Measurements and numerical modeling of strain partitioning and interplate coupling in NW Oregon in cooperation with PANGA

Award Number: **99HQGR0014**

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Program element: II, (Research on Earthquake Occurrence and Effects)
Key words: GPS-Campaign, Strain Measurements

Investigations

1999 campaign During the first year in cooperation with Oregon State, we were able to re-occupy the existing GPS network in NW Oregon, to install and occupy 16 new GPS sites in the Portland region (Figure 1), to process the data, and to compare to earlier GPS measurements of the USGS and Cascades Volcano Observatory. Results were presented at several meetings (see below).

2000 campaign During the year 2000 in cooperation with University of Washington, we were able to occupy again the existing GPS network in NW Oregon, to densify the network near the coast by utilizing county survey marks and GPS data, to expand the network eastward by re-occupying some of the 1998 NGS sites, and to assist in occupation of Washington State sites (Figure 2). We completed processing the 2000 data, and compared to earlier GPS measurements.

Modeling We continued to develop finite-element models to help understand the observed GPS results. In particular, we are seeking physically robust alternatives to half-space dislocation models that can be used to assess seismic hazards more realistically.

Results

We processed all available campaign and continuous data using the GAMIT/GLOBK software analysis package. We estimated site positions and velocities in the ITRF96 reference frame, then rotated the velocities about the NA-ITRF96 pole of DeMets and Dixon [1999] to put them in a North America reference frame (Figure 3). This view reveals a strong rotation of Oregon about a pole in NE Oregon. By simultaneous inversion of the GPS vectors and coastal tilt data of Reilinger and Adams [1982], we estimated both the plate locking and rotation [McCaffrey et al., 2000]. Removing the rotation of Oregon from the GPS vectors shows clear influence of plate locking in an ENE direction (Figure 4).

The expanded network allows us to start to separate the strains from rigid body rotations. This is an important distinction because the rotational velocities, if mistaken for strain, could lead to higher estimates of plate coupling and seismic hazards. At this point it appears that a rotation of the Oregon forearc at about 1 degree per Ma about a pole in NE Oregon (near Pendleton, OR) accounts for the largest part of the velocities of the Oregon coastal sites in the North America reference frame. This pole is very close to the one estimated from geology and paleomagnetism by Wells et al. [1998] indicating that the rotation has probably been going on for the past 10-12 Ma.

We also estimated the distribution of plate locking on the southern Cascadia thrust in Oregon by a formal inversion using both GPS and tilt data as constraints [McCaffrey et al. 2000]. The results suggest that plate locking is largely offshore (Figure 5). (We argue that the apparent onshore locking is an artifact of using the modeling using a half-space dislocation model [Williams and McCaffrey, 1999, 2000]). Residuals relative to the rotation / plate locking model do not show large regions of correlated, unmodeled vectors at the level of the uncertainties, which is about 1 mm/yr (Figure 6), indicating that the majority of the motion of Oregon sites relative to North America is explained by rotation and subduction zone coupling. No fast, upper plate faults are indicated by these results.

Future work

Future directions of research include repeating the GPS measurements to continue to decrease the velocity uncertainties. Greater accuracy in the crustal strain will allow us to examine details of both subduction zone strain and upper plate faulting which both lead to significant earthquake hazards. We feel also that the use of half-space dislocation models for the interpretation of geodetic data and subsequent assessment of hazards must be looked at carefully. Our preliminary work with finite-element models based on a plate model and with force-balance constraints give results and implications for hazards that are significantly different than those inferred from half-space dislocation models.

Non-technical summary

Our measurements with the Global Positioning System are showing the motions and deformation of Oregon that are caused by tectonic forces acting on it. We are finding that the motion is largely a rigid-body rotation possibly caused by a push from the Basin and range to the southeast, from California to the south, or from drag of the subducted seafloor beneath. The rigid rotation of Oregon is consistent with its lack of seismicity, at least as compared to Washington State. The rotating Oregon block appears to converge with North America in Northern Washington state and continued GPS results will elucidate this possibility.

Data availability

Raw GPS data and site velocities are archived at UNAVCO.

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- Williams, C.A., and R. McCaffrey, Estimation of the Rate of Stress Accumulation Along the Cascadia and Sumatra Subduction Zones Constrained by Geodetic Observations, Fall AGU 2000.

Papers published from this work

- McCaffrey, R., M. D. Long, C. Goldfinger, P. C. Zwick, J. L. Nabelek, C. K. Johnson, and C. Smith, Rotation and Plate Locking at the Southern Cascadia Subduction Zone, ***Geophysical Research Letters***, vol. 27, no. 19, p. 3117-3120, October, 2000.

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- Williams, C.A., and R. McCaffrey, Estimation of the Rate of Stress Accumulation Along the Cascadia and Sumatra Subduction Zones Constrained by Geodetic Observations, Fall AGU 2000.

Figures

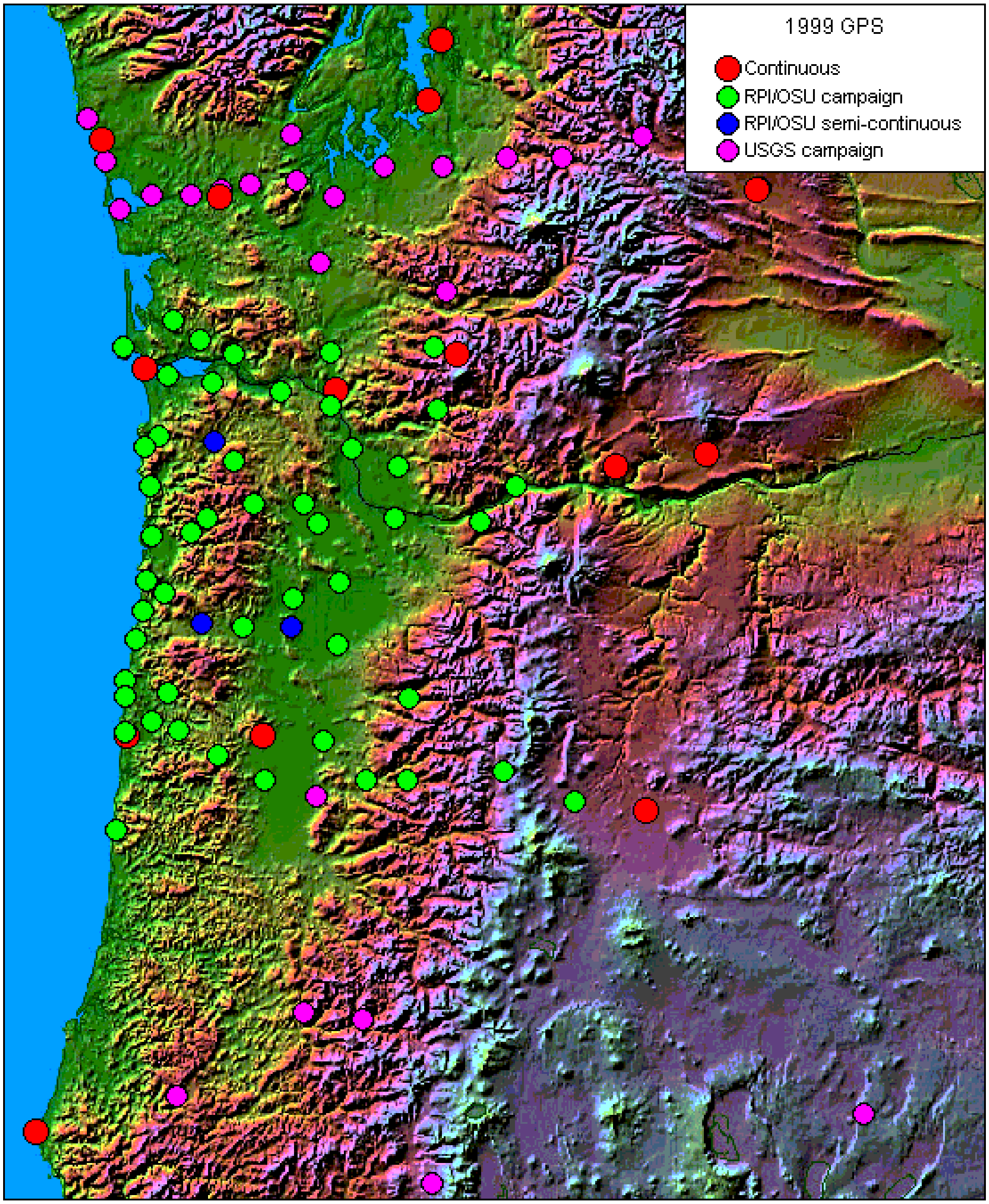

Figure 1. GPS sites occupied during 1999.

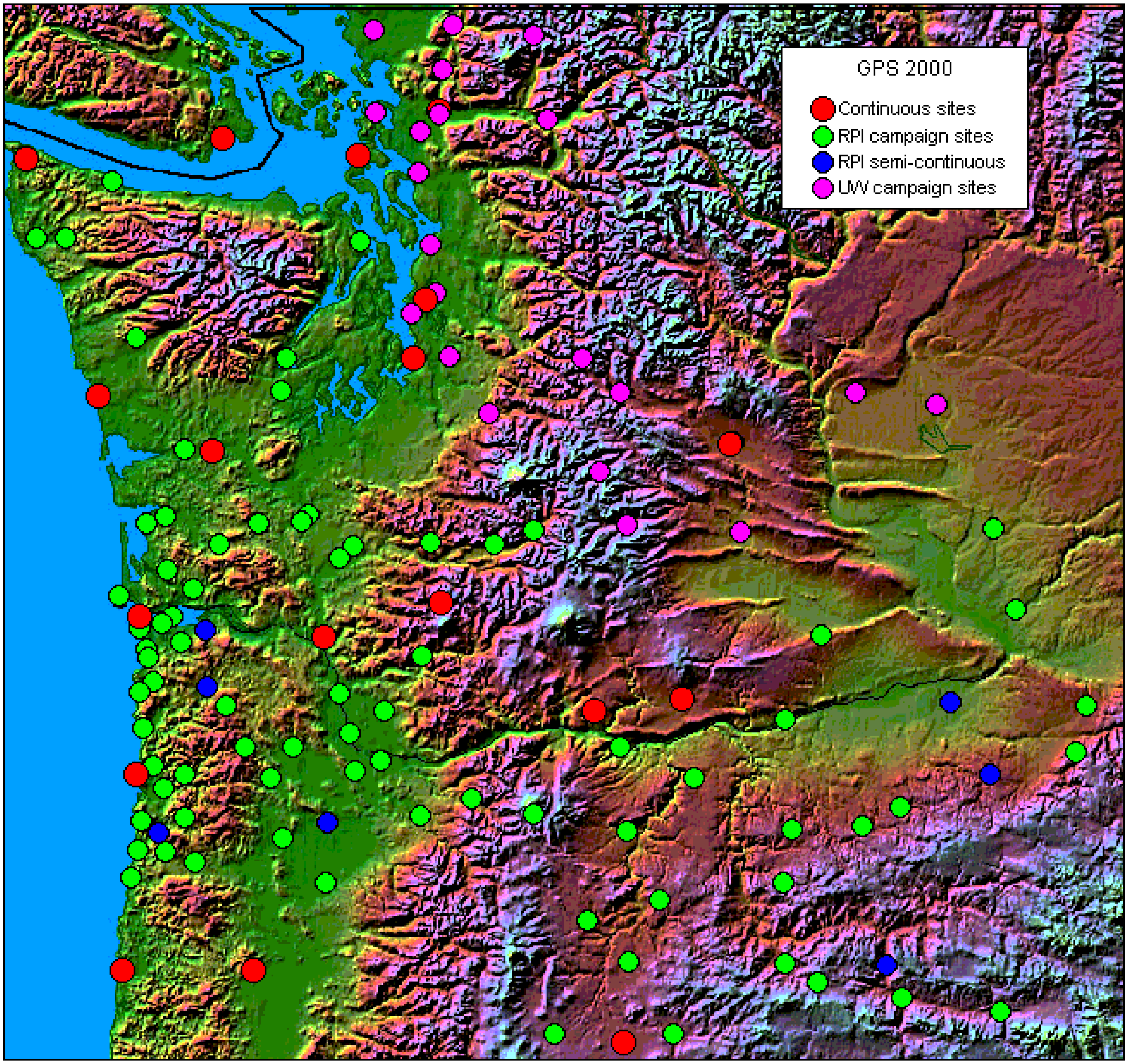

Figure 2. GPS sites occupied during 2000.

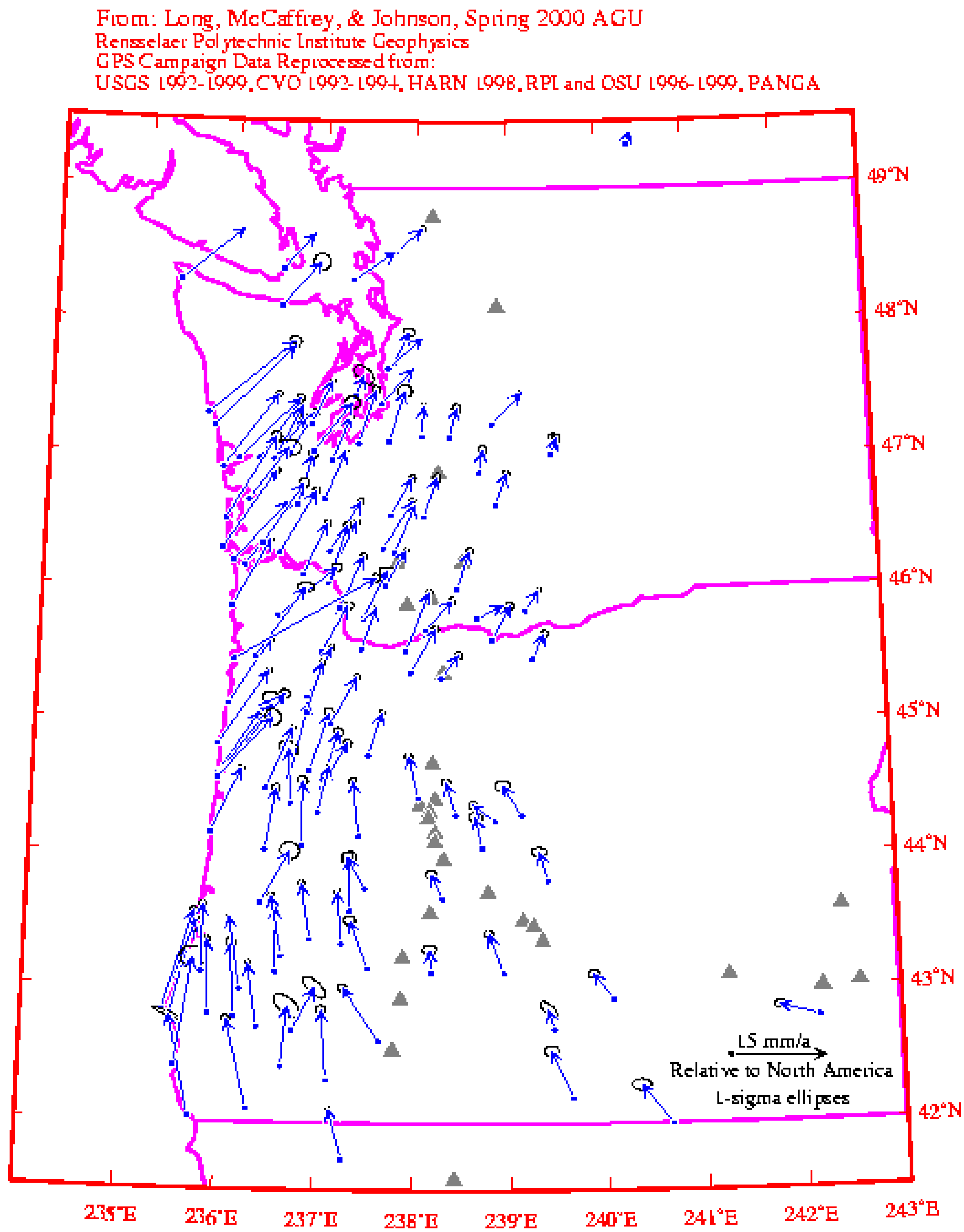

Figure 3. GPS site velocities in the North America reference frame. This view shows the strong rotation of western Oregon relative to North America. Error ellipses are 1-sigma.

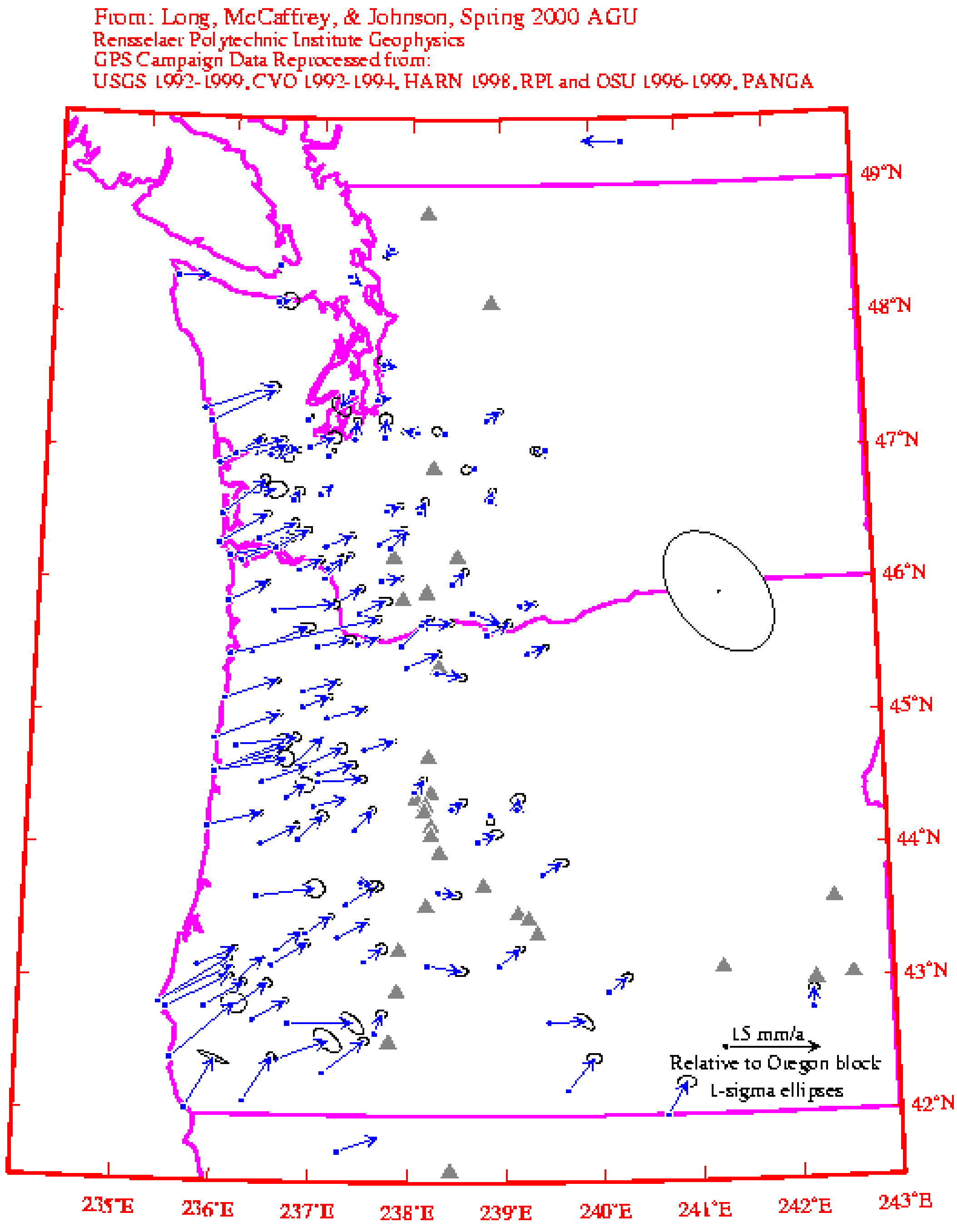

Figure 4. GPS site velocities relative to the rotating Oregon block (ie rotation removed from vectors). This view shows the influence of the plate locking on strains along the coasts of Oregon and Washington. Error ellipses are 1-sigma. The large ellipse in NE Oregon shows the location of the pole of rotation (1-sigma ellipse) of W Oregon relative to North America.

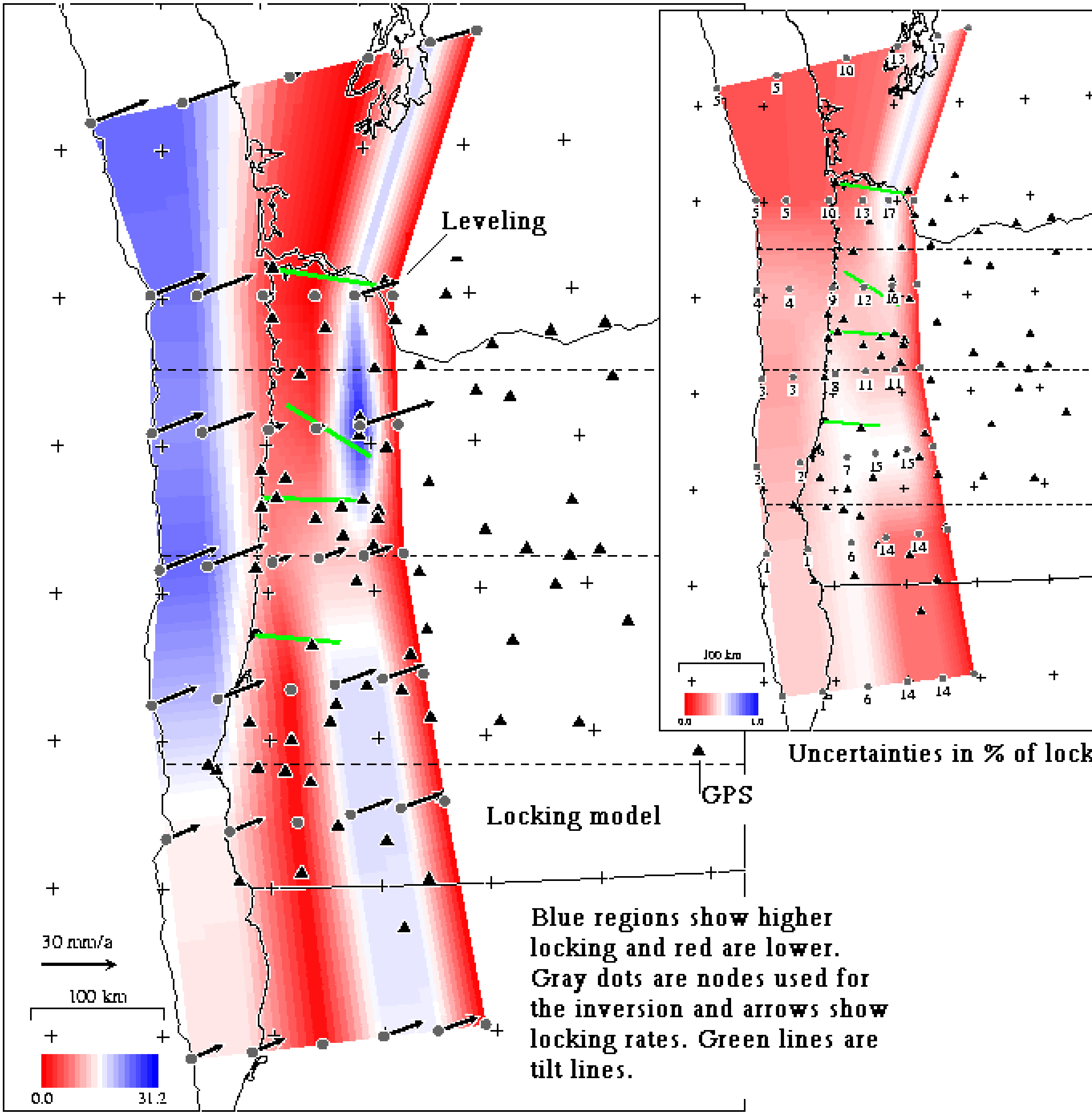

Figure 5.Best-fit plate locking model based on inversion of GPS (triangles) and leveling lines (green lines). Gray dots show node locations on thrust fault. Nodes are aligned along depth contours every 10 km. Numbers below nodes in right plot are parameter indices, nodes sharing an index have same values of locking in the inversion. Arrows show inferred locking rates at nodes. Blue shading indicates greater locking. Tic spacing is 1 degree. (b) Standard deviations is the fraction of plate locking from the inversion.

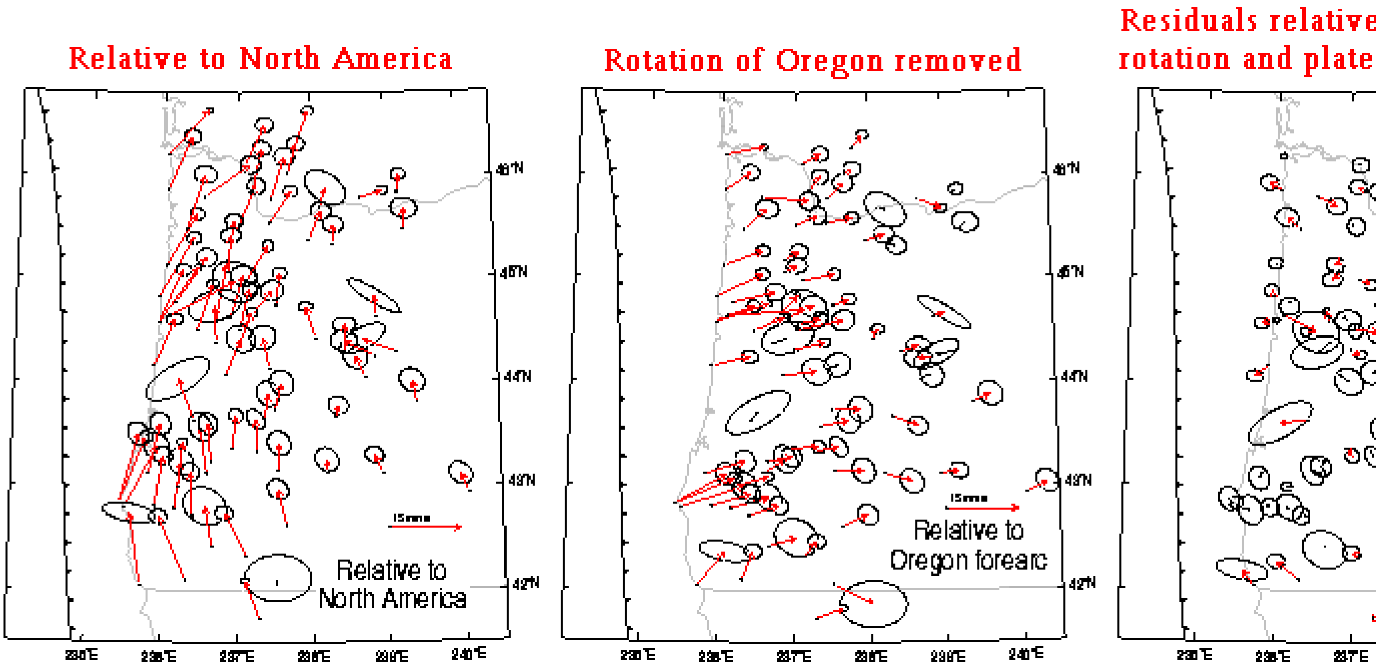

Figure 6. GPS data used in the inversion presented by McCaffrey et al. [2000]. On left are vectors relative to North America, in middle are vectors relative to rotating Oregon block, and at right are the residuals relative to rotating block and plate coupling model.