Highlights of Geodetic Measurement of the Rifting of Continental Lithosphere in the Walker Lane Western Great Basin, United States

Bill Hammond, G. Blewitt, C. Kreemer, J. Bormann, S. Jha
University of Nevada, Reno, Reno, NV 89557
whammond@unr.edu

University of Nevada, Reno

Nevada Bureau of Mines and Geology

earthscope www.earthscope.org

Active Rifting in the Walker Lane

Are Different Parts of the Walker Lane in Different Stages of Continental Rifting?

The Walker Lane is a zone of active crustal deformation in the western Great Basin which accommodates roughly 25% of the motion between the Pacific and North America plates. Its contemporary deformation, as detected with precise GPS measurements, is predominantly shear with a relatively small component of extension. This deformation is released through a complex system of normal, dextral and sinistral faults that describe a distinct province between the Sierra Nevada/Great Valley (SNGV) microplate and the Basin and Range. The rate of slip on these faults and the kinematics of through-going deformation have been the subject of several GPS studies which are being addressed using block modeling of the northern, central and southern sections [Hammond et al., 2010; Jha et al., 2009; Bormann et al., 2009].

Active transtension in the Walker Lane may be similar to the processes that formed basins prior to rifting in the Gulf of California. It has been suggested that the amount of cumulative offset, and shorter length of faults indicate that it has a lesser degree of development than the San Andreas fault [Wesnousky, 2005]. If so then the amount of Walker Lane structural development also varies along strike, and hence different locations in the Walker Lane can stand as proxies for different degrees of structural development of transtensional rifts in continental lithosphere.

There are substantial along-strike variations in geophysical characteristics in the Walker Lane. These include crustal structure, organization of faulting, geodetically measured deformation characteristics, elevation of valley bottoms, amount of cumulative offset of fault systems, width of the actively deformating zone, and strain rates. One example of these variations is the high standing valley bottoms in the northern Walker Lane versus the below-sea-level bottom of Death Valley in the southern Walker Lane. On balance these characteristics tend to indicate a greater extent of rifting in the south compared to the north. If these variations are related to "degree of development" of a rift, then the Walker Lane may serve as an extremely fruitful locality for the study of the process of continental rifting.

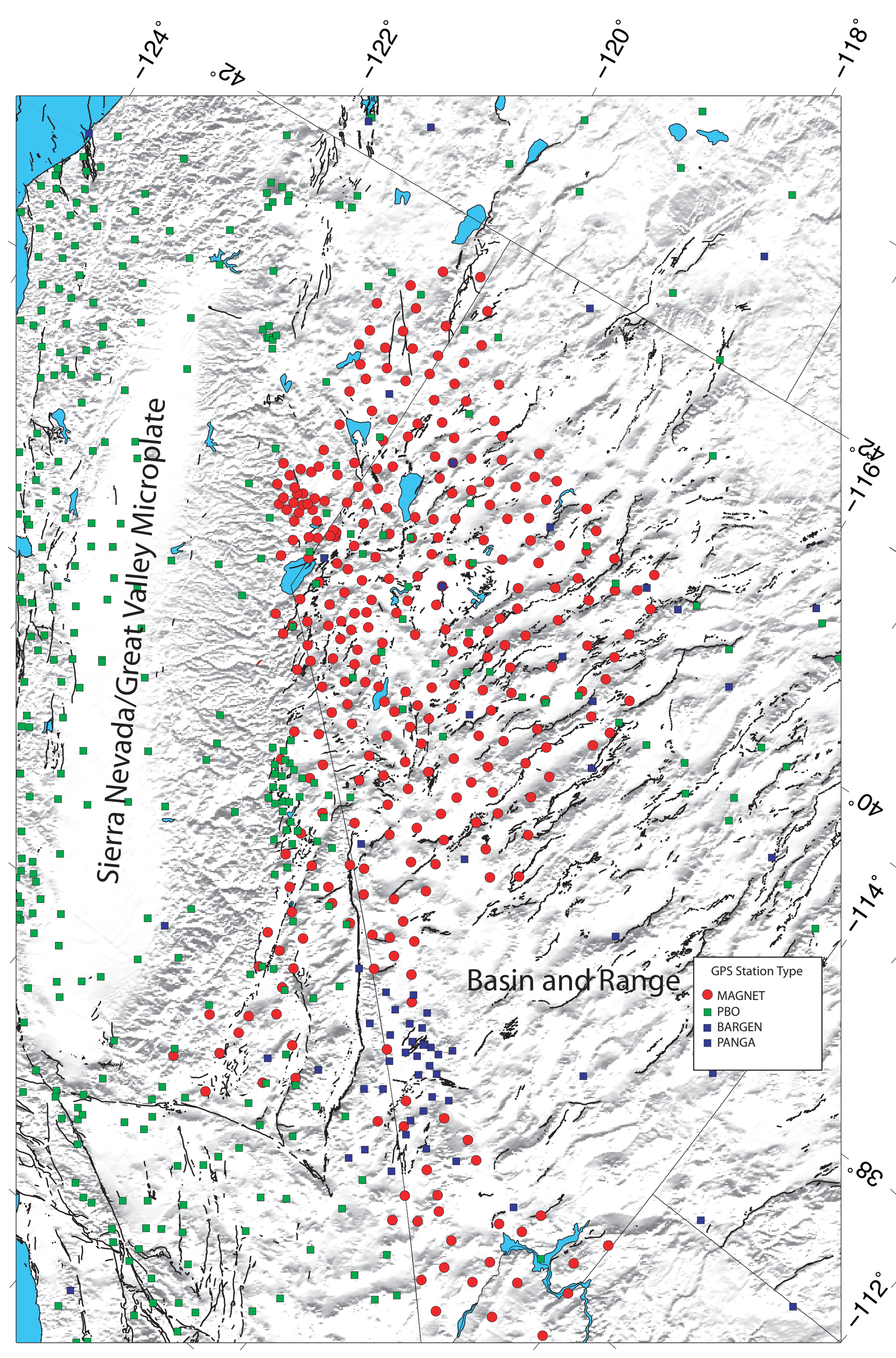
Here we present:

1) The status of geodetic networks in the western Great Basin which include the EarthScope Plate Boundary Observatory (PBO) and the Mobile Array of GPS for Nevada Transtension (MAGNET).

2) Results from modeling crustal blocks motions using GPS and geologic data.

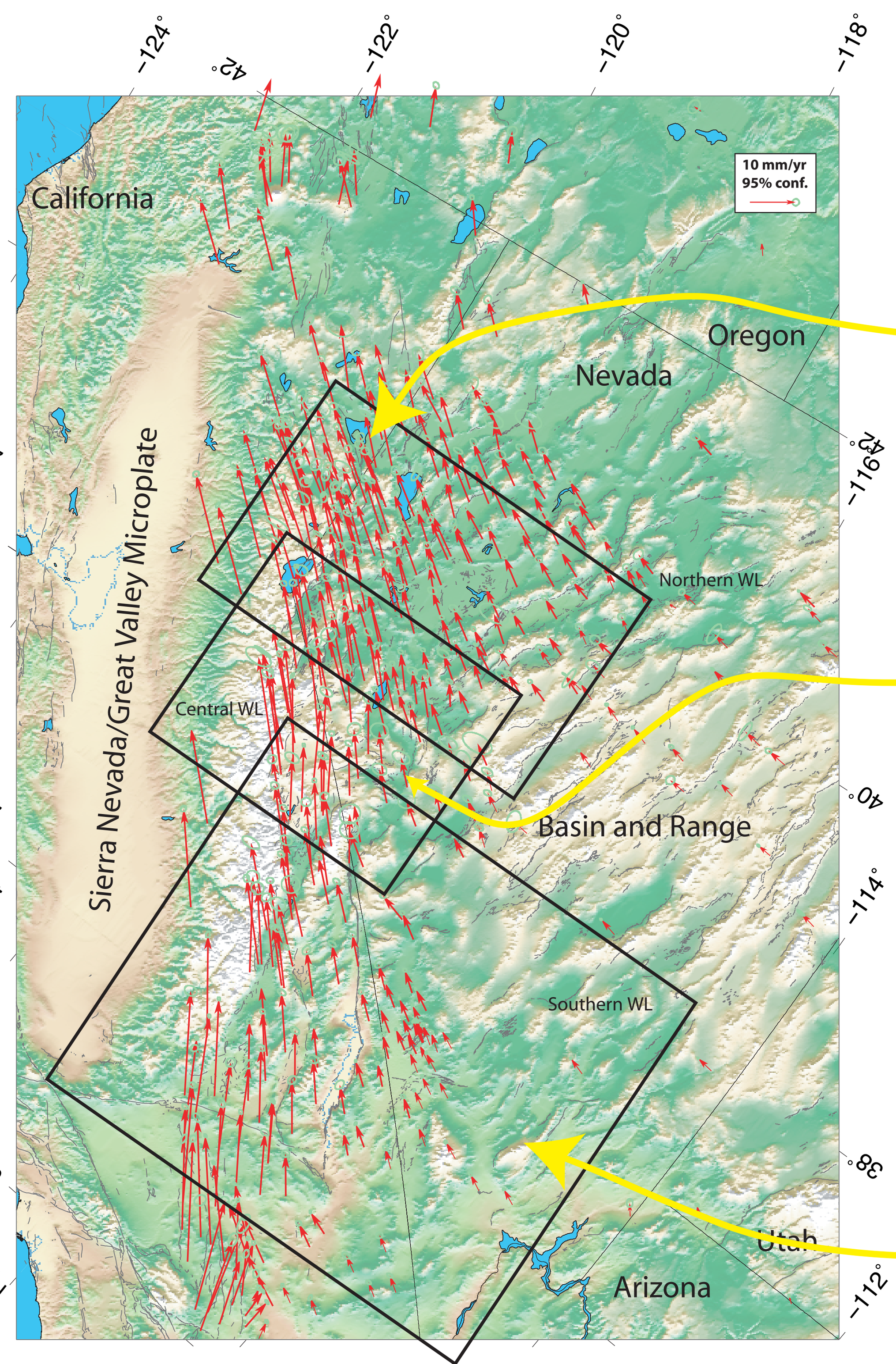
3) Simple estimates of the variation in crustal deformation characteristics along the strike of the Walker Lane that may be symptomatic of the extent of rifting.

The MAGNET GPS Network



Above) GPS sites of the EarthScope Plate Boundary observatory (PBO), nucleus networks (e.g. PANGA and BARGEN), and the Mobile Array of GPS for Nevada Transtension (MAGNET) which is operated by the University of Nevada, Reno. MAGNET coverage of the Walker Lane is nearly complete at 20 km spacing. A number of the sites, especially those in southern Nevada, have been established but not surveyed enough to estimate a velocity (above right). MAGNET sites are "semi-continuous" in most locations, and are surveyed multiple times per year, but for about 1/3 of the network are surveyed episodically (yearly or every other year) as funds and logistics allow.

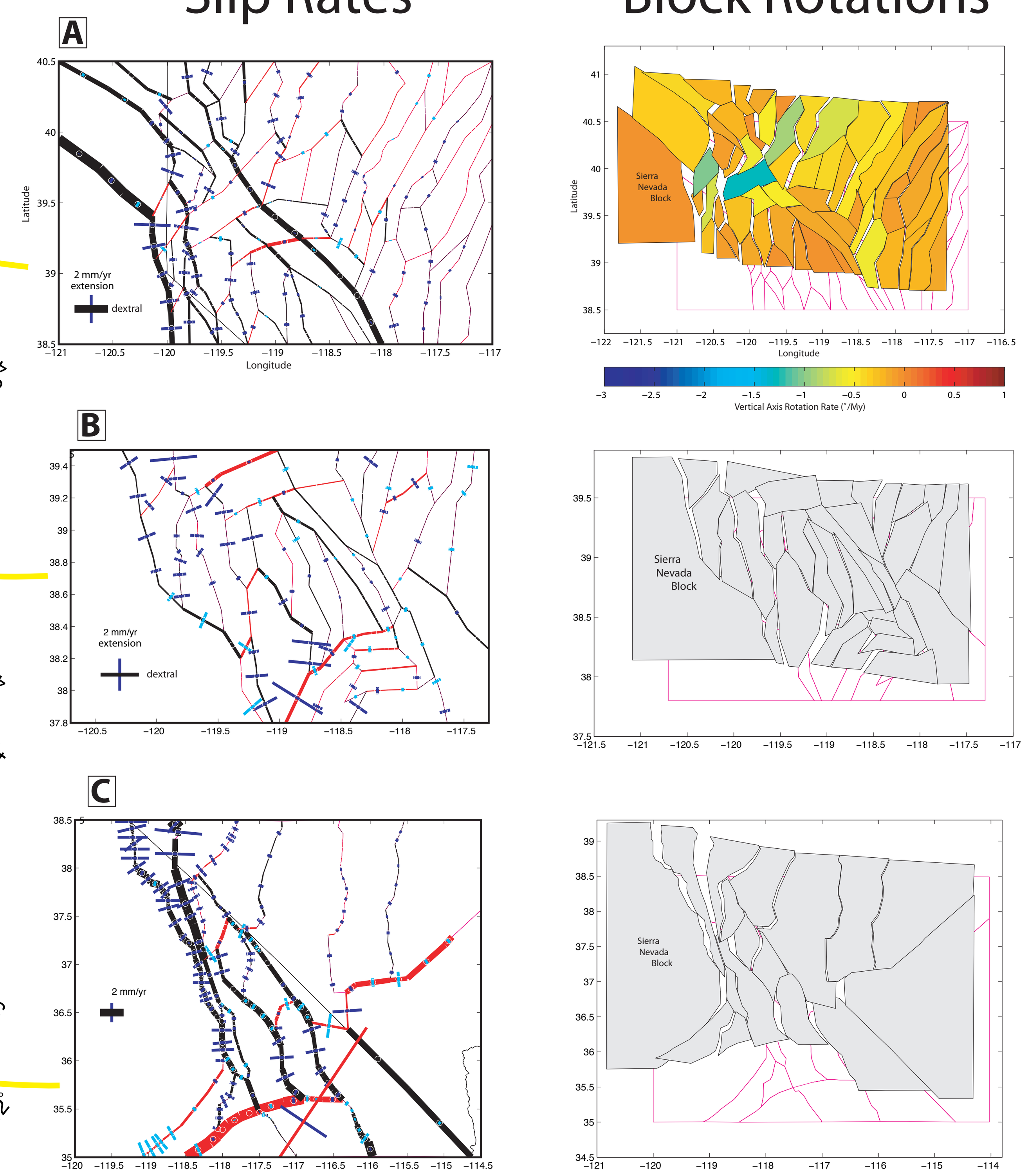
GPS Velocities



Above) GPS velocities in a North America fixed reference frame. Approximately 10 mm/yr of deformation is ongoing across the Walker Lane, but the width of the deformation zone varies from north to south. Black boxes indicate the locations of individual block modelling studies (above right). Velocities near San Andreas fault system are omitted for clarity of rates on and east of the Sierra Nevada. Most (but not all) of the sites in these network (above left) have been surveyed for 2.5 or more years, a point at which the velocity is relatively stable. Additional surveys will be necessary to achieve uncertainties of <0.3 mm/yr for all sites.

Block Models of Crustal Deformation

Slip Rates | Block Rotations



Above) Three block models that depict slip rates on faults (left) and the motions of crustal blocks (right) as constrained by GPS data in the northern (top), central (middle) and southern (bottom) Walker Lane. Thickness of black (red) lines is dextral (sinistral) slip rate. Length of blue (cyan) lines indicates horizontal extensional (thrust) slip rate. The block displacement figures are a massively exaggerated view of the estimate of long-term block motion (interseismic velocity minus estimated fault locking effects).

Our block modeling uses a similar methodology as other recent models of western US deformation (e.g. McCaffrey et al., [2005]; Meade and Hagar, [2005]), but focuses on the Walker Lane, uses a greater number of GPS velocities (e.g. using new PBO data), and includes a a greater number of blocks to capture the details of deformation.

(A) Results for the northern Walker Lane indicate that the greatest rates of slip are farthest west, adjacent to the Sierra Nevada/Great Valley microplate (SNGV). There is also a concentration of higher dextral slip rates on the eastern edge of the Walker Lane, near the Benton Springs, Gumdrop and Petrified Springs faults. Normal slip, however, appears to be distributed across the Walker Lane. The Mohawk Valley Fault, which likely forms the northeast boundary of the SNGV, has the largest slip rate in the model (~2.7 mm/yr).

(B) The central Walker Lane shows less concentration of the dextral slip towards the boundaries, and substantial left-lateral slip in the Mina Deflection. This area appears to transfer the high concentration of deformation seen between the White Mountains and the Sierra Nevada, eastward to the Benton Springs/Petrified Springs dextral zone. This modeling is preliminary.

(C) In the Southern Walker Lane the normal and dextral slip rates are roughly evenly distributed between Death Valley, Panamint/Saline Valley and the Owens Valley, in contrast to the northern Walker Lane.

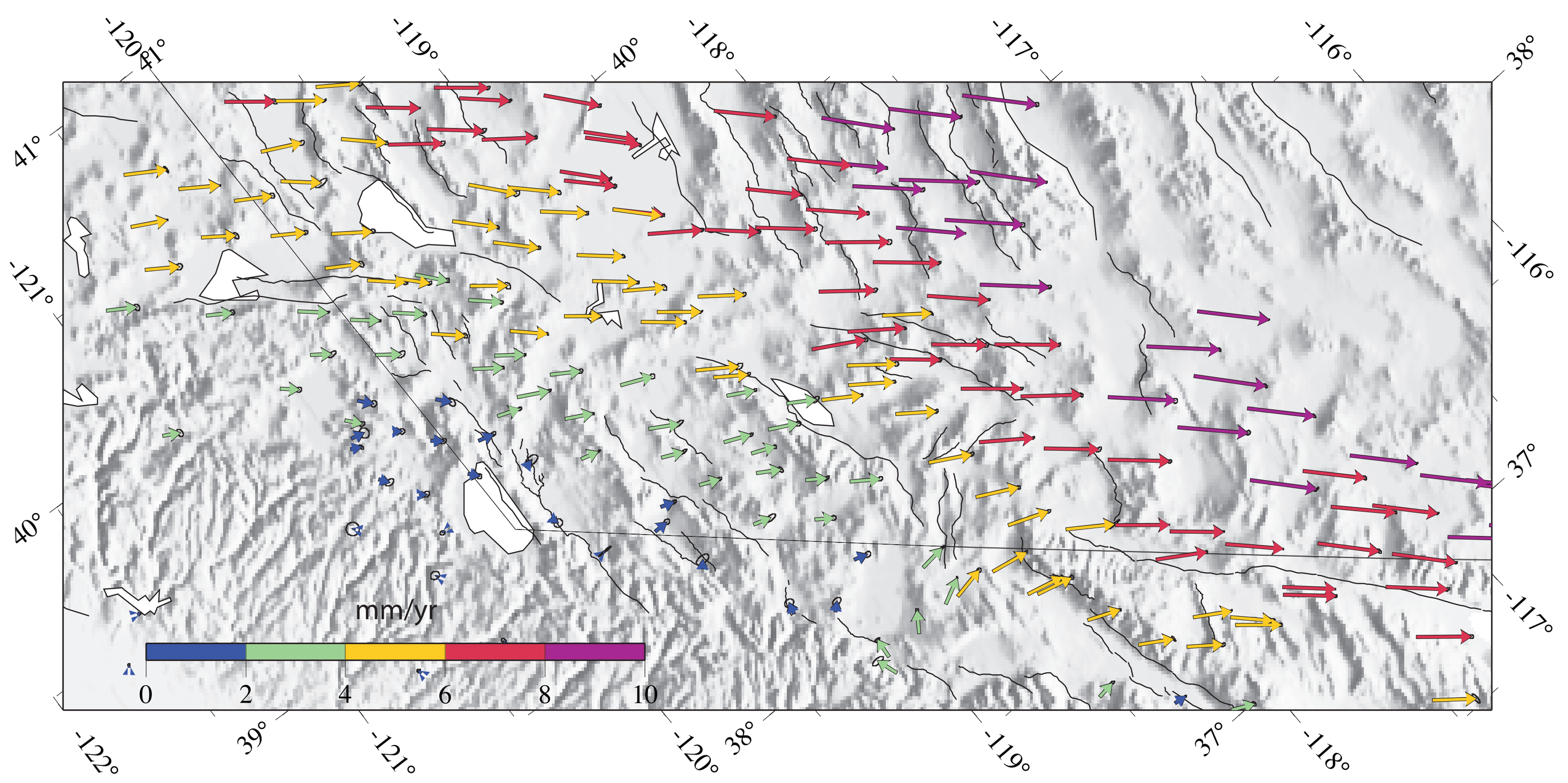
In all three of these models corrections have been applied to the GPS velocity field that compensate for the effcts of postseismic viscoelastic relaxation from 19th and 20th century earthquakes [Hammond et al., 2009; Hammond et al. , 2010].

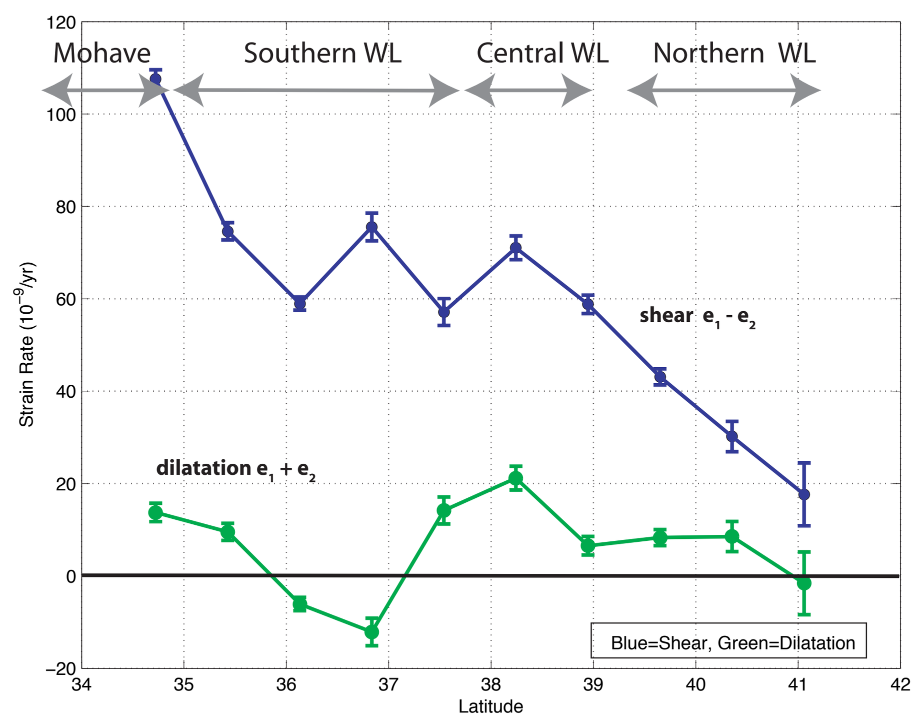
Below Left) GPS velocities in an oblique view of the northern Walker Lane. Here the velocities are with respect to the nothern part of the Sierra Nevada/Great Valley microplate (SNGV), and the projection of the map is around the Sierra Nevada/North America Euler pole of rotation. In this figure velocities parallel to the figure boundary move parallel to the SNGV/NA relative motion. Colors indicate the magnitude of velocity in this reference frame.

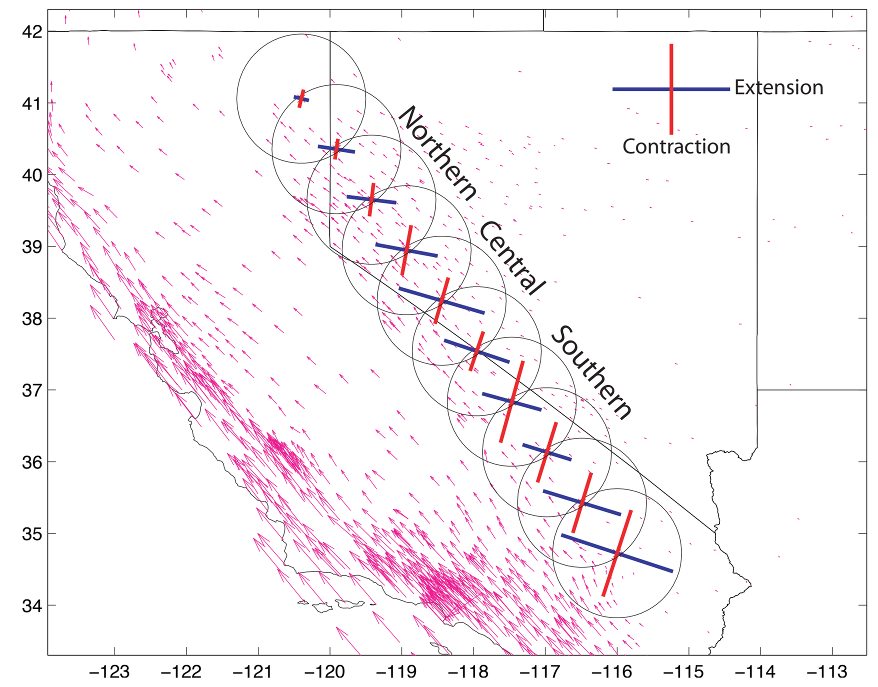
The figure provides an illustration of the tearing away of the SNGV from the interior of the Great Basin, and how this strain is focused near the boundary of the microplate. This deformation is likely a response to misalignment of the eastern boundary of the SNGV with respect to its direction of motion [Unruh, 2003]. Velocities near Honey Lake/ Mohawk Valley are parallel to these dextral faults, and the gradients in velocity are normal to the faults.

Below) The intensity of the contemporary shear strain rate ($e_1 - e_2$) is a strong function of latitude in the Walker Lane (blue line below left, and tensor strain axes below right). This is associated with a widening of the deformation zone from south to north. There are also more subtle changes in the style of deformation that are marked by transitions between positive and negative dilatation (green line below). These changes can be seen clearly in the block models (above right) and may be related to changes in strike of the SNGV/Basin and Range boundary, strength variations in the Walker Lane lithosphere, and/or amount of cumulative slip on the faults that are accommodating the deforamtion.

These variations may be related to "degree of development" of the Walker Lane rift. They and other properties that vary from north to south may indicate that the Walker Lane is presently in various stages of rifting that could eventually lead to more extreme attenuation of the lithosphere. If so the Walker Lane may serve as an extremely valuable case study of continental rift-forming processes.







References

Bormann, J., W. C. Hammond, C. Kreemer, G. Blewitt, and S. G. Wesnousky (2009), Geodetic constraints on shear accommodation in the northern Walker Lane, western Nevada, USA, Eos transactions AGU, 90(52) Fall Meet Suppl., Abstract G33B-0651.
Hammond, W. C., C. Kreemer, and G. Blewitt (2009), Geodetic constraints on contemporary deformation in the northern Walker Lane: 3, Postseismic relaxation in the Central Nevada Seismic Belt, in Late Cenozoic Structure and Evolution of the Great Basin – Sierra Nevada Transition, edited by J. S. Oldow and P. Cashman, pp. 33-54, Geological Society of America.
Hammond, W.C., Kreemer, C., Blewitt, G., Plag H.-P., 2009, The effect of viscoelastic postseismic relaxation on estimates of interseismic crustal strain accumulation at Yucca Mountain, Nevada, Geophys. Res. Lett., in press.
Hammond, W.C., G. Blewitt, C. Kreemer, Crustal deformation of the northern Walker Lane and Basin and Range from GPS measurements, in prep.
Jha, S., W. C. Hammond, C. Kreemer, and G. Blewitt (2009), New GPS constraints on Owens Valley fault slip rates, Eos transactions AGU, 90(52), Fall Meeting Supplement, Abstract G23A-0666.
McCaffrey, R. (2005), Block kinematics of the Pacific-North America plate boundary in the southwestern United States from inversion of GPS, seismological and geologic data, Journal of Geophysical Research, 110, B7, doi:10.1029/2004JB002207.
Meade, B. J., and B. H. Hagar (2005), Block models of crustal motion in southern California constrained by GPS measurements, Journal of Geophysical Research, 110, B03403, doi:10.1029/2004JB003209.
Unruh, J. R., J. Humphrey, and A. Barron (2003), Transtensional model for the Sierra Nevada frontal fault system, eastern California, Geology, 31, 4, 327-330.
Wesnousky, S. G. (2005), The San Andreas and Walker Lane fault systems, western North America: transpression, transtension, cumulative slip and the structural evolution of a major transform plate boundary, J. Struct. Geol., 27, 1505-1512.