Global Forecast of Shallow Earthquakes Using Geodesy on Land and Plate Tectonics at Sea

01HQGR0021

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Investigations Undertaken

1. Revision of the global plate boundary model (PB2001→PB2002), based on detailed reviews and additional literature sources. The model now has 52 plates and 13 orogens.

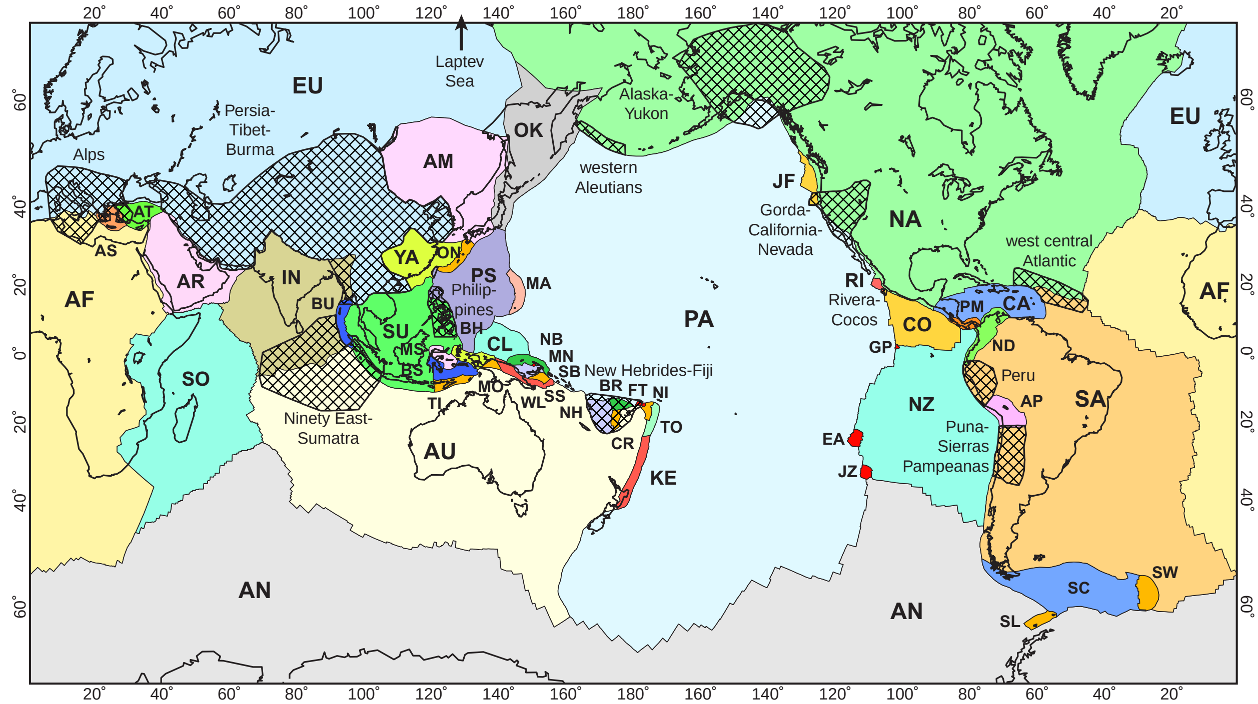
2. Creation of kinematic finite-element program NeoKinema, and associated mapping program NeoKineMap, and testing of the package on simple idealized models.

3. Compilation of geodetic velocities for all orogens worldwide.

4. Application of NeoKinema to compute the long-term-average velocity field of western North America (the Gorda-California-Nevada orogen) based on geologic slip rates, geodetic benchmarks, and stress direction data.

Results

1. In the previous report we described our global plate boundary model PB2001, which included digitized boundary outlines and estimated Euler poles for 42 plates (compared to the 14 plates of NUVEL-1). When this was submitted for publication, we received some very helpful and detailed reviews, particularly one by Brian Taylor. Based on this input (plus an additional year of reading in the literature), we have now prepared a revised model (PB2002) which has 52 plates and 13 non-rigid orogens. The 10 additional plates are (generally West to East): Caroline (CL), North Bismarck (NB), Manus (MN), New Hebrides (NH), Conway Reef (CR), Balmoral Reef (BR), Futuna (FT), Galapagos (GP), Panama (PM), and North Andes (ND). The 13 orogens are (generally West to East): Alps, Persia-Tibet-Burma, Laptev Sea, Ninety East-Sumatra, Philippines, New Hebrides-Fiji, western Aleutians, Alaska-Yukon, Gorda-California-Nevada, Rivera-Cocos, Peru, Puna-Sierras Pampeanas, and west central Atlantic. A low-resolution Mercator map of this model is below.



For purposes of analyzing plate-boundary seismicity, we used objective and automated criteria to divide all boundaries into one of 7 types: subduction zone, oceanic convergent boundary, oceanic transform fault, oceanic spreading ridge, continental rift boundary, continental transform boundary, and continental convergent boundary. By assigning all large 20th-century shallow earthquakes to the most probable adjacent boundary (or to a plate interior), we obtained seismicity samples large enough to allow preliminary determinations of the corner magnitudes in each class, as well as other parameters of the modified Gutenberg-Richter frequency-magnitude relations. These results will be slightly revised in light of plate model PB2002 as soon as it is accepted for publication.

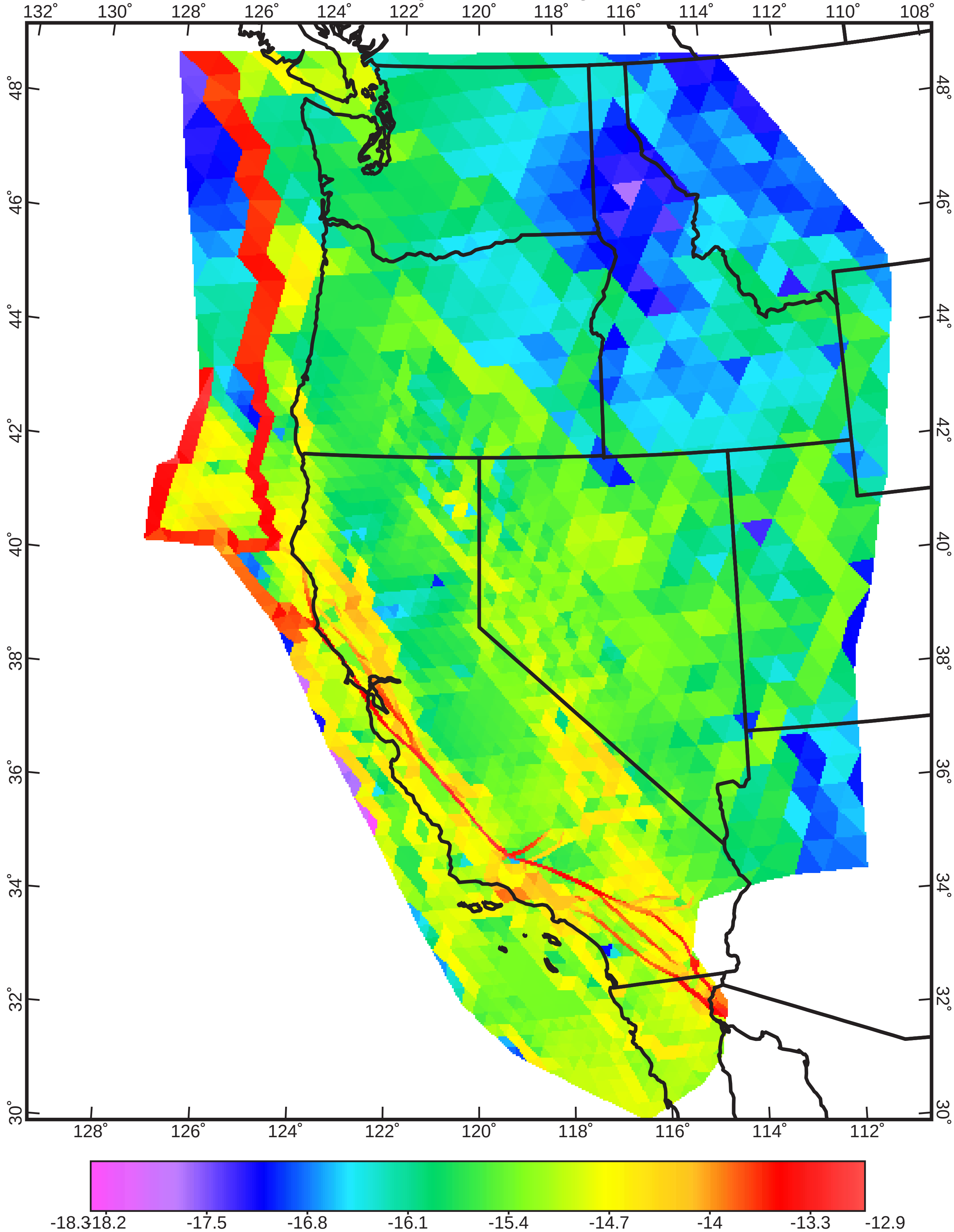
2. New kinematic finite-element program NeoKinema solves for long-term-average velocity fields and fault slip rates in deforming lithosphere, based on plate-tectonic velocity boundary conditions and three kinds of information about the interior of an orogen: (1) geologic slip rates of an unlimited number of faults, with standard deviations (which may be large); (2) geodetic velocities of benchmarks, either in fixed or free-floating velocity reference frame, with covariance matrix; (3) stress-direction data. Faults need not be explicitly represented in the finite element grid. The geodetic data are corrected for local effects of temporary fault locking by an iterative procedure. The strain rates of non-faulting finite elements are determined by a balance between (a) minimization of viscous dissipation, and (b) conformity to principal strain rate directions interpolated from the stress-direction data.

The spherical-triangle finite elements used in NeoKinema were described by Kong and Bird [1995, JGR, 100, 22129]. The algorithm for interpolating stress directions comes from Bird and Li [1996, JGR, 101, 5435]. The algebra used to incorporate fault-related strain rates (and anisotropic flexibilities) was described by Bird [1998, Tectonics, 17, 780]. The primary new feature of NeoKinema is that it accepts geodetic velocities as input, and uses the full covariance matrix of the velocity components in order to find the true maximum-likelihood velocity solution. If there is any uncertainty concerning the velocity reference frame of the geodetic data, there is a switch permitting to the covariance matrix to be augmented in a way which makes the network free-floating in Eulerian velocity space (while retaining relative velocities). In addition, geodetic velocities are corrected for temporary effects of shallow fault locking by summation of analytic rectangular-dislocation-in-elastic-halfspace solutions. Each feature of the program has been tested separately in idealized artificial problems.

3. Geodetic benchmark velocities have been compiled for each of the 13 orogens that are to be modeled with NeoKinema. This was done by Zhenkang Shen, who has the necessary expertise and connections in the geodetic community. We wish to acknowledge the very valuable compilation already performed by Corne Kreemer and Bill Holt in preparation for the Global Strain Rate Map project. Other important sources include the Southern California Earthquake Center, Ayhan et al.[2002, BSSA] (Turkey), Darby and Beavan [2001, JGR] (New Zealand), the Crustal Motion Observation Network of China, the USGS web site, and the UNAVCO web site. When available, we have collected covariance matrices of velocity components, not just error ellipses for each benchmark in isolation.

4. NeoKinema has been applied to model neotectonics of the Gorda-California-Nevada orogen in the western United States, from the Gorda "plate" on the W, to the Gulf of California on the S, Yellowstone on the E, and Victoria on the N. Data comes from 378 active or potentially-active faults, 298 benchmarks of the WUSC002 solution [Bennett et al., 1999], and 2080 stress directions from the World Stress Map 2000 [Mueller et al., 2000]. The F-E grid has 1813 nodes and 3468 triangular elements of 30-km and 60-km dimensions. Results of this first application are very plausible, and confirm the concept of a Sierra Nevada-Great Valley plate moving ~9 mm/a NW. After a few local artifacts are investigated and eliminated (primarily by better gridding), the model will be used to compute various measures of long-term seismic hazard. It is already apparent from the map of predicted strain rates (below) that 20th-century seismicity levels in western Oregon, the Wasatch Front area of Utah, and the Las Vegas region have been less than their long-term-average expectations.

Total Strain-Rate, including Faulting: $\log_{10}$ of greatest principal rate
Fault, stress, & geodetic data; grid GCN7.6



Reports Published (cumulative)

Kagan, Y., D. D. Jackson, Y.-F. Rong, and P. Bird (1999) Plate tectonics and earthquake potential on the Pacific rim (abstract), EOS Trans. AGU, Fall Meeting Supplement, p. F680.

Bird, P., Y. Y. Kagan, H. Houston, and D. D. Jackson (2000) Earthquake potential estimated from tectonic motion (abstract), Eos Trans. AGU, Fall Meeting Supplement, p. F1226-F1227.

Bird, P., Y. Y. Kagan, and D. D. Jackson (2002), Plate tectonics and earthquake potential of spreading ridges and oceanic transform faults, in: S. Stein and J. T. Freymueller (editors), *Plate Boundary Zones*, AGU Geophysical Monograph, 130, in press for September 2002.

Bird, P. (resubmitted) An updated digital model of plate boundaries, submitted to Geochemistry, Geophysics, Geosystems in October 2001; reviewed May 2002; revised July 2002.

Bird, P. (submitted) Neotectonic velocity field of the western United States: A new maximum-likelihood solution (abstract), EOS Trans. AGU, 2002 Fall Meeting Supplement.

Data Availability

Global plate boundary model PB2002 is available by request in a revised but provisional version. [Changes could still be required prior to final acceptance for publication.] The model is contained in a set of 4 ASCII files and one Microsoft Excel™ spreadsheet:

PB2002_boundaries.dig: Digitized lines separating pairs of plates.

PB2002_plates.dig: Digitized outlines for each of the 52 plates (This is the same information as in PB2002_boundaries, but in a different format.)

PB2002_zones.dig: Digitized outlines of the 13 zones of distributed deformation, within which the rigid-plate model is not expected to be accurate.

PB2002_steps.dat: Flat-file table of information for each digitisation step along plate boundaries, including relative velocity vector, elevation, seafloor age, and classification into one of 7 plate boundary classes.

PB2002_poles.xls: Table of plate name abbreviations, areas, and Euler vectors.

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Non-Technical Project Summary

We are preparing a global probabilistic forecast of earthquakes by determining the long-term rates of fault slip, and of strain between faults, and assuming that future seismicity will be proportional to these rates. We have updated the global plate model to include 38 small plates and 13 non-rigid orogens. We have created a finite-element program, NeoKinema, for computing the long-term-average velocity field (including fault slip rates) in any orogen based on geologic slip rates, geodetic benchmark velocities, and stress directions. We have applied this method to the Gorda-California-Nevada orogen in the western United States, obtaining a map of long-term-average strain rates which will be converted to a forecast of seismicity. The conversion of strain rate to forecast seismicity will use the empirical ratios determined by the analysis of plate boundaries worldwide, and reported last year.