Deep Fault Structure Beneath the Mojave from a High Density, Passive Seismic Profile

Report for SCEC Award #17098

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1. Project Overview

Abstract

The purpose of this project was to deploy the test phase of a high resolution, passive seismic array in the Mojave region. In May 2018, we deployed 19 broadband instruments from the new UT Austin quick deploy pool. The seismometers were deployed in a dense line, with inter-station spacing of 2-4 km over the ~40 km line; sites were chosen with permission from the Bureau of Land Management to reside on hard rock locations. The deployment spanned 1 week and was led by Robert Porritt with the help of three undergraduate students from UT Austin. The deployment is aimed at addressing two main questions that are fundamental to understanding the geologic framework and mechanical behavior of the Mojave lithosphere, including: 1) What is the distribution of ECSZ strain below the seismogenic layer in the Mojave lithosphere? And 2) How was the Mojave lithosphere modified in response to Laramide flat-slab subduction? Data gathering and analysis associated with this 'Mojave Broadband Seismic Experiment' will commence in the coming months, and we hope to have some initial interpretations to present at the upcoming Annual SCEC meeting in September. The results of this project will be used to evaluate fault loading beneath the Eastern California Shear Zone, and to help populate and test models of lithospheric structure and anisotropy for use in the SCEC Community Rheology, Velocity, and Stress Models.

SCEC Annual Science Highlights

Exemplary Figure

Figure 1

SCEC Science Priorities

3.b, 3.a, 1.b

Intellectual Merit

The Intellectual Merit associated with this project includes:

1) Better imaging of the deep fault structure and distribution of strain (localized vs. distributed) beneath the Eastern California Shear Zone, with implications for basal loading of upper crustal faults, postseismic relaxation and earthquake cycle models.
2) Improved understanding of the Laramide lithospheric modification in the Mojave mantle lithosphere, including determining the composition of the lower crust (schist or no schist), the role of duplexing in the mantle lithosphere, and the hydration state of the lower crust and upper mantle, with implications (as above) for fault loading, postseismic relaxation, and earthquake cycle models.

Broader Impacts

Broader impacts include the following:

1) The high resolution seismic line focused on the Mojave region is complementary to efforts associated with developing the SCEC Community Rheology Model, particularly since the CRM community has identified the Mojave region as the ideal locality for implementing an initial version of the CRM
2) The project leverages several additional sources outside of SCEC, including NSF grants award to all three PIs and UTIG funding via Becker's startup for the seismometer pool.
3) The work being conducted is highly interdisciplinary and will facilitate broad synthesis of from a range of observations.
4) The project has already involved three UT undergraduate students who assisted with the deployment and got first hand experience in observational seismology.

Project Publications

This project is in the early stages so there are no publications at this stage. We will conduct a service run in the Fall of 2018 and conduct the first data analysis then.

2. Technical Report

Project Goals

Understanding how plate-boundary deformation is accommodated in the lower crust and upper mantle in continental lithosphere is fundamental to our understanding of fault systems. The partitioning of strain into specific rock constituents and the associated deformation mechanisms, for example, controls the relative contributions of different compositional layers to regional lithospheric strength, and the degree to which strain localizes at depth [e.g. Brace and Kohlstedt, 1980; Kohlstedt et al., 1995]. It also determines under which conditions continental domains can be considered as relatively rigid blocks [e.g. McKenzie and Jackson, 1983; Avouac and Tapponnier, 1993; McCaffrey, 2005; Thatcher, 2009], partially decoupled crustal and mantle layers [e.g. McNutt et al., 1988; Burov and Diament, 1995], or a vertically uniform "thin viscous sheet" [e.g. England and McKenzie, 1982; Platt et al. 2008]. Observations of continental lithosphere deformation are typically indirect, sourced from a variety of techniques such as earthquake depth distributions [e.g. Molnar and Chen, 1982; Doser and Kanamori, 1986; Maggi et al., 2000; Sloan et al., 2011], potential field data [e.g. McGinnis et al., 1979; Tassara et al., 2007; Panet et al., 2010], observations of seismic velocities and anisotropy [e.g. Porter et al., 2011; Lin et al., 2010; Silver and Chan, 1991; Lev et al., 2006; Shapiro et al., 2004; Long and Becker, 2010], and viscoelastic models of displacements following large earthquakes and glacial or lake unloading [e.g. Thatcher, 1983; Bills et al., 1994; Burgmann and Dresen, 2008, Hearn & Thatcher, 2015]. Some actively deforming regions are, however, also host to young volcanoes that sample mantle and lower crustal material in the form of xenoliths; these can be used to place direct constraints on deep-seated deformation and to better constrain and complement larger-scale geophysical measurements [e.g. Titus et al., 2007; Behr and Hirth, 2014; Chatzaras et al., 2015; Behr and Smith, 2016].

The Mojave region in southeastern California is one such locality where a broad range of observations on lithospheric deformation has been collected, and where young volcanoes sample the lower crust and lithospheric mantle (Fig. 1). The region has experienced several Cordilleran tectonic events over the Cenozoic, including Laramide flat-slab subduction in the late Cretaceous [Barth and Schneiderman, 1996; Saleeby, 2003], followed by significant E-W-oriented lithospheric extension and associated volcanism from the early Miocene through the late Pleistocene [Glazner et al., 1989, 2002]. Currently, the Mojave region straddles the boundary between San Andreas transform-related deformation and Basin and Range extension and is host to a distributed network of NW-SE-striking strike-slip faults known as the Eastern California Shear Zone [ECSZ; e.g. Dokka and Travis, 1990]. The protracted Cenozoic history and modern-day tectonic activity in the area has likely produced complex deformation patterns, both old and new, in the deep crust and lithospheric mantle that both geophysical and xenolith studies can help to tease apart. It is a key region where slip is transferred along the plate boundary off the main fault [e.g. Savage et al., 2001; Meade and Hager, 2005; Becker et al., 2005; Platt and Becker, 2010; Chuang and Johnson 2011], but its role in the future evolution of the plate boundary is unclear [e.g. Herbert et al., 2016; Evans et al., 2016; Thatcher et al., 2016]. The relative richness of background datasets, including post-seismic studies [e.g. Freed and Burgmann, 2004; Pollitz et al., 2001], the relatively well constrained geologic history, and the relevance to California seismic hazard, make the Mojave an important place to study the progressive modification of the lithosphere in response to evolving plate motions. Permanent seismic stations are scarce (Fig. 1), but new seismological observations pertaining to the downward continuation of faults in the ECSZ could be usefully compared to similar efforts of densely imaging other cross sections on the San Andreas fault.

Our goal in this project was to deploy the test phase of a high resolution, passive seismic array in the Mojave region. We deployed nineteen intermediate period instruments from the new UT Austin quick deploy pool, and in the coming months will analyze those data streams. The deployment is aimed at addressing two main questions that are fundamental to understanding the geologic framework and mechanical behavior of the Mojave lithosphere:

1) What is the distribution of ECSZ strain below the seismogenic layer in the Mojave lithosphere?

2) How was the Mojave lithosphere modified in response to Laramide flat-slab subduction?

Summary of Work Conducted During this Funding Cycle

UTIG postdoctoral researcher Rob Porritt conducted a scouting trip in Fall of 2017, and initiated the required permitting and environmental impact assessment with the Bureau of Land Management. The northern line from our original SCEC proposal was chosen for the deployment because of ease of access and permitting; plans for the alternative southern line were abandoned because of prohibitive charges for deployment on the 29 Palms Marine base. The chosen transect falls within the Mojave National Preserve, Bristol Mountains BLM wilderness, and Mojave Trails National Monument, and we have been in contact with all three of these agencies. In April 2018, Rob Porritt and three UT undergrads installed 19 seismometers via direct burial at the locations shown in Figure 1. The major components of the seismometers include a weak motion velocity sensor (seismometer) called an MBB2 and an analog to digital recorder called a Minimus. These are two state of the art pieces of equipment in passive seismic recording. The MBB2, from Metrozet, a division of Kinemetrics, is the latest sensor available and has a typical broadband flat response between 120 seconds and 160 Hz in a form-factor approximately the size of a soda can. The Minimus, from Güralp, is a compact datalogger which hosts a wide-array of built in sensors including an accelerometer, a magnetometer, and thermometer, and has 64Gb of built-in recording capabilities. In addition to the successful deployment in May, PI Schulte-Pelkum visited Behr and Becker at UT Austin in late April to discuss the deployment and the science goals associated with the data analysis.

Planned Future Activities

PIs Behr, Becker and Schulte-Pelkum and postdoc Porritt will continue synthesizing existing geologic and geophysical data for the Mojave region in collaboration with Geologic Framework coordinators Oskin and Shaw. Schulte-Pelkum, Becker, and Porritt will conduct the initial analysis of the profile data, perform standard receiver function analysis, put receiver function results in the regional deep deformation field context based on SCEDC permanent station data, including rock fabric and shear zone imaging at depth using the method developed by Schulte-Pelkum and Mahan (2014a,b), assess site data quality, and conduct initial S and SKS splitting measurements as well as anisotropic receiver function analysis.

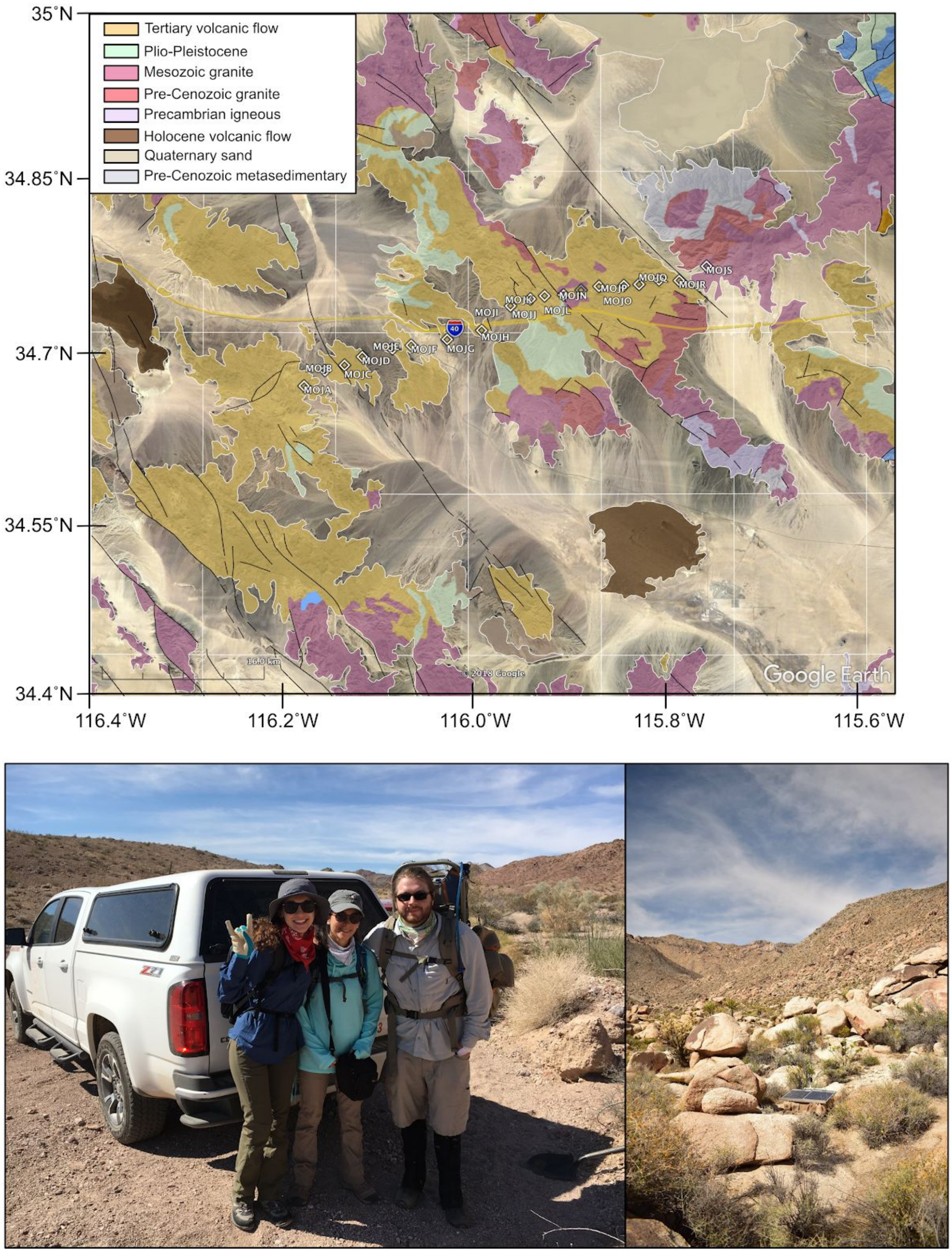

Figure 1. [Top] Installed station locations and corresponding hard rock geologic units. [Lower left] The 3 UT undergraduates who participated in the deployment, from left: Ashlyn Zare, Jacqueline Rambo, and Daniel Ortega-Arroyo. [Lower right] An example station installed amongst the ferns and granites. Only visible are the solar panels on the top of the box.