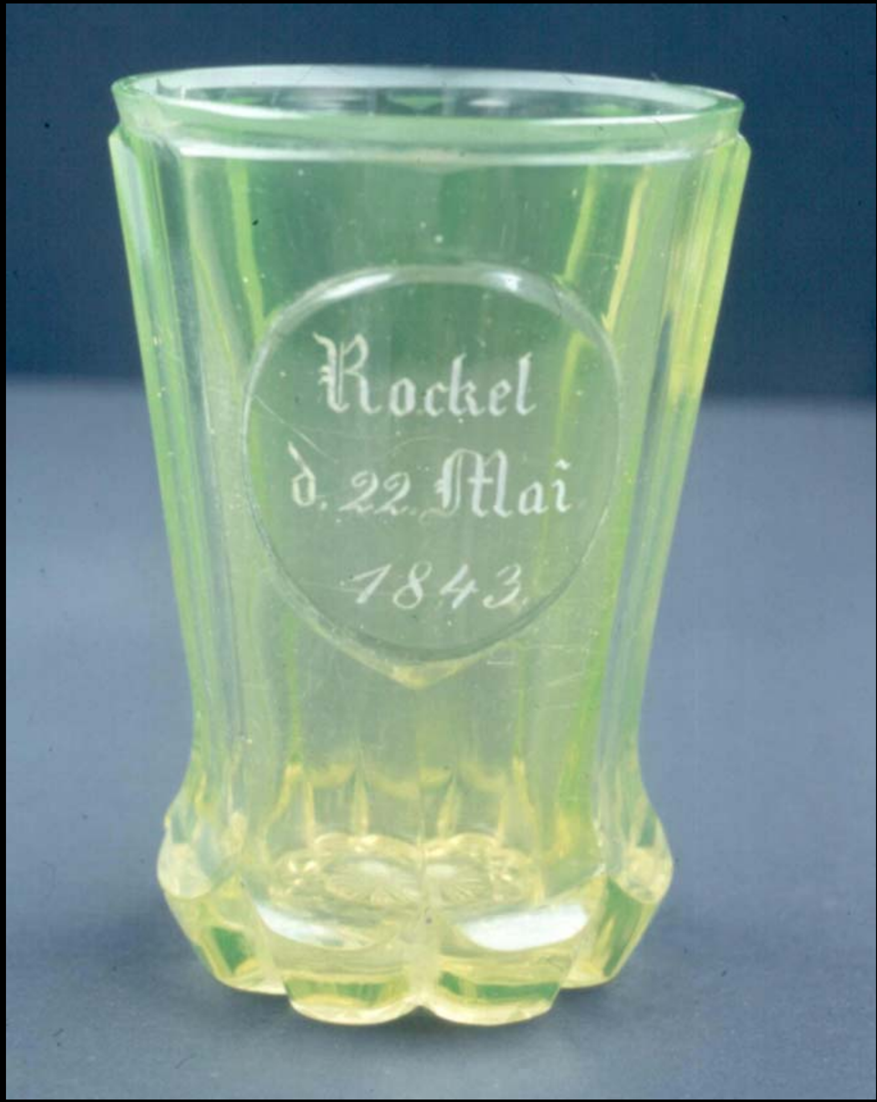
G.A. Wagner

Anwendungsbeispiele - Archäologie

- Urangläser sind recht gut zu datieren
- Echtheitsdatierungen



G.A. Wagner