2012 SCEC Proposal

Title

Paleoseismic investigation along the inferred northernmost extent of the 1857 rupture: Do large southern San Andreas Fault ruptures extend into the creeping section?

Principal Investigators

Dr. Nathan A. Toké
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(I will mentor two UVU undergraduates as a part of this project)

Submitted collaboratively with

Dr. J Ramón Arrowsmith
and
J. Barrett Salisbury (Ph.D. Student)
School of Earth and Space Exploration
Arizona State University

Amount Requested

$25,192 (UVU) & $22,569 (ASU)
and
15 Radiocarbon Samples

Proposal Categories

Data Gathering and Products

Special Fault Study Area: Parkfield

Disciplinary Committee

Earthquake Geology

Interdisciplinary Focus Area

Southern San Andreas Fault Evaluation (SoSAFE)

SCEC 4 Science Objectives

2a (Data gathering: long term earthquake chronologies and slip per event investigation)
4c (Improved fault zone mapping using LiDAR)
4a (Providing new geologic data related to the Parkfield Special Fault Study Area)

Proposed Start Date: February 1, 2012

Technical Description

Introduction to the Problem: Does the creeping section rupture along with the southern San Andreas Fault?

Over the last ~150 years contrasting modes of slip have distinguished the locked southern San Andreas Fault (SAF) from the creeping central section (Figure 1; e.g., Toké and Arrowsmith, 2006). However, reports following the 1857 Fort Tejón Earthquake – the last great SAF earthquake to impact southern California – suggest that the 1857 rupture extended at least 80 km to the northwest of Cholame, CA, far into the creeping section (Sieh, 1978 from Wood, 1955, Johnson, 1905, and Barton, 1876). In Sieh's dissertation (1977), he references a figure drawn by Johnson (1905) which indicates the rupture displaced a corral by several meters 20 km northwest of Parkfield:

> *Johnson (1905, p. 76) remarks that "Mr. Tracey in '61 [1861] traced [the] crack into San Benito Cy. [County]", at least 80 km northwest along the fault from Cholame. In my judgement, the "crack" almost certainly refers to fresh fissuring and not to the general pre-existing rift topography. Thus the 1857 rupture extended into San Benito County. Johnson's crude sketch of a corral, here assumed to be somewhere near the head of Cholame Creek about 40km northwest of Cholame, suggests that he observed it to be offset about 10 to 30 feet (3 to 9 m) in 1905. This may indicate several meters of slip in 1857 at points well northwest of Cholame.*

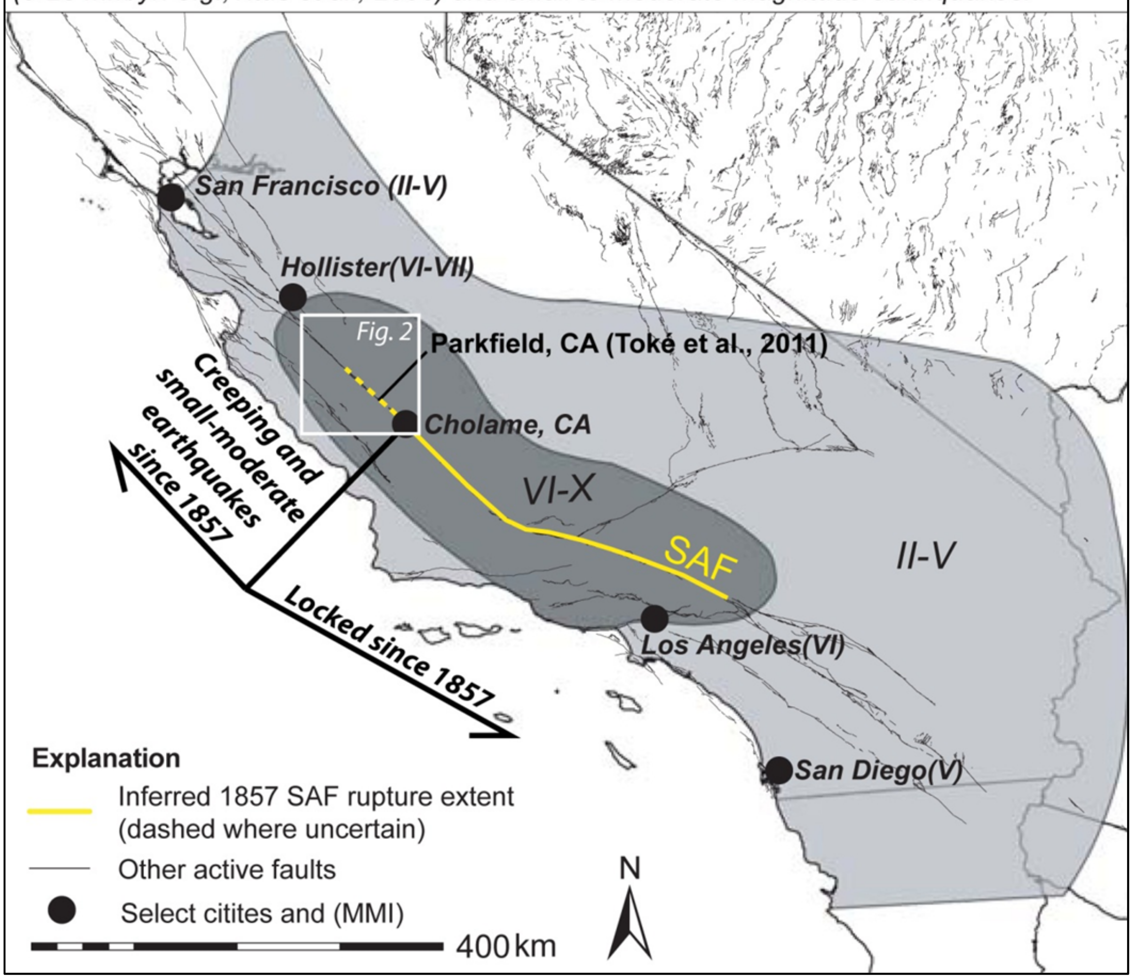
Despite this historical account of multi-meter ground rupture on the creeping section, little effort has been made to quantify the role of large earthquakes along this part of the SAF.

Research from the SAFOD fault zone drilling project (e.g., Zoback, 2010) has shown that fault zone material, including talc (Moore and Rymer, 2007) and clays (Schleicher, 2010), along this part of the SAF probably reduces the frictional strength of the fault zone and promotes fault creep. Additionally, the only paleoseismic site for more than 100 km northwest of Cholame, CA (the Millers Field site at Parkfield: Toké et al., 2011 and Toké et al., 2006) revealed a thousand year record of fault zone stratigraphy which displayed structures consistent with displacement from fault creep and the few centimeters of surface cracking associated with historic M6 Parkfield earthquakes. These results contrast the historical accounts of the 1857 rupture extending through Parkfield and to the northwest. However, strike-slip earthquakes do not necessarily leave behind strong evidence of their displacement across their entire rupture length (e.g., Ambraseys, 1969) and low friction material within a fault zone does not preclude the possibility of stress accumulation and the production of large earthquakes or their dynamic penetration into a velocity-strengthening creep dominated zone.

It is an attractive hypothesis to presume that recently-observed slip behavior is representative of long term SAF behavior in central California. However, this hypothesis has not been rigorously tested. Toké et al. (2011) made progress toward this goal by measuring a slip rate for the Parkfield section of the SAF. Their measurement, from an offset channel incised into a ~1000 year old fluvial terrace (and thus over a ~10 m fault normal aperture), indicates a late Holocene slip rate of 26.2 +6.4/-4.3 mm/yr, potentially several millimeters per year less than rates measured on the Carrizo section of the SAF (33.9 +/- 2.9 mm/yr; Sieh and Jahns, 1984) and geodetically-determined rates for the SAF in central California (~35 mm/yr e.g., Meade and Hager, 2005). Because Toké et al. did not observe good evidence of large surface ruptures at this site (neither filled fissures nor buried colluvial scarp deposits) they favored the hypothesis that a lower slip rate at Parkfield can be accounted for by distributed slip along sub-parallel structures. This explanation has been used to account for increases fault creep when rates are measured at wider fault-perpendicular distances across the creeping section (Titus et al., 2006, Arrowsmith, 2011).

Challenging the presumption of predominantly single modes of slip along individual San Andreas Fault segments is an important test for advancing earthquake science and assessing current earthquake hazards forecasts (e.g., Wills et al., 2008). An alternative model is that over periods longer than the past thousand years, large earthquakes have ruptured the central California creeping section. This bi-modal model of slip release may balance the slip rates estimated by Toké et al. (2011) and Titus et al., (2006) with those to the southeast by contributing slip not accounted for in existing historic or paleoseismic slip budgets that span only the past thousand years. In addition to historical accounts of multi-meter rupture of the creeping section in the 1857 earthquake, Ben Zion et al. (1999) proposed a model of self-driven mode switching along faults where over time, slip along the fault may alternate at irregular, but statistically governed, intervals between periods of clustered large earthquakes with high moment release and periods of moderate moment release due to creep and small earthquakes.

Figure 1. *The 1857 Fort Tejón Earthquake rupture may have extended 80 km northwest of Cholame, CA into the central California creeping section of the SAF (Sieh, 1977). This is 60 km northwest of Parkfield, CA. The extent of 1857 Modifed Mercalli Intensities (MMI) were drawn after Toké and Arrowsmith, 2006 and Sieh, 1978. The town of Cholame coincides spatially with a change in the mode of historical fault slip. Since 1857 the SAF has been locked to the southeast and to the northwest it has slipped due to creep (0-28 mm/yr: e.g.,Titus et al., 2006) and small to moderate magnitude earthquakes.*



An earthquake geology approach, preliminary work, and the role of climate in the production of characteristic channel offsets.

Earthquake geology offers at least two approaches to help test the contrasting models of uni and bimodal slip along the creeping section of the SAF. One method is to determine this section's slip rate from offset landforms that are more than several thousand years old. If the slip rate recorded by older landforms is the same as rates measured from younger offset landforms (~ 26 mm/yr: Toke et al., 2011) and historical slip from creep (~28 mm/yr: Titus, 2006) then slip in large earthquakes is not required to balance the long term slip budget. However, if the long term slip rate of this section of the fault is found to be similar to rates measured by far field GPS (~35 mm/yr) then either accelerated creep or large earthquakes are required to balance the slip budget over long time spans. A second approach, which would provide a more definitive answer about the role of large earthquakes, is through paleoseismic excavation. Paleoseismic records extending several thousands of years into the past may present evidence for large surface ruptures. If so, then the model of uni-modal slip release is rejected and we would need to re-characterize earthquake hazard for central California and reconsider the potential for extreme events that rupture both the central and southern SAF in a single earthquake. Such a result would call for an explanation of how stress is accumulated in the presence of low friction material within the fault zone, a question directly related to issues of fault complexity that is addressed by the Parkfield Special Fault Study Area proposal (Thurber, 2011).

We have conducted a preliminary assessment of the creeping section of the SAF (Parkfield to San Juan Bautista) using the B4 and Northern California EarthScope LiDAR Project data (processed at OpenTopography) in an effort to assess the style and magnitude of fault-offset geomorphic features and the potential for paleoseismic sites along the fault reach. Through remote mapping of the fault trace (following the approach of Zielke et al., 2010), we identified 41 small-scale (2-20 m) offset stream channels, many of which are in areas of low fault complexity where most of the fault slip should be concentrated within a narrow zone. These 41 measurements reveal that throughout most of the creeping section the minimum offset length is ~5 m, however several offsets of 2-3 m were observed. We have also identified seven clusters of potential paleoseismic sites (Figure 2a). These sites are located within areas of varying fault complexity. One of the most promising sites is a series of three sag ponds located ~25 km northwest of Parkfield, only 0.7 km from a high-quality, 9.7-11 m channel offset (Figure 2b). This is about half the distance Mr. Tracey traced the fault northwest of Cholame in 1861, meaning that the site may preserve evidence of large offset from the 1857 earthquake and potentially other similar ruptures.

Probing the apparent 5 m minimum-offset cluster throughout the southern creeping section addresses a second major science question, in addition to establishing a long paleoseismic record for the same extent of the fault. This will represent a step towards understanding the role of climate-driven channel incision events in earthquake slip-per event studies. In paleoseismic studies, it has commonly been assumed that stream channels form more frequently than the earthquakes that offset them, but recent work by Grant Ludwig et al. (2010) suggests that for the nearby Carrizo section of the SAF, this may not be the case. Instead, large-scale, climate driven incision events in southern California may occur at a similar frequency, or perhaps even less frequently than earthquake recurrence of approximately a century (e.g., Akciz, et al., 2010). Therefore climatic variations may set the magnitude of offset clusters along the fault with synchronous formation of offset features. If so, clusters of offset magnitudes once attributed to characteristic earthquake events may actually represent an overarching climate signal. The southern creeping section of the SAF is an excellent location to test this hypothesis which has broad reaching implications for the entire fault system and the field of earthquake geology. This second science question relates directly to the first question: If the fault has been creeping constantly for many thousands of years, without large earthquakes, then any distinct clusters in stream offset magnitudes must be due to periodic changes in climate which drive channel incision.

Proposed Research

This project has two research objectives. To test the existing models of uni-modal or bi-modal slip release behavior along the creeping section of the SAF and understand the broader implications for earthquake hazards related to extremely large events in Southern to Central California we propose to conduct paleoseismic investigations at one of the seven preliminary sites identified along the creeping section of the SAF to provide a long chronology of fault zone stratigraphy (and potentially earthquakes) for this section of the fault (Figure 2a). To examine the role of climate in the production of characteristic channel offsets we propose to continue documenting geomorphic offsets along this section of the fault and into the Parkfield section, following remote analyses with extensive field validation. This second part of the project is aimed at understanding the distribution of offset magnitudes and the climatic and tectonic drivers that govern their formation. Addressing these two science questions in parallel provides field work efficiency and has the potential to mutually enhance the respective interpretations. During our documentation of small channel offsets we will also document landforms with larger offsets for future targeted slip rate studies.

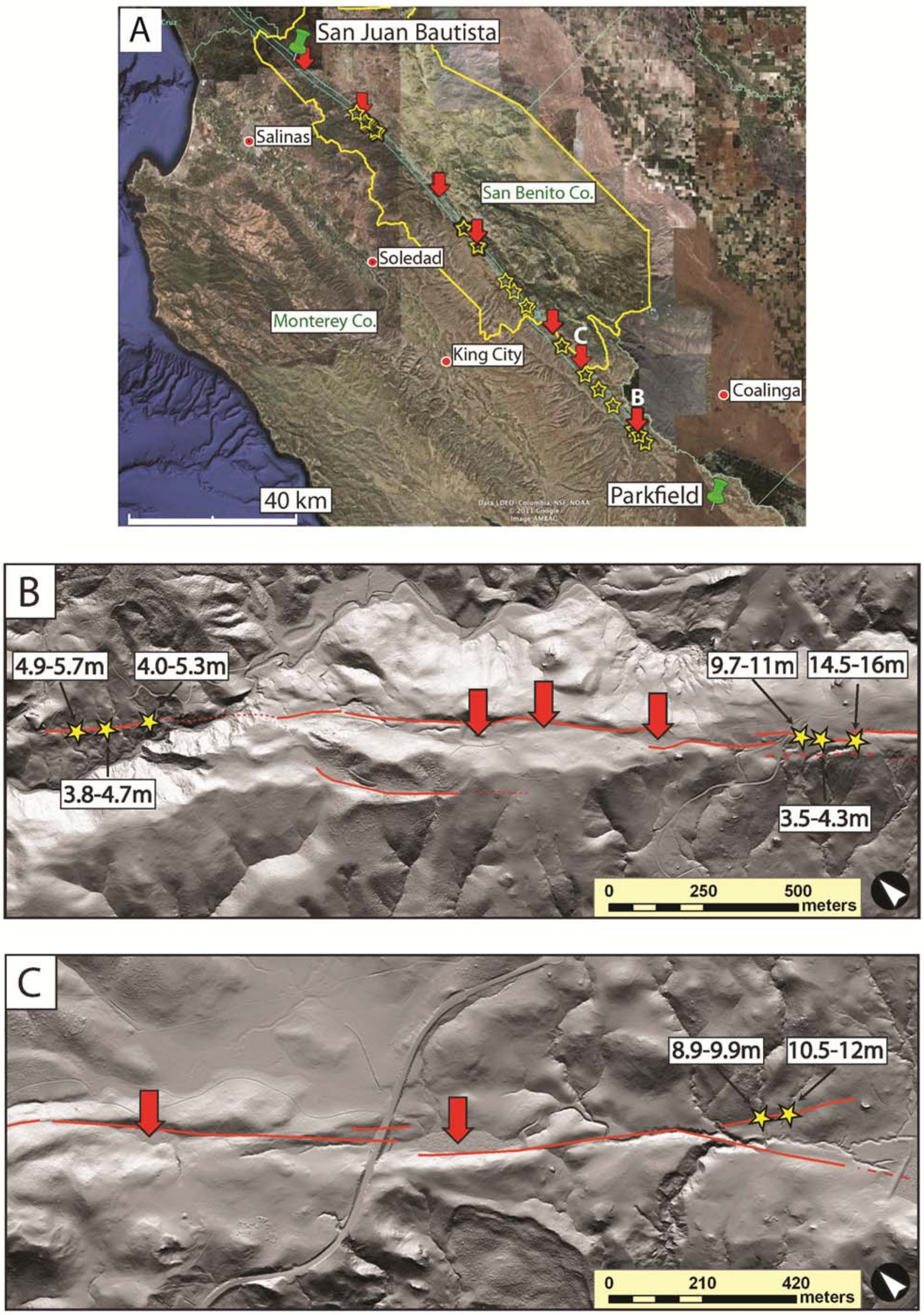
Project Management and methodology

This project is collaborative between UVU and ASU and has four components:

C1) Remote geomorphic and structural (fault trace) mapping using LiDAR and aerial photographs to identify and characterize sites for paleoseismic investigation and document the distribution of channel offsets along the southernmost creeping section of the SAF (e.g., Zielke et al., 2010; Arrowsmith and Zielke, 2009, and building on preliminary results from Toké, 2011).
C2) Field reconnaissance mapping of potential paleoseismic sites and field documentation of geomorphic offsets that were identified via remote methods.
C3) Paleoseismic field work (excavation and documentation of structural relationships).
C4) Data analysis and report production.

A majority of this research will be carried out by J. Barrett Salisbury as a part of his Ph.D. dissertation research with J R. Arrowsmith at Arizona State University. Salisbury will take the lead role on publication of our results (**C4**). N. Toké (as a new assistant professor at Utah Valley University) will mentor two UVU undergraduate geology majors from his Earthquake and Landslides course as they develop small research components related to the overarching goals of this project. These students will present their projects at the annual SCEC meeting. **C1** will be led by Salisbury who has developed expertise in LiDAR mapping applications during his M.S. at SDSU and Toké will supervise additional remote mapping support by the undergraduates from UVU. **C2)** During the spring of 2012, Salisbury and Toké will make an initial field visit to assess potential sites and meet with land owners to arrange field permissions. **C3)** ASU (Arrowsmith, Salisbury, and another student) and UVU (Toké and two undergraduate geology majors) will conduct collaborative paleoseismic trenching over approximately one month during the summer of 2012. Additional time will be spent by Salisbury et al. assessing geomorphic stream offsets along the creeping section of the fault during the summer months. As is customary we will host a ‘trench party’ field review open to the SCEC community about three quarters of the way through the paleoseismic field work. Arrowsmith and Toké will jointly manage the project overall.

Figure 2. *A) Locations of LiDAR-mapped channel offsets (yellow stars) and candidate paleoseismic sites (red arrows) along the creeping section of the SAF from Parkfield to San Juan Bautista (green pushpins) with San Benito County outlined in yellow. Both candidate sag pond paleoseismic sites and offset channels are clustered along this section of the SAF. The two southernmost clusters of paleoseismic sites and nearby offset channels (with their estimated displacement magnitudes) are shown in panels B and C.*



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Utah Valley University
Budget Explanation

February 1st, 2012 through January, 2013

Direct Costs

A.	**Salaries and Wages**		
		Nathan A. Toké (PI), 0.75 months summer salary	$4,583
		2 UVU undergraduates, 5 weeks (9$/hour)	$3,600
		Total salaries and wages	**$8,183**
B.	**Benefits**		
		Fringe (PI) 22.6%	$1,036
		Fringe (Undergraduate Researchers) 10.6%	$ 382
		Total Fringe Benefits	**$1,417**
E.	**Travel**		
		Rental vehicle and gas for one month	$1,500
		Lodging for one month (3 people)	$2,000
		Food for one month (20$/day x 3 people)	$1,800
		Travel to SCEC meeting PI and two students	$1,200
		Total Travel	**$6,500**
G.	**Other Direct Costs**		
		Mapping and logging related field supplies	$1,000
		Publication Expenses (printing, page charges)	$1,500
		Excavation expenses (back hoe, pumping, shoring)	$3,000
		Total Other Direct Costs	**$5,500**
		TOTAL DIRECT COST:	$21,601
		INDIRECT (37.4% - Only charged for A and B)	$3,591
		TOTAL PROPOSED COST:	**$25,192**

(To save cost we have included most of the 'other direct costs' within the UVU budget because UVU does not charge an indirect cost on this category while ASU does)

GEOCHRONOLOGY REQUEST

Radiocarbon: 15 samples: Because we are proposing paleoseismology and will potentially need to date multiple event horizons, we request 15 radiocarbon samples through the SCEC geochronology fund. We have successfully used this in the past for our Parkfield research (Toké, et al., 2011). Radiocarbon is a good choice for dating material considering the California Coast Range's climate and topography.

Arizona State University
Budget Explanation

February 1st, 2012 through January, 2013

Direct Costs

A.	**Salaries and Wages**	
	Arrowsmith (co-I)	$1389
	Graduate Student summer salary	$5949
	Total salaries and wages	**$7338**
B.	**Benefits**	
	Fringe (co-I)	$462
	Fringe (Graduate student)	$630
	Total Fringe Benefits	**$1092**
E.	**Travel**	
	Rental vehicle and gas for one month	$1500
	Lodging for one month (shared; 3 people)	$2000
	Food for one month (20$/day x 3 people)	$1800
	Travel to SCEC meeting one graduate student	$ 300
	Total Travel	**$5600**
G.	**Other Direct Costs**	
	Consumed field survey materials	$200
	Summer tuition	$914
	Total Other Direct Costs	**$1114**
	TOTAL DIRECT COST:	$15114
	INDIRECT (@52.5%--minus tuition)	$7445
	TOTAL PROPOSED COST:	**$22,569**

Facilities Equipment and Other Resources

Utah Valley University

The Department of Earth Science at UVU shares equipment among faculty. As a department we have most of the basic field equipment necessary to conduct earthquake geology investigations (field survey equipment and excavation tools). Combined with ASU's resources, see below, the project will be well supported. Additionally, Toké has a pending request for startup equipment funds in the amount of $18,600. These funds may support the purchase of additional paleoseismic field equipment, a trench photography set up (another is owned by ASU), updates to UVU's RTK GPS Survey equipment, a field laptop and printer, and additional small purchases.

Facilities Equipment and Other Resources (continued).

Arizona State University

Resources for this work at ASU include instrumentation for the collection of data in the field and for the analysis of those data in the laboratory. Two Leica-Wild TCM 1100 total stations (consisting of an electronic theodolite and electronic distance meter (EDM)) permit the digital recording of high precision, 3-D determinations of the locations of sighted targets with a linear accuracy of 3 mm and a precision of ± 2 ppm. Other instruments include a portable differential GPS surveyor (with sub-mm accuracy), other standard survey equipment, and a laser rangefinder equipped with digital compass and inclinometer. Field data storage and reduction are enabled by field laptops and PDAs that are charged, when necessary, using portable, flexible solar arrays. Helium balloon and kite-based aerial photography systems are available for detailed documentation of important landforms and field sites (http://activetectonics.la.asu.edu/kites/index.html). We have camping and field equipment to support earthquake geology investigations in remote settings.

The School of Earth and Space Exploration houses a well-equipped computational infrastructure for quantitative geomorphology and active tectonics research. A full suite of GIS and image processing software is available (e.g., ArcGIS, Envi, ERDAS Imagine), and a variety of macros to carry out the requisite analyses have already been written and tested. In addition, we now have a well-developed set of software and methodologies for digitizing field geologic maps and integrating these with DEM data, orthorectified satellite images, GPS sample localities, digital field photographs, etc. For finite element and boundary element modeling, we use FIMOZ, POLY3D, and DIS3D.

The Geomorphology groups at Arizona State University are housed in substantial laboratory space with student offices. In these laboratories and related facilities, available computer hardware tools include ~20 desktop computers, numerous laptop computers, a FreeBSD data server, 5 linux-based server class machines, ~10 Tb online file storage, CD/DVD writers, flatbed scanner and black and white/color printers. We maintain active web sites where research results and data are presented and frequently updated: http://geomorphology.sese.asu.edu/ & http://activetectonics.la.asu.edu. We also employ a systems administrator/programmer for technical assistance, computer systems support and programming assistance a full time GIS analyst for support of quantitative geomorphology and active tectonics research.

Current and Pending Support

Nathan A. Toké - Utah Valley University

Nathan Toké is a new tenure-tracked assistant professor in the Department of Earth Science at Utah Valley University (UVU) as of fall 2011. His appointment is a 9 month academic appointment. This is his first external grant application at UVU. He has one pending internal grant, which is directly related to the goals of this project:

- Scholarly Activities Grant (SAC) grant for $3,120 plus 3 hours of teaching release time. The money requested will be used to fund student time to develop earthquake geology research projects along the San Andreas and Wasatch Faults and prepare for field investigations. This project is directly related to the proposed research herein and will not consume additional PI time.

Current and Pending Support (continued)

J Ramon Arrowsmith – Arizona State University

Current

1) Arizona State University 9-month academic appointment
2) Coll.Res: Is the Holocene Slip Rate Along the Altyn Tagh Fault 10 mm/y, 30 mm/y, or both? Infilling a 2-6 ka Data Gap Using 14C, OSL, and Stream Recon; NSF; $195,494; 6/15/2006-7/31/2012; 0.25 mo. summer.
3) Collaborative Research: Facility Support: Building the INTERFACE Facility for Em-Scale, 3D Digital Field Geology (includes supplement); NSF-Division of Earth Sciences; $186,840; 9/15/2007-2/28/2012; 0.25 mo. summer.
4) Facility Support: Open Topography - A National Hub for High Resolution Topographic Data, Tools, and Knowledge; NSF-Division of Earth Sciences; $307,462; 9/15/2009-8/31/2012; 0.5 mo. summer.
5) RAPID: Airborne Lidar Scan of the 4 April 2010 Sierra El Mayor, Baja California Earthquake Rupture; NSF-National Science Foundation; EarthScope; $112,381; 4/16/2010-4/30/2012) 0 mo. summer.
6) Collaborative Research with Arizona State University and San Diego State University - Repeatability, accuracy, and precision of surface slip measurements from high-resolution topographic data; USGS NEHRP; $40,015; 1/1/2011-12/31/2011; 0.5 mo. summer.
7) Bridging Data, New Technologies, and Communities to Enable and Communicate EarthScope Exploration and Discovery; NSF-EarthScope; $2,450,744; 5/1/2011-4/30/2015; 1 mo. summer.
8) New slip rate estimates from Wallace Creek and Phelan Creek paleoseismic sties: Re-sampling, Re-dating and Re-synthesizing, 2/01/2011-1/31/2012, $19,844, Southern California Earthquake Center, 0.25 mo sum.
9) Preliminary Analysis of the El Mayor-Cucapah Earthquake Surface Rupture with Pre- and Post-Event Airborne Lidar Data; 2/01/2011-1/31/2012, $21,000, Southern California Earthquake Center, 0.25 mo sum.

Pending

1) Collaborative Research: 3-D near-field coseismic deformation from differential LiDAR with application to the El Mayor-Cucapah earthquake; NSF-EarthScope; $99,258; 1/1/2012-12/31/2013; 0.25 mo. summer.
2) Structural characterization of fault zones using high-resolution digital topography, multispectral remote sensing, and geomechanical modeling; $23,824; 2/01/2012-1/31/2013, Southern California Earthquake Center, 0 mo sum.
3) *Paleoseismic investigation along the inferred northernmost extent of the 1857 rupture: Do large southern San Andreas Fault ruptures extend into the Creeping section? (Lead PI: Nathan Toke); $22,569 2/01/2012-1/31/2013, Southern California Earthquake Center, 0.125 mo sum.*
4) Centimeter-resolution fault topography and earthquake displacements from UAV photogrammetry (Lead PI: Edwin Nissen); $24,520; 2/01/2012-1/31/2013, Southern California Earthquake Center, 0 mo sum.
5) New slip rate estimates from Wallace Creek and Phelan Creek paleoseismic sties: Re-sampling, Re-dating and Re-synthesizing, 2/01/2011-1/31/2012, Southern California Earthquake Center, 0.25 mo sum