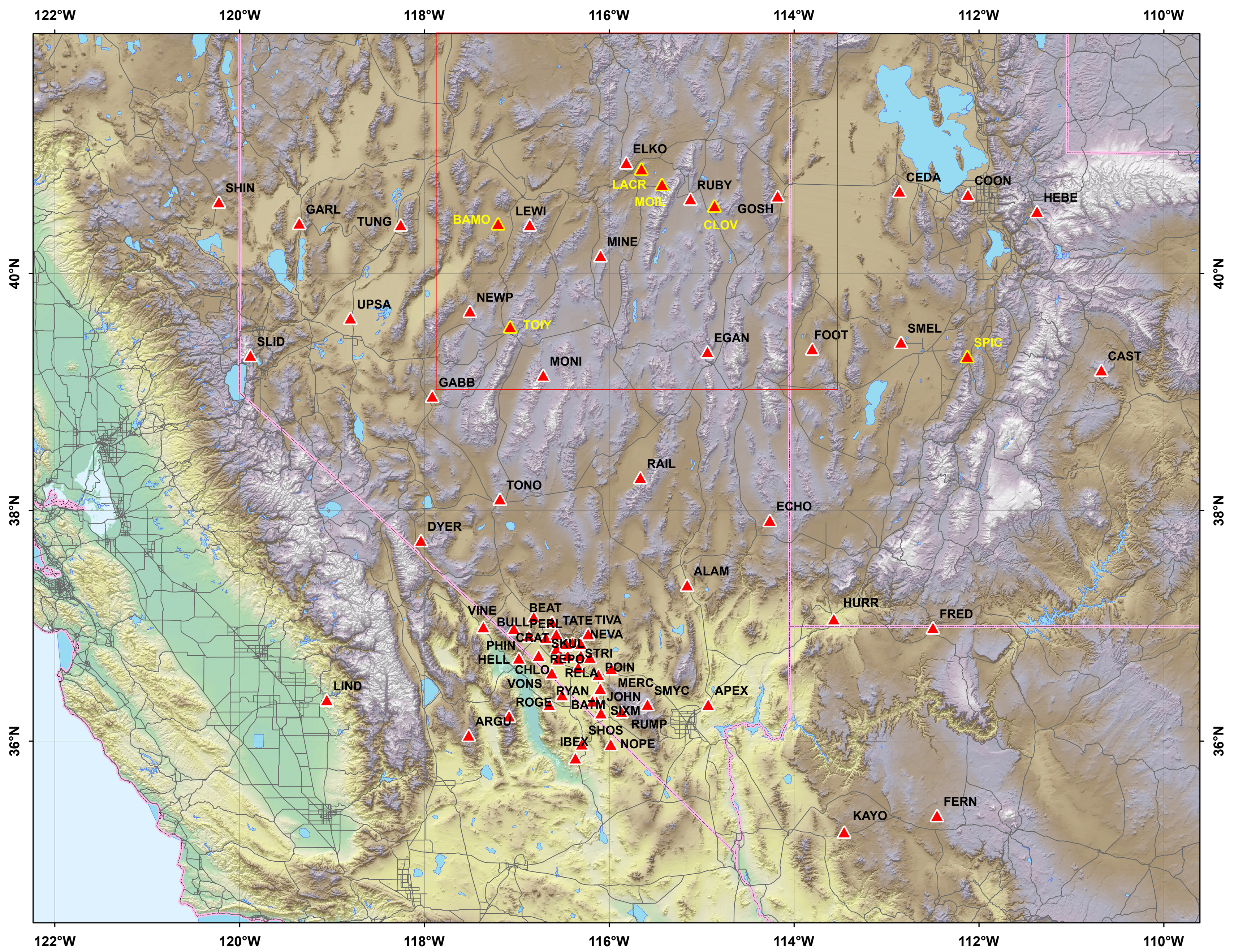
WESTERN NORTH AMERICA NEVADA GPS PROJECT, 2006

Faculty Participants: Brian Wernicke, Mark Simons, Kerry Sieh
Postdocs: Richard Briggs, Kevin Mahan
Staff: Jeff Genrich

Abstract

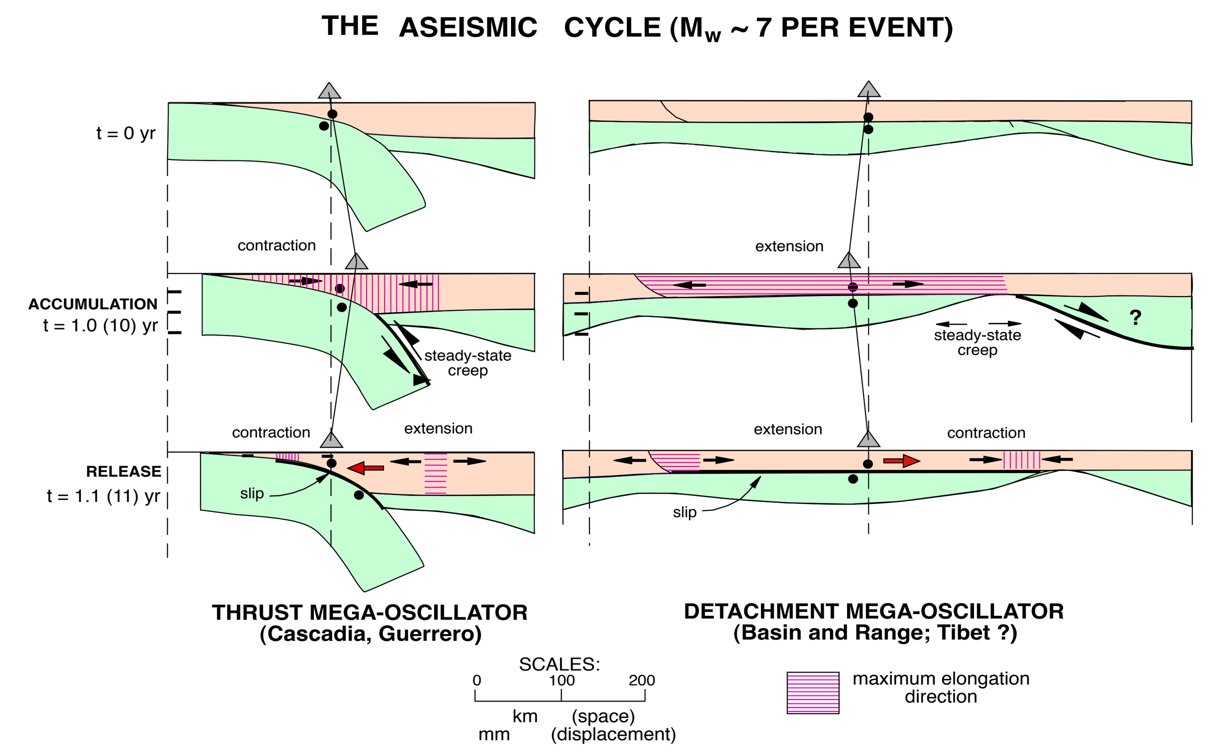
The Nevada GPS project was funded as a strategic augmentation of planned Earthscope continuous GPS sites in the Basin and Range, with the objective of producing dense enough coverage to observe and model apparent migratory strain in north-central and eastern Nevada. As extensively discussed in TO western US working group meetings, and published this summer (Davis JL, Wernicke BP, Bisnath S, et al., 2006, Nature - see below), this region of the Basin and Range forms a boundary zone between accelerating sites in the western Basin and Range and non-accelerating sites to the east. These large-aperture observations over the last decade are the first to suggest relatively efficient anelastic energy transfer across a deforming plate boundary zone at human timescale, which in turn could be a major control on the seismic cycle and rheology of the lithosphere. Full characterization of strain waves down to ~100 km wavelength will be possible with the ~30 km site spacing of the densified network.



Map of western North America showing the locations of continuous GPS stations operated by the California Institute of Technology under the auspices of the National Science Foundation, the Department of Energy's Yucca Mountain Project and the Tectonics Observatory. As of Novemeber 2006, there are 74 stations operating in California, Nevada, Utah, and Arizona. Six GPS sites funded by the Tectonics Observatory are highlighted in yellow. New sites built this year as part of the Yucca Mountain in southern Nevada project are identified with roman textface.

Tectonic Implications

We speculate that an episodically creeping detachment horizon ~500 km wide at or near the base of the crust may provide a general explanation for the velocity changes. In one scenario, the mantle would either translate or stretch smoothly below the horizon, imparting a westward component of shear traction on the base of the crust (<1997-~2000). Top-to-the-east plastic yielding along the horizon translates the crust eastward en bloc, as internal stretching and shear of the crust continues. Yielding thus relaxes stress on the eastern margin of the accelerating domain (where baselines ELKO-GOSH and EGAN-FOOT were contracting at ~0.5 and 1 mm/yr, respectively), and focuses strain accumulation (2000–3), and subsequently strain release (2003-4) along the western margin of the domain. An active decoupling zone at the base of the crust under the Nevada Basin and Range, accompanied by magmatic injection, has long been suspected on the basis of nearly continuous, bright seismic relections along the Moho. Like the GPS velocity change, these reflections also die out near the Nevada-Utah border, suggesting the reflection Moho is a coherent structure that episodically yields, thereby transferring strain energy hundreds of kilometers across the province.



Subcontinental-scale Transient Deformation along Pacific-N. America Boundary

Davis, J.L., Wernicke, B.P., Bisnath, S., Niemi, N.A., Elosequi, P., 2006, Nature 441: 1131-1134

Transient tectonic deformation has long been noted within ~100 km or so of major plate boundary faults zones and within active volcanic regions, but do transient motions also occur at larger scales within plates? We report the first geodetic evidence for a coherent, subcontinental-scale change in tectonic velocity along a diffuse, ~1000-km wide deformation zonebased on continuous GPS observations over the last decade across the Basin and Range province Basin and Range deformation absorbs approximately 25% of Pacific-North America right-lateral transform motion, expressed by east-west extension in Utah and north-northwest right-lateral shear in western Nevada and eastern California. Changes in site velocity define a sharp boundary near the centre of the province oriented roughly parallel to the north-northwest relative plate motion vector. From 1999.5 to 2001.0, sites to the west of this boundary slowed relative to sites east of it by ~1 mm/yr.

Relatively localized transients are known to occur as both seismic and episodic aseismic events1, and are generally ascribed to motions of magma bodies, aseismic creep on faults, or elastic or viscoelastic effects associated with earthquakes. However triggering phenomena and systematic patterns of seismic strain release at subcontinental (~1000 km) scale along diffuse plate boundaries, have long suggested that energy transfer occurs at larger scale. Such transfer appears to occur by the interaction of stresses induced by surface wave propagation and magmas or groundwater in the crust , but do mechanisms not directly associated with earthquakes also exist?

We have addressed this issue by constructing the Basin and Range Geodetic Network (BARGEN), the first 1000 km-aperture continuous GPS network to be deployed across an actively deforming plate boundary zone. Eighteen sites, comprising an east-west transect between latitudes 39°N and 41°N (map above), began recording in 1996–7; time series are now long enough for us to obtain statistically reliable estimates of any changes in velocity that might occur on a regional scale. Dual-frequency GPS phase data were first analyzed in the usual way using GAMIT/GLOBK, resulting in estimated average velocities and time series in a North American reference frame. The average horizontal velocities of the sites rise from near zero in the east to ~3 mm/yr due west across western Utah, remain relatively constant across eastern Nevada, and then rotate northwestward and progressively increase up to ~12 mm/yr in the Sierra Nevada.

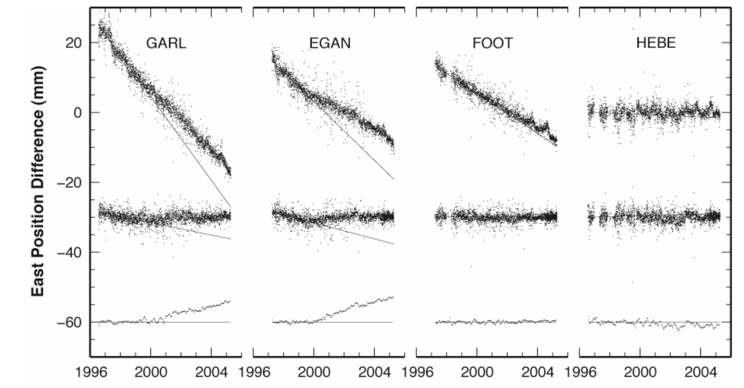
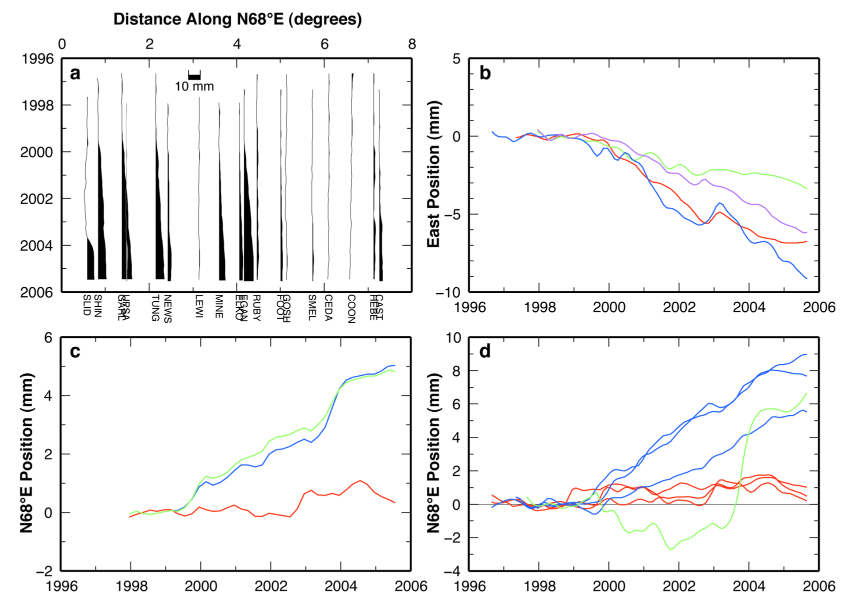
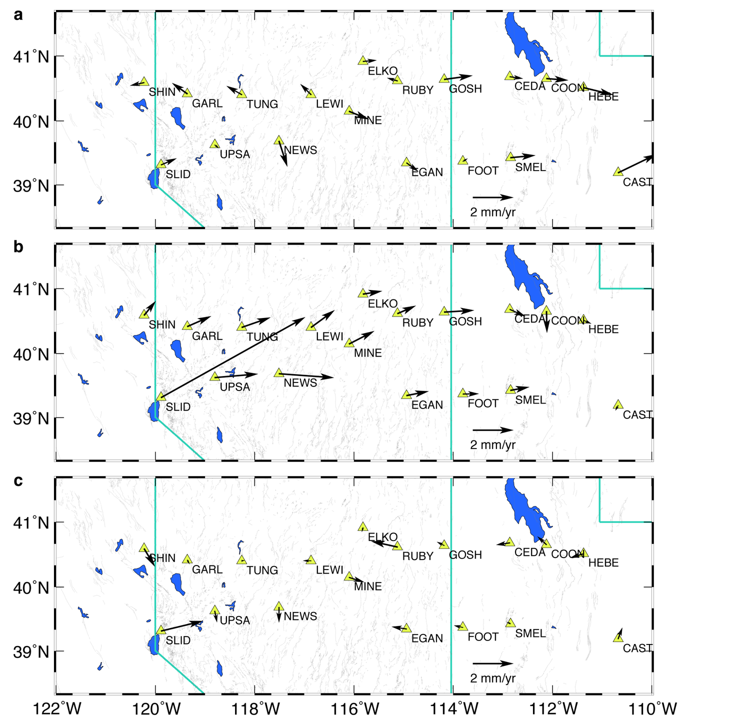


Illustration of the post-analysis procedure, using time series of east position for four BARGEN sites. Top: "Raw" time series, in a North-America-fixed geodetic reference frame. Error bars are omitted for clarity, but are generally ~1 mm. The straight line is the best-fit straight line using points from the first 2.5 years. Middle: Residuals of the raw time series from a best-fit model consisting of a straight line and seasonal (annual and semi-annual sinusoids) terms. A spatial filter5 with mean, rate, and acceleration constrained to zero has been applied. Bottom: Residuals smoothed with a Gaussian filter of width 0.04 yr (~15 days), and sampled every 0.04 yr. A model based on a linear fit to the first 2.5 yr of data has been removed. The evolution of these final time series thus indicates deviation from temporally linear motion.

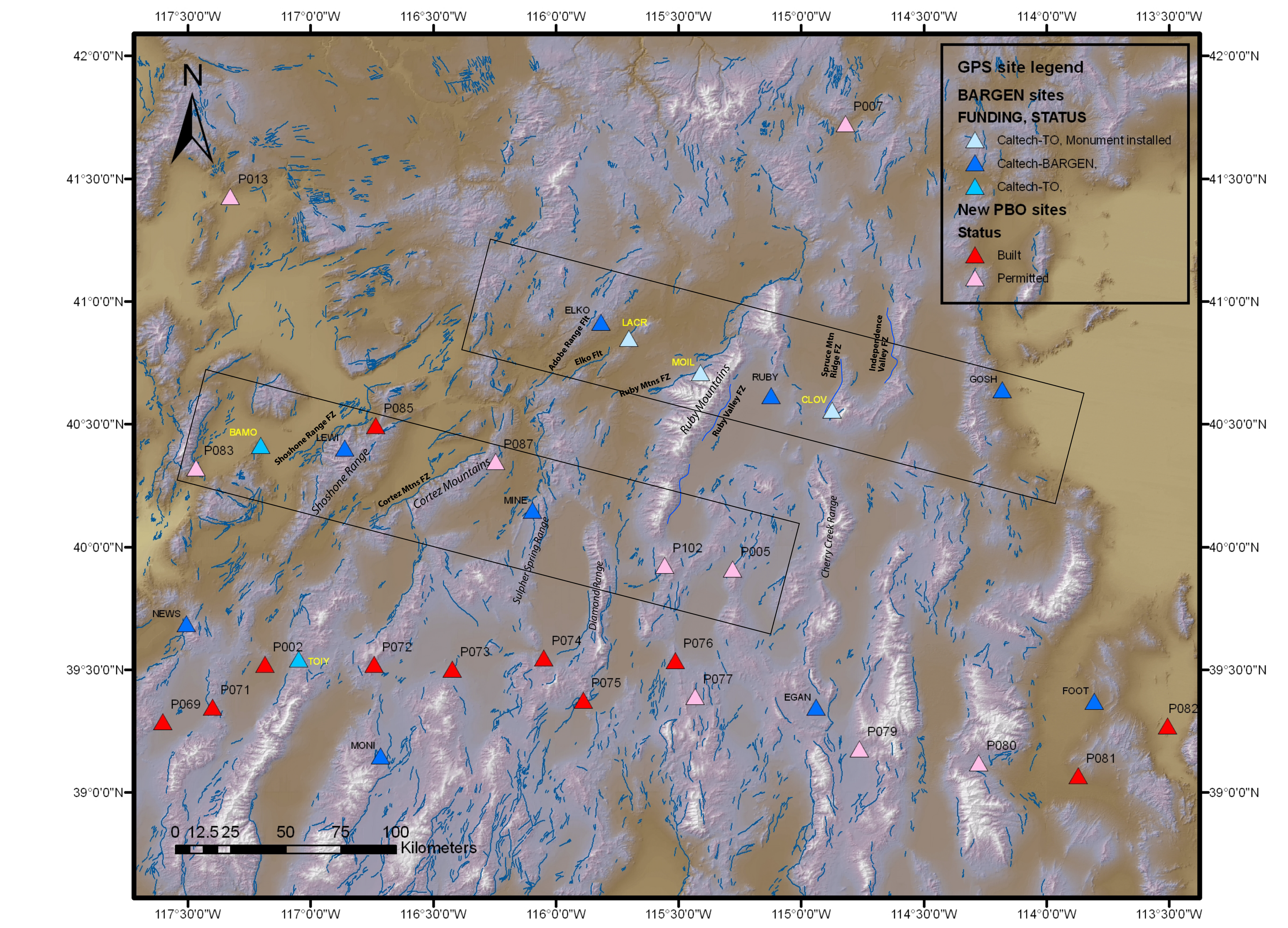


Analysis of spatial variation of nonlinear deviations. **a**, Smoothed time series of smoothed position deviations from linear motion in the direction N68°E, projected along a great circle with azimuth N68°E near the centre of the network. Where these deviations are positive, the space between the trace and zero has been shaded black. The significant deviations occur in the western part of the network. **b**, East components of intersite vectors for EGAN-FOOT (red), ELKO-GOSH (green), GARL-HEBE (blue), and MINE-SMEL (purple). GARL-HEBE, which spans the entire network east-west, and EGAN-FOOT, which spans a short distance in the centre of the network show nearly identical deviations, indicating an abrupt boundary for velocity changes in eastern Nevada. **c**, Regionally averaged non-linear deviations of N68°E position. Red: Eastern BARGEN (HEBE, FOOT, COON, CAST, CEDA, SMEL, GOSH, and RUBY). Green: TUNG, ELKO, EGAN, LEWI, NEWP, GARL, UPSA, and SHIN. Blue: Same as green plus SLID. Only data from a common epoch range (1997.86–2005.18) were used. The figure demonstrates that the velocity change has moved the western part of the network, on average 3–4 mm eastward or northeastward compared to the eastern part of the network. The shorter period features that are anticorrelated are artefacts of the spatial filtering technique, but may indicate regional coherence on these time scales at amplitudes less than ~1 mm. **d,** N38°E position time series for three groups of sites. Red: eastern sites RUBY, FOOT, and HEBE. Blue: western sites EGAN, MINE, and GARL. Green: Site SLID.



Differences of horizontal velocity for one-year periods relative to the average velocities for the period 1997.0-2002.0. a) Differences for the calender year 2002. b) 2003. c) 2004. 1 sigma errors for each component are ~0.4 mm yr^{-1} Note "displacement wave" beginning with eastward motion of Utah sites in 2002 prior to SLID's large motion in 2003 (correponding to a magmatic injection event beneath Lake Tahoe), which accompanied by west by eastward motion of all Nevada and some Utah sites. This behavior suggests largely aseismic transfer of strain energy at 1000 km length scale.

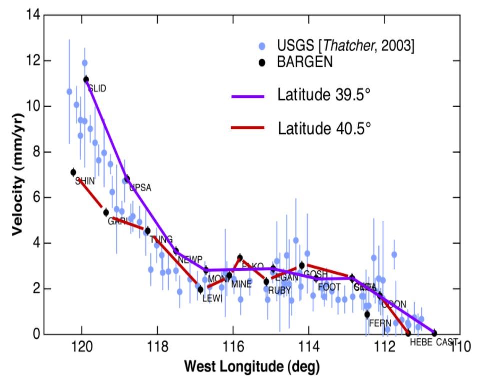
The current project plan, as both TO and PBO sites come on-line, is to begin archiving and annual processing of data from the group of sites shown in the map below and listed in the table below, which consists of approximately 35 sites. In conjunction with this work, we hope to begin an investigation of the only major normal fault along the transects for which no paleoseismological slip estimate is available, the Ruby Valley fault zone. This fault bounds the east side of the Ruby Mountains, Nevada, just west of site Ruby (Figure 1). In addition, over the next year we will begin dislocation modeling efforts to test the hypothesis that velocity changes are the result of rapid transient slip (of order cm/yr) on the down-dip extensions of the large active normal faults along the transect (see below).

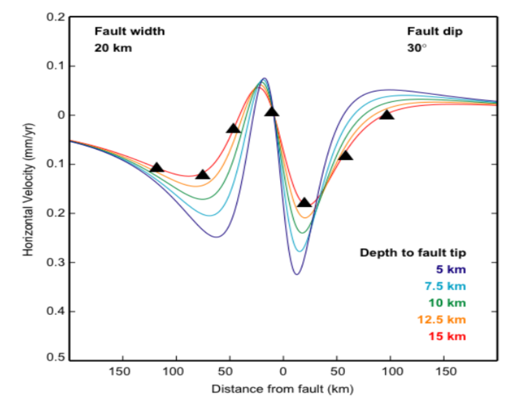


Siting for three new continuous TO sites (CLOV, MOIL and LACR) was completed in early fall 2005, densifying the existing BARGEN transect that includes sites ELKO, RUBY and GOSH (see above). Permits were secured by the summer of 2006, and monumentation has been completed. Electronics installation and bringing the sites on-line will begin in early November 2006. Close coordination between TO and the PBO siting committee enabled all of the earlier proposed densification of the Mount Lewis area to be absorbed by PBO, such that the transect including TO sites BAMO and TOIY will be densified to ~30 km station spacing. The close station spacing will permit robust testing of elastic dislocation models for individual faults, including the western range front faults for the Ruby Mountains, Cortez Range and Shoshone Range, as well as comparison of geodetic rates with previous estimates of late Cenozoic strain release rates from paleoseismological methods. Robust velocity estimates (± 0.2 mm/yr intersite velocity) will be available by fall 2008.

Are Basin and Range normal faults creeping episodically in their lower regions?

The original BARGEN network included site spacing across central Nevada of about 80 km, with significant (1-2 mm/yr, about 10 sigma) amplitude of velocity variations for sites near latitude 40°N. This is a surprising result because overall this part of Nevada is not systematically deforming, i.e. the velocities as a whole define a remarkably stable tectonic block (red curve, showing west velocities as a function of longitude, diagram at lower right). The simplest hypothesis to explain these variations is rapid, transient creep on the deep portions of Basin and Range normal faults in the area, which would be most obvious in a slowly straining region. Calculations of surface deformation due to deep crustal creep on a Basin and Range faults (below, right) show that at 80 km spacing we are sampling at less than half the Nyquist frequency for the waveforms predicted by fault creep at depth. With the strategic augmentation of three new TO continuous GPS sites (coming on-line in November 2006) and about five sites from the national PBO, we will have about 14 sites at ~40 km spacing covering the geodetically complex region of contractile and extensional strain near BARGEN sites TUNG, LEWI, MINE, ELKO, RUBY, and GOSH. These stations from two en echelon arrays that cross the major normal faults in the region (see site location figure). With this station spacing, we will be able to indentify and test physical models that might explain such waveforms. The high velocity accuracy we expect after about 2 years (roughly, the size of the triangles shown on the models below), the GPS data will rigorously limit the range of possible models.





new PBO sites

PBO Dot #	Status or earliest data	Longitude (deg. E)	Latitude (deg. N)	Location
P002	Built	-117.187	39.521	Austin
P005	Permitted	-115.279	39.910	Wild Horse Point
P007	Permitted	-114.820	41.724	Salmon Falls Creek
P013	Permitted	-117.329	41.428	Spring Creek
P069	Built	-117.605	39.288	Campbell Creek
P071	Built	-117.401	39.347	Railroad Pass
P072	Jun-05	-116.741	39.521	Dry Creek
P073	Built	-116.424	39.501	Twin Spring Hills
P074	Built	-116.050	39.546	Devon Peak
P075	Permitted	-115.889	39.374	Pinto Summit SW
P076	Oct-06	-115.513	39.536	Dry Mountain
P077	Permitted	-115.432	39.389	Raven Loft
P079	Permitted	-114.763	39.175	Wagner Flat
P080	Permitted	-114.277	39.119	Willow Patch Spring
P081	Apr-06	-113.871	39.067	Middle Point
P082	May-06	-113.505	39.269	Smelter Hills
P083	Permitted	-117.468	40.321	Tobin Range
P085	Sep-06	-116.736	40.495	Slaven Canyon
P087	Permitted	-116.247	40.349	Cortez Flat
P102	Permitted	-115.556	39.925	Little Bald Mtn

new Tectonics Observatory sites

SITE	Status or earliest data	Longitude (deg. E)	Latitude (deg. N)	250K_QUAD
LACR	install Nov 2006	-115.704	40.851	
MOIL	install Nov 2006	-115.411	40.710	
CLOV	install Nov 2006	-114.874	40.558	

BARGEN sites now part of PBO

SITE	Status or earliest data	Longitude (deg. E)	Latitude (deg. N)	250K_QUAD
NEWS	Oct-97	-117.509	39.686	Millett
TOIY	Feb-03	-117.049	39.542	Millett
FOOT	Mar-97	-113.805	39.369	Delta
ELKO	Oct-97	-115.817	40.915	Elko
RUBY	Jul-96	-115.123	40.617	Elko
GOSH	Jul-96	-114.180	40.640	Elko
EGAN	Mar-97	-114.939	39.345	Ely
LEWI	Jul-96	-116.862	40.404	Winnemucca
MINE	Oct-97	-116.096	40.148	Winnemucca
BAMO	Feb-03	-117.205	40.413	Winnemucca

BARGEN sites part of southern B & R network (Yucca project)

SITE	Status or earliest data	Longitude (deg. E)	Latitude (deg. N)	250K_QUAD
MONI	Mar-99	-116.716	39.148	Millett