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Fission-track and K-Ar Ages of Natural Glasses

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A study of the problems associated with fission-track dating of glass

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FISSION-TRACK AND K-Ar AGES OF NATURAL GLASSES

By C. W. NAESER, G. A. IZETT, and J. D. OBRADOVICH

ABSTRACT

Considerable experimental evidence points to the conclusion that fission-track ages of natural glasses are either equal to or less than K-Ar or fission-track zircon ages of the same sample. To further test the hypothesis that fission-track ages of glasses are minimum ages, owing to track fading or annealing at ambient temperatures during geologic time, we dated 38 samples of upper Cenozoic natural glasses for which K-Ar or zircon fission-track ages are available. Of the 24 samples of *nonhydrated* glass we dated (23 obsidians and one tektite), 12 have fission-track glass ages that are concordant (2-sigma level) with K-Ar ages, and 12 have fission-track ages that are markedly younger than the K-Ar ages. In contrast, only one of 14 fission-track ages of *hydrated* glass shards from samples of upper Cenozoic ash beds is concordant (2-sigma level) with fission-track ages of coexisting zircon microphenocrysts; the remaining 13 samples have fission-track glass ages significantly younger than fission-track zircon ages from coexisting zircon microphenocrysts.

The plateau-annealing technique developed by D. Storzer and G. Poupeau in 1973 was used to correct some of the anomalously young annealed fission-track glass ages. The plateau fission-track glass ages of 10 of the samples were found to be near the K-Ar or zircon fission-track ages. Plateau-annealing data for two of the nonhydrated glasses (one obsidian and one tektite) show that they have not been annealed.

The geometry factor used in the fission-track dating of zircon using a muscovite detector was found to be 0.5, which is in accord with previous experimental determinations of this factor by A. J. W. Gleadow and J. F. Lovering in 1977.

INTRODUCTION

Considerable experimental evidence points to the conclusion that whereas some fission-track ages of natural glasses are concordant with isotopic ages, most are younger. This information is well known among most fission-track geochronologists; however, many potential users of fission-track glass ages may not be aware of this problem, and it is to users of fission-track glass ages that this paper is directed. Moreover, a few fission-track geochronologists who only date glass shards may not be attuned to the problem of track annealing, inasmuch as they do not compare their fission-track ages with those determined on other materials. It is then, the chief purpose of this paper to present additional experimental evidence that many nonhydrated natural glasses, including obsidians and tektites, yield fission-track ages that are significantly younger than K-Ar ages of the same material. In addition, fission-track ages of nearly all samples of hydrated glass shards from upper Cenozoic ash beds are significantly younger than fission-track ages of zircon microphenocrysts separated from the ash beds. The young fission-track ages of the glasses result from track fading (annealing) under ambient conditions during geologic time.

Another purpose of this paper is to show that some naturally annealed glasses can give corrected fission-track ages using the plateau-annealing technique of Storzer and Poupeau (1973). Finally, we will briefly review a few of the critical factors that affect the fission-track dating of zircons.

FISSION-TRACK ANNEALING

One of the first materials to be successfully dated using the fission-track method (Fleischer and Price, 1964a) was natural glass, which was preceded only by mica (Price and Walker, 1963). A number of different types of natural glasses, including tektites and impact glasses, have been dated since the first work in 1964 (Fleischer and Price, 1964b; Fleischer and others, 1965a; Gentner and others, 1967, 1969). Fission tracks have also been used to date obsidians, pitchstones, and basaltic glasses (Fleischer and Price, 1964b; Storzer, 1970; Suzuki, 1970; McDougall, 1976, and Wagner and others, 1976). In addition, silicic pumice and volcanic glass shards have been dated (Fleischer and Price, 1964a; Seward, 1974).

The fission-track ages reported by Fleischer and Price (1964a) and in other papers are generally equal to or less than the age of natural glass as determined by other isotopic dating methods, principally K-Ar. The fact that fission-track ages of glass (usually) and other minerals (occasionally) are younger than K-Ar ages from the same rock led to the discovery (Fleischer and others, 1965b) that fission tracks anneal during heating of a glass or mineral in the laboratory and, by inference, also in natural situations. Fleischer and others (1965b) found that heat, rather than pressure, is the chief factor producing fission-track fading or annealing; pressure of 1 million kilopascals had only a minor effect on the annealing properties of a tektite they studied.

Annealing under natural conditions has been documented in a number of cases; usually annealing is detected when a fission-track age is significantly younger than expected, based on geologic criteria. Storzer and Wagner (1969) first reported that physical evidence of track fading could be detected by comparing the diameters of fossil tracks to the diameters of neutron-induced tracks in the same material. Where track fading has occurred, the diameters of fossil tracks are appreciably smaller than diameters of induced tracks. In several hydrated glasses we have studied, a marked difference occurs between the diameters of fossil and induced tracks. Even if the difference in diameters is barely detectable, the fission-track age will be very much less than quench age of the glass.

Storzer and Wagner (1969) developed an empirical curve that relates fossil- and induced-track diameters in partially annealed glasses in order to correct the age of formation of the glass. This method is time consuming and tedious.

A far more satisfactory method for correcting fission-track ages of partially annealed glass was developed by Storzer and Poupeau (1973). Their method consists of heating, at progressively higher temperatures, a pair of samples consisting of a natural-state glass and an irradiated glass. A fission-track age calculated from the fossil- and induced-track counts after each heating step shows that the apparent age of the glass gradually increases until a constant ratio of fossil tracks to induced tracks results (plateau age). After the plateau is reached, the age remains constant with increased temperature until at a critical temperature range all tracks are annealed. We have found this to be a satisfactory method for correcting partially annealed glasses. McDougall (1976) reported that these methods did not give satisfactory results when applied to oceanic basaltic glasses.

DATING OF NONHYDRATED NATURAL GLASSES

We dated 24 samples of nonhydrated natural glass (obsidian and tektite) by the fission-track method, and their ages and associated analytical data are listed in table 1. Descriptions of the localities where the glasses were collected are given in table 2, and table 3 reports K-Ar analytical data for samples not previously reported on. These natural glasses were chosen from a large group in our collection because they appear very fresh and because they are essentially free of microlites and crystallites, which can make fission-track dating impossible. Many obsidians are crowded with microlites and crystallites (gobulites and trichites), and these form fission-track-like etch pits following etching with hydrofluoric acid. The etch pits of the microlites and crystallites are difficult to separate from real fission tracks formed from the spontaneous decay of ^{238}U, and accordingly, calculated ages based on counts including the microlite and crystallite etch pits are not reliable. The ages of the natural glasses range from about 30 m.y. to about 0.1 m.y. Among these glasses are obsidians from 21 widely scattered localities in Western North America, a vitrophyre of a welded tuff from Wyoming, an obsidian from South America, and a tektite (moldavite) from Czechoslovakia.

K-Ar age determinations are reported in table 1. The K-Ar ages were calculated or recalculated using the constants for the radioactive decay and abundance of ^{40}K recently recommended by the International Union of Geological Sciences Subcommittee on Geochronology (Steiger and Jager, 1977). Of the 24 natural glasses of table 1, 12 have fission-track ages that are significantly younger than the K-Ar ages of the same material. (The ages are discordant at the 2-sigma level.) A plot of the fission-track and K-Ar ages is shown in figure 1.

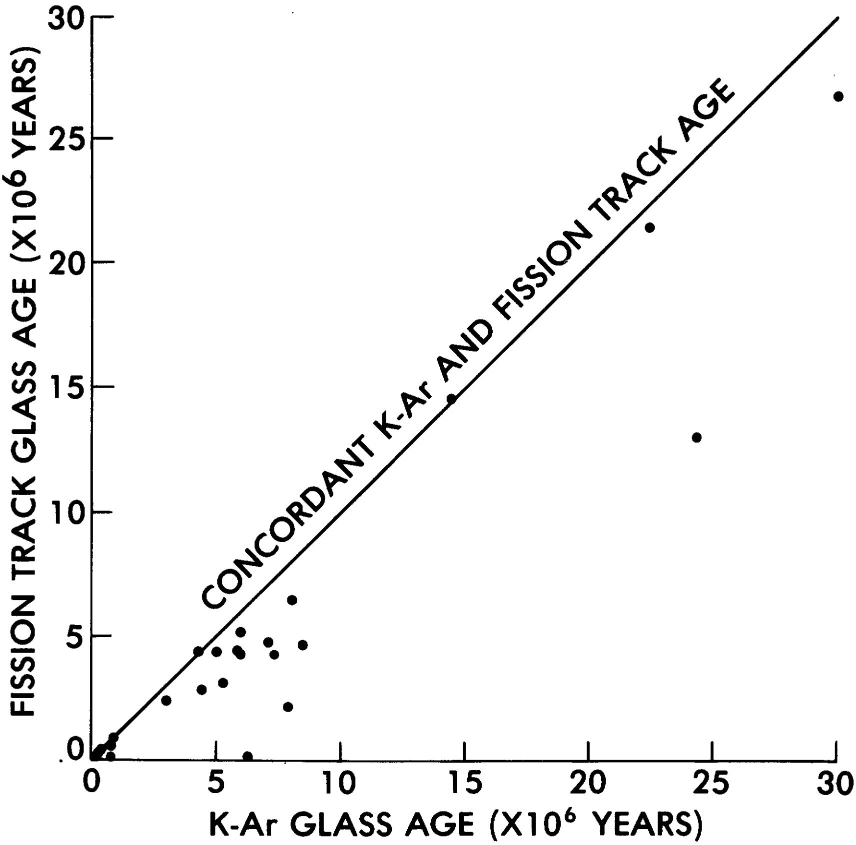

FIGURE 1.—Diagram showing the relationship between the K-Ar ages and the fission-track for a group of natural glasses numbered and listed in table 1.

Special comments are required concerning the age of several of the glasses: specifically, the obsidians from Glass Buttes, Oreg. (table 1, no. 14), Beaver Creek, Colo. (table 1, no. 22), and Big Sand Spring Valley, Nevada (table 1, no. 23). These samples are probably the best examples illustrating why fission-track ages of glass tend to be discordantly younger than K-Ar ages. Two different samples of glass from the obsidian flow of Glass Buttes, Oreg. (table 1, no. 14), were dated. One was a surface sample collected by Charles Vitaliano of Indiana University, and the other was a subsurface sample collected by E. H. McKee of the U.S. Geological Survey from about 1 meter below the surface. The surface sample has an apparent fission-track age of 1.5 ± 0.2 m.y. In contrast, the subsurface sample has a fission-track age of 4.4 ± 0.3 m.y., which is concordant with the K-Ar age of this obsidian (5.04 ± 0.73 m.y.; McKee and others, 1976). Another glass (table 1, no. 23; table 3, DKA 3317) that has discordant fission-track and K-Ar ages was collected from surface exposures in the Big Sand Spring Valley of Nevada, a region of the country known for very hot summers and sparse vegetation to provide shade. The discordancy between the fission-track and K-Ar age is about 13 m.y. The fission-track and K-Ar ages of the Beaver Creek obsidian flow (table 1, no. 22) are concordant at about 21-22 m.y. This sample came from surface exposures high in the San Juan Mountains of Colorado (about 3,470 m above sea level), from a north-facing slope (Lipman and others, 1969). Based on the above data, it appears that solar radiation impinging on a black obsidian in hot, dry climates can raise the temperature of the glass enough to cause track fading. It is therefore necessary, when collecting glass for fission-track dating, to minimize solar-induced track fading by quarrying back.

DATING HYDRATED GLASS SHARDS

Fission-track ages of 14 samples of hydrated glass shards were determined, and the ages and analytical data are listed in table 4. The samples were taken from volcanic ash beds of late Cenozoic age in the Western United States, and information concerning their localities is given in table 5. These 14 samples of volcanic ash were chosen for several reasons: (1) The glass shards of the samples have large platy bubble walls that make track counting efficient; (2) their stratigraphic and paleontologic age is known; and (3) fission-track zircon ages are available for all the samples (table 2).

To prepare the glass shards for fission-track counting, they were all etched in 1:1 HF and H_2O at room temperature for 45 seconds, and the obsidians and tektites were etched for varying times between 10 and 15 seconds in HF (48 percent). In preparing the glass shards for dating, the sample was sieved to provide the coarsest shards possible, and the glass was separated from its crystal content by use of bromoform and bromoform-acetone mixtures. The sample was then split into two parts. One part was mounted and used for the fossil-track density, and the other fraction was irradiated for the induced count. The obsidians and tektites were processed in a slightly different way. Large pieces of glass were crushed, and the coarse-sand-size fraction was used for dating. This was done to minimize any heterogeneity of the uranium content of the glass. After sizing, the sample was split; several hundred grains were mounted for the fossil count, and several hundred other grains were placed in aluminum foil packages for irradiation.

After irradiation, the glasses were mounted in epoxy and polished. The mounts containing the grains for the fossil-track and induced-track counts were then etched together back to back in an HF and H_2O solution. After etching, the fission-track densities of the glasses were determined by counting the tracks in transmitted light at magnifications of 500 (Naeser) or 787 (Izett). The fossil tracks were not removed by heating prior to irradiation. Heating of the hydrated glass shards would change the water content of the glass, which would have a marked effect on the etching characteristics and the natural-state age of the glass. The induced-track density was determined by subtracting the fossil-track density from the total track density in the irradiated samples.

The percentage of samples showing annealing effects is greater for the hydrated glass shards shown in table 4 than for the nonhydrated obsidians of table 1. Over 90 percent (13 of 14) of the volcanic ash samples studied have fission-track glass ages younger than the fission-track ages of coexisting zircon microphenocrysts. The results of these studies for the fission-track dating of the shards, shown in table 4 and figure 2, are not all that surprising in light of the studies of Lakatos and Miller (1972 a, b). They showed that when obsidian is hydrated in the laboratory, the temperatures at which annealing takes place are markedly lower than in the nonhydrated glass. Their data show that a significant percentage of the tracks present in a glass containing 2.2 percent H_2O would be annealed at ambient surface temperatures. Most glass shards from upper Cenozoic ash beds have water contents in excess of 4 percent, which means that some annealing might be expected in glass shards from beds of this age.

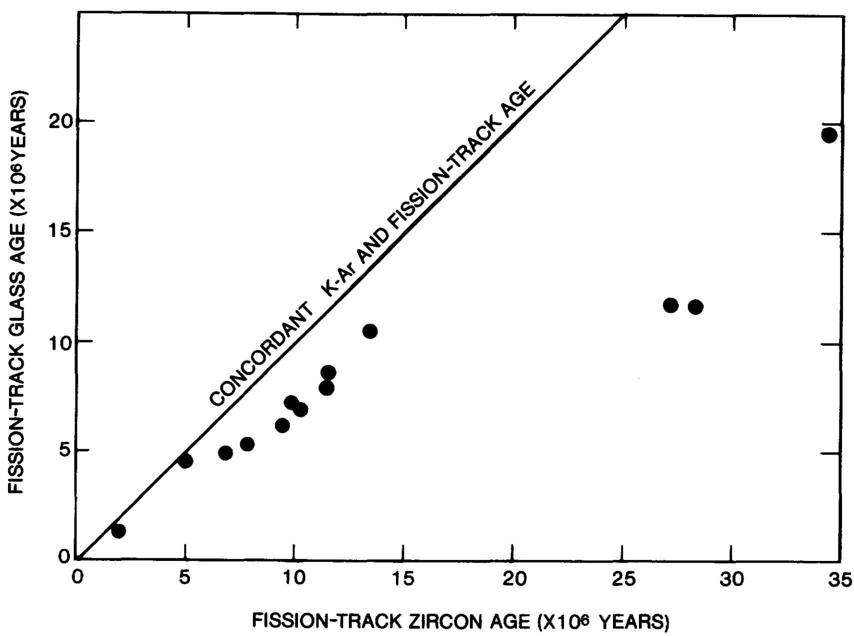

FIGURE 2.—Diagram showing relationship between glass fission-track age and zircon fission-track age of hydrated glass shards from upper Cenozoic ash beds in the Western United States.

PLATEAU ANNEALING

As mentioned, two procedures exist whereby partially annealed glasses can be treated in order to correct apparent fission-track ages for track annealing. One technique is to measure a large number of diameters of fossil and induced tracks of a sample and, by relating the average track diameters of the fossil and induced tracks, correct the apparent age. In this technique, it is critical that the materials used for measuring the diameters of the fossil and induced tracks be etched under identical conditions (temperature, time, and acid concentration).

A second technique is the plateau annealing method developed by Storzer and Poupeau (1973), and because it is less time consuming and less tedious, we selected 12 samples from tables 1 and 4 to date by this technique. Two of the samples have concordant fission-track glass and K-Ar ages at the 2-sigma level, and the other 10 have fission-track glass ages that are markedly discordant with either K-Ar or fission-track zircon ages. Plateau annealing ages and their associated analytical data for the 12 samples are listed in table 6. The samples that have discordant fission-track glass ages are characterized by having fossil-track diameters that are much smaller than diameters of induced tracks for samples that were etched under identical conditions. These smaller fossil-track diameters were noted for both obsidians and glass shards that have discordant fission-track ages.

For the plateau-annealing experiments, we crushed the glass to pass a 425-μm sieve and prepared two 0.1-g splits. One of the splits was irradiated and, following irradiation, was again split into four or five parts, and each part was placed into a small aluminum foil package. An aluminium foil package of the nonirradiated glass was also prepared. The two packages were placed in a tube furnace and heated for 1 hour at a temperature between 150° and 200°C. This heating process was repeated with another pair of samples at a higher temperature. We used temperatures between 150° and 350°C for samples 1, 9, 10, 11, and 12 of table 6, and the other samples of table 3 were heated to only about 200°C. We determined from the stepwise heating experiment that heating a sample for 1 hour is generally sufficient to reset the apparent fission-track glass age to near the K-Ar or fission-track zircon age. Following heating, the samples were mounted in epoxy and polished. Each pair of samples was etched back to back for the same time in the same acid, and the tracks were counted at the same magnification. The results of the plateau-annealing experiment are shown graphically in figure 3.

The plateau fission-track ages of the natural glasses that have concordant fission-track and K-Ar ages (macusanite and moldavite; table 6, nos. 1 and 9) remained unchanged after stepwise heating, although the fossil- and induced-track densities in both natural glasses were 50 percent

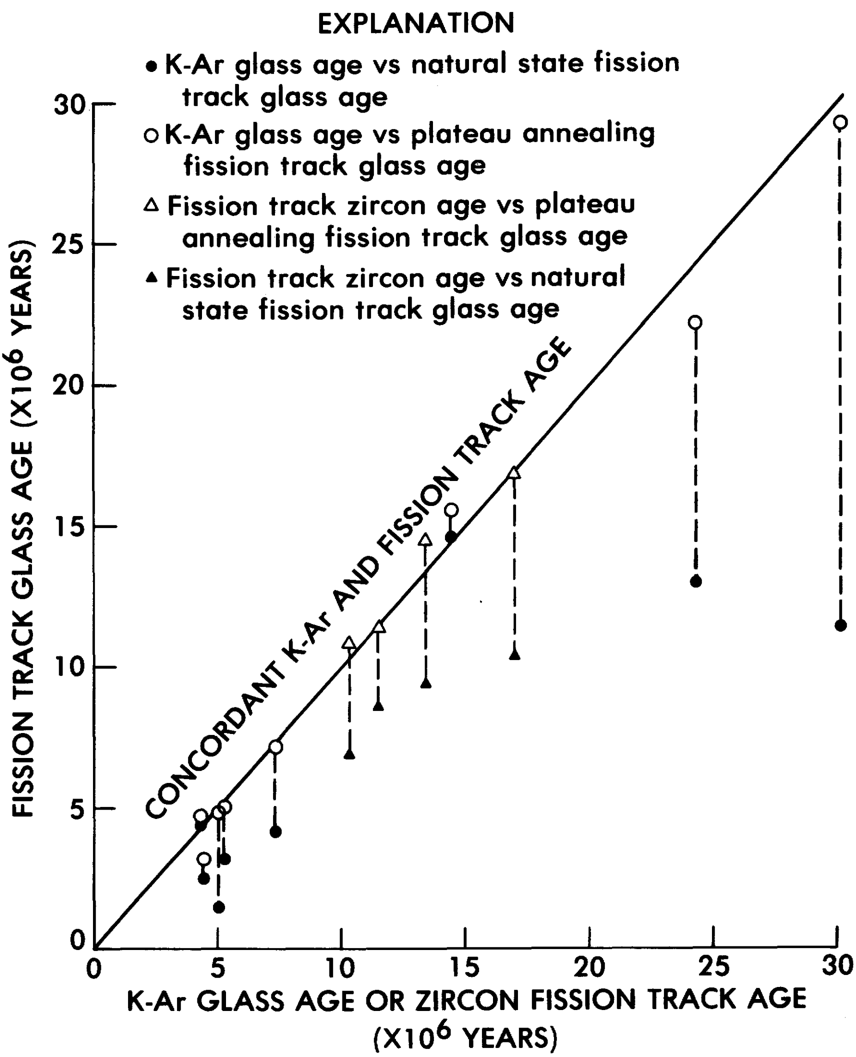

FIGURE 3.—Plateau annealing diagram showing relationship between K-Ar glass age or zircon fission-track age (*x* axis) and natural state or plateau annealing fission-track glass age (*y* axis). Dashed lines show amount of age resetting accomplished during plateau annealing procedure.

lower than in the natural-state material after the final heating step. These results indicate there had been no track fading in the natural-state material in the two samples.

The samples that have natural-state discordant ages show a pattern of increasing age with increasing temperature, as shown in figure 4. Counting fission tracks in the hydrated glass shard samples that were

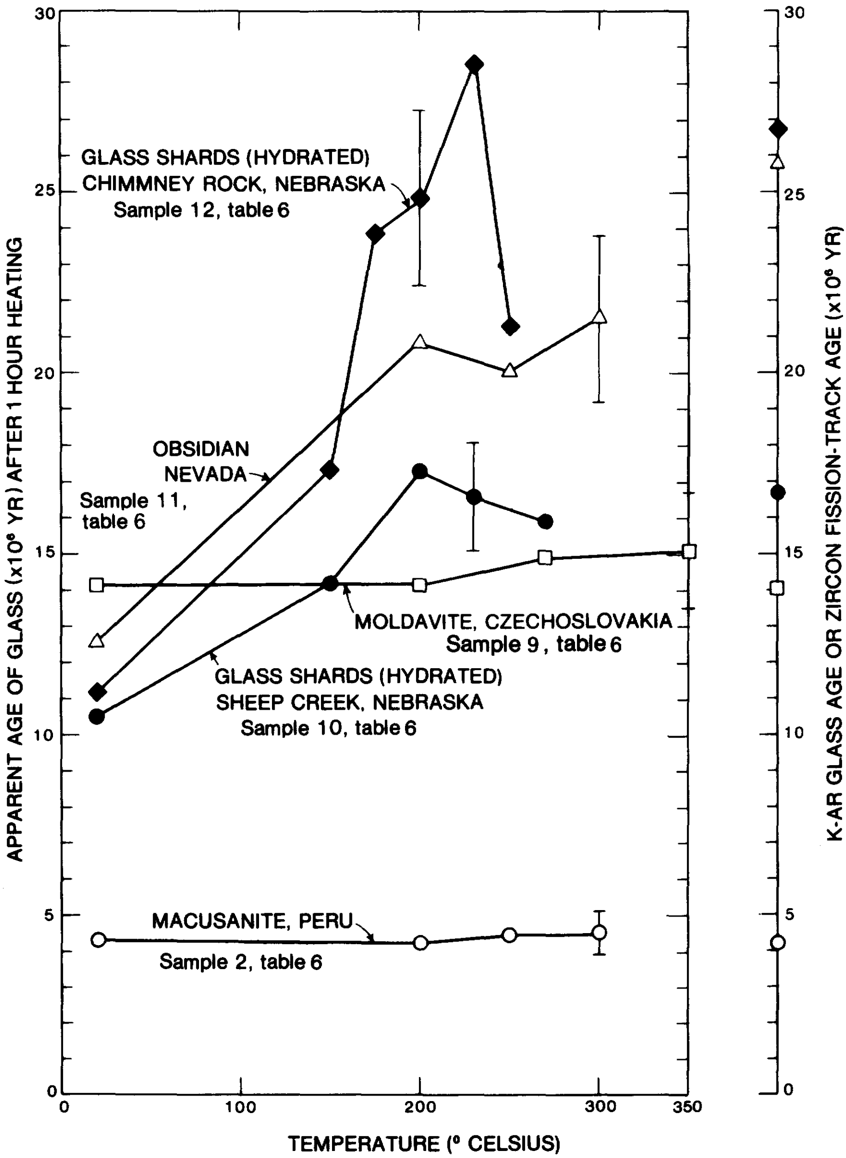

FIGURE 4.—Fission-track plateau annealing diagram for selected samples of table 6, showing the apparent fission-track glass ages of the samples after heating at various temperatures for 1 hour, compared with the K-Ar glass age or fission-track zircon age of the sample. Error bars indicate + one standard deviation.

heated above 200° is very difficult. The glass shards fracture badly during dehydration and are crazed to such an extent that finding flat, clean surface areas to count is difficult. We ascribe the decrease in the apparent age at the highest temperatures of some samples (table 6, nos. 10 and 12) to this phenomenon. Of the 12 samples studied that have discordant natural-state fission-track glass ages, 10 have plateau-annealing ages concordant with K-Ar or fission-track zircon ages at the 2-sigma level. The obsidian from Cougar Mountain, Oreg., was heated at only 225°C for 1 hour; perhaps it should be heated at higher temperatures in order to reach a plateau age. MacDougall concluded that heating for 1 hour at 200°C was enough to place basaltic glasses in the plateau region of the age-versus-temperature curve. The other glass that remained discordant after heating is the obsidian from Nevada. It is possible that because of the amount of initial discordance, 50 percent, some of the fossil tracks may have been totally annealed and, therefore, the age could not be corrected to the K-Ar age by the plateau method.

DISCUSSION OF ZIRCON FISSION-TRACK AGES

In fission-track dating, the investigator must make a choice among several possible numbers to substitute for "constants" in the fission-track age equation:

$$t = \frac{1}{\lambda_d} \ln \frac{\rho_s \, \lambda_d \, \sigma \, I \, \phi}{\rho_i \, \lambda_f} + 1$$

Where t =age in years,
ϕ =neutron dose,
λ_d =total decay constant for ^{238}U,
ρ_s =spontaneous-track density,
ρ_i =induced-track density,
σ =thermal neutron fission cross section for ^{235}U,
λ_f =decay constant for spontaneous fission of ^{238}U,
I =ratio of $^{235}U/^{238}U$.

The first of these decisions involves the value for the spontaneous fission of ^{238}U (λ_f). Two decay constants are currently being used in fission-track dating—one at about 8.4×10^{-17} yr^{-1} (Spadavecchia and Hahn, 1967; Wagner and others, 1975; and Thiel and Herr, 1976), and the second near 7.0×10^{-17} yr^{-1}. There is a difference of about 17 percent between these two constants. The second decision involves a choice between two calibration values (Cu or Au) used to determine the uranium content of a material to be dated. The U.S. National Bureau of Standards has an excellent set of calibrated glasses available for determining the neutron dose (Carpenter and Reimer, 1974) used for a particular dating experiment. These glasses were irradiated with Cu and Au foil dosimeters at the National Bureau of Standards. Because the copper values are 10 percent lower than the gold values, a choice must be made of which value to use.

If we use λ_f–7.03×10^{-17} yr^{-1} (Roberts and others, 1968) and the Cu values for the neutron dose calibration, we get the best agreement with K-Ar ages. We have dated 51 zircon separates from subvolcanic and volcanic rocks whose ages are between 0.6 and 70 m.y. These rocks have been dated by the K-Ar method using one or more of the following minerals: biotite, hornblende, plagiolase, and sanidine. A least-squares analysis of the K-Ar and fission-track age data gives a slope of 0.996 and a correlation coefficient of 0.997. Other combinations of decay constant and neutron dose calibration constant yield ages as much as 20 percent too young (8.4×10^{-17} yr^{-1},Cu) or 12 percent too young (8.4×10^{-17} yr^{-1},Au). This empirical method of calibration is not the most satisfactory procedure, but with the present controversy concerning fission-track decay constants, we feel that this is the best method to produce ages that are compatible with K-Ar ages and are therefore geologically useful.

Another possible source of error that can affect the accuracy of a zircon fission-track age is the so-called "geometry factor." When a zircon is dated, the fossil tracks are counted on an internal surface of a zircon grain, and the induced tracks are counted on the cleavage surface of a low-uranium muscovite (<10 ppb U), which covered the zircon during neutron irradiation. A basic assumption is that half as many tracks are recorded from the fission of ^{235}U in the muscovite detector as would be recorded in a zircon crystal. A geometry factor of 0.5 indicates that the zircon and the muscovite have similar etching and counting efficiencies (Fleischer and others, 1975). Reimer and others (1970) questioned the validity of using a geometry factor of 0.5 for zircon in a muscovite detector. In their experiment they compared internal and external tracks in a crystal and determined that the ratio was not 0.5. However, they did not compare the internal tracks with those in a muscovite detector. Their results raised some doubts about the validity of using a geometry factor of 0.5, but Gleadow and Lovering (1977) determined the geometry factor as used in the external detector method to be 0.5 for apatite, sphene, and zircon. Using a zircon provided by Gleadow, from the Mud Tank Carbonatite of the Hart's Range, Northern Territory, Australia, we also have determined the geometry factor for the zircon-muscovite pair to be 0.5. Carbonatite zircon ages determined by the population and external detector methods are equal and are as follows:

Population method	*External detector method*
273 ± 14 m.y.	262 ± 20 m.y.

$\lambda_f = 7.03 \times 10^{-17}$ yr^{-1}

± is 2 standard deviations

During these geometry experiments, it became obvious that some of the zircons had many fewer tracks than other members of the population. A check of the tracks in the muscovite showed that the zircons all have the same amount of uranium. It was also noted that the etched surfaces of the zircons with low track densities had characteristics different from those of the zircons with high track densities, even though the shape of the tracks is identical. Twelve grains were chosen that showed divergent surface characteristics of the etched surface. These grains were counted for their induced-track density. After counting, they were mounted on the end of a wire needle. With the use of the Wilcox spindle stage (Wilcox, 1959), the angle between the polished surface and the optic (c) axis of the zircon was measured. The results are shown in figure 5. Those grains whose polished surface was subparallel (±15°) to the optic axis had twice as many tracks as the muscovite detector. As the angle between the optic axis and the polished surface of the zircon increased, the track density decreased; and the geometry factor became greater than 0.5. Zircons, because of their general elongate shape, will invariably be mounted for counting with the c axis subparallel to the microscope stage. This coincidence minimizes the chance of counting a zircon with an unknown geometry factor. As was noted earlier, the surface texture showed differences as well. The grains that had the highest track densities also had the sharpest polishing scratches. As the track density decreased the scratches became almost invisible. Apparently, the etching rate is much greater normal to the c axis that parallel to the c axis. It should be noted that these effects were observed and measured on induced tracks in an annealed crystal. The behavior of fossil tracks may be different. If the

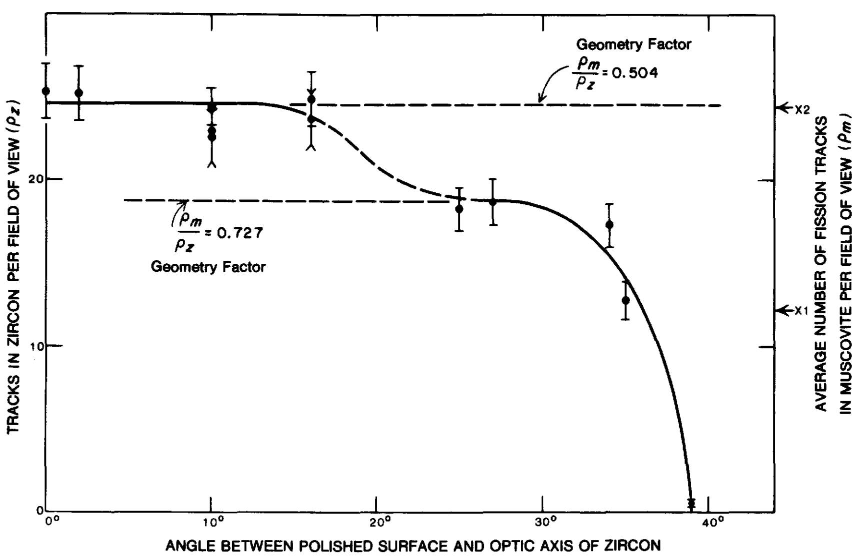

FIGURE 5.—Diagram showing the change in the ratio of induced fission tracks (external surface) in muscovite (ρ_m) to the induced fission tracks (internal surface) in zircon (ρ_z) from the Mud Tank Carbonatite, Australia, as a function of the angle between a polished surface and the optic axis of zircon grains. Error bars are one standard deviation about the mean. X1= Track density in muscovite, X2=2 times track density in muscovite.

surface to be counted is carefully chosen (that is, if it has sharp scratches and gives a flash figure), a geometry factor of 0.5 is valid and can be used with confidence.

Figure 5 shows that as the angle between the *c* axis and the polished surface approaches 45°, the geometry factor approaches infinity. This suggests that the 101 or 111 faces are far more soluble than the 100.

CONCLUSIONS

The results of this study show that any fission-track glass age must be considered a minimum age. In the case of glass shards from upper Cenozoic volcanic ash beds, only 1 sample out of 14 studied provided concordant fission-track ages on glass and zircon.

Track fading in samples collected at the surface of an outcrop is a real problem in fission-track dating of natural glasses. This result is in direct conflict with the findings of Boellstorff and Steineck (1975), who concluded that a reduction in diameter of the fossil tracks does not affect the age, and that annealing probably does not take place at ambient temperatures.

Some glasses that have been affected by track fading can be corrected with the plateau-annealing procedure of Storzer and Poupeau (1973) to give concordant results. It should be noted that this procedure does not always yield concordant results (McDougall, 1976, and this study). Therefore, a glass fission-track age that has been "corrected" must also be considered a minimum age.

We conclude that the geometry factor as used in the fission-track dating of zircon with muscovite detectors (0.5) is valid if the *c* axis of the crystal is subparallel (±15°) to the polished surface being counted.

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TABLES 1–6

TABLE 1.—*Fission-track and potassium-argon ages of upper Cenozoic natural glasses*

[Errors assigned to ages are 1 sigma about the mean. Fission-track age de-
by G.A. Izett. Fission tracks etched for about 10 seconds in 48 percent
tracks counted at x720 by Izett and x625 by Naeser]

No.	Locality (short name)[1]		Neutron flux (ϕ) (10^{15}n cm^{-2})	Spontaneous-track density[2] (ρ_s) (10^3 tracks cm^{-2})	Induced-track density[2] (ρ_i) (10^3 tracks cm^{-2})
1	Crystal Spring-----		0.53	0.246 (7)	58.5 (279)
2	Obsidian Cliff-----		2.47	.271 (9)	283 (593)
3	Cougar Pass--------		.53	.912 (13)	143 (372)
4	Big Southern Butte-		2.72	.811 (27)	498 (569)
5	Bearskin Butte-----		.922	[5].0373 (1)	125 (309)
6	Mineral Range------		.53	.789 (3)	44.0 (213)
7	Owens River--------		.922	2.03 (29)	125 (521)
8	West Queen Canyon--		1.30	4.07 (110)	102 (784)
			1.17	3.80 (129)	83.5 (643)
9	No Agua------------		1.30	6.20 (47)	202 (300)
10	Grassy Lake Reservoir quadrangle.		1.71	9.88 (84)	236 (489)
11	Macusani-----------		.922	23.3 (723)	296 (830)
		N	.922	19.6 (476)	240 (1,893)
12	Cougar Mountain----		2.47	2.10 (20)	122 (471)
			2.72	2.95 (84)	151 (732)
13	Teton Pass quadrangle.		1.30	5.94 (54)	99.1 (152)
14	Glass Buttes-------		2.72	4.58 (196)	170 (834)
15	Mount Edziza-------		1.19	16.5 (505)	283 (3,272)
		N	1.30	19.8 (96)	294 (339)
16	Squaw Butte--------		2.47	4.5 (214)	141 (416)
			2.72	4.4 (84)	171 (667)
17	Teton Pass quadrangle.		1.71	5.90 (113)	102 (433)
			.53	6.38 (91)	28.5 (52)
18	Horse Mountain-----		2.72	7.08 (101)	242 (520)
19	Drews Ranch--------		2.47	5.22 (273)	184 (1,084)
20	McComb Butte-------		2.47	2.46 (14)	167 (643)
21	Czechoslovakia-----		2.69	9.12 (130)	99.8 (414)
		N	2.69	9.57 (242)	106 (327)
22	Beaver Creek-------		2.53	63.9 (415)	491 (601)
			1.30	62.8 (705)	209 (490)
			1.71	62.3 (296)	299 (306)
23	Big Sand Spring Valley.		1.30	67.3 (320)	390 (395)
		N	2.69	50.2 (401)	679 (787)
			1.30	54.7 (691)	308 (512)
24	Nathrop------------		1.30	114 (164)	335 (649)
			2.52	117 (211)	650 (277)

See footnotes on following page.

from 24 localities in the western United States, Peru, Canada, and Czechoslovakia

terminations preceded by N were made by C. W. Naeser; all others were hydrofluoric acid; a few samples etched as long as 15 seconds. Fission

No.	Fission-track glass age[3] (m.y.)	K-Ar glass age[4] (m.y.)	Source of K-Ar age
1	0.13±0.05	0.08 ±0.003	Table 3.
2	.14± .05	.183± .003	Do.
3	.20± .06	6.26 ± .06	Do.
4	.27± .05	.31 ± .02	Armstrong and others (1975).
5	[6].02	.75 ± .1	H. H. Mehnert (written commun., 1975).
	.59± .12		
6	.58± .30	.79 ± .08	Do.
7	.90± .17	[7].92 ± .1	Gilbert and others (1968, p. 302, KA2081).
8	3.1 ± .31	[8]5.28 ± .22	Table 3.
	3.2 ± .30		
9	[6]2.4 ± .36	3.91 ± .27	H. H. Mehnert (written commun., 1976).
10	4.3 ± .5	5.99 ± .06	Table 3.
11	[9]4.3 ± .2	4.3 ±1.5	Barnes and others (1970, p. 1543).
	4.5 ± .2		
12	[6]2.5 ± .6	4.42 ± .34	McKee and others (1976).
	[6]3.2 ± .4		
13	4.7 ± .7	8.48 ± .08	Table 3.
14	4.4 ± .3	5.04 ± .73	McKee and others (1976).
15	[10]5.2 ± .3	[11]6.00 ± .06	Table 3.
	5.2 ± .6		
16	[6]4.7 ± .4	5.85 ± .67	McKee and others (1976).
	[6]4.2 ± .5		
17	5.9 ± .6	8.06 ± .08	Table 3.
	7.1 ±1.5		
18	[6]4.8 ± .5	7.10 ± .14	McKee and others (1976).
19	[6]4.2 ± .3	7.33 ± .34	Do.
20	[6]2.2 ± .6	7.91 ± .09	Do.
21	[12]14.2 ±1.4	[13]15.1 ± .7	Gentner and others (1963).
	14.5 ±1.2		
22	19.4 ±1.2	22.4 ± .9	Lipman and others (1970, p. 2345).
	23.3 ±1.4		
	21.3 ±1.8		
23	[6]13.4 ±1.0	26.4 ± 3	Ekren and others (1974, p. 605).
	[6]11.9 ± .7	24.3 ± .3	Table 3.
	[6]13.8 ± .8		
24	26.4 ±2.3	[14]30.0 ± 1.5	Van Alstine (1969, p. 18)
	27.1 ±2.5		

TABLE 1.—*Fission-track and potassium-argon ages of upper Cenozoic natural glasses for 24 localities in the western United States, Peru, Canada, and Czechoslovakia*—Continued

[1]See table 2 for complete name and description of locality.

[2]Numbers in parentheses show total number of tracks counted in each sample.

[3]Decay constant used: $\lambda_f = 7.03 \times 10^{-17}$ yr^{-1}.

[4]All K-Ar ages calculated or recalculated using the following, recently revised decay constants: $\lambda_b = 4.962 \times 10^{-10}$ yr^{-1}; $\lambda_\varepsilon + \lambda_{\varepsilon'} = 0.581 \times 10^{-10}$ yr^{-1}; ^{40}K/K = 1.167×10^{-4} atom/atom (Steiger and Jager, 1977).

[5]No fossil fission tracks seen; age calculated by assuming the presence of one track.

[6]Sample had fossil fission-track annealing, as indicated by marked track diameter reduction.

[7]Age of suspected source-area material.

[8]Obsidian reported to underlie basalt flows (Crowder and others, (1972). Basalt that caps Benton Range several kilometers southwest of this locality was dated 3.41±0.07 m.y. (average of 7 whole-rock K-Ar ages on samples spread along 3 km of outcrop) and 3.51±0.06 m.y. (average of 12 whole-rock K-Ar ages on age of 12 whole-rock K-Ar ages on one hand sample) by Dalrymple and Hirooka (1965). Biotite from the basalt gave a K-Ar age of 3.25±0.30 m.y. Mankinin and Dalrymple (1972) reported an ^{40}Ar-^{39}Ar age of 3.45±0.48 m.y. for the basalt.

[9]Fission-track glass age of 4.3±0.4 reported by Fleischer and Price (1964b). (Not recalculated with revised decay constant.)

[10]Aumento and Souther (1973, p. 1162) report a fission-track glass age of 3.1±0.1 m.y. (Not recalculated with revised decay constant).

[11]Obsidian is from a pebble in fluvial deposits overlying basalt flows dated by the K-Ar method at 4.10±0.6 m.y. (average of three whole-rock age determinations).

[12]Gentner and others (1967) report a fission-track glass age for similar material of 14.1 m.y. (average of five determinations). Fleischer and Price (1964b) report fission-track glass ages of 15.3, 12.6, and 12.2 m.y. (Not recalculated with revised decay constants.)

[13]Age for similar material.

[14]K-Ar sanidine ages of 28.7±0.3 and 29.8±0.9 reported by Van Alstine (1969, p. 18).

TABLE 2.—*Descriptions and localities of samples listed in table 1.*

No.	Locality	Description	Collector	Sample No.
1.	Crystal Springs, Yellowstone National Park, Wyoming.	Obsidian from rhyolite flow----	R. L. Christiansen-	None.
2.	Obsidian Cliff, Yellowstone National Park, Wyoming.	------do----------------------	---do-------------	None.
3.	Cougar Pass, Wyoming, sec. 14, T. 45 N., R. 107 W. (unsurveyed; Forest Service arbitrary grid).	------do----------------------	F. S. Fisher-------	None.
4.	Big Southern Butte, Idaho (Armstrong and others, 1975).	------do----------------------	W. P. Leeman-------	74-23
5.	Bearskin Mountain, Mineral Range, Utah. NW 1/4 sec. 20, T. 27 S., R. 8 W.	------do----------------------	P. W. Lipman-------	75L56
6.	Baily Ridge, Mineral Range, Utah. NE 1/4 SE 1/4 sec. 2, T. 27 S., R. 9 W.	------do----------------------	----do------------	75L17
7.	Along Owens River near Bishop, Inyo County, Calif. SW 1/4 NE 1/4 sec. 21, T. 6 S., R. 32 E.	Obsidian pebbles in sedimentary rocks below the Bishop Tuff.	G. A. Izett--------	75G46
8.	West Queen Canyon, Benton quadrangle, Mineral County, Nevada. SW 1/4 sec. 16, T. 1 N., R. 31 E.	Obsidian from rhyolite flow----	W. J. Carr---------	EWC-33-73
9.	No Aqua, N. Mex. (Lipman and others, 1970).	Obsidian from rhyolite dome----	P. W. Lipman-------	66L234A
10.	Grassy Lake Reservoir quadrangle, Teton County, Wyo. Center south line sec. 19, T. 47 N., 117 W.	Basal vitrophyre of Conant Creek Tuff.	J. D. Love---------	None.
11.	Macusani, Peru. (Barnes and others, 1970).	Obsidian pebbles in terrace deposits.	I. Friedman--------	None.
12.	Cougar Mountain, Oregon (McKee and others, 1976).	Obsidian from rhyolite dome----	G. W. Walker-------	MO73-32

TABLE 2.—*Descriptions and localities of samples listed in table 1.*—Continued

No.	Locality	Description	Collector	Sample No.
13.	Teton Pass quadrangle, Teton County, Wyo. NE 1/4 sec. 36, T. 41 N., R. 118 W.	Obsidian from rhyolite intrusive.	J. D. Love---------	None.
14.	Glass Buttes, Oregon (McKee and others, 1976).	Obsidian from rhyolite dome----	G. W. Walker-------	M073-33
15.	Mount Edziza, British Columbia-----------	Obsidian from rhyolite boulder described by Aumento and Souther (1973).	R. Aumento---------	DF596
16.	East of Squaw Butte, Oregon (McKee and others, 1976).	Obsidian from rhyolite dome----	N. S. MacLoud------	MS-70
17.	McNeely Ranch, Teton County, Wyo. North of Mosquito Creek in SE 1/4 NW 1/4 sec. 33, T. 41 N., R. 117 W.	Obsidian from rhyolite intrusive.	J. D. Love---------	None.
18.	Horse Mountain, Oregon (McKee and others, 1976).	Obsidian from rhyolite dome----	E. H. McKee--------	M073-41
19.	Drews Ranch, Oregon (McKee and others, 1976).	----do------------------------	----do------------	M073-43
20.	McComb Butte, Oregon (McKee and others, 1976).	----do------------------------	----do------------	M073-39
21.	Czechoslovakia----------------------------	Tektite-----------------------	H. Faul-----------	DF981
22.	Beaver Creek, San Juan Mountains, Colorado (Lipman and others, 1970).	Obsidian----------------------	P. W. Lipman-------	65L161A
23.	Big Sand Spring Valley, Nye County, Nev. Ten km north of Black Rock Summit, lat. $38^{\circ}35'$ N., long $115^{\circ}54'$ W.	Apache tears from rhyolite flow.	P. P. Orkild-------	0.15776
24.	Nathrop, Colo. North end of Ruby Mountain (Van Alstine, 1969).	Obsidian apache tears from rhyolite flow.	P. W. Lipman-------	66L2304

Table 3.—*K-Ar analytical data for obsidian samples of table 1 not previously listed in published reports*

[All analyses by J. D. Obradovich. Decay constants: $\phi_\beta = 4.962 \times 10^{-10}\ yr^{-1}$; $\phi_\varepsilon + \varepsilon' = 0.581 \times 10^{-10}\ yr^{-1}$; ^{40}K abundance: $^{40}K = 1.167 \times 10^{-10}$ atom/atom K]

No.	Locality (short name)[1]	Original Sample No.	K_2O (weight percent)	Radiogenic ^{40}Ar		K-Ar age (m.y.)
				In sample (10^{-11} g/g)	Percent of total ^{40}Ar	
1	Crystal Spring-----------	DKA-2489	4.85	0.0558	30.7	0.08 ±0.003
2	Obsidian Cliff-----------	DKA-2466	4.98	.131	29.7	.183± .003
8	West Queen Canyon--------	DKA-3355	4.14	3.79	12.1	5.28 ± .22
10	Grassy Lake Reservoir quadrangle.	DKA-3098	5.00	4.27	70.8	5.99 ± .06
15	Mount Edziza-------------	DKA-3318	4.22	4.40	54.4	6.00 ± .06
3	Cougar Pass--------------	DKA-3330	3.46	3.76	82.4	6.26 ± .06
17	Teton Pass quadrangle----	DKA-3328	3.25	4.56	75.3	8.06 ± .08
13	Teton Pass quadrangle----	DKA-3331	3.47	5.12	79.8	8.48 ± .08
23	Big Sand Spring Valley---	DKA-3317	4.23	18.0	96.9	24.3 ± .3

[1] See table 2 for complete name and description of locality.

TABLE 4.—*Fission-track ages of cogenetic glass shards and zircon microphenocrysts separated from upper Cenozoic ash beds from the western United States*

[z = zircon; g = hydrated glass shards; (N)z = zircon age determined by C. W. Naeser; all others by G. A. Izett. Leaders (---) indicate data not available]

No.	Locality		Neutron flux (ϕ) (10^{15}n cm^{-2})	Spontaneous-track density[1] (ρ_s) (10^3 tracks cm^{-2})		Induced-track density[1] (ρ_i) (10^6 tracks cm^{-2})		Fission-track age[2] (m.y.)
1	Borchers locality, Kansas.	z	----	----		----		[3]1.96±0.6
		g	1.16	2.94	(70)	0.162	(297)	1.3 ±0.17
2	Dalton, Nebr.--------	z	1.15	529	(88)	7.33	(910)	5.0 ±0.25
		g	1.18	12.5	(15)	.193	(371)	4.5 ±1.2
3	Hemphill County, Tex.	z	1.09	1160	(313)	11.1	(2,728)	6.8 ±0.2
		g	1.10	16.8	(449)	.227	440)	4.9 ±0.33
4	Balcom Canyon, Calif.	(N)z	1.18	573	(130)	5.16	(585)	7.8 ±0.4
		g	5.03	18.0	(13)	1.03	(380)	5.3 ±1.5
5	Espanola basin, New Mexico.	(N)z	1.10	1350	(153)	9.47	(493)	9.4 ±0.9
		g	1.78	14.9	(157)	.253	(347)	6.2 ±0.6
6	Browns Park, Colo.---	z	1.28	766	(227)	6.10	(1,248)	9.8 ±0.4
		(N)z	1.02	1140	(163)	7.01	(503)	9.9 ±0.4
		g	1.09	21.6	(183)	.196	(638)	7.2 ±0.6
7	Cherry County, Nebr.-	z	1.22	776	(291)	5.48	(1,824)	10.3 ±0.3
		g	1.16	24.9	(108)	.250	(541)	6.9 ±0.7
8	Espanola basin, New Mexico.	(N)z	1.10	1190	(132)	6.88	(382)	11.4 ±1.1
		g	2.09	21.2	(55)	.331	(228)	8.0 ±1.2

TABLE 4.—*Fission-track ages of cogenetic glass shards and zircon microphenocrysts separated from upper Cenozoic ash beds from the western United States*—Continued

No.	Locality		Neutron flux (ϕ) (10^{15}n cm^{-2})	Spontaneous-track density[1] (ρ_s) (10^3 tracks cm^{-2})		Induced-track density[1] (ρ_i) (10^6 tracks cm^{-2})		Fission-track age[2] (m.y.)
9	Middle Park, Colo.---	z	1.22	943	(201)	5.97	(1,284)	11.5 ±0.9
		g	1.18	22.2	(210)	.182	(699)	8.6 ±0.7
10	------do-------------	z	1.23	567	(55)	3.08	(108)	13.5 ±1.1
		(N)z	1.07	1440	(173)	6.93	(417)	13.3 ±0.6
		g	1.18	25.1	(411)	.169	(280)	10.5 ±0.8
11	Sioux County, Nebr.--	z	1.32	3680	(434)	16.6	(1,804)	17.5 ±0.5
		(N)z	1.33	1200	(288)	5.77	(695)	16.5 ±0.6
		g	2.47	20.0	(291)	.313	(889)	9.4 ±0.6
12	Helvas Canyon, Nebr.-	z	1.23	4140	(605)	11.0	(1,578)	27.6 ±0.6
		(N)z	1.23	4150	(577)	10.6	(737)	28.8 ±0.8
		g	1.16	35.5	(77)	.210	(177)	11.7 ±1.8
13	Chimney Rock, Nebr.	(N)z	1.06	4550	(548)	10.6	(641)	27.2 ±0.9
		g	1.71	41.3	(107)	.362	(436)	11.7 ±1.3
14	Uinta County, Wyo.--	(N)z	.977	7450	(1,439)	12.62	(1,219)	34.4 ±0.7
		g	1.95	66.9	(191)	.399	(403)	19.5 ±1.7

[1]Numbers in parentheses show total number of tracks counted in each determination.

[2]Error shown is ±1 sigma. $\lambda_f = 7.03 \times 10^{-17}$ yr^{-1}.

[3]Fission-track age reported by Naeser, Izett, and Wilcox (1973).

TABLE 5.—*Descriptions and localities of samples listed in table 4.*

No.	Locality	Description	Collector	Sample No.
1.	Borchers locality, in NW 1/4 NE 1/4 sec. 21, T. 33 S., R. 28 W., Meade County, Kans.	Silver-gray volcanic ash (type B Pearlette ash) about 0.6 m thick underlying upper Neogene sedimentary rocks that contain the Borchers fauna of Hibbard (1941).	G. A. Izett and R. E. Wilcox.	72G100
2.	Dalton, Nebr. Roadcut along State Highway 383 about 4 km north of Dalton, in NW 1/4 SW 1/4 sec 9, T. 17 N., R. 49 W., Morrill County, Nebr.	Silver-gray volcanic ash about 1.0 m thick interlayered in sedimentary rocks of the uppermost part of the Miocene Ogallala Formation (Kimball Formation of Stout, 1971).	G. A. Izett-------	73G200
3.	Hemphill County, Tex., in SE 1/4 NE 1/4 NE 1/4 sec. 59, blk. A-2 (locality 20 of Reed and Longnecker, 1932).	Silver-gray volcanic ash about 1.0 m thick interlayered in Miocene sedimentary rocks rocks of the Ogallala Formation that contain the type Coffee Ranch Hemphill fauna.	G. A. Izett, G. R. Schultz, and P. W. Lambert.	68G67
4.	Balcom Canyon, in NE 1/4 SE 1/4 sec. 16, T. 3 N., R. 20 W., Ventura County, Calif.	Silver-gray volcanic ash about 0.1 m thick interlayered in Miocene sedimentary rocks of the Modelo Formation.	J. D. Obradovich--	71-0-3
5.	Espanola basin, in SE 1/4 sec. 31, T. 20 N., R. 9 E., Espanola 7 1/2-minute quadrangle, Santa Fe County, N. Mex.	Silver-gray volcanic ash about 2 m thick interlayered with the Miocene Pojoaque Member (Tesque Formation) of Galusha and Blick (1971).	G. A. Izett and T. Galusha.	74G327
6.	Browns Park. Roadcut along State Highway 318 in SW 1/4 NW 1/4 sec. 21, T. 9 N., R. 101 W., Moffat County, Colo.	Silver-gray volcanic ash about 8 m thick interbedded in sedimentary rocks of the uppermost part of the Browns Park Formation (Miocene).	G. A. Izett-------	68G86
7.	Cherry County, Nebr., in NE 1/4 SE 1/4 sec. 15, T. 32 N., R. 70 W.	Silver-gray volcanic ash in lower part of the Caprock Member (Skinner and others, 1968) of the Ash Hollow Formation of Lugn (1939) (equivalent to the Miocene Ogallala Formation) about 15 m above the Burge fossil mammal quarry.	M. R. Skinner-----	73G223

TABLE 5.—*Descriptions and localities of samples listed in table 4.*—Continued

No.	Locality	Description	Collector	Sample No.
8.	Espanola basin, in SE 1/4 sec. 36, T. 20 N., R. 8 E., Espanola 7 1/2-minute quadrangle, Santa Fe County; N. Mex.	Olive-gray volcanic ash about 1 m thick in the Miocene Pojoaque Member (of Galusha and Blick, 1971).	G. A. Izett-------	74G326
9.	Middle Park, in SW 1/4 SE 1/4 sec. 32. T. 2 N., R. 80 W., Grand County, Co.	Silver-gray volcanic ash bed about 1.0 m thick interlayered in the Miocene Troublesome Formation.	----do-----------	68G105
10.	Middle Park, NE 1/4 SE 1/4 sec. 24, T. 1 N., R. 80 W., Grand County, Colo.	Olive-gray volcanic ash bed about 1.0 m thick interlayered in the upper part of the Miocene Troublesome Formation.	----do-----------	None.
11.	Sioux County, Nebr. Head of Merychippus Draw.	Olive-gray volcanic ash bed about 1.0 m thick interbedded in the upper part of the Ogallala Formation (Sheep Creek Formation of Lugn, 1939).	G. A. Izett, M. R. Skinner, and J. G. Honey.	73
12.	Helvas Canyon, in NW 1/4 NW 1/4 sec, 6, T. 20 N., R. 55 W., Scotts Bluff County, Nebr.	Chalky-white volcanic ash bed about 1.2 m thick above the base of the Gering Sandstone of the Arikaree Group (Miocene).	G. A. Izett-------	65
13.	Chimney Rock. South of Chimney Rock on the main butte in the SW 1/4 SW 1/4 sec. 17, T. 20 N., R. 52 W., Morrill County, Nebr.	Chalk-white volcanic ash bed about 0.8 m thick interbedded in the lowest part of the Gering Sandstone (of the Miocene Arikaree Group) about 0.3 m above the base of the Gering.	----do-----------	70G15
14.	Uinta County, Wyo., in SW 1/4 NE 1/4 SE 1/4 sec. 17, T. 16 N., R. 120 W.	Ash bed in Gooseberry(?) Member of Fowkes(?) Formation.	James Honey-------	None.

TABLE 6.—*Fission-track plateau annealing ages of natural glasses*

[Fission-track determinations prefixed by an N made by C. W. Naeser; all other
is one standard deviation about the

No.	Locality	Material		Furnace temp.[1] (°C)	Neutron flux ϕ (10^{15}n cm^{-2})	Spontaneous-track density[2] (ρ_s) (10^3 tracks cm^{-2})	
1	Macusani, Peru---	Macusanite		---	0.922	23.3	(723)
		(obsidian)	N	---	.922	19.6	(476)
			N	---	2.09	19.0	(213)
				200	2.09	20.4	(97)
			N	200	2.09	19.4	([illegible]45)
				250	2.09	12.8	(61)
			N	250	2.09	12.0	(152)
				300	2.09	9.89	(47)
			N	300	2.09	9.34	(118)
2	Cougar Mountain, Oreg.	Obsidian----		---	2.47	2.10	(20)
				225	2.72	2.95	(84)
3	Glass Buttes, Oreg.	---do------		---	2.47	1.42	(137)
				---	2.72	4.58	(196)
				225	2.47	2.2	(187)
4	West Queen Canyon, Nev.	---do-------		---	1.17	3.80	(129)
				220	1.78	2.90	(124)
5	Drews Ranch, Oreg.	---do-------		---	2.47	5.22	(273)
				225	2.47	4.36	(145)
6	Cherry County, Nebr.	Glass shards		---	1.16	24.9	(108)
				210	3.33	19.6	(117)
7	Middle Park, Colo.	---do------		---	1.18	22.2	(210)
				210	3.33	11.9	(38)
8	Middle Park, Colo.	---do-------		---	1.18	25.1	(411)
				210	3.33	19.9	(53)
9	Czechoslovakia---	Moldavite---		---	2.69	9.12	(130)
			N	---	2.69	9.57	(242)
				198	2.69	9.40	(134)
			N	198	2.69	8.8	(223)
			N	275	2.69	7.48	(189)
				350	2.69	5.26	(100)
			N	350	2.69	4.82	(122)

from the western United States, Peru, and Czechoslovakia

fission-track determinations by G. A. Izett. Precision of fission-track ages
mean. λ_f = 7.03 x 10^{-17} yr^{-1}]

No.	Induced-track density[2] (ρ_i) (m.y.)	Fission-track age (m.y.)	Other reported ages (m.y.)	Reference
1	296 (830)	4.3±0.2	4.3 ±1.5	K-Ar age reported by Barnes and others (1970, p. 1543).
	240 (1,893)	4.5±0.2		
	51.6 (721)	4.6±0.3		
	613 (411)	4.2±0.5		
	518 (755)	4.7±0.3		
	360 (242)	4.4±0.6		
	316 (460)	4.7±0.4		
	276 (309)	4.5±0.7		
	239 (349)	4.9±0.5		
2	122 (471)	2.5±0.6	4.42±0.34	K-Ar age reported by McKee and others (1976).
	151 (732)	3.2±0.4		
3	140 (386)	1.5±0.2	5.04±0.73	Do.
	170 (834)	4.4±0.3	1.5±0.2	Fission-track glass age.[3]
	66.8 (252)	4.9±0.5		
4	83.5 (643)	3.2±0.30	5.28±0.22	K-Ar age from table 3 (no. 8).
	63.3 (301)	5.1±0.31		
5	184 (1,084)	4.2±0.3	7.33±0.34	K-Ar age reported by McKee and others (1976).
	88.9 (443)	7.2±0.7		
6	250 (541)	6.9±0.8	10.3±0.6	Fission-track zircon age from table 4 (no. 7).
	361 (453)	10.9±1.1		
7	182 (699)	8.6±0.6	11.5±1.8	Fission-track zircon age from table 4 (no. 9).
	348 (323)	11.4±2.0		
8	169 (280)	9.4±0.7	13.5±2.2	Fission-track zircon ages from table 4 (no. 10).
	274 (421)	14.5±2.1	13.3±1.1	
9	99.8 (414)	14.7±1.4	15.1±0.7	K-Ar age reported by Gentner and others (1967).
	106 (327)	14.5±1.2		
	98.6 (412)	15.3±1.5		
	99.2 (306)	14.3±1.2		
	78.3 (241)	15.4±1.5		
	54.1 (395)	15.6±1.7		
	49.8 (307)	15.6±1.6		

TABLE 6.—*Fission-track plateau annealing ages of natural glasses*

No.	Locality	Material		Furnace temp.[1] (°C)	Neutron flux ϕ (10^{15}n cm^{-2})	Spontaneous-track density[2] (ρ_s) (10^3 tracks cm^{-2})	
10	Sioux County, Nebr.	Glass shards		---	2.47	20.0	(292)
			N	---	2.47	22.0	(185)
				149	2.47	21.9	(290)
			N	149	2.47	21.0	(177)
				204	2.47	20.5	(268)
				204	2.47	22.2	(187)
				225	2.47	21.1	(183)
				225	2.47	15.0	(126)
				250	2.47	15.4	(23)
11	Big Sand Spring Valley, Nev.	Apache tears		---	1.30	67.3	(320)
				---	2.69	50.2	(401)
			N	---	1.30	54.7	(691)
				200	2.09	55.5	(116)
			N	200	2.09	61.4	(776)
				250	2.09	38.3	(182)
				250	2.09	37.1	(469)
				300	2.09	28.2	(134)
			N	300	2.09	21.2	(268)
12	Chimney Rock, Nebr.	Glass shards		---	1.71	41.3	(107)
			N	---	1.71	36.2	(195)
				153	1.71	46.3	(120)
			N	153	1.71	41.2	(222)
				179	1.71	48.6	(126)
			N	179	1.71	43.2	(216)
				204	1.71	46.7	(121)
			N	204	1.71	38.6	(207)
				227	1.71	54.0	(140)
			N	227	1.71	36.3	(121)
				250	1.71	31.3	(61)
			N	250	1.71	22.4	(121)

[1]Samples were heated at the indicated temperature for one hour prior to
[2]Numbers in parentheses show total number of tracks counted in each de-
[3]Determination on a sample collected by Charles Vitaliano.

from the western United States, Peru, and Czechoslovakia—Continued

No.	Induced-track density[2] (ρ_i) (10^3 tracks cm^{-2})		Fission-track age (m.y.)	Other reported ages (m.y.)	References
10	313	(889)	9.4±0.7	15.1	K-Ar age reported by Evernden and others (1964, KA891).
	285	(861)	11.4±0.9		
	210	(846)	15.3±1.0		
	223	(685)	13.9±1.2		
	171	(1,455)	17.7±1.2		
	181	(570)	18.1±1.5		
	176	(505)	17.7±1.5		
	134	(418)	16.5±1.6		
	139	(266)	16.4±3.4		
11	390	(395)	13.4±1.0	26.4±3.0	K-Ar age reported by Eckren and others (1974, p. 605).
	679	(787)	11.9±0.7		
	308	(512)	13.8±0.8	24.3±0.3	K-Ar age from table 3 (no. 23).
	342	(258)	20.3±2.4		
	337	(560)	22.8±1.3		
	242	(302)	19.8±1.9		
	215	(354)	21.6±1.5		
	155	(238)	22.7±2.5		
	122	(201)	21.7±2.1		
12	362	(436)	11.7±1.2	30.2	K-Ar age reported by Evernden and others (1964, KA981).
	331	(991)	11.2±0.9		
	278	(351)	17.0±1.8		
	224	(715)	18.8±1.4		
	197	(424)	25.2±2.6		
	171	(569)	25.8±1.9		
	168	(415)	28.4±3.0		
	174	(572)	22.7±1.8		
	176	(597)	31.3±2.9		
	136	(466)	27.3±2.3		
	156	(247)	20.5±2.9		
	97.9	(329)	23.4±2.5		

analysis. Leaders (---) indicate samples that were not heated.
termination.

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