2nd PBO Workshop Mini-Proposal

The Baja California Shear Zone: A strain by-pass south of the San Andreas "big bend" in northern Baja California

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The primary objectives of the Plate Boundary Observatory (PBO) facility are to create a four-dimensional image of crustal deformation in western North America and to characterize the dynamics of this deformation. By illuminating the spatial and temporal patterns of deformation, the PBO facility will shed light on the rheological structure of the crust and lithosphere, the force systems driving deformation, and the nature of strain transients associated with earthquakes, particularly how they affect fault interactions within diffuse continental fault systems. The primary instrument of the PBO will be a network consisting of more than 1000 continuous GPS (CGPS) stations comprised of a backbone array, which will provide a synoptic view of Pacific-North America-Juan de Fuca plate interactions, and several dense clusters of CGPS instruments to be deployed in areas requiring greater spatial and/or temporal resolution.

Northwest Baja California (Figure 1) represents an ideal focal point for one of PBO's dense deployments of CGPS stations. The fault zones of this region play an important kinematic role in accommodating Pacific-North America relative plate motion, allowing strain to by-pass the large restraining bend in the San Andreas fault to the north (the "big bend") by transferring fault slip from the Gulf of California westward to fault zones in coastal and offshore southern Alta California. Although existing Baja campaign GPS measurements (supplemented by extremely sparse CGPS coverage) have begun to delineate the distribution of strain accumulation across this part of the plate boundary zone [e.g., *Bennett et al.*, 1996; *Dixon et al.*, 2000a] as well as providing constraints on Pacific-North America relative plate motions [e.g., *Dixon et al.*, 1991; *Bennett et al.*, 1996; *Antonelis et al.*, 1999; *Dixon et al.*, 2000b], it is clear that significant densification of geodetic measurements, in both space and time, is necessary; precise measurement of the distribution and sum of deformation accommodated within this Baja California shear zone is crucial to an understanding of the kinematics of the greater Pacific-North America plate boundary zone as a whole; the distribution of deformation and the nature of fault interactions within this shear zone, moreover, have direct implications for fault zone rheology and seismic hazards in northern Baja and southern Alta California.

The Baja California shear zone is an important component of the transition from relatively narrow and fairly well defined ocean-like ridge-transform signatures in the southern Gulf of California to the diffuse transform deformation of northern Baja California and southern Alta California. A long standing question that can be directly addressed with a dense deployment of CGPS stations is therefore how fault slip is transferred from the northern Gulf of California--the core location of this transition from ocean spreading to continental transform deformation--to the fault zones of northwest Baja. These fault zones include the Agua Blanca, San Miguel-Vallacitos, and Laguna Salada fault zones. The details of strain accumulation across these fault zones have important implications for the nature of this transition [e.g., *Goff et al.*, 1987; *Nagy and Stock*, 2000]. Most of the faults in northern Baja, furthermore, are not pure strike-slip faults, but instead involve some amount of fault-perpendicular extension or contraction. By integrating a dense CGPS network in the vicinity of these faults with the broader scale PBO network, we would be able to quantify, for the first time, the components of strain accumulating normal to these fault zones.

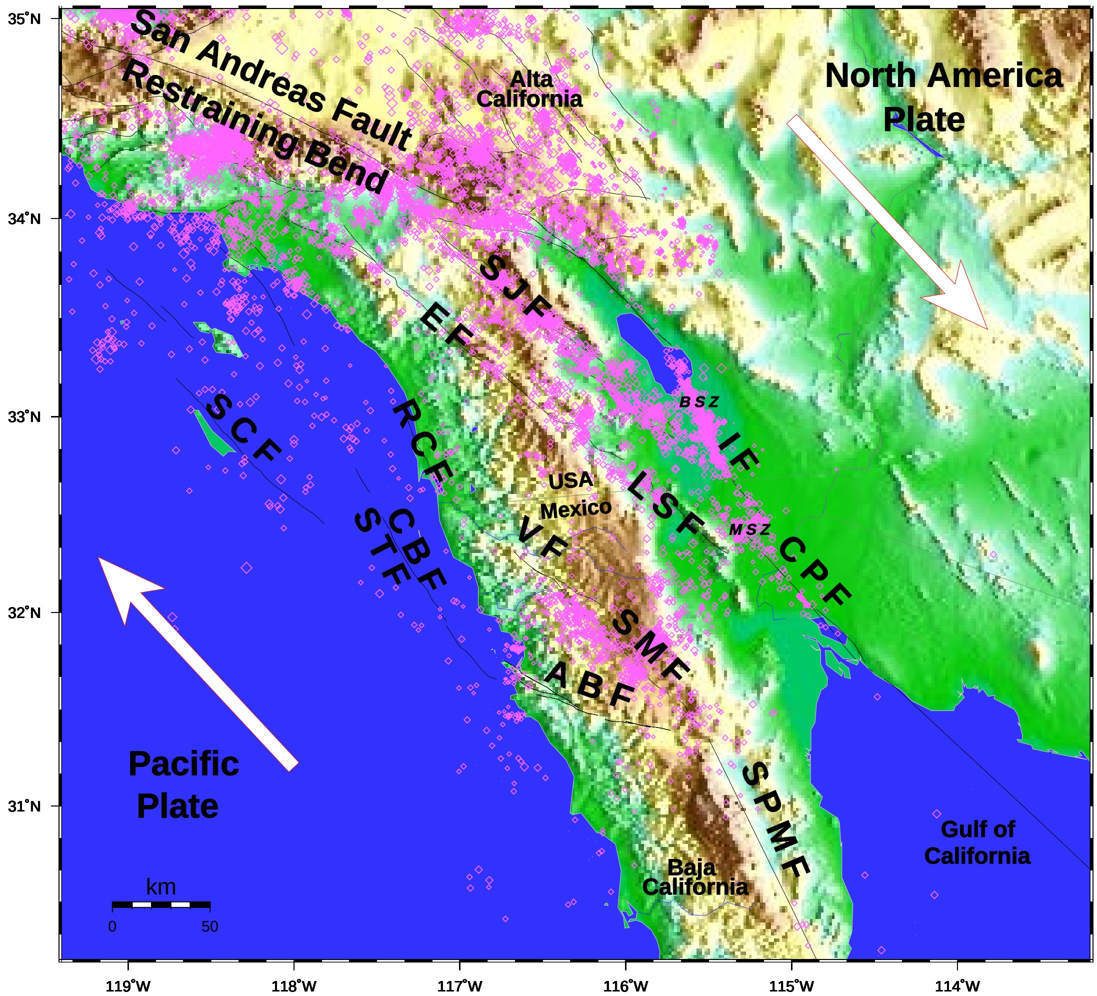

Figure 1 Location map showing major Quaternary fault zones and seismicity of northern Baja California, Mexico, and southern Alta California, USA. Arrows show the sense of relative motion between the Pacific and North America plates. ABF = Agua Blanca fault, BSZ = Brawley Seismic Zone, CBF = Coronado Bank fault, CPF = Cerro Prieto fault, EF = Elsinore fault, IF = Imperial fault, LSF = Laguna Salada fault, MSZ = Mexicali Seismic Zone, RCF = Rose Canyon fault, SCF = San Clemente fault, SJF = San Jacinto fault, SMF = San Miguel fault, SPMF = San Pedro Martir fault, STF = San Diego Trough fault, VF = Vallacitos fault.

How fault slip is transferred from the faults of northern Baja California to the faults of coastal and offshore southern Alta California, including the Coronado Bank, San Diego Trough-Bahia Soledad, San Clemente, Rose Canyon, and Elsinore fault zones, as well as the newly discovered Oceanside and Thirtymile Bank blind thrusts [*Rivero et al.*, 2000], remains another important as yet unanswered question that the PBO will be well suited to address. A dense array of stations in northwest Baja is clearly a prerequisite for complete coverage of the Pacific-North America plate boundary zone at the latitude of Ensenada. To the extent that the faults of northern Baja are kinematically linked to those of coastal and offshore Alta California, a concentration of CGPS stations in northwest Baja will also provide important constraints on the slip rates of these Alta California fault zones and associated seismic hazards.

The distribution of deformation in northwest Baja, moreover, has implications for fault zone dynamics and time dependent deformation processes. The relatively quiescent Agua Blanca fault zone is an active major right lateral fault zone cutting across northern Baja with total offset of at least 15 km [*Allen*, 1960], whereas the seismically active San Miguel-Vallacitos fault zone to the northeast, in contrast, exhibits a total offset of only 250 m [*Hirabayashi et al.*, 1996]. Is the difference in seismic behavior indicative of these fault zones being in opposite stages of the earthquake cycle, or is the difference attributable to the different orientations of these fault zones with respect to the direction of relative plate motion, one being favored over the other, or perhaps to differences in the strength and/or age of these fault zones? The distribution of deformation along and between these fault zones thus bears on fault zone rheology, the nature of transient deformation associated with past earthquakes, fault-fault interactions, as well as seismic hazards assessment [e.g., *Dixon et al.*, 2000a]. Dense arrays of CGPS stations are capable of detecting, in only a few years, small amplitude patterns in the deformation field potentially related to large historic earthquakes (Figure 2) [e.g., *Wernicke et al.*, 2000; *Bennett et al.*, 2000]. A dense CGPS array targeting the Agua Blanca and San Miguel-Vallacitos fault zones may thus present a unique opportunity to simultaneously achieve many of the scientific goals of the PBO.

Comparison of new GPS determinations of Pacific-North America plate motion from IGS stations, site velocities from campaign GPS in northern Baja, site velocities from CGPS stations of the SCIGN network in southern Alta California, and spreading rates in the Gulf of California since 3.5 Ma imply that Pacific-North America relative plate motion has been accommodated by both sea floor spreading in the Gulf of California and decelerating slip along faults offshore peninsular Baja California [*DeMets and Dixon*, 1999]. This transfer of Baja California to the Pacific plate may not yet be complete; in fact, as much as 3-4 mm/yr of right lateral fault slip appears to be accommodated along on an unidentified fault or faults offshore peninsular Baja [*Dixon et al.*, 2000b; *Fletcher et al.*, 2000]. CGPS stations in northwest Baja California, supplemented by CGPS stations on the islands offshore peninsular Baja (e.g. Isla Guadalupe) are needed in order to quantify this offshore deformation. Stations offshore Baja would also greatly assist with the definition of a stable Pacific plate, which would surely benefit a large number of PBO investigations.

A dense cluster of CGPS stations in northern Baja would thus bear on a variety of PBO's scientific objectives. We therefore recommend that the PBO facility include a total of 50 stations (25 shared with the dense array to be deployed in the vicinity of the San Andreas fault system) in northwest Baja. This array should include a heavy concentration of approximately 35-40 CGPS stations around the Agua Blanca and San Miguel-Vallacitos fault zones (to affect station spacing comparable to that proposed for the San Andreas system), an approximately 7-12 station augmentation to the SCIGN and PBO arrays in the vicinity of the Rose Canyon fault zone--the northwest continuation of the San Miguel-Vallacitos fault zone--in southern Alta California (again with the objective of uniform station coverage), and 2-3 stations on the far islands offshore peninsular Baja California (e.g., Isla Guadalupe) in order to fully capture the total deformation rate across the plate boundary zone.

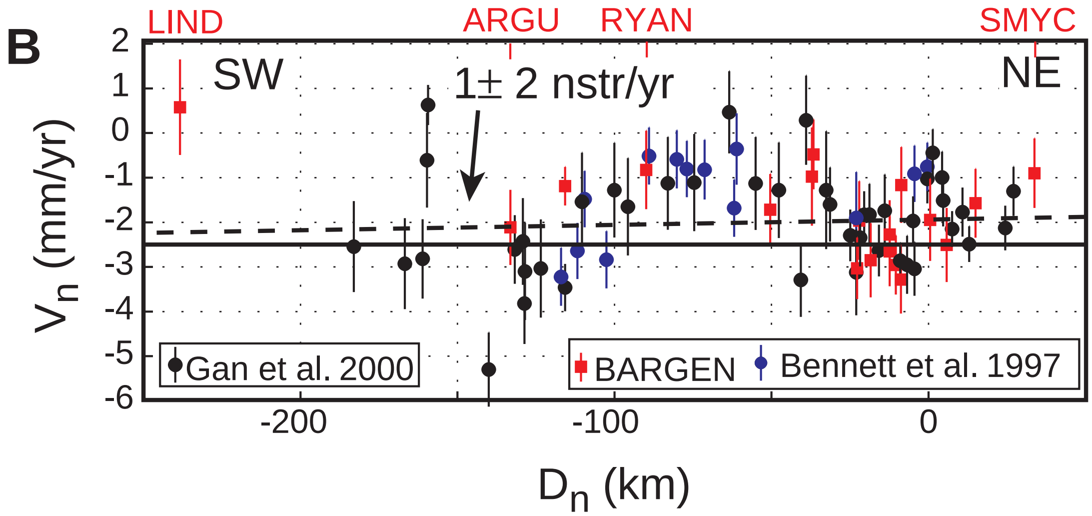

Figure 2 Shear zone perpendicular components of the eastern California shear zone (ECSZ) strain field across the Death Valley region showing an anomalous oscillatory pattern in the strain field possibly associated with the 1872 Owens Valley earthquake. N62E components of velocity estimates are projected onto a N62E plane. Dn and Vn indicate distance and velocity normal to the direction of ECSZ shear. Dn is measured from a point in the Nevada Test Site. Data from less than 2 years of BARGEN CGPS data (red), and campaign data modified from *Bennett et al.* [1997](blue) and *Gan et al.* [2000](black). Error bars represent one standard deviation. Dashed line represents the uniform extensional strain model. Net extension across the region is insignificant (1+-2nstr/yr). The solid horizontal line represents the motion of the eastern Basin and Range with respect to the Colorado Plateau. The small offset between the dashed and solid line (<1mm/yr) between the best fit to the velocity estimates (strain model) and the kinematic model for the eastern Basin and Range (a block model) reflects reference frame differences.

The new geodetic measurements that we propose will complement ongoing field studies, mapping, and geodynamic modeling aimed at a better characterization of the segmentation, kinematics, and architecture of the important faults of northern Baja California. This multidisciplinary effort will greatly facilitate explanation of the space-time pattern of seismic-energy release and surface deformation in northern Baja California.

References

Allen, C. R., L.T. Silver, F.G. Stehli, Agua Blanca fault -- a major transverse structure of northern Baja California, Mexico, *Bull. Seis. Soc. Am.*, 71, 457-482, 1960.

Antonelis, K. D.J. Johnson, M. M. Miller, R. Palmer, GPS determination of current Pacific-North America plate motion, *Geology*, 27, 299-302, 1999.

Bennett, R.A., W. Rodi, and R.E. Reilinger, GPS Constraints on Fault Slip Rates in Southern California and Northern Baja, Mexico, *Journ. Geophys. Res.*, 101, 21,943-21,960, 1996.

Bennett, R.A., J.L. Davis, P. Elosegui, B.P. Wernicke, J.K. Snow, M.J. Abolins, M.A. House, G. L. Stirewalt, and D. A. Ferrill, Global Positioning System Constraints on Fault Slip Rates in the DeathValley Region, California and Nevada, *Geophys. Res. Lett.*,24, 3073-3076, 1997.

Bennett, R.A., B.P. Wernicke, N.A. Niemi, A.M. Friedrich, J.L. Davis, Contemporary strain fields in the northern Basin and Range province from BARGEN continuous GPS data, to be submitted to *Journ. Geophys. Res.*, 2000.

DeMets, C., T.H. Dixon, New kinematic models for Pacific-North America motion from 3 Ma to present, I: evidence for steady motion and biases in the NUVEL-1A model, *Geophys. Res. Lett.*, 13, 1921-1924, 1999.

Dixon, T.H., G. Gonzalez, S.M. Lichten, D.M. Tralli, G.E. Ness, J.P. Dauphin, Preliminary determination of Pacific-North America relative motion in the southern Gulf of California using the Global Positioning System, *Geophys. Res. Lett.*, 18, 861-864, 1991.

Dixon, T.H., J. Decaix, F. Farina, R.A. Bennett, F. Suarez-Vidal, J. Fletcher, Present-day slip rate for the Agua Blanca and San Miguel-Vallacitos faults in northern Baja California, Mexico, to be submitted to *Journ. Geophys. Res.*, 2000a.

Dixon T.H., F. Farina, C. DeMets, F. Suarez-Vidal, J. Fletcher, B. Marquez-Azua, M. Miller, O. Sanchez, P. Umhoefer, New kinematic models for Pacific-North America motion from 3 Ma to present, II: Tectonic implications from Baja and Alta California, *Geophys. Res. Lett.*, submitted, 2000b.

Fletcher, J.M., B.W. Eakins, R.L. Sedlock, R. Mendoza-Borunda, R.C. Walter, R.L. Edwards, and T.H. Dixon, Quaternary and Neogene slip history of the Baja-Pacific plate margin: Bahía Magdalena and the southwestern borderland of Baja California, *EOS, Trans. AGU*, 2000.

Gan, W., J.L. Svarc, J.C. Savage, W.H. Prescott, Strain accumulation across the eastern California shear zone at latitude 36.5N, *Journ. Geophys. Res.*, 16,229-16,236, 105, 2000.

Goff, J. A., E. A. Bergman, S. Solomon, Earthquake source mechanisms and transform fault tectonics in the Gulf of California, *Journ. Geophys. Res.*, 92, 10,485-10,510, 1987.

Hirabayashi, C.K., T.K. Rockwell, S.G. Wesnousky, M.W. Stirling, F. Suarez-Vidal, A neotectonic study of the San Miguel-Vallacitos fault, Baja California, Mexico, *Bull. Seis. Soc. Am.*, 86, 1770-1783, 1996.

Nagy, E.A., J.M. Stock, Structural controls on the continent-ocean transition in the northern Gulf of California, *Journ. Geophys. Res.*, 105, 16,251-16,269, 2000.

Rivero, C., J.H. Shaw, K. Mueller, Oceanside and Thirtymile Bank blind thrusts: Implications for earthquake hazards in coastal southern California, *Geology*, 28, 891-894, 2000.

Wernicke, B.P. A. M. Friedrich, N.A. Niemi, R.A. Bennett, J.L. Davis, A “broadband” perspective on the dynamics of plate boundary fault systems from the Basin and Range Geodetic Network (BARGEN) and geologic data, *GSA Today*, in press, 2000.