FINAL TECHNICAL REPORT

Mapping, Assessment, and Digital Compilation of the Southern Maacama Fault, Sonoma County, for the Northern California Quaternary Fault Map Database: Collaborative Research with William Lettis & Associates, Inc., and the U.S. Geological Survey

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ABSTRACT

A fault strip-map along the southern Maacama fault emphasizes active traces of the fault using 2008 LiDAR imagery in a one-kilometer swath along the fault. The Maacama fault is an active strike-slip fault of the San Andreas transform boundary, located parallel to and east of the San Andreas fault within Sonoma and Mendocino counties, California. The 54-km-long southern segment extends north from Santa Rosa to Hopland. Mapped active fault strands are classified as *certain*, *somewhat certain*, and *uncertain* based on levels of confidence that the feature was formed by active faulting rather than another geomorphic process. Fault scarps are considered the most certain evidence of Holocene activity, followed by sag ponds, offset drainages, ponded alluvium and linear breaks-in-slope. Lines of saddles, seeps, and linear drainages or valleys are considered uncertain evidence as they may be associated with bedrock contacts or inactive faults.

The LiDAR data provide an exceptional view of landscape detail, and the data are ideal for mapping and interpretation of geomorphic features in this rugged, forested terrain. As a result, many of the features shown in our fault-strip maps were not identified by previous mapping efforts, and a number of features mapped by previous workers as candidate active faults have been remapped or eliminated.

In general, the southern Maacama fault is characterized by poor geomorphic expression. Active fault features (all classes of certainty) are present along only 22.5 km (41%) of the 54-km length of the fault. Those features classified as *certain* and *somewhat certain* comprise only 6 km (11%) of the length of the fault. Mountainous terrain underlain by weak bedrock subject to landsliding may partially account for the lack of active geomorphic features. There are significant gaps within which no geomorphic expression of the fault could be found. The longest of these gaps, approximately 8 km in the northern Asti 7.5-minute quadrangle, is only partially explained by the presence of extensive landslides.

At the southern end of the fault, active fault features taper off and terminate about two-thirds of the way across the Mark West Springs 7.5-minute quadrangle, and all strands mapped within this quadrangle fall into the u*ncertain* category. If the active trace of the southern Maacama fault terminates well within Mark West Springs 7.5-minute quadrangle, strain is likely transferred from the Rodgers Creek to the southern Maacama fault north of the city of Santa Rosa.

1.0 Introduction

The Maacama fault is an active strike-slip fault of the San Andreas transform boundary, located parallel to and east of the San Andreas fault within Sonoma and Mendocino counties, California. Divided into northern and southern segments by Jennings (1994) based on a change in strike, the southern segment comprises 54 km of the total 144-km-long fault (Hart and Bryant, 2001). At its southern end, near the city of Santa Rosa, the fault initiates as a right stepover from the Rodgers Creek fault zone (Hart, 1998) and trends north-northwestward through the California Coast Ranges. Documentation and mapping of active and potentially active fault strands are important for characterizing seismic hazards in the rapidly growing greater Santa Rosa urban area, and for understanding the distribution of slip among eastern strands of the San Andreas fault system.

We present a map of active strands of the southern Maacama fault interpreted from recently acquired (May, 2008) high resolution airborne Light Detection and Ranging (LiDAR) data that cover a 1-km swath along the main fault trace. The LiDAR data are supplemented with information from field reconnaissance, literature review, and interpretation of stereoscopic aerial photography. The resulting map data are compiled in a format suitable for incorporation in the Northern California Quaternary Fault Map Database (NCQFMD). The project was funded by the National Earthquake Hazards Reduction Program (NEHRP) under grant award #8HQGR0056, and conducted in collaboration with the U.S. Geological Survey (USGS). This research directly addresses Priority III in the FY2008 Announcement for the Northern California panel, to update and refine the NCQFMD.

2.0 Geologic setting and previous work

The southern Maacama fault is located in the Mayacmas Mountains near the western front of the range (Figure 1). The geology in the fault zone, summarized on Wagner and Bortugno's (1982) geologic map compilation, consists of rocks of the Franciscan assemblage, Sonoma volcanic rocks (Fox et al., 1985), and Neogene and Quaternary basin fill deposits. McLaughlin (1978; 1981) conducted a detailed geologic study of the area that was largely focused on the geologic environment of the Geysers geothermal field, but included mapping of the Maacama fault zone in the Asti and Jimtown 7.5-minute USGS quadrangles. McLaughlin and Nilsen (1982) described a late Neogene pull-apart basin complex along the southern Maacama fault in the vicinity of Big and Little Sulphur Creeks. Fox (1983) mapped strands of the Maacama fault zone along with late Neogene and Quaternary units in the Napa County/Sonoma County area. Most recently, McLaughlin and others completed new detailed geologic mapping of the Mark West Springs 7.5-minute quadrangle (2004a) and the Santa Rosa 7.5-minute quadrangle (2008). Their mapping represents the best depiction of the bedrock trace of the Maacama fault in this area, however, the map does not document Quaternary fault-related geomorphic features or provide estimates of relative activity.

Gealey (1951) named the Maacama fault zone on the geologic map of the Healdsburg 15-minute quadrangle, which encompasses the Jimtown, Healdsburg, and Geyserville 7.5-minute quadrangles. The fault is based on relationships between bedrock units. However, he also cited evidence of renewed movement on this and other bedrock faults in the area, specifically noting ponded alluvium in two locations on the east side of the Maacama fault.

The most focused previous efforts to map Quaternary fault strands within the southern Maacama fault zone are those of Herd et al. (1977) and Huffman and Armstrong (1980). Both conducted reconnaissance fault and lineament mapping at 1:24,000 scale based largely on interpretation of aerial photography and topographic maps. A comparison of their work with the results of this study is found in the discussion section. Pampeyan and others (1981) and Upp (1989) mapped the northern Maacama fault, overlapping the northern portion of the study area in the Hopland quadrangle (Fig. 1).

Previous mapping along the Maacama fault zone was compiled in the Fault Evaluation Reports (FERs) of the California Geological Survey (Smith, 1982; Bryant, 1982; Hart and others, 1983; California Geological Survey, 2002). The FERs were prepared under the Alquist-Priolo earthquake fault zoning act, and include fault strip maps of the southern Maacama fault zone (Bryant, 1982; Smith, 1982; Hart and others, 1983). The fault strip maps, published on compact disk (California Geological Survey, 2002), delineate previous fault strand and lineament mapping.

Fault mapping along the southern Maacama fault zone has been compiled into a draft version of the National Quaternary Fault and Fold Database. The California Geological Survey has worked with the USGS to put together the California portion of the database (USGS/CGS, 2006; Hart and Bryant, 2001). The database sheet assembled for the Maacama fault (data sheet # 30; 30a, north section, 30b, south section) includes a comprehensive list of references including previous fault strand mapping along the Maacama fault zone and summaries of paleoseismic trench investigations to date (Hart and Bryant, 2001). The mapped trace of the southern Maacama fault in the database is not simply a compilation of previous work. The compilers have interpreted and connected segments that were previously mapped as discontinuous in order to present a continuous mapped fault.

The southern termination of the fault zone is unclear. According to Bryant (1982), who compiled fault mapping of Herd et al. (1977) and Huffman and Armstrong (1980), the fault zone terminates in the Mark West Springs quadrangle where it steps southwest to the Rodgers Creek fault zone. Bryant (1982) based the southeast termination on absence of evidence of Quaternary landforms produced by faulting. However, more recent bedrock mapping by McLaughlin and others (2004a, 2008) extends the Maacama fault, as a bedrock feature, all the way across the Mark West Springs quadrangle into Rincon Valley in the Santa Rosa quadrangle to the south. In gathering the LiDAR data, it was assumed that the fault may extend this far south and the LiDAR data were collected accordingly.

3.0 Methods

The study area transects portions of the Santa Rosa, Mark West Springs, Mount St. Helena, Jimtown, Asti, Healdsburg, Geyserville, Cloverdale, and Hopland 7.5-minute USGS topographic quadrangle sheets (Fig. 1).

The LiDAR data were collected with funding from the National Science Foundation (NSF) through GeoEarthscope Geo Plate Boundary Observatory, flown and processed by National Center for Airborne Laser Mapping (NCALM) under contract through UNAVCO. The LiDAR data consist of a digital elevation model of the bare earth (i.e. excluding vegetative cover), from which we created a hillshade image with a resolution of 0.5 m, and a topographic contour map

with a 1-m contour interval. We also used GIS functions to create maps of slope, and slope change, to help highlight fault-related features

Mapping was conducted primarily in the GIS environment on the computer screen; features were drawn by hand with the mouse. We had access at the click of a button to georectified images of the FER maps (CGS, 2002), Herd and others (1977) mapping, and published geologic maps. To begin, so as not to bias our results, mapping was done without referring to previous mapping. After we had completed a first draft, we systematically reviewed previous mapping and re-evaluated each strand that others had mapped. A relatively small number of additions and revisions were made in the course of this review.

Field checking was limited to a single day on which we visited approximately eight sites. This level of field reconnaissance was appropriate given the poor geomorphic expression of the fault, the lack of roads in the Mayacmas Mountains, and the difficulty of obtaining access on private property.

We approached the mapping seeking positive evidence of active faulting. Unlike the northern Maacama fault, where Holocene slip rates are known from creep measurements and paleoseismic studies (Prentice, 2005; Galehouse, 2002), the activity of the southern Maacama fault has not yet been established. It is not clear how much of the Holocene slip documented on the northern Maacama fault similarly occurs on the southern Maacama. It has not yet been established how far to the south active faulting extends, or where and how much slip is transferred to the Rodgers Creek fault. Although active traces of the southern Maacama fault are not well established, the trace of the fault as a bedrock feature is well known (e. g. McLaughlin, 1978, 2004a, 2008).

A fault scarp was considered to be the most certain evidence of active faulting. A fault scarp is not likely to have been formed by another geomorphic process, such as landslides or fluvial processes, and is a common feature of active strike-slip faults. Other features, such as sag ponds, offset drainages, ponded alluvium, lines of saddles, breaks-in-slope, and troughs, were also considered to be evidence of active faulting, though some of these features may be pre-Holocene.

Linear drainages, linear valleys, lines of saddles, and breaks-in-slope were generally not considered positive evidence of active faulting. Geologic maps of the fault zone show numerous bedrock faults and bedrock contacts oriented sub-parallel to the trend of the fault. Such linear geomorphic features may result from differential erosion along bedrock contacts or older faults, and thus are not unique indicators of Quaternary movement. These features are included if they are aligned with other more clearly active fault-related features, and are typically assigned a low certainty.

Because the primary data source for our fault strip-map is a one-km wide swath of LiDAR data, we have confined our map to the LiDAR-covered area. Although it is possible that primary fault scarps of the Maacama fault lie either east or west of the LiDAR swath, we found that the fault scarps that we mapped were primarily located near the center of the swath, leaving no impression that increased swath width would have led to better depiction of active fault scarps. However, bedrock mapping by McLaughlin (1978, 2004) does show a few bedrock strands of the Maacama fault that fall outside the LiDAR-covered area. If additional LiDAR data become available in the future, it would be prudent to search for additional fault strands.

4.0 Results

Our product is a revised fault map for the southern Maacama fault zone (Plates 1 through 9). The fault mapping is keyed by color as follows: (1) *active fault – certain (red)*, (2) *active fault – somewhat certain (orange)*, and (3) *active fault – uncertain (green).* The combined *fault features* dataset is an improvement from, and should be considered a revision in place of, previous depictions of the southern Maacama fault (Herd and others, 1977; Huffman and Armstrong, 1980; CGS, 2002; Hart and Bryant, 2001).

Active faults are classified as *certain*, *somewhat certain*, and *uncertain* based on levels of confidence that the feature was formed by active faulting rather than another geomorphic process. Faults mapped as *certain* are those for which active faulting is the only process that reasonably could have created the feature. Features mapped as *somewhat certain* are judged likely to be a fault scarp, but a small possibility exists that it may have been formed by another process, such as fluvial erosion, grading, differential erosion of contrasting bedrock lithologies, landsliding, etc. Features mapped as *uncertain* have origins that could be equally related to active faulting or to other processes.

As part of our documentation of features along the Southern Maacama fault, we have also mapped landslides, active channels, and ponded water bodies, and have depicted slopes greater than 20 degrees. In general, these are areas where fault features are not observed. Each mapping unit is depicted as a separate layer in the fault map database as described below.

Each fault strand is assigned a unique four-digit number keyed to a table of fault strand attributes (Table 1). The table and digital data follow the standards of the NCQFMD (http://geomaps.wr.usgs.gov/sfgeo/quaternary/).

4.1 Description of Map Units

<u>Active fault- certain</u>

The *active fault-certain* layer depicts landscape features thought to be created by Holocene fault displacement. Fault scarps are the primary feature mapped.

The underlying assumption is that the Holocene-active Maacama fault creates identifiable fault scarps. When identifying active fault scarps, we evaluated other candidate explanations for scarps, including fluvial terrace risers, landslide headscarps, road cuts, and bedrock strike ridges. The active fault scarps are linear or gently arcuate in trend and are not likely to have been formed by these other mechanisms. Identifiable fault scarps are not found in areas of active landslides nor on slopes greater than 20 degrees, from which we infer that surface processes within these areas, in the time since the last fault displacement, have eliminated identifiable scarps.

Because we used LiDAR data, we located scarps based on the LiDAR-derived topographic maps and hillshade images. The resolution of the LiDAR data, as defined by pixel width, is 0.5 m. Therefore, the degree of accuracy of delineating the base of scarp on the LiDAR image is within 3 m in all cases and in most cases within 2 m. The accuracy within 2 or 3 m is a function of

operator variability in using the pen tool in ARCMAP to delineate the feature visible on the LiDAR image. Because the LiDAR data allow a high degree of location accuracy, we ranked all mapped landscape features to the same location criteria (rank 1, <3m, as described in the table of fault strand annotations accompanying the data base).

Active fault – Somewhat certain

Although the active trace of the Maacama fault is optimally located where fault scarps are preserved, the fault also can be located from other geomorphic features if a fault scarp is not present. The *active faults-somewhat certain* layer captures such features as offset drainages, sag ponds, and ponded alluvium.

Active fault - Uncertain

Landscape features, that by themselves may not be positive evidence for active faulting (such as lines of saddles and breaks-in-slope), are included as *active fault-uncertain* if they are spatially associated (that is, along trend) with other more *certain* or *somewhat certain* features. *Active fault-uncertain* may include fault-line scarps, ponded alluvium undergoing dissection, lines of saddles, breaks-in-slope, linear escarpments, and certain linear valleys. A fault-line scarp is an escarpment whose primary morphology is caused by differential erosion of contrasting rock units on either side of a fault, however, the fault need not be active. Other linear escarpments may represent older fault scarps whose primary morphology has been subdued and diffused by subsequent slope movement, or by the ponding of alluvium against the scarp partially obscuring it. The LiDAR data set is uniquely suited to the identification of these types of features because the highly resolved bare-earth topography allows for distinction of whether these features are on trend with other more *certain* or *somewhat certain* features.

A type of feature generally omitted from consideration was the linear drainage. Linear drainages may develop in a number of different geologic settings; they may result from differential erosion along bedrock contacts or may follow weak rocks in an inactive fault zone. As they are not unique to active faults, they were not mapped as indicating an active fault. However, they may be included as part of an active trace identified on proximity to other features.

Landslides

The landslide layer depicts earthflows and slumps that have distinctive landslide morphology indicative of active downslope mass movement of colluvium. The earthflow morphology includes grassy, subdued slopes with a distinctive “melted ice cream topography” that are bordered by sharply defined headscarps and sidescarps. Within earthflow terrain, gullies usually are shallow and not deeply incised. In contrast, inactive earthflows or competent sandstone terrain, which are not mapped in the landslide layer, have incised valleys and usually host trees.

Active stream channels and floodplains

This layer depicts active channels and adjacent floodplains at least 10 m in width. The purpose of depicting this layer is to show areas of active fluvial processes where fault scarps would not be preserved. Floodplains exhibited bar and swale morphology indicative of periodic inundation. Smooth surfaces were considered terraces and were not included in this map unit.

Ponds and lakes
This layer depicts stock ponds, reservoirs, and other bodies of water larger than 100 square meters. The purpose of depicting this layer is to show areas where fault scarps would not be visible on LiDAR imagery as the ground surface is obscured by standing water.

Slopes greater than 20 degrees
This layer consists of a GIS-computed, raster-based image that shows all slopes greater than 20 degrees. LiDAR data provided the topographic information for this computation. The layer shows areas that may be too steep to preserve Holocene fault scarps. Rapid mass wasting, rock slides, creep, and gullying (typical of steep slopes), may remove fault scarps relatively quickly. Thus, we find that fault features are not apparent on slopes greater than twenty degrees.

4.2 Geomorphic Expression of the Southern Maacama Fault

In general, the southern Maacama fault is characterized by poor geomorphic expression. Active fault features (all classes of certainty) are present along only 19 km (41%) of the 54-km length of the fault (Table 2, and Plates 1 through 9). Those features classified as *certain* and *somewhat certain* comprise only 6 km (11%) of the length of the fault.

In the few areas where fault scarps are well expressed, individual strands are typically discontinuous with lengths of tens to hundreds of meters arranged in a left-stepping en-echelon pattern. Scarps are usually east facing. Because individual fault strands tend to be more northerly trending than the average trend of the fault zone, left steps are required to move from one fault strand to the next. This pattern can be seen in strands 1002 through 1008, 1011 through 1013, and 1038 through 1051 (Plates 1 through 9).

To test the hypothesis that active geomorphic processes are obscuring active fault features, we compared our mapped faults with our mapped areas of active geomorphic processes. In general, fault features are not found in areas mapped as active landslides, active stream channels, flood plains, and steep slopes.

5.0 Discussion

Relative to previous studies, we find few geomorphic features that can be attributed with certainty to active faulting. Gealey (1951), Huffman and Armstrong (1980), and Herd et al. (1977) each made original observations and noted features they interpreted as indicating active faulting on the southern Maacama fault. Gealey describes the Maacama fault zone primarily as a bedrock feature, but mentions several features he feels suggest recent movement. First, he describes areas of ponded or “perched” alluvium within the Mayacmas Mountains at Miller Creek and between Sausal and Gird Creeks and interprets them as indicating recent faulting with southwest directed dip-slip. Huffman and Armstrong (1980) add the head of Crocker Creek to the list of drainages with ponded alluvium. LiDAR data clearly show these areas are ponded alluvium, but we infer that they are not likely to represent Holocene active faulting based on their smoothness, dissection by modern streams, and lack of visible fault scarps. They may, however, be the result of early to middle Quaternary-aged faulting.

Possible right-lateral offset of drainages have been noted by previous workers between Franz and Sausal Creeks (Huffman and Armstrong, 1980; Gealey, 1951). LiDAR data do show four adjacent drainages on the Asti 7.5-minute quadrangle (Plate 3) that appear to have right-lateral offsets. However, further examination suggests that two of the drainages may be diverted laterally to pass around a resistant bedrock knob. Lateral offsets are not observed north or south of this local area.

Tectonic tilting of the extensive Quaternary terrace surface south of Maacama Creek is suggested by Huffman and Armstrong (1980), but is not borne out by LiDAR data. This terrace sits approximately 200 feet above creek level and is indeed sloped to the northwest in a direction inconsistent with modern terraces of Maacama Creek. LiDAR data show that this terrace may instead have been formed by Franz Creek to the south. The terrace appears to be a dissected remnant of an alluvial fan formed when the Franz Creek flowed north through a wind gap between the two drainages. Terrace remnants at similar elevations can be found along Franz Creek upstream of the wind gap.

In 1977 Herd, Helley, and Rogers systematically mapped the southern Maacama fault from aerial photography and topographic features on USGS 7.5-minute topographic quadrangle maps. This mapping is the primary source of the fault traces shown on the Fault Evaluation Reports of the California Geological Survey (Bryant, 1982; CGS, 2002). Herd and others (1977) mapped linear drainages, breaks-in-slope, sag ponds, lines of seeps, and scarps. Because they included linear drainages as indicators of the fault, they mapped many more fault traces than we map. As mentioned above, we deliberately do not map linear drainages as fault traces because linear drainages are not unique indicators of active faulting. In addition, because their primary data sources (1:20,000-scale aerial photography in which trees obscure the ground, and 1:24,000-scale topographic maps) are not as detailed and accurate as the LiDAR data (bare earth topography with 0.5 m resolution), they omit subtle features visible on the LiDAR imagery.

Our depiction of the southern Maacama fault is similar in extent, but differs in detail, relative to state hazard maps.. The California Geological Survey identifies Alquist-Priolo (AP) Fault Rupture Hazard Zones in California and publishes these maps in a 7.5-minute quadrangle format (Bryant and Hart, 2007). These maps identify fault strands thought to pose a rupture hazard and, in addition, identify a hazard zone that includes a narrow buffer about each strand. Our mapped fault strands, within all confidence categories (with a few exceptions), lie within the previously mapped AP hazard zones. We identify several fault strands within the Cloverdale and Mark West Springs quadrangles that lie outside these zones (Figs. 2 and 3).

6.0 Summary and Conclusions

A fault strip-map along the southern Maacama fault emphasizes active traces of the fault as mapped from 2008 LiDAR data collected in a one-kilometer swath along the fault. Fault scarps are most indicative of active faulting, followed by offset drainages, sag ponds, ponded alluvium, and linear breaks-in-slope. Lines of saddles, seeps, and linear drainages or valleys are considered uncertain evidence as they may be associated with bedrock contacts or inactive faults.

The LiDAR data provide an exceptional view of landscape detail, and the data are ideal for mapping and interpretation of geomorphic features in this rugged, forested terrain. The small scale of many active-fault features and the dense tree cover in the Mayacmas Mountains make traditional mapping from aerial photographs and 1:24,000-scale topographic maps challenging. As a result, many of the features shown in our fault-strip maps had not been identified by previous mapping efforts. Likewise, a number of features mapped by previous workers as candidate active faults have been eliminated based on our mapping using bare-earth LiDAR imagery.

In general, the southern Maacama fault has poor geomorphic expression. Active fault features (all classes of certainty) are present along only 22.5 km (41%) of the 54-km length of the fault (Table 2, and Plates 1 through 9). Those features classified as *certain* and *somewhat certain* comprise only 6 km (11%) of the length of the fault.

Mountainous terrain underlain by weak bedrock subject to landsliding may partially account for the lack of active geomorphic features. We conclude that over much of the fault length, hillslope processes dominate over the active fault processes, and thus active landsliding subdues and ultimately eliminates active fault scarps.

There are significant gaps within which no geomorphic expression of the fault could be found. The longest of these gaps, approximately 8 km in the northern Asti 7.5-minute quadrangle, can be partially explained by the presence of extensive landslides where mass movements can quickly remove evidence of active faulting. However, significant portions of the gap are free of mappable landslides.

The location of the southern terminus of the fault has not been confidently established by previous studies. Hart and Bryant (2001) report a 54-km length for the fault, and the AP Fault Rupture Hazards Zone maps (Bryant and Hart, 2007; CGS, 2002) show the fault zone terminating 4.6 km from the northern boundary of the Mark West Springs 7.5-minute quadrangle (Figure 3). Our mapping from LiDAR data confirms that geomorphic expression of active faulting terminates in the Mark West Springs quadrangle, but shows three discontinuous *uncertain* strands extending south of the AP fault rupture hazard zone. Given the lack of confidence associated with these three strands, we conclude that the active trace of the southern Maacama fault may indeed terminate in the northern half of the Mark West Springs quadrangle as suggested by CGS (2002).

If the active trace of the southern Maacama fault terminates in the northern half of the Mark West Springs 7.5-minute quadrangle, it is unlikely that strain is transferred from the Rodgers Creek fault to the southern Maacama across Rincon Valley in Santa Rosa, as has been suggested by McLaughlin and others (2007). Instead, strain may be transferred well north of the city of Santa Rosa. Further research to identify specific structures along which slip is transferred will help assess seismic hazard associated with the southern Maacama fault in the Santa Rosa area.

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Table 1. Fault Features of the Southern Maacama Fault

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1001	Maacama fault zone	30b	Alignment of springs, saddles and break-in-slope - possible east facing scarp with ponded alluvium - may be related to landsliding	SHK	LiDAR	02/04/09	Uncertain	Certain	1	434
1002	Maacama fault zone	30b	Linear saddle and trough	SHK	LiDAR	01/07/09	Uncertain	Certain	1	245
1003	Maacama fault zone	30b	Linear drainage with two sag ponds	SHK	LiDAR	01/07/09	Somewhat Certain	Certain	1	493
1004	Maacama fault zone	30b	East-facing scarp (~2 m high) (could be line of bedrock knobs)	SHK	LiDAR	01/07/09	Uncertain	Certain	1	192
1005	Maacama fault zone	30b	East-facing scarp (~3 meters high)	SHK	LiDAR	07/14/08	Certain	Certain	1	243
1006	Maacama fault zone	30b	East-facing scarp (~1-2 m high)	SHK	LiDAR	01/07/09	Certain	Certain	1	171
1007	Maacama fault zone	30b	East-facing scarp along sag pond (modified to be a reservoir) (~2m high)	SHK	LiDAR	07/14/08	Certain	Certain	1	288
1008	Maacama fault zone	30b	Possible right lateral offset and alignment of saddles possible east facing scarp, change in depth of stream incision	SHK	LiDAR	02/04/09	Somewhat Certain	Certain	1	244
1009	Maacama fault zone	30b	Southeast-facing scarp (~1m high) (very subtle)	SHK	LiDAR	01/07/09	Uncertain	Certain	1	97
1010	Maacama fault zone	30b	Linear break-in-slope parallel with adjacent fault strand	SHK	LiDAR	02/04/09	Uncertain	Certain	1	174
1011	Maacama fault zone	30b	East-facing scarp (~4-6 m) includes alignment of blind saddles	SHK	LiDAR	06/10/08	Certain	Certain	1	270

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1012	Maacama fault zone	30b	East-facing scarp (~6-7 m) includes alignment of blind saddles and breaks in slope	SHK	LiDAR	01/07/09	Certain	Certain	1	649
1013	Maacama fault zone	30b	East-facing scarp (~2 m) subtle - may be a bedrock knob	SHK	LiDAR	01/07/09	Uncertain	Certain	1	66
1014	Maacama fault zone	30b	Linear break-in-slope / east-facing scarp (maybe coincident with geologic contact)	SHK	LiDAR	02/04/09	Uncertain	Certain	1	52
1015	Maacama fault zone	30b	Linear break-in-slope / east-facing scarp (maybe coincident with geologic contact)	SHK	LiDAR	07/14/08	Uncertain	Certain	1	82
1016	Maacama fault zone	30b	Alignment of sag ponds, trough, saddle	SHK	LiDAR	01/07/09	Somewhat Certain	Certain	1	444
1017	Maacama fault zone	30b	Linear break-in-slope	SHK	LiDAR	02/04/09	Uncertain	Certain	1	103
1018	Maacama fault zone	30b	Linear break-in-slope	SHK	LiDAR	02/04/09	Uncertain	Certain	1	107
1019	Maacama fault zone	30b	Northeast-facing scarp (~2-4 m high) (may be geologic contact or fluvial)	SHK	LiDAR	01/07/09	Uncertain	Certain	1	86
1020	Maacama fault zone	30b	Northeast-facing scarp (<2 m high)	SHK	LiDAR	01/07/09	Uncertain	Certain	1	98
1021	Maacama fault zone	30b	Linear break-in-slope and saddle	SHK	LiDAR	02/04/09	Uncertain	Certain	1	177
1022	Maacama fault zone	30b	Northeast-facing scarp (~4 m high) (coincident with a geologic contact)	SHK	LiDAR	06/10/08	Uncertain	Certain	1	97
1023	Maacama fault zone	30b	Hillside bench (may be related to bedrock structure)	SHK	LiDAR	02/04/09	Uncertain	Certain	1	91
1024	Maacama fault zone	30b	Ponded alluvium and linear valley with truncated spurs and saddles	SHK	LiDAR	01/09/09	Uncertain	Certain	1	509

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1025	Maacama fault zone	30b	Saddle and break-in-slope	SHK	LiDAR	02/04/09	Uncertain	Certain	1	192
1026	Maacama fault zone	30b	Closed depression in alignment with saddle	SHK	LiDAR	02/04/09	Uncertain	Certain	1	82
1027	Maacama fault zone	30b	Linear drainage with alignment of 3 reservoirs	SHK	LiDAR	01/07/09	Uncertain	Certain	1	831
1028	Maacama fault zone	30b	East-facing scarp (~2 m high) (may be formed by landslides or fluvial processes - alignment of break-in-slope)	SHK	LiDAR	01/07/09	Uncertain	Certain	1	172
1029	Maacama fault zone	30b	Alignment of break-in-slope on backside of bench, and stream deflections, and saddle	SHK	LiDAR	02/05/09	Uncertain	Certain	1	540
1030	Maacama fault zone	30b	Alignment of saddles, ponded alluvium, on a high bench	SHK	LiDAR	02/05/09	Uncertain	Certain	1	245
1031	Maacama fault zone	30b	East facing scarp (~1-2 m high) Knob at south end of feature may be due to geology	SHK	LiDAR	01/07/08	Uncertain	Certain	1	201
1032	Maacama fault zone	30b	Possible east-facing scarp (~1-2 m high)	SHK	LiDAR	01/07/09	Uncertain	Certain	1	492
1033	Maacama fault zone	30b	Linear break-in-slope east facing (coincides with geologic contact)	SHK	LiDAR	02/05/09	Uncertain	Certain	1	502
1034	Maacama fault zone	30b	Linear break-in-slope and saddles	SHK	LiDAR	07/15/08	Somewhat Certain	Certain	1	581
1035	Maacama fault zone	30b	East-facing scarp (~1-4 m high)	SHK	LiDAR	06/10/08	Certain	Certain	1	129
1036	Maacama fault zone	30b	Linear break-in-slope / east-facing scarp - in alignment with other features (may be fluvially modified)	SHK	LiDAR	01/09/09	Uncertain	Certain	1	131

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1037	Maacama fault zone	30b	Linear break-in-slope, and possible right-lateral stream offset (stream has been channelized around the vineyard)	SHK	LiDAR	07/15/08	Somewhat Certain	Certain	1	1164
1038	Maacama fault zone	30b	Possible NE facing scarp (2m)	SHK	LiDAR	02/05/09	Somewhat Certain	Certain	1	115
1039	Maacama fault zone	30b	Linear mountain front: break-in-slope and triangular facets (possibly fluvial scarp cut by Russian River or possible thrust fault)	SHK	LiDAR	07/15/08	Uncertain	Certain	1	1500
1040	Maacama fault zone	30b	Linear mountain front: break-in-slope and triangular facets (possibly fluvial scarp cut by Russian River or possible thrust fault)	SHK	LiDAR	02/05/09	Uncertain	Certain	1	429
1041	Maacama fault zone	30b	Linear mountain front: break-in-slope and triangular facets (possibly fluvial scarp cut by Russian River or possible thrust fault)	SHK	LiDAR	02/05/09	Uncertain	Certain	1	885
1042	Maacama fault zone	30b	Linear break-in-slope, and alignment of saddle, and line of seeps	SHK	LiDAR	07/15/08	Uncertain	Certain	1	1379
1043	Maacama fault zone	30b	Fault line scarp – break-in-slope - flat lying alluvium at base of steep hillslope. Possible offset drainage	SHK	LiDAR	01/07/09	Somewhat Certain	Certain	1	228
1044	Maacama fault zone	30b	Right laterally offset stream, saddle, and line of seeps	SHK	LiDAR	07/15/08	Somewhat Certain	Certain	1	238
1045	Maacama fault zone	30b	East-facing scarp (~2m high)	SHK	LiDAR	07/10/08	Uncertain	Certain	1	103
1046	Maacama fault zone	30b	Linear drainage - aligned with edge of reservoir	SHK	LiDAR	02/04/09	Uncertain	Certain	1	844
1047	Maacama fault zone	30b	Ponded alluvium with linear break-in-slope	SHK	LiDAR	07/22/08	Uncertain	Certain	1	306

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1048	Maacama fault zone	30b	Alignment of bench, and east facing fault scarp (~2 m high) accentuated by grading along the margin of the reservoir	SHK	LiDAR	01/09/09	Certain	Certain	1	442
1049	Maacama fault zone	30b	Alignment of saddles and benches	SHK	LiDAR	01/09/09	Uncertain	Certain	1	449
1050	Maacama fault zone	30b	Alignment of saddles and benches	SHK	LiDAR	01/09/09	Somewhat Certain	Certain	1	522
1051	Maacama fault zone	30b	Linear break-in-slope, additionally modified by grading for road (geologic contact coincides with feature)	SHK	LiDAR	12/23/08	Uncertain	Certain	1	98
1052	Maacama fault zone	30b	Alignment of break-in-slope, and saddles (possible landslide origin)	SHK	LiDAR	01/09/09	Uncertain	Certain	1	173
1053	Maacama fault zone	30b	Alignment of break-in-slope and saddles- HHR have similar feature	SHK	LiDAR	07/22/08	Uncertain	Certain	1	648
1054	Maacama fault zone	30b	East-facing scarp (4-6 m high) (within andesite geologic unit - may be due to difference in geology?)	SHK	LiDAR	12/23/08	Uncertain	Certain	1	104
1055	Maacama fault zone	30b	East-facing scarp (<2 m high) (within andesite geologic unit - may be due to difference in geology?)	SHK	LiDAR	12/23/08	Uncertain	Certain	1	148
1056	Maacama fault zone	30b	Alignment of saddle and break-in-slope	SHK	LiDAR	02/05/09	Uncertain	Certain	1	284
1057	Maacama fault zone	30b	East-facing scarp (1-2 m high) (within andesite geologic unit) - may be due to difference in geology?)	SHK	LiDAR	12/23/08	Uncertain	Certain	1	261
1058	Maacama fault zone	30b	Alignment of saddles and linear trough	SHK	LiDAR	01/09/09	Uncertain	Certain	1	188
1059	Maacama fault zone	30b	Alignment of saddles, drainage initiations, and is a linear ridge	SHK	LiDAR	07/22/08	Uncertain	Certain	1	857

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1060	Maacama fault zone	30b	Linear break-in-slope	SHK	LiDAR	01/09/09	Uncertain	Certain	1	111
1061	Maacama fault zone	30b	Saddle, linear drainage and seeps	SHK	LiDAR	07/22/08	Uncertain	Certain	1	626
1062	Maacama fault zone	30b	Possible east-facing scarp	SHK	LiDAR	06/11/08	Uncertain	Certain	1	246
1063	Maacama fault zone	30b	West-facing scarp (Possible)	SHK	LiDAR	06/11/08	Uncertain	Certain	1	230
1064	Maacama fault zone	30b	East-facing scarp (1-3 m high)	SHK	LiDAR	01/09/09	Uncertain	Certain	1	418
1065	Maacama fault zone	30a	East-facing scarp (<2 m high)	SHK	LiDAR	06/10/08	Certain	Certain	1	239
1066	Maacama fault zone	30a	West-facing scarp and alignment of springs	SHK	LiDAR	02/04/09	Somewhat Certain	Certain	1	308
1067	Maacama fault zone	30a	West-facing scarp and line of sag ponds	SHK	LiDAR	02/04/09	Certain	Certain	1	779
1068	Maacama fault zone	30a	Linear break-in-slope / east-facing scarp	SHK	LiDAR	07/14/08	Uncertain	Certain	1	356
1069	Maacama fault zone	30a	Linear depression	SHK	LiDAR	02/04/09	Somewhat Certain	Certain	1	1303
1070	Maacama fault zone	30a	East-facing scarp (~2-4 m high) two offset drainages and alignment with spring	SHK	LiDAR	02/04/09	Certain	Certain	1	391
1071	Maacama fault zone	30a	West-facing scarp (~2-3 m high) in alignment with spring	SHK	LiDAR	02/04/09	Certain	Certain	1	410

Strand No.	Fault Name	Fault ID	Feature Description	Map By (1)	Method	Last Updated	Fault Certainty (2)	Location Certainty (3)	Location Certainty Rank (3)	Length (m)
1072	Maacama fault zone	30a	Linear east-facing scarp (~1-2 m high) aligned near the margin of old landslide - possibly modified by erosion	SHK	LiDAR	02/04/09	Somewhat Certain	Certain	1	149

Notes: (1) SHK = Janet Sowers, Jeff Hoeft, and Harvey Kelsey
(2) Fault certainty is the certainty that the feature is the result of active faulting, as opposed to another geomorphic process
(3) Location certainty is the certainty in the location of the fault, quantitatively expressed as Rank; Rank 1 indicates the fault is located within 3 meters.

Table 2. Active Fault Trace Properties

	No. of Traces	Length: Range	Length: Average	Summed Length	Percentage of Entire Fault (54 km*)
Certain	7	129-650 m	313 m	2,192 m	4%
Somewhat Certain	9	115-1165 m	448 m	4,030 m	7%
Uncertain	48	52-1500 m	339 m	16,286 m	30%
Total	64	52-1500 m	352 m	22,510 m	41%

*Hart and Bryant, 2001.
Note: Calculations include data for the southern Maacama fault only, strands numbered 1001 through 1064 on Plates 1 through 9 and Table 1.

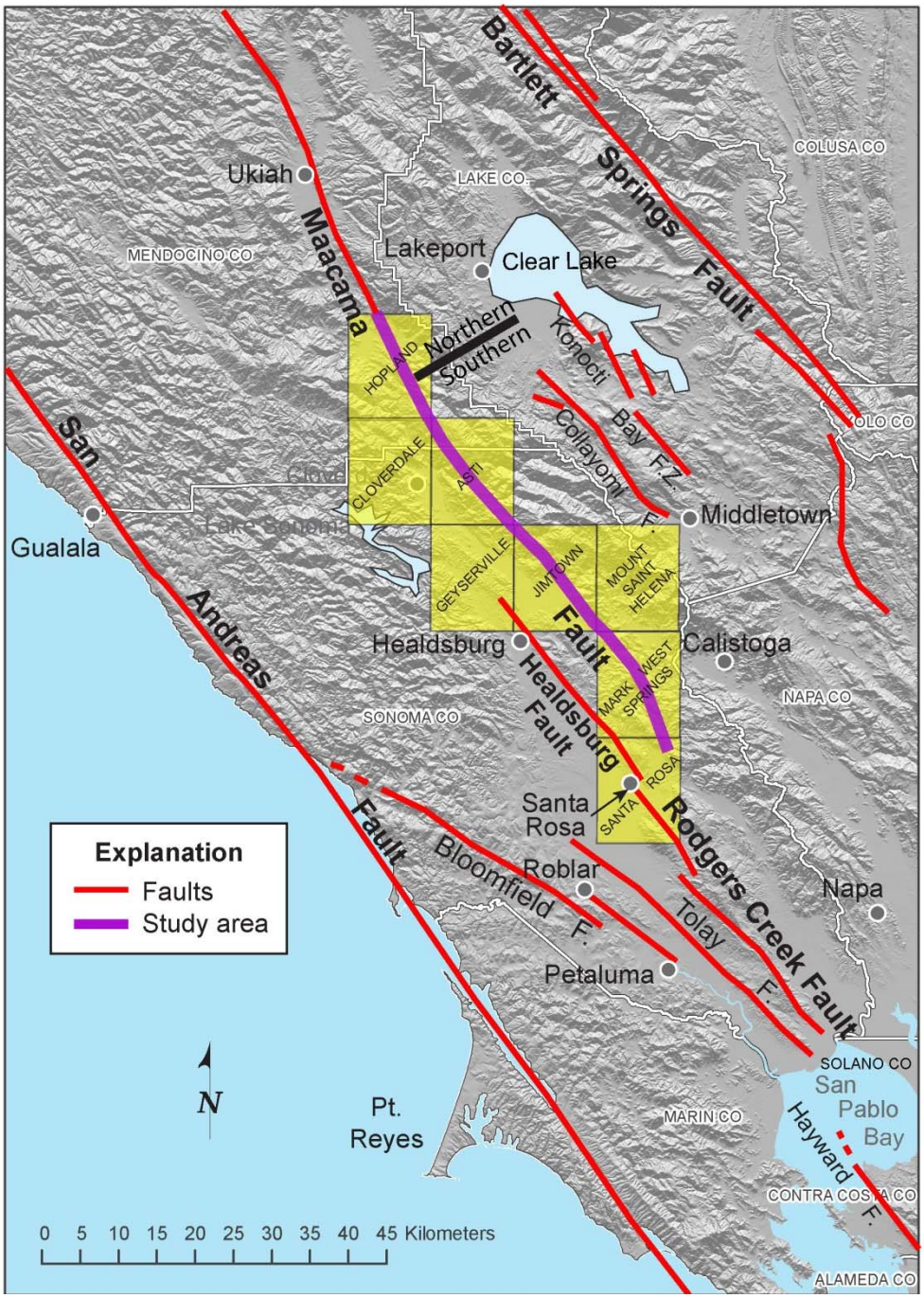


Figure 1. The Southern Maacama fault study area is a one-km-wide zone (wide purple band) extending from the Santa Rosa area north to the Hopland area. Mapping from LiDAR data was conducted within this zone. Named rectangles indicate the U.S. Geological Survey 7.5-minute quadrangles.

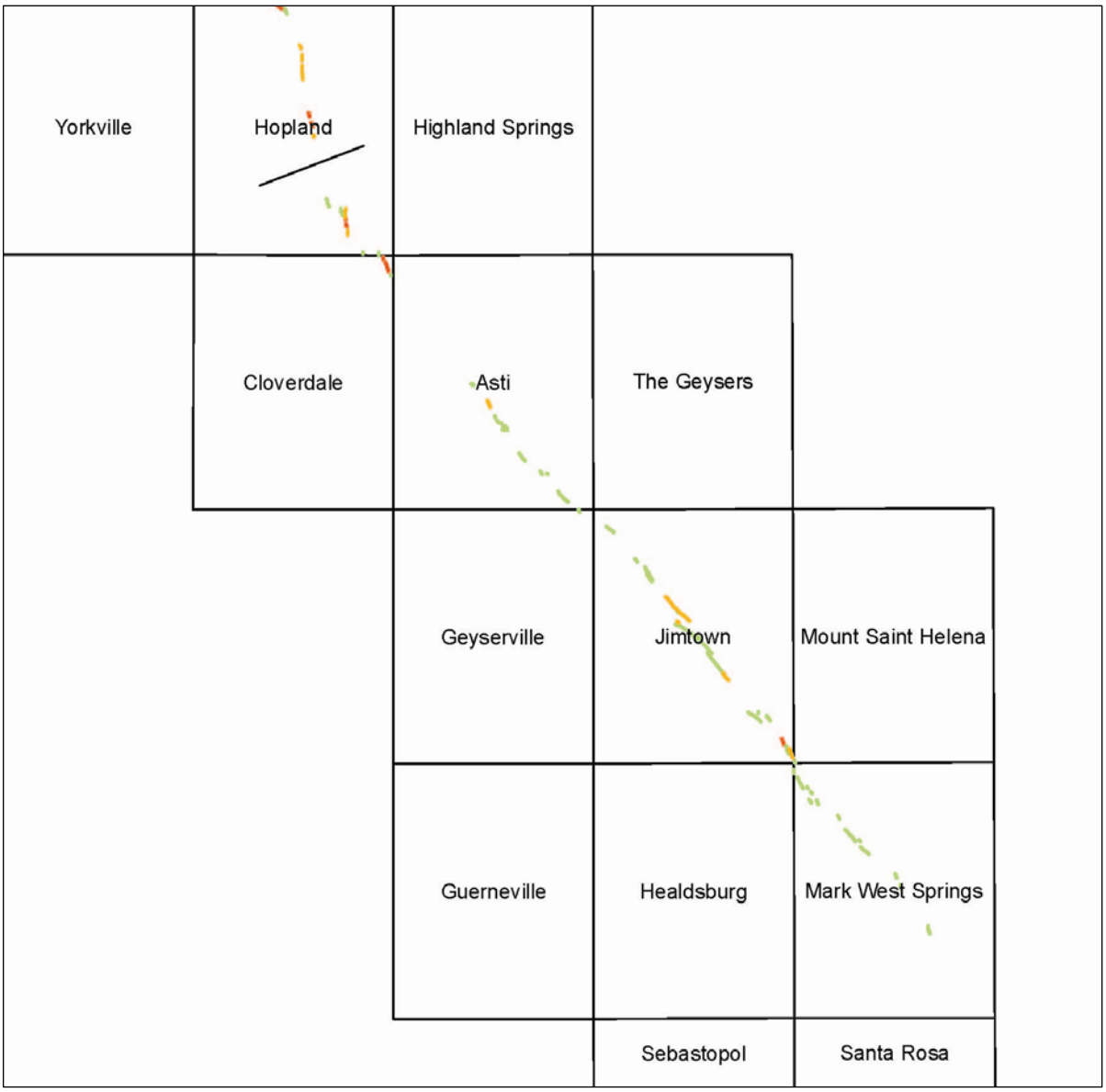


Figure 2. Summary distribution of fault strands mapped. Color indicates the degree of certainty that the feature mapped is an active fault strand. Red = Certain; Orange = Somewhat Certain; Green = Uncertain. The diagonal line in the Hopland quadrangle divides the southern and northern sections of the Maacama fault. Grid indicates boundaries and names of U.S. Geological Survey 7.5-minute quadrangles.

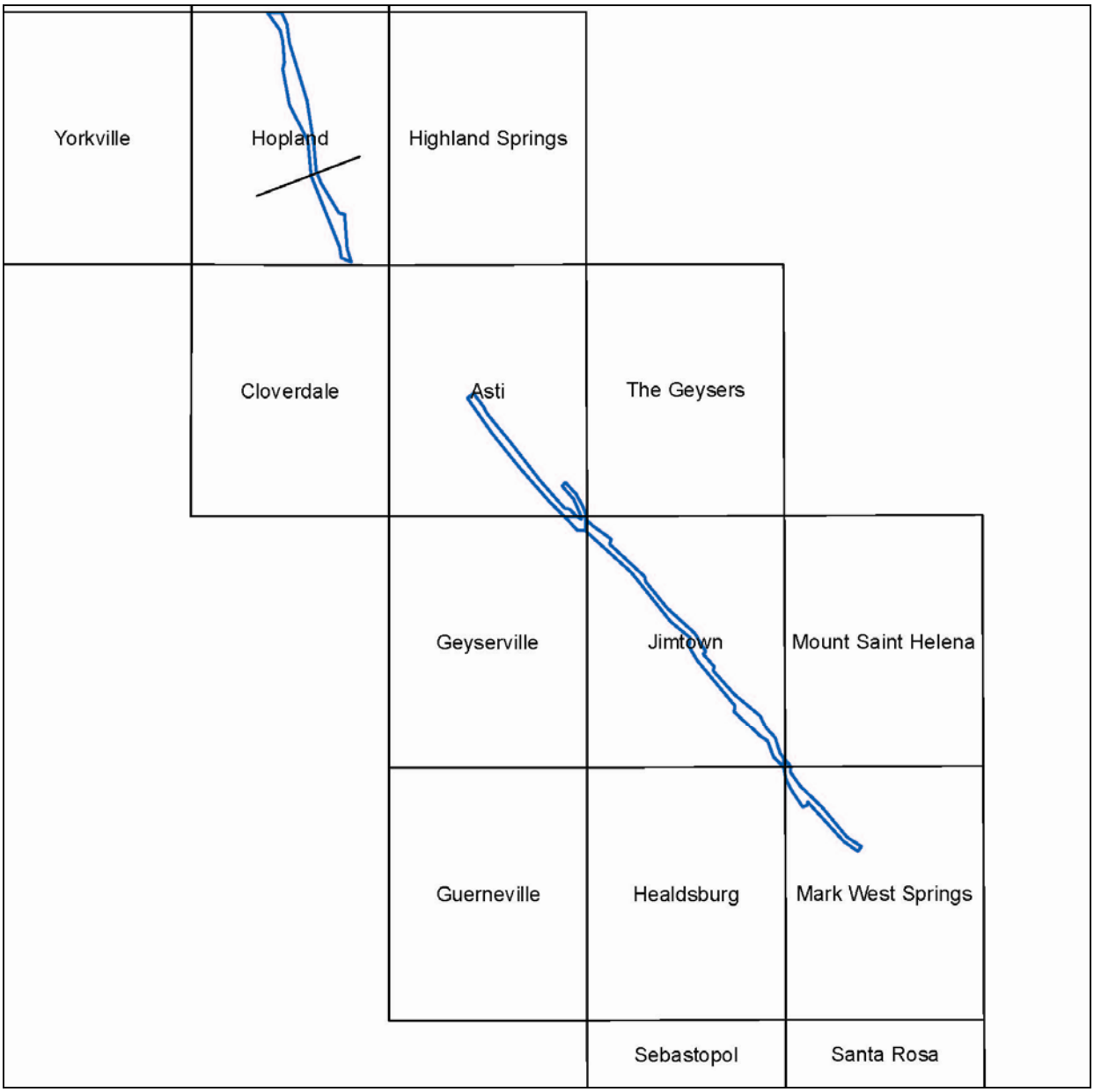
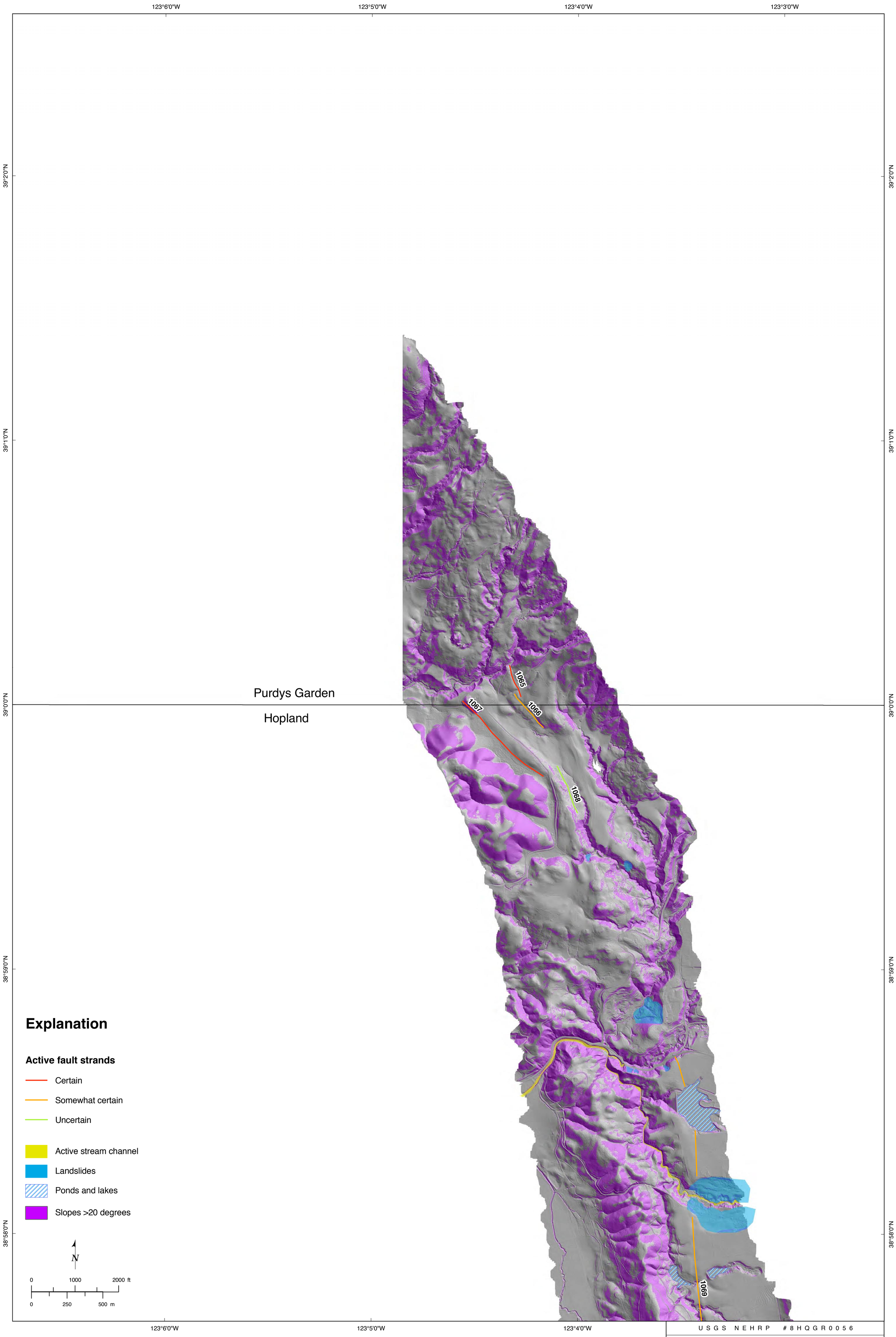


Figure 3. Alquist-Priolo Fault Rupture Hazard Zones for the study area (Bryant, 1982). The diagonal line in the Hopland quadrangle divides the southern and northern sections of the Maacama fault. Grid indicates boundaries and names of U.S. Geological Survey 7.5-minute quadrangles.



USGS NEHRP #8HQGR0056

Active Strands of the Southern Maacama Fault

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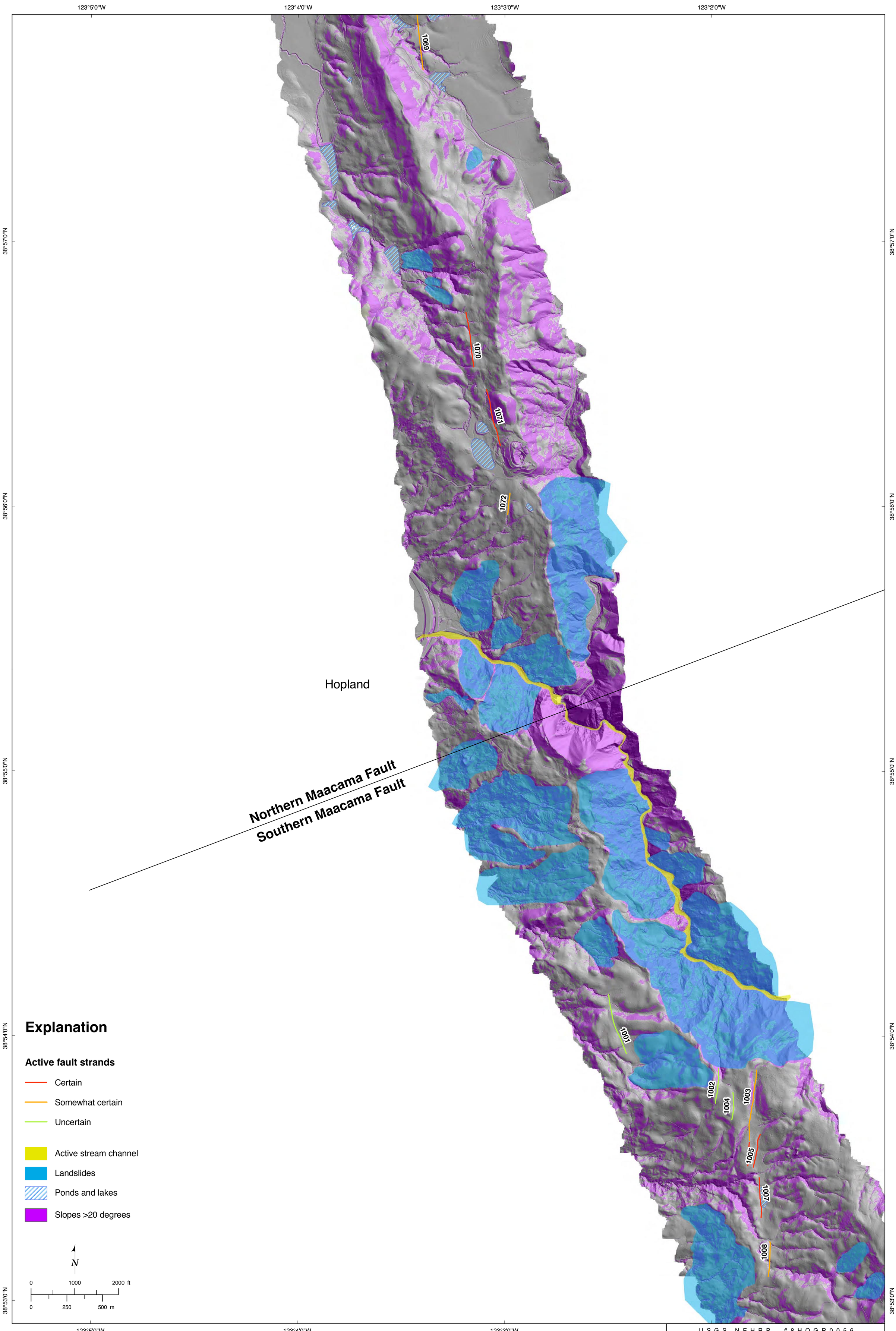
Plate 1 of 9

2/24/09 Smaacama022409_plate1.mxd 1960 Maacama Fault



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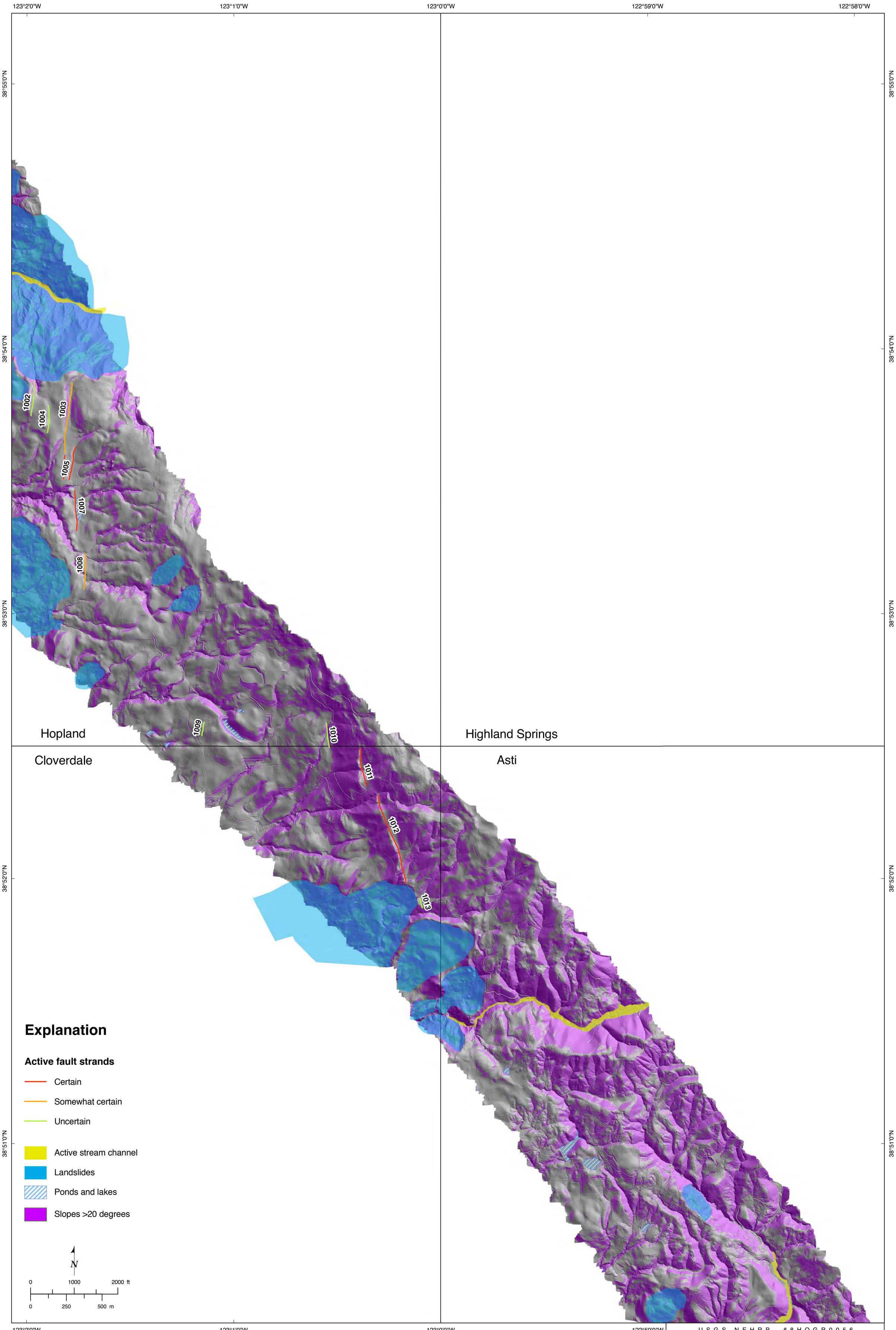
Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. | Plate 2 of 9

2/24/09 Smaacama022409_plate2.mxd 1960 Maacama Fault



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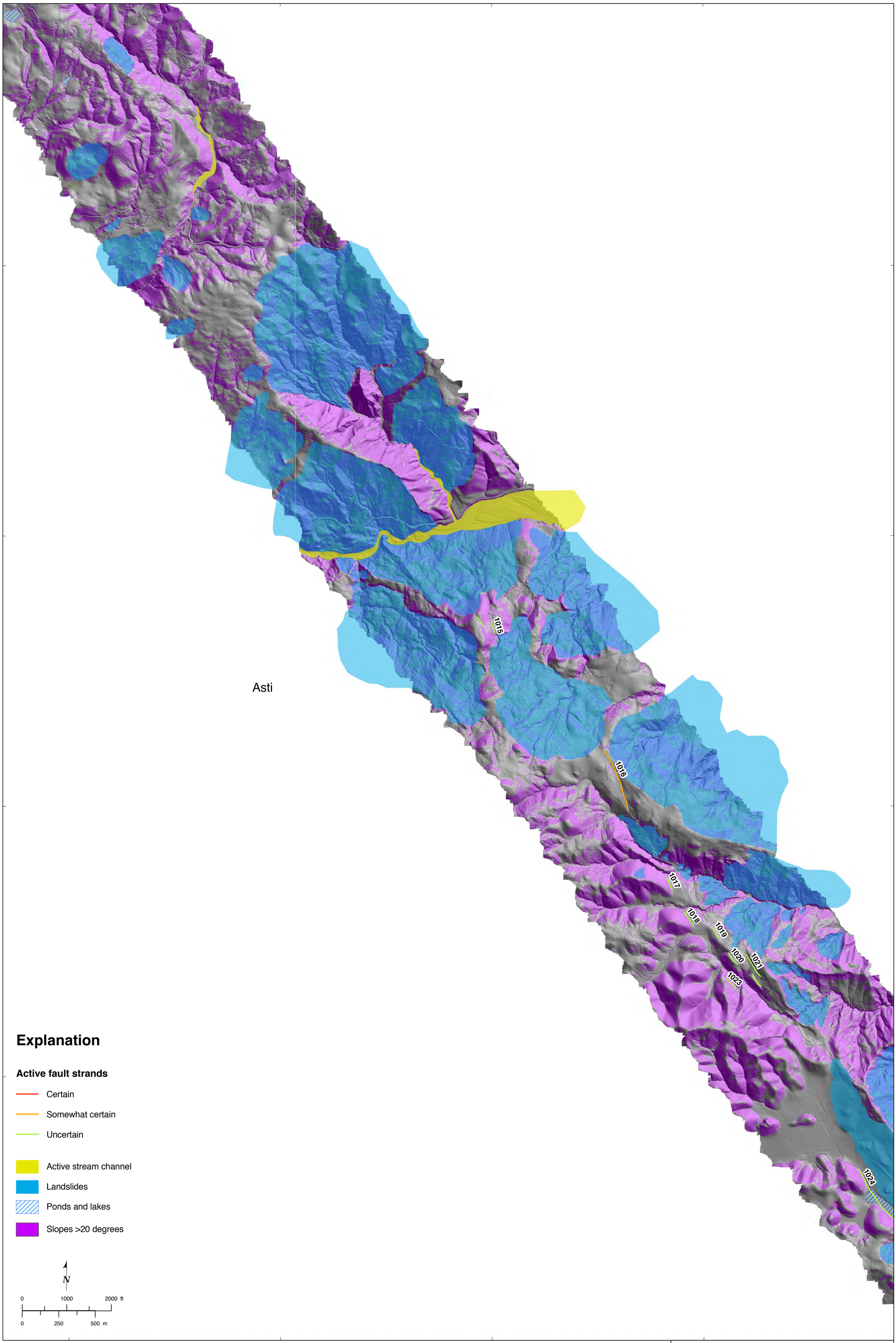
Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. Plate 3 of 9

2/24/09 Smaacama022409_plate3.mxd 1960 Maacama Fault



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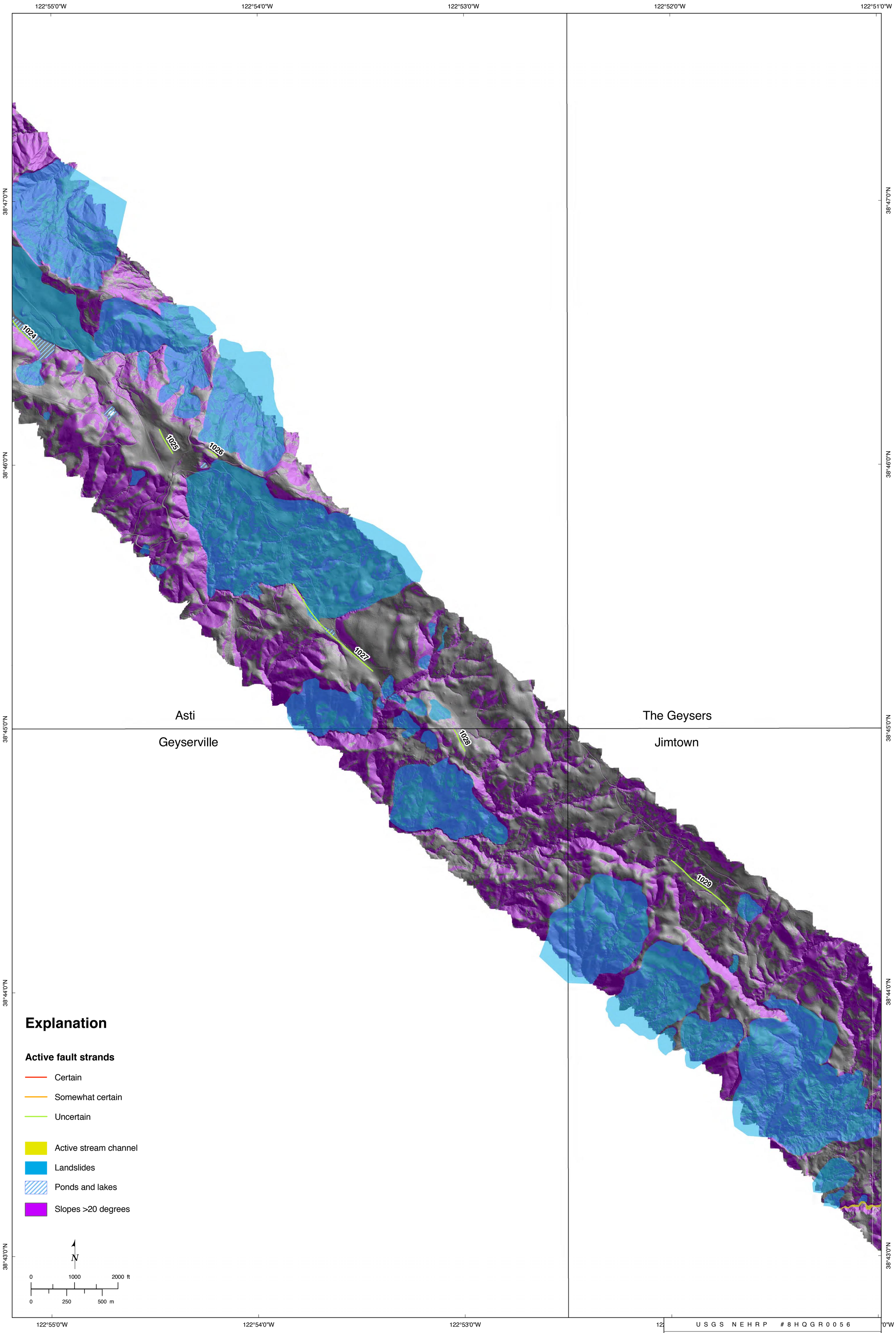
Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. Plate 4 of 9

2/24/09 Smaacama022409_plate4.mxd 1960 Maacama Fault



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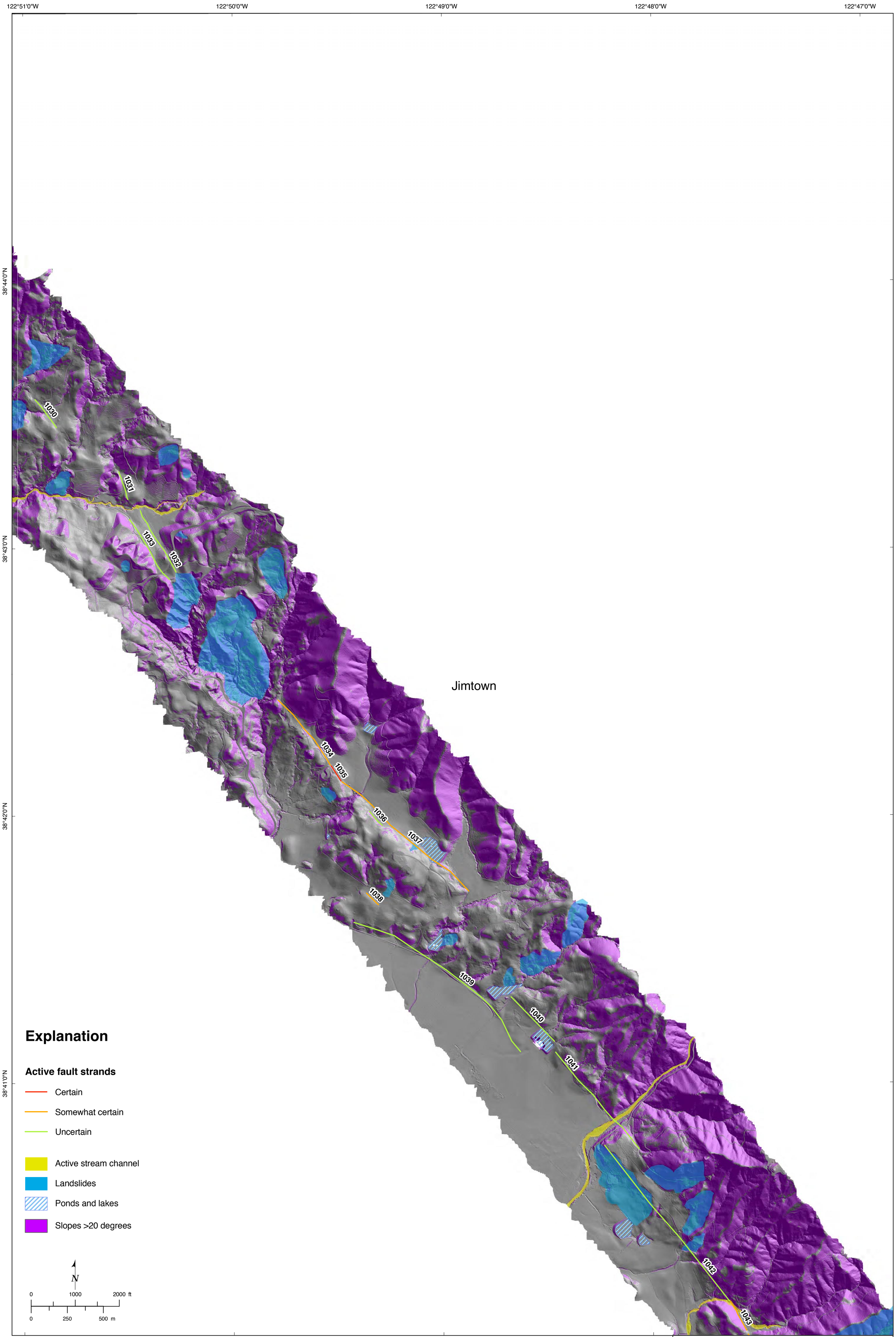
Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. Plate 5 of 9

2/5/09 Smaacama022409_plate5.mxd 1960 Maacama Fault



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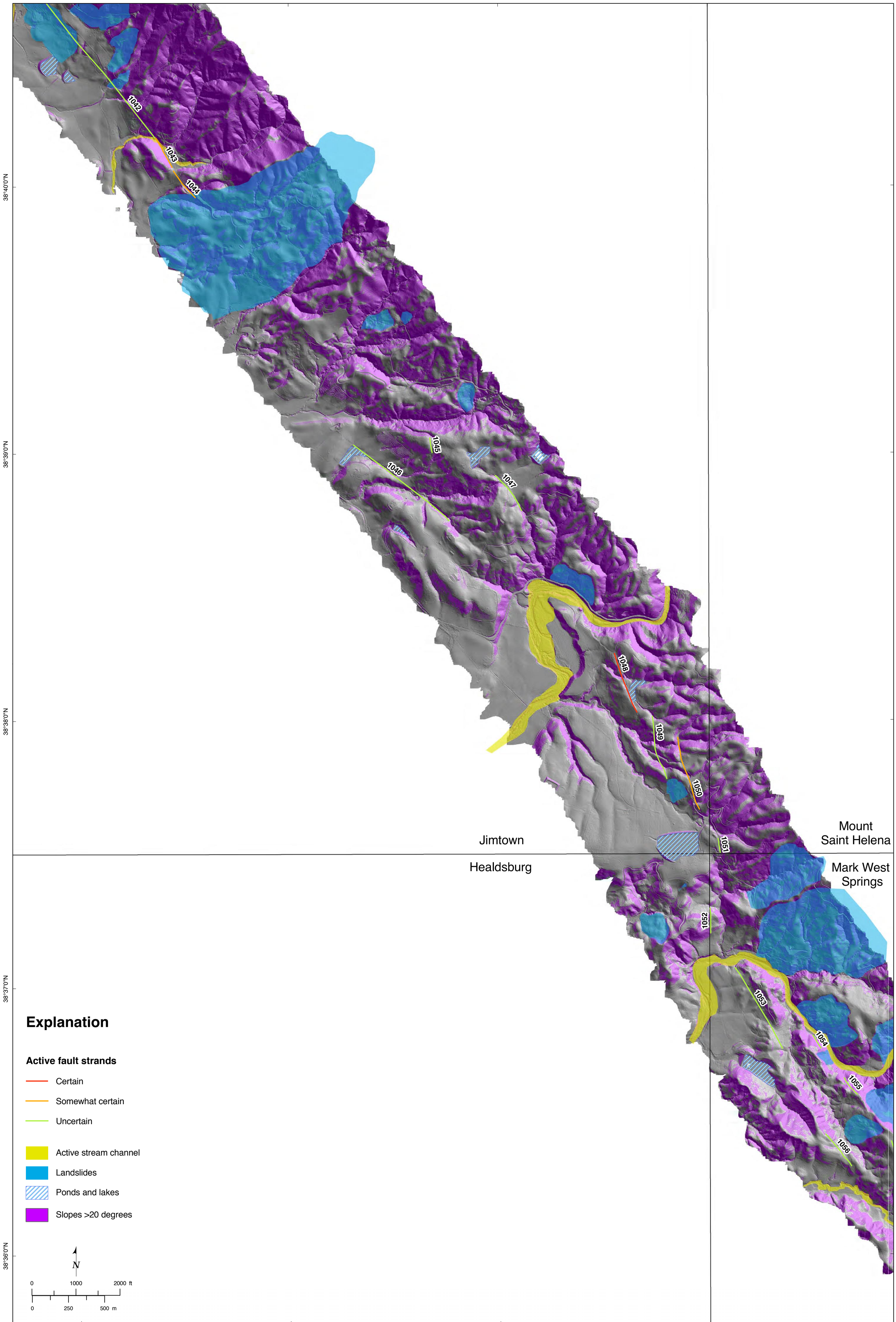
Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. Plate 6 of 9

2/24/09 Smaacama022409_plate6.mxd 1960 Maacama Fault



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Active Strands of the Southern Maacama Fault

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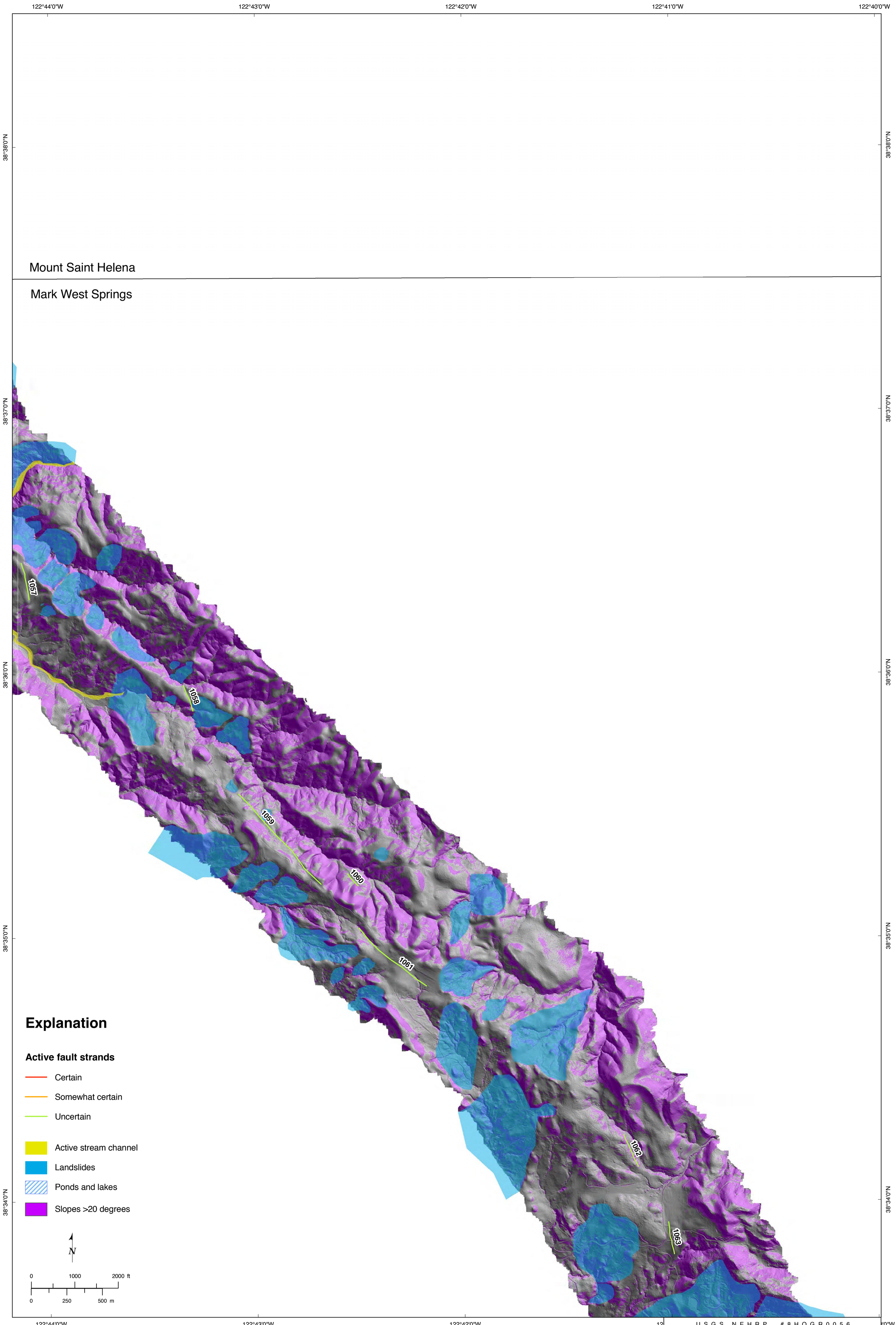
2/24/09 Smaacama022409_plate7.mxd 1960 Maacama Fault



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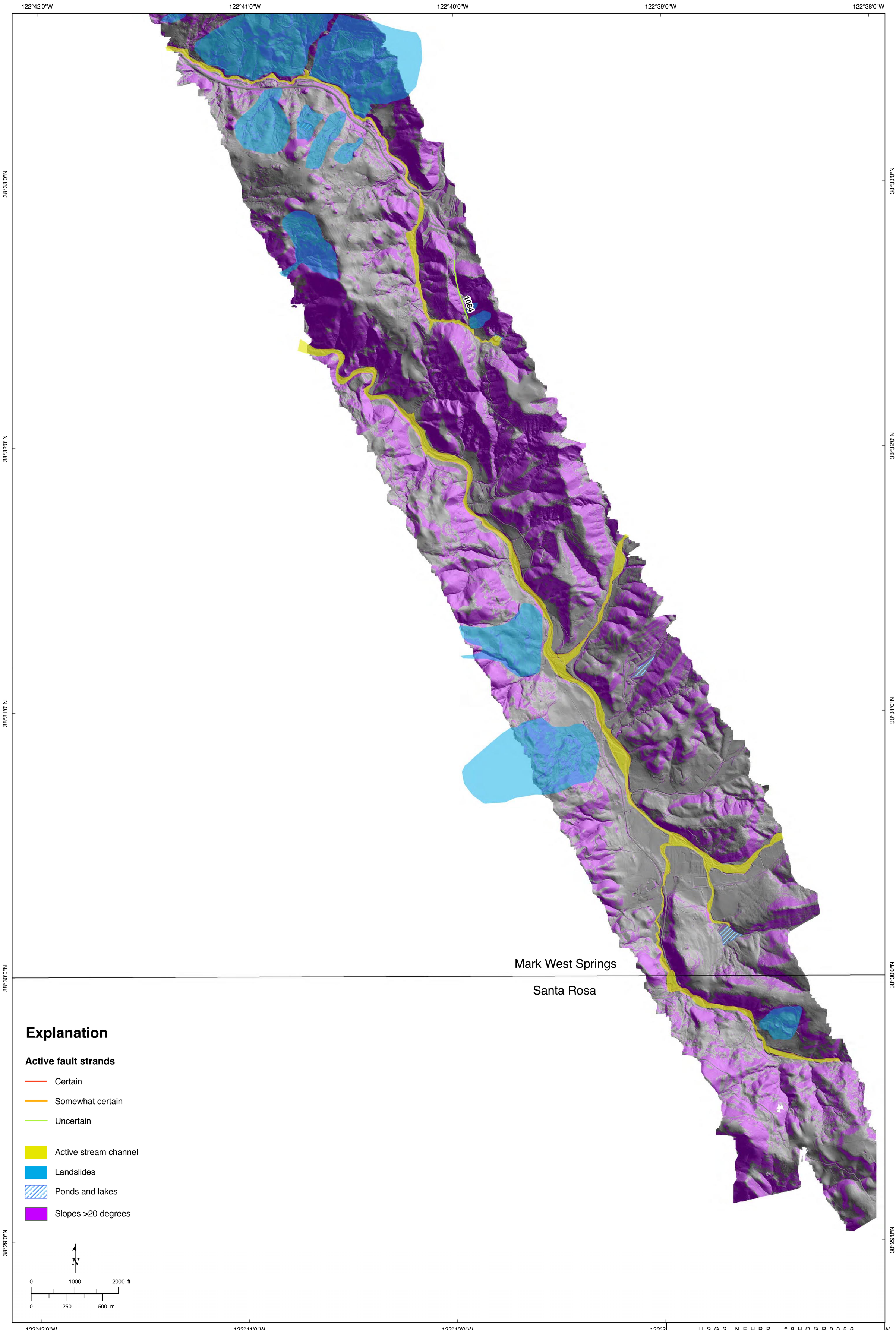
Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. Plate 8 of 9

2/24/09 Smaacama022409_plate8.mxd 1960 Maacama Fault



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Active Strands of the Southern Maacama Fault

WLA William Lettis & Associates, Inc. | Plate 9 of 9

2/24/09 Smaacama022409_plate9.mxd 1960 Maacama Fault