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UPLIFT ALONG THE SALT LAKE SEGMENT OF THE WASATCH FAULT FROM APATITE AND ZIRCON FISSION TRACK DATING IN THE LITTLE COTTONWOOD STOCK

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Abstract—Apatite from granite samples out of the Little Cottonwood stock of north-central Utah range in age from about 7 Ma at 1500 m elevation to about 11 Ma at 3500 m elevation and give an uplift rate of 0.68 mm yr^{-1} during this time period. Zircons from some of the same samples range in age from about 9 Ma at 1500 m elevation to 20 Ma at 3500 m, and probably represent an uplifted partial annealing zone. The uplift is associated with movement along the Wasatch fault which borders the stock on its western margin. The calculated uplift rates from the apatite ages in this study agree well with rates found by other workers along the central segments of the Wasatch fault using a variety of methods.

INTRODUCTION

UPLIFT rates, both long and short term, along the Wasatch fault of central Utah are critical in predicting the future behavior of the fault. Several studies have examined uplift along the fault using different methods, such as trenching (e.g. Lund and Schwartz, 1987; Machette and Lund, 1987; Nelson *et al.*, 1987; Schwartz and Coppersmith, 1984; Swan *et al.*, 1980), examination of fluid inclusions (Parry and Bruhn, 1986, 1987), and fission track dating of apatites (Naeser *et al.*, 1983; Evans *et al.*, 1985). These earlier studies, in particular the trenching studies along the fault, have shown that the Wasatch fault has a number of segments (Fig. 1), each of which ruptures somewhat independently of the others (Machette *et al.*, 1986, 1987). In this study, we examine the uplift history in the Salt Lake segment of the Wasatch fault. Samples were collected from the Little Cottonwood stock (Fig. 2) located near the southern end of the Salt Lake segment. A study by Naeser *et al.* (1983) using the same methods was farther to the north along the fault located in the Weber fault segment. Evans *et al.* (1985) used apatite fission track dating of samples from the Little Corriwood stock to determine the uplift history from the Salt Lake segment. Their study was independent of ours and we were unaware of their work until we had completed our project. The results from both studies agree very well and will be compared later in the paper.

The Little Cottonwood stock is a 28–31 Ma (biotite and hornblende K–Ar ages) intrusion of quartz monzonite (Crittenden *et al.*, 1973). Fluid inclusion studies by Parry and Bruhn (1986, 1987) suggest that the stock may have been emplaced up to 11 km below the surface. Since its emplacement, the stock appears to have had a relatively simple history of rapid initial cooling to near the present geothermal gradient, followed by subsequent uplift and erosion to its present elevation and exposure.

METHODS

Fission tracks in apatite and zircon begin to accumulate when the rate of track production exceeds the rate of track annealing. A mineral has reached its so-called "closure temperature" when track annealing becomes insignificant compared to track production. For apatite this closure temperature is fairly low, around 105°C for time periods of about 1 Ma (Naeser, 1979a), but may be higher if the cooling rate is more rapid. For zircon the closure temperature is higher, somewhere between 175°C and 300°C, perhaps near 210–225°C (Hurford, 1983; Zaun and Wagner, 1985). A range of temperatures exists between the closure temperature and some higher temperature where tracks accumulate, but where the annealing of tracks is still significant. This range of temperatures has been called the "zone of partial annealing" (Naeser, 1979b). A series of apatite and zircon ages from different elevations within an uplifted rock body can be used to provide a cooling and uplift history. For those parts of the pluton that were below the zone of partial annealing prior to initiation of uplift, the age–elevation information can provide the rate of uplift. Samples that were within the zone of partial annealing generally cannot be used to provide information on uplift rates, but can be of some use in determining the time of initiation of uplift.

We separated apatites and zircons from the samples using standard heavy liquid and magnetic

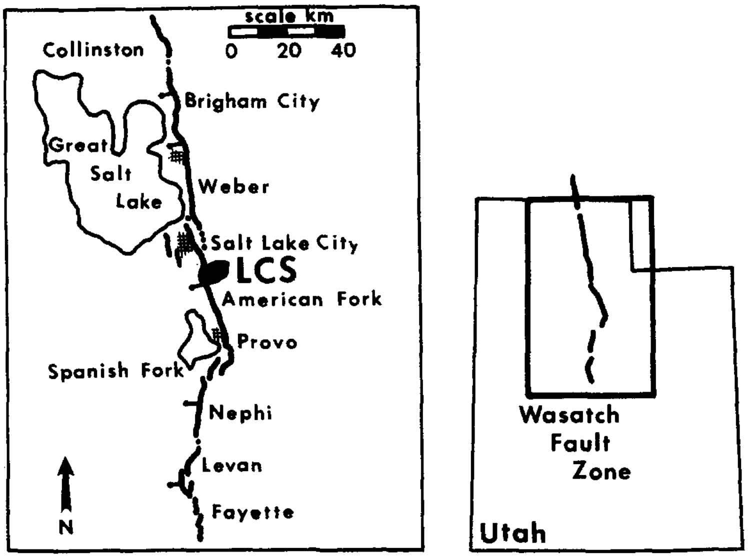

FIG. 1. Location of the Wasatch fault with ten named segments of the fault shown (modified from Lund and Schwartz, 1987). Little Cottonwood stock (LCS) is shown near the southern end of the Salt Lake segment.

separation techniques. The population method of fission track dating was used to date all of the apatite samples and the external detector method was used for the zircons. All apatites were etched in 7% HNO_3 for 45 s at 25°C. Zircons were etched in a eutectic melt of KOH–NaOH until all tracks were well etched, approximately 10–15 h at 235°C. The samples were irradiated, along with National Bureau of Standards (NBS) reference glass SRM-962, in the U.S. Geological Survey Triga reactor. The thermal neutron fluence for apatites was determined by comparing the fission track density in glass SRM-962 with the density in another sample of the same glass irradiated in the NBS RT-3 site with a copper foil detector (Carpenter and Reimer, 1974). In age calculations, the following constants were used: $\lambda_d = 1.55 \times 10^{-10}\,\mathrm{yr}^{-1}$; $\lambda_f = 7.03 \times 10^{-17}\,\mathrm{yr}^{-1}$; $U^{235}/U^{238} = 0.00725$. The values used here have given us an

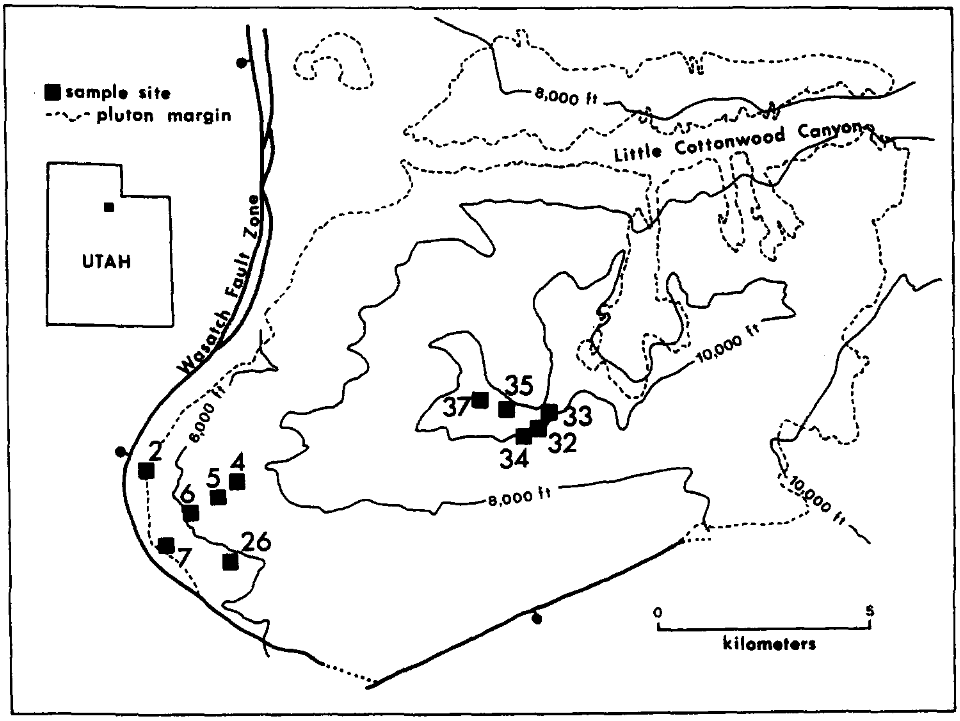

FIG. 2. Sample collection sites within the Little Cottonwood stock. The dashed line represents the exposed margin of the stock. The Wasatch fault is truncated at the southern margin of the stock by a southward dipping normal fault that connects the Salt Lake and American Fork segments of the Wasatch fault.

Table 1. Apatite fission track data

Elevation (m)	Sample No.	No. of grains	Fossil† density	Fossil tracks	Induced† density	Induced tracks	Neutron dose n cm^{-2} × 10^{14}	Dose counts	Age (Ma) ±(2 s)
1520	2	100	1.021	(98)	6.250	(600)	8.81	(4348)	8.6 ± 2.5
1520	2	100	0.771	(74)	6.375	(612)	8.81	(4348)	6.4 ± 2.0*
1600	7	100	0.552	(53)	4.083	(392)	8.81	(4348)	7.1 ± 2.4
1789	26	100	0.573	(55)	3.844	(369)	9.02	(3332)	7.9 ± 2.7
1875	6	100	0.594	(57)	4.135	(397)	9.34	(2053)	8.0 ± 2.1
2103	5	100	0.396	(38)	2.656	(255)	9.34	(2053)	8.3 ± 3.0
2243	4	100	0.844	(81)	5.760	(553)	8.81	(4348)	7.7 ± 1.6
2243	4	150/100	0.826	(119)	6.073	(583)	8.81	(4348)	7.2 ± 1.5*
3011	34	100	0.604	(58)	3.979	(382)	8.81	(4348)	8.0 ± 2.6
3133	32	100	0.854	(82)	4.750	(456)	8.81	(4348)	9.5 ± 2.6
3133	32	150	0.681	(98)	4.611	(664)	8.81	(4348)	7.8 ± 1.8*
3170	33	100	0.521	(50)	2.594	(249)	8.86	(3332)	10.6 ± 3.6
3271	35	100	0.990	(95)	5.021	(482)	8.81	(4348)	10.4 ± 2.4
3271	35	125	0.950	(114)	4.792	(575)	8.81	(4348)	10.4 ± 2.2*
3429	37	100	0.802	(77)	3.896	(374)	8.78	(3332)	10.8 ± 2.8

*Samples counted by Kowallis.
†Track densities are tr cm^{-2} × 10^4.

Table 2. Zircon fission track data

Elevation (m)	Sample No.	No. of grains	Fossil† density	Fossil tracks	Induced† density	Induced tracks	Mica detector tracks cm^{-2}	Mica counts	Age (Ma) ±(2 s)
1520	2	6	2.356	(1072)	6.870	(3126)	176,025	(3436)	9.3 ± 0.8
1875	6	7	3.011	(792)	7.510	(1975)	176,025	(3436)	10.9 ± 1.0
2243	4	4	2.941	(647)	7.155	(1574)	176,025	(3436)	11.2 ± 1.2
3133	32	4	5.982	(1322)	7.973	(1762)	176,025	(3436)	20.4 ± 1.6
3429	37	4	6.341	(1078)	8.947	(1521)	176,025	(3436)	19.3 ± 1.6

All samples counted by Kowallis.
†Track densities are tr cm^{-2} × 10^6.

accurate age for the Fish Canyon tuff and have been used by other workers for the same reason (Naeser *et al.*, 1981). Zircon ages were calculated using a zeta value of 310 ± 4, determined from several irradiations of SRM-962 glass along with zircons from the Fish Canyon tuff. The errors for the ages were determined using the method described by Galbraith (1984) for the population technique and by Green (1981) for the external detector method.

Table 1 contains the count data for apatites and Table 2 the data for zircons. The track counts for apatites are rather low because of low track densities. This is due to a combination of young age and low uranium concentrations in the grains. The low track densities prevented us from obtaining track length information from these samples.

RESULTS AND DISCUSSION

Apatite and zircon ages from lower elevations give, as expected, younger ages than those from higher

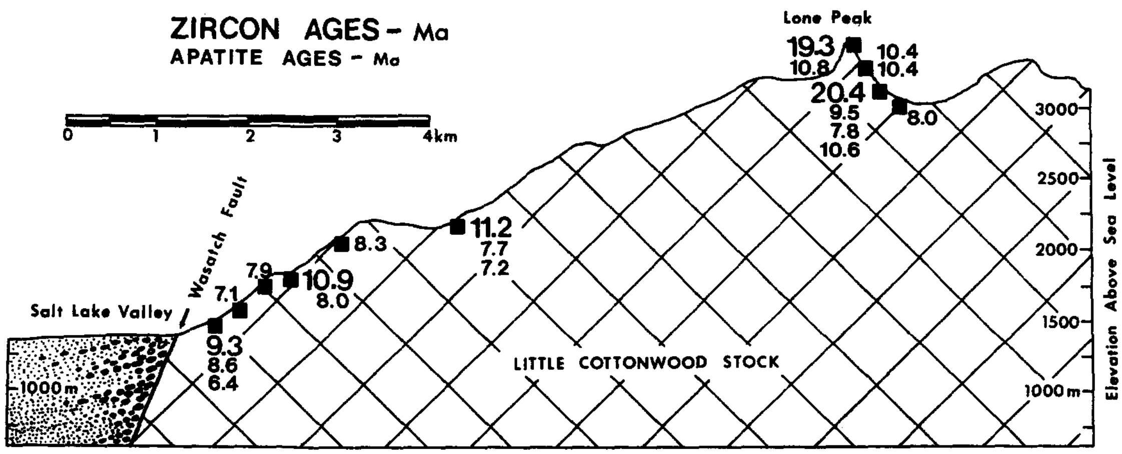

FIG. 3. Topographic profile of the Little Cottonwood stock area from southeast to northwest across the Wasatch fault Zircon fission track ages (large numbers) and apatite fission track ages (small numbers) are shown.

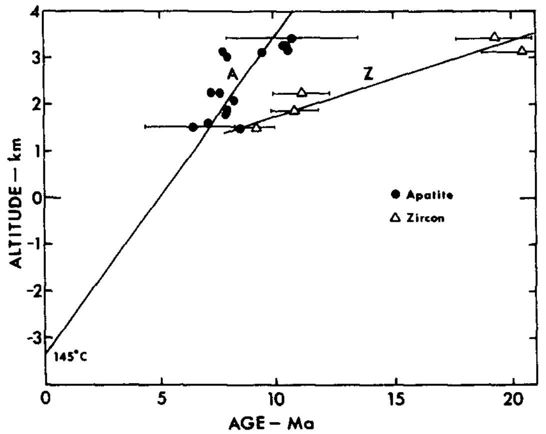

FIG. 4. Age altitude plot of apatite and zircon fission track ages from the Little Cottonwood stock. Least squares regression lines are drawn through the apatite ages (A) and zircon ages (Z). The error bars are two standard errors of the mean.

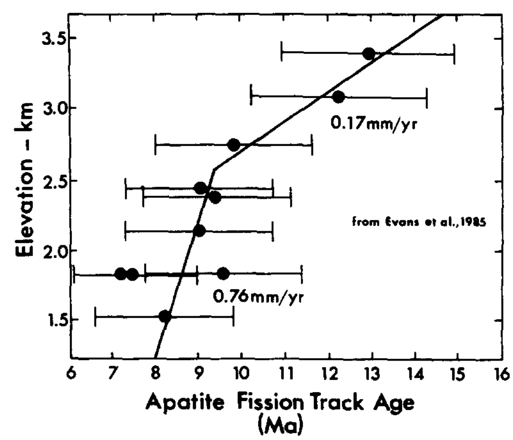

FIG. 5. Age vs elevation plot of apatite fission track ages determined by Evans *et al.* (1985). Uplift rates determined by them from the data are shown.

elevations (Fig. 3). Figure 4 is a plot of age vs elevation for the apatite and zircon ages obtained from the Little Cottonwood stock with least squares regression lines fit separately to the apatite and zircon data. Error bars are shown for a few typical samples. The apatite ages range from about 7 to 11 Ma and give an uplift rate of 0.68 mm yr^{-1} for the least-squares line. This is a very reasonable uplift rate along the Wasatch fault and it is consistent with rates that have been determined by other research conducted along the fault (Table 3). In addition, our data is compatible with the data obtained independently by Evans *et al.* (1985) using apatite fission track dating on samples from the Little Cottonwood stock (Fig. 5). They proposed an uplift rate of 0.76 mm yr^{-1} from about 10 Ma to the present, and a rate of 0.17 mm yr^{-1} prior to 10 Ma. Even though the errors on their ages do not justify the two uplift rates, the older rate of 0.17 mm yr^{-1} is very close to the slope of our zircon line at 0.16 mm yr^{-1}. However, this is not an older, slower period of uplift, but probably represents the uplifted partial annealing zone. We believe that all of our zircon ages are from an uplifted partial annealing zone for tracks. It is possible that the uppermost apatite ages reported by Evans *et al.* (1985) are also partial annealing ages. There is some suggestion from the three low elevation samples of an inflexion in the zircon data (Fig. 4). This may indicate that these samples are from near the bottom of the uplifted zircon partial annealing zone.

Naeser *et al.* (1983) report that Amoco found the geothermal gradient in the Salt Lake Valley to be approximately 30°C km^{-1}. This means that at a depth of approximately 3.5 km below the present exposed base of the stock exists the isotherm of zero age for the apatite grains, if a closure temperature of 105°C is used. If, on the other hand, we extrapolate the uplift rate line back to the zero age, as in Fig. 5, a depth of about 4.8 km (3.3 km below sea level) is projected as the depth of total annealing. This discrepancy may be related to either: (1) a higher effective closure temperature for fission tracks in apatite because the cooling rate was fairly rapid; or (2) simply the scatter in the apatite data.

In conclusion, fairly rapid uplift of the Little Cottonwood stock began about 11 Ma and has proceeded at a rate of about 0.6 to 0.7 mm yr^{-1}. This suggests a minimum of about 6.5–7.5 km of uplift for this time period. This amount is less than the 11 km of uplift proposed by Parry and Bruhn (1986, 1987).

Table 3. Uplift rate comparison along Wasatch fault

Source	Method	Fault segment	Uplift rate
Swan *et al.*, 1980	Radiocarbon	Weber	1.0–1.8 mm yr^{-1}
Naeser *et al.*, 1983	Fission track	Weber	0.8 mm yr^{-1} (last 5 Ma)
			0.4 mm yr^{-1} (last 10 Ma)
Machette and Lund, 1987	Radiocarbon	American Fork	1.0 mm yr^{-1}
Swan *et al.*, 1980	Radiocarbon	Provo	1.0 mm yr^{-1}
Schwartz and Coppersmith, 1984	Radiocarbon	Salt Lake	0.67–0.83 mm yr^{-1}
Parry and Bruhn, 1986	Fluid inclusions	Salt Lake	0.67 mm yr^{-1}
This study	Fission track	Salt Lake	0.68 mm yr^{-1} (last 10 Ma)

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