7. J. S. Hogan, thesis, New York University (1968); in the atmospheres of Mars and Venus, the primary maximum of ionization will develop close to the altitude at which the neutral particle density is 2×10^{10} particle cm^{-3}.
8. H. E. Hinteregger, L. A. Hall, G. Schmidtke, *Space Res.* **5**, 1175 (1965).
9. M. Roemer, *Veroeffentlichung Univ. Sternewarte Bonn No. 68* (1963), p. 146.
10. *Solar-Geophysical Data* (U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service, Washington, D.C., 1969).
11. The factor $\bar{a}$ is obtained from the expression

$$\bar{a} = \omega/\pi$$

where ω is the sunset hour angle at the height of the maximum in EUV heating; ω is related to the occultation latitude ϕ, the solar declination δ, the altitude of maximum heating Z_{EUV}, and the radius of the planet r by

$$\omega = \text{arc cos} \frac{\cos\theta}{\cos\phi \cos\delta} - \tan\phi \tan\delta$$

where θ is the sunset zenith angle given by

$$\theta = 90° + \text{arc cos} [r/(r + Z_{EUV})]$$

12. The exospheric temperature on Venus was estimated to be $650° \pm 50°K$ from the Mariner 5 ultraviolet photometry data [C. A. Barth, L. Wallace, J. B. Pearce, *J. Geophys. Res.* **73**, 2451 (1968)]. A maximum electron density of $9.0 \pm 1.0 \times 10^4$ electron cm^{-3} was observed at an altitude of about 120 km on Mars according to the Mariner 4 occultation data [G. Fjeldbo and V. R. Eshelman, *Planet. Space Sci.* **16**, 1035 (1968)]. A maximum electron density of $5.5 \pm 0.5 \times 10^5$ electron cm^{-3} was observed at about 140 km on Venus according to Mariner 5 data [A. Kliore, G. S. Levy, D. L. Cain, G. Fjeldbo, S. I. Rasool, *Science* **158**, 1683 (1967)].
13. The spread in the calculated T_E corresponds to the range in the assumed values for the photo-ionization heating efficiency on Mars (0.25 to 0.45) and Venus (0.19 to 0.35).
14. The altitude of peak ionization on Venus is relative to a planetary radius of 6052 km. No estimate of the uncertainty in the altitude of the observed peak electron density on Venus has been published.
15. Supported by National Academy of Sciences–National Research Council associateships at the Goddard Institute for Space Studies. We thank Drs. R. Jastrow and S. I. Rasool for their advice and criticism, and Dr. A. Kliore for supplying us with the projected coordinates for the Mariner 6 and 7 occultations.

12 May 1969

Etching Fission Tracks in Zircons

Abstract. *A new technique has been developed whereby fission tracks can be etched in zircon with a solution of sodium hydroxide at 220°C. Etching time varied between 15 minutes and 5 hours. Colored zircon required less etching time than the colorless varieties.*

Zircon is an ideal mineral for dating rocks by tracks caused by the spontaneous fission of U^{238}. It is a common accessory mineral in igneous, metamorphic, and sedimentary rocks; it retains fossil fission tracks at fairly high temperatures (*1*), and from almost any suite of zircons there would be grains with a track density suitable for counting (*2*) because of a wide natural range in uranium content. Routine fission-track dating of zircons has been hampered by the difficulty of etching fossil fission tracks. Phosphoric acid has been used (*2*) to etch the fission tracks in zircon, but this requires high temperatures (375° to 500°C). Etching time is also critical. Overetch of a few seconds results in precipitation of small crystals on the surface of the zircon that obscure the fission tracks.

The etching technique described herein produces tracks (Fig. 1) similar to those developed by the phosphoric acid; however, the disadvantages of phosphoric acid technique are eliminated. The zircons (−60 to +200 mesh) are mounted in epoxy (*3*) and polished to expose an interior surface. Interior surfaces are used, as there may be fossil fission tracks on external surfaces caused by uranium in adjacent minerals. After it is polished, the epoxy mount is immersed in sodium hydroxide heated to 220°C. The etching solution consists of 20 g of NaOH and 5 g of H_2O (100*N*); the container used is a covered 35-ml platinum crucible. The mount is placed in the crucible with the zircon side down. The length of time necessary to etch the zircons varies. Purple Precambrian zircons were etched in 15 minutes, whereas colorless Oligocene zircons required 4 hours in the etching solution. Two mounts are prepared, and the first mount is given a 1.5-hour etching period, to gauge the amount of time necessary to etch the zircon. If no tracks are found after 1.5 hours, the grains are placed in fresh etching solution for 1 to 2 hours more; if the sample is overetched, the other mount is then etched for a shorter time, usually 15 to 45 minutes, depending on the degree of overetching.

The epoxy mount is dissolved in the process of etching; therefore, the grains must be recovered and remounted for irradiation with neutrons. The zircons are embedded in Lexan by placing them on a glass slide which is then heated to 190°C. A small square of Lexan is then pressed on top of the zircons. The zircons embedded in Lexan plastic are placed next to an external detector of muscovite (*4*) and placed in a reactor for neutron irradiation. After irradiation the fossil tracks are counted in the zircon, and the induced tracks are counted in the muscovite detector.

The NaOH etch technique was used successfully to determine the zircon age for the Inconsolable Granodiorite of California by fission tracks. The results agree with the K-Ar age determined from hornblende from the same granodiorite (Table 1). A discordancy between K-Ar ages on the hornblende and biotite is paralleled by a similar discordancy in fission-track ages between zircons and apatite and can be accounted for by their dissimilar annealing properties. As the annealing temperature of zircon is higher than that of apatite (*1*, *6*), one would expect that, if the fission track ages of coexisting zircons and apatite are different, the zircon would be older.

Table 1. Mineral ages from the Inconsolable Granodiorite (MG-3).

Mineral	Fission track* (million years)	K-Ar (million years)
Zircon		
Grain 1	97 ± 10	
Grain 2	100 ± 10	
Apatite (*5*)	91 ± 9	
Hornblende (*4*)		98
Biotite (*4*)		87

* $\lambda_f = 7.03 \times 10^{-17}$ yr^{-1} (*8*); a glass standard was used as a flux monitor.

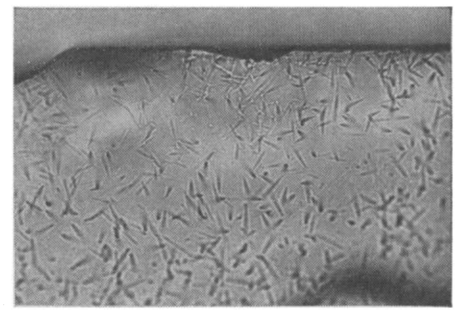

Fig. 1. Fission tracks in a zircon from the Inconsolable Granodiorite of California, etched by sodium hydroxide solution heated to 220°C for 2 hours. The field of view is approximately 60 × 90 μ.

C. W. NAESER

Astrogeologic Studies Branch, U.S. Geological Survey, Menlo Park, California 94025

References and Notes

1. R. L. Fleischer, P. B. Price, R. M. Walker, *J. Geophys. Res.* **70**, 1497 (1965).
2. ———, *ibid.* **69**, 4885 (1964).
3. C. W. Naeser, *Bull. Geol. Soc. Amer.* **78**, 1523 (1967).
4. R. L. Fleischer, C. W. Naeser, P. B. Price, R. M. Walker, U. B. Marvin, *Science* **148**, 629 (1965).
5. R. W. Kistler, P. C. Bateman, W. W. Brannock, *Bull. Geol. Soc. Amer.* **76**, 155 (1965).
6. C. W. Naeser and F. C. W. Dodge, *ibid.*, in press.
7. C. W. Naeser and H. Faul, *J. Geophys. Res.* **74**, 705 (1969).
8. J. H. Roberts, R. Gold, R. J. Armani, *Phys. Rev.* **174**, 1482 (1968).
9. I thank K. F. Fox and F. C. W. Dodge (U.S. Geological Survey) and R. L. Fleischer (General Electric Company) for assistance in experimentation and preparation of this report. Publication authorized by the director, U.S. Geological Survey.

14 April 1969