Geological mapping of the San Andreas Fault near Parkfield California

A proposal for support of M.S. student Lela Prashad at Arizona State University

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Introduction

Problem

Geologic mapping along fault zones not only provides valuable information about the activity of the fault, such as rupture patterns and recurrence intervals, but it becomes a context for detailed studies (e.g., McCalpin, 1996). Fault structures that reflect the mechanics of fault rupture can be revealed through the use of paleoseismology, geophysical profiling, and imaging. These studies require a traditional geologic map to provide a tie to the Earth's surface.

Along the San Andreas Fault (SAF) in south central California, numerous studies have been conducted but few have been high-resolution geologic mapping projects. The SAF is the major plate boundary structure for the US Cordillera. It accommodates at least 70% of the relative motion between the North America and Pacific plates and dominates the long-term earthquake strain release for California (e.g., Wallace, 1990). Our understanding of crustal-scale fault mechanics is based to a large extent on research emphasizing the SAF, yet the controls on fault strength remain debated (e.g., Zoback, et al., 1987 and Scholz, 2000). Detailed conclusions about the motion along and mechanics of the SAF can only be confidently made with detailed geologic mapping of the fault zone. An important place to begin making high-resolution geologic and geomorphic maps of the fault zone is Parkfield, California (Figure 1).

The SAF at Parkfield has ruptured about every 20 years since 1857, the most recent of which occurred in 1966 (see Roeloffs, 2000 for an up-to-date review). In 1985, a major monitoring effort was established to "catch" the next earthquake (e.g., Bakun and Lindh, 1985). To date, the event has not occurred, but we have learned much about the character of strain accumulation and release in this area of transition between fault creep to the northwest and a locked portion to the southeast in the Cholame-Carrizo Plain area (Roeloffs, 2000). Initiated nearly 10 years ago and now part of the Earthscope initiative, fault zone drilling at Parkfield is ongoing. Logging and monitoring continue in a 2.2 km pilot hole (http://www.icdp-online.de/html/sites/sanandreas/index/index.html). The San Andreas Fault Zone Observatory at Depth (SAFOD) will be 4 km deep and penetrate the SAF obliquely in a number of places to sample fault zone rocks, fluids, pressure state, and to leave monitoring strings in place.

We propose to map a portion of 5 quadrangles at 1:12,000 scale emphasizing the geology along the San Andreas Fault zone at Parkfield, in collaboration with USGS scientists (Figure 2). Existing mapping is too coarse for applications such as interpreting the rupture history of the SAF zone in the Parkfield area or as context for interpretation of observations from the SAFOD experiment.

Existing geologic mapping

Existing geological mapping for portions of the Parkfield area are insufficient for the basic science and applied hazard problems identified above (see Figure 3 for outlines of published maps of the area). T. W. Dibblee mapped the area in the 1960s and the results of his work are published as Dibblee (1973 and 1980). However, the fairly well known 1973 map stops about 10 km southeast of Parkfield and is 1:62,500. Unpublished geological mapping of Dibblee compiled digitally by C. Wentworth of the USGS is shown in Figure 4. The map is compiled at 1:250,000. It is too coarse for the research questions of interest, but does provide a valuable context for the mapping we propose. Brown (1970) produced a 5 mile wide strip map of active fault breaks, but did not map the geomorphic or Quaternary geologic units. Sims (1988 and 1990) produced 1:24,000 scale geologic maps along the 1966 Parkfield rupture.

Ongoing mapping

Michael J. Rymer of the USGS Earthquake Hazards Team has mapped a portion of the Stockdale Mountain quadrangle with limited support as part of site characterization work for SAFOD (Figure 3). His experience with the Sims mapping is that it is not sufficiently detailed along the fault zone. He noted several basement slivers along the SAF that were not mapped, and the structural complexity within the Tertiary units is underrepresented in the 1988 and 1990 maps.

Geological mapping as fundamental part of M.S. thesis

Our proposed mapping will constitute a major portion of the M.S. thesis of Lela Prashad at Arizona State University, with the scientific questions focused on the structural geology of the fault zone and earthquake geology characterization of the Parkfield segment of the SAF.

Location and geologic setting

Figure 2 shows the outline of the swath of mapping to be completed as part of this project. It has an area of approximately 120 km^2. A quadrangle has an area of ~ 160 km^2. Mapping at 1:12,000 over the period of about 30 field days is reasonable given the terrain, geology, and our experience. If we cover the target area sufficiently and field time remains, we will expand the coverage to priority areas to elucidate significant geologic relationships.

The geologic framework at Parkfield is one of great contrast across the SAF. The basement on the northeast side of the SAF is predominantly the Jurassic-Cretaceous Franciscan formation, and it represents the exhumed high pressure paleoaccretionary complex and its oceanic crustal floor of the Mesozoic convergent Cordilleran margin (e.g., Page, 1981). Basement rocks of dominantly granodioritic composition dominate the southwest side and represent a crustal unit called the Salinian block that has been displaced from hundreds of km southeast along the SAF (e.g., Irwin, 1990). Mid to late Tertiary sedimentary rocks were deposited in a marine environment during the early stages of development of the SAF and along with the Mesozoic units are strongly folded with axes nearly parallel to the SAF (e.g., Page, 1981). Tertiary-Quaternary units are locally (mostly) derived medium to coarse-grained clastic rocks including the Plio-Pleistocene Paso Robles formation (e.g., Galehouse, 1967).

Purpose and justification

Geological mapping at 1:12,000 scale along the SAF at Parkfield will provide geologic information at a quality and scale commensurate with the degree of geophysical attention it has received over the last 20 years. With so much work focused there, the geological mapping is surprisingly limited. Mapping along the fault zone will document:

- The contrasting basement, Mesozoic, and mid-Tertiary geologic units across the SAF and provide field examples of samples to be observed in the SAFOD borehole.

- The stratigraphy of the Paso Robles formation and other Plio-Quaternary units that preserve the record of large scale landscape reorganization with continuing uplift and SAF motion in the Coast Ranges (e.g., Page, et al., 1999).
- The late Quaternary and active hillslope (with special emphasis on landslide complexes) and fluvial units. We will develop a terrace chronosequence for Cholame Creek—the major drainage of the watershed. A flight of well developed terraces has developed in the lower portion of the drainage basin. Those surfaces provide excellent markers for deformation and could be targets for ^{14}C and cosmogenic methods in future studies.

Geologic mapping will constrain the geologic structure in the region. These field investigations permit us to develop knowledge of the materials in the area and their temporal and spatial relationships. With the application of standard structural analyses such as downplunge methods, we will develop detailed cross-sections and three-dimensional models of the geologic structure along the fault zone constrained by the surface geology and tempered by our understanding of the geologic relations among the units.

Data gathered in this project will aid in our ability to interpret the shallow structure of the fault zone as imaged geophysically. For example, a recent study by Hole, et al. (2001) illuminated the upper 1 km structure of the SAF. They imaged steep reflectors underneath the surface trace of the SAF that then dip southwestward to potentially explain the apparent offset of shallow seismicity with the surface trace of the fault. Along with Unsworth, et al., 2000, they provided interpretations of a 1-km wide vertical wedge of porous sediment or fractured rock immediately southwest of the active fault trace (Hole, et al., 2001) and a low conductivity zone extending to a depth of 4km–just above the microearthquake activity.

A highly detailed Plio-Quaternary stratigraphic record for the area around the SAF at Parkfield is necessary for quantification of deformation along the fault zone. This record is also an essential foundation for understanding the development of structures and the evolution of landforms along the fault (Brown, 1970). Strike-slip faults produce mappable secondary structures such as stepovers and splays. These features would certainly be seen at the scale at which we propose to map. Knowing the detailed geologic and structural history of the region is essential to understanding the kinematics of the SAF. Finally, tectonic landscapes created by the fault, such as shutter ridges and beheaded channels, must be mapped to observe the geologically recent effects of the fault on the surface of the earth.

With a fully developed stratigraphic record, detailed mapping of tectonic geomorphology, and the mapping of secondary strike-slip structures, the map Prashad will create will be important on its own. It will be possible to draw conclusions about past earthquakes by looking in detail at displaced strata and landforms. The mapping of the fault trace, at this scale, will indicate how the fault is accommodating its movement. The map will also become part of a growing pool of knowledge about the fault on toward the southeast through the Carrizo Plain. Geological mapping along the Cholame and Carrizo sections of the SAF (50 to 200 km southeast of Parkfield) have provided important documentations of fault zone structure and tectonic landforms with which we are beginning to develop geometric models for the upper few km of the SAF and other strike-slip fault (e.g., Young, et al., 2002; Stone, 2000; Sieh and Jahns, 1984; and Arrowsmith, 1995). During the summer of 2001, Rymer and Prashad did some preliminary mapping in Parkfield (~10 days). We discovered a new, active segment of the SAF that is characterized by sag ponds and shutter ridges. The SAFOD drilling project began shortly after our mapping project and this fault, named Buzzard Canyon Fault, was found in the drill core, in line with our projection of the fault trace. This is an example of the benefits of mapping the area around Parkfield: a chance to correlate surface mapping with data from the drilling project. Rarely does anyone have the opportunity to do this.

Strategy for performing the geologic mapping

Our research team has significant field experience in the southern Coast Ranges and so we are familiar with field logistics (see below for documentation of experience). We have budgeted about $1500 for per diem and lodging and will supplement with some personal funds as well. We will seek coordination with some of the other geophysics teams at the site (Virginia Tech and Duke University) and try to rent a house or trailer (this was done recently by one of our colleagues who was studying gas flux along the SAF in Parkfield). The alternative will be a mixture of camping and inexpensive hotels (likely when we go to town to shop every few days). It is impossible work in the area in the rainy season. Other seasons only require 2 wheel drive. We have had good success with rentals of Ford Rangers in other projects, so we will do the same this time. Arrowsmith will drive to the site at no cost to the project during his field time.

We will perform all of our mapping in close collaboration with Rymer. Importantly, he has a well developed relationship with the local landowners and has blanket permission to work in most of the large ranches in the area and has offered to help coordinate access. In addition, he has a variety of high quality basemap data available digitally from which we can choose the most appropriate aerial photographic or topographic bases for our field mapping efforts. Prashad will do all of the mapping, but will be accompanied by a field assistant, Rymer, or Arrowsmith at all times for safety and field review. We will walk out all contacts, gathering structural information as we go, and documenting good exposures with photographs and sketches. We will map not only the main geologic units, but also geomorphic features such as those indicated above. Arrowsmith's research group maintains a wide set of field tools including GPS, excavation tools, compasses, digital and analogue cameras, etc. so that the field mappers will be well equipped.

Prashad is highly skilled in Geographic Information Systems and she will compile all geologic and geomorphic mapping digitally and we will submit digital files as well as hardcopy printouts as we deliver the results of this mapping to the USGS and other interested colleagues. The computing facilities in Arrowsmith's research group are sufficient for this work.

Timetable and mentoring strategy

With USGS EDMAP support, we will enthusiastically dedicate ourselves to the mapping task. The table below outlines a timetable and major milestones and tasks to be accomplished, largely by Prashad. Arrowsmith has great interest in this project and will supervise progress closely, review mapping in the field and office (as well as contribute some), and help to develop the scientific interpretations leading from the work. Arrowsmith will spend at least two weeks directly supporting this mapping effort at Parkfield and another several weeks over the 12 months of the project in the tasks outlined above. Rymer's mapping and geophysical studies will continue at Parkfield. Given that he has already spent more than a week with Prashad in the field and in numerous conversations with Arrowsmith, we are confident that our collaboration will actually include time in the field together. Many other earth scientists will come through the area during the proposed mapping period for geophysical projects, field trips, and work at the drilling site and we will visit with them and offer field tours as well as seek input and review of our work.

Project timetable and milestones

Summer 2003	**First ½ Fall Semester 2003**	**Second ½ Fall Semester 2003**	**Spring 2004**
Fund project.	30 mapping days for Prashad with field assistant/Arrowsmith/Rymer at Parkfield	Submit interim geologic map ("field sheets")	Prepare and review final maps and report and submit.
Compilation and review of existing data		Compile new geologic mapping in GIS	Present research results to colleagues
Plan field campaign with Rymer and organize basemap data			M.S. thesis writing and possible manuscript preparation.

Deliverables

1:12,000 digital geologic map and database of the Parkfield area centered along the San Andreas Fault covering approximately 120 km^2.

1:12,000 digital geomorphic map and database of the Parkfield area centered along the San Andreas Fault covering approximately 120 km^2.

We will follow submission and format specifications as outlined in the USGS EDMAP program announcement when submitting these maps and their explanations.

Project personnel

Supervising professor: J Ramón Arrowsmith, Associate Professor of Geology at Arizona State University. Professor Arrowsmith has taught at ASU since 1995. His research emphasizes the interaction of tectonic and surface processes in the development of the landscape. He has a great interest in field geologic mapping and mapping methods.

Selected major mapping projects supervised and performed:

- 1:6,000 mapping along the SAF in the southern Carrizo Plain (Arrowsmith, 1995)
- Active fault trace mapping along the Altyn Tagh fault, Xinjiang China: 250 km-long digitally compiled map (Washburn, et al., 2001 and in review).
- Geological mapping of the piedmont of the White Tanks Mountains, Cave Creek area, and Union Hills with the aid of advance remote sensing methods (all prior USGS EDMAP projects for which we submitted our maps). Publications include Robinson and Arrowsmith 2002 and Holloway and Leighty 1998 (Arrowsmith was co-advisor of Holloway's M.S.).
- Geological mapping of the San Andreas Fault zone along the southern portion of the Cholame segment (Stone, 2000—Arrowsmith was M.S. advisor).
- Principal investigator on two major geoinformatics-related grants. We are emphasizing digital geologic maps and geologic mapping (http://www.geoinformaticsnetwork.org/swgeonet).

Geological mapping teaching experience:

- Courses taught with significant mapping components: GLG310 Structural Geology; GLG362/598 Geomorphology, GLG 510 Advanced Structural Geology.
- Field courses taught: GLG416 Field Geophysics, GLG455 Advanced Field Geology, 1st week and modules of GLG451/452 Field Geology I/II.

M.S. Student Lela Prashad

Lela Prashad is in her second semester at ASU in the research group of Arrowsmith. She came to us highly recommended and recruited with her B.S. degree in geosciences from Trinity University in San Antonio Texas. There she graduated with honors and was the recipient of the Edwin E. Eckert Scholarship in Geology for two years and the South Texas Geological Society Chairman's Award in 2000. She was involved in two Keck Consortium projects and her senior thesis was presented at the annual Keck Symposium in 2000.

Ms. Prashad graduated from Trinity in 2000 and worked for the USGS in Menlo Park for 18 months before coming to ASU. At the USGS, she gained much practical ability with digital earth science data, working first as an intern with the Coastal Marine group (where she built a major Arcview project on US Coastal Marine resources) and then moving to join the Earthquake Hazards group. With them and under the supervision of Dr. Carol Prentice, Lela worked to develop a detailed strip map of the SAF along the Peninsula section of the San Francisco Bay Area. This data system includes historic and contemporary ground and aerial photography as well as mapped active and inactive fault traces, urban development, and regulated ground rupture areas. While Lela has been at ASU, she has been employed by Arrowsmith and has largely built the regional earth science datasystem for the Colorado Plateau-Basin and Range-Transition zone (http://www.geoinformaticsnetwork.org/swgeonet).

Other support

We have no other support for this proposed mapping project.

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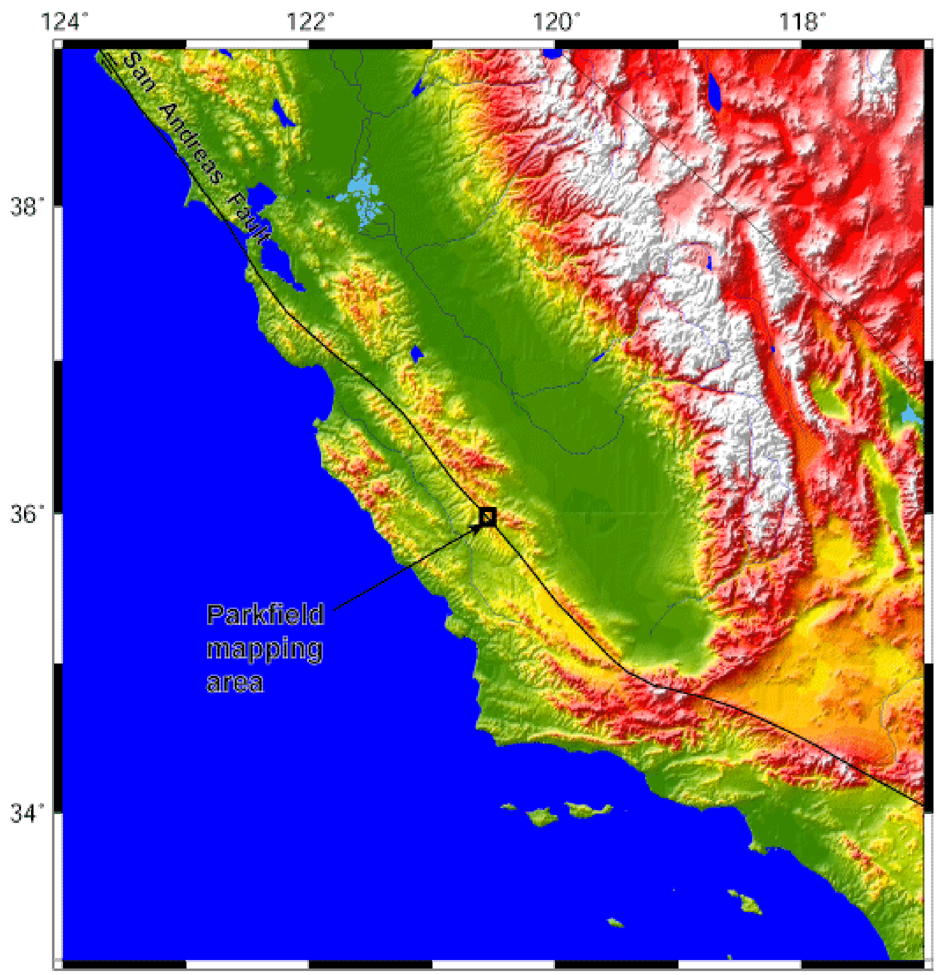

Figure 1. *Digital topography of central California and a portion of Nevada showing the situation of the San Andreas fault (SAF) in the California Coast Ranges and the location of our proposed mapping area at Parkfield.*

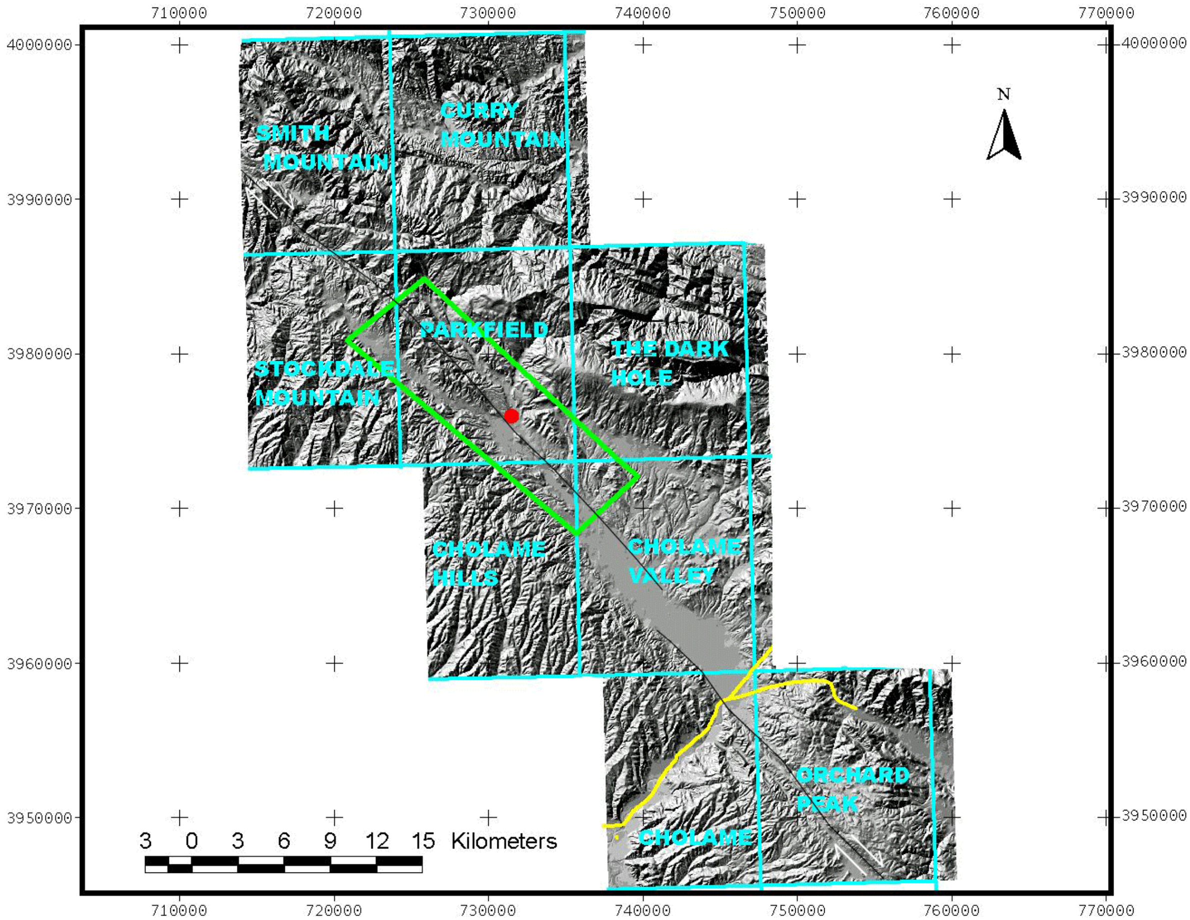

Figure 2. Index map of study area showing USGS quadrangles and UTM grid. Black line shows approximate surface trace of SAF. Note prominent right step in surface trace in the Cholame Valley. Green polygon shows our proposed mapping along the SAF. Red dot shows the location of the town of Parkfield and the yellow lines indicate State Highways 46 and 41. Map produced by Prashad.

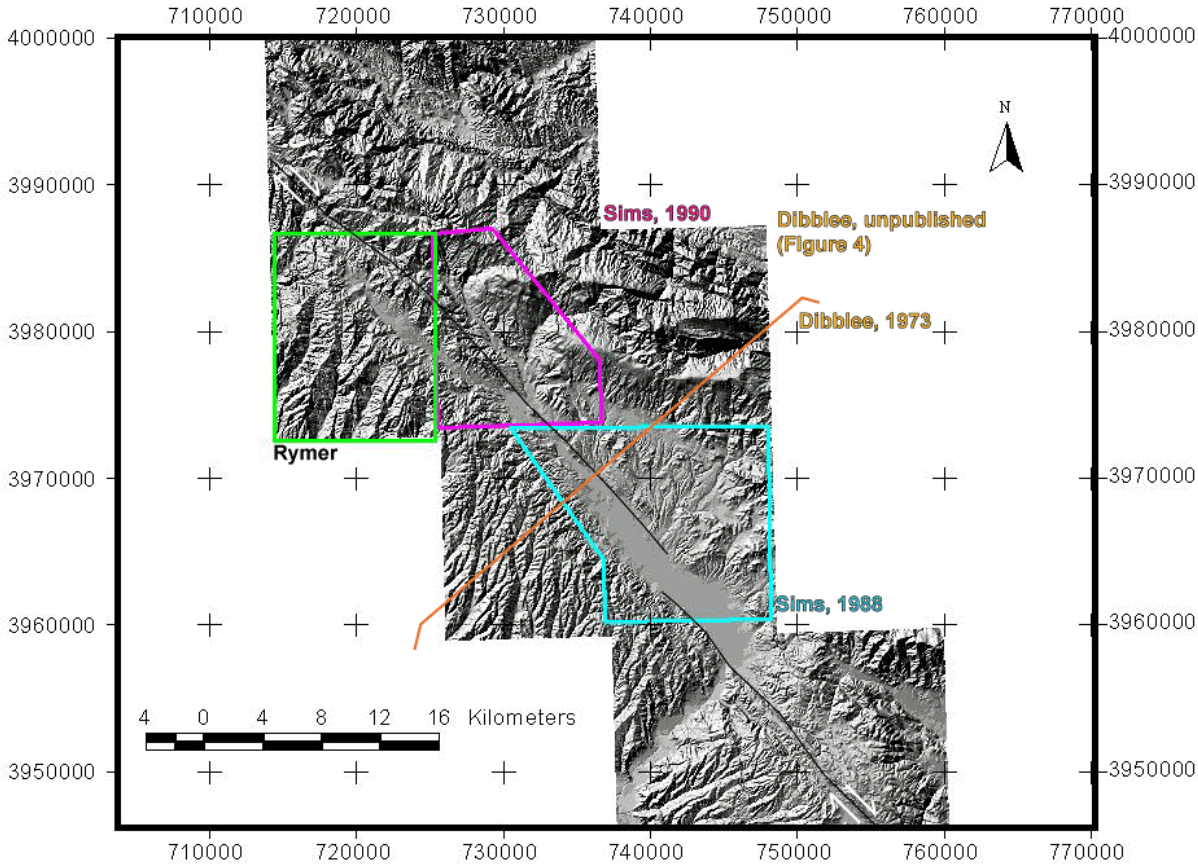

Figure 3. Index map of study area showing published geologic mapping for the area and UTM grid. Map of Dibblee, 1973 extends southeast of the orange line while the unpublished mapping shown in figure 4 extends northwest from there. Mapping of Sims, 1988, and 1990 is shown in the center of the area, while the unpublished mapping of M. J. Rymer emphasizes covers the Stockdale Mtn. Quadrangle. Black line shows approximate surface trace of SAF. Map produced by Prashad.

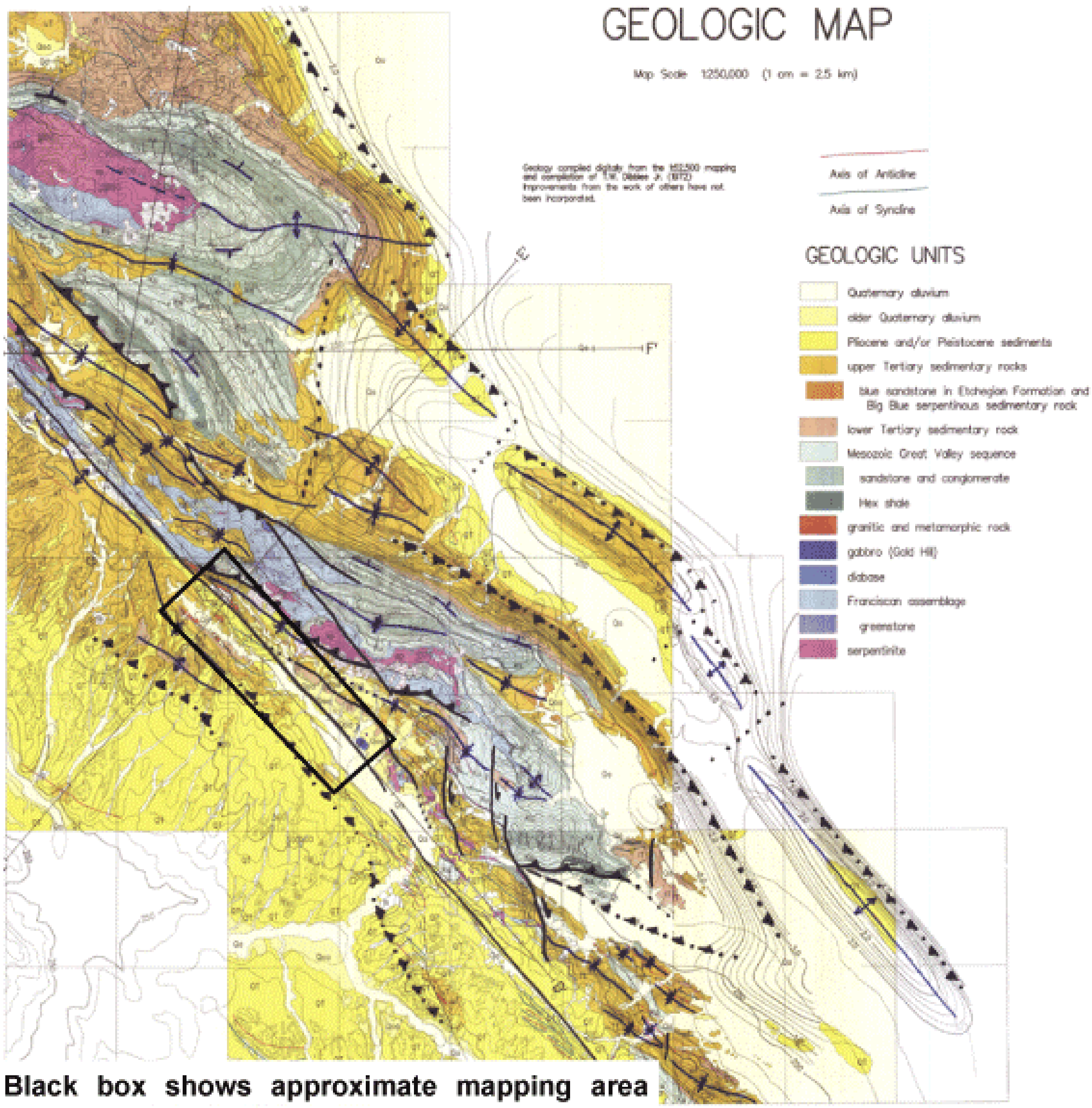

Figure 4. Unpublished digital rendition by C.M. Wentworth (USGS) of T.W. Dibblee's 1:62,500-scale geologic maps of the Parkfield region. Bold lines highlight the principal structures from interpretation of geologic, gravity, and magnetic data (Wentworth, et al., 1992). These data show the well developed geologic framework within which M. J. Rymer's mapping to date and our proposed mapping are situated (see Figures 2 and 3). This also shows the potential for collaboration with USGS colleagues and digital compilation of the wealth of earth science data available for Parkfield. Black polygon shows our proposed mapping area.

National Cooperative Geologic Mapping Program
Educational Geologic Mapping Program Element
Proposed Total Budget
Note: Must include totals of all requests for MS and PhD funded students from a University or College.

Budget Category	Amount Requested	Proposed University Amount
SALARIES:		
Student(s)	$6,981	$0
Faculty Supervisor	------------------------	$7,240
	$	$
	$	$
	$	$
Total Salaries:	$6,981	$7,240
FRINGE BENEFITS:		
Supported by negotiated rate agreement check one: (x) yes ( ) no	$698	$1,086
	$	$
	$	$
Total Fringes:	$698	$1,086
FIELD EXPENSES		
Per Diem	$1,575	$0
Vehicle cost	$0	$600
Mileage	$0	$0
	$	$
	$	$
Total Field Expenses	$1,575	$600
MISCELLANEOUS SUPPLIES		
Office and laboratory supplies (itemize)	$0	$300
Drilling	$0	$0
Map digitizing costs	$0	$0
Other	$0	$300
	$	$
	$	$
Total Miscellaneous Supplies	$0	$600
Total Direct Cost:	$9,254	$9,526
Indirect Cost (50%)	$4,627	$4,763
TOTALS	$13,881	$14,289

National Cooperative Geologic Mapping Program
Educational Geologic Mapping Program Element

Attachment E
University: Arizona State University
Proposal Short Title: Geologic Mapping at Parkfield, CA

Proposed Individual Project Budget

Note: Must include totals of all requests for MS and PhD funded students from a University or College.

Budget Category	Amount Requested	Proposed University Amount
SALARIES:		
Student(s)	$6,981	$0
Faculty Supervisor	------------------------	$7,240
	$	$
	$	$
	$	$
Total Salaries:	$6,981	$7,240
FRINGE BENEFITS:		
Supported by negotiated rate agreement check one: (x) yes ( ) no	$698	$1,086
	$	$
	$	$
Total Fringes:	$698	$1,086
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Vehicle cost	$0	$600
Mileage	$0	$0
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	$	$
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	$	$
	$	$
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