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LIDAR MAPPING OF THE BENNETT VALLEY FAULT—DEFINING A CONNECTION BETWEEN MAJOR PLATE-BOUNDARY FAULTS IN NORTHERN CALIFORNIA

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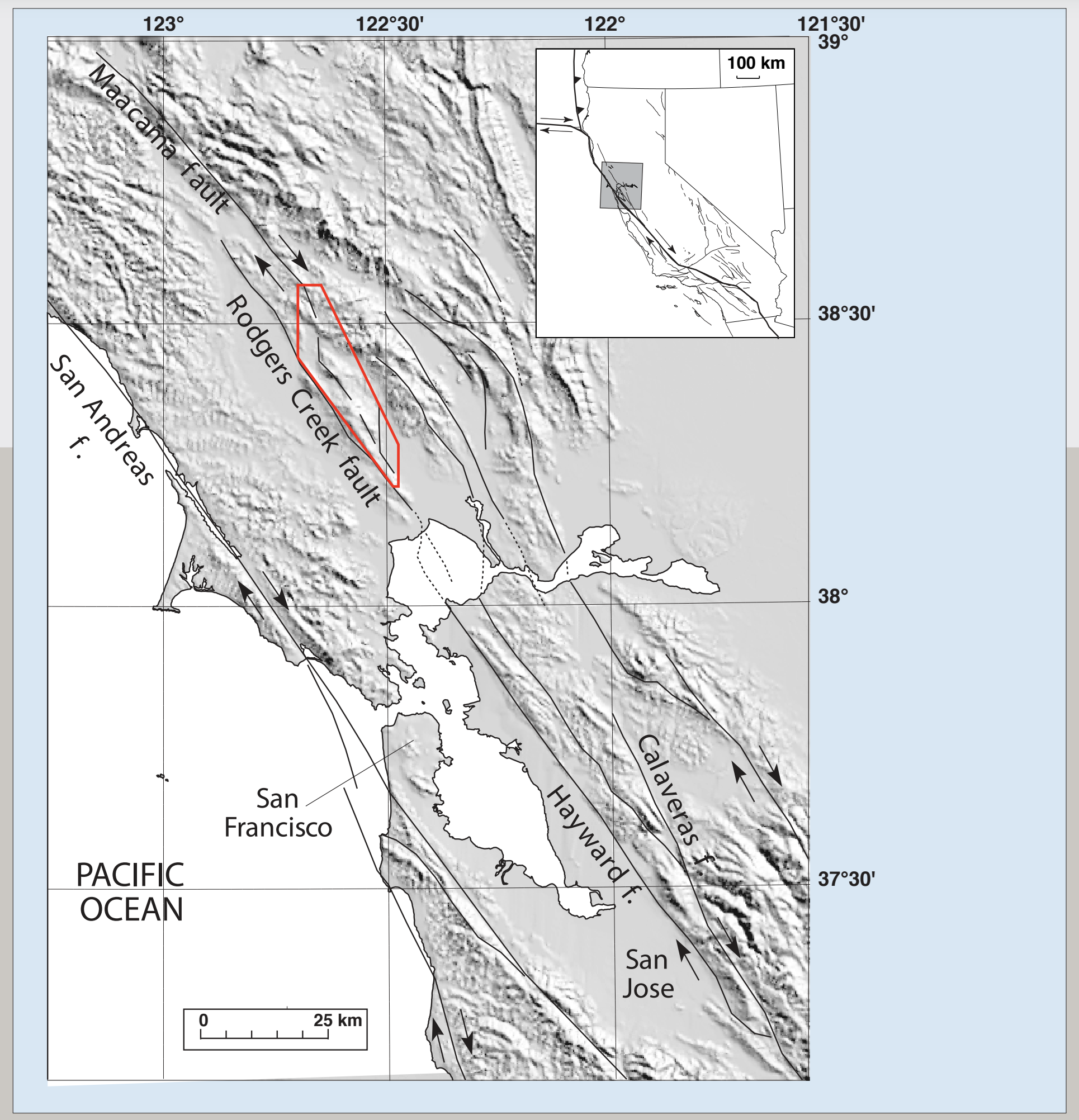
Abstract (Introduction & Motivation)

Rodgers Creek and Maacama faults form a major strand of the San Andreas plate boundary system north of San Francisco, accommodating ~6-12 mm/yr of dextral shear, but how and where slip transfers between these subparallel, overlapping faults has remained unclear. The Bennett Valley fault (BVF) is the structural continuation of the Maacama fault southward, and geologic mapping shows that strands of the BVF approach to within 0.5 km of the Rodgers Creek fault. However, aside from a relatively short section at its north end, the BVF has not been recognized as active during the Holocene. In this study, we use lidar-derived high-resolution topography to search for fine-scale geomorphic evidence of recent faulting. The BVF traverses the flanks of Sonoma and Bennett Mountains, where possible expression of surface faulting may be obscured by vegetation. Through careful inspection of topographic slope- and hillshade images, we have identified a broadly distributed network of fault strands, several of which appear to connect directly to the Rodgers Creek fault. At its north end, the BVF connects to a section of the Maacama fault designated as late Quaternary in age; in this area, we have mapped a similarly distributed array of subtle fault traces that link up with more clearly expressed Holocene traces of the Maacama fault to the north.

The finding of an active-fault link between the Rodgers Creek and Maacama faults identifies an avenue of slip-rate transfer—and the potential for complex earthquake-rupture pathways— between these major neighboring faults. Our mapping also highlights the significance of distributed zones of surface faulting, which have mostly escaped detection, but which may be identifiable with high-resolution imaging such as provided by airborne lidar. Distributed fault zones have recently been host to significant earthquakes in the Western U.S. (in particular, 2014 Napa, 2019 Ridgecrest, and 2020 Monte Cristo Range) and thus have gained attention, but because such faults are not well mapped and studied, their contribution to hazard is poorly constrained and may be underappreciated.



Index map of study area (red polygon)

Methods

In this study, we map geologically recent (probable late Holocene) rupture along the Bennett Valley and southern Maacama fault zones as interpreted from topographic features identified on lidar-derived imagery from a high-density (13.7 points per square meter) 2013 airborne lidar survey of Sonoma County[1]. For each mapped strand, we include a description of identifying features and their clarity of expression and assign a confidence level to our interpretation. We also judge the location accuracy of faulting represented by our linework (either "accurately located" to within 20 m, or "approximately located" to within 60 m), which commonly reflects the width of the (zone of) features, and we further indicate if the mapped fault appears to be part of a broader zone of possible surface deformation.

Examples of fault mapping

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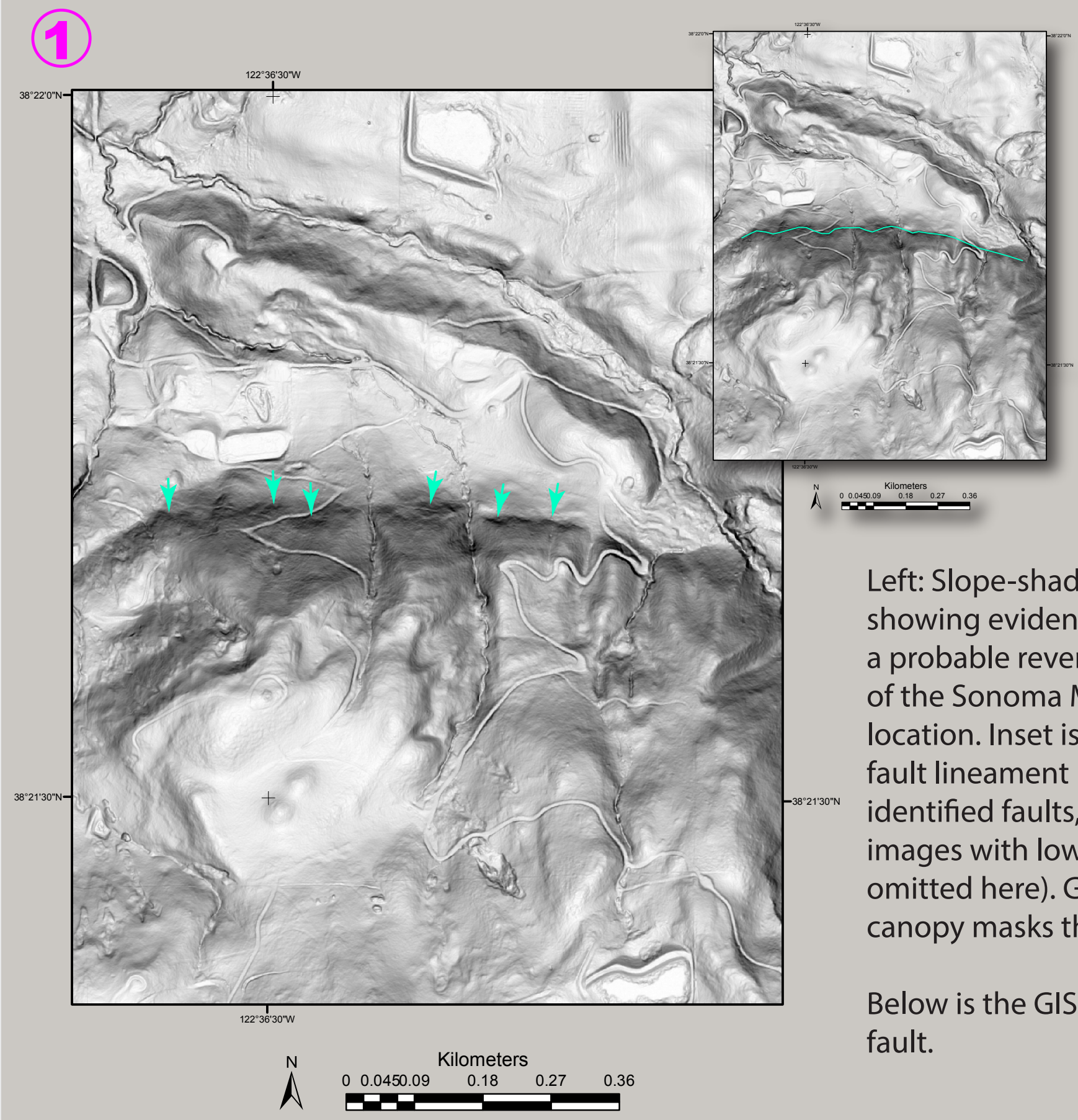
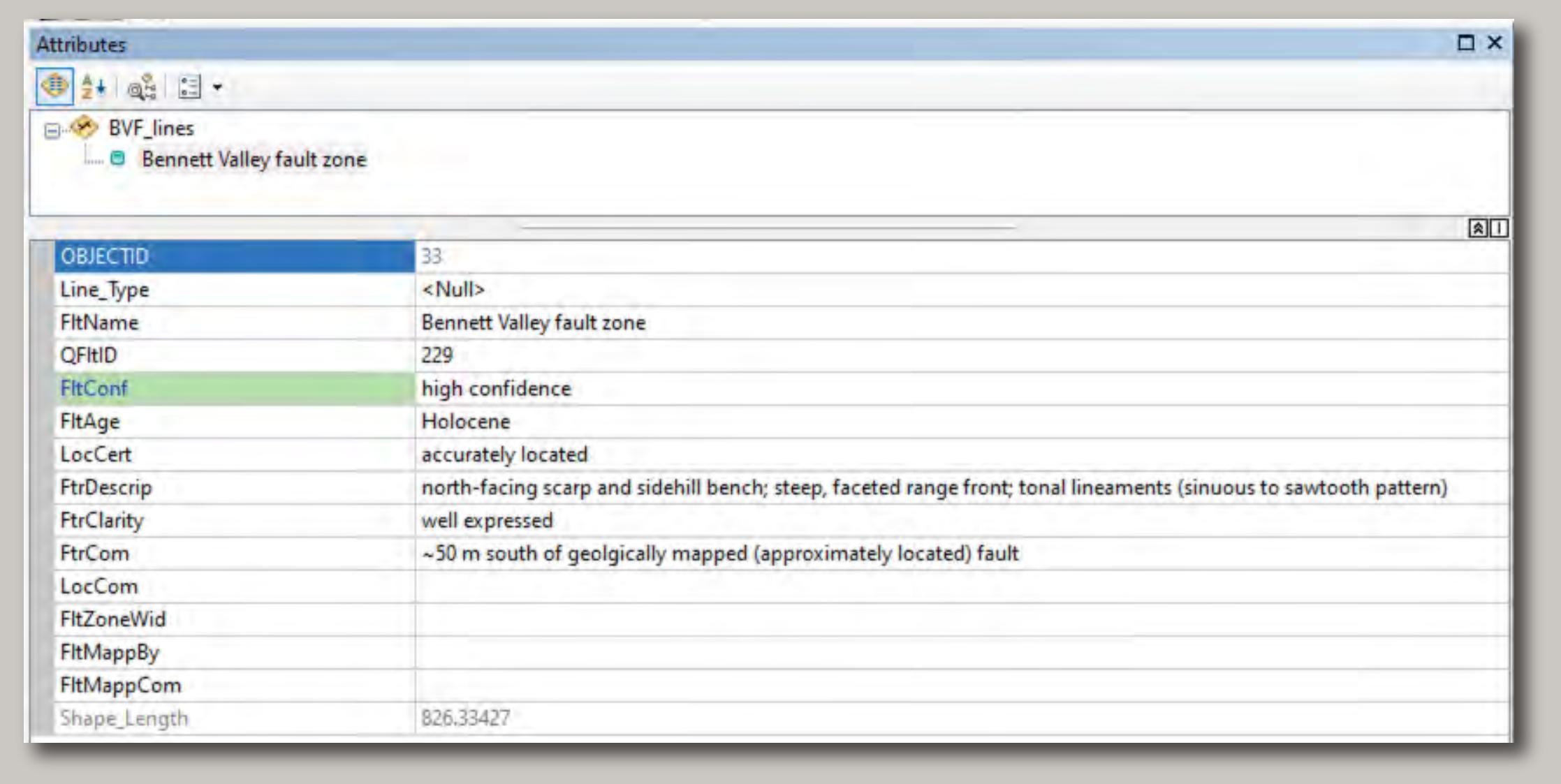


Left: Slope-shade image (vertical illumination) showing evidence of surface rupture (arrows) along a probable reverse fault that bounds the north flank of the Sonoma Mountains. See map at far right for location. Inset is the same image annotated with fault lineament mapping (note that less-confidently identified faults, which are more clearly visible on images with lower-altitude illumination, have been omitted here). Google Earth image shows how tree canopy masks the fault.

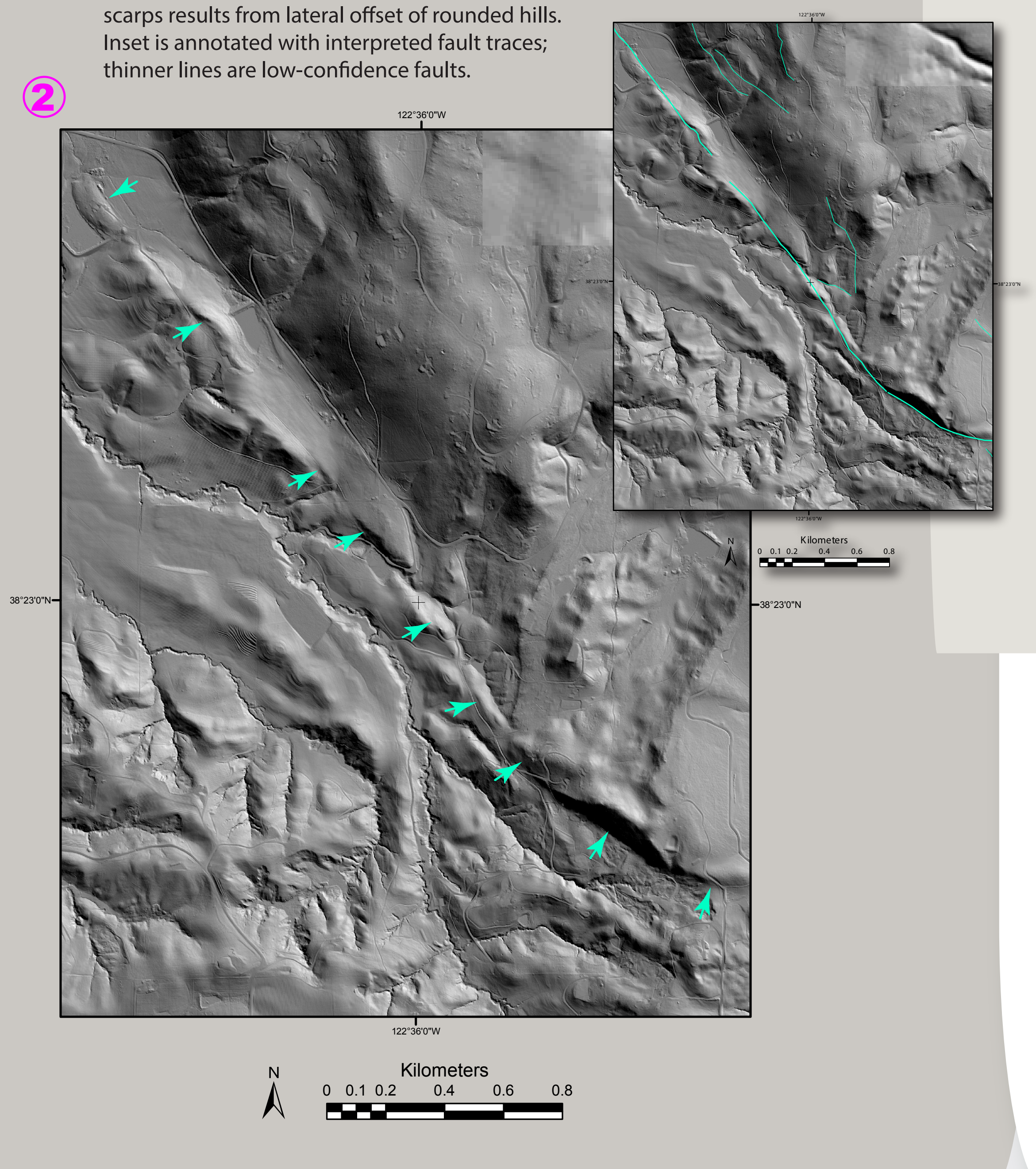
Below is the GIS attribute table for the illustrated fault.



OBJECTID	33
Line_Type	<Null>
FltName	Bennett Valley fault zone
QFltID	229
FltConf	high confidence
FltAge	Holocene
LocCert	accurately located
FtrDescrip	north-facing scarp and sidehill bench; steep, faceted range front; tonal lineaments (sinuous to sawtooth pattern)
FtrClarity	well expressed
FtrCom	~50 m south of geolgically mapped (approximately located) fault
LocCom	
FltZoneWid	
FltMappBy	
FltMappCom	
Shape_Length	826.33427

Lidar hillshade image (illuminated from northeast) showing clear geomorphic expression of recent faulting (arrows). See map at far right for location. Alignment of small east- and west-facing scarps results from lateral offset of rounded hills. Inset is annotated with interpreted fault traces; thinner lines are low-confidence faults.

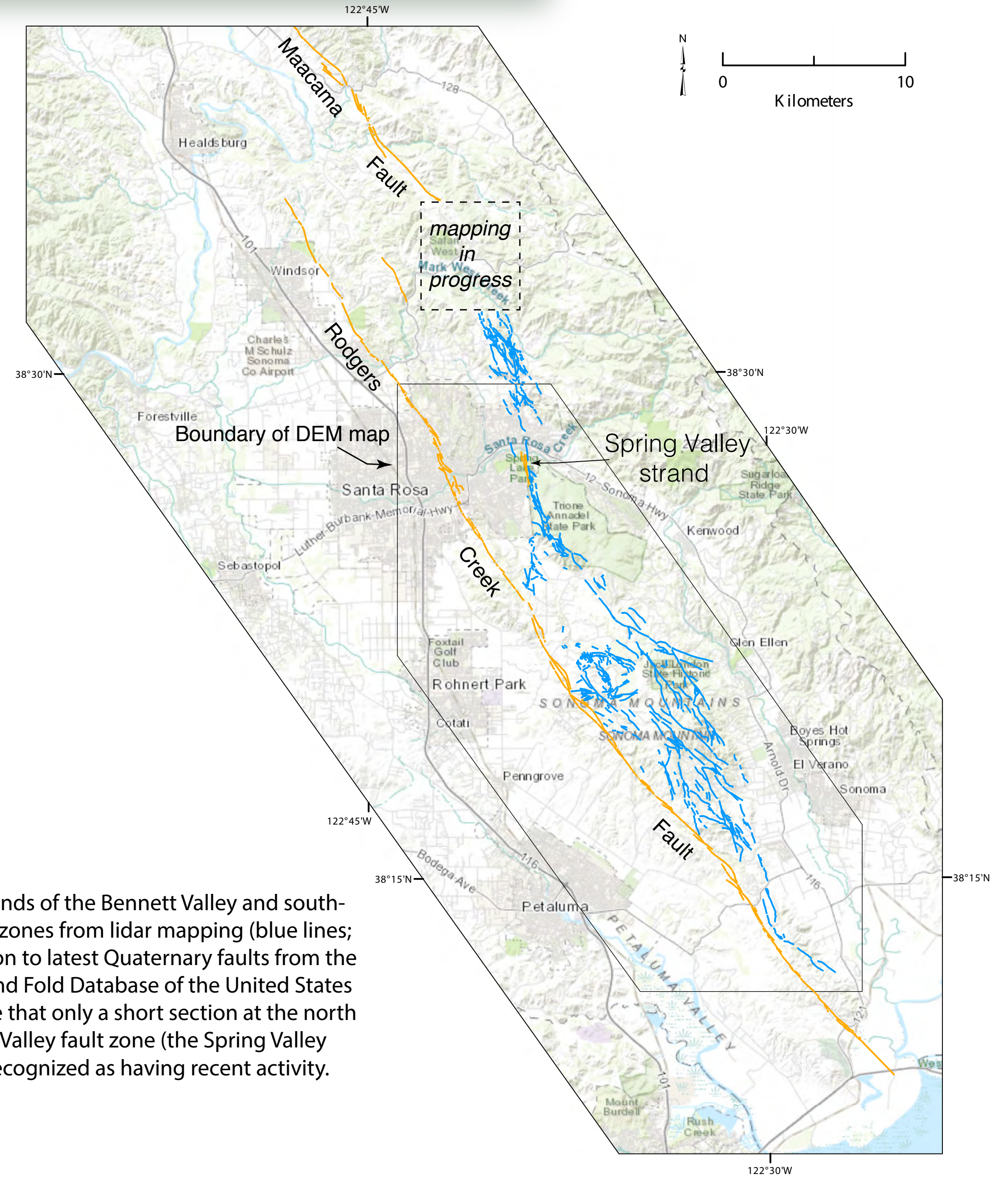
②



Interpretation

The continuity and configuration of recent surface rupture documented in this study provide evidence that the Bennett Valley fault zone (BVFZ) is actively accommodating transpression at the restraining bend in the southern Rodgers Creek fault (RCF) and, together with newly mapped active traces of the southern Maacama fault, is transferring dextral slip between the overlapping Rodgers Creek and Maacama faults, which constitute a major strand of the Pacific-North American plate boundary in northern California.

The Sonoma Mountains appear to be a long-term manifestation of uplift within the BVFZ and attest to stability in the location of the fault block northeast of the RCF relative to the restraining bend. The absence of microseismicity in the vicinity of the restraining bend suggests that compression is inhibiting strain release in this area. Farther north, the localization of faulting and seismicity along the margins of the Bennett Valley gravity high points to the impact of preexisiting crustal structure on active faulting and suggests that this dense body of rock is more rigid than the surrounding basement, as postulated by Langenheim et al. (2010). We conjecture that this body of rock may have influenced development of the Sonoma Mountains uplift and perhaps, as well, the restraining geometry of the RCF.

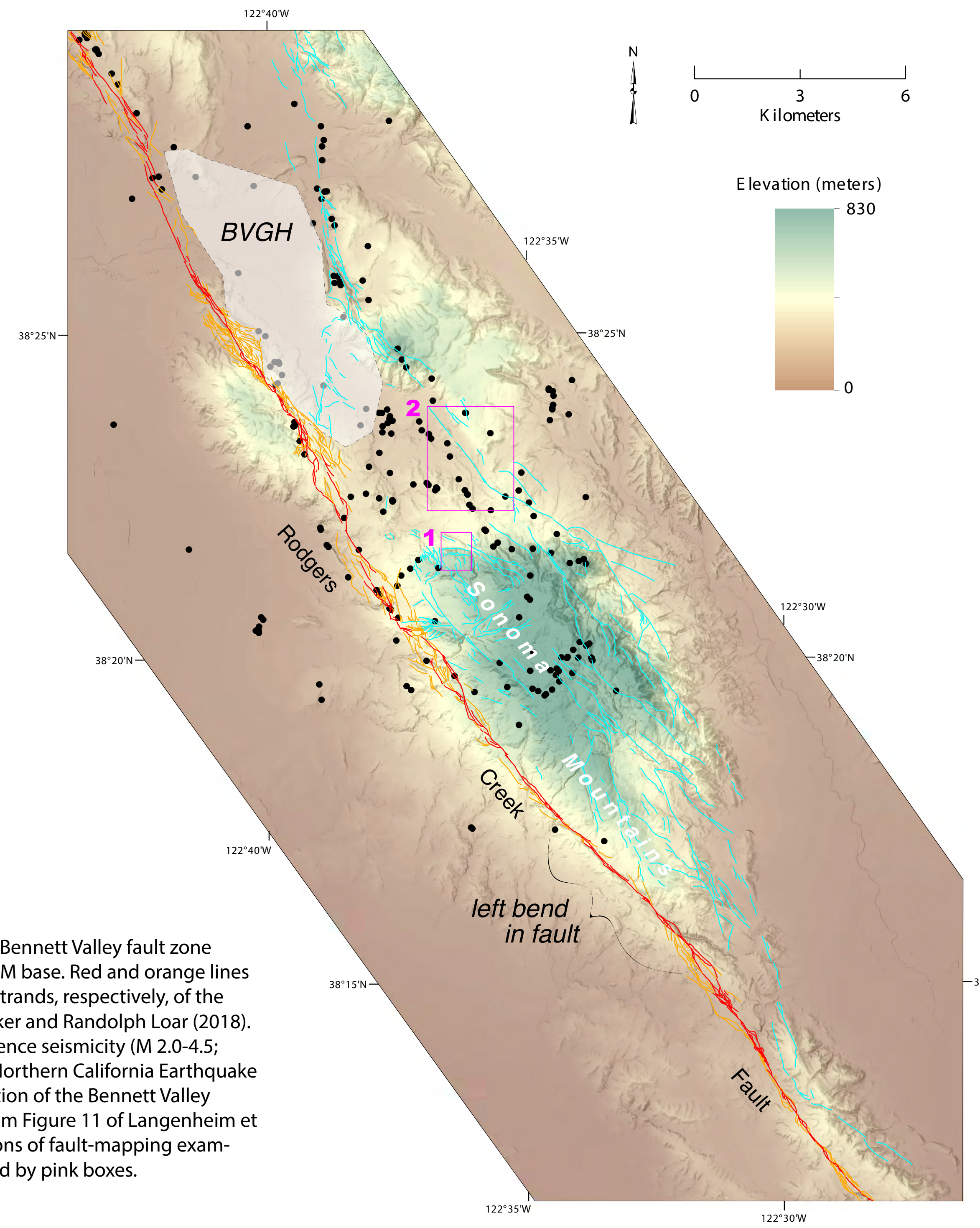


Recently active strands of the Bennett Valley and southern Maacama fault zones from lidar mapping (blue lines; this study) in relation to latest Quaternary faults from the Quaternary Fault and Fold Database of the United States (orange lines). Note that only a short section at the north end of the Bennett Valley fault zone (the Spring Valley strand) had been recognized as having recent activity.

Observations

Detailed mapping using lidar topography indicates that the entirety of the Bennett Valley fault zone (BVFZ) and its continuation to the north as the southern Maacama fault has had geologically recent (late Holocene) surface rupture. In most areas, recent faulting is diffuse and covered by forest canopy, explaining why, with the exception of the well-developed Spring Valley strand, it had remained undetected. Many strands within the BVFZ have classic geomorphic expression of recently active strike-slip or oblique-slip faulting, such as alignments of sidehill benches, scarps, linear troughs, offset drainages, and juxtaposed landforms. However, many other strands are less confidently mapped from the character of lidar tonal lineaments and proximity to better-defined faults.

At its south end, the surface trace of the BVFZ approaches to within several hundred meters of the principal displacement zone of the Rodgers Creek fault (RCF); northward at a prominent ~16° left-restraining double bend in the RCF, the BVFZ assumes a more northerly strike, broadens, and diverges from the RCF. The southern RCF is conspicuously aseismic to a latitude immediately north of this restraining bend (~38°20'N). The BVFZ is widest (up to 8 km) and most complex along its central section where it bounds and permeates the high-elevation terrain of the Sonoma Mountains on the north side of the RCF restraining bend and resumes an overall strike subparallel to the RCF. The BVFZ connects to the RCF in map view at several locations in this area and likely converges with it at depth. North of the Sonoma Mountains, the BVFZ is much narrower and appears to define the northeast margin of a prominent gravity high (the Bennett Valley gravity high), which is bounded on the southwest by the RCF. The source of this gravity high is unclear from surface exposures but is most likely dense Mesozoic rocks (Langenheim et al., 2010). A branch of the BVFZ that extends south from the north-striking Spring Valley strand (but is much less well developed) bisects this gravity high and connects to the RCF.



Recently active strands of the Bennett Valley fault zone (cyan lines) shown on lidar DEM base. Red and orange lines are principal and distributed strands, respectively, of the Rodgers Creek fault from Hecker and Randolph Loar (2018). Black circles are double-difference seismicity (M 2.0-4.5; 1984-August 2021) from the Northern California Earthquake Data Center; BVGH is the location of the Bennett Valley gravity high approximated from Figure 11 of Langenheim et al., (Geosphere, 2010). Locations of fault-mapping examples shown at left are indicated by pink boxes.

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[1] Lidar data provided by NASA Grant NNX13AP69G, the University of Maryland, and the Sonoma Vegetation Mapping and Lidar Program (https://doi.org/10.5069/G9G73BM1); processing services provided by the OpenTopography Facility with support from the National Science Foundation under NSF Award Numbers 1226353 and 1225810.