A tale of 10 plutons—Revisited: Age of granitic rocks in the White Mountains, California and Nevada

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ABSTRACT

^{40}Ar/^{39}Ar incremental heating analysis and conventional K-Ar age determinations on plutonic rocks of the White Mountains define two stages of magmatic emplacement: Late Cretaceous, between ca. 90 Ma and 75 Ma, and Middle–Late Jurassic, between ca. 180 and 140 Ma. The Jurassic stage can be divided into two substages, 180–165 Ma and 150–140 Ma. Thermal effects of the younger plutons on the older granitoids partially to completely reset ages, making it difficult to determine the age of emplacement and cooling of several of the plutons even by ^{40}Ar/^{39}Ar incremental heating analyses. New data together with published ages and regional geochronological synthesis of the Sierra Nevada batholith indicate that regions within the batholith have coherent periods or episodes of magmatic activity. In the White Mountains and Sierra Nevada directly to the west there was little or no activity in Early Jurassic and Early Cretaceous time; magmatism took place during relatively short intervals of 15 m.y. or less in the Middle and Late Jurassic and Late Cretaceous periods. The new K-Ar and ^{40}Ar/^{39}Ar analyses of granitoids from the White Mountains help, but do not completely clarify the complex history of emplacement, cooling, and reheating of the batholith.

INTRODUCTION

In his presidential address to the Geological Society of America in 1967, entitled “A tale of ten plutons,” Krauskopf (1968) chose the granitic rocks of the Inyo batholith in the White Mountains of California and Nevada to exemplify the complex and seemingly chaotic relationships of many natural phenomena that do not readily lend themselves to human attempts to impose order on nature. This provocative paper discussed 10 plutons that exhibit as many similarities or differences within themselves as they do with each other, and whose relationships to the rocks they intrude are variable and ambiguous. Their mode of emplacement can be interpreted in many ways; their relationship to regional tectonic features can likewise be seen in different lights. Even one of the most fundamental features of the 10 plutons, their relative ages, is difficult to ascertain except in a few cases where crosscutting relationships are clear. Similar rock types have widely different ages, and dissimilar bodies sometimes prove to be the same age.

At the time of Krauskopf’s paper very few radiometric ages were available to aid in determining the chronology of the Inyo batholith in the White Mountains. At the time he asked, “Suppose, for example, that we had radiometric dates for all the granites, as we surely will have in a very few years; would this information solve the problem [of their chronology]?” The problem was, in fact, compounded by the first group of radiometric dates (Crowder et al., 1973). Of the 10 plutons discussed by Krauskopf, only 1 yielded K-Ar ages that were unequivocal. One was dated using a single biotite sample, thus there was no cross check on the age, and the other plutons yielded discordant mineral pair ages, different ages on different samples presumed to be from the same granitic body, or both. The 25 age determinations in Crowder et al. (1973), combined with K-Ar ages from the southern part of the White Mountains (McKee and Nash, 1967) and nearby granitoids from the Sierra Nevada, Benton Range, and northernmost White Mountains (Evernden and Kistler, 1970), define two broad periods of granitic emplacement in which most of the 10 White Mountain plutons fit: Jurassic (140–190 Ma) and Late Cretaceous (70–85 Ma). The actual emplacement age of most of the 10 plutons was still not known. It was clear that the younger intrusive events were accompanied by enough regional heat to alter the K-Ar ages of the older rocks by different amounts. The argon loss and subsequent reduction in age was not uniform throughout the plutons and it was different for biotite and hornblende, the two minerals used for dating.

The purpose of this study is to demonstrate whether the two-stage model (190–140 Ma and 85–70 Ma) can be supported using new data derived from ^{40}Ar/^{39}Ar geochronology. ^{40}Ar/^{39}Ar incremental heating experiments offer a means of judging the argon retention history of a mineral and a way to evaluate a suite of ages. Analysis of the age spectra using the criteria of Lanphere and Dalrymple (1978) can help distinguish between samples that have undergone some amount of argon redistribution or loss and those that are essentially undisturbed and give a reliable cooling age. A disturbed or discordant age spectrum produced during an incremental heating experiment is good evidence of partial argon loss during the geologic history of the pluton. Ideally, the cooling age of the body should define an age plateau. If subsequent heating during the geologic history of the pluton is slight, the plateau will include most or all the argon released at the various temperature steps. If the temperature following emplacement is great enough to release argon from the pluton, a poorly defined plateau, or no plateau at all, may result. If the release is complete the age spectrum would define a new plateau with no hint of the original crystallization age. For this study, 13 ^{40}Ar/^{39}Ar incremental heating experiments were completed on biotite or hornblende from 11 of the White Mountain plutons. In addition, K-Ar ages were obtained from the mineral separates.

GEOLOGIC SETTING

Granitic rocks underlie ≈1300 km^2 of the White Mountains of California and Nevada (Figs. 1 and 2). About half of the rocks that crop out in these mountains are granitoids that are well exposed because of the great relief (>2400 m) and arid climate. These rocks, referred to as the Inyo batholith by Anderson (1937), are considered part of the much larger Sierra Nevada batholith with which they are presumably connected beneath Owens Valley (Fig. 1).

In the northern part of the White Mountains 13 plutons have been mapped (Krauskopf, 1971;

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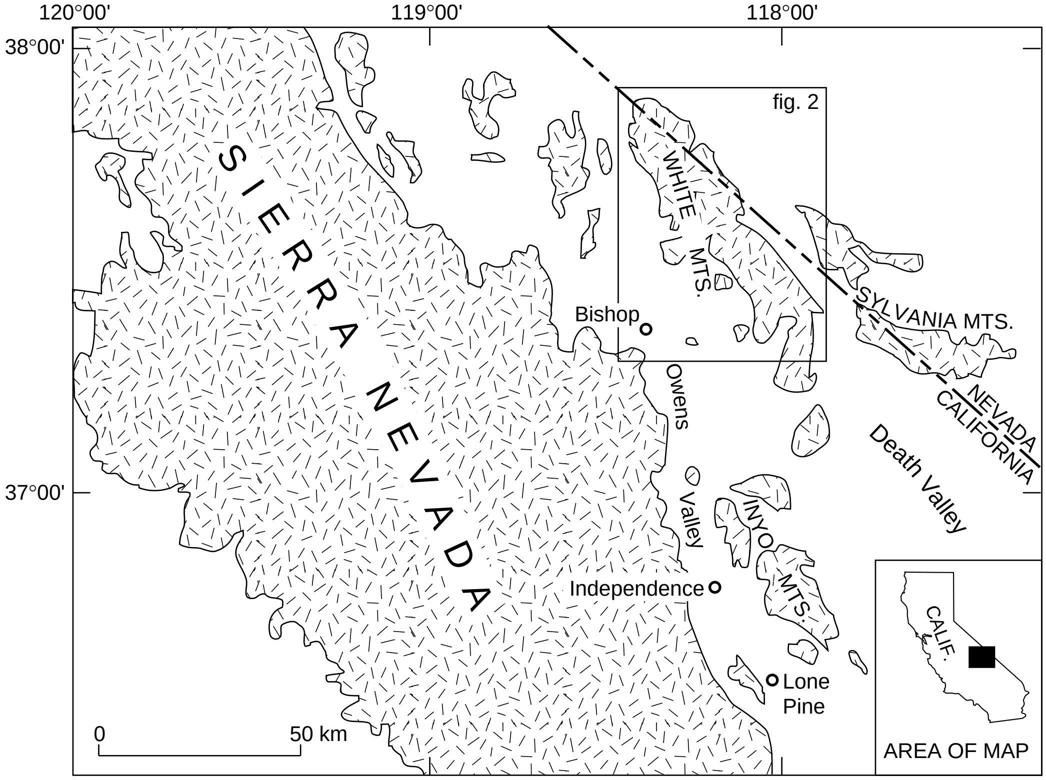

Figure 1. Index map showing part of the central Sierra Nevada batholith. Granitic rocks of the White Mountains discussed in this study are shown in Figure 2. Granitic rocks are patterned.

Crowder and Sheridan, 1972; Crowder et al., 1972; Robinson and Crowder, 1972; McKee et al., 1983) and 10 of them were the topic of the 1968 Krauskopf paper. As Krauskopf pointed out, however, the exact number of plutons is unclear. Some plutons may be isolated bodies separated by weakly metamorphosed stratified rock; these are the Birch Creek, Redding Canyon, Marble Canyon, and the Sage Hen Flat plutons (Fig. 2). These plutons have different compositions and textures from the granite bodies closest to them and are easily counted as individual bodies. Other granitoids such as the Mount Barcroft granodiorite (Fig. 2) have two parts separated by compositionally different granitic rock of the McAfee pluton. The two separated parts of the Mount Barcroft granodiorite generally look alike but yield different, and probably reset, K-Ar ages (Crowder et al., 1973). The ages may be partially reset, representing different amounts of argon loss from a single older granitic body; they may be partially reset, but belong to two different older bodies; or possibly one retains an original cooling age and the other is reset. They were counted as two plutons by Krauskopf (1968). To varying degrees the other six plutons discussed in Krauskopf (1968) have features that allow them to be mapped or classified as separate plutons, although with reservations. For example, the Marble Canyon and the Cabin Creek plutons (Fig. 2) show more variation within themselves than might be expected between different bodies (Krauskopf, 1968). Other larger granitic bodies, such as the granite of Pellisier Flats (Fig. 2), have several quite different phases that, if not within the mapped boundaries of the pluton, might be considered two or more plutons.

GEOCHRONOLOGY

K-Ar and ^{40}Ar/^{39}Ar Age Determinations

We analyzed 13 samples of biotite or hornblende by ^{40}Ar/^{39}Ar incremental heating techniques (Table 1). The samples were irradiated for 50 hr in the U.S. Geological Survey TRIGA reactor in Denver, Colorado, at a power of 1 Mw. Irradiation flux was monitored by use of the SB-3 biotite standard (162.9 Ma). Corrections used in the U.S. Geological Survey Menlo Park laboratory for Ca- and K-derived isotopes were described by Dalrymple and Lanphere (1971, 1974). A 60° sector, 15.2-cm-radius, Nier-type mass spectrometer was used for argon analysis. The number of heating steps was determined by the amount of argon released at low temperatures and ranged from 4 to 12. Most samples exhibited fairly uniform release at temperatures between ≈700 and 950 °C, and seven or eight heating steps were used.

Results

Conventional K-Ar and recombined ^{40}Ar/^{39}Ar total fusion ages are the same for each of the 13 samples analyzed (Table 2). Eight of these samples produce well-defined age plateaus from the incremental heating analysis and corresponding isochron plots that agree with the K-Ar and total fusion ages. Five of the incremental heating samples have age spectra that do not define a plateau and show evidence of significant argon loss or other disturbance.

Boundary Peak Pluton. The youngest pluton in the White Mountains is the Boundary Peak pluton at the north end of the range (Fig. 2). This granitic body is almost completely surrounded by the significantly older Pellisier Flats pluton, except at the south end, where it contacts the Cabin Creek pluton or is separated from the slightly older Marble Creek pluton by a small amount of Late Proterozoic metasedimentary rock. Biotite from the Boundary Peak pluton (1 *in* Fig. 2), dated by K-Ar and ^{40}Ar/^{36}Ar incremental heating techniques, yields concordant ages of ca. 73 Ma (Tables 1, 2, and 3). A published age (Crowder et al., 1973), recalculated

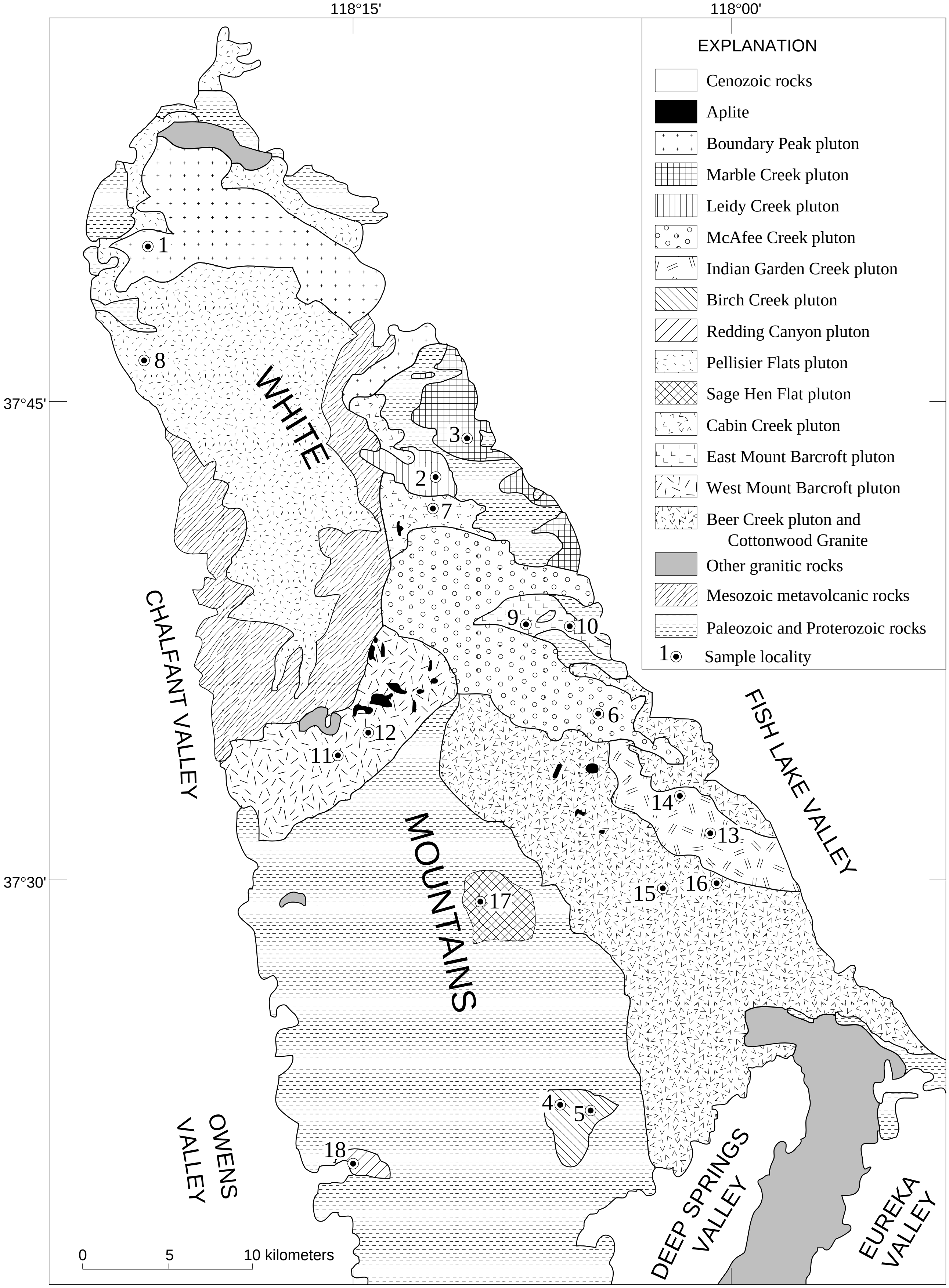

Figure 2. Map showing plutons of the White Mountains, showing sample locations. Numbers refer to text and tables. Geology modified from Bateman (1992) and McKee and Nelson (1967).

TABLE 1. RESULTS OF ^{40}Ar/^{39}Ar INCREMENTAL HEATING ANALYSES OF GRANITIC PLUTONS IN THE WHITE MOUNTAINS, CALIFORNIA AND NEVADA

Number (Fig. 2)	Temp. (°C)	^{40}Ar/^{39}Ar	^{37}Ar/^{39}Ar	^{36}Ar/^{39}Ar	^{40}Ar (moles)	^{40}Ar rad (%)	K/Ca	^{39}Ar (%)	Age ± 1σ (Ma)
1		Boundary Peak pluton			Biotite			J = 0.007480†	
	525	5.253	0.06895	0.012251	5.892E-13	31.1	7.11	2.1	21.91 ± 2.23
	625	6.789	0.015358	0.007598	1.090E-12	66.9	31.9	1.4	60.26 ± 3.28
	725	6.060	0.02318	0.002153	6.858E-12	89.4	21.1	7.3	71.71 ± 0.66
	800	5.750	0.02008	0.001081	1.318E-11	94.4	24.4	14.0	71.79 ± 0.38
	875	5.730	0.011578	0.000592	1.246E-11	96.9	42.3	13.0	73.40 ± 0.41
	950	5.834	0.02543	0.001075	7.959E-12	94.5	19.3	8.4	72.90 ± 0.58
	1025	5.801	0.013595	0.000515	1.549E-11	97.3	36.0	15.9	74.61 ± 0.35
	1100	5.671	0.014772	0.000555	2.141E-11	97.0	33.2	22.5	72.77 ± 0.29
	1400	5.698	0.04124	0.000708	1.465E-11	96.3	11.9	15.4	72.57 ± 0.36
		Total gas age = 71.69 ± 0.72							Plateau age = 72.95 ± 0.73
2		Leidy Creek pluton			Biotite			J = 0.008569†	
	500	7.916	0.02819	0.011658	1.341E-11	56.4	17.4	12.5	67.79 ± 0.46
	550	5.326	0.010939	0.000549	2.906E-11	96.9	44.8	23.4	78.05 ± 0.27
	600	5.355	0.02644	0.000670	1.121E-11	96.2	18.5	9.0	77.97 ± 0.47
	700	5.433	0.03758	0.000913	1.922E-11	95.0	13.0	15.5	78.07 ± 0.33
	800	5.596	0.02328	0.000969	2.139E-11	94.8	21.0	16.8	80.22 ± 0.32
	900	5.426	0.014788	0.000655	1.599E-11	96.4	33.1	12.7	79.07 ± 0.37
	1000	5.444	0.11955	0.000861	1.036E-11	95.4	4.10	8.3	78.56 ± 0.50
	1200	5.512	0.2707	0.000581	2.343E-12	97.2	1.81	1.8	80.97 ± 2.04
		Total gas age = 77.36 ± 0.40							Plateau age = 78.69 ± 0.41
3		Marble Creek pluton			Biotite			J = 0.007145†	
	475	9.868	0.2485	0.03286	1.139E-14	1.8	1.97	0.4	2.23 ± 11.79
	525	7.858	0.13086	0.012699	7.032E-13	52.3	3.74	1.1	52.22 ± 4.41
	600	7.587	0.09213	0.008284	1.829E-12	67.8	5.32	2.4	65.08 ± 2.12
	700	6.636	0.004470	0.001833	8.462E-12	91.8	109.6	9.3	76.83 ± 0.58
	800	6.384	0.016789	0.000872	2.143E-11	95.9	29.2	23.4	77.23 ± 0.31
	875	6.404	0.018972	0.000999	6.877E-12	95.3	25.8	7.5	77.01 ± 0.70
	975	6.434	0.02634	0.001115	1.053E-11	94.8	18.6	11.5	76.98 ± 0.49
	1075	6.334	0.016715	0.000684	2.135E-11	96.7	29.3	23.3	77.31 ± 0.31
	1400	6.377	0.03380	0.000791	1.927E-11	96.3	14.5	21.0	77.47 ± 0.33
		Total gas age = 76.32 ± 0.77							Plateau age = 77.24 ± 0.77
6		McAffe Creek pluton			Biotite			J = 0.008186†	
	550	8.374	0.02245	0.008673	1.096E-11	69.4	21.8	12.9	83.80 ± 0.41
	600	5.971	0.015609	0.000580	1.945E-11	97.1	31.4	23.0	83.62 ± 0.35
	650	6.186	0.04280	0.001336	7.707E-12	93.6	11.4	9.1	83.53 ± 0.68
	700	6.060	0.04360	0.000895	1.184E-11	95.6	11.2	14.0	83.59 ± 0.48
	750	6.094	0.02787	0.000988	7.725E-12	95.2	17.6	9.1	83.67 ± 0.68
	800	6.093	0.004643	0.000945	5.810E-12	95.3	105.5	6.8	83.81 ± 0.88
	900	6.128	0.02628	0.001186	8.809E-12	94.2	18.6	10.4	83.32 ± 0.61
	1000	6.172	0.02772	0.001260	9.727E-12	93.9	17.7	11.5	83.63 ± 0.56
	1200	6.164	0.2501	0.001389	2.658E-12	93.6	1.96	3.2	83.25 ± 1.86
		Total gas age = 83.61 ± 0.45							Plateau age = 83.64 ± 0.45
7		Cabin Creek pluton			Biotite			J = 0.008908†	
	500	9.305	0.02589	0.014198	1.197E-11	54.9	18.9	9.0	80.25 ± 0.58
	550	5.790	0.016075	0.001211	2.889E-11	93.8	30.5	20.5	85.20 ± 0.31
	600	5.602	0.02788	0.000752	1.366E-11	96.0	17.6	9.8	84.40 ± 0.44
	700	5.616	0.02898	0.000693	1.185E-11	96.3	16.9	8.4	84.88 ± 0.49
	800	5.671	0.02656	0.000867	2.024E-11	95.4	18.5	14.4	84.94 ± 0.35
	900	5.612	0.02825	0.000725	2.040E-11	96.1	17.3	14.6	84.67 ± 0.35
	1000	5.629	0.02508	0.000997	2.903E-11	94.7	19.5	21.0	83.70 ± 0.30
	1200	5.686	0.3399	0.000994	3.045E-12	95.2	1.44	2.2	84.99 ± 1.66
	1400	8.786	0.9800	0.02161	1.978E-14	28.2	0.50	0.0	39.35 ± 118.33
		Total gas age = 84.20 ± 0.44							Plateau age = 84.60 ± 0.44

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using the 1977 decay constants, also is ca. 73 Ma. The plateau from the Boundary Peak biotite (Fig. 3, Table 2) contains >96% of the ^{39}Ar released from the sample, with only very minor loss of ^{40}Ar at the low-temperature steps. Some minor disturbance of the plateau is reflected in the 1025 °C step that is significantly older (at a 95% confidence level) than other plateau increments. Excluding the 1025 °C step from the plateau and isochron calculations yields similar ages and a mean standard weighted deviates value (MSWD) of <2, indicating that most of the disturbance is related to the 1025 °C step. We conclude that the elevated age for the 1025 °C step reflects only minor disturbance of the sample, and because inclusion of that step has a negligible effect on the plateau age, our best estimate of the age of this pluton is the plateau age of 73.0 ± 0.7 Ma. The K-Ar age of 72.9 ± 2.5 Ma is concordant with all the other ages derived from the ^{40}Ar/^{39}Ar values, but has about three times the analytical uncertainty.

Leidy Creek Pluton. The Leidy Creek pluton is exposed a few kilometers south of the Boundary Peak pluton and as little as 400 m west of the Marble Creek pluton in the northeastern part of the White Mountains (Fig. 2). It is a small body that has sharp intrusive contacts with Late Proterozoic metasedimentary rocks or with the Cabin Creek pluton, which is more than twice as old. The Leidy Creek granitoid resembles some phases of the nearby Marble Creek pluton and is the same age. Biotite from the Leidy Creek pluton

TABLE 1. *(Continued)*

Number (Fig. 2)	Temp. (°C)	^{40}Ar/^{39}Ar	^{37}Ar/^{39}Ar	^{36}Ar/^{39}Ar	^{40}Ar (moles)	^{40}Ar rad (%)	K/Ca	^{39}Ar (%)	Age ± 1σ (Ma)
7		Cabin Creek pluton			Hornblende		J = 0.0115§		
	700	27.82	1.1210	0.009633	1.871E-12	90.1	0.437	1.6	457.0 ± 13.21
	765	5.256	1.5301	0.004128	3.098E-13	78.9	0.320	1.6	84.16 ± 16.14
	840	5.698	2.213	0.003314	7.576E-13	85.7	0.221	3.3	98.75 ± 7.72
	900	6.800	5.387	0.002851	8.735E-12	93.8	0.091	29.0	128.10 ± 0.95
	950	7.562	5.613	0.002253	1.438E-11	97.0	0.087	41.6	146.58 ± 0.74
	975	7.365	6.732	0.002359	2.978E-12	97.7	0.072	8.8	144.02 ± 2.86
	1000	7.471	6.498	0.001843	4.768E-12	99.5	0.075	13.6	148.61 ± 1.87
	1100	7.571	7.207	0.004076	8.737E-14	91.5	0.068	0.3	138.97 ± 93.12
	1400	7.149	10.863	0.003069	1.188E-13	99.3	0.045	0.4	142.52 ± 70.15
		Total gas age = 144.11 ± 1.04					Plateau age = 146.70 ± 0.97		
8		Pellisier Flats pluton			Hornblende		J = 0.0113§		
	700	7.363	0.3523	0.006028	6.708E-13	76.1	1.39	2.1	110.72 ± 9.78
	765	4.806	0.9774	0.000663	3.639E-13	97.4	0.501	1.4	93.00 ± 15.20
	850	4.545	3.488	0.002051	3.386E-12	92.6	0.140	14.0	83.97 ± 1.51
	900	4.732	4.449	0.002138	6.755E-12	93.9	0.110	26.4	88.67 ± 0.83
	950	5.051	5.549	0.002351	1.250E-11	94.8	0.088	45.3	95.40 ± 0.55
	975	4.782	6.178	0.002672	2.505E-12	93.6	0.079	9.7	89.34 ± 2.14
	1050	4.482	6.857	0.002286	1.960E-13	96.9	0.071	0.8	86.80 ± 26.40
	1400	5.303	10.056	0.003173	8.380E-14	97.2	0.048	0.3	102.83 ± 72.81
		Total gas age = 91.68 ± 0.75					No plateau		
9		East Mount Barcroft pluton			Biotite		J = 0.010422†		
	500	7.807	1.3371	0.018437	4.214E-13	31.5	0.366	0.7	45.64 ± 6.60
	550	7.180	0.2775	0.009030	3.119E-12	63.0	1.77	2.8	83.15 ± 1.65
	600	5.555	0.06822	0.002600	1.342E-11	86.1	7.18	11.6	87.76 ± 0.49
	625	5.035	0.09326	0.000807	1.576E-11	95.2	5.25	13.6	87.98 ± 0.43
	725	4.986	0.017288	0.000345	1.082E-11	97.8	28.3	9.2	89.43 ± 0.57
	800	5.141	0.13019	0.000791	1.013E-11	95.5	3.76	8.5	90.02 ± 0.60
	900	4.928	0.09839	0.000479	2.803E-11	97.1	4.98	24.2	87.80 ± 0.33
	1100	4.905	0.09779	0.000490	3.368E-11	97.0	5.01	29.2	87.34 ± 0.31
	1400	5.203	0.5345	0.002123	3.322E-13	88.6	0.916	0.3	84.67 ± 15.35
		Total gas age = 87.59 ± 0.46					Plateau age = 88.01 ± 0.46		
10		East Mount Barcroft pluton			Biotite		J = 0.009133§		
	500	9.065	0.03546	0.011345	1.150E-11	63.0	13.8	8.8	91.70 ± 0.63
	550	6.857	0.03638	0.001461	3.623E-11	93.7	13.5	24.6	102.85 ± 0.35
	600	6.796	0.03528	0.000848	1.728E-11	96.3	13.9	11.5	104.71 ± 0.46
	700	6.700	0.03559	0.000973	1.162E-11	95.7	13.8	7.9	102.64 ± 0.60
	800	6.462	0.05401	0.001391	1.297E-11	93.6	9.07	9.3	97.02 ± 0.52
	900	6.383	0.03498	0.001134	1.807E-11	94.7	14.0	13.0	96.96 ± 0.42
	1000	6.748	0.05047	0.001181	3.118E-11	94.8	9.71	21.2	102.46 ± 0.35
	1400	7.452	0.3750	0.001554	5.941E-12	94.2	1.31	3.7	112.09 ± 1.15
		Total gas age = 101.02 ± 0.52					No plateau		
12		West Mount Barcroft pluton			Biotite		J = 0.010138§		
	550	8.601	0.10795	0.007041	1.413E-11	75.8	4.54	7.7	115.48 ± 0.65
	575	7.404	0.16175	0.002517	1.607E-11	90.0	3.03	8.5	117.95 ± 0.58
	675	7.017	0.07080	0.000942	4.086E-11	96.0	6.92	21.5	119.17 ± 0.39
	750	7.083	0.10750	0.000749	2.245E-11	96.9	4.56	11.6	121.32 ± 0.48
	850	6.643	0.11823	0.000977	3.153E-11	95.7	4.14	17.6	112.64 ± 0.40
	950	6.954	0.14827	0.000926	3.352E-11	96.1	3.30	17.8	118.28 ± 0.41
	1100	7.439	0.14588	0.000879	3.085E-11	96.5	3.36	15.2	126.81 ± 0.45
	1400	12.884	17.610	0.02292	2.671E-13	58.2	0.027	0.1	133.74 ± 29.83
		Total gas age = 118.91 ± 0.60					No plateau		

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(2 *in* Fig. 2), dated by K-Ar and ^{40}Ar/^{39}Ar techniques, yields concordant ages of ca. 77.4 Ma (Tables 1, 2, and 3). A published age (Crowder et al., 1973) recalculated using the 1977 decay constants is the same within analytical uncertainty. The age spectrum for this sample is similar to the Boundary Peak spectrum (Fig. 3). Both spectra show evidence of minor ^{40}Ar loss at the low temperature step(s), followed by a concordant plateau over the remainder of the ^{39}Ar release, but having a slightly older discordant step between ≈50% and 70% of the ^{39}Ar release. As with the results from the Boundary Peak biotite, exclusion of the discordant step in the plateau and isochron calculations yields similar ages as well as MSWD values of ≈1.5 and an initial ^{40}Ar/^{39}Ar ratio not significantly different from 295.5. Because the discordant step appears to reflect only minor disturbance and has a negligible effect on the age, we consider the plateau age 78.7 ± 0.4 Ma to be the best estimate of the age of the Leidy Creek pluton.

Marble Creek Pluton. The Marble Creek pluton is exposed along the east edge of the White Mountains ≈1.5 km south of the southern edge of the Boundary Peak pluton (Fig. 2). Metasedimentary rocks of the Late Proterozoic Wyman Formation separate these granitic bodies and also separate the Leidy Creek pluton from the Marble Creek body. Granitic rocks in the Marble Creek pluton are varied and include coarsely porphyritic to fine-grained aplitic types that have pronounced similarities to the Leidy Creek granitoid. This similarity led Crowder et al. (1973) to speculate that they are the same age and to imply that they might be parts of the same larger pluton. Biotite from the Marble Creek pluton (3 *in* Fig. 2), dated by K-Ar and ^{40}Ar/^{39}Ar techniques, yields concordant ages of ca. 77.2 Ma (Tables 1, 2, and 3). Three biotite dates published by Crowder et al.

TABLE 1. *(Continued)*

Number (Fig. 2)	Temp. (°C)	^{40}Ar/^{39}Ar	^{37}Ar/^{39}Ar	^{36}Ar/^{39}Ar	^{40}Ar (moles)	^{40}Ar rad (%)	K/Ca	^{39}Ar (%)	Age ± 1σ (Ma)
13		Indian Garden Creek pluton			Biotite			J = 0.010722[§]	
	475	17.573	0.6452	0.04470	2.515E-13	25.1	0.759	0.2	83.32 ± 19.98
	500	10.999	0.2796	0.02477	4.868E-13	33.6	1.75	0.4	70.06 ± 8.71
	535	8.517	0.3068	0.012730	2.294E-12	56.0	1.60	1.4	90.02 ± 2.40
	575	7.173	0.06273	0.005086	1.000E-11	79.0	7.81	5.2	106.39 ± 0.75
	600	6.462	0.12474	0.002510	1.186E-11	88.5	3.93	6.2	107.41 ± 0.64
	625	6.244	0.04631	0.001403	1.885E-11	93.3	10.6	9.6	109.28 ± 0.48
	650	6.085	0.04243	0.000764	2.070E-11	96.2	11.5	10.5	109.82 ± 0.46
	675	6.050	0.012166	0.000529	1.816E-11	97.3	40.3	9.2	110.40 ± 0.49
	700	6.096	0.017396	0.000472	1.285E-11	97.6	28.2	6.4	111.54 ± 0.61
	750	6.105	0.14930	0.000839	1.033E-11	96.0	3.28	5.2	109.94 ± 0.72
	850	5.994	0.12556	0.001106	2.039E-11	94.6	3.90	10.7	106.44 ± 0.45
	950	5.891	0.05506	0.000713	3.494E-11	96.3	8.90	18.3	106.57 ± 0.37
	1100	6.137	0.13129	0.001116	3.002E-11	94.7	3.73	15.4	109.00 ± 0.40
	1400	6.334	0.4558	0.002219	2.361E-12	90.1	1.07	1.2	107.15 ± 2.74
	Total gas age = 108.01 ± 0.55							No plateau	
15		Beer Creek pluton			Hornblende			J = 0.011044[§]	
	700	20.27	3.070	0.02558	1.007E-12	63.9	0.159	1.8	241.51 ± 13.86
	775	10.087	5.518	0.004256	1.776E-11	91.8	0.088	44.6	176.26 ± 0.79
	825	9.797	5.492	0.003598	1.909E-11	93.5	0.089	48.5	174.49 ± 0.75
	1400	9.832	6.887	0.005153	1.927E-12	90.0	0.071	5.1	168.92 ± 5.17
	Total gas age = 176.23 ± 1.05							Plateau age = 175.25 ± 0.99	
18		Redding Canyon pluton			Biotite			J = 0.009550[†]	
	525	7.211	0.06559	0.010937	3.330E-12	55.2	7.47	2.6	67.29 ± 1.24
	625	6.208	0.05706	0.006400	1.958E-12	69.5	8.59	1.4	72.88 ± 2.21
	725	6.249	0.02954	0.002591	2.135E-11	87.7	16.6	12.0	92.04 ± 0.39
	800	6.118	0.02394	0.001137	2.637E-11	94.5	20.5	14.0	96.92 ± 0.36
	875	6.063	0.05093	0.001489	1.648E-11	92.7	9.62	9.0	94.35 ± 0.44
	950	5.980	0.08979	0.001989	1.553E-11	90.2	5.46	8.9	90.62 ± 0.44
	1025	5.831	0.04207	0.001575	2.788E-11	92.0	11.6	16.0	90.13 ± 0.33
	1100	5.947	0.12791	0.001172	4.216E-11	94.3	3.83	23.1	94.09 ± 0.31
	1400	6.276	0.4648	0.001017	2.547E-11	95.7	1.05	13.0	100.66 ± 0.37
	Total gas age = 93.20 ± 0.48							No plateau	

Notes: Argon isotopic ratios reported here have been corrected for procedural blanks, mass discrimination, and radioactive decay. Apparent ages calculated from these ratios are also corrected for atmospheric contamination and nucleogenic interference, using the reactor corrections listed above. J values are calculated relative to an age of 162.9 Ma for the SB-3 biotite standard used as the neutron fluence monitor for all samples. Plateau ages are inverse variance weighted means; uncertainty in the plateau ages is reported as the standard deviation about the weighted mean.

[†] Reactor corrections: $(^{36}\text{Ar}/^{37}\text{Ar})_{\text{Ca}}$ = 0.000269; $(^{39}\text{Ar}/^{37}\text{Ar})_{\text{Ca}}$ = 0.00067; $(^{40}\text{Ar}/^{39}\text{Ar})_{\text{K}}$ = 0.0051.

[§] Reactor corrections: $(^{36}\text{Ar}/^{37}\text{Ar})_{\text{Ca}}$ = 0.000269; $(^{39}\text{Ar}/^{37}\text{Ar})_{\text{Ca}}$ = 0.00067; $(^{40}\text{Ar}/^{39}\text{Ar})_{\text{K}}$ = 0.0091.

TABLE 2. SUMMARY OF RADIOMETRIC AGES FROM THE WHITE MOUNTAINS OF CALIFORNIA AND NEVADA

Pluton	Krauskopf no. (1968)	Mineral dated	^{40}Ar/^{39}Ar total fusion	^{40}Ar/^{39}Ar plateau	^{40}Ar/^{36}Ar vs. ^{39}Ar/^{36}Ar isochron	^{36}Ar/^{40}Ar vs. ^{39}Ar/^{40}Ar correlation	K-Ar	K-Ar; Pb/U previously published	Estimated emplacement age (Ma)
Boundary Peak	N/A	Biotite	71.7 ± 0.7	72.9 ± 0.7	73.1 ± 0.9	73.6 ± 1.0	72.9 ± 2.5	73.7 ± 2.2*	72.9
Leidy Creek	7	Biotite	77.4 ± 0.4	78.7 ± 0.4	75.2 ± 1.6	75.1 ± 1.5	N/A	75.6 ± 2.2*	78.7
Marble Creek	5	Biotite	76.3 ± 0.8	77.2 ± 0.8	77.7 ± 0.8	77.7 ± 0.8	78.7 ± 2.5	79.5 ± 2.2*	77.2
Birch Creek	N/A	Biotite	N/A	N/A	N/A	N/A	N/A	79.2 ± 2.4[†] 82.0 ± 2.4[†]	81.0
McAfee Creek	6	Biotite	83.6 ± 0.5	83.6 ± 0.5	83.6 ± 0.4	83.6 ± 0.4	85.7 ± 2.7	85.4 ± 2.6*	83.6
Cabin Creek	4	Biotite	84.2 ± 0.4	84.6 ± 0.4	83.5 ± 1.4	83.4 ± 1.3	87.2 ± 2.7	88.4 ± 2.7*	146.7
		Hornblende	144.1 ± 1.0	146.7 ± 1.0	143.5 ± 8.9	146.3 ± 2.3	151.4 ± 4.4	152.8 ± 5.1*	
Pellisier Flats	9	Hornblende	91.7 ± 0.7	N.P.	N.P.	N.P.	88.0 ± 2.7	92.0 ± 3.0* 89.6 (Pb-U)[§]	92(?)
East Mount Barcroft	2	Biotite	87.6 ± 0.5	88.0 ± 0.5	87.6 ± 0.6	87.9 ± 0.7	89.8 ± 2.7	92.0 ± 3.0*	165(?)
		Biotite	101.0 ± 0.5	N.P.	N.P.	N.P.	102.9 ± 3.0	105.3 ± 3.5*	
West Mount Barcroft	1	Biotite	118.9 ± 0.6	N.P.	N.P.	N.P.	120.8 ± 3.6	161 (Pb-U)[§] 165 (Pb-U)[#]	165
Indian Garden Creek	8	Biotite	108.0 ± 0.6	N.P.	N.P.	N.P.	107.2 ± 3.0	110.9 ± 3.4*	165(?)
Redding Canyon	N/A	Biotite	93.2 ± 0.5	N.P.	N.P.	N.P.	91.2 ± 2.7	N/A	165(?)
Sage Hen Flat	10	Biotite	N/A	N/A	N/A	N/A	N/A	133.3 ± 4.0[†]	141.4
		Hornblende	N/A	N/A	N/A	N/A	N/A	141.4 ± 5.0[†]	
Beer Creek	3	Hornblende	176.2 ± 1.0	175.3 ± 1.0	167.5 ± 8.7	168.3 ± 5.8	167.8 ± 6.0	173.8 ± 6.0*	175.3

Note: Age in Ma ± 1σ. N/A = not applicable; N.P. = No plateau.

*Crowder et al. (1973).

[†] McKee and Nash (1967).

[§] Stern et al. (1981).

[#] Gillespie (1979).

TABLE 3. POTASSIUM-ARGON AGES OF GRANITIC PLUTONS IN THE WHITE MOUNTAINS, CALIFORNIA AND NEVADA

Pluton	Locality (Fig. 2)	Material	K$_2$O (%)	^{40}Ar rad (mole/g × 10^{-9})	^{40}Ar rad (%)	Age ± σ (Ma)
Boundary Peak	1	Biotite	9.24	0.9905	84.6	72.9 ± 2.5
Leidy Creek	2	Biotite	8.77	0.9755	55.2	75.6 ± 2.2[†]
Marble Creek	3	Biotite	9.14	1.0584	73.8	78.7 ± 2.5
Birch Creek	4	Biotite	9.03	1.090	87.0	82.0 ± 2.4[§]
	5	Biotite	8.77	1.022	83.0	79.2 ± 2.4[§]
McAfee Creek	6	Biotite	9.52	1.2026	86.8	85.7 ± 2.7
Cabin Creek	7	Biotite	9.39	1.2085	89.9	87.2 ± 2.7
		Hornblende	0.962	0.2198	78.4	151.4 ± 4.4
Pellisier Flats	8	Hornblende	1.058	0.1374	80.7	88.0 ± 2.7
East Mount Barcroft	9	Biotite	9.20	1.2201	90.6	89.8 ± 2.7
	10	Biotite	9.32	1.4202	90.0	102.9 ± 3.0
West Mount Barcroft	12	Biotite	9.11	1.6390	92.0	120.8 ± 3.6
Indian Garden Creek	13	Biotite	9.18	1.4600	89.3	107.2 ± 3.0
Beer Creek	15	Hornblende	0.933	0.2362	80.0	167.8 ± 6.0
Sage Hen Flat	17	Biotite	7.22	1.438	89.0	133.3 ± 4.0[§]
		Hornblende	1.35	0.286	91.0	141.4 ± 5.0[§]
Redding Canyon	18	Biotite	8.09	1.090	89.1	91.2 ± 2.7

Notes: Conventional K-Ar age determinations were made on all of the samples used for ^{40}Ar/^{39}Ar experiments (Table 1). The analyses were performed using standard isotope-dilution techniques similar to those described by Dalrymple and Lanphere (1969). Potassium analyses were performed by a lithium metaborate flux fusion-flame photometer technique using lithium as an internal standard (Ingamells, 1979). Ages were calculated using decay constants recommended by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jäger, 1977). Ages from older studies (McKee and Nash, 1967; Evernden and Kistler, 1970; Crowder et al., 1973) have been recalculated using these constants. Errors were calculated using standard propagation of error techniques (Taylor, 1982) and represent the estimated analytical uncertainty at 1σ.

[†] Crowder et al. (1973).

[§] McKee and Nash (1967).

(1973) are 72.5 ± 2.2 Ma, 76.3 ± 2.2 Ma, and 79.6 ± 2.2 Ma (recalculated using the 1977 decay constants), which overlap the ages determined for this study. The age spectrum from the ^{40}Ar/^{39}Ar experiment (Fig. 3, Table 2) shows evidence of minor ^{40}Ar loss at the low-temperature steps, followed by a concordant plateau over the remainder of the ^{39}Ar release that amounts to >95% of the total ^{39}Ar released. The isochron and correlation calculations show no evidence of disturbance of the plateau. We consider the plateau age of 77.2 ± 0.8 Ma to be the best estimate of the age of the Marble Creek pluton.

Birch Creek Pluton. The Birch Creek pluton is in the central part of the White Mountains ≈5 km northwest of Deep Springs Valley (Fig. 2). It is a relatively small (≈7.5 km^2 of outcrop) body completely surrounded by Late Proterozoic metasedimentary rocks. This pluton was not dated for this study. Because of its small size, complete separation from other granitic bodies, and uniform texture and composition, there has never been much doubt that the Birch Creek pluton is a single pluton and not part of a large complex granitic complex such as most of the plutons farther north in the White Mountains—the plutons that prompted Krauskopf's (1968) paper. Two K-Ar ages on biotite (Table 2) from widely separated samples of the Birch Creek pluton (4 and 5 *in* Fig. 2) yield concordant ages of ca. 81 Ma (recalculated from McKee and Nash [1967] using the 1977 decay constants). We consider the age of 81 Ma to be the best estimate of the age of the Birch Creek pluton.

McAfee Creek Pluton. The McAfee Creek pluton is on the east side of the White Mountains adjacent to the south edge of the slightly younger Marble Creek pluton (Fig. 2). Around most of the rest of its periphery it is in sharp contact with other significantly older plutons. The McAfee Creek body is a uniform biotite quartz monzonite easily distinguished from the surrounding plutons. Biotite from the McAfee Creek pluton yields concordant K-Ar and ^{40}Ar/^{39}Ar ages of ca. 83.6 Ma (Tables 1, 2, and 3). Two published K-Ar ages (Crowder et al., 1973), recalculated using 1977 decay constants, are 85 ± 2.6 Ma and 87.5 ± 2.6 Ma; the former is concordant with the new analysis, and the latter is slightly older than the new ages (although statistically indistinguishable at 95% confidence). The age spectrum from the ^{40}Ar/^{39}Ar experiment shows no evidence of ^{40}Ar loss or disturbance; 100% of the ^{39}Ar release defines a plateau (Fig. 3) with an age of 83.6 ± 0.4 Ma. We consider the plateau age of 83.6 ± 0.4 Ma to be the best estimate of the age of the McAfee Creek pluton.

Cabin Creek Pluton. The Cabin Creek pluton is composed of two separate small bodies (outcrop area ≈25 km^2) in the east-central part of the White Mountains (Fig. 2). The two portions of this pluton are separated by <0.5 km by the ca. 79 Ma Leidy Creek pluton. Other parts of the pluton are in contact with the 73 Ma Boundary Peak pluton on the north, the ca. 84 Ma McAfee Creek pluton on the south, and Late Proterozoic strata on the east and west. The Cabin Creek granodiorite differs from the surrounding granitoids (Boundary Peak, Leidy Creek, and McAfee Creek plutons) by the occurrence of hornblende as well as biotite as a common rock-forming mineral. Both hornblende and biotite from the Cabin Creek granodiorite were dated for this study.

Hornblende (7 *in* Fig. 2) yielded a K-Ar age of 151.4 ± 4.4 Ma (Table 3), in agreement with a published age of 152.8 ± 5.1 Ma (Crowder et al., 1973), recalculated using the 1977 constants. An ^{40}Ar/^{39}Ar incremental heating analysis on this sample gave a plateau age of 146.7 ± 1.0 Ma (Fig. 3, Table 2), but shows evidence of some ^{40}Ar loss. The initial heating step, which gave an age of 457 ± 13 Ma, includes <2% of the total ^{39}Ar release and is interpreted as representing only a small amount of unsupported or excess ^{40}Ar. Following this step, a pattern of steadily increasing ages in the lower temperature steps, composing ≈35% of the total ^{39}Ar release, is interpreted as reflecting ^{40}Ar loss due to a later heating event. In this case, the total amount of ^{40}Ar loss appears to be less than ≈3%, thus the plateau, composing nearly 65% of the total ^{39}Ar release, is considered a probable cooling age for the hornblende.

Biotite from the same sample gives additional evidence of a heating event that followed emplacement of the Cabin Creek granodiorite. The lower argon closure temperature of biotite (≈350 °C) relative to hornblende (≈450 °C) indicates that biotite would be affected more by a later heating event than hornblende in the same sample, and the K-Ar and ^{40}Ar/^{39}Ar results bear this out. The biotite K-Ar age of the Cabin Creek

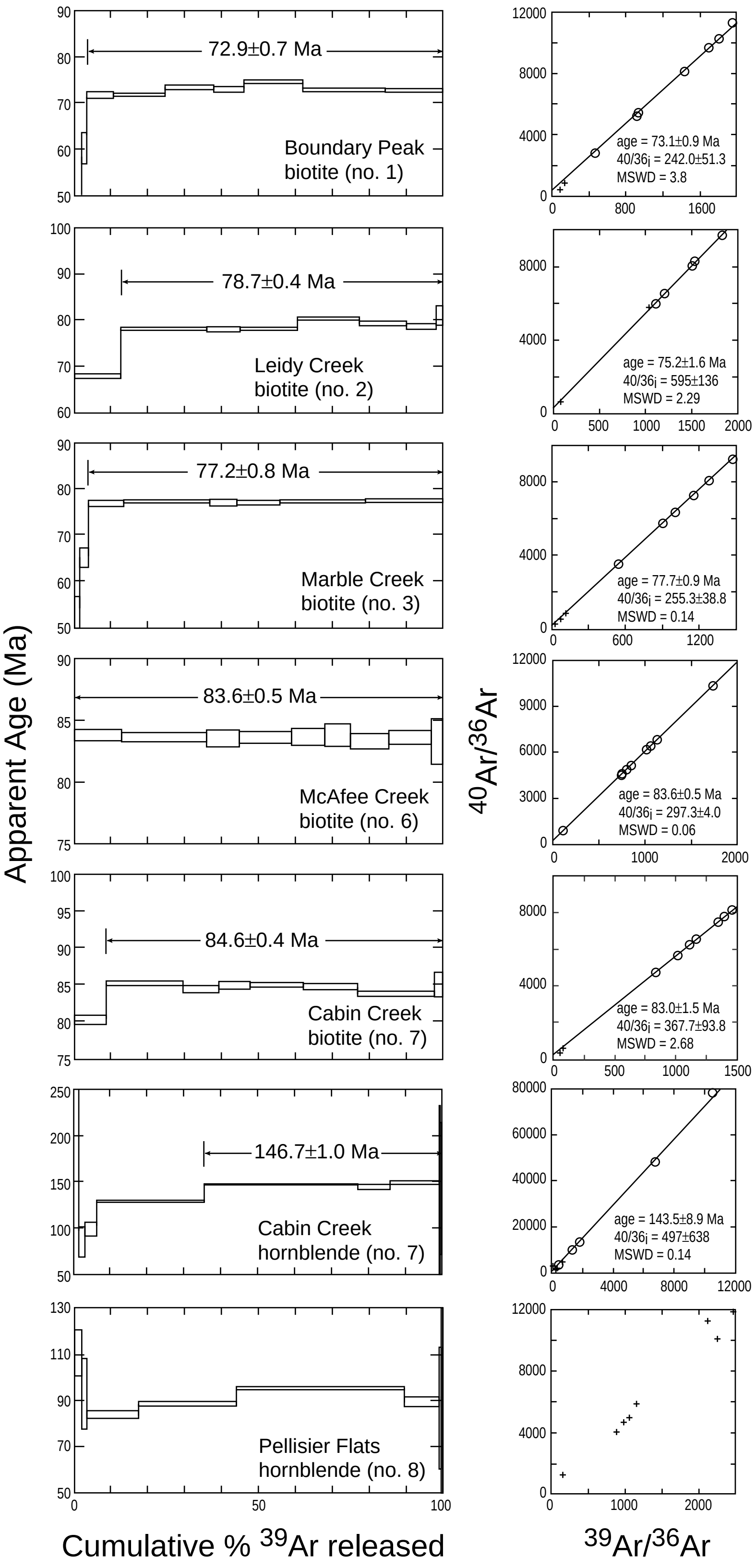

Figure 3 (at left and on facing page). ^{40}Ar/^{39}Ar age spectra and ^{40}Ar/^{36}Ar vs. ^{39}Ar/^{36}Ar isotope correlation diagrams for granitic rocks in the White Mountains. Errors on the age spectra are 1σ. Number in parentheses refers to Figure 2. On isotope correlation diagrams, circles indicate plateau increments, plusses are nonplateau increments.

granodiorite is 88.4 ± 2.7 Ma (Table 3), concordant with a published age by Crowder et al. (1973) of 88.4 ± 2.7 Ma (recalculated using the 1977 constants). An ^{40}Ar/^{39}Ar incremental heating analysis of the biotite (Fig. 3, Table 2) yielded a plateau composing >90% of the total ^{39}Ar release with an age of 84.6 ± 0.4 Ma. Only minor disturbance of this spectrum is apparent, which includes evidence of slight ^{40}Ar loss in the first heating step, and a subtle pattern of decreasing apparent ages on the plateau steps, perhaps reflecting ^{39}Ar recoil from fine-grained recrystallization or alteration phases. This disturbance is reflected in the isochron and isotope correlation calculations by MSWD values of ≈2.7, although the isochron age is concordant with the plateau age.

Comparison with the age of the coexisting hornblende indicates that the biotite spectrum represents a nearly complete resetting of the age of the biotite from the original cooling age of ca. 147 Ma by a later thermal event ca. 85 Ma. This age corresponds to that of the large McAfee Creek pluton, which borders the Cabin Creek pluton on the south, although the Cabin Creek pluton is also intruded by the 79 Ma Leidy Creek pluton. The fairly well-defined plateau age of 85 Ma for the Cabin Creek biotite suggests that the biotite age was reset at that time, and that intrusion of the younger and smaller Leidy Creek pluton perhaps resulted in only minor additional ^{40}Ar loss expressed by the initial 80 Ma step of the ^{40}Ar/^{39}Ar release (Table 2). In spite of this younger thermal event, the higher argon retentivity of hornblende appears to have preserved an original cooling age. Later heating indicated by the completely reset biotite age is reflected in the argon loss of the low-temperature steps of the hornblende spectrum. The hornblende plateau age of 146.7 ± 1.0 Ma is considered to be the best estimate of the age of the Cabin Creek granodiorite, although it could be older.

Pellisier Flats Pluton. The Pellisier Flats pluton is a large, compositionally and texturally variable granitic body in the northern part of the White Mountains (Fig. 2). It is intruded by, and encloses, the 73 Ma Boundary Peak pluton in the northernmost part of the range and is encircled by Mesozoic metavolcanic rocks elsewhere in the range. At no place is it in contact with other plutons of the Inyo batholith. This granitoid is mostly coarse-grained hornblende-biotite quartz monzonite with large phenocrysts of orthoclase near its margins grading into a mafic poor medium-grained granite in its core. Along the west front of the range, the western side of the pluton is intensely sheared, forming a north-trending zone of crushed and deformed rock ≈1 km wide and >5 km long. In this zone and locally elsewhere in the pluton, recrystallization of

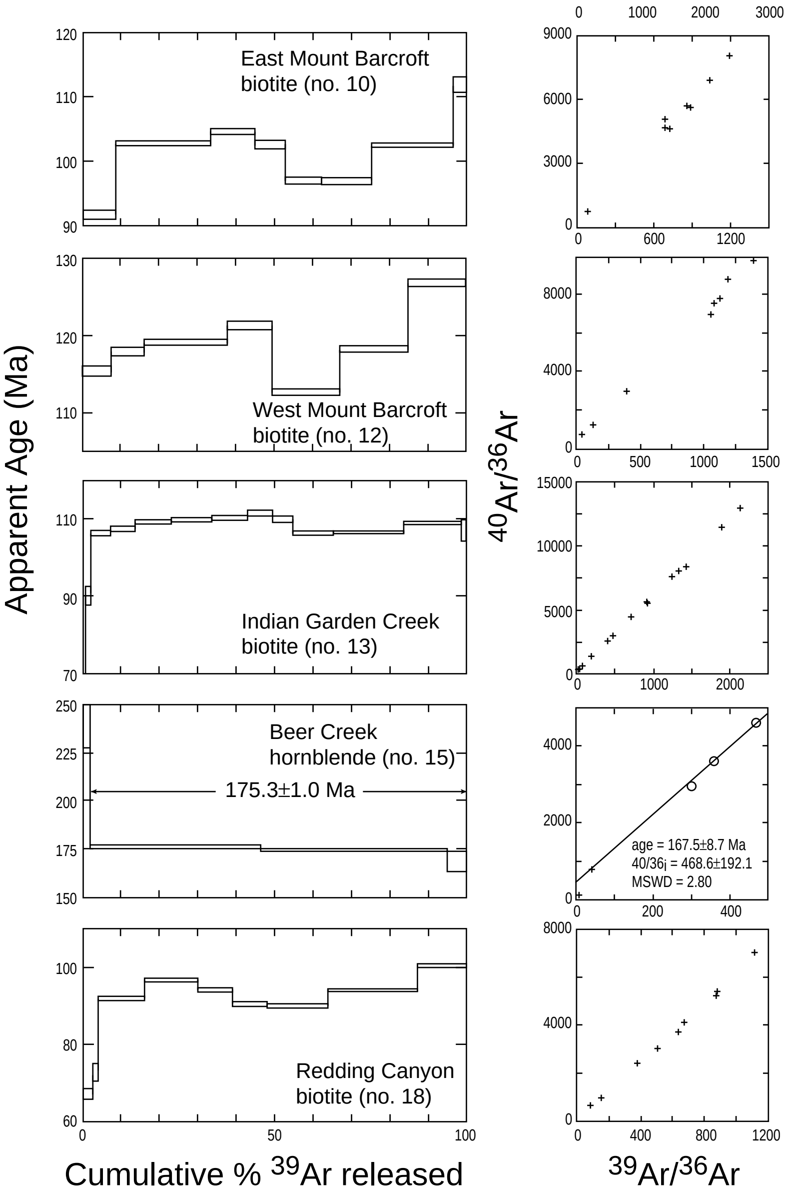

Figure 3. ***(Continued).***

hornblende and biotite is extensive (Crowder et al., 1973).

Hornblende from the Pellisier Flats quartz monzonite (8 *in* Fig. 2) yielded a K-Ar age of 88.0 ± 2.7 Ma (Tables 1, 2, and 3), in agreement with a published age of 92.0 ± 3.0 Ma (Crowder et al., 1973; recalculated using the 1977 constants) and in general agreement with a poorly constrained reversely discordant U/Pb age of 89.6 determined by Stern et al. (1981). An ^{40}Ar/^{39}Ar incremental heating analysis of this sample does not give a plateau (Fig. 3, Table 2), indicating that the hornblende has been subjected to some thermal or alteration event following crystallization. The first two heating steps, which compose <4% of the total ^{39}Ar released, give slightly older ages that appear to represent either a small amount of excess ^{40}Ar absorbed on the surfaces of the mineral grains, or perhaps ^{39}Ar recoil effects from fine-grained alteration products that rim the grains. The pattern for the next 85.8% of the ^{39}Ar release is of gradually increasing, but not overlapping, ages of 84.0 Ma, 88.7 Ma, and 95.4 Ma. The final step for the last 9.7% of the ^{39}Ar release is 89.3 ± 2.1 Ma. The recombined total fusion age of this analysis is 91.7 ± 0.8 Ma, concordant with the K-Ar ages and in good agreement with the U/Pb age (Table 2). Because of the similarity between the K-Ar, ^{40}Ar/^{39}Ar, and U/Pb ages, we speculate that a thermal or alteration event resulted in some minor redistribution of Ar or K without significant loss of ^{40}Ar, as seen by the disturbance of the release spectra, resulting in little change in the age of crystallization. The 73 Ma Boundary Peak pluton, which is ≈4 km from the collection site of the dated sample, may have thermally disturbed the hornblende but not significantly changed the age recorded by the U/Pb, K-Ar, and ^{40}Ar/^{39}Ar analyses of ca. 90 Ma.

East Mount Barcroft Pluton. The Mount Barcroft pluton consists of two bodies in the central part of the White Mountains separated by as little as 2 km from each other by the younger McAfee Creek pluton (Fig. 2). They were classified as one pluton (Emerson, 1966) because they are similar dark, mafic-rich, quartz-poor granitoids, but there is some likelihood that each may be a distinctive intrusive body not as closely related as their general petrologic similarity suggests (Krauskopf, 1968). In addition to their complete separation, a number of minor differences including grain size, number of aplite dikes, variable contact relationships, and possibly their ages, reinforced this division and led Krauskopf (1968) to use the unofficial names of Barcroft West and Barcroft East plutons. We follow this nomenclature.

The east Mount Barcroft pluton is a small elongate body ≈12 km^2 that intrudes Late Proterozoic strata on its eastern side and is intruded by the ca. 84 Ma McAfee Creek pluton around its western flanks. Two samples of biotite from this granitic rock were dated by K-Ar and ^{40}Ar/^{39}Ar techniques. One was from a part of the pluton enclosed by the McAfee Creek granitoid (9 *in* Fig. 2), the other was from part of the pluton surrounded by Late Proterozoic strata and ≈3 km from the first sample (10 *in* Fig. 2). The ages are not concordant and both show evidence of argon loss in the ^{40}Ar/^{39}Ar incremental heating analysis (Fig. 3, Table 1).

Biotite from the east Mount Barcroft pluton from sample locality 9 (Fig. 2), collected ≈1 km from the McAfee Creek pluton, yields a K-Ar age of 89.8 ± 2.7 Ma and a slightly disturbed ^{40}Ar/^{39}Ar plateau age of 88.0 ± 0.5 Ma (Tables 1, 2, and 3; Fig. 3). Minor disturbance of the plateau, which includes ≈95% of the total ^{39}Ar release, is manifested by slightly older ages in two fractions between ≈30% and 45% of the total ^{39}Ar release that are 1.5–2.0 m.y. older than the 88 Ma age yielded by the remainder of the plateau fraction. Comparison of this spectrum with biotite from locality 10 (Fig. 2), also from the east Mount Barcroft pluton, but farther from the younger McAfee Creek pluton and enclosed by Paleozoic sedimentary rocks, indicates that biotite from sample locality 9 (Fig. 2) represents a reset age.

Biotite from locality 10 (Fig. 2) yields concordant K-Ar and ^{40}Ar/^{39}Ar recombined total fusion ages of ca. 102 Ma (Tables 1, 2, and 3). The ^{40}Ar/^{39}Ar age spectrum, however, shows evidence of significant disturbance and does not yield a plateau (Fig. 3). Apparent ages from the spectrum range from 92 to 112 Ma, but the release pattern of rising and falling apparent ages is not readily interpretable, possibly resulting from more than one period of reheating. This disturbed spectrum is evidence of ^{40}Ar redistribution and loss and probably represents a minimum age for the pluton of ca. 100 Ma.

We conclude that both samples from the east Mount Barcroft pluton reflect ages that have been variably reset by one or more younger thermal events. The younger age of ca. 88 Ma for biotite from sample locality 9 can be attributed to the proximity (≈1 km) of this sample to the 84 Ma McAfee Creek pluton. Intrusion of this pluton apparently provided enough heat to nearly completely reset this biotite to an age of ca. 88 Ma. The slightly older age for biotite from sample locality 10 of ca. 100 Ma and the disturbance of the ^{40}Ar/^{39}Ar spectrum indicate that the age of this sample was only partially reset by intrusion of the McAfee Creek pluton, probably undergoing less heating because it is farther (≈2.5 km) from the McAfee Creek pluton. Although these data suggest a minimum age of ca. 100 Ma for the east Mount Barcroft pluton, regional considerations suggest a substantially older age. No plutonism of ca. 100 Ma is known in the region, whereas several bodies were emplaced ca. 160–175 Ma, so it seems more likely that the east Mount Barcroft pluton is Jurassic in age.

West Mount Barcroft Pluton. The west Mount Barcroft pluton is exposed over an area of ≈60 km^2 in the central and western part of the White Mountains (Fig. 2). It intrudes Late Proterozoic sedimentary rocks along its southern edge, where a narrow contact aureole occurs. The pluton intrudes or is in fault contact with Mesozoic metavolcanic rocks on the north. Aplite dikes are abundant in this part of the pluton. On the east, the west Mount Barcroft pluton is intruded by the McAfee Creek pluton.

Biotite from the west Mount Barcroft pluton (12 *in* Fig. 2) yields a K-Ar age of 120.8 ± 3.6 Ma and a recombined ^{40}Ar/^{39}Ar total fusion age of 118.9 ± 0.6 Ma (Tables 1, 2, and 3). The age spectrum for this sample does not define a plateau (Fig. 3), showing evidence of significant disturbance. Apparent ages range from ca. 113 Ma to 127 Ma, and none of the adjacent steps overlap within their analytical uncertainty. The spectrum suggests a minimum age for the biotite of ca. 120–125 Ma. No indication of an original age of crystallization and no hint of the age of the later thermal event exists, except that it is probably younger than the youngest apparent age of 112.6 ± 0.4 Ma. A number of plutons in the northern part of the White Mountains have ages of ca. 80–90 Ma, so it seems likely that the heating event that affected the west Mount Barcroft pluton was this age. The adjacent McAfee Creek pluton is ca. 84 Ma and the Pellisier Flats pluton a few kilometers to the north is probably ca. 90 Ma. One or both of these plutons could have produced the heat that released ^{40}Ar from the Mount Barcroft biotite and partially reset the ages.

Attempts to determine the age of the west Mount Barcroft pluton using a different K-bearing mineral also produced spurious results. Two different samples of intergrown amphibole and pyroxene yielded ages of 226.4 Ma (Crowder et al., 1973) and 667.2 Ma (McKee, 1994, unpub. age). Both ages are significantly older than seems plausible on the basis of regional geologic relationships. The older of the two contained more pyroxene relative to amphibole that is reflected in a lower K_2O value of 0.128 wt% K_2O versus 0.847 wt% K_2O for the more amphibole-rich sample. Pyroxene is a problematic mineral for K-Ar dating (Dalrymple and Lanphere, 1969) because of its low K_2O content and because it often carries excess ^{40}Ar. These results suggest that the variable amounts of intergrown pyroxene are responsible for the anomalously old ages.

U/Pb ages of zircons from the west Mount Barcroft pluton are 161.1 Ma (Stern et al., 1981) and 165 Ma (Gillespie, 1979). These ages, on different samples analyzed in different laboratories, are nearly concordant and may be close to the age of crystallization of the west Mount Barcroft pluton.

Indian Garden Creek Pluton. The Indian Garden Creek pluton on the east side of the range is a relatively small body that intrudes, and is mostly surrounded by, the Beer Creek pluton (Fig. 2). It is a massive, uniform, fine-grained biotite quartz monzonite similar to small aplite bodies in the Beer Creek pluton and to fine-grained parts of the McAfee Creek pluton that crop out a short distance to the north.

Biotite from the Indian Garden Creek pluton (13 *in* Fig. 2) yields a K-Ar age of 107.2 ± 3.0 Ma and a recombined ^{40}Ar/^{39}Ar total fusion age of 108.0 ± 0.6 Ma (Tables 1, 2, and 3). The incremental heating analysis yields a disturbed spectrum (Fig. 3), although >95% of the ^{39}Ar release gives apparent ages that range between 106 and 112 Ma. No part of the spectrum, however, yields a plateau according to established definitions (Lanphere and Dalrymple, 1978), and isotope correlation calculations give MSWD values of ≈12, indicative of significant geologic error. We interpret this release spectrum as representing a disturbed age. It is not the original age of crystallization or the age of thermal disturbance. The thermal event is probably younger than the ca. 106 Ma age of the youngest significant argon release steps.

We speculate that the Indian Garden Creek pluton has been variably heated by the 84 Ma McAfee Creek pluton that crops out a few kilometers to the north. Another sample of Indian Garden Creek quartz monzonite (14 *in* Fig. 2), collected ≈3 km northwest of the sample analyzed here and nearer the 84 Ma McAfee Creek pluton, yielded a K-Ar age of 88.4 ± 2.7 Ma (Crowder et al., 1973; recalculated using 1977 constants). This sample was apparently more nearly reset to the thermal age of the McAfee Creek pluton, whereas the sample more distant yields a disturbed age of ca. 108 Ma. The age of emplacement of the Indian Garden Creek pluton is unknown, but may be as old as ca. 165 Ma.

Beer Creek Pluton. The Beer Creek pluton, also referred to as the Cottonwood porphyritic adamellite (Emerson, 1966) and in part the Cottonwood granite (Bateman, 1992), is a large granitic body in the central and eastern part of the White Mountains (Fig. 2). It extends at least 30 km to the southeast, where it forms most of the Sylvania Mountains and crops out at the northern end of Death Valley (Fig. 1) (McKee and Nelson, 1967; McKee, 1985). It is one of the largest granitic bodies in the White and Inyo Mountains region. The Beer Creek granitoid is a distinctive porphyritic rock with ≈30% large (10–50 mm long) phenocrysts of pink to gray orthoclase. Mafic minerals include hornblende and biotite. In the White Mountains the pluton is intruded by the McAfee Creek and Indian Garden Creek plutons. The contact with these granitic bodies is sharp. The contact with Late Proterozoic and early Paleozoic sedimentary rocks is also sharp, although local zones of garnet-epidote skarn are developed where the quartz monzonite intrudes argillaceous carbonate rock.

Hornblende from the Beer Creek pluton (15 *in* Fig. 2) yields a K-Ar age of 167.8 ± 6.0 Ma (Table 3), concordant with the 173.8 ± 6.0 Ma age reported by Crowder et al. (1967) and concordant with the recombined ^{40}Ar/^{39}Ar total fusion age of 176.2 ± 1.0 Ma (Tables 1 and 2). The incremental heating analysis of this sample defines a plateau with an age of 175.3 ± 1.0 Ma (Fig. 3). The plateau from the Beer Creek hornblende contains >93% of the ^{39}Ar released from the sample, with only a very minor amount of excess ^{40}Ar at the low-temperature step. Another sample of hornblende from a locality in the Beer Creek pluton ≈3 km from the site of the sample described above (16 *in* Fig. 2) yielded a K-Ar age of 179.7 ± 6.0 Ma (Crowder et al., 1973; age recalculated using the 1977 constants). This is in agreement with K-Ar and ^{40}Ar/^{39}Ar ages described above and reinforces our best estimate of the age for the Beer Creek pluton of ca. 175 Ma.

Sage Hen Flat Pluton. The Sage Hen Flat pluton, a felsic fine-grained biotite hornblende quartz monzonite in the central part of the White Mountains, is a small (≈15 km^2) isolated body completely surrounded by Late Proterozoic and early Paleozoic sedimentary rocks (Fig. 2). Its small size, equidimensional outcrop pattern, and lack of intrusive contact with other granitoids group it with the Birch Creek and Redding Canyon plutons, which are similar in these respects. The other plutons in the White Mountains are larger, have irregular shapes, and are at least partially in contact with other granitic bodies. Because no intrusive relationships with other granitoids are exposed, the relative age of the Sage Hen Flats pluton, other than younger than early Paleozoic, cannot be determined. Biotite and hornblende from a sample of Sage Hen Flat quartz monzonite (17 *in* Fig. 2) yield K-Ar ages of 133.3 ± 4 Ma and 141.4 ± 5 Ma, respectively (McKee and Nash, 1967; ages recalculated using the 1977 constants). Although these ages overlap within their analytical uncertainty, we consider that the hornblende age is more likely to represent the age of cooling and crystallization of the Sage Hen Flat pluton. The ca. 141 Ma age is slightly younger than the ca. 147 Ma Cabin Creek pluton. The Sage Hen Flat pluton may represent the later stages of the major Middle Jurassic intrusive event in the White-Inyo Mountains–central Sierra Nevada, or it may be a separate, small, Late Jurassic pulse of magmatism (Fig. 4).

Redding Canyon Pluton. The Redding Canyon pluton is one of the smallest plutons in the White Mountains, having an outcrop area of ≈3 km^2 (Fig. 2). It is an isolated, equidimensional body, on the west side of the range, and is completely surrounded by Late Proterozoic and early Paleozoic sedimentary rocks. It is a porphyritic medium- to coarse-grained biotite quartz monzonite.

Biotite from the Redding Canyon pluton (18 *in* Fig. 2) yielded a K-Ar age of 91.2 ± 2.7 Ma (Table 3), and a recombined ^{40}Ar/^{39}Ar total fusion age of 93.2 ± 0.5 Ma (Table 1). The age spectrum does not define a plateau (Fig. 3). The heating steps produce a group of discordant ages ranging from ca. 90 to 100 Ma, indicating a disturbed argon system. Its age may have been partially reset by a heating event younger than ca. 90 Ma, but may not have completely reequilibrated to this second event. It is not possible to determine the original cooling age of the Redding Canyon pluton from the available data. It is probably older than the recombined ^{40}Ar/^{39}Ar total fusion age of 93.2 ± 0.5 Ma, but how much is speculative; perhaps it is as old as ca. 165 Ma, the age of emplacement of many granite bodies in the White-Inyo Mountains and the central part of the Sierra Nevada.

DISCUSSION OF AGES

The ages of several plutons in the White Mountains are not clear and unraveling the complex relationships of these bodies to each other, and to the Sierra Nevada batholith as a whole, remains a problem. A long and complicated history of intrusion, cooling, and reheating is reflected by the suite of ages shown in Figure 4. Some pluton ages do seem to be established by the K-Ar and ^{40}Ar/^{39}Ar analysis of biotite and hornblende from the 13 plutons. Other ages are difficult to reconcile except by complicated, and perhaps incorrect, reasoning. A period of granitic emplacement and cooling in the northern part of the White Mountains from ca. 84 to 73 Ma is documented by the K-Ar and ^{40}Ar/^{39}Ar incremental heating analyses of five plutons (Boundary Peak, Marble Creek, Leidy Creek, Birch Creek, and McAfee Creek). This intrusive event is also reflected by a completely reset biotite age of 84.6 Ma from the Cabin Creek pluton and partially reset ages of ca. 88 Ma for the east Mount Barcroft pluton and 92 Ma for the Pellisier Flats pluton.

Several plutons in the White Mountains give K-Ar and ^{40}Ar/^{39}Ar ages in the range of ca. 85–125 Ma. Without exception, all of these ages are suspect and most are demonstrably too young. For example, the Cabin Creek pluton gives an ^{40}Ar/^{39}Ar plateau age on biotite of 85 Ma, but an ^{40}Ar/^{39}Ar plateau age of 147 Ma on hornblende (a more reliable mineral in terms of argon retention) from the same sample more likely represents the emplacement age of the pluton. The west Mount Barcroft pluton gave a disturbed ^{40}Ar/^{39}Ar age of ca. 120 Ma, but U/Pb ages of 161 Ma (Stern et al., 1981) and 165 Ma (Gillespie, 1979) are probably more reliable estimates of the emplacement age. Hornblende from the Pellisier Flats pluton gave a disturbed ^{40}Ar/^{39}Ar age spectrum, suggesting a minimum age of ca. 92 Ma. Although this age appears to be consistent with a ^{206}Pb/^{238}U age of 89.6 Ma (Stern et al., 1981), the U/Pb age is suspect, showing reverse discordance with a ^{207}Pb/^{235}U age of 82.4 Ma and a ^{208}Pb/^{232}Th age of 74.4 Ma. It is possible that all these ages are too young. K-Ar ages on hornblende of 98 Ma (Crowder et al., 1973) and biotite of 157 Ma (Evernden and Kistler, 1970) taken from widely separated sites tentatively correlated with the Pellisier Flats pluton suggest that the pluton has undergone considerable thermal disturbance and may be Jurassic in age. It is also possible that the inconsistency of these ages might reflect sampling of one or more unrecognized plutons of different ages within currently mapped boundaries of the Pellisier Flats pluton. As Crowder et al. (1973) noted, the correlation of the isolated body that yielded the 157 Ma age with the Pellisier Flats pluton is tenuous. In any case, the emplacement age of the Pellisier Flats pluton is unresolved by new data presented here. We tentatively consider the Pellisier Flats pluton to be ca. 90 Ma. Three other plutons in the 85–140 Ma age group yield disturbed ^{40}Ar/^{39}Ar age spectra that are interpreted to be minimum ages: the Indian Garden Creek pluton (>110 Ma), the Redding Canyon pluton (>92 Ma), and the east Mount Barcroft pluton (>102 Ma). Actual emplacement ages of these plutons are unknown. K-Ar, ^{40}Ar/^{39}Ar, and U/Pb ages provide no conclusive evidence of pluton emplacement in the White Mountains between ca. 85 and 140 Ma. Plutons of this age are not recognized elsewhere in the region. Therefore, we consider all ages in the 85–140 Ma range suspect, and provisionally assign most plutons yielding these ages (Indian Garden Creek, Redding Canyon, and east Mount Barcroft) to the Jurassic.

Two other ages of emplacement and cooling for granitoids in the White Mountains are documented if the ^{40}Ar/^{39}Ar plateau ages reflect valid cooling ages. Hornblende from the Cabin Creek pluton, which gives a reset biotite age of 84.8 Ma, yields an ^{40}Ar/^{39}Ar plateau age of ca. 147 Ma. The Beer Creek pluton in the southern part of the White Mountains yields an ^{40}Ar/^{39}Ar plateau age of ca. 175 Ma. The ca. 147 Ma and 175 Ma ages of granitic emplacement are consistent with ages of other plutons in the central part of the Sierra Nevada batholith (Evernden and Kistler, 1970), the southern part of the White Mountains (McKee and Nash, 1967), and the Inyo Mountains (Ross, 1969; Sylvester et al., 1978; Dunne et al., 1978; Chen and Moore, 1982), that yield generally similar radiometric ages. The Sage Hen Flat pluton, probably ca. 141 Ma, and the west Mount Barcroft pluton, with U-Pb ages of 161 and 165 Ma (Stern et al., 1981; Gillespie, 1979), record additional granitic magmatism during these Middle and Late Jurassic stages of plutonism.

Other generalizations can be made about the time of granitic emplacement in the White Mountains (see Fig. 4). Emplacement started in Middle Jurassic time, or ca. 175 Ma. It may have continued through the Jurassic or there may have been two pulses; one from 175 to 165 Ma, and the second between 150 and 140 Ma. No plutonism between these age groups is known. About 55 m.y., or the entire first half of the Cretaceous, elapsed with no further granitic emplacement. This period was followed by intrusion and cooling of a number of plutons in Late Cretaceous time between ca. 85 Ma and 75 Ma. Heat from these granitoids affected nearby older rocks, resetting or partially resetting the age of biotite and,

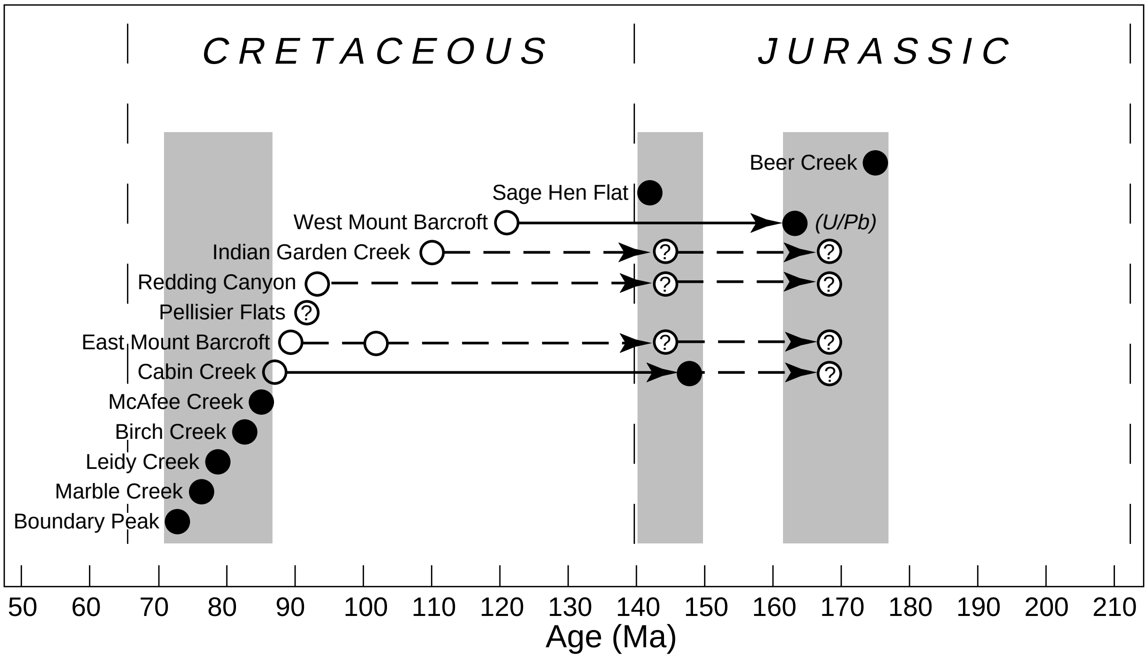

Figure 4. Estimated age of plutons in the White Mountains, California and Nevada, showing probable emplacement ages (solid circles), and disturbed or reset ages (open circles) with solid lines indicating probable emplacement ages and dashed lines indicating age estimates based on ages of known plutons in the region (queried ages). Emplacement ages are based on K-Ar, ^{40}Ar/^{39}Ar, and U/Pb (for west Mount Barcroft) age determinations. The ages define three intervals of emplacement (Middle Jurassic, Late Jurassic, and Late Cretaceous), shown in gray.

in some places, hornblende. These partially reset ages are difficult to recognize from sparse age analysis and impossible to evaluate from K-Ar data alone. Even using ^{40}Ar/^{39}Ar incremental heating analyses, the original age of cooling or resetting cannot be determined if the argon system is only partially reequilibrated. An intermediate age with no plateau in the release spectra results from this partial loss of argon; the original age of cooling may be significantly older than the partially reset age or it may be only slightly older. Because of this we can only guess at the age of the east Mount Barcroft (88 Ma), Pellisier Flats (90 Ma), Redding Canyon (93 Ma), and Indian Garden Creek (110 Ma) plutons, all of which yield only disturbed ages. We have chosen to place them in one of the recognized periods of plutonism for the central part of the Sierra Nevada batholith (mostly in the 160–180 Ma Inyo Mountains intrusive epoch of Evernden and Kistler, 1970; see Fig. 4).

The periods of emplacement and cooling of the granitoids in the White Mountains of California and Nevada correspond closely to the intrusive epochs of the central part of the Sierra Nevada batholith recognized by Evernden and Kistler (1970) on the basis of 250 dated samples from the batholith as a whole (Fig. 1). The youngest group, the 70–90 Ma Cathedral Range epoch, is the most clearly defined group in the White Mountains, because many of the plutons are in this age bracket, which is the youngest event and hence not disturbed by subsequent thermal activity. The 132–140 Ma Yosemite epoch of Evernden and Kistler is represented in the White Mountains by two small plutons, Cabin Creek and Sage Hen Flat. The Indian Garden Creek and Redding Canyon plutons, which yield only disturbed ages, may belong in this intrusive epoch, although we have provisionally placed them in the older Inyo Mountains epoch. The oldest granitic rocks in the White Mountains, the west Mount Barcroft and the Beer Creek plutons, are within the 180–160 Ma Inyo Mountains intrusive epoch.

CONCLUSIONS

The difficulty in understanding the history of the Inyo batholith in the White Mountains does not lie in the techniques used to study the plutons that compose it but is, in part, the more subtle problem of understanding pluton emplacement. The problem is compounded by difficulty in distinguishing two or more granitic rocks that may look alike and have ambiguous contact relationships. If the interpretation of the various field relationships (i.e., mapped contacts, definition of discrete plutonic bodies) is not correct, study of the proposed plutons will produce a mixture of conflicting data. Newer and better analytical techniques will not bring order to a situation that is not correctly resolved. The new ages reported here, however, appear to help resolve the chronology of pluton emplacement on the White Mountains.

Application of ^{40}Ar/^{39}Ar radiometric dating techniques to plutons in the White Mountains part of the Sierra Nevada batholith adds to understanding their history. For example, strong compositional and textural similarities between the Marble Creek and Leidy Creek plutons led Krauskopf (1968) to speculate that they may be the same pluton. ^{40}Ar/^{39}Ar plateau ages for these plutons are the same within analytical uncertainty and add evidence that they may be parts of the same body separated by a narrow septum of metamorphic rocks. However, possible correlation of the east and west Mount Barcroft plutons is not resolved by these new data, because both yield only clearly disturbed and discordant ^{40}Ar/^{39}Ar ages. Ages of the Indian Garden Creek, Redding Canyon, and Pellisier Flats plutons remain unresolved, although the evidence from the Ar release clearly indicates that they have been profoundly affected by heating associated with the youngest plutonism. In these cases, ^{40}Ar/^{39}Ar age spectrum analyses are sufficient only to confirm that possibly suspect K-Ar ages represent partially reset ages that do not reflect the age of pluton emplacement and cooling. Other ^{40}Ar/^{39}Ar plateau ages for the Cabin Creek and Beer Creek plutons appear to represent reliable emplacement ages.

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