FINAL TECHNICAL REPORT

Award number: G10AP00034 and G11AP20057 (moved to PSU)

Title: Western US fault slip rates and regional strain rates from inversion of geologic, seismologic and geodetic data

Period of award: 2/15/2011 – 2/14/2012

Principal Investigator:
Robert McCaffrey
Portland State University
Dept. of Geology
Portland OR 97207-0751
r.mccaffrey@pdx.edu

Program Element I

Abstract

High-accuracy geodetic (Global Positioning System – GPS) velocities are becoming widely available for the deforming regions of the western US and should be used in earthquake hazards assessments. We combined GPS-derived surface velocities, uplift rates, geologic fault slip vectors (rates and directions) and earthquake slip vector azimuths to derive block models of western US kinematics. The models included estimates of locking on the Cascadia subduction zone and slip rates on crustal faults. We generated detailed models for the regions of the Snake River Plain and Cascadia and a general model for the western US. This work addressed some of the Priorities for National Research: I. *Develop methods that use geodetic data for estimating slip rates along faults or across regions and recurrence of earthquakes that can be applied to seismic hazard analysis.* III *Define uncertainties of parameters and equations used in developing the U.S. National Seismic Hazard map. Construct models to integrate seismic, geologic and geodetic measures of deformation in kinematically self-consistent models of crustal deformation from which hazard estimates can be derived.*

Western US Block models

For the western US there are thousands of GPS, hundreds of fault slip vectors, and hundreds of earthquake slip vector azimuths that can be used to constrain the motions of crustal blocks. The kinematics of the western US are represented by a finite number of elastic or elastic-plastic blocks. The blocks are separated by faults along which the relative motions are taken up.

In this work we generated block models for portions of the western US and one incorporating the entire region. The models utilize available GPS, fault slip and earthquake slip data (McCaffrey 1995; 2002). The approach was as described in the southwestern US (McCaffrey 2005), the Pacific Northwest (McCaffrey et al. 2007), and the western US (Pearson et al. 2010).

New GPS velocities are available in several parts of the region. The PBO velocity field is available as of August 2011 and SCEC's CMM4 is now available (Shen et al., 2011). In addition we occupied about 40 sites near Portland and coastal Oregon to focus on the Gales Creek fault (Lancaster et al., 2011). More than 5000 velocities are now available throughout the region. Since the velocities are often in different reference frames, they are rotated to a common North American frame as part of the block-model inversion.

Earthquake slip vector azimuths are also used as constraints on the kinematics. The earthquakes are those on the faults used in the block model. The details of how the inversion is performed are given in the papers cited above and are not repeated here.

The outputs of the procedure that are of interest to hazards assessments are predicted slip rate vectors (rates and directions) on major fault segments, the locking depth estimate (which influences the estimated moment rate), and the strain rates that are not specifically associated with elastic strain around the major faults. We have found from our studies that the final model do a very good job of matching the geologic fault slip vectors and the GPS simultaneously.

The specific block models we generated are for the Snake River Plain (SRP; Fig. 1), Pacific Northwest (PNW; Figs. 2 and 3) and for the entire western US (Fig. 4). In the SRP region we found that the Snake River Plain moves westward relative to North America as a rigid entity, and that shear must occur along its NW and SE boundaries where it abuts the extending Basin and Range. This work also included compiling many additional GPS observations in cooperation with the Idaho National Laboratory (shown in Fig. 2). For the Pacific Northwest (PNW) we generated a block model similar to the one by McCaffrey et al. (2007), while utilizing up-to-date GPS velocities, and also included vertical leveling data published by Burgette et al. (2009) to constrain locking on the Cascadia subduction zone (Fig. 3). In that work we show that the vertical and GPS can both be matched with a single locking model, which is being incorporated into the updated hazard map. For the western US model (Fig. 4) we compiled 14 separate velocity fields to constrain the motions and strain rates of the blocks. These results are described in the papers by Payne et al. (2012), McCaffrey et al. (2012) and Pearson et al. (2012).

Related Publications:

Payne, S. J., R. McCaffrey, R.W. King, and S. A. Kattenhorn, A new interpretation of deformation rates in the Snake River Plain and adjacent basin and range regions based on GPS measurements, Geophysical Journal International, doi:10.1111/j.1365-246X.2012.05370.x, 2012.

Pearson, C. F., R. S. Snay, R. McCaffrey, Towards an integrated model of the interseismic velocity field along the western margin of North America, International Association of Geodesy Symposia, in press, 2012.

McCaffrey, R., R. W. King, S. J. Payne, and M. Lancaster, Active tectonics of northwestern US inferred from GPS-derived surface velocities, J. Geophys. Res., submitted, 2012.

Payne, S. J., R. McCaffrey, and S. A. Kattenhorn, Extension Driven Right-lateral Shear in the Centennial Shear Zone Adjacent to the Eastern Snake River Plain, Idaho, Lithosphere, submitted, 2012.

Related Meeting abstracts and presentations:

Pearson, C., R. Snay and R. McCaffrey (2009) Towards an improved model of the secular velocities in the western US: C F Pearson, R A Snay, R McCaffrey Eos Trans. AGU, 89(54), Fall Meet. Suppl., Abstract G11B-0638.

McCaffrey, R., King, R W, Payne, S J, (2010). The Pacific Northwest GPS Velocity Field (Invited), G22A-05, AGU Fall.

Schmalzle, G.M., M. S. Baker, R. McCaffrey, R. W. King, B. Osmanoglu, (2011). Measuring active deformation of the Yakima fold and thrust belt using GPS and InSAR, G11A-0858, AGU Fall.

Lancaster, M. N., R. McCaffrey, R. W. King, (2011). GPS Investigation of Active Faults in Northwestern Oregon, G11A-0859, AGU Fall.

McCaffrey, R., S. J. Payne, R. W. King, (2011). Applying plate tectonics to continents (Invited), T34D-02, AGU Fall.

Pearson, C., R. Snay and R. McCaffrey (2011) Towards an integrated model of deformation along the western margin of North America Abstract submitted to the IUGG meeting Melbourne Australia 28 June – 7 July

McCaffrey, R., and R.W. King, (2011). Cascadia Locking, presented at workshop on the eastern edge of rupture zones of great Cascadia earthquakes, Dec. 15.

McCaffrey, R., R.W. King, and S. Payne (2012). Cascadia Locking and Crustal Deformation, presented at Workshop on Pacific NW portion of national seismic hazard maps, Seattle, March 21-22.

References Cited

Burgette, R.J., R.J. Weldon, and D.A. Schmidt, (2009), Interseismic uplift rates for western Oregon and along-strike variation in locking on the Cascadia subduction zone: J. Geophys. Res., 114, B01408, doi:10.1029/2008JB005679.

Lancaster, M. N., R. McCaffrey, R. W. King, (2011). GPS Investigation of Active Faults in Northwestern Oregon, G11A-0859, AGU Fall.

McCaffrey, R., (1995) DEFNODE user's guide, http://www.pdx.edu/~mccaf/defnode/

McCaffrey, R., (2002). Crustal block rotations and plate coupling, in Plate Boundary Zones, S. Stein & J. Freymueller, editors, AGU Geodynamics Series 30, 101-122.

McCaffrey, R., (2005) Block kinematics of the Pacific - North America plate boundary in the southwestern US from inversion of GPS, seismological, and geologic data, J.Geophys. Res. 110, B07401, doi:10.1029/2004JB003307.

McCaffrey, R., A. I. Qamar, R. W. King, R. Wells, G. Khazaradze, C. A. Williams, C. W. Stevens, J. J. Vollick, and P. C. Zwick, (2007) Fault locking, Block Rotation and Crustal Deformation in the Pacific Northwest, Geophysical Journal International, v. 169, p. 1315-1340, doi:10.1111/j.1365-246X.2007.03371.x.

McCaffrey, R., R. W. King, S. J. Payne, and M. Lancaster, (2012). Active tectonics of northwestern US inferred from GPS-derived surface velocities, J. Geophys. Res., submitted.

Payne, S. J., R. McCaffrey, and R.W. King, (2008). Strain rates and contemporary deformation in the Snake River Plain and surrounding Basin and Range from GPS and seismicity, Geology, 36, 647-650.

Payne, S. J., R. McCaffrey, R.W. King, and S. A. Kattenhorn, (2012). A new interpretation of deformation rates in the Snake River Plain and adjacent basin and range regions based on GPS measurements, Geophysical Journal International, doi:10.1111/j.1365-246X.2012.05370.x.

Pearson, C., R. McCaffrey, J. L. Elliott, R. Snay, (2010). HTDP 3.0: Software for coping with the coordinate changes associated with crustal motion, Journal of Survey Engineering.

Pearson, C. F., R. S. Snay, R. McCaffrey, (2012). Towards an integrated model of the interseismic velocity field along the western margin of North America, International Association of Geodesy Symposia, in press.

Shen, Z.-K., R. W. King, D. C. Agnew, M. Wang, T. A. Herring, D. Dong, and P. Fang, (2011). A unified analysis of crustal motion in southern California 1970-2004: The SCEC Crustal Motion Map, J. Geophys. Res., in press.

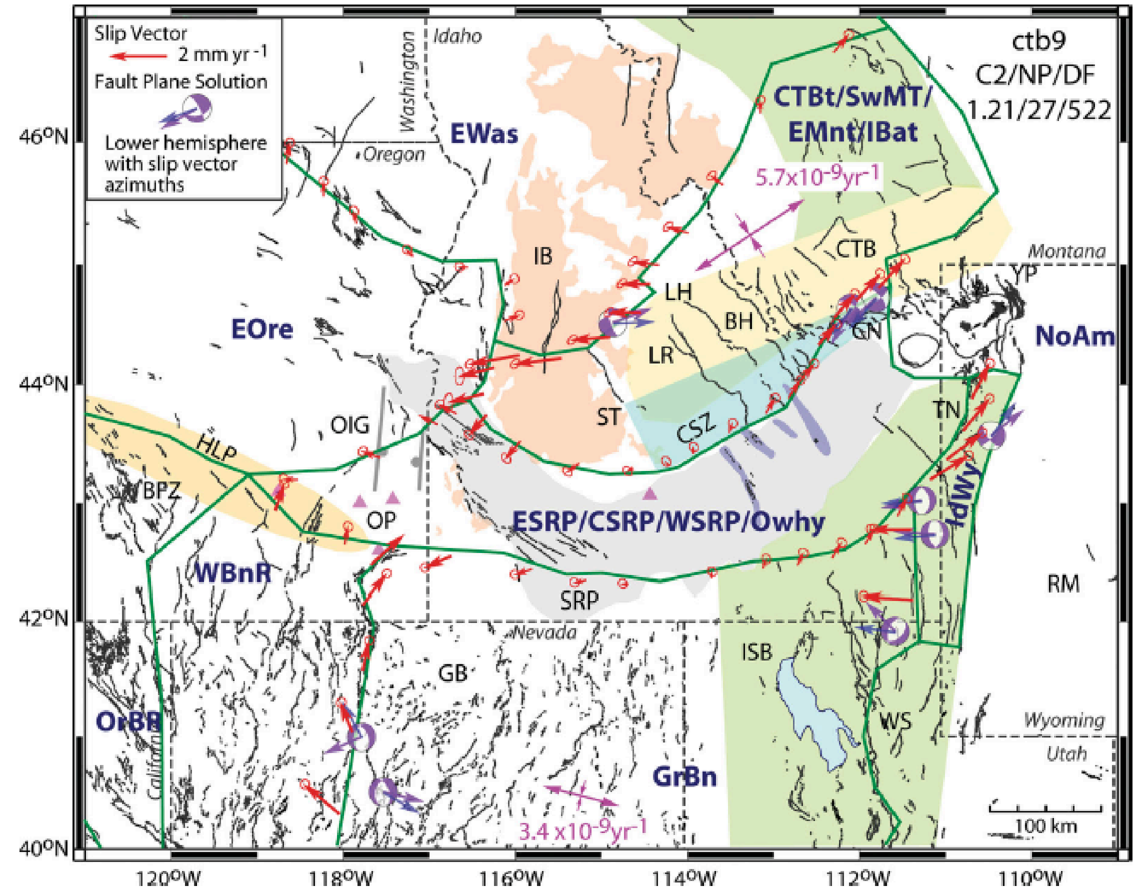

Fig. 1. Block model of the Snake River Plain region (from Payne et al., 2012). Red arrows show fault slip rates and purple arrows are internal strain rates (with rates adjacent).

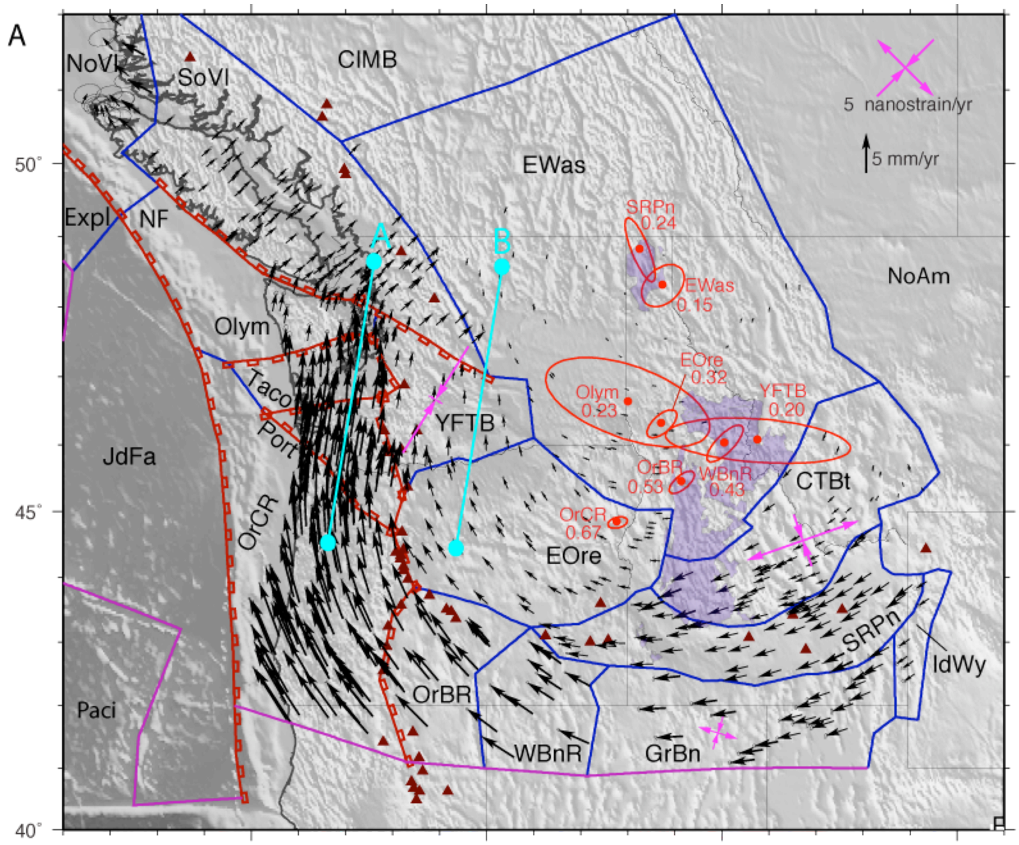

Fig. 2. Block model of the Pacific Northwest (McCaffrey et al., 2012). Blocks are designated by four-letter code. Block boundaries in red represent faults where locking was applied; teeth are on hanging wall. Blue and purple lines are free-slip block boundaries. Vectors show the velocity field after removal of elastic strain rates. Triangles are volcanoes. Line A shows baseline from Corvallis OR in the south to Bellingham WA in the north where the permanent shortening is 5.0 ± 0.5 mm/yr. Line B shows parallel baseline in the backarc where the permanent shortening is 1.9 ± 0.5 mm/yr. Also shown are poles of rotation (red ellipses are 68% confidence) and principal strain rates (purple) for the blocks. Poles are identified by the block code and the rotation rate in °/Myr (all are clockwise looking from above). Principal strain rates are in nanostrain/yr (= 10^{-9} /yr); scale in upper right. Shaded region is the Idaho Batholith.

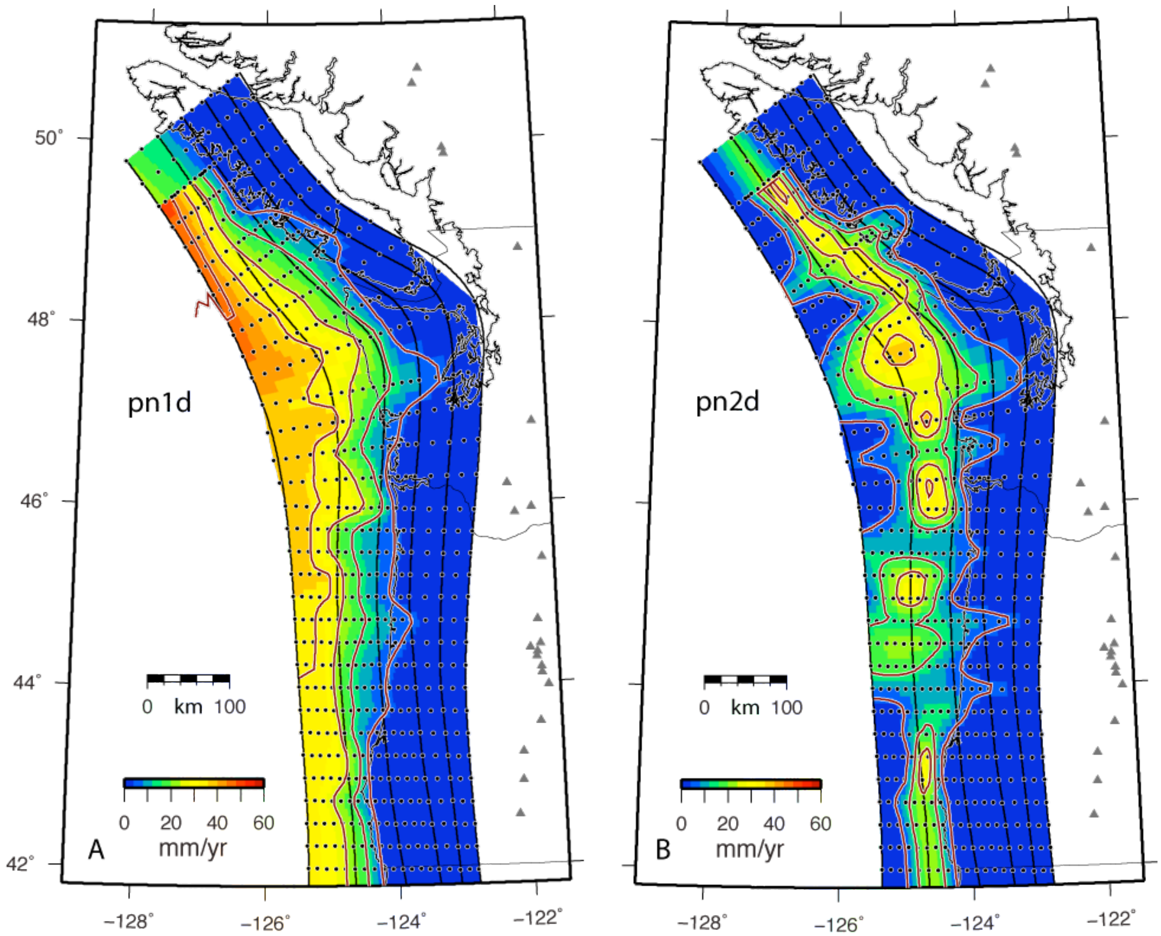

Fig. 3. Model results for two parameterizations of locking on the Cascadia subduction zone (McCaffrey et al., 2012). Colors and contours are of the slip deficit rate, in mm/yr. Slip deficit rate contours are 5, 15, 25, 35 and 45 mm/yr. (A) Tapered transition zone of variable width, depth and taper but locked to trench. (B) Gaussian distribution of locking with depth. The two models give similar fits to the data but are very different in locking offshore.

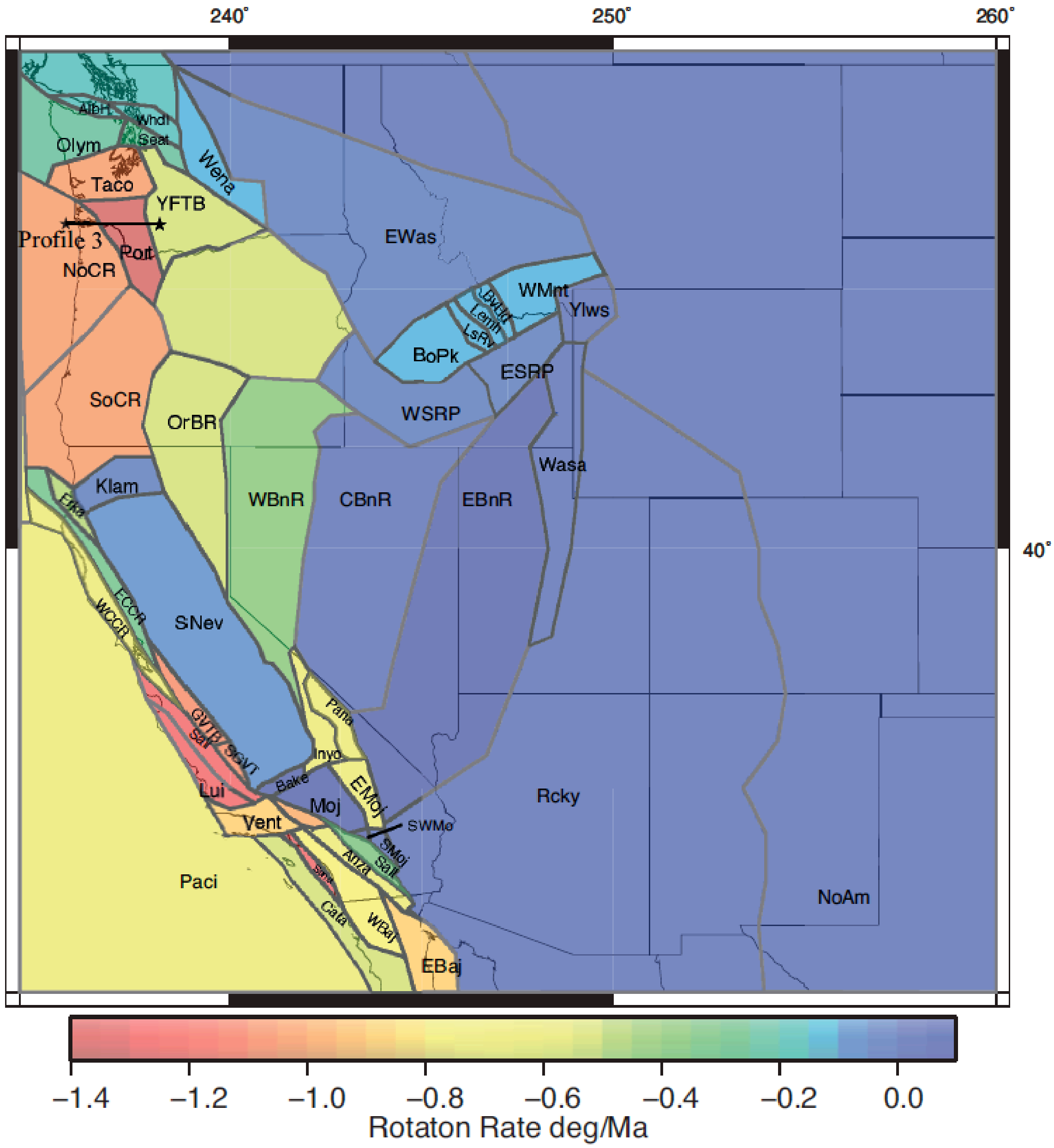

Fig. 4. Preliminary block model of the western US (from Pearson et al., 2012). Color codes represent spin rates in North American reference frame. In general blocks closer to the Pacific Plate spin faster, suggesting block motions are driven by Pacific – North America shear.