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Identifying elusive piercing points along the North American transform margin using mixture modeling of detrital zircon data from sedimentary units and their crystalline sources

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SUPPLEMENTAL DOCUMENTATION

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DATA AND METHODS

Detrital Zircon Geochronology

Mineral separation

Sample preparation at Colorado School of Mines included a jaw crusher and disc mill for grain disaggregation and density separation on a Wilfley Table. The heaviest fraction was run over a slope Frantz magnetic separator set to 0.2–1.6 Amps in 0.2 Amp increments to remove any ferromagnetic minerals. The zircon grains were then separated using heavy (> 2.85 g/cc) liquid methods (Methylene Iodide).

U-Pb LA-ICP-MS Analysis

The geochronology data for samples analyzed for this study were collected at the University of Arkansas TRAIL Lab (https://icp.uark.edu/the-ub-geochronology/) using their ESI NWR 193nm Excimer Laser Ablation System and Thermo Scientific iCapQ Quadrupole Mass Spectrometer. Zircon grains were mounted on double-sided tape and chosen at random for analysis. The data were collected using the following laser and mass spectrometer settings: 25 micron spot size, 200 shot bursts (10Hz rep rate for 20 seconds), ∼15 second gas blank, and then washout (total analysis length is about 50 seconds), 800 mL/min He flow, and a power setting of 40% and a fluence (energy of laser divided by area of illumination) of ∼3.5 J/cm^2. The following samples were run with n=120 grains in November of 2018: upper Modelo (t6), lower Modelo (t5), Vaqueros (t4), basal Vasquez (t2), Matilija (t1) and Juncal (t0) Formations. Samples from the Vasquez (t3) and Pico (t7) Formations were run in June 2019 and n=150 grains were selected. The analysis used Plešovice

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(Sláma et al., 2008) as primary standard, 91500 (Wiedenbeck et al., 1995) as secondary standard and R33 (Black et al., 2004) as tertiary (backup) standard. Five analyses of the primary standard, then five secondary standards were repeated three times for calibration. Throughout the rest of the analyses, 10 samples were shot, followed by 1 tertiary, secondary and primary standard, then 10 more samples followed by only the secondary and primary standards. This pattern was repeated for the all analyses.

Data were reduced using Iolite software and the excel template named "Zircon U-Pb Data Reduction Template.xls" originally created by Lisa Stockli, Owen Anfinson and modified by Kelly Thomson (Table S1). For zircon <1300 Ma, the $^{206}Pb/^{238}U$ ages were used and for zircon >1300 Ma, the $^{207}Pb/^{206}Pb$ ages were used. Several age cutoffs were tested, but the 1300 Ma cutoff best displayed the distinct geochronological signature of each parent source. The only apparent difference when using younger age cutoffs was that the approximately 1200 Ma zircon present in sample t2 had several small peaks between 1200–900 Ma with unusual isochron estimations that were attributed to Pb loss. Barth et al. (1995) also reported these finding in the San Gabriel anorthosite from SHRIMP microprobe ages. Discordant grains were discarded using the following cutoff parameters: 30% $^{206}Pb/^{238}U$–$^{207}Pb/^{206}Pb$ discordance filter for $^{207}Pb/^{206}Pb$ ages, -15% $^{206}Pb/^{238}U$–$^{207}Pb/^{206}Pb$ reverse discordance filter for $^{207}Pb/^{206}Pb$ ages, 10% error cutoff for $^{206}Pb/^{238}U$ ages, and 15% $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ discordance filter for $^{206}Pb/^{238}U$ ages. After data reduction, we found that using 91500 as the primary standard resulted in ages much closer to those of our parent source ages from the literature. Both the $^{206}Pb/^{238}U$ age (1062.4 ± 0.8 Ma) and $^{207}Pb/^{206}Pb$ age (1065.4 ± 0.6 Ma) of the 91500 standard reported through CA-TIMS dating (Wiedenbeck et al., 1995) are much closer to the ∼1200 Ma zircon in sample MN-16-08 than the Plešovice standard ($^{206}Pb/^{238}U$ age = 337.16 ± 0.6 Ma, $^{207}Pb/^{206}Pb$ age = 337.96 ± 0.61 Ma, CA-TIMS) (Sláma et al., 2008). An equal number of 91500 and Plešovice analyses were collected, so the reduction only involved switching the primary and secondary standards and repeating the data reduction with the same parameters.

Sediment Mixture-Modeling

Selecting Parent Populations

All published zircon geochronology ages found in the region were originally included as parents in the mixture modeling. However, there were several instances where we decided to remove or combine published zircon populations as potential parent sources. As a sensitivity analysis, the parents were tried in many different combinations and those parents that never contributed to the children were disregarded as a potential source. The list of detrital zircon data sources used in the mixture modeling is included in Table S2.

Jurassic zircon ages are sparse in the area and Cretaceous zircon ages are found in many of the same areas due to the long history of the Farallon subduction zone. For this reason, we combined the Jurassic and Cretaceous ages together as one parent population, preferring higher numbers over spatial uniqueness.

Zircon from the Pelona Schist (exposed in the Sierra Pelona) have both Mesozoic and Paleoproterozoic age peaks (Jacobson et al., 2000), but only a small peak at ∼1200 Ma, and no peaks between 1500–1300 Ma. The Sierra Pelona could be a sediment source for both Miocene and Pliocene samples (t4–t7). However, when included in the mixture models, it overfit the data and was therefore removed. For example, the mixture model for the Juncal (t0) and Matilija (t1) Formations included a significant percentage of Pelona Schist. This was interpreted as the model preferring one parent with two age populations that are very similar to two other parents (Cretaceous–Jurassic and the Mendenhall Gneiss). It is unlikely that the Sierra Pelona contributed to t0 or t1 because both detrital samples have zircon in the 1500–1300 Ma range and a several ∼1200 Ma grains. Therefore, it is more likely that the Precambrian zircon in the detrital samples were sourced from the southern edge of the San Gabriel anorthosite and the aureole in the Mendenhall Gneiss and not from the distal Sierra Pelona.

Sediment Unmixing Modeling Program

A python script (i.e. Jupyter notebook) named VenturaBasinMixing.ipynb (https://github.com/clarkgilbert/VenturaBasin-sediment-mixing) was heavily modified from the Sediment Unmixing Modeling python package available at (Sharman and Johnstone, 2017). The program accepts detrital zircon data in the template of Table S2. The program uses a forward-modeling approach at estimating what mixture of a fixed number of parents likely contributed to a child population based on a predefined comparison metric. Here we use a forward model in an inverse approach by examining a large number of models with different parameters to find the best fitting parameters (mixing coefficients). Each parent is specific and predefined by looking at the available detrital zircon data in the region. The mixture models use the following equation

$$KDEMix = MixCoeff_1 * KDE_{P1} + MixCoeff_2 * KDE_{P2} + MixCoeff_n * KDE_{Pn} \tag{1}$$

where the output is a kernel density estimate (KDEMix). This best-fit mixture is the sum of each potential parent's kernel density estimate (KDE) multiplied by its mixture coefficient. The equation for the kernel density estimator can be expressed as (Silverman, 2018; Vermeesch, 2013):

$$KDE\,(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_1}{h}\right) \tag{2}$$

where in this case K is a Gaussian kernel and h is the bandwith of 1.5 Ma. In this study, the Vmax value of the Kuiper statistic (Saylor and Sundell, 2016) is calculated for an entire distribution, and used to evaluate the goodness of fit for each. All of our forward mixture models would have a set of mixing coefficients, which are used to create the mixed PDP via Equation 1, and the single Vmax value is calculated between the entire observed PDP and the mixed PDP. We then try many combinations of mixture coefficients and find the mixture coefficient combination that produces the smallest Vmax. Every parent distribution is therefore present in every part of the mixed Vmax. However, some parent distributions might not have any grains at certain ages and are therefore zero. The mixture of each parent that contributed to a given child is reported in percent (Fig. 3) with a resolution of 0.01 (1%). The vertical separation between the child kernel density estimate (black line) and the best-fit mixture model (red dashed line) shows how closely the model fits the data. We used a method of resampling with replacement bootstrap method reported in Malkowski et al. (2019) as a sensitivity analysis and to report uncertainties within the best-fit mixtures. This permutation method randomly removes a zircon date from the given parent and child distributions and randomly substitutes another date in the distribution. This sensitivity analysis hints at how much changing the ages in our predefined parents affects our models. Peaks in the kernel density estimates defined by fewer zircon dates are typically more sensitive to the bootstrapping. Our study reports the permutation results for 10,000 iterations with an optimized search. However, a brute force search was conducted on 1,000 iterations as another test and the results did not change from those of the optimized search. Therefore, we assume that the optimized search is not arbitrarily ignoring portions of the distributions.

Reconciling ID-TIMS and LA-ICP-MS dates

Models that used parent distributions composed of zircon dates collected using high precision isotope dilution-thermal ionization mass spectrometry (ID-TIMS zircon) posed problems with mixture model results. When ID-TIMS dates reported by Barth et al. (1995) were used to create a parent distribution for the San Gabriel anorthosite (Fig. 2), the mean varied by up to 20 Ma from any calculated means of the age peaks from the child distributions of zircon dates collected from the LA-ICP-MS method. In effect the best-fit mixture model would include a contribution of the Triassic Mount Lowe Granodiorite even though no zircon dates of that age existed in the unimodal child population. We hypothesize that because the LA-ICP-MS dates are not within uncertainty of the high precision ID-TIMS dates, and they are comprised of younger dates, the model includes younger dates to skew the mean down. Luckily, Barth et al. (2001) also used sensitive high-resolution ion microprobe (SHRIMP) methods to reanalyze the same zircon previously analyzed by ID-TIMS methods. Calculated errors in SHRIMP dates used for the parent distribution for the San Gabriel anorthosite were similar to those in the child distribution of LA-ICP-MS zircon dates and were used to create the parent age distribution.

Sandstone Automated Mineralogy (SAM)

Standard thin sections (27 x 46 mm) were made from the same samples used for both detrital zircon geochronology and sandstone automated mineralogy (SAM) analysis with the exception of sample t7. No thin section was made for t7 because the sandstone was so disaggregated that it would need epoxy impregnation, which could introduce selection bias. Automated mineralogy analyses were conducted at the Automated Mineralogy Lab at Colorado School of Mines, using their TESCAN Integrated Mineral Analyzer (TIMA) system (https://geology.mines.edu/laboratories/automated-mineralogy-laboratory/). The model number for this system is Tescan-Vega-3 Model LMU VP-SEM. A 7 µm increment was chosen for the energy dispersive X-ray spectrometer (EDS) with a light cutoff of >35% to focus only on the heavy (brightest) minerals with a higher resolution. Acceleration voltage=24 keV and beam intensity=14 for all analyses.

Data reduction involved identifying minerals within the samples based on their chemical makeup (EDS response), and a proprietary mineral-model database at the Automated Mineralogy Lab was utilized. Samples from the following formations had $\geq$1% of unidentified minerals: Juncal (t0=4.6%), Vasquez (t3=1.0%), Vaqueros (t4=1.3%) and lower Modelo (t5=1.0%), while the other 4 had only trace ($\leq$1%) amounts. Non-unique minerals or minerals with low concentrations were grouped by mineralogy (Table S4).

UNCERTAINTY IN THE DEPOSITIONAL AGES OF THE VASQUEZ AND VAQUEROS FORMATIONS

Vasquez Formation

The Oligocene coarse-grained red beds found north of Lake Piru and in Canton Canyon have historically been assigned to the Sespe Formation due to their stratigraphic position (Bohannon, 1975; Dibblee, 2010, 1989; Crowell, 2003). However, the finer-grained fluvial-deltaic deposits of the Sespe Formation were deposited further south from an extra-regional

Results of Mixture Modeling of Detrital Zircon Data

Function	Vmax	1000 iterations per model

Parent name	N analyses
CJ	246
LG	33
SGA	35
MG	39

		Vmax values	Modeled parent contributions (percent p50 (p2.5 - p97.5))			
Child name	N analyses	[p50 (p2.5 - p97.5]	CJ	LG	SGA	MG
t7	131	0.35 (0.28 - 0.44)	0.44 (0.22 - 0.58)	5.13e-17 (0.0 - 0.06)	3.32e-17 (0.0 - 0.02)	0.55 (0.41 - 0.77)
t6	115	0.31 (0.19 - 0.46)	2.22e-16 (0.0 - 0.10)	1.73e-17 (0.0 - 0.01)	3.02e-17 (0.0 - 0.07)	1.0 (0.89 - 1.0)
t5	102	0.38 (0.26 - 0.51)	0.23 (0.13 - 0.44)	4.72e-17 (0.0 - 1.85e-13)	6.05e-17 (0.0 - 1.08e-13)	0.77 (0.56 - 0.87)
t4	118	0.29 (0.18 - 0.43)	7.07e-17 (0.0 - 0.1)	3.58e-17 (0.0 - 0.02)	0.06 (0.0 - 0.32)	0.92 (0.68 - 1.0)
t3	144	0.22 (0.16 - 0.30)	0.06 (7.64e-20 - 0.22)	0.367 (0.275 - 0.47)	0.49 (0.29 - 0.58)	0.08 (9.4e-21 - 0.22)
t2	118	0.34 (0.20 - 0.50)	1.68e-17 (0.0 - 0.03)	2.18e-17 (0.0 - 0.047)	0.94 (0.80 - 1.0)	0.05 (0.0 - 0.20)
t1	98	0.20 (0.14 - 0.28)	0.33 (0.16 - 0.47)	1.49e-06 (0.0 - 0.11)	4.47e-4 (0.0 - 0.15)	0.63 (0.46 - 0.79)
t0	112	0.19 (0.14 - 0.27)	0.23 (0.06 - 0.42)	0.09 (1.93e-18 - 0.21)	0.125 (1.13e-18 - 0.29)	0.56 (0.26 - 0.77)

Table S3: Results of the mixture modeling used in this study. The median (p50), and bounds on the 95% confidence interval (p2.5 and p97.5) are reported for both the Vmax values and modeled parent contributions for each bootstrapped model.

source in the Basin and Range province (Ingersoll et al., 2018). In contrast, the alluvial deposits near Lake Piru have clast sizes up to 7 m (Bohannon, 1975) and are similar to the Vasquez Formation at its type section in the Soledad Basin (Hendrix and Ingersoll, 1987). We interpret that the Oligocene deposits at Lake Piru are part of the Vasquez Formation, not the Sespe Formation.

The depositional age of the Vasquez Formation in the Soledad Basin is unknown because no diagnostic fossils have been reported. However, plagioclase within volcanic units near the base of the Vasquez Formation yielded potassium-argon (K-Ar) dates of 20.7 $\pm$ 0.8 (Woodburne, 1975), 24.5 $\pm$ 0.8 and 25.6 $\pm$ 2.1 Ma (Crowell, 1973). Hendrix and Ingersoll (1987) used these K-Ar dates and the recognition of early Miocene vertebrate fossils in the overlying Tick Canyon Formation to interpret that the Vasquez was deposited between 21 and 25 Ma. Frizzell Jr and Weigand (1993) reported a whole-rock K-Ar date of 23.6 Ma, which corroborated the previous dates of Crowell (1973), and interpreted that volcanism in the Vasquez Formation happened between 25.6–23.6 Ma (Hoyt et al., 2018).

Correlation of the Vasquez Formation between the Soledad and Ventura basins is difficult and we recognize this uncertainty. The Vasquez Formation in the Soledad Basin is >5000 m thick with volcanic units near its base, while at Lake Piru in the eastern Ventura Basin, it is only 90 m thick and does not contain recognizable volcanics. Despite these differences, we interpret that they are at least partially correlative due the similarities in grain size, composition, texture, mineralogy, and sedimentological structures between them. No fossils have been reported from the Vasquez Formation at Lake Piru, but we assume that it is older than 21 Ma, especially because the base of the overlying Vaqueros Formation is also interpreted to be Oligocene in the region.

Vaqueros Formation

The exact age of the Vaqueros Formation at Lake Piru is unknown and was interpreted from nearby studies. The age of the Vaqueros Formation has been debated since it was first described by Hamlin (1904) in Vaqueros Creek near Monterey, California. Unfortunately this nomenclature was used throughout California based on outdated biostratigraphic correlations until Thorup (1943) formalized the type section to include 600 m of marine sandstone and siltstone. Loel and Corey (1932) designated a "Vaqueros Formation" for the unit based on the presence of the gastropod species *Turritella inezana*, but did not honor strict stratigraphical constraints (Edwards, 1971). Addicott (1972) defined the "Vaqueros Stage" by adding other molluscs and designating it as late Oligocene to early Miocene (Blake, 1983). Two studies used magnetic stratigraphy to demonstrate that molluscs of the "Vaqueros Stage" are found in rocks as old as 27.5 Ma at Big Mountain 20 km south of Lake Piru (Prothero et al., 1996), but as young as ∼17 Ma in the Santa Ana Mountains (Prothero and

Mineral Name	Juncal t0 MN-16-06*	Matilija t1 MN-16-07*	basal_Vasquez t2 MN-16-08*	Vasquez t3 MN-16-05*	Vaqueros t4 MN-17-11*	lower_Modelo t5 EDF-17-1*	upper_Modelo t6 MN16-04*	Granite CC-17-GR*
Quartz	32.1	43.1	6	13.2	41	38.6	38.7	36.1
Orthoclase	17.3	21.5	7.7	10.6	20.7	25	21.2	25.3
Plagioclase	27.9	28.1	57.1	60.1	28.3	28.6	32.5	32.6
Muscovite	1.3	1.5	0.8	0.9	1.8	0.9	1.5	3
Biotite	2.5	1	7.6	2.6	2.3	2.1	2.6	2.6
Chlorite	0.8	0.2	2.9	0.4	0.1	0	0.1	0
Apatite	0.2	0.1	1.5	0.5	0	0.1	0.2	0
Pyroxene/ Amphibole	0.1	0.6	6.2	6.2	0.8	0.3	0.7	0
Garnet	0.9	0.1	0.6	0.1	0.2	0.1	0	0
Epidote	0.7	1.6	2.2	1.9	0	0	0	0
Tourmaline	0.5	0	0	0	0.1	0.1	0	0
Other Silicates	1	0	0	0	0.1	0.1	0	0
Zircon	0	0	0	0	0	0	0	0
Titanite	0.1	0.1	0.4	0.2	0	0	0	0
Rutile	0.3	0.1	0.2	0.1	0.1	0.2	0.1	0
Ilmenite	0	0.1	1.9	0.5	0.3	0	0.2	0
Chromite	0	0	0	0	0	0	0	0
Fe oxides	0.3	0	0.6	0.1	0.1	0	0	0
Other oxides	0	0	0	0	0	0	0	0
Sulfates	0	0	0	0	0.1	0	0	0
Olivene	0	0	0.1	0	0.2	0	0	0
Other REE	0	0	0	0	0	0	0	0
Carbonates	7	0	0	0	0	0	0	0
Clay Minerals	2	1.3	2.5	1.4	2.3	3	1.3	0.1
Clinochlore	0.1	0	0.2	0.2	0	0	0	0
Ankerite+clay	0.1	0	0.1	0	0	0	0	0
[Unclassified]	4.5	0.6	1.2	0.9	1.3	1	0.7	0.1
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table S4: Automated mineralogy reported as modal abundance (area percent of each mineral phase) for Ventura Basin samples. All analyses were completed on the TIMA platform at Colorado School of Mines. Original sample names used in field are denoted by asterisk (*).

Donohoo, 2001) approximately 110 km to the southeast. These studies demonstrated that the fauna of the Vaqueros stage lived between 28–17 Ma (late Oligocene to late Miocene) and therefore are not particularly useful as index fossils.

The following criteria were used to predict the age of the Vaqueros Formation in Piru Creek, and the implications that alternative hypotheses could have on the interpretations in this study. A detailed biostratigraphy study at Big Mountain (22 km to the south of the outcrop in Piru Creek determined that the lowest part of the section was late Zemorrian (late Oligocene) in age (Blake, 1983). However, this interpretation is based on shallow water benthic foraminifera that are difficult to correlate to other California stages based on deep-water bathyal fossils (Edwards, 1971; Blake, 1983). The fauna in the upper two members of the Vaqueros Formation at Big Mountain are equivalent to the lower Rincon Shale at Los Sauces Creek ∼60 km to the west near Carpenteria, California (Edwards, 1971; Blake, 1983). The base of the Rincon Shale is interpreted as early Miocene 80 km to the west at the Tajiguas Landfill near Santa Barbara, California (Stanley et al., 1994) and (Prothero and Donohoo, 2001) interpreted this entire section of Rincon Shale to be either 23.2–22.2 Ma or 21.5–20.0 Ma based on magnetostratigraphy.

It is unclear if the section through the Vaqueros at Piru Creek are age-equivalent to the section at Big Mountain because the Vaqueros Formation is overlain by the Conejo Volcanics (Blundell, 1983) and the Rincon Shale is not present. The Conejo Volcanics have been K-Ar dated at 15.9 $\pm$ 0.8 Ma (Turner and Campbell, 1979) and have an Ar-Ar date range of 17.1–16.3 Ma (Weigand et al., 2002), which suggests that there was significant period of nondeposition or erosion between the two units. However, studies based on biostratigraphy (Blake, 1983) and magnetic stratigraphy (Prothero et al., 1996) support the conclusion that the base of the Vaqueros Formation is Oligocene at Big Mountain.

How the section of the Vaqueros Formation and the overlying Rincon Shale at Lake Piru correlates in age to other basins is currently unknown. Although the youngest reported age of the Vaqueros Formation is ∼17 Ma, its top must be older than 17.4 Ma, which is the reported age of the base of the Modelo Formation at Lake Piru (Yeats et al., 1994). More than 600 m of Rincon Shale lies between these two surfaces. If this section is correlative to the section at Tajiguas Landfill, then the base of the Rincon Shale is at least 20 Ma (Prothero and Donohoo, 2001) and the top of the Vaqueros Formation is older than 20 Ma. The overlying Vasquez Formation at Lake Piru is between 21 and 25 Ma if it is equivalent to its type section in the Soledad Basin. Therefore, we assume that the depositional age of sample t4 from the Vaqueros Formation is older, likely between 25–20 Ma. However, due to the uncertainty in correlating to nearby sections, we use a conservative age range of 27.5–18 Ma for the Vaqueros Formation piercing point (box t4) described below.

PUBLISHED RECONSTRUCTIONS

Reference	Fault Name	Right Slip	Timing	Notes
Crowell (1954)	San Gabriel	60 km total		Restoring Alamo-Frazier Mountain to similar basement rocks in San Gabriel Mountains
Crowell (1962)	San Gabriel	35 km	Oligocene–Middle Miocene	Offset of Eocene and Oligocene 'megabreccias' in the Soledad Basin
Bohannon (1975)	San Gabriel	60 km total		Required to juxtapose the Oligocene Sespe conglomerates in Canton Canyon to the anorthosite and Mount Lowe Granodiorite source in the San Gabriel Mountains. Cites (Crowell, 1954)
Ehlig (1982)	San Gabriel	60 km total		
Ehlert (1982)	San Gabriel	60 km total	Miocene	Correlates upper part of the Mint Canyon and Caliente Formations with Chocolate Mountains based on the presence of rapakivi-textured clasts
Crowell (1982)	San Gabriel-Canton	60 km total	12 to ∼14 Ma, ended at ∼5 Ma	Claims timing is only valid if earlier fault offset the Sespe Conglomerates
Crowell (1982)	San Gabriel	55 km		Restore 25–30 Ma Sespe Conglomerates to their source region near the Big Tujanga Wash in the western San Gabriel Mountains
Crowell (1982)	Canton		10.5–8.5 Ma	
Powell (1993)	San Gabriel-Canton-Vasquez Creek fault	42–46 km total	12–13 Ma to present	Restores Frazier Mountain block to Mount Pinos and the eastern Orocopia Mountains
Powell (1993)	Canton	13 km	13–10 Ma	Assumes that the anorthosite bearing Modelo Formation is fully offset. However, if it is not fully offset, movement could have began at 16–14 Ma based on finding no evidence of faulting before the end of the Saucian

Table S5: Summary of published restorations showing the timing and magnitude of slip along the San Gabriel–Canton fault system.

Powell (1993)	San Gabriel	21–23 km	10–6 Ma	Timing is based on fossil evidence of the age of units interfingering with the Violin Breccia in Ridge Basin and the distance that it is offset from its source area in Frazier Mountain
Powell (1993)	San Gabriel	3–5 km	6–4 Ma	
Powell (1993)	Vasquez Creek Fault	≤∼5 km	6 Ma to present	Offset of quartz diorite units used as piercing points. Any restoration 5 km causes the units to misalign. Also known as the south branch of the San Gabriel Fault. Timing is based on offset of Pacoima and Big Tujunga Canyons
Matti and Morton (1993)	San Gabriel	≤∼44 km total		22 km on north branch based on restoring Mount Lowe Granodiorite 'tail' with main body, 22 km on south branch based on their "proposal that the fault has displaced the left-lateral Malibu Coast-Santa Monica-Raymond fault from the Evey Canyon-Icehouse Canyon fault in the southeastern San Gabriel Mountains"
Yeats et al. (1994)	San Gabriel	60 km total	10–5 Ma	Offset of the Precambrian Mendenhall Gneiss and anorthositic rocks from near Frazier Mountain and the western San Gabriel Mountains (Crowell, 1962; Ehlig and Crowell, 1982)
Yeats et al. (1994)	Canton	≥23 km	10 Ma	Canton Fault dies out in the Miocene Devil Canyon Congomerate, meaning at least 23 km of slip happened prior to deposition
Yeats et al. (1994)	San Gabriel		Miocene because Mint Canyon Formation is offset (Ehlig et al., 1975;) and Ehlert, 1982)	60 km Alamo-Frazier source for breccia in Mint Canyon Formation in Soledad Basin. Timing of Initiation: Clarendonian and Barstovian verterbrate stage fossils and Tuff beds in the Mint Canyon. Zircon fission-track ages of 10.1 ± 0.08 Ma and 11.6 ± 1.2 Ma (J. Obradovich and T.H McCulloh in Terres Luyendyk, 1985)
Yeats et al. (1994)	San Gabriel	35–56 km	10–5 Ma	Right slip of at least 35 km but possibly as much as 56 km is required to place the lower Mohnian Devil Canyon Conglomerate next to its probable source in the San Gabriel Mountains
Yeats et al. (1994)	San Gabriel	35–60 km	10–5 Ma	Offset of gneiss clasts Violin Breccia in Ridge Basin to appropriate source area
Yeats et al. (1994)	Devil Canyon		10-5 Ma	Interprets that the Canton Fault rejoins the SGF north of the Castaic Hills oil field and therefore it cannot continue into the San Fernando Valley. He thinks that the Devil Canyon Fault could have taken some of that slip
Yeats et al. (1994)	San Gabriel	≥30 km	10–5 Ma	The apex of the Hasley submarine fan is offset at least 30 km from its inferred source region in the San Gabriel Mountains
Yeats et al. (1994)	San Gabriel	0 km	Pliocene >2 Ma	The upper Fernando Formation is correlative across the San Gabriel Fault, suggesting most of the fault movement on the northern strand ceased before then. However, he places some caveats on biostrat correlation, etc.
Yeats et al. (1994)		∼10 km shortening	Post SGF movement	
Rumelhart and Ingersol (1997)	San Gabriel	50–60 km total	12 Ma–5 Ma	Timing: rapid sedimentation rates in the adjacent Los Angeles basin; Total slip: The Modelo Formation in the Santa Monica Mountains contains almost no Ca-rich plagioclase, suggesting that the Los Angeles basin was 50 km to the south and sediments from the SGA were blocked by the Simi Uplift and directed into the eastern Ventura Basin
Ingersol and Rumelhart (1999)	San Gabriel	60 km total	10–5 Ma	This publication is focused more on the transrotation. They just put 60 km of SGF slip and cite Crowell (1982)
Yeats (2001)				Miocene Caliente Formation of Lockwood Valley (Ehlig et al., 1975; Ehlert, 1982)
Yeats (2001)		≥35 km		lower Mohnian Devil Canyon Conglomerate of the upper Modelo (Crowell, 2003)
Yeats (2001)		≥30 km		Uppermost Mohnian-"Delmontian" Hasley Conglomerate at the base of the Towsley Formation and source in San Gabriel Mountains
Nourse et al. (2002)	North branch of San Gabriel	22 km	∼9-5 Ma	Necessary to restore the main Mount Lowe Granodiorite complex to its 'tail' south of the San Gabriel Fault. The 15 km of slip on the Sawpit Canyon-Clamshell fault would add offset east of this tail.

Table S5 *(cont.)*: Summary of published restorations showing the timing and magnitude of slip along the San Gabriel–Canton fault system.

Nourse et al. (2002)	Sawpit Canyon-Clamshell fault	15 km		
Nourse et al. (2002)	South branch of San Gabriel		ca. 12 Ma and likely before north branch movement	
Crowell (2003)	San Gabriel-Canton	∼75 km total	16–5 Ma	Alignment of the Caliente and Mint Canyon Formations, which would add another 15 km from the original offset of Frazier Mountain to the western San Gabriels
Crowell (2003)	Canton	∼35 km	16–11 Ma	Offset of the Mint Canyon (Soledad Basin) and Caliente Formations (Plush Ranch Basin); older normal fault (possibly the Canton Fault) with no strike-slip component active prior to ca. 18 Ma to deposit the Sespe Conglomerates in Canton Canyon.
Crowell (2003)	San Gabriel	≥45 km	between ∼11 Ma and 5 Ma (Crowell, 1986)	Offset of 6.5–9 Ma Devil Canyon Conglomerate to source area in the San Gabriel Mountains
Crowell (2003)	San Gabriel	∼25 km	10–5 Ma	Offset of ∼6.5 Ma Hasley Conglomerate to source area in the San Gabriel Mountains
Crowell (2003)	San Gabriel	∼45 km	10–5 Ma	Offset of Violin Breccia in Ridge Basin to appropriate source area
Crowell (2003)	San Gabriel	0 km	∼5 Ma	Beds of the Hungry Valley Formation are not offset by the San Gabriel Fault, whose deposition is assumed to postdate movement on the San Gabriel Fault.
Crowell (2003)	Alamo-Frazier Mountain	5 km shortening	post 5 Ma	Repetition of the belt of the Violin Breccia in the Hardluck slice
Yeats and Stitt (2003)	Canton	30 km		Offset of Sespe? Fine grained deposits in subsurface Placerita Oilfield to congomerates in Piru Creek and Canton Canyon
Yeats and Stitt (2003)	San Gabriel			
Ingersoll et al. (2014)	San Gabriel	∼40 km	12–6 Ma	Claims 12–6 Ma in abstract, but 12–5 Ma in text, citing Crowell, Hendrix, etc. No explanation for the change
Ingersoll et al. (2014)	Canton	∼30 km	18–12 Ma	Cites Crowell (2003b) but moves slip initiation to 18 Ma to align with start of transrotation
Coffey et al. (2019)	Canton		18 Ma to after ca. 13 Ma	60–70 km total on San Gabriel-Canton Fault system
Coffey et al. (2019)	San Gabriel		sometime between 13 and 9 Ma	
Hoyt et al. (2018)	San Gabriel-Canton	∼42 to ∼70 km	San Gabriel 10–5 Ma; 18 Ma Canton	Partial similarities in petrology between Mint Canyon and Caliente Formations
Nourse et al. (2020)	San Gabriel	40–60 km	12–5 Ma	Cites others' work

Table S5 *(cont.)*: Summary of published restorations showing the timing and magnitude of slip along the San Gabriel–Canton fault system.

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