Christopher Madden, M.S.

Project Consultant
(714) 231-1524
madden@earthconsultants.com

Mr. Madden has seven years of experience locating and characterizing active faults for planning, development and research. He employs state-of-the-art techniques, including remote sensing, digital field mapping, 2-D and 3-D fault trenching, and drilling to help clients understand and mitigate the impact of active faulting to their projects. Mr. Madden has conducted and overseen geotechnical fault investigations for housing, school and dam design along the major faults in southern California, including the San Andreas, San Jacinto, Garlock, Chino, and Elsinore faults. He has also participated in projects to characterize fault hazards for large public infrastructure projects in Europe and Central America. He is an active member of the research community and is involved in studies to characterize the timing, frequency and interaction of earthquakes on major fault systems around the world. His work through ECI, Central Washington University and Oregon State University has produced some of the first data on active fault systems in Panama, Taiwan, Nepal, Portugal, Pakistan and Afghanistan.

EDUCATION

Ongoing PhD. studies, Oregon State University 2007 - present
Seismic potential and hazard along the Himalayan frontal thrust system, Pakistan

M.S. Geological Sciences, Central Washington University 2002
Record of Holocene and Latest Pleistocene Activity on the Mesquite Lake Fault: Insights into Fault Interaction in the Eastern California Shear Zone

B.A. Geology, Diplomacy and World Affairs, Occidental College 1997

PROFESSIONAL HISTORY

Earth Consultants International (partner)
- Project Consultant 2007 - present
- Senior Staff Consultant 2003 – 2007
- Staff Consultant 2001 – 2003

Central Washington University
- Research and Teaching Assistant 1999 – 2001

PROFESSIONAL AFFILIATIONS

American Geophysical Union
Southern California Earthquake Center
Association of Engineering Geologists
Seismological Society of America

SELECTED PROJECT EXPERIENCE

International

Project Manager for a program to train Panamanian engineers to install and maintain a global positioning system network to monitor fault movements in central Panamá; ongoing. In 2006, ECI helped the Autoridad del Canal de Panamá (ACP) design a permanent global positioning system (GPS) network to monitor slip on several active faults identified by ECI in central Panama. In a follow-up contract, Mr. Madden trained ACP engineers to identify stable sites for the GPS stations using a combination of satellite imagery and field reconnaissance. Through geomorphic analysis we were able to find sites that are not impacted by landslides and other mass wasting processes. In 2008, ECI will lead the installation of two of the GPS monuments to train ACP engineers to install an additional four sites.

Co-Field Manager for an investigation of the potential surface rupture hazard posed by the Pedro Miguel and Miraflores faults to the existing Pedro Miguel and Miraflores Locks, for the Autoridad del Canal de Panamá (ACP), Panamá; 2007. Findings by ECI that the Pedro Miguel and Miraflores faults are both active near the Panama Canal Zone triggered ACP to retain ECI for additional studies of both faults to make a determination as to whether they pose a surface rupture hazard to the existing Pedro Miguel and Miraflores Locks. Based on an analysis of historical data consisting of topographic and geologic maps and eighty years worth of geological boring logs, geophysical transects of the Miraflores Lake (by Technos Inc.), and new detailed geological field mapping, backhoe trench data, and boreholes drilled within Miraflores Lake, we determined that both faults lie outside the lock footprints, but that the approach causeways are at risk of damage. One of Mr. Madden's primary contributions to this project was to show that splays of the Pedro Miguel fault die out south of the Pedro Miguel Locks.

Co-Field Manager for a detailed kinematic investigation of the Pedro Miguel and Miraflores faults within the footprint of the proposed Borinquén Dam portion of the Canal Expansion Project, for the Autoridad del Canal de Panamá (ACP), Panamá; 2006-2007. As part of the new Panama Canal Expansion Project, the 5-km long Borinquén Dam is proposed to separate the new third lock from the existing Pedro Miguel and Miraflores Locks. Findings by ECI that both the Pedro Miguel and Miraflores faults are active triggered ACP to retain ECI for additional studies of both faults to precisely locate and define the active fault traces near the proposed new dam, and to develop, based on detailed three-dimensional trenching studies of the fault, a kinematic model of the Pedro Miguel fault to be used in the design of Borinquén Dam to resist future fault rupture failure. In addition to trenching strands of both faults, Mr. Madden's work on this project focused on creating a real-time GIS database of trench and fault information in the field using tablet computers, and managing digital data for over 40 trenches.

Research Geologist for paleoseismic investigation of the Main Frontal Thrust, Nepal; 2006, 2001. Mr. Madden participated in an international collaboration between California State University, Northridge; University of Grenoble, France; and the Geological Survey of Nepal to determine whether earthquakes along the Himalayan frontal thrust fault system produce surface rupture. These data are imperative for

determining the magnitude and return time for earthquakes in seismic hazard models. In 2001 we excavated trenches along a portion of the fault in eastern Nepal that broke in the 1934 Mw ~8 Bijar earthquake. Surprisingly, we found that the last surface rupture in this area occurred much earlier, around 1100 A.D. This earthquake produced approximately 17 m of displacement, equivalent to a high-Mw 8 earthquake. Based on these findings, we suggest that only the largest earthquakes along the Himalayan front rupture to the surface, and that "smaller" earthquakes, such as the 1934 event, are blind. We returned to Nepal in 2006 to trench the frontal thrust in westernmost Nepal, an area with no reported earthquakes in 500 years. We found evidence for a large surface rupturing earthquake approximately 500 years ago, likely corresponding to documented reports of a devastating earthquake in 1505.

Geologist for fault hazard investigation to determine activity of the Pedro Miguel fault system for design of the Panama Canal expansion, for the Autoridad del Canal de Panamá (ACP), Panamá; 2006. Recent findings by ECI that the Pedro Miguel fault has a tectonic geomorphic signature consistent with a late Quaternary fault led the ACP to contract with ECI for an emergency investigation designed to generate quantitative data on the fault's seismic history. During the geomorphic study, we had identified a prospective trenching site in the Cocolí area immediately west of the Miraflores Lock with good accessibility, a geomorphically well-constrained fault location, and likely to contain appropriately aged deposits useful to characterize the fault. ECI excavated 15 trenches across and parallel to the fault zone, measured laterally displaced (offset) channel deposits, and collected samples of organic materials and sediments that allowed us to date some of the offset sediments. Based on the data collected, we determined that the Pedro Miguel fault is active, having ruptured two or three times in the past about 1,400 years.

Geologist for geomorphic field reconnaissance to assess the activity of late Quaternary faults in central Panama for expansion of the Panama Canal; 2006. ECI was retained to review a large area centered on the Panama Canal Zone for indications of active faults that should be considered in the seismic hazard model being prepared as part of the design of the Canal expansion project. Using stereo aerial photographs, a 10-m digital elevation model (DEM), helicopter reconnaissance, and extensive field verification and geomorphic mapping, ECI identified that the Azota, Pedro Miguel, and Miraflores faults are active and should be incorporated into the seismic hazard model. To aid with this effort, Mr. Madden developed a computer-based field mapping system using GPS to locate our position relative to structures mapped on aerial photographs and DEMs. This methodology proved invaluable for identifying geomorphic features in the dense Panamanian jungle and managing field data in real time.

Geologist for Paleoseismic investigation of the Vilarica fault in northeastern Portugal to provide seismic design parameters for the proposed El Sabor Dam; 2005. The purpose of this study was to determine the recurrence interval and slip per event for earthquakes on the Vilarica fault to aid in seismic design of the El Sabor dam. Paleoseismic trenches at three sites near the dam showed that the most recent event on the Vilarica fault occurred between 4.7 and 13.8 ka, the penultimate event occurred just prior to 16 ka, and a third event after 25 ka. A 3-D trench network resolved 6-7 m of cumulative slip during the last two earthquakes. These data suggest the fault

produces relatively large earthquakes in the magnitude range of M7.1 - M7.7, with relatively long, but irregular return periods. Work on this project was facilitated by Mr. Madden's implementation of a new digital trench logging system that produced report-ready trench logs in the field.

Research Geologist, Paleoseismic investigation of the Rueisuei segment of the Longitudinal Valley fault, Taiwan; 2004. Mr. Madden trained a graduate student from Central Washington University in paleoseismic techniques while conducting research on the creeping Longitudinal Valley fault (LVF) in eastern Taiwan. Exposures from two trenches across the fault revealed evidence for two, and possibly three large earthquakes in the latest Holocene. This work showed that although the LVF is creeping, some strain is released in large earthquakes, similar to the Hayward fault in California.

Geologist, Earthquake damage assessment for the 2002 Nahrin, Afghanistan earthquake; 2002. Robert Yeats and Mr. Madden evaluated the geologic setting and damage patterns from the 2002, Mw 6.1 Nahrin, Afghanistan earthquake to determine whether extensive loss of life resulted from site-specific conditions, such as earthquake-induced landslides and liquefaction, or from poor construction methods. Site visits to over 50 villages in rural Afghanistan showed that most damage resulted from poor construction methods and that slightly better engineering during reconstruction could substantially reduce fatalities during future temblors in this earthquake-prone region. In some cases we suggested relocation of villages that had been impacted by earthquake-induced landslides or ridgetop shattering.

California

Field Manager for a geomorphic flood hazard investigation for a proposed housing development in the Coachella Valley, California; 2007. ECI was retained to assist in the development of a realistic flood hazard model to aid in flood mitigation planning for a large residential development. We used a dated soil-chronosequence developed just south of the project site, aerial photo analysis and geomorphic field mapping to evaluate the recency of flooding on the fan. Once the active channels for 100- and 500-year flood events were identified, we surveyed several channel cross-sections across the fan to accurately calculate the depth of past flooding. These data were then incorporated into realistic flood hazard models for use in the design and layout of the new development.

Field Manager for a seismic hazard assessment of the San Vicente Dam Raising Project, Phase IV, San Diego California; 2006. This project involved detailed field mapping, trenching and petrographic analysis of a fault known to underlie San Vicente Dam that, if found to be active, could severely impact the plans to raise the level of the dam, thereby increasing the capacity of the reservoir that provides most of San Diego's drinking water. The fault was first identified in the 1940s during construction of the dam, but its recency of activity appears to have not been assessed at that time. Based on our work we demonstrated that the fault resulted from emplacement of the Mt. Woodson granodiorite, has experienced only very minor post-Cretaceous slip, and is therefore not likely to pose a future surface fault rupture hazard to the dam.

Project Manager for stability assessments of sites for permanent global positioning system (GPS) instruments of the Plate Boundary Observatory, southern California; 2006. Earthscope's Plate Boundary Observatory will include over 1000 instruments to monitor active faulting in the western United States. ECI was contracted to identify stable sites for 15 GPS monuments in the landslide-prone Coast Ranges of southern California. Mr. Madden used aerial photo analysis, map interpretation and field reconnaissance to assess and select each site and then negotiated long-term land-use agreements with property owners.

Co-Principal Investigator, Paleoseismic investigation of the Garlock fault to determine earthquake recurrence and interaction between fault segments; 2006. ECI was funded by the Southern California Earthquake Center to extend the prehistoric earthquake record of the central Garlock fault. We excavated trenches across a playa site that preserved a nearly continuous early Holocene record of deposition. Preliminary results show that the site preserves evidence for 5 to 10 earthquakes between 4 and 10 ka. We presented our findings at the 2006 annual meeting of the Southern California Earthquake Center. This work is still in progress.

Field Manager for the Seismic Hazard Assessment, San Vicente Dam, San Diego California, Phase II; 2005. ECI assessed the origin and activity of the inferred "Right Abutment Fault" that, if found to be active, could severely impact the plans to raise the level of San Vicente Dam. Following a detailed study of the fault that included geologic mapping, trenching and petrographic analysis of rock samples collected from the fault zone, we demonstrated that the fault is a minor structure that predates uplift of the Peninsular Ranges in the late Cretaceous and therefore does not pose a surface-fault rupture hazard to the dam.

Geologist/Field Project Manager for a new master-planned resort community at Tejon Ranch, Southern California; 2001-2002; 2005. Encompassing about 60 square miles of land consisting of broad valleys to steep mountains, this proposed residential/resort community will be built out over the next 10 to 20 years. This geologically diverse site is vulnerable to numerous hazards, including ground rupture from active faults, strong seismic shaking, liquefaction, small to large landslides, debris/mudflows, and thick deposits of compressible soils. In order to evaluate the original design concept, we undertook an extensive background review of published literature, along with a geomorphic analysis of the landforms using aerial photographs and Landsat imagery. Mr. Madden oversaw the excavation of numerous fault trenches to constrain the location of active faulting in the hillside terrain. These data were incorporated into a geological constraints and opportunities map, which was used by the landowner and the design team to reduce the amount of mitigation needed by avoiding areas with severe geologic impacts, and utilizing those regions with minimal impacts for the majority of the development.

Principal Investigator, Paleoseismic study of the western segment of the Garlock fault, Kern County, California, 2004-2005. The purpose of this study was to date late Holocene earthquakes on the western Garlock fault to look for patterns of prehistoric seismicity. We opened paleoseismic trenches across a sag pond developed on a small step-over on the fault and exposed a record of five earthquakes in the last ~6,000

years. Four of the earthquakes occurred in the last 2,700 years, preceded by an extended period of seismic quiescence. These findings correlate to paleoseismic results from the central segment of the fault that reveal evidence for four earthquakes in the last 2,000 years preceded by a seismic lull. These findings suggest that the two segments have experienced similar late Holocene rupture histories involving a late Holocene cluster of events. The study is funded with a grant from the U.S. Geological Survey. Mr. Madden presented the findings of this study at the 2005 annual meeting of the American Geophysical Union.

Geologist for a faulting and folding hazard assessment of four new Police Facilities in the City of Los Angeles; 2005. The City of Los Angeles retained Earth Consultants International to undertake a detailed fault hazard assessment of the proposed new Emergency Operations Center (EOC), Metro Jail, a relocated Rampart police station, and an enlarged Hollenbeck station. All four facilities are located within the possible zone of deformation above the Coyote Pass Escarpment, the near-surface manifestation of an active blind thrust fault. Mr. Madden oversaw the trenching study at the Rampart site that showed the site is north of the zone of active deformation. Existing geotechnical borings at the Metro Jail, existing geotechnical and six new borings at the EOC, and 20 new borings at Hollenbeck, showed that the EOC and Metro Jail sites are north of the active deformation zone, but that the Hollenbeck facility is impacted not only by fold growth and tilting, but also by a transfer fault that has segmented the fold hinge. Using the borehole data we developed a model of fold growth and surface deformation and tilting over the past several hundred thousand years, to predict the location and magnitude of future coseismic deformation, and possible surface projection of the transfer fault beneath the proposed Hollenbeck facility.

Field Manager for a fault trenching investigation to locate and characterize potentially active faults beneath the Belmont Learning Center in downtown Los Angeles, California; 2003-2004. Mr. Madden coordinated and participated in the placement, excavation and logging of nearly 6,000 feet of trenches to locate, and if possible, evaluate the activity of faults beneath the proposed school site. Although much of the site was found to be free of faults, a 50-foot-wide fault zone was found to extend across the footprint of two of the main buildings. The age of the faults in this zone could not be determined on site because the soils needed to determine activity had been stripped during grading and earlier oil activities. We therefore estimated the amount of slip per earthquake for this fault zone, assuming that it moves co-seismically with earthquakes on the buried thrust faults that underlie the Los Angeles metropolitan area.

Field Manager for Active Fault Constraints Investigation phase of the Planning and Environmental Impact Report for the 17,000-acre "Centennial" project, a new master planned residential community proposed in northern Los Angeles County; 2001-2002. Earth Consultants International was tasked with identifying, characterizing, and constraining the active fault hazards within this master planned community immediately adjacent to the San Andreas fault and near to the Garlock fault. During the first phase of the study, we created a GIS-based fault map of the site based on an analysis of aerial photographs, satellite imagery, previously mapped faults, and field mapping. From this analysis, we identified 13 areas for additional field study. During

the Phase 2 studies, Mr. Madden oversaw an extensive trenching program to quantitatively evaluate the activity and width of those faults that had the potential to impact the proposed development. Based on data collected from 27 fault trenches, including soil-age analysis and OSL dating, we established structural setbacks for two of the faults.

SELECTED PUBLICATIONS

Madden, C., Rubin, C.M., and Streig, A., 2006, Holocene and Latest Pleistocene Activity on the Mesquite Lake Fault Near Twentynine Palms: Implications for Fault Interaction: *Bulletin of the Seismological Society of America*, Vol. 96, pp. 1305-1320.

Lavé, J., Yule, D., Sapkota, S., Basenta, K., **Madden**, **C.,** Attal, M., and Pandey, R., 2005, Evidence for a Great Medieval Earthquake (~A.D. 1100) in Central Himalaya, Nepal: *Science*, Vol. 307, pp. 1302-1305.

Yeats, R., and **Madden, C.**, 2003, Damage from the Nahrin, Afghanistan Earthquake of March 25, 2002: *Seismological Research Letters*, Vol. 74, No. 3, pp.1051-1054.