References and Notes

1. W. H. Munk, *Deep-Sea Res.* **13**, 707 (1966).
2. J. D. Woods, *J. Fluid. Mech.* **32**, 791 (1967).
3. J. S. Turner, *Deep-Sea Res.* **14**, 599 (1967).
4. M. R. Howe and R. I. Tait, *ibid.* **17**, 963 (1970); R. I. Tait and M. R. Howe, *Nature (Lond.)* **231**, 178 (1971).
5. The observational techniques and the way salt fingers form shadowgraph images are described elsewhere (A. J. Williams 3rd, in preparation).
6. M. E. Stern, *J. Fluid Mech.* **35**, 209 (1969).
7. P. F. Linden, *Deep-Sea Res.* **20**, 325 (1973).
8. The interface region of Fig. 2A occurs beneath a salinity maximum at 1210 m. The temperature and salinity are 9.65°C and 35.90 per mil at 1210 m and 8.65°C and 35.73 per mil at 1310 m. The layer immediately above the interface at 1263.5 m is 2.3 m thick, and the layer below is 1.9 m thick. Each of these layers is terminated by an interface less sharp than the one at 1263.5 m.
9. C. S. Albro, thesis, Woods Hole Oceanographic Institution and Massachusetts Institute of Technology (1972).
10. The autonomous platform "Autoprobe," which carried the instruments, was designed and built by K. H. Burt, the salinity-temperature-depth profiler was designed by N. L. Brown, and I developed the optical instrument; all of the development was done at the Woods Hole Oceanographic Institution. The laboratory tank tests were performed by C. S. Albro. P. J. Hendricks assisted in acquiring the data. I thank Burt, Brown, Albro, and Hendricks for their contributions. The development of the instrumentation was sponsored by ONR contract N00014-66-CO241; NR 083-004, and the study of the Mediterranean outflow was supported by the Oceanography Section of the National Science Foundation, NSF grant GA-37767. This is Contribution No. 3081 from the Woods Hole Oceanographic Institution.

27 December 1973; revised 28 January 1974

Attempt to Date Early South African Hominids by Using Fission Tracks in Calcite

Abstract. *Calcite crystals extracted from marrow cavities of bones found in hominid-bearing breccias from Makapansgat and Swartkrans were studied for fossil tracks. The absence of the expected numbers of tracks in these and in calcites from Beds I and II, Olduvai Gorge, combined with the results of laboratory heating experiments, indicates that track annealing has occurred at ambient temperatures and precludes the widespread use of calcite for fission track dating.*

At the present time there exist no radiometric dates for the early hominid remains from South Africa, so that all attempts to define a time scale for this fossil lineage, and indeed to correlate the various South African sites, have been based on indirect methods such as analysis of faunal assemblages or, more recently, on geomorphological studies [for an excellent recent review of age estimates for the South African hominids see (*1*)]. In view of the importance of correct age determinations for reconstructing the evolution of the early hominids and for intermeshing the South African fossils with those from East Africa, we have attempted to date by fission tracks samples from two of the South African cave sites, Makapansgat and Swartkrans. The indirect dating methods suggest ages of ~3 and ~2 million years, respectively, for the hominid remains from these sites (*1*).

All of the South African hominid remains occur in limestone deposits, and in many cases the bone marrow cavities are lined with large, clear calcite crystals (Fig. 1a) which presumably grew relatively soon after the bones themselves were deposited. On the basis of an earlier report (*2*) that fission track dating of calcite is feasible, such crystals seemed ideal because (i) they have remained since their deposition in a protected cave environment and therefore should never have experienced temperatures high enough to erase fission tracks, and (ii) the size and optically clear quality of the crystals are optimal for fission tract studies The South African samples analyzed were numerous crystals from marrow cavities in bones from the red, pink, and gray (hominid-rich) breccias at Makapansgat and crystals from the travertine overlying the orange breccia at Swartkrans. In addition we have studied calcite crystals from Beds I and II, Olduvai Gorge (*3*).

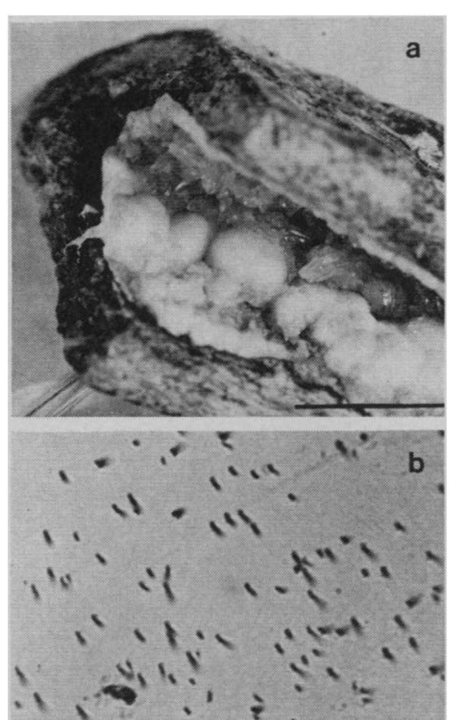

Fig. 1. (a) Milky botryoidal and clear euhedral calcite in marrow cavity of a bone from the hominid-rich gray breccia at Makapansgat. Scale bar, 1 cm. (b) Californium-252 fission tracks in one of the clear euhedral crystals shown in (a). The tracks were etched by using the solution described in the text. Scale bar, 20 μm.

The solutions used by Sippel and Glover (*2*) to etch fission tracks in calcite produce rectangular pits similar to dislocation etch pits rather than the more desirable linear tracks with small cone angles that are produced in other minerals under proper etching conditions. Thus, our initial experiments revolved around an attempt to develop a better etching solution for calcite. The most satisfactory etchant that emerged, one which produces beautiful narrow tracks with small cone angles (Fig. 1b), is the olivine etch described by Krishnaswami *et al.* (*4*), with NaOH added to *p*H 12 (*5*). Other etchants that we found to be almost as satisfactory are 2*M* NaOH, the olivine etch (*4*) without added NaOH, or a saturated solution of disodium ethylenediaminetetraacetate mixed with an equal volume of 5 percent acetic acid.

The uranium concentrations of the various calcites are given in Table 1. These values were determined by using the induced fission track method (*6*) for individual calcite crystals. Except for the travertine sample from Swartkrans, where considerable variation from crystal to crystal was observed, the uranium content measured in different crystals from the same sample or from the same bone marrow cavity is quite constant. The variation from sample to sample, however, is more than two orders of magnitude. The most logical explanation for this large variation is difference in uranium concentration of the groundwater from which the calcite precipitated, although if this is the case the difference between 64-7-7A and 70-6-29M from Bed II, Olduvai Gorge, is difficult to explain. There are no obvious geological differences between these two lacustrine beds (*7*). For one chip of pink breccia from Makapansgat, a section was made through an embedded bone fragment and the distribution of uranium was studied in the section as a whole. The calcite crystals projecting into the bone marrow cavity contain < 10 parts per billion (ppb) uranium, while the bone itself, to which crystals are attached, contains 2.3 parts per million (ppm). The uranium concentration in the bulk of the breccia away from bone fragments is ~ 80 ppb. While bone is well known to be an open system with respect to uranium [for example, see (*8*)], the calcite appears not to have accumulated uranium since its crystallization.

The age of Bed I, Olduvai Gorge, is well documented at ~ 2 million years (*9*). For a uranium concentration of 40 ppm (Table 1) the expected track density is $\sim 4 \times 10^4$ tracks per square centimeter. However, no spontaneous tracks were seen in the two calcite samples from Bed I. We also observed no spontaneous tracks in the calcite samples from the South African cave deposits. Hay (*7*) has assured us that the Bed I crystals have never experienced temperatures greater than $\sim 30°C$. According to Sippel and Glover (*2*) tracks in calcite should be completely unaffected by this low temperature over 2 million years. Thus, it was necessary to redo the heating experiments in order to check the accuracy of the reported annealing characteristics.

Track fading can be described by an equation of the type $t_a = Ae^{U/kT}$, where t_a is the annealing time for a given track density reduction, U is the activation energy, T the temperature, k Boltzmann's constant, and A another constant. Our heating experiments, performed on neutron-irradiated Olduvai Gorge calcites, indicate that the activation energy for complete track erasure is similar to that reported by Sippel and Glover (*2*) (35 kcal/mole or 1.5 ev) but that the temperatures for annealing (over a given time) are considerably lower (that is, the value of A in the annealing equation is different). Our data, extrapolated to 2 million years, indicate that tracks will anneal completely at a temperature of $\sim 20°C$. The difference between our results and those of Sippel and Glover (*2*) can be attributed to two factors: (i) The etching solution used by them produced pits difficult to distinguish from dislocations. Since dislocations anneal at higher temperatures than do fission tracks, this may partly account for the higher temperatures they report. (ii) They did their annealing measurements on an exterior surface that had been irradiated with fission fragments, whereas our experiments were done with neutron-induced fission tracks crossing an interior surface. It is known (*10*) that tracks crossing external surfaces are more resistant to thermal annealing than are internal tracks. The latter approximate the natural case better than the former.

Table 1. Uranium concentration in the calcite samples studied.

Sample	Uranium content (ppm)
Bed I, Olduvai Gorge	
69-6-17-G	39
62-7-9-U	40
Bed II, Olduvai Gorge	
64-7-7A	44
70-6-29M	0.049
Swartkrans travertine	1–2*
Makapansgat (marrow cavity)	
Pink breccia, lower cave	< 0.010
Grey breccia, lower cave	< 0.010

* Variable.

Our annealing experiments indicate that the lack of spontaneous fission tracks in the calcite samples is due to track annealing at ambient temperatures. We were unable to locate any more thermally resistant phases suitable for fission track dating in the South African samples, and in fact it is unlikely that any exist in a limestone terrain. Thus, disappointingly, it appears that fission track dating will not provide an absolute chronology for the South African Australopithecines and that in general calcite will not be a useful mineral for fission track dating.

D. MACDOUGALL*, P. B. PRICE
Department of Physics, University of California, Berkeley 94720

References and Notes

1. P. V. Tobias, *Nature (Lond.)* **246**, 79 (1973).
2. R. F. Sippel and E. D. Glover, *Science* **144**, 409 (1964).
3. Makapansgat samples were provided by courtesy of P. V. Tobias; C. K. Brain and R. Hay collected the Swartkrans and Olduvai Gorge samples, respectively.
4. S. Krishnaswami, D. Lal, N. Prabhu, A. S. Tamhane, *Science* **174**, 287 (1971).
5. Suggested by D. Lal.
6. P. B. Price and R. M. Walker, *Appl. Phys. Lett.* **2**, 23 (1963).
7. R. Hay, personal communication.
8. K. K. Turekian and J. L. Bada, in *Calibration of Hominoid Evolution*, W. W. Bishop and J. A. Miller, Eds. (Scottish Academic Press, Edinburgh, 1972), p. 171.
9. L. S. B. Leakey, J. F. Evernden, G. H Curtis, *Nature (Lond.)* **191**, 478 (1961); R. L. Fleischer, P. B. Price, R. M. Walker, L. S. B. Leakey, *Science* **148**, 72 (1965).
10. I. D. Hutcheon and P. B. Price, unpublished results.

* Present address: Geological Research Division, Scripps Institution of Oceanography, La Jolla, California 92037.

22 May 1974

Acetylcholine Noise: Analysis after Chemical Modification of Receptor

Abstract. *The elementary voltage pulses ("shot effects") produced by the action of acetylcholine molecules on the receptor were studied by analyzing the membrane voltage fluctuations ("noise") after acetylcholine application at the frog neuromuscular junction. The amplitude of these pulses was decreased after treatment with a disulfide-bond reducing agent. The shot effect may thus depend on the structure or conformation of the receptor molecule.*

Interaction of transmitter molecules with their specific receptors produces an ionic permeability change in the postsynaptic membrane. This change permits the flow of synaptic current which, in turn, depolarizes the membrane. A new approach to understanding this process was introduced by Katz and Miledi (*1*), who succeeded in studying transmitter-receptor interaction at a molecular level by analyzing fluctuations in membrane voltage after acetylcholine (ACh) application, a phenomenon termed "ACh noise." They showed that the postsynaptic effect of ACh is composed of a great number of elementary events which they called "shot effects." These presumably reflect the activation of single receptor molecules by the transmitter. They also showed that different agonists (such as carbachol) produce different shot effects. To see whether the shot effect could also be modified by causing a structural change in the receptor molecule itself, we treated a cholinergic synapse with dithiothreitol (DTT), which decreases the postsynaptic sensitivity to ACh by reducing a specific disulfide bond situated a few angstroms away from the anionic site of the receptor (*2, 3*). This effect can only be reversed by subsequent reoxidation, for instance, by 5,5′-dithio-bis(2-nitrobenzoic acid) (DTNB) (*2, 3*). We now report that treatment with DTT affects the elementary permeability events produced by ACh, probably by decreasing both their amplitude and duration.