Geodynamics of a Nascent Plate Boundary Zone:
The Eastern California Shear Zone (ECSZ)

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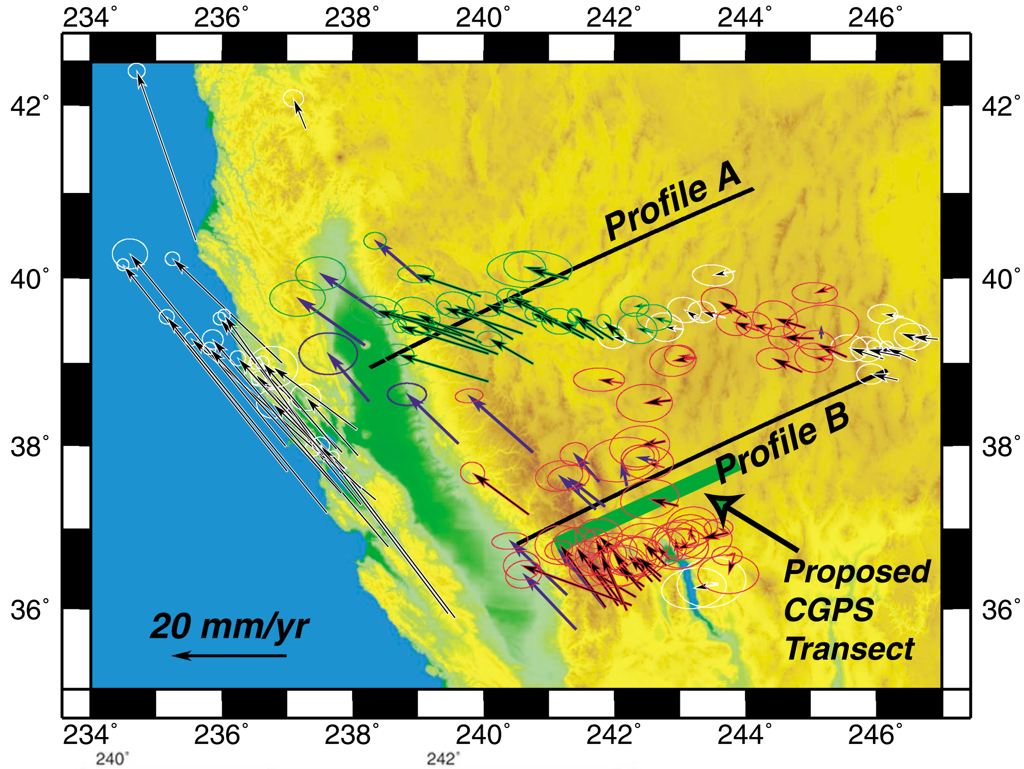
PROJECT SUMMARY

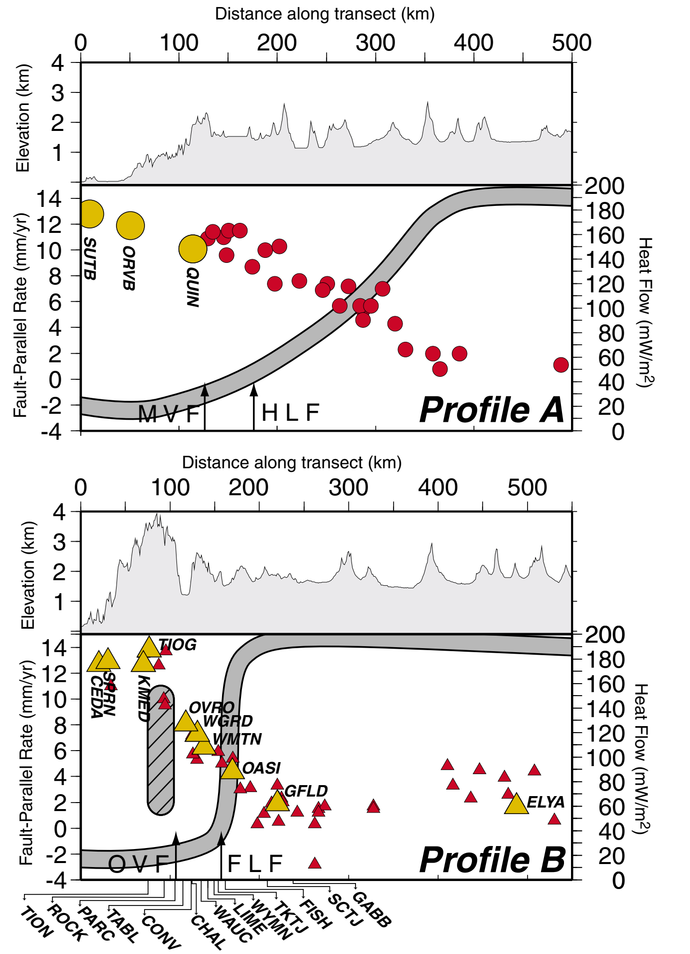
The ECSZ serves as a major component of the Pacific – North America plate boundary, accommodating 20-25% of the total plate rate. Over more than 500 km of plate boundary the displacement between the Pacific and North America plates is accommodated along two primary plate boundary shear zones – the San Andreas system and the ECSZ. On a transect perpendicular to Long Valley Caldera (LVC), the ECSZ is quite narrow but widens considerably to the south (and possibly north). We propose a continuous GPS transect utilizing ~ 20 CGPS instruments about 100 km south of LVC (slip primarily on two faults systems: Owens Valley and Death Valley-Furnace Creek). In combination with proposed arrays/transects in the LVC region, we can separate LVC from ECSZ tectonics. This transect crosses the middle of the rupture zone of the 1872 Owens Valley earthquake, allowing us to investigate the role of the earthquake cycle in surface strain pattern.

The present localization of strain and the deformational history of the ECSZ show patterns of strain partitioning within continental plate boundaries that can be exploited to place real constraints on the rheology of the plate boundary and the driving forces which lead to strain partitioning. Although the system is complex, the combination of detailed observations of present-day plate boundary deformation (including patterns of Quaternary faulting and regional geophysical data) with 3-D geodynamic modeling provides the means to discriminate among models of plate boundary deformation. We propose new GPS observations and geodynamical modeling to test the following hypotheses:

- ***Hypothesis 1:*** *The ECSZ represents a throughgoing plate bounding shear zone, fully analogous to a plate boundary, and may soon (next few million years) develop into the main plate boundary as the plate boundary continues to migrate inland and the San Andreas is abandoned.*
- ***Hypothesis 2:*** *The localization of strain producing the ECSZ is controlled by a relatively abrupt change in viscosity from higher values beneath the Sierra Nevada block to lower values within the western Basin and Range, reflected in surface heat flow.*
- ***Hypothesis 3:*** *The motion of the Sierra Nevada – Great Valley tectonic block (~ 12-14 mm/yr relative to stable North America) is driven by the combination of shear coupling along the San Andreas plate boundary shear zone and forces produced through convergence in the Transverse Ranges .*
- ***Hypothesis 4:*** *Initiation of the ECSZ was primarily driven by the opening of the Gulf of California (~ 4-8 Ma). The development of the Transverse Ranges may reflect either a cause or an effect of the formation of the ECSZ .*

Our ability to make high resolution determinations of present day deformation in concert with sufficiently refined numerical models of such deformation allow these previously intractable tectonic questions to be addressed.





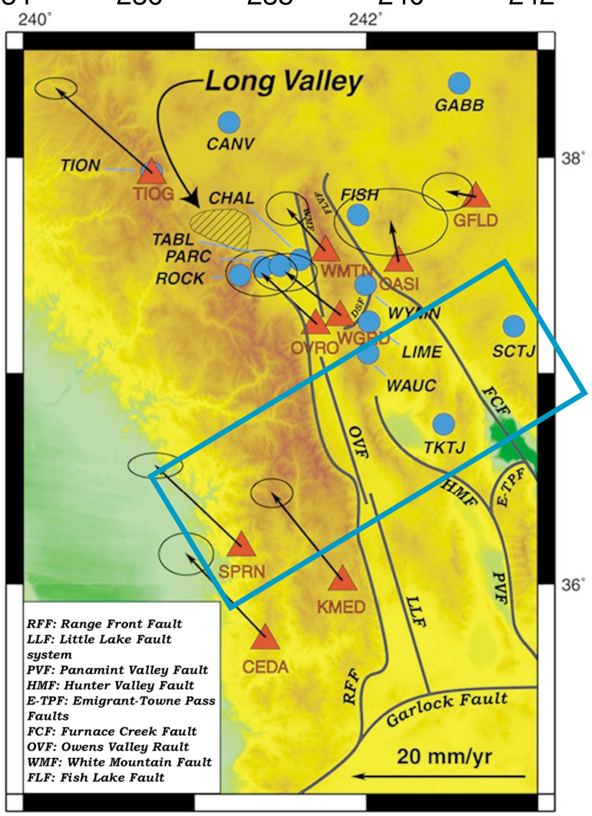


Fig. 1. Regional GPS coverage and results.

(Upper Left) Map shows proposed CGPS transect (green line) in relation to a subset of GPS results reported for the region (http://quake.wr.usgs.gov/QUAKES/ geodetic/gps). Locations of profiles (~ perpendicular to plate motion) for northern (green colored vectors/error ellipses) and southern (red colored vectors/error ellipses) transects are shown. Blue colored vectors (Dixon et al. (2000)) are shown in both transects.

(Upper Right) GPS results projected onto profiles across the ECSZ ~ perpendicular to Sierra – North America motion. Transects show GPS results partitioned into the ‘fault-parallel’ component with regional heat flow (shaded bands) and topography (Heat flow data from: www.smu.edu/~geothermal/).

Profile A: transect crossing the ECSZ at approximately 39° N (Thatcher et al., 1999; Dixon et al., 2000). Dixon et al. data shown by large circles. [MVF – Mohawk Valley Fault; HLF – Honey Lake Fault].

Profile B: transect crossing the ECSZ at ~ 36°-37° N. Dixon et al., shown as large triangles; data from other regional studies as smaller triangles. Heat flow data from the Long Valley region are shown by shaded/hatched region. [OVF – Owens Valley Fault; FLF – Fish Lake Fault]. Note the correspondence between the zone of GPS velocity gradient and the transition zone in heat flow; narrower in the southern profile, broader in the northern profile.

(Lower Left) Detail of current GPS sites in vicinity of proposed transect (oulined box). Relationship to faults in region is shown along with geographic relation to Long Valley.

PROJECT DESCRIPTION

The apparent focusing of deformation near the western edge of the Basin and Range is suggested by Quaternary fault patterns (Wallace, 1984; Dokka and Travis, 1990) and seismicity (Eddington et al., 1987). More recently this focusing has been confirmed by space geodesy (Dixon et al, 1995; Bennett et al., 1998; Thatcher et al., 1999; Dixon et al., 2000; Gan et al., 2000) (Fig. 1). This region has been termed the Eastern California Shear zone (ECSZ) reflecting its along-strike coherency and strain localization (Sauber et al., 1986, 1994; Dokka and Travis, 1990; Savage et al., 1990)

These results argue that the ECSZ serves as a major component of the Pacific – North America plate boundary, accommodating 20-25% of the total plate rate. Additionally, the GPS results reported by Dixon et al. (2000) demonstrate a relatively rigid behavior for the Sierra Nevada – Great Valley block. Thus over more than 500 km of plate boundary (~ 35°-40°N) the relative displacement between the Pacific and North America plates is accommodated along two primary plate boundary shear zones – the San Andreas system and the ECSZ with little deformation between those two shear boundaries (at least at upper crustal levels).

Dixon et al [2000] demonstrate a close correlation between maximum surface velocity gradient and the major change in surface heat flow in the western Basin and Range (Fig. 1). The correlation suggests that strain is accommodated in weaker regions, and indicates a close correspondence between upper crustal weak zones (faults) and regions of hot, weak lower-crust/upper-mantle. This correlation between near surface deformation (faulting, seismicity, and strain) with deeper structures extends to depths of at least 100 km [as imaged by p-wave tomography (Dueker, 1999)]. The width of the region showing the high crustal-velocity (displacement) gradient (~10 mm/yr velocity gradient between the eastern edge of the Sierra Nevada and Goldfield, Nevada) and horizontal changes in surface heat flow is ~ 50-100 km in the region covered by the Dixon et al. (2000) transect (Fig. 1). This may not be a general pattern for the ECSZ. Thatcher et al. (1999) demonstrate a substantially broader deformation zone (at 39°N) with some partitioning of velocity changes between the eastern edge of the Sierra and the Central Nevada seismic belt several hundred km to the east (Fig. 1). The heat flow transition is also broader along that profile.

Slightly to the south of the Dixon et al. (2000) profile, the principal faults accommodating ECSZ deformation, the Owens Valley and Death Valley-Furnace Creek fault zones, are separated by up to 200 km (Fig. 1); however, the relative activity of these two fault zones is unclear and is a focus of current research. The intervening Hunter Mountain-Panamint Valley fault may also be important (Gan et al., 2000; Zhang et al., 1990). There is also a discrepancy in the literature between the geologic slip rate on the Owens Valley fault zone (2 mm/yr; Beanland and Clark, 1994) and the geodetic estimate (6-7 mm/yr). Some "discrepancies" between fault slip rates estimated from geodesy and estimated from geological studies might be due to poorly understood rheology and its influence in the modeling of the geodetic data. Thus it is important to incorporate improved rheological models that account for the visco-elastic behavior of the lower-crust and upper-mantle, good geologic constraints that delineate the timing of past earthquakes and the geometries of that earthquake slip, and other 3-D effects. With these additional constraints, the increasingly precise geodetic data can be used not only to infer more accurate slip rates for active faults, but also to test subsets of rheological models and geodynamic histories.

Geologic data support approximately 9-23% of the plate motion occurring within the ECSZ since its initiation (Dokka and Travis, 1990); while recent GPS results indicate that currently approximately 20-25% of the motion occurs within a relatively narrow shear zone within the ECSZ (Dixon et al., 2000; Gan et al., 2000). Motion along the shear zone initiated between 10 and 6 Ma; timing coincident with the initiation of opening of the Gulf of California between 12-5 Ma (Stock and Hodges, 1989; Holt et al, 2000); The formation of the ECSZ represents of change in the kinematics for the Great Valley - Sierra Nevada block which prior to ~8 Ma moved more westerly, driven by the opening of the Basin and Range (Wernicke and Snow, 1998). Bellier and Zoback, (1995) find evidence for a change in the direction of stress in the Walker Lane belt between 10 and 7 Ma, at the same time motion is thought to have been initiated along the southern ECSZ. Presently, the Sierra Nevada block is moving as a rigid body to the northwest at 13-14 mm/yr with minor amounts of rotation (Hearn and Humphreys, 1998, Dixon, 2000).

Shear is accommodated along northwest trending, right-lateral strike-slip faults separated by north-northeasterly trending normal faults that possibly serve to transfer motion between the parallel strike slip faults (Dokka and Travis, 1990; Reheis and Sawyer, 1997). Since 10 Ma, ~65 km of dextral offset has accumulated along faults in the Mojave region (Dokka and Travis, 1990), an amount similar to the ~68 km of offset suggested along the Walker Lane Belt to the north (Cashman, 1996). Dixon et al (1995), and Reheis and Dixon (1996) suggest that the Death Valley-Furnace Creek-Fish Lake Valley faults initially accommodated the majority of the motion of the Sierra Nevada Block, whereas recently the more westerly Owens Valley-White Mountain fault has increasingly accommodated deformation. The narrowness of the ECSZ at 38°N may just be a coincidence, since this is where the two faults systems, both currently active, cross.

Proposed GPS Transects

The ability of GPS (or any other) geodetic data to distinguish among a set of kinematic hypotheses is tied critically to 1) the accuracy of the individual station velocities; and 2) the spatial sampling density (number of stations). Our proposed transect of continuous stations will significantly improve this picture, especially if combined with proposed transects to the north and south by other groups (which we strongly support) . First, the additional observations from continuous stations will provide accurate site velocities after just a few years. Second, the number of stations crossing the ECSZ with reportable velocities will greatly increase (Fig. 1). We also propose to augment any transect of continuous stations with a network of campaign sites to provide some three-dimensional sampling. The location of these additional sites will both provide improved resolution of any 'curvature' and asymmetry in the GPS velocity field and also improve our isolation of long valley effects from the GPS 'plate boundary' velocities. Proposed station spacing on the transect should be about 10 km, and attention will have to be paid to site monumentation in the alluvial valleys and basins (e.g. Owens Valley, Fish Lake Valley) where 'ground noise' and spurious monument motion is likely to be much higher compared to bedrock sites on the intervening ranges.

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