Geohazard Assessment for the Frank R. Howard Memorial Hospital, Willits, California

Gary D. Simpson
SHN Consulting Engineers & Geologists, Inc. 812 W. Wabash
Eureka, CA 95501
gsimpson@shn-engr.com

ABSTRACT

This paper describes geologic and geotechnical investigations for the proposed relocation of the Frank R. Howard Memorial Hospital in Willits, Mendocino County, California. The proposed hospital site is located just east of the active Maacama fault, within the Alquist-Priolo Earthquake Fault Zone, on the Holocene floodplain of Haehl Creek; therefore, thorough investigations of surface fault rupture hazard, liquefaction potential and other geotechnical issues were completed. The investigation of surface fault rupture was complicated by the presence of Holocene sediments underlying the floodplain to depths of up to 25 feet. Therefore, a series of large stepped pits were excavated at the site, extending to depths in excess of 30 feet in order to expose pre-Holocene strata. Stratigraphic evidence for past surface fault rupture was evaluated in late Pleistocene age, fine-grained alluvial sediments exposed in the lower portion of the deep pit exposures, and provided positive evidence for the absence of past surface rupture within the proposed hospital footprint. Several buried trees were encountered deep in the excavations, some in growth position, which provided valuable age control. Subsequent collaborative research of the paleoseismic history of the Maacama fault at the site with a U.S. Geological Survey-funded team resulted in understanding of the precise fault location, preliminary event timing, and minimum slip rate. Liquefaction potential was determined to be a significant hazard at the site. The hazard was mitigated within the proposed hospital footprint by removal of susceptible materials, mixing (to homogenize previously stratified sandy and clayey materials), and replacement as engineered fill. This remove/replace mitigation method was implemented to a depth of up to 21 feet beneath the ground surface. Site specific ground response was initially calculated following the methods outlined in the 2001 California Building Code, and later revised to reflect updated methods presented in the 2007 California Building Code. Geohazard mitigation plans have been reviewed and approved by the California Geological Survey and Office of Statewide Health Planning and Development, and construction of the hospital was completed in August 2014.

Introduction

The Frank R. Howard (FRH) Memorial Hospital has been serving central Mendocino County from its current location in central Willits since 1928 (Figure 1). As the region has grown, the existing facilities have become outdated and no longer meet the community needs nor current seismic code. Therefore, the need to modernize and expand the existing hospital facilities was identified, and the decision was made to develop a new regional hospital complex. Due to a lack of space on the existing hospital campus, however, the new FRH hospital would have to be re-located to a new site. Property

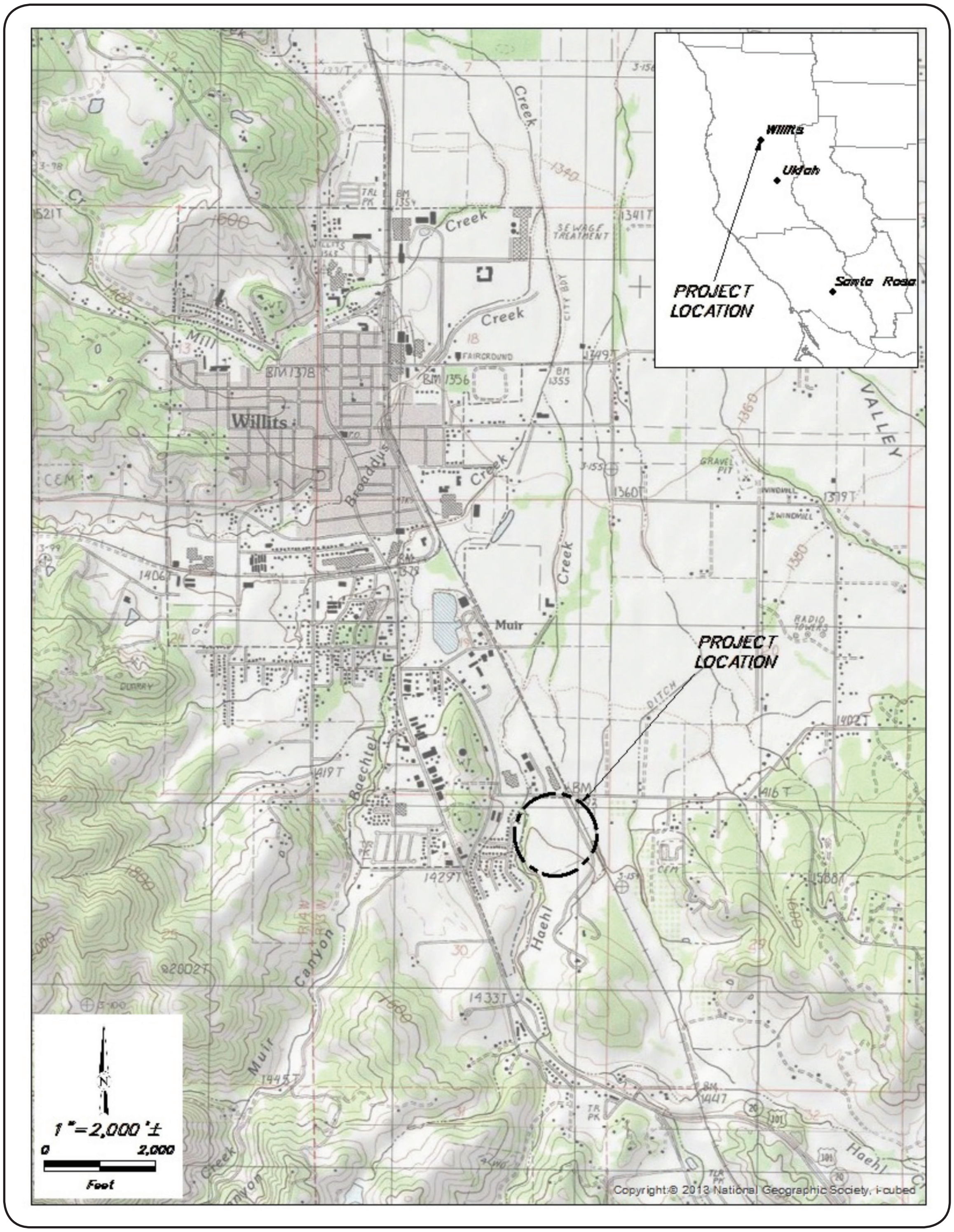

Figure 1. Location of the Frank R. Howard Hospital study site in southern Little Lake Valley.

offered by a local benefactor seemed ideal; a large undeveloped parcel on flat ground just outside of town. This site, however, is located just east of the mapped trace of the active Maacama fault, within an Alquist-Priolo Earthquake Fault Zone, on the Holocene floodplain associated with nearby Haehl Creek (Figures 2 and 3). The new hospital was determined to be economically feasible only if the donated land could be used, so an extended geologic and geotechnical investigation ensued. This paper describes the efforts related to characterization and mitigation of surface fault rupture and soil liquefaction, as well as a brief discussion of the characterization of strong ground motion.

Little was known about the geologic site conditions prior to the onset of fault rupture hazard investigations, which began in 2001 and continued through 2004. The fault studies at the hospital site were conducted in conjunction with similar investigations on adjacent parcels to the south and southeast, where a residential subdivision and Senior Assisted Living facility were proposed (the individual study areas are shown on Figure 3; SHN, 2004a, 2004b, 2003). These studies resulted in an awareness that the site conditions offered a unique opportunity to evaluate fault history and seismic potential, which led to a collaborative research-level study involving geologists from SHN and the U.S. Geological Survey (USGS), URS Corporation, and Humboldt State University (Fenton et al., 2002; Larsen et al., 2005; Prentice et al., 2014). In all, these investigations resulted in nearly 4000 feet of paleoseismic trenching, including at least 13 fault crossings (Figure 3).

Geotechnical site conditions, to evaluate liquefaction potential and other soil engineering concerns, were evaluated through an extensive program of subsurface investigation and laboratory testing (SHN, 2004). The site was found to be underlain by potentially liquefiable soils within the upper 17 to 21 feet. A variety of soil improvement and deep foundation options were considered and a large-scale mitigation effort ensued.

The investigations described in this paper generally followed the requirements described in the currently available version of the California Geological Survey's Note 48, the "Checklist for the Review of Engineering Geology and Seismology Reports for Public Schools, Hospitals, and Essential Services Buildings" (note that over the duration of this investigation significant evolution of Note 48 occurred). The results of the geologic and geotechnical investigations were rigorously reviewed by the lead regulatory agency, the Office of Statewide Health Planning and Development (OSHPD), with collaboration from the California Geological Survey (CGS). Geohazard mitigation strategies were fully vetted by the agencies, as were the results of construction observation and testing during mitigation efforts. This work was completed primarily during 2006 and 2007. Following a lengthy design and review process, additional geotechnical borings were drilled at the site in 2010 to provide confirmation of post-mitigation soil conditions and to develop design-level geotechnical parameters.

Geologic Setting

The project site is located within the Coast Ranges physiographic province of northern California, in an area sometimes referred to as the "Mendocino Highlands" (Figure 1). This area is characterized by a distinct north-northwest trending structural grain, which is manifested in a regional pattern of subparallel ridges and valleys. Post-Pliocene northward migration of the Mendocino triple junction and subsequent right-lateral strike-slip faulting associated with development of the San Andreas transform fault system is largely responsible for this structural pattern. Structural development associated with the active transform faulting has resulted in the formation of a series of large down-dropped valleys across the Mendocino Highlands (for example, Ukiah valley, Little Lake valley, Laytonville valley; Crowell, 1974 and McLaughlin and Nilsen, 1980, in Pampeyan et al., 1981); the subject site is located in the southern end of the Little Lake valley. Little Lake valley is a deep, sediment-filled basin, the stratigraphy of which is described in Woolace (2005).

Site Geology

The new FRH hospital site is located on the Holocene floodplain of Haehl Creek (Figure 3). Topography of the site is essentially flat (there is a very slight northward slope). A 15- to 20-foot-high pressure ridge located along the Maacama fault west of the hospital site, and the Haehl Creek channel, are the only topographic deviations in the project area. Haehl Creek drains the upland areas south of the valley, flows northward across the Little Lake valley floor in a 20- to 25-foot-deep arroyo (within about 400 to 500 feet west of the site), and joins Baechtel Creek north of the site.

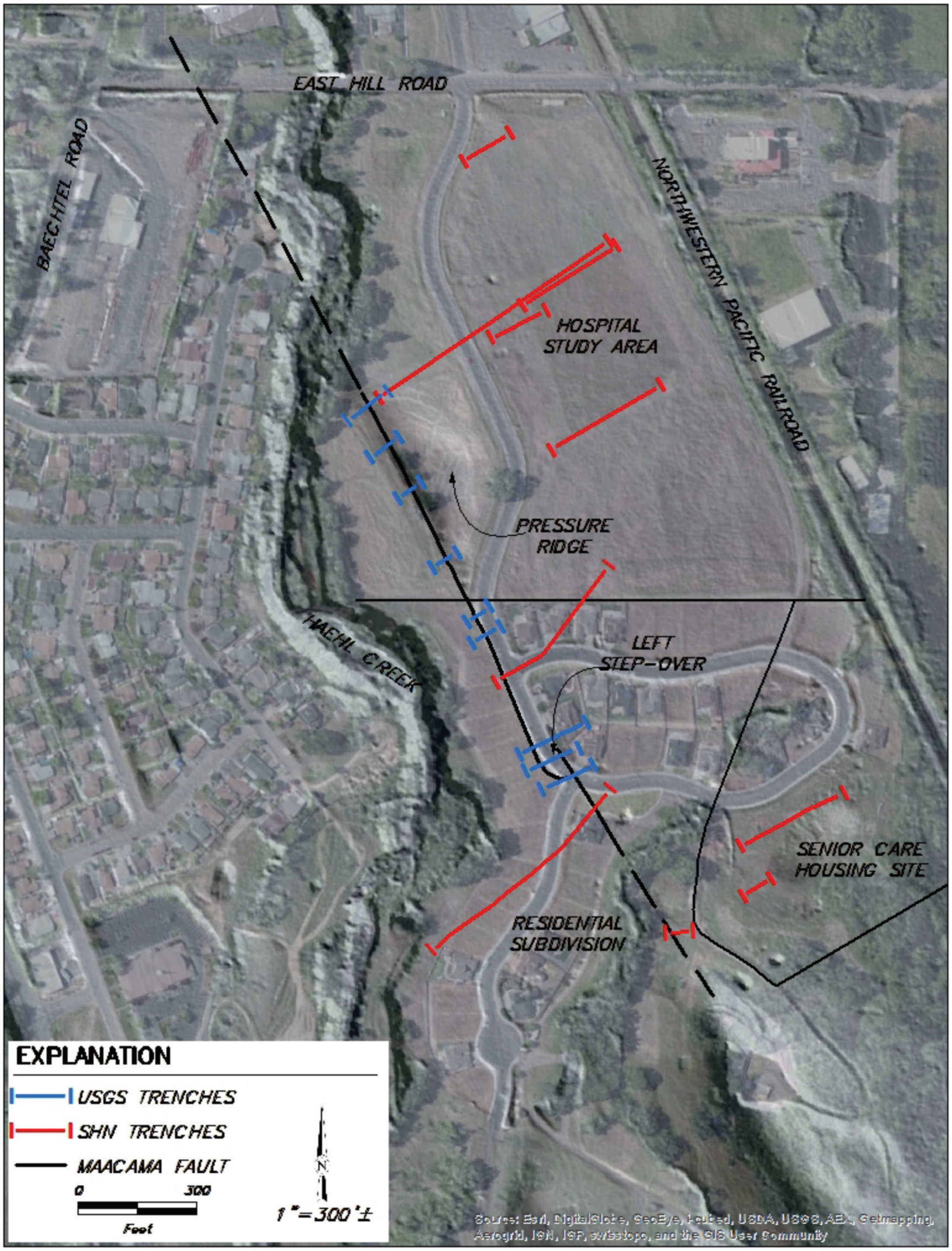

Figure 2. Site map showing the hospital study area relative to adjacent sites, and the location of paleoseismic (USGS) and consultant (SHN) trenches. The northwest trending dashed line is the Maacama fault.

Stream valley walls along Haehl Creek (described in Woolace, 2005), as well as exploratory trenches and borings at the site, have exposed a consistent stratigraphic condition in the study area: a 15 to 25 foot thick deposit of young, unconsolidated granular alluvium overlying broad tabular (1 to 3 foot thick) beds of predominantly fine-grained silty clay deposits (distinctly gray and blue-gray soil colors).

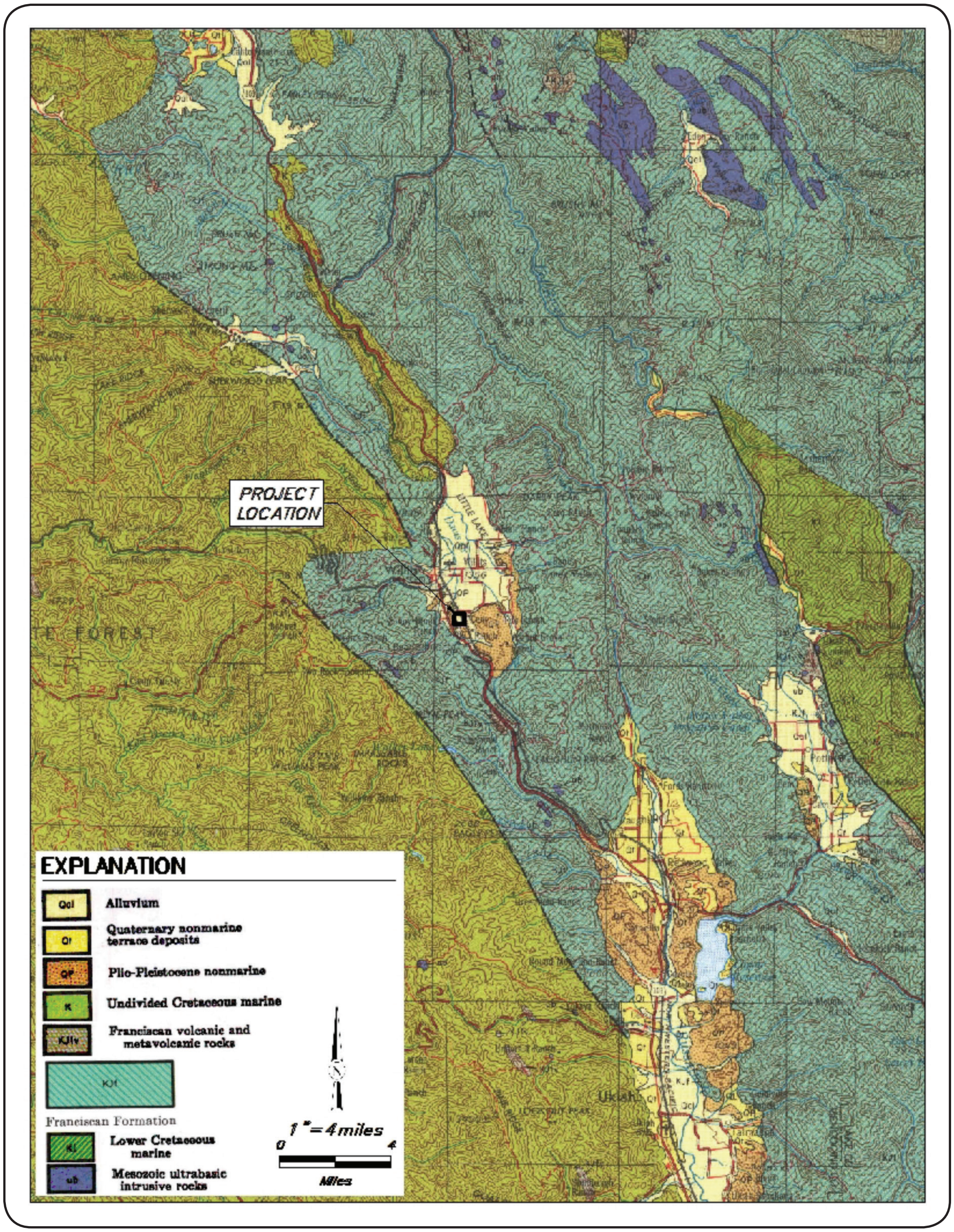

Figure 3. Geologic map of the Little Lake valley region, Mendocino County (Jennings and Strand, 1960).

Radiocarbon dating of charcoal samples collected in trenches and test pits at the hospital site, in the USGS paleoseismic research trenches, and at the Senior Assisted Living facility site, indicates that the surficial Haehl Creek alluvium (mostly silty overbank deposits with intermittent coarse sand and gravel channels) is Holocene in age, with some near-surface channels as young as a few hundred years old (see the compilation of radiocarbon dates in Tables 1 and 2 in Prentice et al., 2014).

The underlying silty clay deposits, inferred to have been deposited in a shallow lake or low energy river's floodplain, are latest Pleistocene in age (for simplicity, we refer to these materials in this paper as "lacustrine" or "shallow lake sediments"). Several trees (redwood, cottonwood, alder) were encountered in trenches within the upper few feet of the fine-grained section, some in upright growth position. Wood samples from these trees and charcoal samples from other exposures of the silty clay sediments yielded age estimates that range from 11,350 yrs before present to as much as 22,870 yrs before present.

These relations indicate a rapid transition near the Pleistocene-Holocene boundary in the Little Lake valley, from a shallow lake/low energy river environment to a higher energy, north-flowing stream system (Haehl Creek) that deposited up to 25 feet of alluvium. The most recent channels forming on the floodplain surface were being deposited within the past few hundred years. Subsequently, Haehl Creek has incised through the entire Holocene alluvial section, and now flows in an incised (20 to 25 foot deep) arroyo with the late Pleistocene silty clay sediments exposed in the channel. The cause of the substantial base level change that resulted in this recent incision is not known.

The Maacama Fault

The Maacama fault, which traverses the western margin of the hospital study area, is an active right-lateral strike-slip fault within the San Andreas fault system. In northern California, transform plate motion at the western edge of the North American crustal plate is distributed across a broad zone that includes the main San Andreas fault as well as a series of inboard strike-slip faults, including the Hayward-Rodgers Creek-Healdsburg-Maacama fault system. Through Mendocino County, the Maacama fault trends roughly N30W, and is approximately 40 km east of the San Andreas fault. The Maacama fault is considered an active fault because of its youthful geomorphic expression, paleoseismic evidence, its association with a linear trend of microseismicity, and distinct evidence of aseismic surface creep. The Maacama fault, however, has not produced a significant historic earthquake, and its seismic hazard potential is poorly understood. The largest historic earthquake in the vicinity of the Maacama fault was a magnitude 4.8 earthquake that occurred near Willits in November 1977; the epicenter was determined to be about 9 miles east of the Maacama fault.

Modeling of geodetic data suggests the Maacama fault accommodates approximately 14 mm/yr of strike-slip motion (Freymueller et al., 1999), while comparison to the Hayward and Rodgers Creek faults suggests about 9 mm/yr (Working Group on California Earthquake Probabilities, 2008). Freymueller et al., (1999) suggest that the Maacama fault poses a significant seismic hazard because it has a high slip rate, and has accumulated a sufficient slip deficit to generate a magnitude 7 earthquake. The aseismic surface fault creep rate is estimated at about 5.7 mm/yr within the town of Willits between 1992 and 2012 (McFarland et al., 2013). Fault creep is evident along a narrow zone (<10 feet) at a number of locations through Willits where cultural features (curbs, pavement, and structures) are displaced or deformed.

Maacama Fault at the Project Site

In the vicinity of the new hospital site, fault location is well constrained based on the presence of tectonic geomorphic features and the results of the many trenching investigations. The most distinctive geomorphic feature at the site is a broad, asymmetric pressure ridge west of the proposed hospital site (Figure 3). The main, active trace of the Maacama fault traverses the steeper southwest face of the pressure ridge. Initial paleoseismic research trenches excavated along the fault in this area (Fenton et al., 2002) were focused on determination of event timing, and found that the pressure ridge is underlain by late Pleistocene silty clay deposits warped upward along the fault, and subsequently buried by mid-Holocene age alluvial deposits of Haehl Creek. Structural and stratigraphic relations in the trenches on the pressure ridge suggest at least four, and perhaps five, surface faulting events during the Holocene (Fenton et al., 2002). Trenches directly southeast of the pressure ridge, in late Holocene alluvial deposits on the Haehl Creek floodplain, exhibit evidence for only a single rupture event (or the effects of aseismic creep). No evidence of faulting has been identified in trenches along the trace mapped by Upp (1982) along the northeast side of the pressure ridge.

There is no geomorphic expression of the fault across the floodplain surface either northwest or southeast of the pressure ridge, although minor features may have been removed by human activity (tilling, minor grading). To the northwest of the pressure ridge, en echelon fractures crossing East Hill Road indicate the location of the creeping fault trace. The fault has not been identified in the banks of Haehl Creek northwest of the pressure ridge, due to poor exposure and heavy brush. Fault location southeast of the pressure ridge is defined by a series of trench exposures. The fault was encountered within a variety of trenches during the U.S. Geological Survey studies, within 2 trenches in SHN's study on the residential subdivision site directly south of the pressure ridge, and within a short trench near the Senior Assisted Living facility site. Of note, the fault is associated with a distinct left step-over directly south of the hospital (Figure 3), where the late Pleistocene silty clay sediments are present, tilted upright, in the shallow subsurface.

Paleoseismic investigation by the USGS and HSU southeast of the pressure ridge focused on evaluation of the slip rate of the Maacama fault at the site. Detailed study of a series of trenches both parallel and perpendicular to the fault allowed the identification of two, and possibly three, paleoearthquakes at the site since 1180 calibrated years (cal) B.P. (Prentice et al., 2014). Offset of a relatively young channel (590-690 yr old) suggests an average slip rate of about 6.4 to 8.6 mm/yr, which exceeds the measured aseismic creep rate (McFarland et al., 2013).

Fault Rupture Hazard Investigation for the Hospital

Approach to Fault Investigation

Subsurface trenching investigations were conducted to evaluate the presence or absence of active fault traces crossing the proposed hospital site. Evaluation of fault rupture potential at the site is complicated by the depth at which suitable materials are located. The Alquist-Priolo (A-P) Act requires evaluation of faulting through the Holocene period (11,000 years); as such, pre-Holocene deposits must be exposed in order to document a sufficient record of fault history. Based on the results of initial radiocarbon dating of charcoal samples collected in preliminary test pits and trenches, it was apparent that subsurface investigations at the hospital site would need to penetrate in excess of 20 to 30 feet to reach Pleistocene deposits.

That depth is too deep for a typical vertical-walled trenching investigation, particularly since the groundwater table is shallow within Little Lake valley, even into the late summer/fall season. Three large pits with sloping, benched side-walls were excavated to provide access to deeper strata (Figure 4). These pits were 60 to 95 feet wide at the ground surface, were excavated with bulldozers and/or large excavators over a one to two week period, and were continuously pumped to lower the groundwater table. Once the large pits were complete, a standard 36" wide trench was excavated on the floor of each pit, penetrating into the upper late Pleistocene silty clay sediments (Figure 5). The trenches on the pit floor were typically 7 to 8 feet deep, making them a total depth 27 to 36 feet below grade, and were shored with standard hydraulic shoring. We cleaned, interpreted and logged the southeastern trench walls, and detailed logs were drafted at a scale of 1" = 2'. Appropriate soil samples were collected and described using standard Unified Soil Classification System terminology and Munsell colors.

Trenches at the site were oriented normal to local fault strike; we assume a fault strike of N30W, therefore trenches were oriented about N60E. The deep trenches were located northwest and southeast of the presumed hospital building footprint (based on preliminary facility layout available at the time of our field studies), and extend far enough to the southwest to preclude faults crossing the footprint within a reasonable range of potential variability. The study area abuts the northeastern margin of the A-P Earthquake Fault Zone, so the excavations were extended to the inferred A-P boundary.

Figure 4. Overview of one of the deep trench excavations for the Frank R. Howard Memorial hospital fault rupture hazard investigation. Holocene alluvial sediments are present in the sidewalls above the floor of the pit; late Pleistocene "lacustrine" sediments are below the pit floor, in the walls of the shored trench. Note the gleyed, gray-colored "lacustrine" spoils on the mid-pit bench, which contrast with the oxidized yellow-brown Holocene alluvial soils.

The precise location of an A-P boundary is often difficult to identify in the field at sites such as this large undeveloped parcel, where it was necessary to project the boundary from distant, poorly defined control points.

Results of Fault Rupture Hazard Investigation

The trenches excavated at the proposed hospital site provided positive evidence for the absence of Holocene faulting within the area studied. Stratigraphic control within the late Pleistocene lake sediments was very good, with distinct, laterally continuous bedding, and no evidence of fault rupture was observed.

In the State of California, surface fault rupture potential is mitigated through an avoidance strategy; specifically, geologic investigations are required to demonstrate that structures are not built over active faults capable of rupturing the ground surface. In the case of critical structures, such as hospitals, a minimum setback of 50 feet from an active fault is required. In this context, the trench layout is used to define a distinct "zone of clearance" relative to the surface rupture potential, within which it is acceptable to build. That zone of clearance is located between the three deep trenches, as shown on Figure 6 (the figure includes the footprint of the hospital, as currently being constructed). The southwestern margin of the zone of clearance is based on a 50-foot setback from a line connecting the southwestern ends of Deep Trenches 2 and 3. This configuration assumes active faulting just beyond the area studied, in this case to the southwest (the known location of the Maacama fault). The cleared area abuts the northeastern margin of the Alquist-Priolo zone, so no special accommodations are required relative to the northeastern trench ends (that is, no setbacks are required).

The geometry of the cleared area permits that a fault terminus associated with a fault striking other than N30W may be present within the buildable area. For example, a N45W trending fault trace

Figure 5. Photograph of typical tabular stratigraphy in late Pleistocene lake sediments in Deep Trench 1. Top of exposure is about 25 feet below grade, the base at about 32 feet below grade. View is of the southeast trench wall.

just beyond the southwestern end of Trench 3 may enter the buildable area, but it must die out before it reaches Trench 2. We concluded that this potential was insignificant to the overall scope of the project because: 1) the potential of this condition is very low (no such faults were observed in shallow trenches across the entire site), and 2) rupture associated with a fault terminus would be minor, and should not pose a significant threat to the structural integrity of the proposed hospital, whose foundation will be reinforced to mitigate strong seismic shaking and liquefaction potential.

Tilting of the ground during a seismic event on the nearby Maacama fault is a consideration (although not a requirement of the A-P Act or other regulatory criteria), as the silty clay lake sediments are warped upward into the fault zone in at least two nearby locations (one of which is the pressure ridge directly southwest of the hospital site). Gentle gradients were observed in several contacts in the deep silty clay sediments, but there was no clear pattern. Even if these observed gradients were associated with structural tilting, the amount of tilt is very minor. If the tilt reflects coseismic deformation, it represents the cumulative tilt of at least the 2 or 3 Holocene rupture events identified by Prentice et al., (2014) in relatively shallow trenches, and perhaps more. As such, at a maximum, the amount of tilt per event would be very minor. If related to aseismic creep deformation, the cumulative tilt over the life of the facility would be negligible.

Due to the size and location of the excavations within the proposed development footprint, it was decided that the pits would be backfilled and compacted as engineered fill to avoid settlement. During the time the pits were open, the excavation contractor continuously spread wet soils to allow drying, and mixed material to blend granular and fine-grained soils. This aeration period allowed the excavated materials to reach optimal moisture conditions for compaction during backfill. Backfill was placed in compacted lifts, with regular oversight and documented quality assurance testing. Backfill was placed to a minimum relative compaction of 90 percent of the maximum density, as determined by ASTM D1557.

Liquefaction Hazard Investigation

Approach to Liquefaction Investigation

An increased potential for soil liquefaction was identified during the initial screening process because of the adverse site conditions; the site is underlain by low density, late Holocene granular alluvial sediments, there is a high groundwater table, and it is located in a seismically active region (adjacent to an active fault). As such, extensive investigation and mitigation of soil liquefaction followed the completion of surface fault rupture studies.

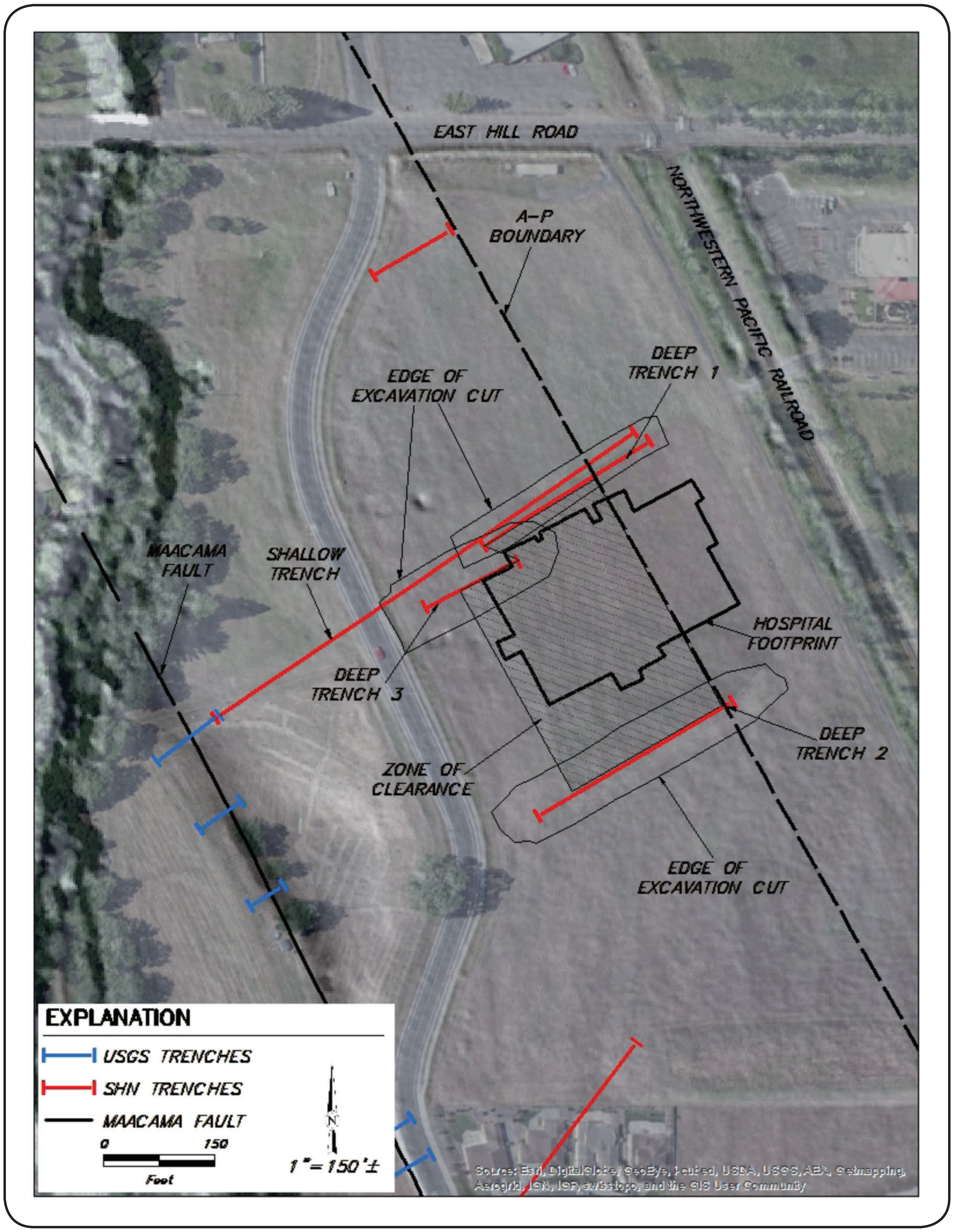

Figure 6. Site map showing the buildable "zone of clearance" relative to surface fault rupture potential, and the footprint of the hospital as currently under construction. Dashed line indicates the northeastern boundary of the Alquist-Priolo Earthquake Fault Zone.

Geotechnical field investigations to evaluate liquefaction potential consisted of the advancement of thirteen boreholes. Drilling was performed using a CME 55 drill rig, using solid stem flight augers above the water table, and mud rotary drilling methods below groundwater. The drill holes were advanced up to a maximum depth of 67 feet below the existing ground surface. Penetration resistance tests were conducted as the borings were advanced.

Selected samples were collected from the borings, and laboratory tests were performed in order to evaluate the characteristics of the materials encountered. Laboratory testing included sieve analyses (ASTM D422), in-place moisture content and density (ASTM D2937), Atterberg limits

(ASTM D4318), direct shear tests (ASTM D3080), unconfined compression tests (ASTM D2166), and consolidation tests (ASTM D2435).

Results of Liquefaction Investigation

Project geotechnical engineers completed quantitative liquefaction modeling based on the sampler penetration resistance and the results of lab testing (textural analyses). Penetration resistance is typically used to represent the relative density of the underlying alluvial sediments, which is a function of the liquefaction potential. The liquefaction analyses were completed using quantitative methods typical of the early 2000's, that is, in accordance with the procedures that were developed during National Center for Earthquake Engineering Research workshops (Youd et al., 2001) and updated by Seed et al., (2003). The potential for soil liquefaction was analyzed for various peak ground accelerations at the site.

The liquefaction analyses included data from 12 of the site borings, and liquefaction potential was indicated in various non-cohesive to low-cohesion sandy soil strata in all the borings, beneath an assumed water table of five feet. Liquefaction potential was identified in isolated zones in the upper 25 feet, within the mid to late Holocene age alluvial sediments, but not within the deeper fine-grained (silty clay) material. In addition to the obvious impacts associated with an earthquake generated along the Maacama fault near the site, inferred shaking levels from scenario earthquakes on both the Bartlett Springs and San Andreas faults were sufficient in the liquefaction modeling to indicate liquefaction potential in some sandy layers. Coseismic settlement values were calculated to range from 1.5 to 3.5 inches.

Liquefaction susceptible materials were not spatially consistent between borings; they appear to be associated with granular materials within channel deposits that are laterally discontinuous across the site (as observed in the trench excavations). This condition suggests the potential for localized loss of soil bearing capacity and a high potential for differential settlement, which can have particularly adverse impacts on structural foundations.

Based on the potential for liquefaction at the site, two general mitigation strategies were initially considered: 1) deep foundation systems that would transfer structural loads downward to the non-liquefiable silty clay sediments at depth, and; 2) ground improvement methods. A variety of deep foundation options were considered (e.g., reinforced concrete piles, stone columns), but these options were not pursued due to cost and the fact that the deep foundation option would not reduce the liquefaction potential at the site (leaving the hospital susceptible to differential settlement that could impact utility connections). Ground improvement options considered included a remove/replace approach similar to that already used during the fault trenching, as well as more exotic methods such as dynamic compaction or various soil grouting techniques.

Because the excavation of soil and replacement as engineered fill had been successfully achieved at the site (using local contractors and equipment) during the fault trench studies, and the method was cost efficient, the Hospital Foundation selected to proceed with a full-scale ground improvement campaign. Thus, in 2007, the loose, potentially liquefiable materials were excavated to a depth of up to 21 feet below grade. The soil was moisture-conditioned (dried), mixed, and replaced as structural fill in thin lifts. The soil was compacted with a large soil compactor (CAT 825H). Prior to the excavation, soil sampled in borings had unit densities ranging from 88 to 108 pcf (average of 99 pcf). The minimum density of the structural fill material following the remediation effort was 110 pcf, with an average of 116 pcf.

Subsequent geotechnical borings were completed within the remediation area in 2010 to provide final geotechnical design criteria. These investigations confirmed the effectiveness of the liquefaction mitigation measures and allowed additional consolidation and shear strength testing. These final, focused investigations were conducted following lengthy and extensive reviews by both the California Geological Survey and Office of Statewide Heath Planning and Development.

Ground Motion Hazard Analysis

Seismic strong ground motions that could affect the hospital were initially estimated by an assessment of historic seismicity and through probabilistic seismic hazard analyses. These initial ground motion assessment were completed per the criteria in the 2001 California Building Code, the relevant code standard at the time of the preliminary investigation, as well as the currently available version of CGS' Note 48, the "Checklist for the Review of Engineering Geology and Seismology Reports for Public Schools, Hospitals, and Essential Services Buildings." The ground motions required at that time for the design of hospital projects included the "Upper-Bound Earthquake" (UBE) ground motion, defined to have a 10 percent chance of exceedance in 100 years (return period of 949 years), and the "Design-Basis Earthquake" (DBE) ground motion, defined to have a 10 percent chance of exceedance in 50 years (return period of 475 years).

The initial probabilistic evaluation of strong ground motion was performed using the computer program FRISKSP (Blake, 2000). The program used three-dimensional faults as earthquake sources to make probabilistic estimates of peak acceleration and uniform hazard spectra. Faults within 60 miles from the site were evaluated. The peak ground accelerations, velocity, and displacement caused by an earthquake are attenuated due to energy losses with increased distance from the seismic source, and the attenuated values were considered in the ground motion models. Estimated peak ground acceleration (g) for the DBE was determined to be 0.68; the acceleration for the UBE was 0.83. The contribution of nearby faults to the ground motion estimate was evaluated through disaggregation of the probabilistic seismic hazards. Based on the disaggregation of the ground motion, the most signficiant contribution to the peak ground acceleration at the site was the Maacama fault, with an assumed M7 earthquake hypocenter beneath the site.

An updated site specific ground motion analysis was completed in 2010 to reflect changes in the California Building Code (2007 version) and CGS' Note 48. Specifically, the 2010 update followed the approach outlined in Section 21.2 of American Society of Civil Engineers (ASCE) 7-05, as modified by the Code Application Notice File No. 2-1802a.6.2 issued by OSHPD on the subject of "Next Generation Attenuation Relations for Use with the 2007 Building Code."

The ASCE 7-05 standard required that the hazard analysis account for regional tectonic setting, geology and seismicity, and the expected recurrence rates and maximum magnitude of earthquakes on known faults and seismic source zones. The 2010 update analysis complied with these provisions by using the USGS 2008 National Seismic Hazard Map seismic model as implemented for the EZ-FRISK seismic hazard analysis software from Risk Engineering, Inc. The ASCE 7-05 standard further requires that the analysis use appropriate regional characteristics of ground motion attenuation, near source effect, and the effect of subsurface site conditions on ground motions. Our analysis complied with these provisions by using the three Next Generation Attenuation (NGA) equations used by the USGS in the 2008 National Seismic Hazard Map for this region, using a site specific value for V_{s30}, and using a method that relates the calculation of the Maximum Rotated Component for the NGA equations to the Somerville Near Source Directivity parameter.

For the 2010 ground motion update, the probabilistic analysis includes a "Maximum Considered Earthquake" (MCE) that is defined as the spectral response represented by a 5 percent damped acceleration response spectrum having a 2 percent probability of exceedance within a 50 year period (associated with a return period of 2,475 years). For the required deterministic analysis, the ASCE 7-05 standard specifies that the spectrum be calculated as 150 percent of the largest median 5 percent damped spectral acceleration computed at that period for characteristic earthquakes on all known active faults within the region. OSHPD Code Application Notice File No. 2-1802A.6.2 modified this requirement to use the 0.84 percentile ground motion instead. The updated ground motion analysis culminates in a site-specific design spectrum.

Based on the results of field and laboratory testing, we estimated a soil shear wave velocity of 200 m/s, or 656 ft/s, and classified the geologic subgrade at the project site as Site Class D, per 2007 CBC Table 1613A.5.2 and Section 1613A.5.5. Based on the site class and the latitude and longitude, we obtained the "code based" spectral response acceleration parameters using the USGS seismic calculator software, "Seismic Hazard Curves, Response Parameters, Design Parameters: Seismic Hazard Curves, and Uniform Hazard Response Spectra," v. 5.0.9a, dated October 21, 2009.

The Outcome

Geologic and geotechnical investigations for the proposed Frank R. Howard Memorial Hospital began in 2001 and continued for the better part of a decade. Site investigation and mitigation over that period was funded by the FRH Hospital Foundation, through private funding and fundraising. Once the hospital site had been cleared by OSHPD, the .Foundation was able to join forces with a private health organization (Adventist Health) to begin development of the new hospital. The ground breaking ceremony for the new Frank R. Howard Memorial Hospital was held in 2013, and the hospital is currently under construction with an anticipated completion date in late 2015.

Acknowledgements

Tom Herman manages SHN's Willits office and has been a driving force behind the forward progress throughout the lengthy investigation and review process. It is fair to state that this hospital project would not have succeeded without his monumental efforts. Initial geologic studies were conducted under the supervision of Tom Stephens. Geotechnical aspects of this work were completed by SHN geotechnical engineers David Bradley, Mark Twede, and Richard Hanford; all outstanding professionals who gracefully negotiated a complex investigative and regulatory pathway. Mr. Twede in particular was responsible for the extensive 2004 geotechnical reporting. The 2010 ground motion update was completed by Jason Buck, SHN Senior Geologist. Technical review of the trenching was provided by William Lettis & Associates, particularly Michael Angell, who enthusiastically embraced his role. OSHPD's engineering geologist, Catherine Slater, provided thorough review of the investigations outlined herein. Carol Prentice, with the U.S. Geological Survey, deserves credit for recognizing the potential for paleoseismic research at the site, then coordinating large collaborative research efforts. Excavation work was completed by the fantastic crew of Garmin and Sons, who worked long, hard hours moving a significant amount of dirt.

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Gary Simpson is a Senior Engineering Geologist who leads the Geoscience group at SHN Consulting Engineers & Geologists in Eureka. He is a graduate of the Humboldt State University geology program, which has fueled a life-long love of all things Quaternary. He has practiced professionally for 26 years in the San Francisco Bay Area and throughout the north coast region. Mr. Simpson is currently serving on the Geology Technical Advisory committee for the Board of Professional Engineers, Land Surveyors, and Geologists. He has a special affinity for active faults and paleoseismology, and has had opportunities to complete trench studies throughout the western U.S. and internationally. He has completed or participated in paleoseismic and fault rupture hazard studies on the northern San Andreas, Hayward, northern Calaveras, San Gregorio, Maacama, Mad River, McKinleyville, and Little Salmon faults, as well as in the New Madrid Seismic Zone and in Israel. He considers himself lucky to be living and practicing in the geologic fun-zone that is the Mendocino Triple Junction region.