PBO Mini Proposal: Measurement of Rates of Deformation Across the Rio Grand Rift and Rotation of the Colorado Plateau

Proposal Team Principal Area of Expertise
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Motivation

The Rio Grande Rift should not be ignored in the PBO initiative. Although extension rates are low [Formento-Trigilio and Pazzaglia, 1998], ignoring the region could lead to a significant misunderstanding of the dynamics and kinematics of the Pacific-North America and North America – Juan de Fuca plate interaction [Turcotte and Schubert, 1982]. Two different densities of stations are necessary. First, the backbone array needs to include stations both east and west of the Rio Grande Rift (stations on the Colorado Plateau). Second, it should be possible to place continuous instruments within and on the margins of the rift zone to quantify rates of extension, and gradients of extension rate from north to south along the rift. Gradients of extension along the rift zone will be important for quantifying rotation rates of the Colorado Plateau. The backbone array will help quantify far-field motions and rotations accommodated across the rift zone. The denser array established along the length of the rift zone will help quantify strain rates within the rift zone, as well as possible testing of active versus passive rifting processes [e.g. Ruppel, 1995].

Recent controversy has centered on the amount of Colorado Plateau rotation, which has significant implications for interpretation of apparent polar wander paths during the Mesozoic. Kent and White [1993] have proposed large rotations with respect to North America of 13.5 ± 3 degrees clockwise, whereas Garza et al. [1998] have proposed a lower rotation of 8.8± 3.6 degrees clockwise relative to stable North America. Kent and White [1993] have argued that much of the rotation of the Colorado Plateau has probably been accommodated by extension across the Rio Grande Rift.

A rotation rate for the Colorado Plateau with respect to North America of less than 0.5°/Myr, if ignored in future dynamic and kinematic analyses, would lead to a significant misunderstanding of Pacific-North America interaction. For example, Shen-Tu et al. [1999] have inferred Pacific plate motion relative to the western margin of the Colorado Plateau using strain rates inferred from Quaternary fault slip rates (Figure 1). Shen-Tu et al. [1999] find that integrated rates of strain lead to a velocity vector direction of Pacific Plate relative to North America (assuming that Colorado Plateau is NOT moving with respect to North America) that is 5-6° anticlockwise of the NUVEL-1A Pacific-North America vector [DeMets et al., 1994]. Humphreys and Weldon [1994] also found such a result using the line integral method. Using GPS data the discrepancy in azimuth of Pacific-North America motion with the NUVEL-1A model is only 2 – 3°anticlockwise at the latitude of 33 – 36° N [Larson et al., 1997; Shen-Tu et al., 1999; Antonelis et al., 1999; Kreemer et al., 2000] (see Figure 2 from Shen-Tu et al., [1999]). Shen-Tu et al. [1999] inferred that the anticlockwise discrepancy of vector azimuth inferred from geologic information indicated that a marginally statistically significant amount of deformation must be occurring offshore of southern and central California [Figure 3]. That is, accounting for such deformation would presumably remove the discrepancy in vector azimuth of 2-3° between Pacific-North America motion inferred from geologic slip rate information and that inferred from

GPS data. An interesting possibility, however, is that some of the discrepancy observed using the geologic slip rate data might be attributed to Colorado Plateau rotation relative to North America. The velocity difference in Figure 3 can be explained, in part, by an anticlockwise rotation rate about a pole that lies at about 40° N, 120° W., with a rate around 0.1 – 0.15°/Myr. Could such a correction pole of rotation indicate that the Colorado Plateau is rotating clockwise relative to North America about a pole in this vicinity and at about this rate? Rotation rates of this magnitude would imply rates of stretching (and shear) of 1 –3 mm/yr across the Rio Grande Rift and would be consistent with total Cenozoic rotation magnitudes. Indications to date that such motions are in fact occurring across the rift zone come from VLBI stations KP-VLBA (32.0°N, 111.6°W, active 6 years) and FD-VLBA (30.6°N, 103.9°W, active 8 years), which show motions relative to stable North America of 3.2±0.4 mm/yr with azimuth 313°, and 2.2±0.4 mm/yr with azimuth 318°, respectively [Ma and Ryan, 1998].

In the larger picture of understanding the dynamics of the plate boundary zone, resolving the kinematics across the Rio Grande rift zone cannot be ignored. Activity along the Rio Grande rift zone can influence the interpretation of all velocity vectors measured west of the rift zone (since many interpretations will hinge on estimates of motions in a North American reference frame). If the Rio Grande Rift is assumed to be inactive (equivalent to the assumption that the Colorado Plateau is not moving with respect to North America) then many of the inferred rates of deformation that lie west of the Colorado Plateau could be in error.

Station Deployment and Reference Frame Problems

In order to measure such low rates of strain across the rift, installation of some permanent stations will be necessary. Also, it will be crucial to determine accurate frames of reference. Reference frame is a significant source of error when determining the rigid body kinematics of suspected plates/microplates. First of all, it is essential that there is a spatially well-distributed network of stations on all the hypothetical blocks under investigation. Rigorous tests can be imposed on fiducial-free solutions [Davies and Blewitt, 2000] to ensure rigidity of station sub-sets, so in that sense, conventional frames are not an issue. Rather, the deployment of an appropriate spatial distribution of stations is critical.

However, even in the case where fiducial-free solutions are used, different values for the net translation rate of a network can map into relative angular velocity, and hence quantities such as spreading rates at plate boundaries [Blewitt and Davies, 1995; Argus, 1999; Blewitt and Lavallee JGR in review]. For plate rotation kinematics, Euler's fixed point of rotation must be assumed. GPS error in realizing crustal kinematics with respect to the Earth center of mass is at a level where small but significant errors can affect interpretation. Quantifying these errors, and mitigating them (e.g., through frame alignment with SLR) is therefore an important issue for investigations of small relative rates of rotation. The study of intracontinental rifts therefore critically depends upon not only an appropriate network design in the near field, but also of the far field, and ultimately the entire global network (which fortunately, is already adequate).

Before submission of a complete proposal (if this pre-proposal is approved), we plan to perform kinematic modeling of existing GPS vectors throughout North America. In the kinematic modeling we plan to test hypotheses (testing various rotation poles of Colorado Plateau-North America) and determine optimal station distribution and error and reference frame tolerance. For example, allowing for Colorado Plateau rotation, and using all available Quaternary fault slip rate information [e.g. Shen-Tu et al., 1999] can discrepancies between Pacific-North America motion inferred from geologic information compared with that inferred from the most recent GPS observations [e.g. DeMets and Dixon, 1999] be removed? What station distribution is optimal to test passive rift processes? What station distribution is best for testing active rift processes? What distribution of stations on the Colorado Plateau, and around the rift zone itself, are best for resolving rotation rates for the Colorado Plateau? If approved, we also plan to seek collaboration with scientists with specific expertise in Rio Grande Rift Tectonics, including possible collaboration with groups at Socorro (New Mexico Tech), University of Texas at El Paso, Albuquerque (UNM), and Las Cruces (NMSU).

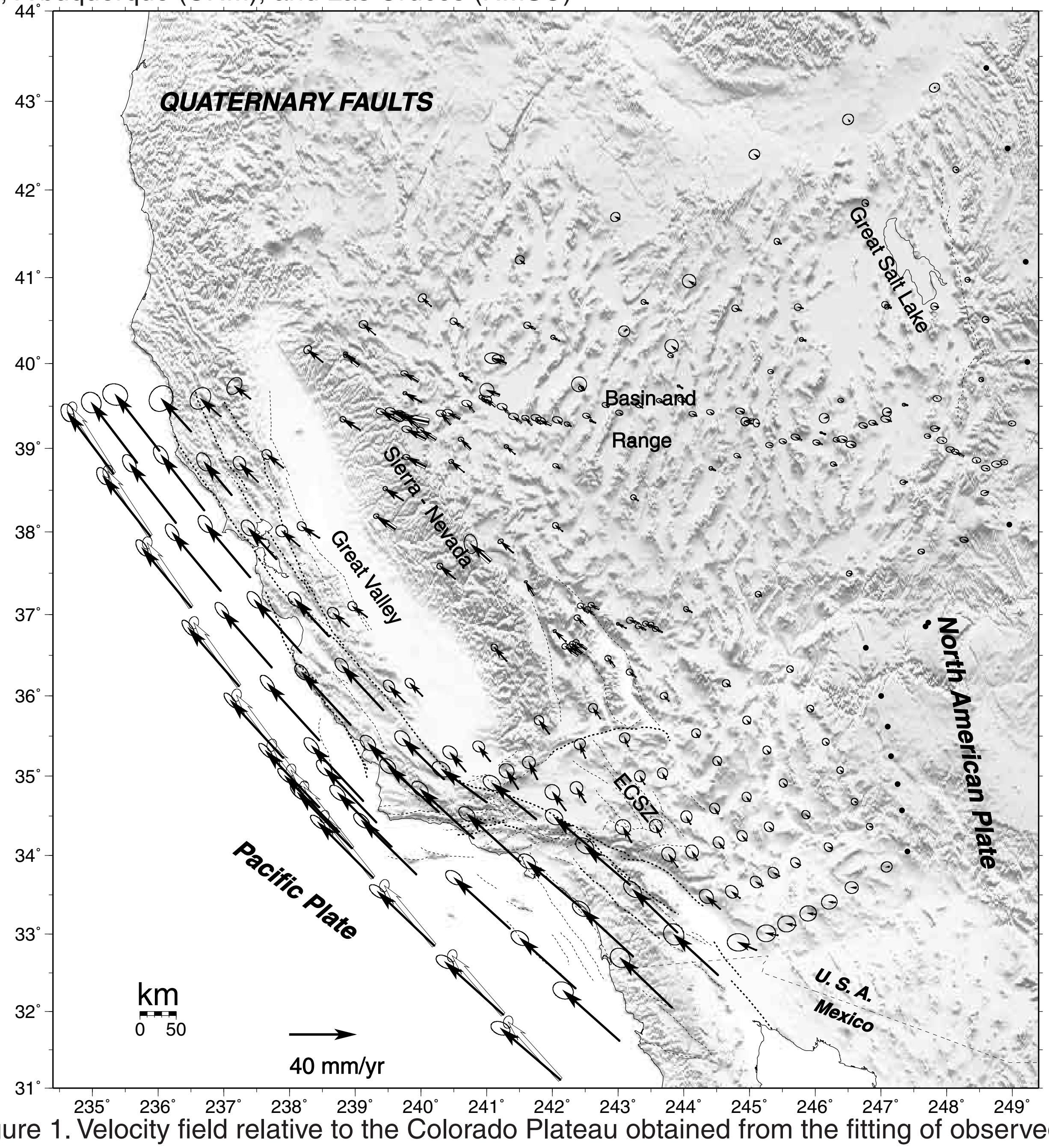

Figure 1. Velocity field relative to the Colorado Plateau obtained from the fitting of observed geological strain rates [see Shen-Tu et al., 1999] with continuous spline functions. Error ellipses are for 95% confidence interval. The open arrows on the Pacific plate show the plate motion direction of Pacific relative to North America from NUVEL-1A [DeMets et al., 1994]. Open arrows in the Basin and Range are GPS velocities from Bennett et al. [1999] and Thatcher et al. [1999]; model vectors from the solution are plotted in black on top of these observations. The total velocity obtained the strain rates is about the same magnitude of NUVEL-1A, but 5-6° counterclockwise of the NUVEL-1A predicted Pacific-North America plate motion.

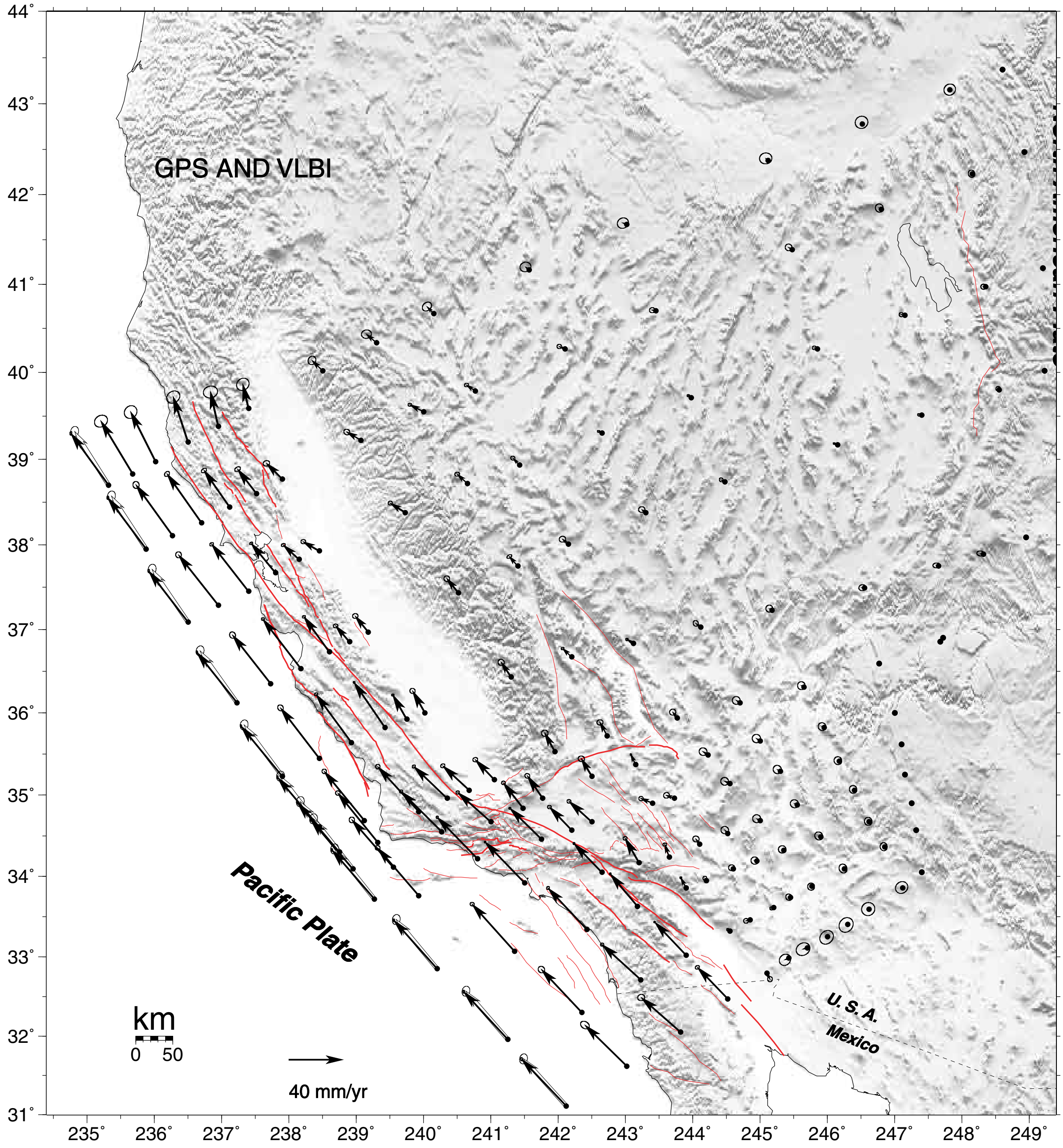

Figure 2. Model velocity field (solid arrows) relative to North America obtained from the inversion of 622 geodetic velocities [see Shen-Tu et al., 1999]. Error ellipses are for 95% confidence. The open arrows on the Pacific Plate are the NUVEL-1A predicted Pacific-North America motion. Model Pacific-North America velocity azimuths are about 2-3° counterclockwise of vector azimuths of Pacific-North America motion predicted by the NUVEL-1A model. However, these differences are not currently significant at the 95% confidence interval.

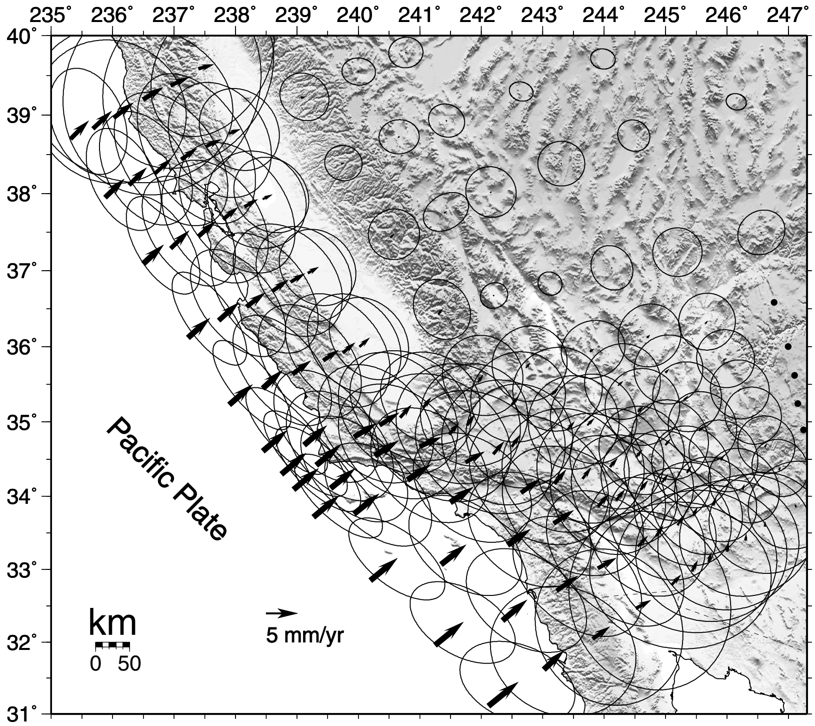

Figure 3. Differential velocity vectors between the velocity fields obtained from inversion of geological strain rates and the velocity field obtained from inversion of geologic data with the NUVEL-1A plate motion applied as a velocity boundary constraint. Error ellipses are for 95% confidence limit and are associated with the velocity solution from the geologic data alone (without the NUVEL-1A constraint). This result shows that a considerable amount of NE-SW convergence is not accounted for by the current fault catalog if the NUVEL-1A model correctly describes Pacific-North America motion. Current GPS data suggest that Pacific-North America motion directions are 2-3° counterclockwise of the NUVEL-1A azimuth, which would reduce the velocity differences here by 1 – 2 mm/yr. An alternative interpretation of the velocity differences that are shown in this figure is that the Colorado Plateau could be moving with respect to North America. A clockwise rotation of the Colorado Plateau about a pole at about 40°N, 120°W, 0.1-0.15°/Myr would explain most of the discrepancy of the azimuths of Pacific-North America vectors, inferred from geologic data and shown relative to the Colorado Plateau, with that inferred from recent geodetic observations.

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