2014 SCEC Proposal

QUATERNARY FAULT SLIP BEHAVIOR OF THE MISSION CREEK FAULT OF THE SOUTHERN SAN ANDREAS FAULT ZONE IN THE SAN GORGONIO PASS, CA

Part I - New Insights from Neotectonics and $^{36}Cl/^{10}Be$ burial dating*

*Note: The research proposed here is part of a collaborative effort, and as such complemented by research proposed in the proposal *Part II – Constraining Sedimentary Provenance and Displacements of Pleistocene Alluvial Fans Systems,* by Drs. Julie Fosdick and Kimberly Blisniuk

Principal Investigator: Dr. Greg Balco, Berkeley Geochronology Center
Co-Principal Investigator: Dr. Kimberly Blisniuk, Berkeley Geochronology Center
Co-Principal Investigator: Dr. Kate Scharer, USGS

Science Objectives Addressed: 1a, 4a, 4b, & 4c

Total Funding Request: $55,233
Proposal Category: San Gorgonio Pass Special Fault Study Area

I. Summary of Proposed Research:

In this proposal we request funding to

(1) *re-evaulate the slip rate history of the Mission Creek fault strand of the San Andreas fault zone (SAFZ) by determining its long-term and short-term slip rate through detailed field mapping and dating of landforms and deposits offset along the fault strand (Fig. 1);* and

(2) *develop, validate, and apply the novel technique of $^{36}Cl/^{10}Be$ burial dating to determine the age of offset alluvial deposits in the 200 ka – 1 Ma age range.*

The Mission Creek fault strand west of Highway 62, located within the San Gorgonio Pass Special Fault Study Area, is currently mapped as an inactive fault by the Earthquake Hazards Program at the USGS and UCERF3 (http://pubs.usgs.gov/of/2013/1165/), the two main sources of seismic hazard assessment in the United States. However, the results of recent work on the Mission Creek fault strand ~30 km to the southeast (Blisniuk et al., 2012) indicate a surprisingly high geologic slip rate of *19-24* mm/yr, approximately half of the ~35-45 mm/yr plate boundary rate between Pacific-North America (PA-NA)(e.g., Demets and Dixon, 1999) . Here we seek to collect data that will differentiate between two kinematic models for the Mission Creek fault strand at this latitude: (1) the fault strand is important and perhaps even dominant in accommodating lateral slip between the PA-NA plates (Fig. 1), or (2) slip on the fault strand decreases drastically towards San Gorgonio Pass area.

The slip rates we propose to determine will provide a crucial test for these contrasting kinematic models. This is a collaborative effort with the proposal titled *'Part II – Constraining Sedimentary Provenance and Displacements of Pleistocene Alluvial Fans Systems,'* by Drs. Julie Fosdick (IU) and Kimberly Blisniuk (BGC). Their proposal will evaluate the sedimentary provenance of displaced and buried alluvial fan deposits that we aim to date in the present proposal. Together, these proposals will directly address two long-term science priorities for SCEC4; namely, *improving our understanding of (1) stress transfer from plate motion to crustal faults and (2) the structural evolution of fault zones and fault systems*. Additional information on slip rates will, in addition, help test and refine kinematic and mechanical models of fault slip in California, therefore complementing other projects by Hermance & Yule (CSUN) and Oskin (UCD) & Chester (T A&M) that aim to investigate veritical uplift rates in the San Gorgonio Pass resgion.

II. Statement of Problem:

The potential for a large magnitude earthquake in the San Gorgonio Pass and Coachella Valley region of the southern SAFZ in California (Fig. 1) is generally considered high. Of particular importance is whether a throughgoing rupture on the SAFZ permissible through the San Gorgonio Pass. It has been hypothesized that earthquake ruptures within the San Gorgonio Pass, located along the restraining bend of the SAFZ, are the result of deformation accommodating both strike-slip motion of PA-NA and uplift due to compression along the restraining bend by either (1) a simple through-going near vertical fault at depth (i.e. Rasmussen and Reeder, 1986; Seeber and Armbuster, 1995, Catchings et al., 2010) or (2) a more complex system of thrust and strike-slip faults that transfer oblique slip (i.e. Morton and Matti, 1993, Matti et al., 1993, Yule and Sieh, 2003). The San Gorgonio Pass region of the SAFZ located between Whitewater Canyon and the northern

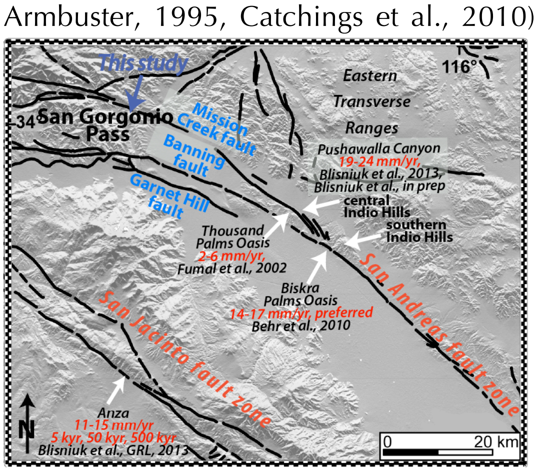


Fig. 1. Location of the study area, the southern San Andreas fault zone in the San Gorgonio Pass and northern Coachella Valley, showing the location of the Mission Creek, Banning and Garnet Hill fault strands. Note published slip rates, prior to those of Blisniuk et al. (2012), on the Mission Creek fault strand suggest a decrease in the slip rate to the northwest. Our study area is located just west of Mission Creek and Highway 62. See Fig. 2 for details.

Coachella Valley is characterized by the Mission Creek, Banning, and Garnet Hill fault strands (Fig. 1). Previous geologic and geomorphic studies from the Coachella Valley (e.g., Keller et al., 1986; Fumal et al., 2002; van der Woerd et al., 1006; Behr et al., 2010) and the San Gorgonio Pass (e.g., Matti et al., 1995; Yule and Sieh, 2003, Yule, 2009) indicate that as the Mission Creek and Banning fault strands diverge from one another in the southern Indio Hills, the majority of slip across the SAFZ is accommodated by the Banning fault strand. In this favored kinematic model of the southern SAFZ, slip along the Mission Creek fault strand decreases northwestward from the Indio Hills and ceases just south of Highway 62, with deformation being progressively transferred to the Banning fault strand (Fig. 1) (e.g., Matti et al., 1993; Yule and Sieh, 2003). The Mission Creek fault strand west of Highway 62 is generally considered inactive because Mission Creek, a large drainage of the San Bernardino Mtns, does not appear to be offset by the fault at this location (Fig. 2) (Matti and Morton, 1993), and this interpretation is reflected by all current seismic hazard maps, such as UCERF3. In this favored model, *a SAFZ earthquake will rupture on the Banning fault strand through a broadly distributed zone of right-lateral, thrust and oblique faults*.

Previous Reseach Results on the Mission Creek fault strand: Contrary to the favored kinematic model for the southern SAFZ, the results from Uranium series dating of pedogenic carbonate and/or ^{10}Be cosmogenic exposure dating of surface clasts from deposits offset in the central Indio Hills imply (1) an unexpectedly fast slip rate of 19-24 mm/yr for the Mission Creek fault strand (1.3-1.6 km since ~70 ka and 44-50 m since ~2.5 ka), and (2) an unexpectedly slow slip rate of 0.4-0.6 mm/yr for the Banning fault strand (<30 m since ~60 ka) (Fig. 2) (Blisniuk et al., 2012). Additional reconstructions on the Mission Creek fault strand in the central Indio Hills also show dextral offsets of ~2.4 to 2.1 km and ~0.8 to 0.6 km, respectively (Fig. 2). 40 ^{10}Be exposure age samples have been analyzed at Lawrence Livermore National Laboratory and we are waiting for corrected Be ratios to calculate ages and slip rates for these offset landforms. In summary, funding from SCEC in 2013 supported fault slip rates over 5 different time intervals (since ~2.5 ka, ~20-40 ka, ~60 ka, ~70 ka and ~100 ka) and at multiple locations on the Mission Creek and Banning fault strands (Fig. 2). Our new results summarized above suggest an alternative kinematic model for the southern SAFZ: a fast slip rate on the Mission Creek fault strand and a slow slip rate on the Banning fault strand, as the two strands diverge from each other in the southern Indio Hills (Figs. 1 & 2). In this alternative model, *a SAFZ earthquake will rupture on the Mission Creek fault strand through relatively narrow dominantly strike-slip fault structure*. Therefore, additional work is needed to better understand how slip along the SAFZ is partitioned in the northwestern Indio Hills. As these new data underscore the seismic hazard posed by the Mission Creek fault strand in this region. For instance, combining these data with published paleoseismic studies for the Mission Creek fault strand at Thousand Palms, which show an average earthquake recurrence interval of

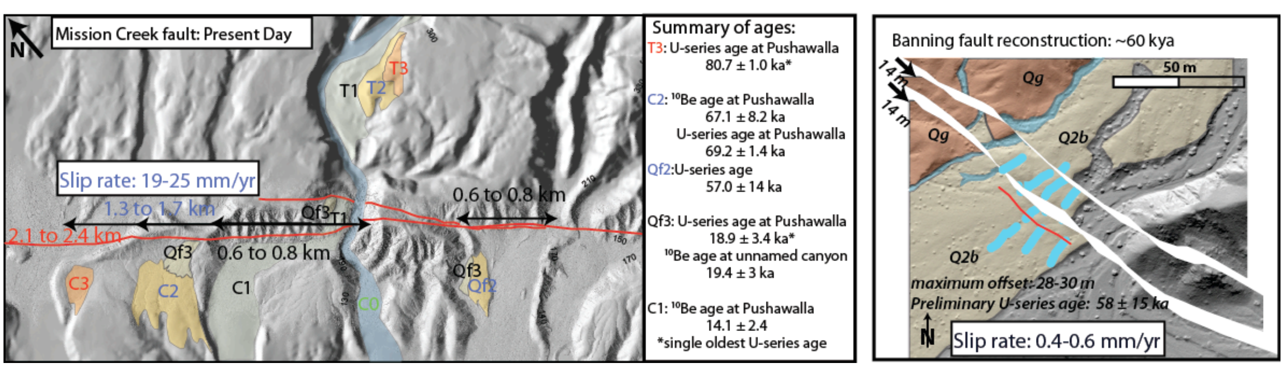


Fig. 2. Left panel, present-day image of beheaded channels (C1, C2, C3) with their corresponding terrace (T3, T2, and T1) offset along the Mission Creek fault strand (red line) in the central Indio Hills, see Fig. 1 for location. Results from C2 indicate a fast slip rate of 19-24 mm/yr. Right panel, maximum reconstruction of the Banning fault strand since ~60 ka in the Central Indio Hills, location is just southwest of C1 in left panel, see Fig. 1 for location.

225 years for the past 5 events since 900 AD (Fumal et al., 2002) implies an average slip per event of ~4.5 m. As the last earthquake to rupture this section of the Mission Creek fault occurred over 300 years ago (ca. 1690), the results of our work indicate that ca. 5.0 to 7.5 m of strain has accumulated since that event.

III Proposed work:

To better assess the deformation accommodated by the Mission Creek fault strand and the hazard potential posed by it, additional work is needed to document the temporal and spatial partitioning of slip along this structure over multiple time-intervals as it enters the in the San Gorgonio Pass region. In reference to the San Gorgonio Pass Science Plan specifically, we anticpate that data from this study will make important contributions to the following tasks and goals: (1) Fill slip-rate data gap, (2) Provide validation for results of mechanical models that evaluate long term horizontal slip rates, (3) Provide inputs for fault geometries used in dynamic rupture models, (4) Provide slip rate data for rupture model refinement.

Slip Rate Sites: In the following paragraphs we briefly describe 3 sites on the Mission Creek fault strand located west of Highway 62, where image interpretation of high-resolution digital topography data (LiDAR) and field inspection of sedimentary deposits and geomorphic landforms indicate promising conditions for determining slip rates over multiple time intervals. All sites are located in the San Bernardino Mtns, just west of the Little San Bernardino Mtns (Fig. 2). As noted above, previous studies suggest the Mission Creek fault strand is inactive here due to the apparent absence of horizontal displacement of Mission Creek and alluvium across the fault strand (e.g., Matti et a., 1993). Here, we present an alternative interpretation of offset landforms and deposits that suggest the Mission Creek fault strand may be active as it enters the San Gorgonio Pass.

Site 1 Displaced Late Quaternary terrace deposits: Site 1 is located west of Mission Creek in an abandoned channel (Fig. 2A). Initial field reconaissance indicates the abandoned channel was previously incised by Mission Creek because a river terrace has been identified within its channel walls (Fig. 2B and 2C). At present the terrace does not have a potential source. However, accounting for fault displacement, Mission Creek, located ~2.4 km east across the fault, is a highly plausible source (see Fosdick and Blisniuk SCEC 2014 proposal). To confidently determine the

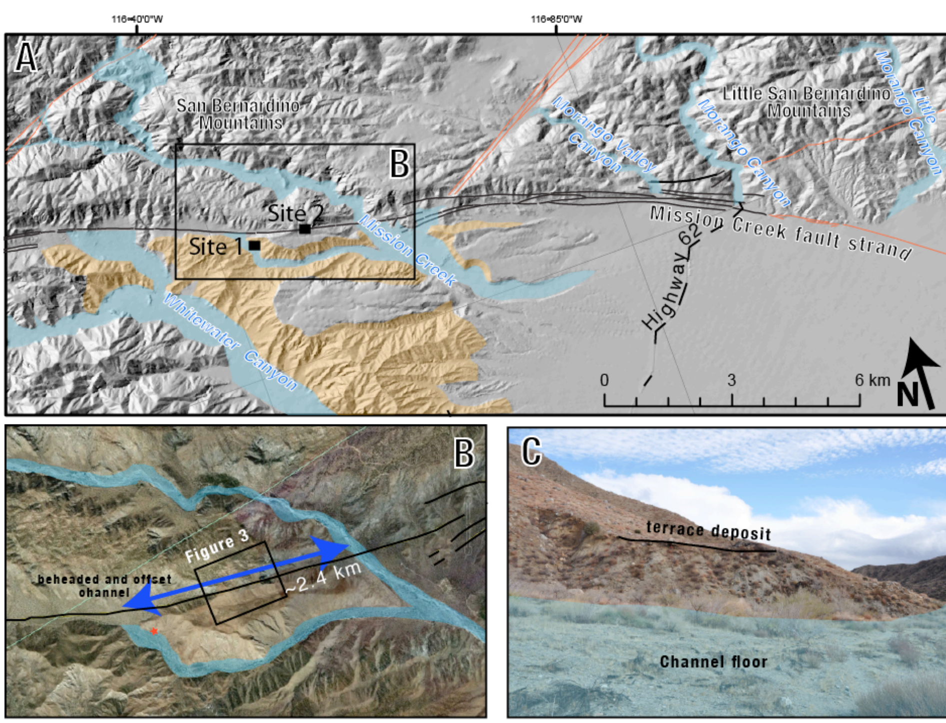


Fig. 2. A. Map of the proposed study area showing the location of buried alluvial fans and an offset terrace west of Highway 62. *Note* the black lines highlighting the mapped inactive section of the Mission Creek fault strand. B. GoogleEarth image showing the location of a deeply incised and beheaded channel along the fault. C. Photo of a terrace deposit located within the beheaded channel. A plausible source for the terrace deposit is Mission Creek located ~2.4 km to the east across the fault.

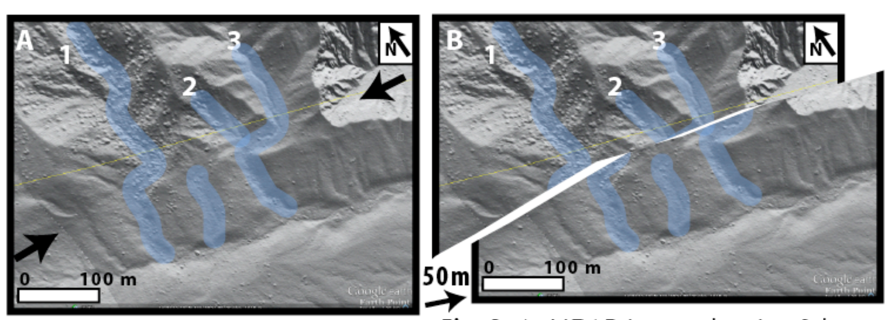
source of the terrace deposit and determine a Late Quaternary slip rate estimate for the Mission Creek fault strand at this location we request funding to complete additional fieldwork to map and date terraces within present-day Mission Creek and the abandoned channel. We request funding for ^{10}Be exposure to date 2 different deposits across the fault, for a total of 12 samples (6 samples for each deposit).

Site 2 Offset active channels: Site 2 is located ~1.5 km to the east of the abandoned channel of Site 1 (Fig. 2B). Here, LiDAR imagery and field observations show 3 Holocene channels deeply incised into older alluvium. These deflected and beheaded channels are offset by ~50 m. In addition, shutter ridges currently block and deflect channel flow from upstream of channel 1 and channel 3 (Fig. 3A). Deposited within the upstream portion of channel 3 is a terrace deposit that appears to record the onset of the shutter ridge damming the mouth of channel 3. To assess the Holocene slip rate at this site, we request funding for 5 radiocarbon ages to date the terrace deposit in channel 3, where field reconaissance indicate a high potential for the presence of sufficient amounts of charcoal suitible for dating.

Site 3 Mid-Quaternary slip rate site: Site 3 is located within Whitewater Canyon and Mission Creek (Fig. 2A). Exposed within the channel walls of Whitewater Canyon and Mission Creek are buried alluvial fans that likely originated from the San Bernardino Mtns and Little San Bernardino Mtns; likely potential sources are Mission Creek, Morongo Valley Creek, Morongo Creek, and Little Morongo Creek. The buried fans exposed within Mission Creek have been mapped as Plio-Pleistocene sediments (e.g., Matti et al., 1993; Yule and Sieh, 2003) and are correlative to buried fan units mapped as Ocotillo Formation (Keller et al., 1982) located ~30 km to the south in the Indio Hills, which are dated to ~1.1 Ma to 0.5 Ma (Kirby et al., 2006). These ages combined with the potenitally fast slip rate for the Mission Creek fault strand and the potential source regions of the fans would suggest the buried fans exposed in Mission Creek and Whitewater Canyon were most likely emplaced between 200 ka – 1 Ma (see Fosdick and Blisniuk SCEC 2014 proposal). To gain information about the long-term slip rate at these sites, we request funding to apply the novel approach of ^{36}Cl/^{10}Be burial dating to the buried fans. This work is proposed in collaboration with Drs. Julie Fosdick and Kimberly Blisniuk, who will carry out a provenance study of the alluvial fans that will distinguish among the potential source drainages; see Fosdick and Blisniuk SCEC 2014 proposal. Thus, piercing lines from their study combined with burial ages from our work will provide information on slip rates between the middle Pleistocene and present, allowing us to collect data on when and if the Mission Creek fault may have slowed in the past. Alternatively, these new data may show the Mission Creek fault did not become inactive.

IV. Burial Dating:

The overall concept of burial dating employs pairs of cosmic-ray-produced nuclides that are produced in a fixed ratio during exposure to the cosmic-ray flux at the Earth's surface, but have different decay constants. If a



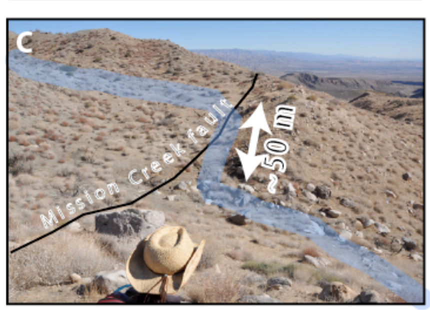
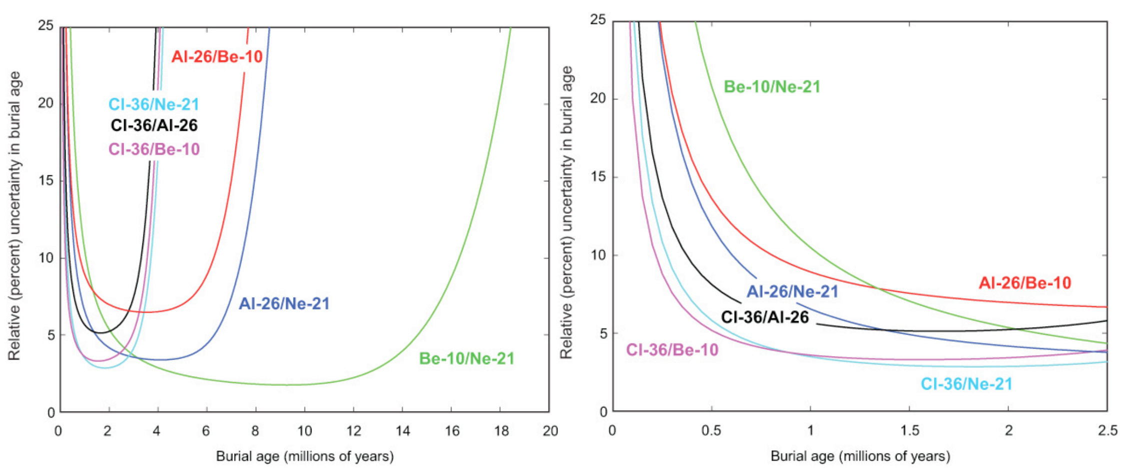


Fig. 3. A. LiDAR image showing 3 late Holocene channels offset along the Mission Creek fault strand. Black arrows show the location of the fault strand. Yellow line is the trace of the Mission Creek fault strand downloaded from the Earthquake Hazards Program at the USGS. B. Realignment of channels 1,2, and 3 by ~50 m. C. Field photo showing the deflection of channel 3 along the fault and the shutter ridge that formed due to movement along the fault.

sample that has been exposed at the surface for a time is buried deeply enough to halt nuclide production, different nuclides decay at different rates, and their ratio diverges from the production ratio (see Granger et al., 2006 for a review of the method). Thus, the ratio of two such nuclides is related to the duration of sediment burial. Because sediment commonly experiences a history of exposure (as sediment grains are detached from parent rock by surface erosion) and burial (as they come to rest in a depositional basin), this method is useful for dating sedimentary sequences.

The precision of burial ages is related to the burial duration and the half-lives of the nuclides in question (Fig. 4). Although the most commonly used pair for burial dating is the ^{26}Al/^{10}Be pair in quartz, the ^{26}Al and ^{10}Be half-lives are relatively long (0.7 and 1.5 Ma, respectively), so it is not well-suited to sediments younger than ca. 0.5 Ma (Fig. 4). Because it is likely that our target alluvial fans are younger than this, we propose to use the ^{36}Cl-in-K-feldspar/^{10}Be-in-quartz pair, which, due to the shorter half-life of ^{36}Cl (0.3 Ma), is expected to be significantly more precise in the desired age range. Although both these nuclides are commonly used for surface exposure dating (e.g., Dunai, 2010), this pair is rarely used in burial dating because it requires two coexisting minerals rather than one. However, it can be used in our target alluvial fans because they are rich in granite clasts containing these two minerals. In addition, a potential limitation of the ^{36}Cl/^{10}Be pair is that ^{36}Cl production rates are composition-dependent, requiring sample-specific estimates of surface production ratios. In this study, however, we can reduce dependence on these estimates because clasts are derived from a limited range of lithologies that outcrop in the source areas across the fault (see Fosdick and Blisniuk SCEC 2014 proposal). Thus, we can directly measure surface production ratios in the lithologies of interest from samples that have not yet been buried. **To summarize, this part of the project will** (i) provide slip rate estimates on the 200 ka – 1 Ma kyr time scale, and (ii) help to develop and validate a dating method that is potentially widely applicable to dating offset landforms in this age range from granitic terrains common in Southern California. To accomplish this, we request funding for 20 burial samples to date the buried fans and 5 surface exposure samples to constrain present-day productions rates of ^{36}Cl.

Fig. 4. Uncertainty estimates for cosmogenic-nuclide burial dating with various nuclide pairs. Nuclide pairs with shorter half-lives have better precision at young ages but shorter useful age ranges.



V. Work Plan

In sum, we request funding for 20 burial dates, 17 cosmogenic exposure dates (12 ^{10}Be and 5 ^{36}Cl) and 5 radiocarbon samples (including 30 ^{10}Be, 25 ^{36}Cl and 5 ^{14}C AMS analyses at CAMS Lawrence Livermore National Laboratory). Because Blisniuk has a postdoctoral appointment at present, Balco is PI for administrative reasons. Blisniuk will lead fieldwork and will collect samples with

Balco, Scharer (via USGS internal funds), and graduate student Louis Lersen. Blisniuk, Balco, and Lersen (under supervision of Blisniuk) will carry out sample processing in laboratories at Stanford University and the University of Washington (which is optimized for ^{36}Cl measurements; see letter of support), and analysis of resulting data. Fieldwork and further sample collection will be conducted in early spring, and sample processing will begin immediately upon notfication from SCEC. Results will be presented at the SCEC annual meeting and integrated into manuscripts for publication.

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Current and Pending Support

Our proposed work in the San Gorgonio Pass Special Fault Study Area is designed in direct collaboration with Drs. Fosdick and Blisniuk to optimize our expertise and funding resources.

GREG BALCO

I. CURRENT SUPPORT

Title: Acquisition of a Noble Gas Analysis Facility for Surface Process Studies at the Berkeley Geochronology Center (co-PI)
Total Award Amount: $ 137,108
Total Award Period Covered: 04/15/12 – 03/31/13, NCE to 3/31/14
Person-Months/Year Committed to Project: 1.00 Cal. Mo/Yr (BGC-funded).

Title: Collaborative Research: P2C2 - Synchronizing the North American Varve Chronology and the Greenland ice Core Record Using Meteoric 10Be Flux
Total Award Amount: $ 35,589
Total Award Period Covered: 09/15/11 – 08/31/14
Person-Months/Year Committed to Project: 1.00 Cal. Mo./Yr. Yrs. 1, 2, 0.50 Cal. Mo. Yr. 3 (NSF-funded).

Title: Antarctic Peninsula Exhumation and Landscape Development Investigated by Low-Temperature Detrital Thermochronometry
Total Award Amount: $ 101,315
Total Award Period Covered: 12/01/12 – 11/30/13
Person-Months/Year Committed to Project: 1.00 Cal. Mo./Yr (NSF-funded)

Title: Production and Diffusion of Cosmogenic Noble Gases: Using Open-System Behavior to Study Surface Processes (co-PI)
Total Award Amount: $ 309,967
Total Award Period Covered: 07/15/13-06/30/16
Person-Months/Year Committed to Project: 0.50 Cal. Mo./Yr (NSF-funded)

II. PENDING SUPPORT

SOURCE: National Science Foundation

Title: Collaborative Research: Terrestrial Exposure – Age Constraints on the Last Glacial Maximum Extent of the Antarctic Ice Sheet in the Western Ross Sea
Total Award Amount: $ 243,613
Total Award Period Covered: 07/01/14-06/30/16
Person-Months/Year Committed to Project: 4.0 Cal. Mo./Yr1&Yr2 (NSF-funded)

Title: Collaborative Research: Developing high-sensitivity AMS analytics for terrestrial cosmogenic nuclides: Pushing analytical limits to better understand Earth's dynamic surface (co-PI)
Total Award Amount: $ 476,429
Total Award Period Covered: 06/01/14-05/31/17
Person-Months/Year Committed to Project: 0.40 Cal. Mo./Yr (NSF-funded)

Title: Collaborative Research: Mantle to watershed to flora: Coupling surface and deep Earth processes to decipher the evolution of the Cascadia-Mendocino Triple Junction margin
Total Award Amount: $ 405,870

Total Award Period Covered: 07/01/14-06/30/18
Person-Months/Year Committed : 1.0 Cal. Mo./Yr1 & Yr2, 0.50 Cal. Mo./Yr3 & Yr4 (NSF-funded)

This proposal:
Title: Quaternary Fault Slip Behavior Of The Mission Creek Fault Of The Southern San Andreas Fault Zone, Ca**:** Part I - New Insights from neotectonics and ^{36}Cl/^{10}Be burial dating
Total Requested Amount: $55,233
Total Award Period Covered: 2/1/14 – 1/31/15
Person-Months/Year Committed : 0.5 Cal. Mo. (NSF-funded)

KIMBERLY BLISNIUK

I. CURRENT SUPPORT

Source: **National Science Foundation EAR Postdoctoral Fellowship**
Project Location: University of California, Berkeley
Title: Examining the mechanical behavior and evolution of the southern San Andreas fault system through determination of Late Quaternary fault slip rates and distinct element simulations
Total Requested Amount: $170,000*
Total Award Period Covered: 01/01/12 – 03/30/13 (includes no cost extension)
Person-Months/Year: 12 Mo./Cal. Yr. (NSF-funded)

Source: **U. S. Geological Survey**
Project Location: Berkeley Geochronology Center
Title: Estimating Geologic Slip Rates on the Southern San Andreas Fault, California: U-Series and ^{10}Be Dating
Total Requested Amount: $88,696
Total Award Period Covered: 12/01/2012 – 11/30/2013
Person-Months/Year: 3 Mo./Cal. Yr. (at no cost to USGS; NSF-funded via Postdoctoral Fellowship USGS-funded)

Source: **Southern California Earthquake Center**
Project Location: Berkeley Geochronology Center
Title: Determining Long-term Slip Behavior on the Mission Creek and Banning Segments of the southern San Andreas Fault Zone: Geochronometry of Offset Landforms
Total Requested Amount: $39,476
Total Award Period Covered: 2/01/2013 – 01/31/2014
Person-Months/Year: 2.0 Mo./Cal. Yr. (at no cost to SCEC; NSF-funded via Postdoctoral Fellowship)

Source: **University of California, Berkeley:** Larsen Grant
Project Location: University of California, Berkeley
Title: Determining the initiation and timing of slip on the San Jacinto fault zone, California
Total Requested Amount: $20,268
Total Award Period Covered: 4/1/14 – 7/30/14
Person-Months/Year: 4 Mo./Cal. Yr. (UCB-funded)

II. PENDING SUPPORT

This proposal
Title: Quaternary fault slip behavior of the Mission Creek fault of the southern San Andreas Fault Zone, CA**:** Part I – New Insights from neotectonics and ^{36}Cl/^{10}Be burial dating
Total Requested Amount: $55,233
Total Award Period Covered: 02/01/14 – 01/31/15

Person-Months/Year Committed to Project: 2.0 Mo./Cal. Yr.

Source: **Southern California Earthquake Center**
Title: Quaternary fault slip behavior of the Mission Creek fault of the southern San Andreas Fault Zone, CA: Part II – Constraining Sedimentary Provenance and Displacements of Pleistocene Alluvial Fans
Total amount requested: $0
Total award period covered: February 1, 2014 – January 31, 2015
Person-Months/Year: 0.0 Mo./Cal. Yr.

Letter of Support from Dr. John Stone, University of Washington

> From: John Stone <stone@geology.washington.edu>
> Subject: Re: Cl-36
> Date: November 23, 2013 4:21:24 PM PST
> To: Greg Balco <balcs@bgc.org>
>
> Hi Greg,
>
> Apologies for the delay in getting this back to you. You and Kim
> would be welcome to come up and put some samples through the lab in
> the new year. I should be back in Seattle by the end of the first
> week in January, or so.
>
> Cheers,
>
> John
>
>
>> Hi John -
>>
>> Following up on our discussion last week, do you mind sending me a
>> short email that I can attach to a SCEC (Southern California
>> Earthquake Center) proposal indicating that you are willing to make
>> the chloride lab available for this purpose? Simply responding to
>> this email would be fine. Thanks awfully much.
>>
>> By the way, I talked to Dylan and he is pretty sure he left a bottle
>> of Cl-37 spike in the CAMS lab, so I am reasonably optimistic about
>> obtaining some for this purpose.
>>
>> -- greg

	YR 1 (2/1/14)	TOTAL
1. Salaries and Wages		
A. Greg Balco, P.I., 0.5 mo., current rate	3,982	3,982
Balco will help select dating sites and samples in field, train Blisniuk in 36-Cl and 10-Be burial data acquisition and interpretation, oversee lab operation to maintain data quality, and co-author publications on results.		
B. Kimberley Blisniuk, Co-P.I., 2.0 mo.,	8,750	8,750
Blisniuk will determine displacements of offset alluvial fans, carry out 36Cl and 10Be dating, and lead in publishing results.		
TOTAL SALARIES & WAGES	12,732	12,732
2. Fringe Benefits		
A. + B. @ 30.22%/year (This is the benefits rate calculated for NSF Indirect Cost Rate proposed for FY 12-13 and is based on actual costs for health, dental, life insurance, worker's comp, etc. compared to total salaries. This is a fixed rate.)	3,848	3,848
TOTAL FRINGE BENEFITS	3,848	3,848
3. Equipment		
None	0	0
TOTAL EQUIPMENT	0	0
4. Travel		
Domestic		
Lab work at Univ. of Washington (Balco & Blisniuk)		
Airfare to and from ($400 per person SF to Sea)	800	800
Lodging for 7 days, 2 persons, $700 each	1,400	1,400
Rental Car 1 weeks	500	500
Meeting: Blisniuk, Balco to 2014 SCEC Annual Meeting (Palm Springs, CA) to present results:		
Airfare to and from ($200 per person SF to PS)	400	400
Lodging for 4 days, 2 persons, $400 each	800	800
TOTAL TRAVEL	3,900	3,900
5. Field work		
Lodging for 1 month in Thousand Palms for both investigators	1,700	1,700
Food ($71 for 30 per days)	2,130	2,130
Transportation, to and from field area ($.565 for 1200 miles)	678	678
TOTAL OTHER DIRECT COSTS	4,508	4,508
6. Other Direct Costs		
Radiocarbon AMS LLNL (5 samples)- SCEC Geochronology	0	0
AMS analysis for Al, Cl and Be- SCEC Geochronology	0	0
17 Be exposure samples: standard self-cost rate for materials ($270 per sample)	4,590	4,590
36Cl and 10Be burial dating: standard self-cost rate for materials and supplies for sample processing and target preparation at Stanford (or UW) Radionuclide Target facility 20 samples @ $350 per sample	7,000	7,000
TOTAL OTHER DIRECT COSTS	11,590	11,590
9. TOTAL DIRECT COSTS	36,578	36,578
10. MODIFIED TOTAL DIRECT COSTS (MTDC - Tot Dir Cost less Equip, less SubAwd in excess of $25K)	36,578	36,578
11. INDIRECT COST 51% of MTDC	18,655	18,655
12. TOTAL PROJECT COST	55,233	55,233

Budget Justification

1. Salaries and wages

PI Balco will help select dating sites and samples in field, train Blisniuk in 36Cl/10Be burial dating data acquisition, processing and interpretation, oversee lab operation at Univ. of Washington to maintain data quality, and co-author publications on results. Co-PI Blisniuk will be lead field mapping, sample collection and slip rate interpretation. She will determine displacements of offset alluvial fans and channels, carry out ^{10}Be exposure dating and 36Cl/10Be burial dating, and lead in publishing results.

A.	G. Balco, 0.5 mo., current rate	3,982
B.	K. Blisniuk, 2 mo.	8,750
	TOTAL SALARIES & WAGES	$ 12,732

2. Fringe Benefits

This is the benefits rate calculated for the NSF Indirect Cost Rate proposed for FY 12-13 and is based on actual costs for health, dental, life insurance, etc. compared to total salaries. This is a fixed rate.

A. & C. @ 30.22%	3,848
TOTAL FRINGE BENEFITS	$ 3,848

3. Equipment

None requested TOTAL EQUIPMENT $ 0

4. Travel

The success of the proposed research relies on extensive laboratory work at the University of Washington. Funds requested include airfare from San Francisco to Seattle, rental car, and per diem. We also request travel funds for Balco and Blisniuk to attend SCEC 2014 Annual Meeting at Palm Springs, CA to present results.

SF-SEA	800
Rental Car	500
Lodging	1,400
SF-PS RT Airfare, $200/person	400
Lodging, 4 days, 2 persons, $400 each	800

5. Field work

Lodging	1700
Food (per diem $71 per day for 30 days)	2130
Transportation, to and from field site ($.565 for 1200 miles)	678
TOTAL TRAVEL	$ 3,900

6. Other Direct Costs

We request funds for ^{10}Be dating and Burial dating: standard self-cost rate for materials and supplies for sample processing and target preparation at Stanford University Cosmogenic Radionuclide Target Preparation Facility and the University of Washington

17 exposure samples, $270 each	4,590
20 burial samples, $350 each	7,000
TOTAL OTHER DIRECT COSTS	$ 11,590

7. TOTAL DIRECT COSTS	**$ 36,578**
8. MODIFIED TOTAL DIRECT COSTS (minus fee remission)	**$ 36,579**
9. INDIRECT COST (56%)	**$ 18,655**
10. TOTAL PROJECT COST	**$ 55,233**