Kinematic Slip Model of the 2021 M 6.0 Antelope Valley, California, Earthquake

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Abstract
We present a kinematic slip model of the 8 July 2021 Antelope Valley earthquake from a finite-source inversion based on regional seismic waveforms and static offsets from Global Positioning System (GPS) and Interferometric Synthetic Aperture Radar (InSAR). Seismic waveforms are employed at 6 s dominant period out to 100 km from the epicenter, and the combined GPS and InSAR datasets cover the near field and far field out to ~100 km and constrain the overall rupture size. The aftershock pattern defines a nearly north-striking, 50° east-dipping fault plane. We find a unilateral rupture along this fault plane propagating southward and updip with predominantly normal slip up to ~1.5 m. The estimated seismic moment of 8.47 x 10^{17} N · m is equivalent to M_w 5.92. A finite-source inversion that retains seismic waveforms and GPS static offsets but omits InSAR range changes yields a seismic moment of 1.08 x 10^{18} N · m (M_w 5.99). Despite vigorous aftershock activity between 10 km and Earth’s surface, coseismic slip is concentrated in the depth interval 7–10 km.

Introduction
The 8 July 2021 M 6.0 Antelope Valley, California, earthquake is the largest to have struck the northern Walker Lane area since 1994 (Fig. 1). It occurred along the eastern edge of the Sierra Nevada range in an area of kinematically linked left-stepping dextral strike-slip faults and north-striking normal faults (Wesnousky, 2005; Rood et al., 2011; Wesnousky et al., 2012). The W-phase moment tensor solution of the National Earthquake Information Center (NEIC) as well as the Global Centroid Moment Tensor (Global CMT) solution (Ekström et al., 2012) are consistent with a fault geometry of nearly pure normal slip on a north-striking fault. The Walker Lane is a tectonic belt of numerous north-northwest-striking subparallel faults that define the western boundary of the Basin and Range province (Wesnousky et al., 2012). These faults generally accommodate both dextral slip and normal slip. The former is exemplified by the 1872 M 7.6 Owens Valley earthquake, whereas the latter is exemplified by paleogeologic investigations (Wesnousky, 2005) and moment tensor solutions (Ichinose, 2003).

The distribution of aftershocks suggests that the mainshock occurred on an ~50° east-dipping fault beneath Little Antelope Valley (Fig. 1). The Global CMT and NEIC fault-plane solutions suggest a nearly due north strike and a centroid depth of ~8 km. Projection of this fault-plane updip would yield a surface trace close to the mapped Slinkard Valley fault, a Quaternary fault west of the Little Antelope Valley (John et al., 1981). Aftershocks occupy a practically continuous section of the defined plane between ~8 and 1 km depth, but deformation data to be discussed indicate that fault slip did not reach Earth’s surface. This raises the question as to how shallow the coseismic slip extended.

Here, we address the kinematics of the mainshock rupture by assembling strong-motion waveforms and static offsets from Interferometric Synthetic Aperture Radar (InSAR) data and...
Global Positioning System (GPS) data. These data constrain the rupture evolution and overall distribution of coseismic slip.

**Data Set**

**Seismic data**

We employ seismic waveforms from 40 regional strong-motion and broadband stations of the Nevada network (NN) and northern California (NC) network within 100 km of the epicenter (Fig. 2). The seismic waveforms are band-pass filtered between 0.025 and 0.167 Hz, and corrected for instrument response to yield three-component seismic velocity (Fig. 3 and Fig. S1, available in the supplemental material to this article). A few records are not amenable to analysis; all components of station WAK, located just 5 km east of the epicenter, are clipped early in the record; amplitudes at VCN are three orders of magnitude lower than at other stations, suggesting inaccurate instrument response; no discernible signal is evident at MEM. Seismic waveforms at the remaining 37 stations are retained for further analysis.

**Geodetic data**

GPS data are available at sites up to ~100 km from the epicenter at semicontinuous MAGNET stations operated by the University of Nevada, Reno and continuous stations from the EarthScope Plate Boundary Observatory/Network of the Americas (NOTA)—stations DECH, P134, P135, P136, P143, P654 (UNAVCO Community 2006, 2007; Lisowski, 2012). Static displacements from these sites are derived from

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**Figure 1.** Mainshock and first seven days aftershock seismicity associated with the 8 July 2021 Antelope Valley earthquake in (a) map view and (b) depth section along a N85°E profile. The gray plane represents the 355°-striking fault plane used in the modeling, and the black box in (a) outlines the area shown in (b). In the inset, the National Earthquake Information Center epicenters of the 1994 M 6.1 Carter Springs, Nevada, earthquake and 2021 Antelope Valley earthquake are shown with green and yellow stars, respectively. Superimposed in (a) are faults of the U.S. Geological Survey (USGS) Quaternary Faults and Fold Database, and superimposed in (b) is the coseismic slip distribution of the preferred model, with the yellow star indicating the relocated hypocenter. OT, Origin time.

**Figure 2.** Strong-motion and broadband stations with contributing seismic waveforms. Superimposed are faults of the USGS Quaternary Faults and Fold Database and the coseismic slip distribution of the preferred model.
Figure 3. Three-component seismograms for selected stations recording the 8 July mainshock, band-pass filtered between 0.025 and 0.167 Hz. Observed and model seismograms are shown with black and red traces, respectively.
daily coordinate solutions produced by the Nevada Geodetic Laboratory in a fixed North America reference frame (Blewitt et al., 2018). To obtain stable estimates, we use 10 days preseismic and 10 days postseismic positions. The resulting horizontal displacements at 22 regional GPS sites are shown in Figure S2. We restrict attention to the horizontal displacements because of the large distance of GPS sites from the rupture zone and the relatively high errors of the vertical GPS displacement estimates. At near-field site LANT, the measured vertical displacement is −56.6 ± 1.5 mm (i.e., subsidence) (Fig. S3), which is useful for comparing with InSAR estimates of subsidence.

We obtained coseismic InSAR images from the Sentinel-1 radar satellite (C Band: 5.6 cm wavelength) operated by the European Space Agency (Fig. 4a,c). We processed synthetic aperture radar images from the satellites into differential interferograms using the Shuttle Radar Topography Mission Digital Elevation Model (Farr et al., 2007) to remove the topographic phase. The interferograms were filtered using an adaptive filter (Goldstein and Werner, 1998), then unwrapped using a statistical-cost, network-flow procedure (Chen and Zebker, 2002) and converted to line-of-sight (LOS) displacement. A first interferogram spanning 4 July 2021 to 10 July 2021 is descending orbit with heading and inclination angles of 189.6° and 42.2°, respectively (Fig. 4a). A second descending Sentinel-1 interferogram spans 4 July 2021 to 9 July 2021, and has average heading and inclination angles of 191.0° and 31.1°, respectively (Fig. 4d). A third interferogram spanning 22 June 2021 to 10 July 2021 is ascending orbit with heading and inclination angles of 350.1° and 43.9°, respectively (Fig. 4g). A fourth interferogram spanning 23 June 2021 to 17 July 2021 is ascending orbit with heading and inclination angles of 349.3° and 33.3°, respectively (Fig. 4i). The LOS displacements recorded in these interferograms suggest about 60–70 mm peak subsidence but no surface slip, consistent with slip along a short (few kilometers in length) rupture concentrated at several kilometers depth.

We also evaluated stacked interferograms for these and other paths spanning the rupture area, with postearthquake acquisition times up to a few weeks after the earthquake. Although the stacked interferograms have reduced noise outside the immediate source region and a similar pattern of negative LOS displacement in the near-source region, they have reduced amplitude of 10–15 mm. Combined descending and ascending stacked interferograms yield 43 mm subsidence at LANT, about 14 mm less than measured with GPS (Fig. S3), and we believe that postseismic processes acting over several weeks contribute postseismic uplift, rendering the stacked interferograms problematic for modeling of coseismic slip. Hence, we restrict attention to the two descending and two ascending interferograms of Figure 4a,d,g,j.

**Coseismic Slip Model**

**Methods**

We follow the method of Pollitz et al. (2019, 2020) for determining the distribution of coseismic slip from the combined dataset of seismic waveforms and static offsets from GPS and InSAR. Although afterslip potentially shapes the LOS displacement fields, because they record deformation a few days beyond the earthquake, we neglect afterslip here because coseismic slip models consistent with the waveform data tend to already match or slightly exceed the amplitude of static displacements.

Green’s functions for both seismic displacements and static displacements are determined using the layered velocity structure of Mangino et al. (1993) shown in Figure S4. We employ path corrections for seismic velocity station by station as detailed in Pollitz et al. (2019). Specifically, we reduce the seismic velocities of this model by up to 4.5% for propagation paths to the north, east, and south, and increase the seismic velocities by up to 5.5% for propagation paths to the west. We find that this prescription of 1D velocity structures permits waveform fitting at the 6 s corner period employed for the seismic data out to 100 km from the epicenter, and that no additional 3D velocity variations appear necessary to fit the data.

The fault geometry is defined by a single plane of length 11.0 km and width 11.1 km with strike/dip/rake of 355°/50°/−98°, respectively (Fig. 1). This is a compromise between the Global CMT east-dipping fault-plane solution of 1°/51°/−98° and the overall 350° strike of area faults. Although this dipping plane is parallel to the lineation of aftershocks, its location is below most of these aftershocks (Fig. 1b). This is based on trial models where relatively deep candidate planes are most consistent with the InSAR data. We explored two-plane models involving an additional west-dipping normal fault intersecting this east-dipping fault at ~10 km depth, which is tenuously defined by the aftershock pattern (Fig. 1). In trial models we obtain very minor slip on the west-dipping fault with negligible improvement in the fit to the data, hence we focus on the one-plane model with the defined east-dipping plane.

We estimate the hypocenter of the rupture using high-frequency travel times to the three closest seismic stations.
Figure 4. Observed line-of-sight (LOS) displacements for (a) Sentinel-1 path descending orbit from 4 July 2021 to 10 July 2021, (d) Sentinel-1 descending orbit path 42 from 3 July 2021 to 9 July 2021, (g) Sentinel-1 ascending orbit path 137 from 22 June 2021 to 10 July 2021, and (j) Sentinel-1 ascending orbit path 64 from 23 June 2021 to 17 July 2021. Corresponding model LOS displacements are shown in parts (b), (e), (h), and (k) for the preferred model of coseismic slip shown in Figure 5a. Corresponding residuals are shown in parts (c), (f), (i), and (l). Blue and red colors denote motions toward and away from the satellite, respectively. Superimposed are the model fault plane and faults of the USGS Quaternary Fault and Fold Database.
(WAK, SJC, and EBPB). This results in a shift of +0.3 s to the NEIC origin time and a hypocenter location about 4 km north of the NEIC hypocenter (Fig. S5 and Table S1; NEIC hypocenter at 38.819° N, 119.487° W, 7.5 km depth and revised hypocenter at 38.542° N, 119.487° W, 10.3 km depth).

We resolve the amplitude of time-dependent slip on this plane using a simulated annealing procedure. The plane is discretized into 1200 rectangular patches, 40 in the along-strike direction and 30 in the along-dip direction. We constrain the slip time functions on these patches to satisfy minimum and maximum rupture velocity of 1.0 and 3.1 km/s (about 90% of the shear wavespeed at seismogenic depth), maximum rise time of 0.9 s, and positive slip (Table S1). Slip is regularized through the squared gradient of net static slip summed over the source patches (equation 8 of Pollitz et al., 2019). We tested different choices of smoothing weight and selected the largest that still allows a good fit to the data. Our choice of smoothing weight yields slip variations at the ~2 km level, much smaller than the wavelength associated with S-wave propagation at 6 s period. Relative weights among the seismic waveform, InSAR LOS displacements, and GPS displacements are chosen such that seismic and geodetic data have roughly equal contribution to data misfit, and InSAR and GPS data have roughly equal contributions to the net geodetic data misfit.

Results
The net coseismic slip is shown in Figure 5a. We find the earthquake to be a north-to-south unilateral rupture propagating both along-strike and up-dip (Fig. 5b). Most of the seismic moment release is from 3.5 to 7 s after rupture initiation (Fig. 5b,d). The seismic moment is \( M_0 = 8.47 \times 10^{17} \) N·m, equivalent to \( M_w = 5.92 \). Rise time varies from 0.1 to 0.6 s in the peak slip region (Fig. 5c). The slip centroid of the preferred model (Fig. 5a) is within ~1 km of 38.50° N, −119.50° E and about 9.0 km depth, similar to but ~1.5 km deeper than the slip centroid obtained in the U.S. Geological Survey (USGS) finite-fault model (see Data and Resources).

The average rupture velocity is 1.9 km/s in the high-slip region. This is larger than the average rupture velocity of 1.5 km/s estimated for the 2020 M 6.5 Monte Cristo range earthquake (Liu et al., 2021), and similar to the 2.0 km/s average rupture velocity estimated for the 2019 Ridgecrest M 6.4 foreshock and M 7.1 mainshock (Goldberg et al., 2020). Results for all these events are consistent with the observation of Goldberg et al. (2020) that immature fault zones tend to be associated with relatively low rupture velocity in seismic events.

Small artifacts in the net slip are evident at the northern and southwestern extremities of the model area (Fig. 5a). This likely arises from errors in dynamic and static Green’s functions due to unmodeled 3D seismic structural variations (Gallović et al., 2015). Unmodeled complexity in the fault geometry, including the possibilities of nonplanar faults and/or auxiliary slip planes, site effects, and model size may also give rise to such artifacts (Hartzell et al., 2007).

Good fits are obtained by the model to the GPS horizontal static offsets and LOS displacements (Fig. S2 and Fig. 4). Misfits to the latter are consistent with root mean square residuals of several millimeters based on inspection of interferograms obtained from several preseismic and postseismic Sentinel passes for all the four paths. Although GPS vertical static offsets are not used in the version, predicted 62 mm subsidence at LANT agrees well with the observed 56.6 mm subsidence (Fig. S3).

Discussion
Uncertainty in the slip distribution arises from the choice of weighting of the geodetic data. This is illustrated by models obtained with lower or higher weight assigned to the geodetic data in the slip inversions. The models of net slip presented in Figure 5a–c consider the preferred weight of geodetic data as well as one-third or three times the preferred weight. The magnitude of inferred net slip is greater for lower weight of the geodetic data, implying that the seismic data are more consistent with a higher-seismic moment rupture than the InSAR, GPS, or both. An inversion with the preferred weight but with InSAR data omitted (Fig. S6d) yields the highest seismic moment \( M_0 = 1.08 \times 10^{18} \) N·m, \( M_w = 5.99 \) of the models considered, suggesting that both seismic waveforms and GPS data are consistent with a seismic moment \( \geq 10^{18} \) N·m, whereas the InSAR data imply a much lower seismic moment. Residual interferograms are systematically high in this case (Fig. S7), highlighting the incompatibility of seismic waveforms and GPS static offsets with InSAR-based static offsets that we have considered.

The overall rupture was emergent, with an ~3 s delay between the origin time and the time of initiation of significant slip (Fig. 5b). It is conceivable that the event initiated with a small foreshock at the location of eventual maximal slip, then a 3 s delay ensued before the mainshock nucleated. Regardless of where the rupture initiated, the timing of slip suggests a cascade of subevents, similar to the behavior of individual subvents in the 2019 Ridgecrest, California, earthquake (Hirakawa...
or it may be diagnostic of a slow nucleation front that takes place before the rupture proceeds under frictional mechanics (Gvirtzman and Fineberg, 2021).

Aftershocks are concentrated in areas of negligible inferred coseismic slip, mostly shallower than 7 km depth and updip of

Figure 5. (a) Net coseismic slip, (b) mean rupture time, (c) rise time on the model fault plane, and (d) source time function; mean rupture time and rise time are shown where slip exceeds 0.1 m. White star indicates the hypocenter location.
the peak slip region over its ~6 km length. They also tend to lie on the hanging-wall side. This may be due to either static or dynamic stress changes in areas proximal to the rupture. The pattern is consistent with other observations of aftershocks of normal-faulting events updip of their main slipping areas and within the hanging wall, for example, for the 2020 M 5.8 Magna, Utah, earthquake (Pang et al., 2020) and other normal-faulting events (Chiaraluce et al., 2003).

Conclusions
We use a combination of seismic waveforms and static offsets from InSAR and GPS to constrain kinematic rupture models of the Antelope Valley earthquake. We find that it was a unilateral rupture with predominantly normal slip on an east-dipping fault, propagating to the south and updip. This slip is concentrated between 7.5 and 10 km depth. The unilateral rupture obtained here is consistent with the USGS finite-fault model obtained using longer period seismic waveforms, but the centroid of the present model is ~1.5 km deeper. A ~3 s delay between the origin time and onset of significant mainshock slip suggests an emergent event with an initially slow nucleation process. Inferred earthquake size is sensitive to the weight of InSAR data; inversions with seismic waveforms and GPS and without/with InSAR yield seismic moment of $1.08 \times 10^{18}$ N · m and $8.47 \times 10^{17}$ N · m, respectively.

Data and Resources
The supplemental material is provided to document the seismic data, Global Positioning System (GPS) horizontal offsets and time series, the reference seismic structure, revised epicenter and origin time, and alternate slip distributions. Seismic waveform data were obtained from the Incorporated Research Institutions for Seismology (IRIS) Data Management Center (http://www.iris.washington.edu/ds/, last accessed July 2021). Sentinel-1 radar data were accessed through ESA’s Copernicus Open Access Hub (https://scihub.copernicus.eu, last accessed August 2021) and the Alaska Satellite Facility’s Vertex site (https://search.asf.alaska.edu, last accessed August 2021). GPS data were obtained from the Nevada Geodesy Laboratory (http://geodesy.unr.edu/index.php, last accessed August 2021). Aftershock locations are from the Advanced National Seismic System (ANSS) Comprehensive Catalog (ComCat) (https://earthquake.usgs.gov/data/comcat/, last accessed August 2021). The Quaternary Fault and Fold Database of the United States was obtained from https://www.usgs.gov/programs/earthquake-hazards/fauls (last accessed August 2021). The U.S. Geological Survey (USGS) finite-fault model is available at https://earthquake.usgs.gov/earthquakes/eventpage/nc73584926/finite-fault (last accessed August 2021). Some plots were made using the Generic Mapping Tools version 4.2.1 (Wessel and Smith, 1998).

Declaration of Competing Interests
The authors acknowledge that there are no conflicts of interest recorded.

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References
Blewitt, G., W. C. Hammond, and C. Kreemer (2018). Harnessing the GPS data explosion for interdisciplinary science, Eos 99, doi: 10.1029/2018EO104623.
Chen, C. W., and H. A. Zebker (2002). Phase unwrapping for large SAR interferograms: Statistical segmentation and generalized network models, IEEE Trans. Geosci. Rem. Sens. 40, 1709–1719, doi: 10.1109/TGRS.2002.802453.
Chiaraluce, L., W. Ellsworth, A. Chiarabba, and M. Cocco (2003). Imaging the complexity of an active normal fault system: The 1997 Colfiorito (central Italy) case study, J. Geophys. Res. 108, 2294, doi: 10.1029/2002JB002166.
Ekström, G., M. Nettles, and A. M. Dziewoñ (2012). The global CMT project 2004-2010: Centroid-moment tensors for 13,017 earthquakes, Phys. Earth Planet. In. 200/201, 1–9, doi: 10.1016/j.pepi.2012.04.002.
Farr, T. G., P. A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodriguez, L. Roth, et al. (2007). The Shuttle Radar Topography Mission, Rev. Geophys. 45, doi: 10.1029/2005RG000183.
Gallović, F., W. Imperatori, and P. M. Mai (2015). Effects of three-dimensional crustal structure and smoothing constraint on earthquake slip inversions: Case study of the Mw6.3 2009 L’Aquila earthquake, J. Geophys. Res. 120, 428–449, doi: 10.1002/2014JB011650.
Goldberg, D., D. Melgar, V. J. Sahakian, A. Thomas, X. Xu, B. W. Crowell, and J. Geng (2020). Complex rupture of an immature fault zone: A simultaneous kinematic model of the 2019 Ridgecrest, CA earthquakes, Geophys. Res. Lett. 47, doi: 10.1029/2019GL086382.
Goldstein, R. M., and C. L. Werner (1998). Radar interferogram filtering for geophysical applications, Geophys. Res. Lett. 25, 4035–4038, doi: 10.1029/1998GL000033.
Gvirtzman, S., and J. Fineberg (2021). Nucleation fronts ignite the interface rupture that initiates frictional motion, *Nat. Phys.* 17, 1037–1042, doi: 10.1038/s41567-021-01299-9.

Hartzell, S., P. Liu, C. Mendoza, C. Ji, and K. M. Larson (2007). Stability and uncertainty of finite-fault slip inversions: Application to the 2004 Parkfield, California, earthquake, *Bull. Seismol. Soc. Am.* 97, 1911–1934, doi: 10.1785/0120070080.

Hirakawa, E., and A. J. Barbour (2020). Kinematic rupture and 3D wave propagation simulations of the 2019 M7.1 Ridgecrest, California, *Bull. Seismol. Soc. Am.* 110, 1644–1659.

Ichinose, G. (2003). Source parameters of eastern California and western Nevada earthquakes from regional moment tensor inversion, *Bull. Seismol. Soc. Am.* 93, 61–84, doi: 10.1785/0120020063.

John, D., J. Giusso, W. Moore, R. Armin, and J. Dohrenwend (1981). Reconnaissance geologic map of the Topaz Lake 15 minute quadrangle, California and Nevada, *U.S. Geol. Surv. Open-File Rept.* 81-273, scale 1:62,500.

Lisowski, M. (2012). CVO GPS Network - DECH-Dechambeau Ranch P.S. Technical report, The GAGE Facility operated by UNAVCO, Inc., GPS/GNSS Observations Dataset, doi: 10.7283/T5DF6PCH.

Liu, C., T. Lay, F. Pollitz, J. Xu, and X. Xiong (2021). Seismic and geodetic analysis of rupture characteristics of the 2020 Mw 6.5 Monte Cristo Range, Nevada, earthquake, *Bull. Seismol. Soc. Am.* 111, 3226–3236, doi: 10.1785/0120200327.

Mangino, S. G., G. Zandt, and C. J. Ammon (1993). The receiver structure beneath Mina, Nevada, *Bull. Seismol. Soc. Am.* 83, 542–560.

Pang, G., K. D. Koper, M. Mesimeri, K. L. Pankow, B. Baker, J. Farrell, J. Holt, J. M. Hale, P. Roberson, R. Burlacu, et al. (2020). Evidence for a Listric Wasatch fault from the 2020 Magna, Utah, earthquake sequence, *Geophys. Res. Lett.* 18, e2020GL089798.

Pollitz, F. F., J. R. Murray, S. E. Minson, C. W. Wicks, J. L. Svarc, and B. A. Brooks (2019). Coseismic slip and early afterslip of the M6.0 August 24, 2014 South Napa, California, earthquake, *J. Geophys. Res.* 120, 2672–2696, doi: 10.1029/2019JB018470.

Pollitz, F. F., J. R. Murray, J. L. Svarc, C. W. Wicks, R. Roeloffs, S. E. Minson, K. Scharer, K. Kendrick, K. W. Hudnut, J. Nevitt, et al. (2020). Kinematics of fault slip associated with the 4-6 July 2019 Ridgecrest, California, earthquake sequence, *Bull. Seismol. Soc. Am.* 120, doi: 10.1785/0120200018.

Rood, D. H., D. W. Burbank, S. W. Herman, and S. Bogue (2011). Rates and timing of vertical-axis block rotations across the central Sierra Nevada-Walker Lane transition in the Bodie Hills, California/Nevada, *Tectonics* 30, TC5013, doi: 10.1029/2010TC002754.

UNAVCO Community (2006). PBO GPS Network - p134-MinersRidgNV2006 P.S. Technical report, The GAGE Facility operated by UNAVCO, Inc., GPS/GNSS Observations Dataset, doi: 10.7283/T5CC0XQM.

UNAVCO Community (2007). PBO GPS Network - P135-Cambridge_NV2006 P.S. Technical report, The GAGE Facility operated by UNAVCO, Inc., GPS/GNSS Observations Dataset, doi: 10.7283/T57M05ZT.

Wesnousky, S. (2005). Active faulting in the Walker Lane, *Tectonics* 24, TC3009, doi: 10.1029/2004TC001645.

Wesnousky, S. G., J. M. Bormann, C. Kremer, W. C. Hammond, and J. N. Brune (2012). Neotectonics, geodesy, and seismic hazard in the Northern Walker Lane of Western North America: Thirty kilometers of crustal shear and no strike-slip? *Earth Planet. Sci. Lett.* 329/330, 133–140.

Wessel, P., and W. H. F. Smith (1998). New, improved version of Generic Mapping Tools released. *Eos Trans. AGU* 79, no. 47, 579, doi: 10.1029/98EO00426.