Supplemental Data 1: Detailed Methods

Geochemistry

Geochemical data presented are from representative Miocene dikes in the Chemehuevi dike swarm collected across the range. Samples were hand-crushed, and pulverized for 3 minutes using a tungsten-carbide mill for whole-rock geochemistry. The resulting powders were fused into glass discs using a Li-borate flux with a flux:sample ratio of 3:1, and 1 drop of LiI non-wetting agent. Beads were prepared using an 11-minute cycle on a single burner XRF-Scientific Phoenix Fusion machine, and analyzed for SiO2, TiO2, Al2O3, FeO, MnO, MgO, Ca2O, Na2O, K2O, P2O5, and trace elements Ba, Sr, and Zr. X-Ray Fluorescence (XRF) analyses were conducted on the Rigaku Supermini200 at Ohio University. Concentrations were determined using the Fundamental Parameters (FP) method (Kansai, 2008) and calibrated against 12 USGS rock standards. BHVO-2 (basalt) was used as the running standard throughout analysis. Based on the repeated analyses of the running standard, relative uncertainty for element oxides was typically 1-2% or less. Relative uncertainty (accuracy and precision) for trace elements was less than 15%. These are comparable to the long-term uncertainties obtained using the Rigaku Supermini200 at OU for major and trace elements.

Geochronology

To constrain the timing of dike emplacement relative to initiation of faulting associated with the Chemehuevi detachment fault system, U-Pb geochronology and allied trace element geochemistry of zircon from dikes of appropriate composition hosted in domains 1 through 5 were completed. Five dikes from those sampled across the footwall (SW and NE regions) were included for zircon U-Pb dating. We note a significant proportion of the Chemehuevi dike swarm are weakly to moderately altered basalt, trachybasalt and basaltic trachyandesite, hosting no appropriate minerals for geochronology (i.e. U-Pb or 40Ar/39Ar); dated samples are therefore limited to dacite and rhyolite dike compositions.

Samples were crushed using mechanical jaw and disk crushers, sieved to <250 µm, and washed in a water bath. Iron oxides and magnetic phases (e.g. pyroxene and amphibole) were removed using Frantz freefall and magnetic barrier separators. Non-magnetic separates were concentrated by density using methylene iodide. Recovered zircon range from large, euhedral grains with well-defined oscillatory zoning and rare embayed cores, to subhedral or subequant grains with weak oscillatory or irregular zoning. For each sample, 20-50 grains between ~40 to 400 µm in long dimension were hand-picked and mounted in epoxy, polished, washed in 1N HCl to prepare for isotopic analyses, and coated with ~100Å thick Au before geochemical analyses.

*Data Collection and Reduction*

U-Pb zircon dating and trace element geochemical analyses were performed at the U.S. Geological Survey–Stanford Ion Microprobe Laboratory using the sensitive high-resolution ion microprobe–reverse geometry (SHRIMP-RG). Prior to analysis, all grains were imaged using both reflected light and cathodoluminescence. These images were used as a guide for avoiding microcracks and inclusions, and for targeting specific zones within grains. SHRIMP-RG analyses were conducted using an O2-primary ion beam accelerated to 10kV with an intensity ranging between 6.9-11.7nA and a spot size ranging between 20-24µm, with a depth of ~2-3 microns. Thirteen to twenty-nine grains were analyzed from each sample with each spot analysis the average of 6 scans through 16 mass stations. Before each analysis, the sample surface was cleaned by rastering the primary beam for 60 seconds to remove surficial common Pb. The primary and secondary beams were simultaneously auto-tuned to maximize transmission. The acquisition routine included analysis of 30Si16O+, 48Ti+, 56Fe+, 89Y+, 155Gd+, 172Yb16O+, 90Zr216O+, 180Hf16O+, 204Pb+, a background measured at 0.046 mass units above the 204Pb+ peak, 206Pb+, 207Pb+, 208Pb+, 238U+, 232Th16O+, and 238U16O+ stepping sequentially through the mass sequence from 46 to 254. Trace element measurements are measured briefly (typically 0.5-2 seconds per analysis) mass order immediately before the geochronology peaks. All peaks are measured with 6 scans (peak-hopping cycles) through the mass sequence. Measurements were made at mass resolutions of M/DM = 9,200-9,600 (10% peak height), which fully separates interfering molecular species, particularly for the rare earth elements, from the isotope of interest. The high-abundance sensitivity and high mass resolution of the SHRIMP-RG, in addition to HCl washing of the mount and rastering the area before data collection assures that the background count-rates are low and any counts found at mass of 204Pb+ are actually from Pb in the zircon and not surface contamination.

Data reduction for geochronology follows the methods described by Ireland and Williams (2003) using the Microsoft Excel add-in programs Squid 2.5 and Isoplot 4. 1 (Ludwig, 2012). U-Pb calibration constant for zircon was calculated based on the variation of *ln*(UO/U) vs. *ln*(Pb/U) of the standard Temora-2 measured during the analytical session with a fixed slope of 2. The measured 206Pb/238U was corrected for common Pb using 207Pb, whereas 207Pb/206Pb was corrected using 204Pb. The common-Pb correction was based on a model Pb composition from Stacey and Kramers (1975); no additional error was propagated from the uncertainty in the model common-Pb composition. Calculated ages for zircon are standardized relative to Temora-2 (416.8 Ma; Black et al. 2004), analyzed every 4th analysis throughout the duration of the analytical session.

Measured, uncorrected U-Pb isotopic ratios are plotted on Tera-Wasserburg concordia diagrams (Tera and Wasserburg, 1972), as they afford a more reliable means for evaluating the coherency of spot analyses than conventional concordia diagrams due to the young age. All ages quoted however are 207Pb corrected weighted average 206Pb/238U ages based on a linear York regression (Table 2; York 1968). We assume the calculated weighted mean ages for zircon from each dike represent crystallization ages at near-solidus conditions.

All reported 206Pb/238U ages and uncertainties for individual analyses include error summed in quadrature from the external reproducibility (1σ standard deviation) of the standard Temora-2 during an individual analytical session (16-24 hours). The calculated weighted mean ages are reported at 2σ standard deviation and include uncertainty propagated from the standard error of the mean for the calculated calibration constant, derived from the reproducibility of the standards. Spots with >85% common 206Pb, overlap with fractures or inclusions are excluded as unreliable ages.

Concentrations of select trace elements (Ti, Fe, Y, Gd, Yb, Hf, U, and Th) were measured and standardized against the well-characterized, homogeneous in-house zircon standard MADDER, calibrated relative to MAD-green (4196 ppm U; Barth and Wooden 2010). MADDER was added to each mount with unknowns, and measured during each analytical session. Average count rates of each element of interest are ratioed to the appropriate high mass normalizing species to account for any primary current drift, and the derived ratios for the unknowns are compared to an average of those for the standards to determine concentrations. Spot to spot precisions (as measured on the standards) vary according to elemental ionization efficiency and concentration. For the MADDER zircon, precisions generally range from ±6%, 4%, 11%, 7%, 3%, 7%, 2%, and 11% for Ti, Fe, Y, Gd, Yb, Hf, U, and Th, respectively (all values at 1σ standard deviation).

Ti-in-zircon temperatures were calculated using measured 48Ti and the recalibrated method of Ferry and Watson (2007). In samples where rutile is present *a*TiO2 = 1; in the absence of rutile (i.e. *a*TiO2 <1) an intermediate value of 0.7 is used. Although aTiO2 is poorly constrained, Hayden and Watson (2007) demonstrate that *a*TiO2 is often greater than 0.5 in Ti-rich crustal rocks, especially those hosting Ti-rich phases including ilmenite and titanite. Thus, an intermediate value for *a*TiO2 of 0.7 is assumed. Quartz is common in all samples analyzed; silica activity is therefore approximated as 1 (i.e. *a*SiO2 = 1.0) for all but sample *BJ14Ch-2*. Analyses with anomalous trace element concentrations – indicative of contamination by targeting an inclusion, fracture or epoxy – are not included in the mean Ti-in-zircon temperatures. Although the solidus temperature for each dike composition is relatively poorly constrained, we interpret the calculated Ti-in-zircon temperatures to indicate crystallization of the analyzed zircon under near-solidus conditions, and use these temperatures and ages to help infer extension and heating of the footwall during regional extension.

**Supplemental References Cited**

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