FINAL TECHNICAL REPORT

Mapping, Assessment, and Digital Compilation of the Connection Between the Rodgers Creek and Maacama Faults, 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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TABLE OF CONTENTS

ABSTRACT	3
1.0 Introduction	3
1.1 Purpose	3
1.2 Geologic setting and previous work	4
2.0 Methods	7
3.0 Results	7
3.1 Fault mapping	8
3.2 Review of seismicity	8
4.0 Discussion	10
5.0 Summary and Conclusions	10
5.1 Major findings	11
5.2 Benefits of this research	11
5.3 Recommendations for future studies	11
6.0 Acknowledgements	12
7.0 References	12
8.0 Bibliography	14

List of Tables

Table 1. Attributes of mapped fault strands

List of Figures

Figure 1. Study area location showing Quaternary faults
Figure 2. Regional seismicity and Faults
Figure 3. 1942 aerial photography of the Spring Valley area
Figure 4. Fault features and Quaternary Geology of Spring Valley
Figure 5. Eastern Santa Rosa Seismicity
Figure 6. Seismicity of the Rodgers Creek Fault-Maacama Fault Stepover
Figure 7. Profile Views of Seismicity:
Figure 8. Longitudinal profile of the Russian River through the Healdsburg Bends
Figure 9. Tectonic model of fault geometry

Appendix (electronic)

Appendix A. GIS database for the Spring Valley strand of the Bennett Valley fault

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ABSTRACT

The connection between the Rodgers Creek fault and the Southern Maacama fault in northern California is characterized by a spatially broad transfer of slip within the 60-km-long and 7-km-wide overlap zone between these two major strike-slip faults. Several discrete structures within the zone appear to play a role in the transfer of slip. As part of this study we map Holocene traces of the most prominent of these structures, the Spring Valley strand of the Bennett Valley fault, which strikes north across the overlap zone in the Santa Rosa metropolitan area. The Spring Valley strand is an active tectonic structure based on its strong geomorphic expression and associated seismicity alignment, yet it appears to transfer only minor amounts of right-lateral slip. Geomorphic expression and seismicity on the Rodgers Creek fault do not measurably decrease north of the Spring Valley strand.

Examination of the constraints provided by seismicity, geomorphology, and known fault geometry permitted development of a preliminary kinematic model of the fault connection. A prominent band of seismicity extending from the West Napa fault to the southern termination of the Southern Maacama fault suggests that the Southern Maacama is a more likely a continuation of that fault rather than the Rodgers Creek fault. Other seismicity alignments suggest additional structures within the overlap zone that may progressively transfer slip from the Rodgers Creek fault to the southern Maacama fault as it continues northward. These include additional north-striking structures, an unnamed reverse fault, and right-stepping en echelon strands. The reverse fault may be responsible for uplift of the hills east of Healdsburg where the Russian River has cut meanders into bedrock. The kinematic model infers the southern Maacama fault to be the northward continuation of the West Napa fault, and the Rodgers Creek fault and southern Maacama fault to progressively join northward to form the Northern Maacama fault.

1.0. Introduction

1.1. Purpose

This study identifies and maps Holocene active faults within a portion of the structurally complex area between the Rodgers Creek and Maacama faults, and considers the constraints provided by seismicity, geomorphology, and known fault geometry to develop a preliminary kinematic model of the fault linkage. Fault mapping focuses on possible Holocene-active portions of the Spring Valley strand of the Bennett Valley fault. The results of the mapping are provided as digital map data in a GIS format for input into the Northern California Quaternary

Fault Map Database (NCQFMD). The work builds on recent mapping of the southern Maacama fault by Sowers and others (2009) and of the Rodgers Creek fault by Hecker and others (2010), and the recently revised compilation of the NCQFMD (USGS, 2009).

Neither the exact location nor the style of dextral slip transfer between the Rodgers Creek and Maacama faults are well known or well understood, despite an estimated 6 to 10 mm/yr fault slip through the zone (Schwartz and others, 1992; Larsen and others, 2006). Documentation of active and potentially active fault strands in the region is 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.

1.2. Geologic Setting and Previous Work

The Rodgers Creek and Maacama faults are major active strike-slip faults that represent the northern extension of the Hayward-Calaveras fault system (Figure 1). The Rodgers Creek fault begins at the north shore of San Pablo Bay and extends northwest through the city of Santa Rosa to the Healdsburg area where it merges with the Healdsburg fault and dies out. The Maacama fault, divided into northern and southern sections by a change in strike north of Cloverdale, begins in eastern Santa Rosa and extends northwest roughly parallel to and about seven kilometers east of the Rodgers Creek fault. The study area is defined as the 60-km long zone of overlap between the two faults, extending from south of Santa Rosa northward to the change in strike in the Maacama fault (Figure 1). From this change in strike a single fault, the Northern Maacama fault, continues northward.

Seismicity patterns (Figure 2) (Waldhauser and Schaff, 2008) show that both the Rodgers Creek and Maacama faults are seismically active over the entire 60-km overlap zone. A number of Quaternary faults have been previously identified in the study area (Figure 1) (USGS/CGS 2009). Some of these may actively transfer slip between the two faults.

The Spring Valley strand of the Bennett Valley fault is the most prominent and well-known structure thought to play a role in connecting the Rodgers Creek fault to the Maacama fault (McLaughlin and others, 2008, Hecker and others, 2006, Hitchcock, 2006). The Spring Valley strand is a north-south striking fault that splays off at the north end of the northwest-striking main strand of the Bennett Valley fault, (USGS and CGS, 2009)(Figure 1). McLaughlin and others (2008) proposed that Rincon Valley and Bennett Valley, two large alluviated valleys in eastern Santa Rosa, constitute a pull-apart basin, formed from extension where the Rodgers Creek fault makes a right stepover to the Maacama fault. The Spring Valley fault is interpreted to be the east-bounding extensional fault of the pull-apart basin.

The Spring Valley strand of the Bennett Valley fault (Figure 1) is identified in recent work by McLaughlin et al. (2008) and unpublished work by Hitchcock (2006) as a candidate for youthful activity in the area between the two major faults. The Spring Valley strand displaces late Quaternary fluvial terraces, bounds a wetland interpreted as a fault-related sag pond, and is marked by a prominent linear escarpment. A vertical alignment of seismicity along the fault trace further supports the interpretation that this is an active structure (Figure 2). Despite geomorphic and seismic evidence, this fault strand is not presently classified as active by the U S. Geological Survey and the California Geological Survey (USGS and CGS, 2009), and is not included as an

Earthquake Fault Zone (Hart, E. W., 1990). Mapping of this fault is a primary focus of this study.

In addition to the Spring Valley strand, the USGS and CGS (2009) recognize part of the Alexander-Redwood Hill fault, located north of Santa Rosa and striking parallel to the Rodgers Creek fault, as a Holocene strike-slip fault (Figure 1). Bryant (1992) makes a thorough evaluation of this fault, thus no independent mapping of the Alexander-Redwood Hill fault was undertaken for this study.

Other structures also may be important. Three lines of evidence suggest that areas well to the north of Santa Rosa play a role in the transfer of slip. First, if the Spring Valley strand transfers significant slip to the Maacama fault along the Spring Valley strand in Santa Rosa, a marked decrease in activity would be expected on the Rodgers Creek fault north of Santa Rosa. This is not observed. The Healdsburg segment of the Rodgers Creek fault continues north past Santa Rosa as a strong geomorphic feature associated with active seismicity (Figure 2). The 1969 Santa Rosa earthquake was located on the Healdsburg segment of the Rodgers Creek fault (Wong and Bott, 1995), north of downtown Santa Rosa. Hecker (2010), using LiDAR data, maps continuous active strands of the fault to 17 km northwest of Santa Rosa, or 6 km southwest of Healdsburg. Further north, Kleinfelder (2003) documents active strands of the Healdsburg fault in trenches for a geotechnical investigation four kilometers north of Healdsburg.

Second, mapping of the southern Maacama fault using LiDAR data in our earlier study (Sowers and others, 2009; Hoeft and others, 2008) shows it to have poor geomorphic expression relative to the Rodgers Creek fault. Fault–related geomorphic features (scarps, dextrally offset drainages, lineations, fault-line scarps, aligned saddles, and aligned seeps) are sparsely distributed, comprising less than 50% of the length of the fault (Sowers and others, 2008, Hoeft and others, 2008). This is attributed to to a combination of active geomorphic processes including landsliding in the Mayacamas Mountains that obscure fault-related features, and a low slip rate for the southern Maacama fault. Geomorphic expression on the southern Maacama strengthens in a northward direction. Sowers and others (2009) and Hoeft and others (2008) suggested that over Holocene and late Pleistocene timescales, strain may be preferentially accommodated along the Rodgers Creek fault and is gradually transferred northward to the Maacama fault across a distributed zone of secondary structures.

Third, instrumented seismicity, relocated using the double-difference methods by Waldhuser and Schaff (2008), reveal both distributed seismicity and seismicity alignments along and between the two major faults from Santa Rosa to Cloverdale. These seismicity patterns are important input to a conceptual kinematic model presented later in this report.

The southern Maacama fault

Bryant (1982), in compiling the fault mapping of Herd et al. (1977) and Huffman and Armstrong (1980), shows the southern Maacama fault zone terminating in the Mark West Springs quadrangle. Bryant (1982) based the southeast termination on the absence of Quaternary landforms affected by faulting. Bedrock mapping by McLaughlin et al. (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 (Figure 1, green lines).

Recent mapping by Sowers and others (2009) uses new LiDAR data flown along the southern Maacama fault to make a detailed map of the fault based on tectonic geomorphic features. The 54-km-long southern segment extends north from Santa Rosa to Hopland. The LiDAR data provided an exceptional view of landscape detail, and were ideal for mapping and interpreting geomorphic features in this rugged, forested terrain. As a result, many of the features shown in the resulting fault-strip maps were not identified by previous mapping efforts, and a number of features mapped by previous workers as candidate active faults were remapped or eliminated.

The results of the mapping are in general agreement with the USGS and CGS (2009) as presented in Figure 1, with the primary exception that fault strands mapped from the LiDAR data are more discontinuous. 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. The southern termination of active fault features is in general agreement with the southern termination of the Earthquake Fault Zone of Bryant (1982).

Alexander-Redwood Hill fault

The Alexander –Redwood Hill fault, located midway between and parallel to the Rodgers Creek and Maacama faults (Figure 1), is mapped by the USGS and CGS (2009) as a 20-km Quaternary fault. In Fault Evaluation Report 233 of the California Geological Survey, Bryant (1992) thoroughly reviews previous work on this fault and conducts an independent field and aerial photo reconnaissance. He identifies 2-km strand of the fault that exhibits sufficient geomorphic evidence of latest Pleistocene to Holocene movement to be recommended for inclusion in a Fault Rupture Hazard Zone (Bryant, 1992). Along this strand, a ridgetop trough associated with a closed depression and linear tonal contrasts is bounded on east and west sides by faults that offset Sonoma volcanics. Trenches excavated across the trough show that faults extend upward to within about a meter of the ground surface and offset colluvial deposits of probable late Pleistocene to early Holocene age. The sense of movement is normal. The origin of movement on the fault is not clear. Bryant (1992) suggests that ridgetop spreading may be taking place as a result of shaking during large earthquakes on nearby Rodgers Creek and Maacama faults. Geomorphic expression of the majority of the 20 km length of the fault is consistent with Quaternary right-lateral strike-slip faulting (Bryant, 1992). The 2-km Holocene-active strand may represent an extensional re-activation of a portion of the pre-existing right-lateral fault.

Data of Waldhauser and Schaff (2008) fail to show a microseismicity alignment coincident with this fault (Figure 6). Bryant (1992) had also noted a lack of a well-defined line of epicenters aligned with the Alexander-Redwood Hill fault, in contrast to the strong seismicity alignments

seen along the Rodgers Creek and Maacama faults. Lack of seismicity may be consistent with a mechanism of ridgetop spreading for this fault.

Bedrock faults in the step-over area
McLaughlin and others (2004, 2008) note a number of other bedrock faults in the study area that have possible evidence of young offset, including the Larkfield, Brush Creek, Detention Home, Mark West, Bennett Valley, Melita-Los Guilicos and Matanzas Creek faults. McLaughlin et al. (2008) suggests that these transtensional faults may collectively accommodate dextral strike-slip partitioned from the Maacama Fault Zone.

2.0 Methods

We identify and characterize fault-related geomorphic features on the Spring Valley strand through interpretation of aerial photography acquired by the U. S. Department of Agriculture (1942) (Figure 3), a pre-reservoir topographic map of the Spring Valley dam area obtained from the Sonoma County Water Agency, field reconnaissance, and interpretation of modern USGS topographic maps including the 10m DEM of the National Elevation Dataset. Also examined were detailed topographic data for the city of Santa Rosa, viewed at the city's website (City of Santa Rosa, 2010).

Faults are mapped and digitized in a GIS environment and the characteristics of each strand documented in an attribute table, suitable for incorporation in the NCQFMD. The database provides a detailed depiction of the active strands, classified by geomorphic expression and relative certainty of Holocene activity. 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.

In addition, we examine other relevant data that may place constraints on stepover geometry and kinematics. These include microseismicity data, and recent mapping of Holocene-active fault traces from LiDAR data (Sowers and others 2009, Hecker, 2010). Seismicity data for the Santa Rosa area were obtained from Wong and Bott (1995) and Waldhauser and Schaff (2008), and are presented on Figures 2, 5, 6, and 7. The Waldhauser and Schaff (2008) seismicity data include events of magnitude 0.5 and above from 1984 through 2004, relocated using a double-difference algorithm. Wong and Bott (1995) relocated the five largest events of the 1969 Santa Rosa earthquake using the largest event recorded by temporary network operated by the U. S. Geological Survey as the master event.

3.0 Results

In this section we present the results of the mapping of the Spring Valley strand of the Bennett Valley fault, and the results of the analysis of seismicity for the larger study area.

3.1 Mapping the Spring Valley Strand

The Spring Valley strand is well expressed on 1942 aerial photography as a linear north-south

trending west-facing escarpment with an elongated marsh and alluviated valley at its base (Figure 3). Mapping of the fault is shown in Figures 4A and 4B. Strands shown in a solid line on are those having geomorphic expression (certain) indicative of Holocene activity. These include strands 2001, 2004, 2005, and 2008 (Figure 4A and 4B, Table 1). The main strand (2001) follows the base of the escarpment. Where it crosses the late Quaternary terrace of Santa Rosa Creek, it is labeled 2004. The combined length of strands 2001 and 2004 is 1.8 km. To the west of the main strand are two shorter parallel strands, 2005 and 2008. Strand 2005 is mapped along an east-facing scarp that forms the west edge of a graben that holds the wetland and displaces a late Quaternary terrace. Strand 2008 is mapped along a west-facing scarp that displaces the same late Quaternary terrace.

Strands of the fault that are less certain to have geomorphic expression of Holocene activity are shown in dashed (somewhat certain) and dotted (uncertain) lines. To the south of Spring Valley the fault splits into two branches, strand 2003 following the linear valley of Spring Creek, and strand 2002 bending east along a line of saddles on the hillslope toward the main trace of the Bennett Valley fault (not shown). Recognizing that saddles and linear drainages can be formed from erosion along zones of weakness in the bedrock such as a bedding plane or older fault, these strands are less certain to be Holocene-active. At the north side of Santa Rosa Creek, low ridges underlain by Pliocene sediments (McLaughlin and others, 2008) exhibit a slight break-in-slope where the main strand projects across them. These are designated strands 2009 and 2010. Continuing north along the eastern margin of Rincon Valley, strand 2011 is an alignment of breaks-in-slope at the valley edge. Displacement of Pleistocene alluvial fans cannot be traced between strands 2011 and 2010, thus it is uncertain whether the fault north of Santa Rosa Creek has been active in the Holocene.

We mapped eleven individual fault strands as shown on Figure 4 and listed in Table 1. As described above, geomorphic expression of the fault weakens to the north and south. Fault length measured in a straight line from the northernmost to the southermost ends of the mapped strands is 7 km. The central 1.8 km of this length is characterized by the strongest geomorphic expression.

3.2 Seismicity

Seismicity patterns provide additional evidence for fault activity. Seismicity that aligns with mapped surface faults suggests activity of these faults. Seismicity alignments in the absence of geomorphic evidence of surface rupture are evidence for the presence of active faults at depth that either do not rupture to the surface or, for other reasons do not have geomorphic expression. Seismicity that appears scattered may indicate distributed deformation as opposed to deformation along discrete fault planes.

Seismicity in eastern Santa Rosa is shown on Figure 5 and in the larger study area on Figure 6 (data from Waldhauser and Schaff, 2008). Colors of the epicenters indicate the presumed associated surface structure. Seismicity on the Rodgers Creek-Healdsburg fault, in red dots, occurs at up to 10 km depth on a southeast-dipping fault plane, thus plots to the east of its surface trace. The southern Maacama fault similarly dips to the southeast (Figure 7C).

Although no historical rupture is documented on any portion of the Bennett Valley fault,

seismicity patterns suggest some activity at depth, especially along the Spring Valley strand. A band of epicenters is closely aligned with the strand (Figures 5 and 6). When viewed using 3-D visualization tools in ArcGIS, hypocenters form a vertical planar alignment (Figure 7A). In addition, analysis of the M_L=5.7 Santa Rosa earthquake on the Rodgers Creek fault, shows a M_L=3.4 aftershock located within 1 kilometer of the Spring Valley strand (Wong and Bott, 1995), suggesting the earthquake may have triggered a response on the Spring Valley strand (Figure 5).

Seismicity on the Spring Valley strand generally mimics the strength of geomorphic expression. The Spring Valley strand does not make a clear connection to geomorphically youthful traces of either the Rodgers Creek or Maacama faults. Similarly, the strong seismicity alignment on the Spring Valley strand stops short of making a connection with seismicity on the southern Maacama fault or the Rodgers Creek fault. At the southern end of the alignment, seismicity is a diffuse cloud that may be associated with the main strands of the Bennett Valley fault.

Parallel to and west of the Spring Valley strand is an alignment of epicenters referred to as the *Rincon Valley alignment*. There is no clear surface expression of any fault associated with this alignment, but the hypocenters form a vertical alignment with a similar orientation to that of the Spring Valley strand.

Analysis of the seismicity of the larger study area (Figure 6) suggests that other structures are present within the fault connection. A distinct band of seismicity splays northwest off the West Napa fault (Figure 2) and extends to the southern Maacama fault (light green dots on Figure 6). We refer to the structure inferred from this seismicity band as the *West Napa Connector*. This seismicity connection suggests that much of slip on the southern Maacama may be transferred from the West Napa fault, rather than from the Rodgers Creek fault. The West Napa connector appears to merge with the southern Maacama fault at a slight change in strike northeast of Rincon Valley. The change is located at approximately the projection of the Spring Valley strand onto the southern Maacama fault.

Seismicity on the Rodgers Creek-Healdsburg fault continues northward past Healdsburg, ending in a cloud of diffuse seismicity in Alexander Valley north of Cloverdale. South of Cloverdale a strong alignment of epicenters in pink is herein referred to as the *Geyserville alignment*. Similar to the Spring Valley alignment, the hypocenters form a vertical roughly north-south striking plane. Unlike the Spring Valley alignment, no expression of a surface fault is evident. Distributed seismicity in yellow near Cloverdale exhibits several weak north-south alignments which may represent north-striking en echelon fault planes.

Seismicity in the vicinity of the Russian River south and east of Healdsburg (orange dots) defines a plane striking roughly N55°W and dipping about 63° to the northeast (Figure 7B). This geometry suggests the presence of a reverse fault intersecting the Rodgers Creek-Healdsburg fault in the Healdsburg area. Uplift on the hanging wall of this fault could account for uplift of the hills east of Healdsburg. The Russian River has incised a series of deep meanders crossing these hills. A longitudinal profile of the Russian River, drawn from the USGS 7.5-minute topographic map, shows a prominent convexity past Digger Bend at the projection of the Healdsburg fault, consistent with reverse slip (Figure 8). We refer to this proposed structure as

the *Russian River reverse fault*.

4.0 Discussion

Based on the interpretation of seismicity patterns and understanding of faulting in the study area, we developed a preliminary kinematic model of the Rodgers Creek-Maacama fault connection (Figure 9). The southern Maacama fault begins east of Santa Rosa where slip is transferred from the West Napa fault via the West Napa connector. The Spring Valley strand projects toward this initiation point. Although geomorphic expression of the southern Maacama fault is weak throughout its length and absent for the southernmost 5 km (Sowers and others, 2009), seismicity clearly shows the fault is active. The Rodgers Creek fault and southern Maacama faults continue northward about 7 km apart for approximately 60 kilometers before eventually completing their merger north of Cloverdale. Within that 60-km-long overlap zone, a combination of discrete structures and distributed deformation appear to gradually transfer slip from the Rodgers Creek fault to the southern Maacama fault, and accommodate internal movement between the faults. Seismicity alignments in the Cloverdale area, including the Geyseville alignment, suggest a series of left-stepping en echelon faults stepping across from the Healdsburg fault to the Maacama fault.

The study area has previously been referred to as a *step-over*, based on a model in which slip on the Rodgers Creek fault "steps" east to the Maacama fault (eg. McLaughlin and others, 2008). In the model presented here, the connection is better described as a "northward merging." The southern Maacama fault and the Rodgers Creek fault merge northward to form the northern Maacama fault. The southern Maacama fault appears to take its slip primarily from the West Napa fault, thus does not require a significant transfer of slip from Rodgers Creek fault at its southern initiation.

Within the zone of overlap there appear to be a number of structures that transfer small amounts of slip in the zone between the two master faults (Figure 9). Identified structures include the Spring Valley strand, the Alexander-Redwood Hill fault, the Russian River reverse fault, and the Geyserville alignment.

5.0 Summary and Conclusions

The connection between the Rodgers Creek fault and the Southern Maacama fault in northern California is characterized by a spatially broad transfer of slip within the 60-km-long and 7-km-wide overlap zone between these two major strike-slip faults. Several discrete structures within the zone appear to play a role in the transfer of slip, including the Spring Valley strand of the Bennett Valley fault. This study provides a map of presumed Holocene active traces of the Spring Valley strand, and considers the constraints provided by seismicity, geomorphology, and known fault geometry to develop a preliminary kinematic model of the fault connection. Major findings, benefits of the research, and recommendations for future studies are summarized in this section.

5.1 Major findings

- The connection between the Rodgers Creek fault and the Maacama fault is a 60-km-long and 7-km-wide zone between the two faults that extends from south of the city Santa Rosa, to north of Cloverdale.
- Over that distance the Rodgers Creek fault, West Napa fault, and southern Maacama fault join northward to form the Northern Maacama fault.
- No single structure transfers all the slip between the faults, instead slip is transferred via a network of structures, many with no surface expression.
- Previously mapped faults in the zone between the two master faults that have geomorphic evidence of Holocene activity include the Spring Valley strand of the Bennett Valley fault, and the Alexander-Redwood Hill fault.
- The mapped trace of the Spring Valley strand has a total length of 7 km, with 1.8 km of that length exhibiting strong geomorphic evidence of Holocene activity. A prominent seismicity alignment follows the mapped trace.
- The Spring Valley strand probably transfers only a minor component of right-lateral slip between the two major faults.
- Other seismicity alignments may represent previously unknown active structures at depth. These include the proposed Russian River reverse fault, the Geyserville alignment and nearby Cloverdale alignment, the West Napa connector and the Rincon Valley alignment.
- Data developed for this study indicate progressive northward merging of slip from the West Napa fault, Southern Maacama fault, Rodgers Creek fault and ancillary structures, to the Northern Maacama fault

5.2 Benefits of this research

This study improves the identification, understanding, characterization and documentation of active fault traces and paleoseismic sites in this region, which in turn will lead to improvements in the source characterization for future iterations of probabilistic ground motion maps. The products of this work ultimately will be published by the U.S. Geological Survey and available in digital form to planners and the earth science community for use in future seismic hazard evaluations in the project region.

Understanding the transfer of slip from the Rodgers Creek fault to the Maacama fault directly impacts the seismic hazard to the city of Santa Rosa, at the southern end of the overlap zone (Figure 1). If structures like the Spring Valley strand have the potential for surface rupture, communities must be made aware of these structures so that these hazards can be mitigated.

This study also contributes to ongoing studies of the distribution and kinematics of slip among dextral faults of the San Andreas system, which are the primary earthquake sources in the San Francisco Bay area. Improved understanding of the San Andreas system will reduce present uncertainties in slip rate, fault behavior and earthquake recurrence used as inputs for seismic hazard and risk models.

5.3 Recommendations for future studies

Additional studies can increase the understanding of this complex fault connection and the associated earthquake hazards. Paleoseismic trenching of the Spring Valley strand will more

precisely locate the fault, and may determine the direction of slip, establish an event chronology, and most importantly, enable a hazard evaluation. This fault is located in an urban area and crosses critical infrastructure including a major water pipeline.

Field examination and collection and examination of detailed topographic data along other known faults and newly identified seismicity alignments may reveal additional active structures. The activity and geometry of the proposed Russian River reverse fault could be studied by surveying a detailed longitudinal profile of the Russian River and its terraces through the Healdsburg bends.

6.0 Acknowledgements

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8.0 Bibliography

No publications have yet resulted from this work.

Table 1. Fault Features of the Spring Valley Strand of the Bennett Valley Fault

Strand No.	Fault Name	Fault name comment	Fault ID	Feature Description	Map By (1)	Method (2)	Last Updated	Fault Certainty (3)	Location Certainty (+/- m)	Length (m)
2001	Bennett Valley fault	Spring Valley strand of fault	229	West-facing scarp bordering wetland and alluvial valley. Possible seep visible as dark spot on 1942 photos. Fault is exposed in canal (McLaughlin and others, 2008)	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Certain	30	1597
2002	Bennett Valley fault	Spring Valley strand of fault	229	Alignment of break-in-slope, linear valley, and saddles	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Med-Certain	100	1050
2003	Bennett Valley fault	Spring Valley strand of fault	229	Linear valley, saddle, merging northward with linear break-in-slope	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Med-Certain	100	1784
2004	Bennett Valley fault	Spring Valley strand of fault	229	West-facing scarp in Late Quaternary fluvial terrace of Santa Rosa Creek	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Certain	30	205
2005	Bennett Valley fault	Spring Valley strand of fault	229	East-facing scarp bordering wetland and late Quaternary fluvial terrace	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Certain	30	1189
2006	Bennett Valley fault	Spring Valley strand of fault	229	Western edge of alluvial valley	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Uncertain	30	620
2007	Bennett Valley fault	Spring Valley strand of fault	229	Break -in-slope on rise, may be west-facing scarp	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Uncertain	30	1445
2008	Bennett Valley fault	Spring Valley strand of fault	229	West-facing scarp in late Quaternary fluvial terrace	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Certain	30	576
2009	Bennett Valley fault	Spring Valley strand of fault	229	Break-in-slope on bedrock ridge, down to the west	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Med-Certain	30	93
2010	Bennett Valley fault	Spring Valley strand of fault	229	Break-in-slope that lines up with projection of fault from south	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Med-Certain	30	247

Strand No.	Fault Name	Fault name comment	Fault ID	Feature Description	Map By (1)	Method (2)	Last Updated	Fault Certainty (3)	Location Certainty (+/- m)	Length (m)
2011	Bennett Valley fault	Spring Valley strand of fault	229	Alignment of breaks in slope in alluvium and colluvium at the margin of Rincon Valley	Sowers/ Kelsey	1942 air photo, USGS DEM	6/22/10	Uncertain	100	2111

(1) SK = Janet Sowers and Harvey Kelsey

(2) U. S. Department of Agriculture, 1942, Black and white aerial photography, 1:20,000-scale, series COF-7, COF-14, and COF-15;
U. S. Geological Survey Digital Elevation Model from the National Elevation Dataset.

(3) Fault certainty is the certainty that the feature is the result of active faulting, as opposed to another geomorphic process

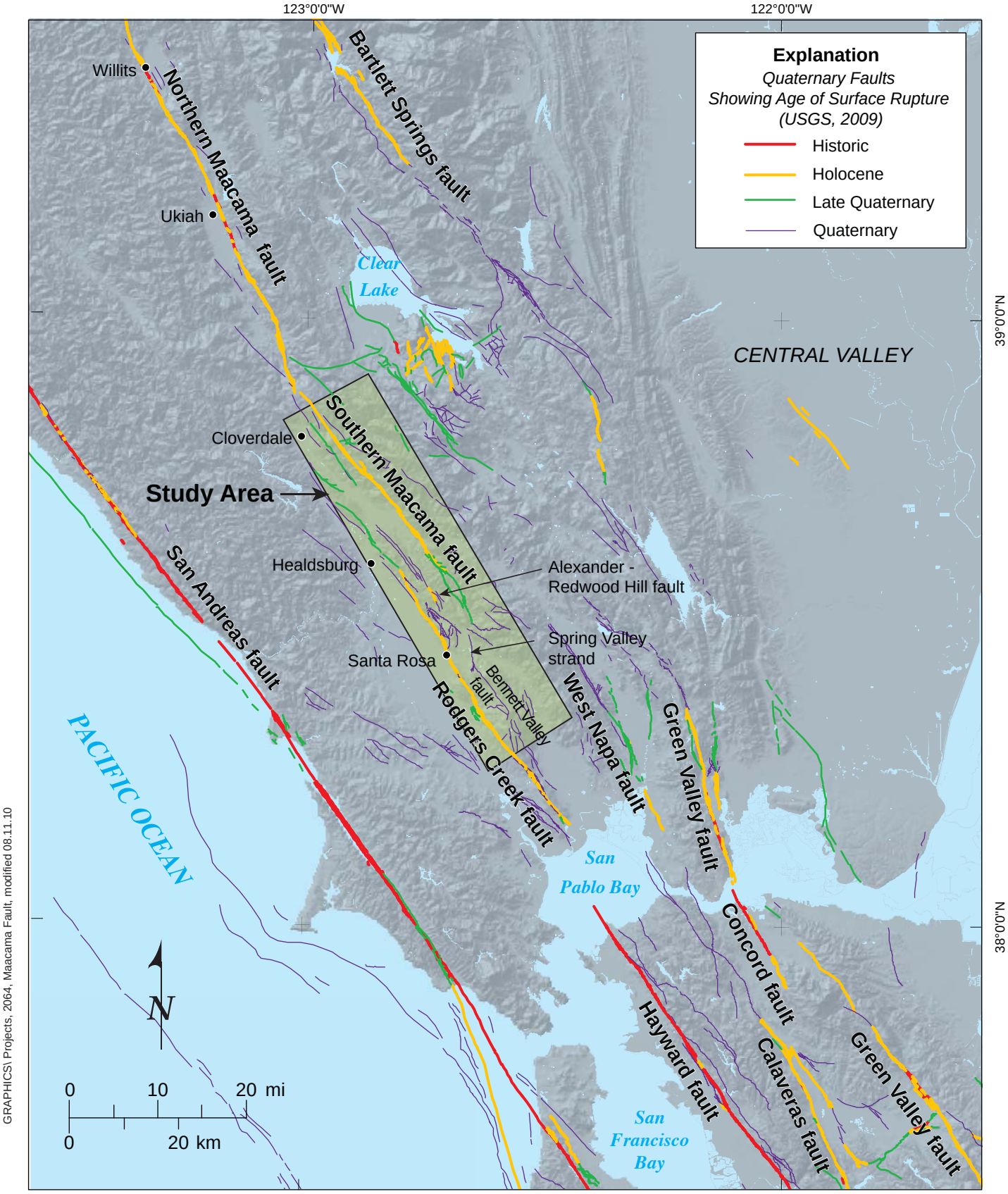
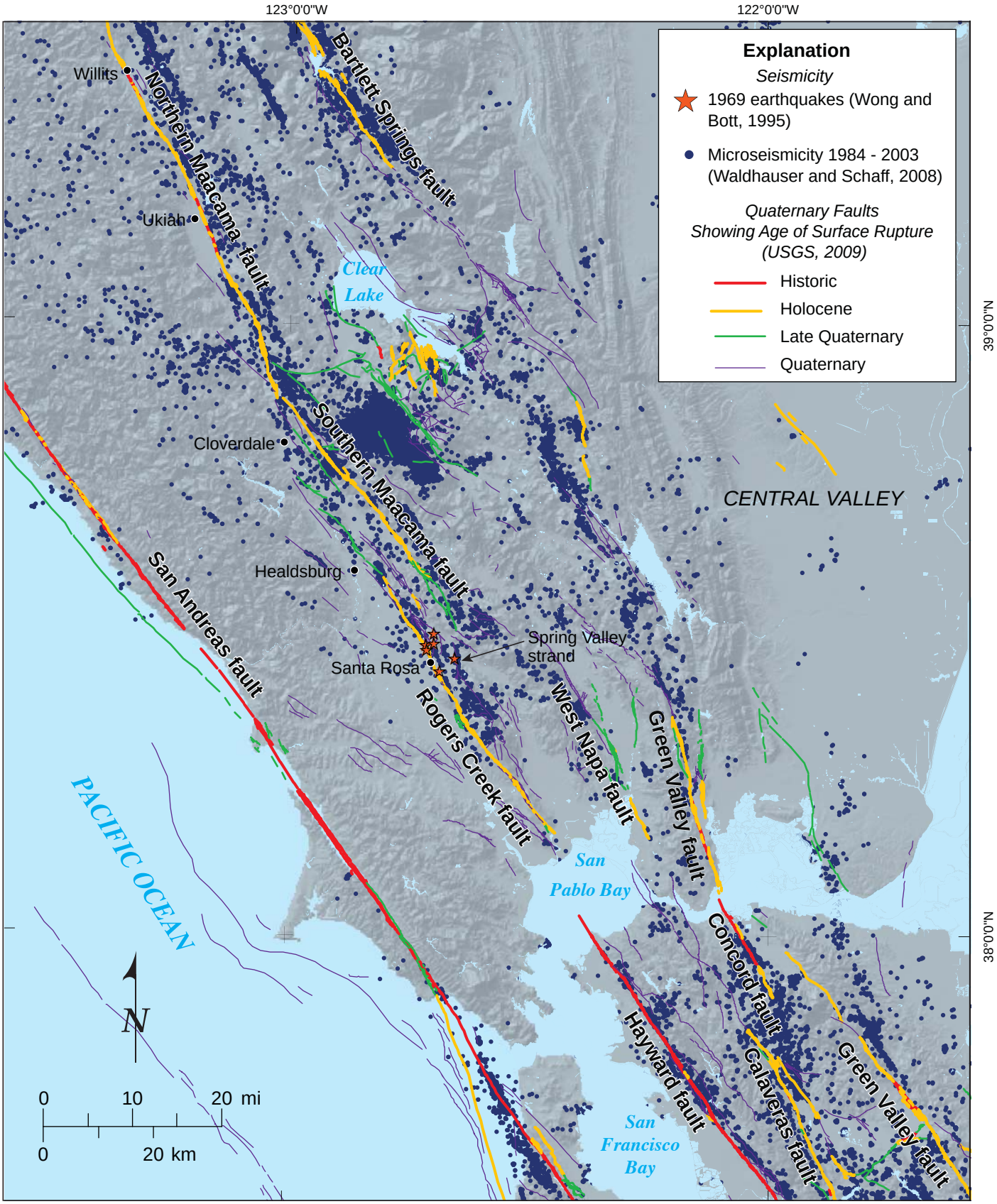


Figure 1. Study area location showing Quaternary faults.



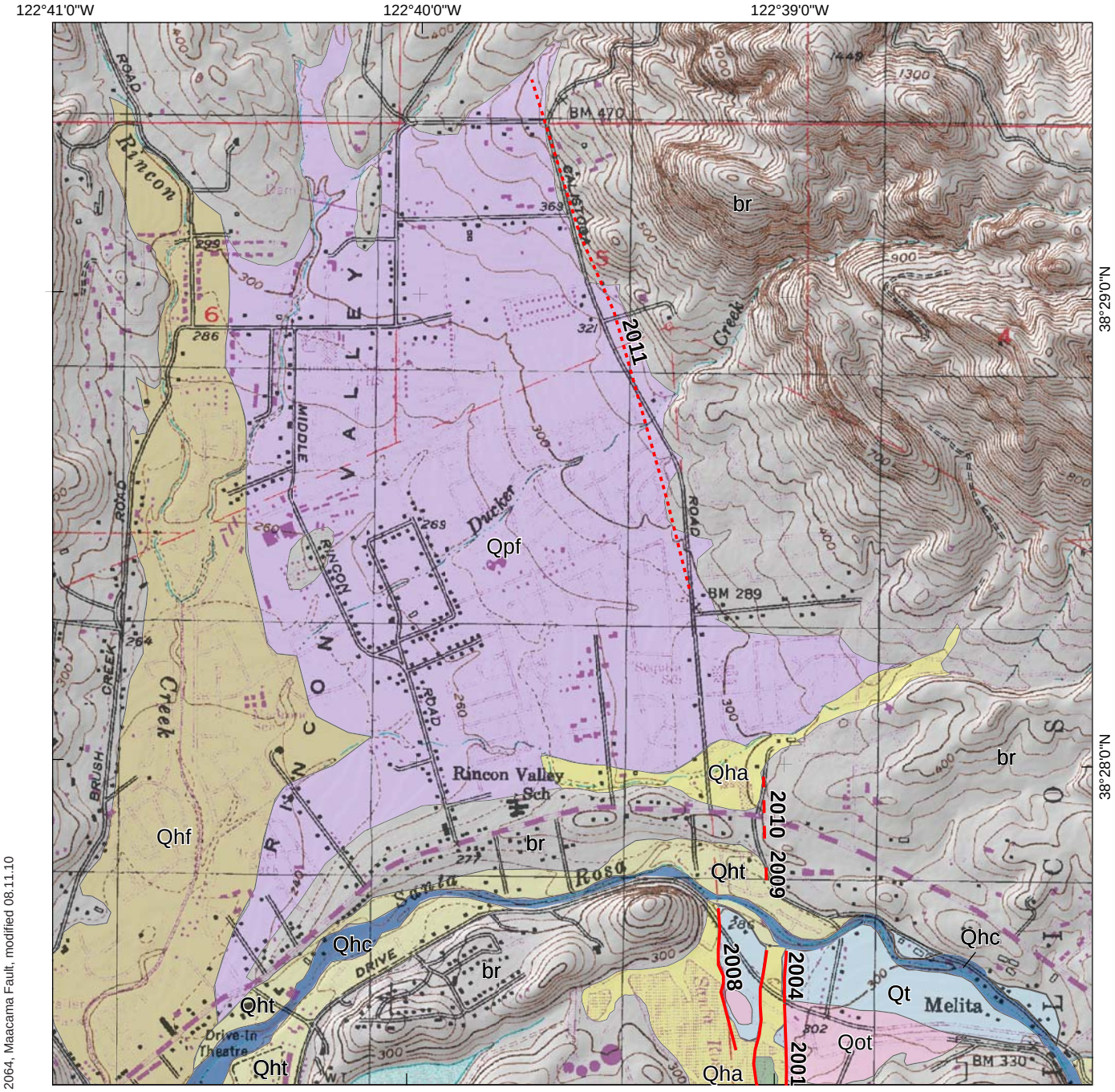
GRAPHICS\ Projects, 2064, Maacama Fault, modified 08.11.10

Figure 2. Regional seismicity and faults.

Sources: 1. USDA 1942 COF-14-25 aerial photograph.
2. USGS 10-meter DEM hillshade.

GRAPHICS\ Projects, 2064, Maacama Fault, modified 08.11.10

Figure 3. 1942 aerial photograph of Spring Valley area.



Sources: 1. USDA 1942 COF-14-25 aerial photograph.
2. USGS 10-meter DEM hillshade.

Explanation

Holocene fault; dashed where somewhat certain; dotted where uncertain

Unit Descriptions

- Qhc — Historical stream channel deposits
- Qht — Holocene terrace deposits
- Qha — Holocene alluvium
- Qhs — Historical marsh deposits
- Qhf — Holocene alluvial fan deposits
- Qt — Late Pleistocene to Holocene terrace deposits
- Qpf — Pleistocene alluvial fan deposits
- Qot — Pleistocene terrace deposits
- br — Bedrock and colluvium

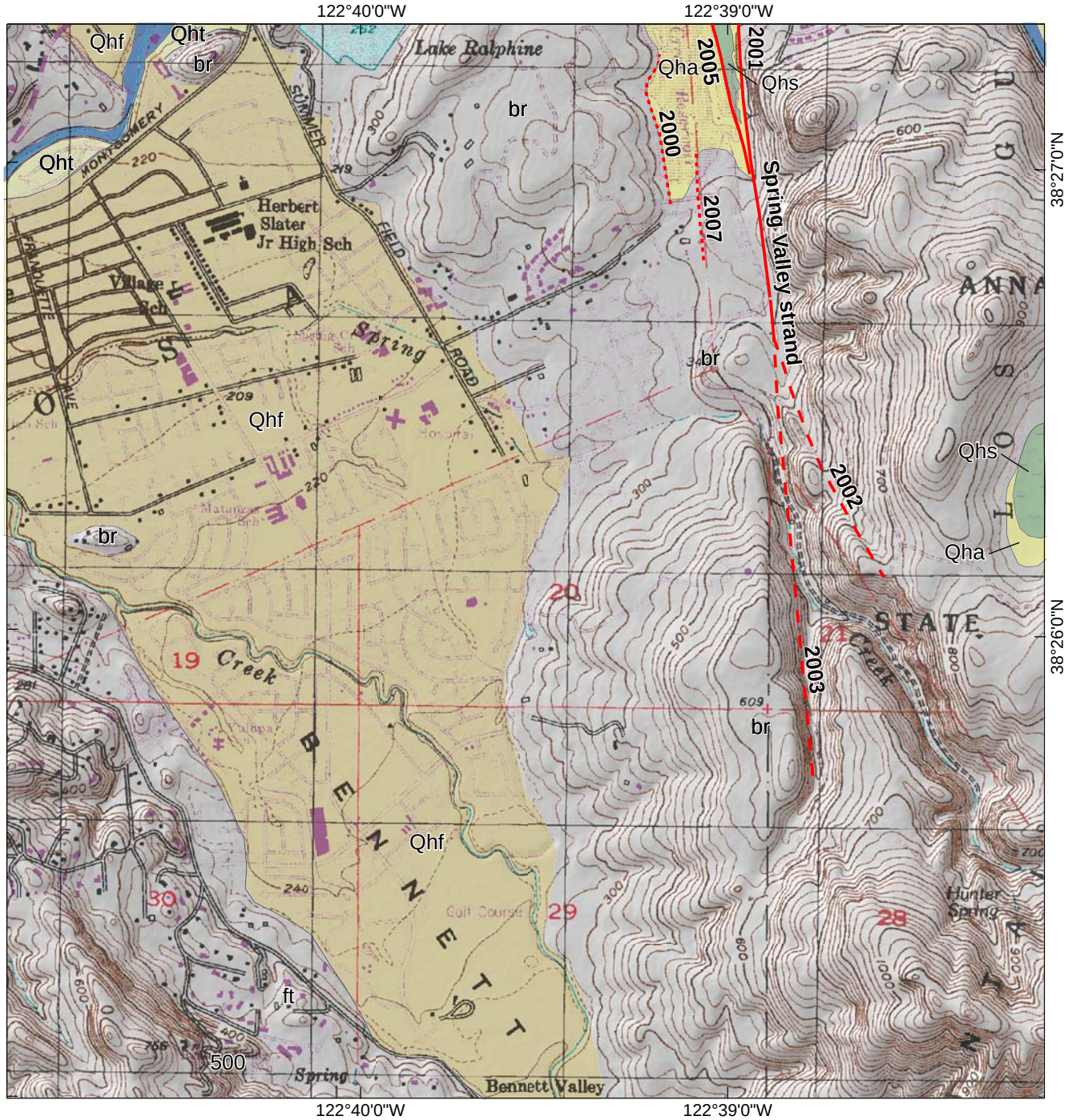
N

0 1,000 2,000 ft.

0 250 500 m

GRAPHICS\ Projects, 2064, Maacama Fault, modified 08.11.10

Figure 4A. Fault features and Quaternary geology of Spring Valley (north).



Sources: 1. USDA 1942 COF-14-25 aerial photograph.
2. USGS 10-meter DEM hillshade.

N

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- Qhc — Historical stream channel deposits
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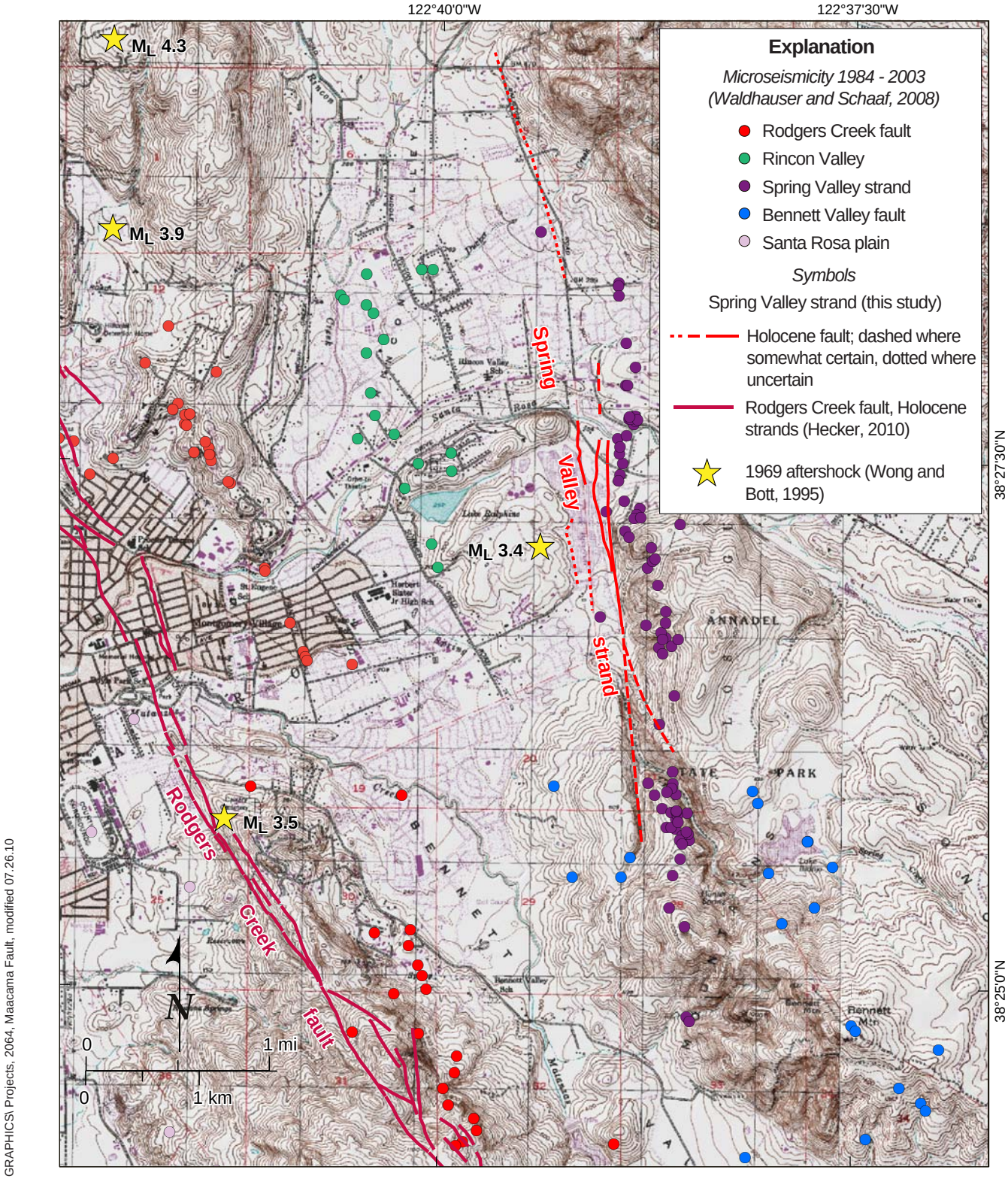
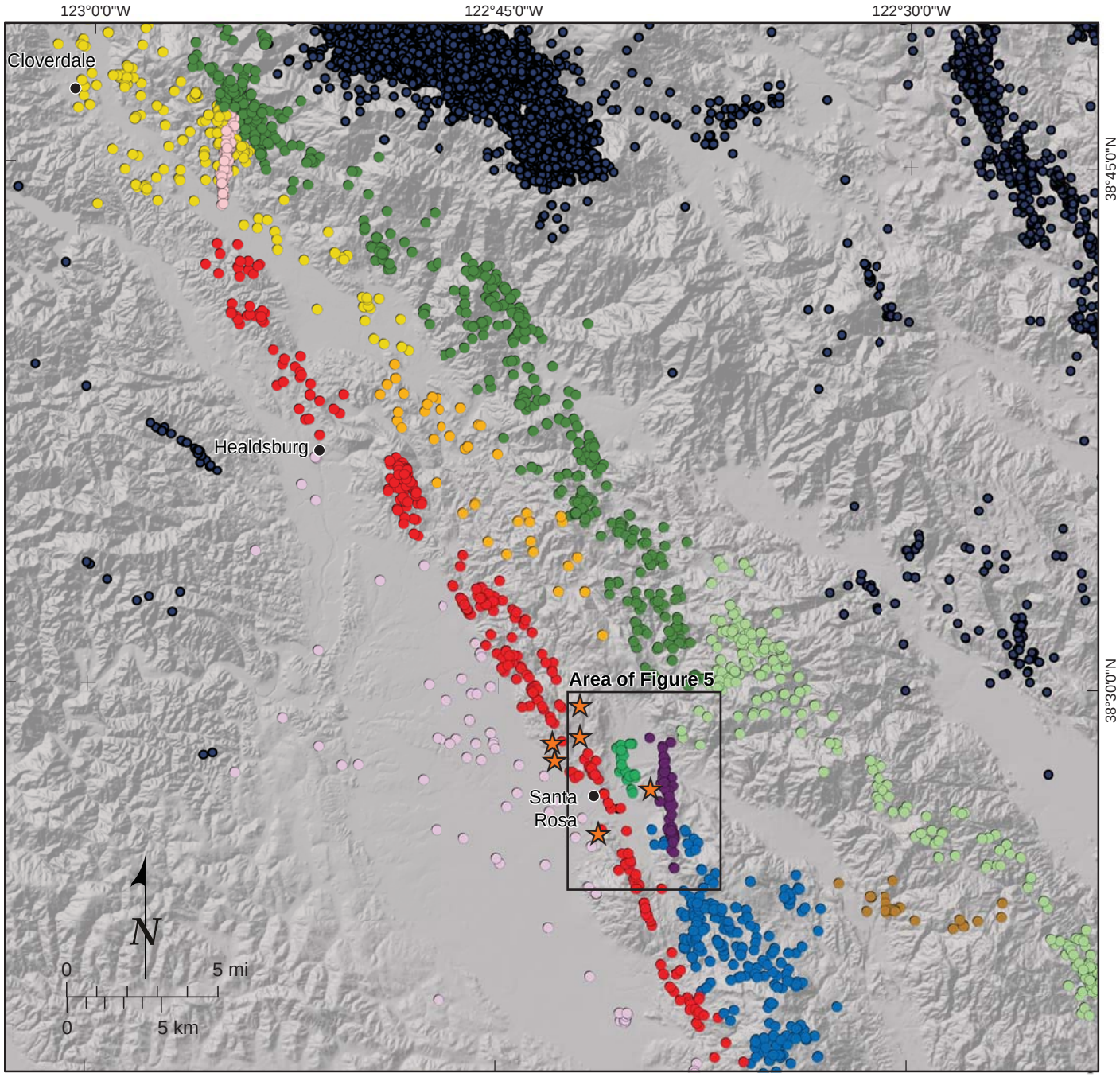
Figure 4B. Fault features and Quaternary geology of Spring Valley (south).



GRAPHICS\ Projects, 2064, Maacama Fault, modified 07.26.10

Figure 5. Eastern Santa Rosa seismicity.



Explanation

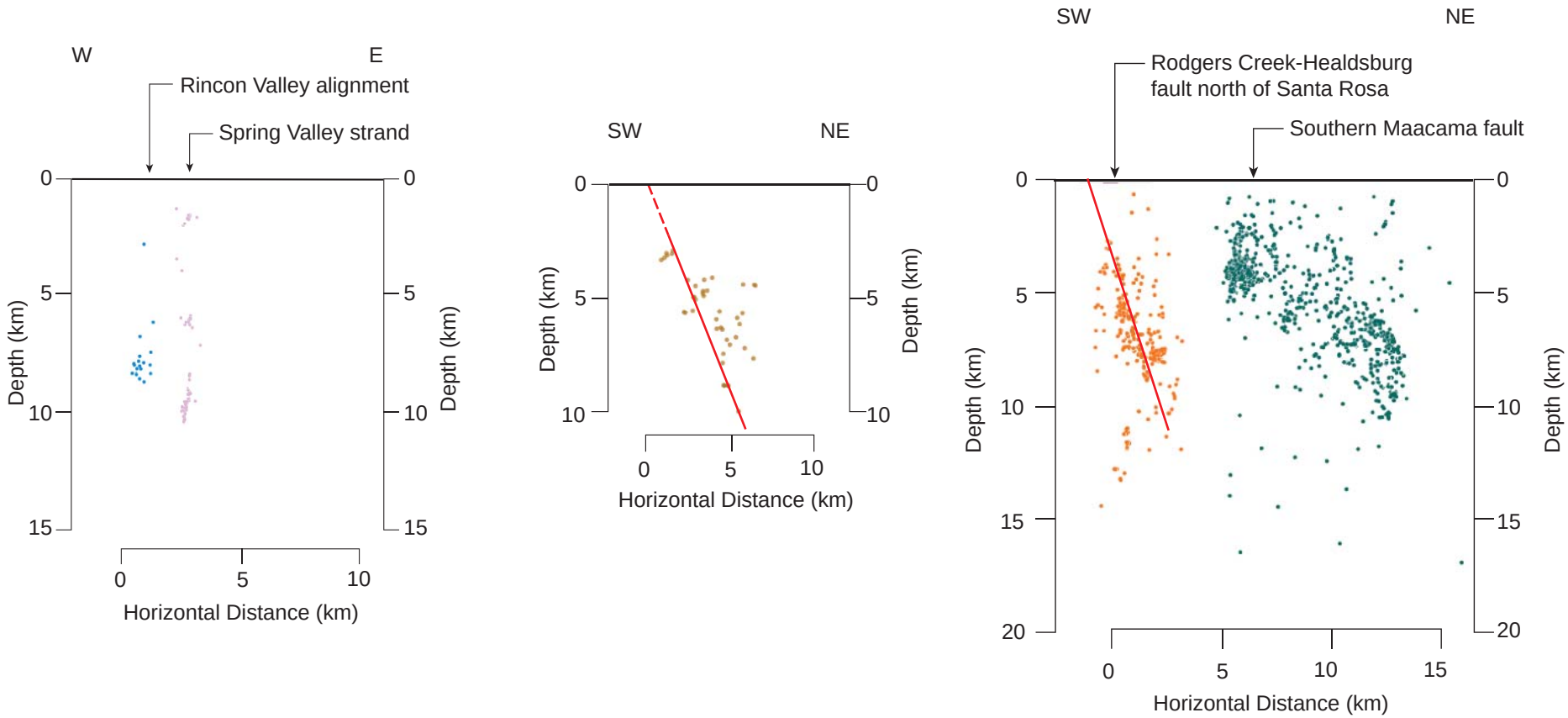
- Bennett Valley fault
- Alexander Valley
- Rodgers Creek - Healdsburg fault
- Geyserville alignment
- Santa Rosa plain
- Rincon Valley alignment
- Spring Valley strand
- Southern Macaama fault
- West Napa connector
- Glen Ellen alignment
- Russian River alignment
- Other microseismicity
- 1969 main shock (Wong and Bott, 1995)

Faults

- Holocene
- Late Quaternary
- Quaternary

GRAPHICS\ Projects, 2064, Maacama Fault, modified 08.11.10

Figure 6. Seismicity of the Rodgers Creek fault-Maacama fault connection.

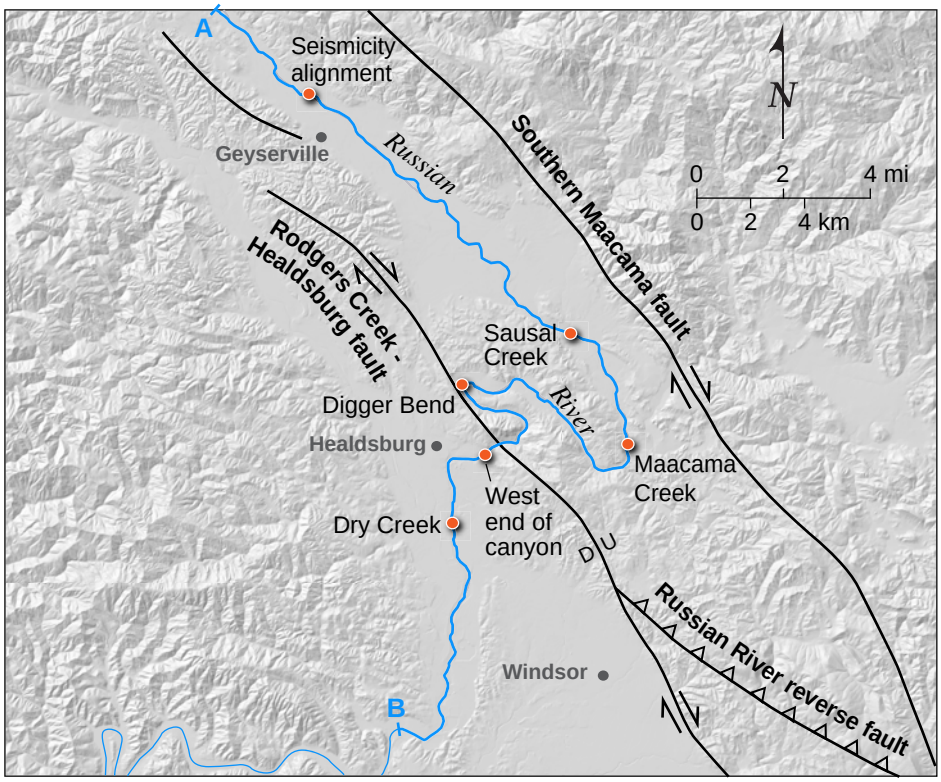


A) View N5˚W along strike of Spring Valley seismicity alignment.

B) View N55˚W along Russian River seismicity alignment.

C) View N35˚W along strike of Rodgers Creek, north of Santa Rosa.

Figure 7. Profile views of hypocenters.



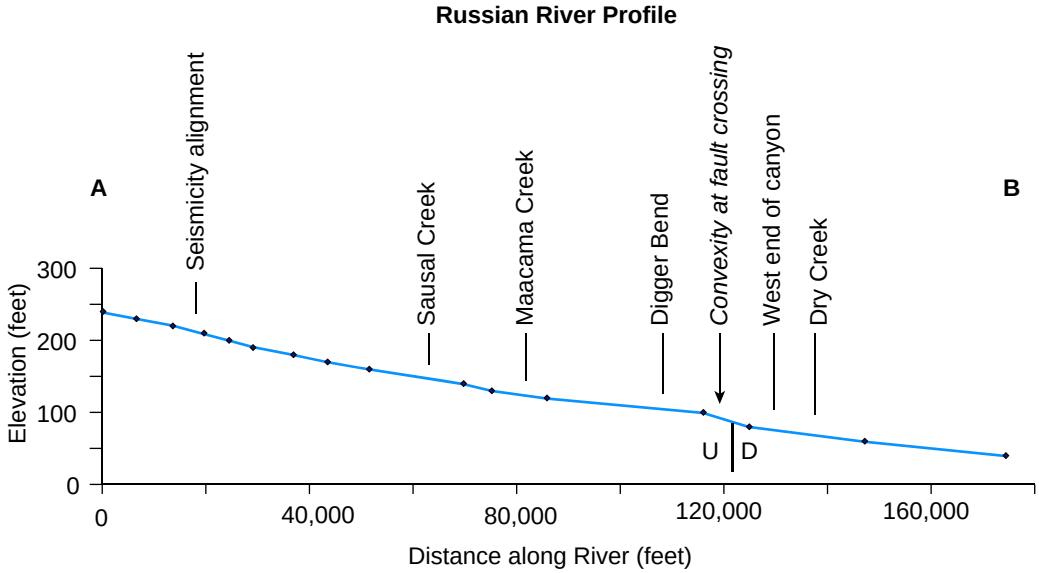


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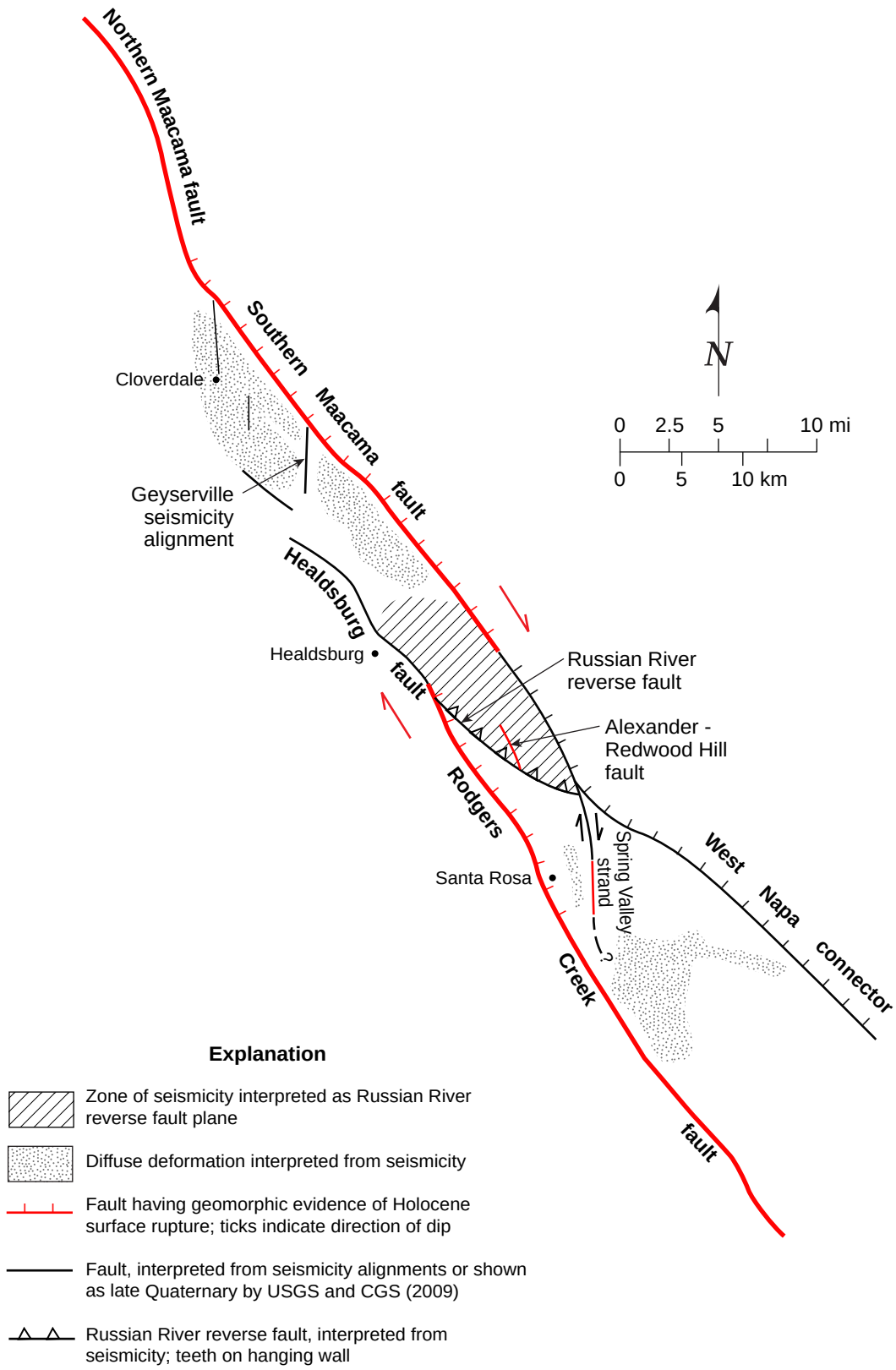
Figure 8. Longitudinal profile of the Russian River through the Healdsburg Bends.



GRAPHICS\ Projects, 2064, Maacama Fault, modified 08.11.10

Figure 9. Kinematic model of the Rodgers Creek-Maacama fault connection.