# THERMAL EVOLUTION AND EXHUMATION OF DEEP LEVEL BATHOLITHIC EXPOSURES, SOUTHERNMOST SIERRA NEVADA, CALIFORNIA-SUPPLIMENTARY DATA AND DISCUSSIONS

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# INTRODUCTION

The Supplementary Data section provides modules of supporting data which are too voluminous to include with the principal thermochronometric data sets presented, as well as providing a description of the various analytical procedures used. New U/Pb zircon data are reported here which supplement the data published in Saleeby et al. (1987), and Pickett and Saleeby (1994). Figure DR1 is simplified from Figure 1, and plotted on it along with the sample numbers are the locations and age groups of published U/Pb zircon ages for samples not included in Table 6. Several different sample number schemes were used in field notes and publications over the ~20 year period that we have studied the Tehachapi complex, and Table DR1 integrates these into one numbering scheme as used in Figure 1 and Table 6. An ~7 year hiatus was introduced into our field studies and sample analyses for the Tehachapi complex due to a suddenly imposed complete lack of accessibility to the field area. We are indebted to the Tejon Ranch Company for allowing us limited accessibility in 2003-2004 which has greatly facilitated the completion of our work to its current state.

## NEW U/Pb ZIRCON AGE DATA

An extensive U/Pb zircon study of the Tehachapi complex was performed by Saleeby et al. (1987), and these data were supplemented by additional analyses published in Pickett and Saleeby (1994). Additional zircon analyses were performed in conjunction with this study in order to more firmly define the igneous history of the Tehachapi complex with a number of subjects for primary focus. These include: 1) The age of pegmatite dikes which represent the last stages of igneous activity for the complex, and also appear to have formed contemporaneously with lowdegrees of partial remelting in hornblende-rich members of the complex. 2) A number of samples that were used for thermobarometric analysis (Pickett and Saleeby, 1993) were not included in the earlier zircon work, and were thus included in our supplementary zircon work as a means of establishing direct links between zircon age data and the thermobarometric data. 3) Earlier U/Pb zircon work did not adequately define pyroxene-bearing tonalite bodies of Bear Valley suite affinity that intrude in complicated patterns through the orthogneissess, particularly in the El Paso Creek to Tunis Creek areas (Fig. SD1). Related to this, some of the original orthogneiss U/Pb zircon data exhibited discordance patterns that presented the possibility that they were extensively remobilized, and/or assimilated by Bear Valley suite intrusives. Some of these data are re-analyzed in the context of new analyses on adjacent samples.

A total of eight pegmatite dikes were collected for zircon work throughout the course of our Tehachapi complex studies. Only four of these samples yielded zircon. Data were reported for one of these in Saleeby et al. (1987). Three new pegmatite ages are reported here. Sample 1b is an  $\sim 1 \text{ m}$ thick dike with sharp edges within BV suite migmatitic gabbro of the Grapevine Canyon area. It yielded sparse fine zircon which gave an apparent concordant age of 98.1±0.7 Ma (Table DR2). For single fraction apparently concordant ages, the <sup>206</sup>Pb/<sup>238</sup>U ages and uncertainties are cited. Sample 5b is texturally homogeneous between pegmatitic and coarse hypidiomorphic granular, and locally intergradational with finer aplitictextured leucosome material at the sample 5 migmatitic diorite site (Figure It likewise yielded a sparse fine zircon population with apparent 5c). concordance of 97.2±0.8 Ma (Table DR2). Sample 9.1 is a deformed felsic dike within the Pastoria Creek gneiss unit. This location is characterized by interlayered two-mica garnet granite and hornblende diorite gneiss. One of the granitic layers (sample 21 of Saleeby et al., 1987) yielded modestly discordant zircon fractions which could be interpreted either as disturbed Pastoria Creek unit-or BVS-equivalent ages. The location was recollected with focus on subordinate pegmatitic domains. The new sample site grades from pegmatitic to aplitic over ~1 meter, and it exhibits both sharp and diffuse contacts with its granitic host which constitutes one of the thicker felsic lenses within the layered orthogneiss. The pegmatitic domain yielded a fine sparse zircon population with apparent concordance at 95.5±0.8 Ma (Table DR2).

Samples 7, 12, 16, and 17 correspond to thermobarometric samples of the Tejon Creek and Pastoria Creek gneiss units. These samples yielded zircon with U/Pb systematics which closely resemble the systematics of numerous gneiss samples analyzed in Saleeby et al. (1987). For each sample, multiple fractions are externally concordant, or very nearly so, and lie in the age range of ca. 115-110 Ma (Table DR2). Samples 11 and 21 are also from a barometric determination sites. These samples are shown below to belong to the BV suite.

Two "orthogneiss" samples reported in the earlier work (WR30 and WR 171 or samples 18 and 19 of Saleeby et al., 1987) yielded discordia arrays that were tentatively interpreted as indicative of ca. 110 Ma ages. These samples are located within the BV suite tonalite body (formerly interpreted as part of the Tejon Creek unit) that is nested between The BV suite gabbro body and the paragneiss body in the lower Tunis Creek to lower El Paso Creek area (Fig. DR1). Subsequent field and petrographic work suggested that this body is more of BV suite affinity with abundant pyroxene-biotite tonalite of Bison Peak unit affinity encasing more

heterogeneous biotite±hornblende±pyroxene(s) tonalite and diorite, locally with gneissic textures. Samples 11 and 11.1 are representative of the more pristine tonalitic members of this body. Sample 11 yielded an internally concordant zircon age of 102.0±0.8 Ma (Table DR2). Sample 11.1 yielded three modestly discordant ages. These data are shown along with the original WR30 and WR 171 data on the Figure DR2 concordia plot (after Ludwig, 2004). The data together form a grossly linear array with a lower intercept at 101±4.3 Ma and a poorly constrained upper intercept at 651±190 Ma. The dispersion of the data off of the lower concordia intercept from a nearly concordant data point is interpreted to indicate that the lower intercept approximates the igneous age of the suite. This age is the same within uncertainty of numerous concordant ages from BV suite intrusives, including the nearby sample 11, and is taken to indicate that the heterogeneous tonalite body is principally BV suite. The high-degree of dispersion of the upper data points along the concordia line is taken to indicate a heterogeneous inherited/entrained suite of zircon which is consistent with the observation of this particular tonalitic body locally assimilating both orthogneiss and paragneiss host rocks. Additional samples (11.2 and 11.3) were taken from relatively homogenous pyroxene-bearing tonalities originally mapped as BV suite intrusives of Bison Peak unitaffinity. These yielded apparently concordant ages of 101.0±0.9 Ma and 100.5±0.8 Ma, respectively (Table DR2), confirming their BV suite affinity. Sample 21 is from a typical hornblende-biotite tonalite of the Bear Valley Springs pluton. It yielded an apparent concordant age of 99.2±0.8 Ma.

## ANALYTICAL POROCEEDURES

## *U/Pb Zircon and Titanite*

Zircon and titanite were separated from 1-5 kg rock samples by standard pulverizing, density contrast, and magnetic susceptibility techniques. Magnetic separation data procedures were aimed toward maximum sample purity and selection of highest integrity grains. Zircon concentrates were washed in hot  $8N \text{ HNO}_3$  for one-half hour prior to splitting into size fractions, titanite fractions the same, but in  $1N \text{ HNO}_3$ . Selected fractions were hand-picked to >99% purity prior to introduction into the TFE bomb capsule. Zircon samples were then given an additional 15-minute warm wash with ultrapure concentrated HNO<sub>3</sub>, both while in the capsule. Dissolution was in concentrated ultrapure HF with a drop of ultrapure concentrated HNO<sub>3</sub> at 225°C for 3 days. Titanite samples were given an additional overnight ultrapure concentrated HNO<sub>3</sub> bomb cycle at 225°C. Following dissolution, the samples were evaporated and rebombed overnight in 6N HC1 prior to spiking. Samples were then spiked with a mixed  $^{205}$ Pb/ $^{235}$ U tracer, and equilibration was obtained in hot 6N HCL within a sealed PFA container overnight on a hotplate.

Dissolution and chemical extraction techniques for zircon entailed cycles of 2N, 3N and 6N HCl, similar to those described in Krogh (1973). Titanite solutions were loaded as 2N HCl, washed with 1N Hbr, and Pb was eluted with 6N HCl. Titanite Pb column washes were evaporated, and redissolved in 7N HNO<sub>3</sub> and loaded on columns and washed in the same, and then U eluted with 1N HBr. Titanite Pb and U extractions each required a second pass through scaled down clean-up columns.

Mass spectrometry was performed on a VG Sector multicollector instrument. Pb and U were run on outgassed Re single filaments with silica gel and graphite loads, respectively. Pb was ionized at ~1400°C and U at ~2000°C, yielding typical ion beam currents of 1 to 5 x 10<sup>-11</sup> A. Regular intercalibrations of the multiple detector system yielded stabilities at the 10ppm level for time periods typically in excess of several hours, and thus Pb and U were run in a static multicollector mode. Large <sup>206</sup>Pb/<sup>204</sup>Pb ratios were measured with the <sup>204</sup>Pb beam directed into a Daly deflection knobphotomultiplier system. The gain factor was stable within 5 per mil over the course of the Pb runs. A 0.13±0.05/amu mass fractionation correction was applied to both U and Pb runs based on replicate analyses of NBS 982, 983 and U500 standards. Error propagations used in the age determinations are outlined in the footnotes of Table DR2.

## *Sm/Nd garnet-whole rock*

Garnet-whole rock matrix separations followed several slightly different procedures. For sample 2, garnets were separated from the whole rock matrix and both splits were run in entirety. Garnets for this sample were generally well-defined euhedral grains free of inclusions. For samples 1, 5 and 15, large (1-4 cm) garnet porphyroblasts and mantling leucosomes were split mechanically out of the rock, sorted and pulverized separately. Remnants of primary hornblende grains were separated and disgarded from the leucosome fractions. Leucosome materials that were included within the garnets were separated from the garnet splits and mixed back into the leucosome fractions. Opaque mineral inclusions within the garnets ,

typically ilmenite, were separated and discarded. For sample 6b, a similar procedure was used as for sample 2, except the garnets contained leucosome-like inclusions as well as rare opaque inclusions. The leucosome inclusions were separated and mixed back into the whole-rock matrix and the opaques were discarded. The whole rock matrix adjacent to the garnet porphyroblasts in sample 6b appeared to include minor leucosome that was not readily distinguished nor separated from the rest of the matrix, in contrast to samples 1, 5 and 15 (i.e. Fig.5).

Spiking and dissolution techniques of the matrix and garnet powders are similar to those discussed in DePaolo (1978). REE extraction techniques used quartz columns (22 cm length, 0.5 cm inside diameter) filled with AG5OWx8, 200-400 mesh cation exchange resin. Samples are dissolved and loaded onto columns in 1 ml of a 1.0 N HCl solution. A clean separation of REE is achieved after major cation extractions in 1.0N and 2.5 N HCl washes and with 4.0 N HCl elution (5 ml wash followed by 10 ml collection). Approximately 100 mg of dissolved sample is loaded on the column, and blanks are <30 pg for Nd, and <10 pg for Sm. To separate Nd and Sm, the REE cut from the cation exchange column is dissolved in a few drops of 0.1 N HCl and loaded onto a quartz column (22 cm x 0.3 cm i.d.) filled with LnSpec® chromatographic resin. Nd is eluted with 0.25 N HCl (total added: ~10 ml) and Sm with 0.5 N HCl (~5 ml added). A clean separation is achieved with blank levels better than 11 pg for Nd and 3 pg for Sm.

Mass spectrometry was performed on a VG Sector multicollector instrument. Nd is loaded in an AG50W-X8, 100-200 mesh resin bead with  $H_3PO_4$  on a single Re filament and ionized at ~1600° C to yield a typical ion beam current of 5 x 10<sup>-11</sup>A, and is analyzed by a five-cup dynamic mode. Sm is loaded in platinized carbon and HCl on a single Re filament and ionized at ~1500° C to yield a typical ion beam current of 5 x 10<sup>-12</sup>A, and run in static mode. Long-term external precisions on La Jolla Nd standard including the time interval covered in this study are ~10 ppm.

#### *Rb/Sr whole rock-biotite*

The Rb and Sr concentration and Sr isotopic data reported in Table 4 were gathered primarily in the Sr isotope laboratory at the USGS in Menlo Park, California with supplemental data gathered at the Caltech facilities. Results are presented for whole-rock and mineral powders milled to less than 200 mesh. Minerals were isolated by standard techniques of magnetic separation and by gravity in heavy liquids. Samples for isotope ratio measurements or isotope-dilution concentration were digested by standard silicate-digestion (HF+HNO3±HClO4) techniques, and Rb and Sr were separated by ion-exchange techniques. Rb and Sr concentrations of wholerock samples were determined by energy dispersive X-ray fluorescence, whereas standard isotope dilution techniques were used to determine these abundances in biotite mineral separates. Concentrations of Rb and Sr by Xray fluorescence are  $\pm$  3%, whereas they are typically  $\pm$  1% or less by isotope dilution. Strontium isotope ratios were determined using a Finnigan MAT 261 mass spectrometer, using the double rhenium filament mode of ionization. Strontium isotopic compositions are normalized to <sup>86</sup>Sr/<sup>88</sup>Sr=0.1194. Measurements of NBS Sr987 standard yield a mean  $^{87}$ Sr/ $^{86}$ Sr of 0.710239±0.000015 over the period of this study. Reproducibility of <sup>87</sup>Sr/<sup>86</sup>Sr values in rock and mineral samples is commonly about  $\pm 0.008\%$ , due largely to sample inhomogeneity. Constants used for Rb-Sr computations are:  $\lambda_{Rb} = 1.42 \times 10^{-11} \text{ yr}^{-1}$ ,  $\frac{86 \text{Sr}}{88 \text{Sr}} = 0.1194$ , and 85Rb/87Rb = 2.59265 (Steiger and Jager, 1977). Whole rock-mineral isochron ages in Table 4 were calculated using the ISOPLOT program of Ludwig (1999).

For samples 4, 9,13, 18 and 20, whole rock Rb/Sr data were gathered by the same techniques as described above and reported in Saleeby et al. (1987). For this study, biotite separates were taken from splits of the original whole rock powders of these samples and analyzed at the Caltech Biotite dissolution was achieved in ultrapure concentrated facilities. HF+HNO<sub>3</sub>+one drop of HClO<sub>4</sub> in a sealed PFA Teflon vial on the hot plate. Spiking was performed prior to dissolution in the vial. Chemical extraction techniques for Rb and Sr utilized quartz columns (22 cm length, 0.5 cm inside diameter) filled with AG5OWx8, 200-400 mesh cation exchange resin. Samples are dissolved and loaded onto columns in 1 ml of a 1.0 N HCl solution. A clean separation of all elements is achieved by eluting Rb and Sr with 2.5 N HCl (total added to collect both cuts: 20-25 ml). Approximately 100 mg of dissolved sample is loaded on the column, and blanks are <100 pg for Rb and Sr. Mass spectrometry for these biotite samples was performed on a VG Sector multicollector instrument. Sr is run by a four-cup dynamic mode and Rb static mode. Sr is loaded in TaO on a single Ta filament, and ionized at ~1700° C to yield a typical ion beam current of 5 x  $10^{-11}$ A. Rb is loaded in silica gel and H<sub>3</sub>PO<sub>4</sub> on a single Re filament and ionized at ~900° C to yield a typical ion beam current of  $5 \times 10^{-10}$ <sup>11</sup>A. Long-term external precisions including the time interval covered in

this study on NBS Sr987 are ~10 ppm. Analytical uncertainties at  $\pm 2\sigma$  are ~0.5-0.75% for  ${}^{87}\text{Rb}/{}^{86}\text{Sr}$ , ~0.002% for  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$ .

#### Ar-Ar Biotite and Hornblende

Ages of biotite and hornblende by the Ar-Ar or <sup>40</sup>Ar/<sup>39</sup>Ar technique (Table 4) were measured in the USGS laboratory in Menlo Park, CA using argon extracted incrementally with a tantalum and molybdenum resistanceheated furnace. Argon increments were purified in a conventional argon extraction system and measured in an on-line, 6-inch radius, 60° sector, Nier-source, single-Faraday-collector mass spectrometer. Samples were irradiated in the core of the U.S. Geological Survey TRIGA reactor at a 1-MW power level. The reactor neutron flux constant, J, was calculated using Taylor Creek Rhyolite sanidine monitor 85G003, with an age of 28.92 Ma, as reported by Duffield and Dalrymple (1990). This age is standardized to an average age of 513.9 Ma for inter-laboratory standard hornblende, MMhb1 (Samson and Alexander, 1987) and to the Menlo Park laboratory biotite standard, SB-3. Potassium and argon isotopic abundances and the decay constants for <sup>40</sup>K used are those recommended by Steiger and Jager (1977). Corrections for neutron-induced interferences were made using correction factors determined by analyzing argon from irradiated fluorite and potassium glass. Plateau ages of Ar-Ar age spectra are defined as the weighted mean ages of contiguous gas fractions representing more than 50% of the <sup>39</sup>Ar released for which no difference can be detected between the ages of any two fractions at the 95% level of confidence (Fleck et al., 1977). Ar-Ar plateau and isochron ages from incremental-heating experiments were calculated using the ISOPLOT program of Ludwig (2001). The plateau and isochron plots are given in Figure DR3.

## (U-Th)/He Zircon

Single zircon crystals were dated following the Li-borate flux melting procedure described Farley et al. (2004). Whole euhedral grains were selected to be as large as possible (typically 100  $\mu$  x 300 $\mu$ ), measured for  $\alpha$  ejection correction following standard procedures (Farley et al., 2005), and loaded into small Pt tubes. The tubes were placed in a vacuum chamber and heated to 1350 °C using a Nd-YAG laser (House et al., 2000). The evolved helium was spiked with <sup>3</sup>He, cryogenically purified, and the <sup>4</sup>He/<sup>3</sup>He ratio determined by quadrupole mass spectrometry. After degassing the Pt tubes

were placed in slightly larger Pt tubes and flux melted at  $1100^{\circ}$ C for one hour using ~ 2 mg of Li-borate flux. The resulting beads were dissolved in hot nitric acid, spiked with <sup>235</sup>U and <sup>230</sup>Th and Th and U isotope ratios analyzed by inductively coupled plasma mass spectrometry at Caltech. The estimated analytical uncertainty on the resulting ages, including blank corrections, is about 6% at  $2\sigma$ . The expanded analytical data are presented in Table DR3.

As revealed by the spread of ages of multiple grains from each sample, the (U-Th)/He age reproducibility is not as good as expected from analytical uncertainties alone. This likely reflects errors in the  $\sigma$  ejection correction factor, probably arising from U, Th zonation in the grains (Reiners, personal communication 2004). On the assumption that the resulting scatter is distributed in a more-or-less Gaussian fashion around the mean value, we used the ISOPLOT program (Ludwig, 2001)to calculate the weighted average and 95% confidence interval from the individual grain ages.

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Sample	Field Station	Lat/Long	Field Setting	Lithology
1	GV1	34.892 118.912	Primary layered cumulate body within orthogneisses locally pervaded with incipient partial melt and garnet residue domains.	Migmatitic hornblende gabbro with cm-scale garnet porphyroblasts and trondjemitic leucosomes
1b	GV1b	ш	Meter-scale dike within incipiently migmatized hornblende gabbro	Trondjemitic pegmatite with subordinate 3 cm-scale biotite grains
2	GV2	34.917 118.923	Series of tabular intrusive bodies concordant within paragneiss and orthogneiss, locally rich in pelite/psammite restite inclusions	Pristine igneous textured garnet biotite tonalite
3	GV4	34.915 118.922	Small homogeneious pendant within orthogniesses and garnet biotite tonalite intrusives	Biotite kyanite K-feldspar migmatitc paragneiss with granitic leucosomes, and sericite-chlorite retrograding
4	PC129	34.925 118.911	Relatively homogeneious domain within layered quartzofeldspathic and mafic gneisses	Annealed gneissic garnet biotite tonalite
5	GC46	34.916 118.859	Massive dioritic domain within locally layered hornblende gabbro that is variably migmatized	Interlayered residual hornblende diorite with extensive trondjemite leucosome and garnet restite layers
5b	04T7		Meter-scale pegmatitic lens with small appendeges within migmatitic diorite	Pegmatitc to coarse-grained hypidiomorphic-textured trondjemite with traces of biotite and garnet
6	PC107	34.914 118.822	Felsic matrix of relatively homogeneous layered gneiss	Annealed garnet-hornblende- biotite tonalite gneiss
6b	PC107a	п	Meter-scale amphibolititc gabbro layer within felsic gneiss	Annealed hornblende gabbro with up to 0.5 cm-scale garnet porphyroblasts locally surrounded by possible leucosome
7	GC33	34.922 118.826	Homogeneous faintly banded orthogneiss	Annealed hornblende-biotite granodiorite gneiss
8	PC32	34.936 118.816	Homogeneous faintly banded orthogneiss	Annealed biotite granodiorite gneiss
9	PC36	34.916 118.794	Homogeneous faintly banded orthogneiss	Annealed epidote-garnet-biotite tonalite gneiss
9.1	PC35b	34.931 118.796	Pegmatitic lens within interlayerd granitic and dioritic gneiss	Pegmatitic biotite-muscovite- garnet granodiorite
10	PC37	34.908 118.787	Homogeneous faintly banded orthogneiss	Protomylonitic biotite granodiorite augen gneiss
11	TC12a	35.002 118.756	Homogeneous intrusive into layered gneisses	Hornblende-biotite tonalite with accessory hypersthene

Table DR1. Information on sample numbers, locations, field setting and lithology

11.1	03T15	34.954 118.712	Homogeneous intrusive into layered gneisses	Hypersthene biotite tonalite
11.2	03T9	34.942 118.710	Homogeneous intrusive body	Hypersthene-hornblende-biotite tonalite
11.3	03T21	34.986 118.659	Homogeneous intrusive body with hornblende-rich dioritic inclusions	Two pyroxene-hornblende-biotite quartz diorite
12	CM657	35.010 118.758	Homogeneous banded gneiss with local hornblende-rich dioritic layers	Annealed hornblende-biotite tonalite with accessory K-feldspar and myrmekite
13	WR643	35.009 118.706	Homogeneous faintly banded orthogneiss	Annealed hypersthene-biotite tonilite gneiss
14	WR86	34.974 118.729	Local well-preserved cumulate layering, and sparce incipient partial melt/garnet residue formation	Hypersthene-hornblende gabbro
15	TC2a	34.980 118.722	Extensively migmatized domain within variably migmatized cumulate gabbro	Hornblende gabbro matrix with densely spaced domains of extensive trondjemitic leucosome/garnet residue formation
16	GC16	35.013 118.644	Homogeneous faintly banded orthogneiss	Annealed biotite granodiorite gneiss with accessory K-feldspar
17	WR27a	34.945 118.672	Homogeneous faintly banded orthogneiss	Annealed with faint plastic deformation overprint hornblende- biotite tonalite gneiss
17b	WR27ab	n	Meter-scale amphibolitic gabbro layer within tonalite gneiss	Annealed hornblende gabbro
17c	WR27ac	u.	An ~5m thick ductile shear zone within interlayered tonalite gneiss and amphibolitic gabbro	Mylonitic hornblende-biotite tonalite gneiss
18	WR39	34.943 118.663	Homogeneous layered felsic gneiss with subordinate amphibolitic diorite layers	Protomylonititc clinopyroxene- hornblende tonalite gneiss
19	GC1	34.981 118.579	Homogeneous intrusive body	Protomylonitic hypersthene- hornblende-biotite tonalite
20	CM9	35.041 118.568	Homogeneous intrusive body with strong magmatic foliation and cm-to meter-scale deformed mafic enclaves	Biotite-hornblende tonalite
21	CM13b	35.215 118.554	Homogeneous foliated intrusive body (note location is ~1 km off NE corner of map area)	Protomylonitic biotite tonalite with accessory K-feldspar

Table DR2. U/Pb Zircon Isotopic Age Data§

	Fraction <sup>†</sup>	Amount Analyzed	ppm	ppm	<sup>206</sup> Pb	206 Pb *	<u>207</u> Pb*	$\frac{207}{\text{Pb}*}$	Ma 206 Pb*	$Ma \frac{^{207}\text{Pb}*}{^{205}}$	$Ma \frac{^{207}\text{Pb}*}{^{206}}$
Sample	(µm)	(mg)	<sup>238</sup> U	$^{206}$ Pb*	<sup>204</sup> Pb	<sup>238</sup> U	<sup>238</sup> U	$^{206}$ Pb *	<sup>238</sup> U	<sup>235</sup> U	$^{206}$ Pb *
1b	<45	0.9	237	3.14	1498	0.01533	0.1015	0.04802	98.1±0.7	98.2	100±7
5	<45	3.4	102	1.41	2624	0.01593	0.1054	0.04800	101.9±0.9	101.8	99±10
5b	<45	1.1	309	4.06	2211	0.01519	0.1005	0.04797	97.2±0.8	97.3	98±6
7	45-63	2.2	598	9.11	5024	0.01760	0.1173	0.04835	112.5±1.0	112.6	117±8
	63-80	3.0	507	7.67	4402	0.01749	0.1165	0.04832	111.7±0.9	111.9	115±9
9.1	<45	2.2	2,510	32.42	8315	0.01492	0.0988	0.04803	95.5±0.8	95.6	101±6
11	<63	2.5	298	4.11	7321	0.01595	0.1057	0.04806	102.0±0.8	102.1	102±6
11.1	<45	1.2	311	4.34	4347	0.01613	0.1074	0.04824	103.1±0.9	103.6	111±7
	45-63	1.7	302	4.26	5162	0.01629	0.109	0.04851	104.2±0.9	105.1	124±8
	63-81	2.1	277	3.99	4909	0.01665	0.112	0.04880	106.5±0.9	107.8	138±8
11.2	<63	2.1	318	4.35	8162	0.01579	0.1045	0.04799	101.0±0.9	101.0	99±6
11.3	<63	2.5	245	3.33	6994	0.01571	0.1042	0.04810	100.5±0.8	100.7	104±6
12	<45	2.9	707	10.61	10021	0.01735	0.1156	0.04832	110.9±0.6	111.1	115±6
	45-63	3.1	622	9.30	9255	0.01727	0.1152	0.04837	110.4±0.9	110.7	117±6
16	<45	1.9	511	7.76	4211	0.01754	0.1171	0.04842	112.1±0.9	112.5	120±8
	45-63	2.6	463	6.97	3929	0.01740	0.1157	0.04821	111.2±1.1	111.2	110±7
17	<45	2.7	402	5.98	5947	0.01719	0.1143	0.04824	109.9±0.8	109.9	111±6
	45-63	2.5	381	5.69	5013	0.01726	0.1151	0.04836	110.3±0.9	110.4	117±7
19	<45	2.1	211	2.87	1056	0.01571	0.1039	0.04797	100.5±1.0	100.4	98±9
	45-63	2.9	194	2.65	924	0.01581	0.1049	0.04814	101.1±1.1	101.3	106±10
21	<45	1.9	471	6.3	7283	0.01551	0.1027	0.04804	99.2±0.8	99.3	101±6

\* Radiogenic; nonradiogenic correction based on 25 picogram blank Pb (1:18.78:15.61:38.50) and initial Pb approximations. (1:18.83:15.63:38.59) for BV suite and (1:18.92:15.64:38.54) for Tehachapi orthogneisses after Pickett and Saleeby (1994)

<sup>†</sup> Fractions separated by grain size and magnetic properties. All fractions shown are non-magnetic splits. Samples hand-picked to 99.9% purity prior to dissolution. Dissolution and chemical extraction techniques modified from Krogh (1973).

§ Decay constants used in age calculations:  $\lambda^{238}$ U = 1.55125 x 10<sup>-10</sup>a<sup>-1</sup> and  $\lambda^{235}$ U = 9.8485 x 10<sup>-10</sup>a<sup>-1</sup> (Jaffey and others, 1971):  ${}^{238}$ U/ ${}^{235}$ U atom = 137.88. All isotopic ratios corrected for 0.13±0.05/amu for mass fractionation. Uncertainties calculated by quadratic sum of total derivatives of  ${}^{238}$ U and  ${}^{206}$ Pb\* concentration and  ${}^{207}$ Pb\*/ ${}^{206}$ Pb\* equations with error differentials defined as 1. isotopic ratio determinations from standard errors( $\sigma/\sqrt{n}$ ) of mass spectrometer runs plus uncertainties in fractionation corrections given above based on multiple runs of NBS 981, 982, 983, and U500 standards; 2. spike concentrations from range of deviations in multiple calibrations with normal solutions; 3. spike compositions from external precisions of multiple isotope ratio determinations; 4. uncertainty in natural  ${}^{238}$ U/ ${}^{235}$ U from Chen and Wasserburg (1981); and 5. nonradiogenic Pb isotopic compositions from uncertainties in isotope ratio determinations of blank Pb and uncertainties in composition of initial Pb as given above.

#### Table DR3 Expanded (U-Th)/He zircon data

- 401				ll nnm	Eblell	Thoom		He nmol/g	massur	Et.	Widthum	l ongth ur	Length um		Mean	2.7	MSW/D 2 ~	0/.
		Raw	Age (Ma) Corrected	0 ppm	F DIK U	та ррш		He hinol/g	mass ug	г	width um	Length u			wear	2-0	W3VD-2-0	70
4	04CPD	74.916601	89.115783	227.212253	0.029677	32.175076	0.079886	96.302715	26.015	0.839384	59.997	388.552	89.115783	5.34694698	86.0	±2.5		2.90%
	04CPE	72.234392	86.585075	315.230098	0.023728	59.661777	0.049088	130.175858	23.596	0.832987	57.14	388.552	86.585075	5.1951045				
	04CPF	68.722713	82.491767	213.739543	0.035616	48.45461	0.061463	84.645836	22.902	0.831878	57.14	377.124	82.491767	4.94950602				
	04EXO	71.33099	86.255805	330.631803	0.043844	76.849182	0.082434	136.117584	17.35	0.82567	57.14	285.7	86.255805	5.1753483				
8	04CPG	55.476502	64.77759	1053.867086	0.005594	1163.322938	0.002044	402.043502	30.495	0.855699	74.282	297.128	64.77759	3.8866554	87.5	±3.5	5.5	6.30%
	04CPH	75.676486	87.792025	981.688834	0.005479	276.414109	0.007804	433.636823	33.427	0.860906	74.282	325.698	87.792025	5.2675215				
	04CPI	68.675304	81.120161	1410.742801	0.005341	179.217297	0.016709	545.951209	23.863	0.845457	65.711	297.128	81.120161	4.86720966				
	04ESQ	75.774618	87.057324	989.890005	0.002129	214.546277	0.004995	431.611055	44.269	0.86936	77.139	399.98	87.057324	5.22343944				
	04ESR	79.122764	93.399978	1554.802515	0.002165	88.886884	0.018989	683.023523	27.712	0.845814	62.854	377.124	93.399978	5.60399868				
	04ESS	73.788811	86.17686	305.159511	0.00949	64.495034	0.022595	129.386126	31.98	0.855126	68.568	365.696	86.17686	5.1706116				
	04EST	75.108221	90.284841	1629.730617	0.00325	145.243935	0.018313	684.317767	17.598	0.830532	59.997	262.844	90.284841	5.41709046				
9	04CSP	66.307102	77.046456	670.218041	0.007713	80.831522	0.025255	249.998273	34.7	0.85962	71.425	365.696	77.046456	4.62278736	91.1	±7.7	18	20%
	04ESW	68.974324	79.083432	494.194402	0.003921	121.141878	0.008123	197.23769	48.063	0.871247	77.139	434.264	79.083432	4.74500592				
	04ESX	78.870454	91.054108	509.009632	0.004455	133.529305	0.008624	233.422224	41.05	0.865084	74.282	399.98	91.054108	5.46324648				
	04ESV	79.885139	93.439202	509.413593	0.004854	163.671989	0.007682	239.707384	37.631	0.853737	65.711	468.548	93.439202	5.60635212				
	04ESU	81.447945	95.664536	710.111902	0.004329	153.244634	0.010168	332.934762	30.288	0.850105	65.711	377.124	95.664536	5.73987216				
	04CSR	84.712221	97.180712	494.74767	0.007961	86.094191	0.018201	239.101539	45.534	0.870532	77.139	411.408	97.180712	5.83084272				
	04CSQ	91.09857	105.156626	450.023417	0.009973	124.27532	0.014452	239.399905	39.878	0.865028	74.282	388.552	105.156626	6.30939756				
10	04CPA	80.349801	94.037371	725.279542	0.007096	141.889221	0.014473	333.918927	34.877	0.853199	65.711	434.264	94.037371	5.64224226	89.4	±8.2	15	17%
	04CPB	88.173274	102.731638	537.934533	0.009129	143.654721	0.013679	276.33939	36.477	0.856968	68.568	417.122	102.731638	6.16389828				
	04CPC	72.826923	87.127244	526.012993	0.015789	146.671365	0.022605	223.403803	21.424	0.83462	59.997	319.984	87.127244	5.22763464				
	04EXL	70.620635	83.887229	358.495194	0.026668	28.607614	0.135215	141.166399	26.78	0.84064	59.997	399.98	83.887229	5.03323374				
	04EXM	66.625342	80.150277	317.345517	0.038288	55.639471	0.093715	120.424866	20.82	0.830061	57.14	342.84	80.150277	4.80901662				
	04CSC	29 264794	35 326151	304 020081	0 029692	114 457375	0 031641	52 764413	19 432	0 827915	57 14	319 984	35 326151	2 11956906				
	04CSD	28.224799	34.242243	279.655865	0.037361	113.043096	0.037163	47.086097	16.656	0.823775	57.14	274.272	34.242243	2.05453458				
	04CSE	28.497685	34.343235	412.66573	0.020608	133.068146	0.025561	68.925694	20.82	0.829301	57.14	342.84	34.343235	2.0605941				
	04EXT	22.87069	26.733303	203.319677	0.047525	44.679018	0.09371	26.628207	25.929	0.855174	77.139	234.274	26.733303	1.60399818				
14	04CRW	79.98325	92.794856	703.995755	0.006081	67.37327	0.025054	315.43212	41.974	0.860736	68.568	479.976	92.794856	5.56769136	85.2	±4.2	6.4	7.50%
	04CRX	72.837148	83.951013	413.432501	0.010111	59.770537	0.027617	170.443522	42.81	0.866582	74.282	417.122	83.951013	5.03706078				
	04CRY	70.852211	82.662516	763.129378	0.006924	172.237567	0.012265	311.582254	33.979	0.85606	68.568	388.552	82.662516	4.95975096				
	04EXR	72.197283	86.629478	435.749407	0.033878	71.718933	0.088441	178.858948	17.215	0.832119	62.854	234.274	86.629478	5.19776868				
	04EXS	66.471091	80.53261	336.077721	0.038156	48.743788	0.110759	126.370642	19.73	0.824153	54.283	359.982	80.53261	4.8319566				
18		68 206045	78 580321	150 028344	0.016686	40 966327	0 030717	59 571511	36 727	0 86704	70 006	308 556	78 580321	4 71481026	76.0	+7 4	17	2.2%
10	04E97	65 132820	73 603252	40 453105	0.038000	13 0310321	0.058007	15 400/62	58 357	0.883058	88 567	300.000	73 603252	4 42150512	70.0	±1.4		2.2/0
	UTLOL	00.102029	10.030202	10.100100	0.000033	10.001300	0.000331	10.700700	00.007	0.000000	00.007	009.90	10.030202	T.TZ 10001Z				
19	04CSJ	61.845858	74.7153	289.586737	0.034074	22.118036	0.15659	99.690393	17.697	0.826603	57.14	291.414	74.7153	4.482918	73.3	±6.8	3.4	9.30%

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	04CSK 04CSL	65.186288 60.135767	75.172511 70.309393	100.007192 145.555899	0.048627 0.039152	22.32668 22.910593	0.084278 0.094257	37.524445 49.619978	35.367 30.481	0.866246 0.854379	79.996 68.568	297.128 348.554	75.172511 70.309393	4.51035066 4.21856358				
20	04CSF	63.978779	75.387721	244.275002	0.026174	76.585315	0.033314	91.751222	27.535	0.847664	65.711	342.84	75.387721	4.52326326	84.2	±7.2	15	18%
	04CSG	67.670509	81.068733	434.133268	0.019759	125.69544	0.027224	171.636586	20.659	0.833568	59.997	308.556	81.068733	4.86412398				
	04CSI	62.891871	75.20905	298.678263	0.027006	104.046844	0.031035	111.104138	21.807	0.835172	59.997	325.698	75.20905	4.512543				
	04EXH	73.869777	85.470012	309.042952	0.024318	70.947224	0.047111	131.709621	34.15	0.86322	77.139	308.556	85.470012	5.12820072				
	04EXI	81.409523	93.460089	221.354376	0.029816	70.187075	0.042272	106.066745	38.667	0.869969	82.853	302.842	93.460089	5.60760534				
	04EXI	83.085257	95.379978	216.996023	0.030397	68.143067	0.043485	106.066745	38.667	0.869981	82.853	302.842	95.379978	5.72279868		<u>.</u>		

1. U and Th concentrations are blank corrected 2. Ft denotes retained fraction of He after Farley et al (1996)

Sample	Sm/Nd	U/Pb	Ar/Ar	Ar/Ar	Rb/Sr	(U-Th)/He
Number	garnet	titanite	hornblende	biotite	biotite	zircon
1	06.8+2.0					
1.	$90.0 \pm 2.9$	-	-	-	-	-
2.	99.0±3.1	-	-			-
<u> </u>	-	-	-	80.8±0.3	$8/.4\pm1.1$	-
4.	-	-	-	-	87.5±1.1	86.0±2.5
5.	95.9±3.0	-	-	-	-	-
	97.2±1.8					
6.	-	_	91.4±0.7	-	89.1±1.2	
6b.	-	-	93.7±1.6	-	-	-
7.	-	-	94.7±0.7	85.1±0.5	87.0±1.1	-
	-		93.4±0.5	86.0±1		
8.	-	-	-	-	_	87.5±3.5
9.	-	-	-	-	89.2±1.1	91.1±7.7
	-		-		88.1±0.8	
10.	-	-	-	-	-	89.4±8.2
	-		-			86.9±1.9
11.	-	-	-	88.0±0.3	86.9±1.3	-
12.	-	96.1±0.7	93.8±0.9	88.0±0.3	-	-
13.	-	997.0±1	-	-	86.6±1.1	-
14.	-	-	-	-	-	-
15.	-	-	-	-	-	-
16.	-	95.1±0.9	-	-	-	-
	-	96.0±1				
17a.	-	-	-	85.1±0.5	86.5±1.2	-
	-	-	-	87.0±1.1	86.7±0.7	-
17b.	-	-	93.0±0.6	-	-	-
	-	-	93.4±0.5	-	-	-

# Table DR4: Error weighted means of thermochronometric data used to constrain cooling paths in Figure 2. Means shown in bold below individual data points used in calculations

# THERMAL EVOLUTION AND EXHUMATION OF DEEP LEVEL BATHOLITHIC EXPOSURES, SOUTHERNMOST SIERRA NEVADA, CALIFORNIA-SUPPLIMENTARY DATA AND DISCUSSIONS

Saleeby, J., Farley, K.A., Kistler, R.W., and Fleck, R.

## FIGURE CAPTIONS

Figure DR1. Generalized geologic map of the western Tehachapi Range showing thermochronmetric sample locations, and symbols showing locations and age groups of U/Pb zircon samples not included in the sample suite of this study (sources same as Figure 1).

Figure DR2. Pb/Pb-U/Pb Concordia diagram for sample 11.1 tonalite and adjacent tonalite gneiss and quartz diorite for which U/Pb zircon data were published in Saleeby et al. (1987)-Samples 18/WR171 and 19/WR30.2. Plotting and Concordia solution from ISOPLOT (Ludwig, 2001).

Figure DR3. Ar/Ar plateau and isochron age plots (Ludwig, 2001) for hornblende and biotite samples. Sample number correlation is as follows: 3-GV4, 6-PC107, 6b-PC107a, 7-GC33, 11-TC12a, 12-CM657, 16-GC16, 17a-WR27a, 17b-WR27b, 17c-WR27c, 21-CM13b. Data Repository item 2007067









GV4 Biotite





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PC107a Biotite



PC107a Biotite

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PC107a Hornblende



PC107a Hornblende

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Southern Sierra Nevada Ar Figures "D"



PC107ab Hornblende



PC107ab Hornblende



PC107ab Hornblende



GC33 Biotite



GC33 Biotite



GC33 Hornblende



GC33 Hornblende



TC12a Biotite



TC12a Biotite



CM657 Biotite



CM657 Biotite



CM657 Hornblende



CM657 Hornblende



GC16 Biotite



GC16 Biotite

Southern Sierra Nevada Ar Figures "E"



WR27a Biotite



WR27a Biotite



WR27ab Hornblende



WR27ab Hornblende



WR27ac Biotite



WR27ac Biotite



WR27ac Hornblende



WR27ac Hornblende

Data Repository item 2007067

Southern Sierra Nevada Ar Figures "A"



CM13 Biotite



CM13 Biotite



CM13 Hornblende



CM13 Hornblende