Dr. Ray Wells, US Geological Survey

"Revolutionary" Tectonics in the Pacific Northwest: The Role of Rotating Microplates and Mega-Blocks Along the Cascadia Convergent Margin

Dr. Ray Wells of the U.S. Geological Survey will present a lecture on the tectonics in the Pacific Northwest. Dr. Wells has been a research geologist for almost 30 years, concentrating on the use of geologic mapping, magnetic rock properties (paleomagnetism) and GPS to solve large-scale problems in the Earth's on-going structural evolution. Ray has produced a simple, hands-on block model of the Pacific Northwest, which he will demonstrate at the talk. Today, over 200 of the models are used in classrooms around the Pacific Northwest.

Deformation and paleomagnetic rotations over the past 50 million years indicate that the Cascadia fore arc is moving northward along the west coast and breaking up into large rotating blocks. Deformation occurs mostly around the margins of a large, relatively non-seismic Oregon coastal block composed of thick oceanic crust. This 400 km-long block is moving slowly clockwise with respect to North America about a rotation pole in eastern Oregon, thus increasing convergence along its leading edge near Cape Blanco and creating an extensional volcanic arc on its trailing edge. Northward movement of the block breaks western Washington into smaller, seismically active blocks and compresses them against the Canadian Coast Mountains. Movement of these blocks may be up to 9 mm/yr, sufficient to produce damaging earthquakes in a broad deformation zone along block margins.

Recent GPS data show that clockwise rotation of Oregon continues today, but the rotations extend throughout the Pacific Northwest. Rotation rates from GPS studies are similar to older paleomagnetic rates. Northward moving Oregon is currently squeezing Washington against slower moving Canada: this constriction has produced the Yakima fold and thrust belt and its analogs, like the Seattle fault, in the forearc. Locally, right lateral shear in the forearc is apparent in the GPS data, consistent with recently discovered right lateral faults in the Portland area that may be seismically active. In a broad sense, the smaller, clockwise rotating blocks of the Pacific Northwest appear to be caught like a giant ball bearing between the much larger Pacific and North American plates.

Biography

Dr. Ray Wells received a dual B.S. in geology and art from Pennsylvania State University in 1972, an M.S. in geology from the University of Oregon in 1975, and a Ph.D. in geology from the University of California, Santa Cruz in 1982. Between 1983 and 1995 he was a Project Chief at the USGS for the *Northwest Urban Corridor Geologic Maps and Synthesis*, the *Plio-Pleistocene Rotations, San Andreas Fault System*, the *Roseburg, Oregon Geologic Map and Synthesis*, and the *Tectonic Framework of the Tillamook Volcanics, Oregon* programs. Between 1991 and 1996 he was the USGS Regional Coordinator for the CASCADIA *Continental Survey Program*, and since 1995 he has been a Project Chief for the *Pacific Northwest Urban Corridor Geologic Mapping* program at the US Geological Survey. He has been an author or co-author on at least 72 publications (a complete list is available on the NCGS website).

RAY E. WELLS

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U.S. Geological Survey, MS 973
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Professional Preparation

B.S.	Pennsylvania State University - Geology, Art	1972
M.S.	University of Oregon - Geology	1975
Ph.D.	University of California, Santa Cruz - Geology	1982

Appointments
1995-present - USGS Project Chief
Pacific Northwest Urban Corridor Geologic Mapping

1991-1996 – USGS Regional Coordinator
CASCADIA Continental Surveys Program

1983-1995 – USGS Project Chief
Northwest Urban Corridor Geologic Maps and Synthesis.
Plio-Pleistocene Rotations, San Andreas Fault System.
Roseburg, Oregon, Geologic Map and Synthesis
Tectonic Framework of the Tillamook Volcanics, Oregon

1972-1982 - Geologist, Graduate Student
Geologist, Washington Division of Geology and Earth Resources, 1980
Geologist, Geological Survey, June 1975 to Jan 1983
NSF Research assistant, UC Santa Cruz, 1978-80
Geologic Field Assistant, Mobil Oil Corporation, 1974
Teaching Assistant, University of Oregon 1972-74
Geologic Field Assistant, Johns Mannville Ltd., 1972

Research Objectives
Block rotations, strain partitioning, and seismic hazards in the Cascadia fore-arc
Coseismic slip in great subduction earthquakes and its relation to crustal structure
Paleomagnetic constraints on continental deformation processes
Plate motions, terrane accretion, and magmatism of the Northwest
Earthquake Surface Ruptures and fault behavior

Invited lectures
10 Invited presentations in Japan, Italy, Canada, England, and Greece.
80 invited lectures and presentations at US Universities and conferences.
Co-convener of 12 AGU and GSA sessions on subduction zones, apparent polar wander, and convergent margin structure and deformation

Synergistic Activities
Oregon State Geologic Mapping Advisory Committee, 1994 to present.
Washington State Geologic Mapping Advisory Committee, 2000 to present.

Member, USGS committee to evaluate Satsop Nuclear Power Plant, WA, 1983.
Member, USGS Review Committee, DOE Site Evaluation, Nevada Test Site, 1988.
Panel Member, Future of Geol. Mapping, Oregon Dept. Geol. and Min. Ind., 1996.
Earthscope PBO workshops
TOTLE – Teachers on the Leading Edge, PNW Tectonic Block models for teachers 2006
GEOPRISMS Alaska Workshop, Session chair, 2011
GEOPRISMS Cascadia Keynote talk, 2012

Collaborators and Other Affiliations

Collaborators and Co-Editors

Graduate Advisors and Post-Doctoral Sponsors

Ph.D. Advisor - Robert S Coe, U.C. Santa Cruz
M.S. Advisor - Brian Baker, Univ. of Oregon (deceased)

Thesis Advisor and Post Graduate-Scholar Sponsor

Post Doc - Peter Haeussler, USGS
USGS Mendenhall Post Doc - Megan Anderson, Colorado College
USGS Mendenhall Post Doc – Sean Bemis, USGS, Univ. of Kentucky
USGS Mendenhall Post Doc – Katie Keranen, University of Oklahoma

EDITORSHIPS, OFFICES, PROFESSIONAL ORGANIZATION

Member, Geological Society of America
Member, American Geophysical Union
Member, Seismological Society of America
Member, American Association for the Advancement of Science
President, Peninsula Geological Society, 2005-07
Editor, Loma Prieta Geologic Setting and Crustal Structure, Professional Paper 1550-E
Co-editor GSA Special Paper on the Columbia River Flood Basalts, 2010-present

ACADEMIC SERVICE

Advisor to Geology Department Tenure Committee, University of Montana, 1986
Dissertation Committee, Earth Science Board, U.C. Santa Cruz, 1987.
Advisor to Faculty of Sciences Dean, Hebrew University of Jerusalem, regarding tenure appointment, 1992.
Advisor to Geoscience Department Promotion Committee, Oregon State University, 1995.
Advisor to Faculty of Sciences promotion committee, Hebrew University of Jerusalem, 2008.
Supervisor of 30 NAGT student and graduate student employees, and interns since 1976.
Mentor to USGS post-Doctoral awardees

HONORS, AWARDS, ELECTED MEMBERSHIPS

Penrose Grant 1974
Aaron & Elizabeth Waters Research Award, U.C. Santa Cruz, 1978.
Branch of Western Regional Geology Best Paper Award, 1985 (*Wells, R. E., and Coe, R. S., 1985).*
Group Special Achievement Award, Loma Prieta Earthquake, 1990.
Branch of Western Regional Geology Best Paper Award, 1990 (*Wells, R. E., and Hillhouse, J. W., 1989).*
Special Achievement Award, Seattle Urban Hazards Workshop, 1999.
Star Award, PNW Project Chief performance, 2002.
Star Award, PNW Project Chief performance, 2010.

Selected Publications

1. **Wells, R. E.**, 1980, Drake Peak, a structurally complex rhyolite center in southeastern Oregon: U.S. Geological Survey Professional Paper, P-1124E, p. E1-E16.

2. **Wells, R. E.**, 1981, Geologic map of the eastern Willapa Hills, Cowlitz, Lewis, Pacific, and Wahkiakum Counties, Washington: U.S. Geological Survey Open-file Report 81-674, (one oversize sheet with text), scale 1:62,500.

3. Magill, J., **Wells, R. E.**, Simpson, R. W., and Cox, A. V., 1982, Post 12 m.y. rotations of southwestern Washington: Journal of Geophysical Research, v. 87, p. 3761-3776.

4. **Wells, R. E.**, Niem, A. R., MacLeod, N. S., Snavely, P. D., Jr., and Niem, W. A., 1983, Preliminary geologic map of the west half of the Vancouver (WA-OR) 1° x 2° Quadrangle, Oregon: U.S. Geological Survey Open File Report 83-591, (oversize sheet with interpretative text), scale 1:250,000.

5. **Wells, R. E.**, Engebretson, D. C., Snavely, P. D., Jr., and Coe, R. S., 1984, Cenozoic plate motions and the volcano-tectonic evolution of western Oregon and Washington: Tectonics, v. 3, p. 275-294.

6. **Wells, R. E.**, and Coe, R. S., 1985, Paleomagnetism and geology of Eocene volcanic rocks of southwest Washington, implications for mechanisms of tectonic rotation: Journal of Geophysical Research, v. 90, p. 1925-1947.

7. **Wells, R. E.**, 1984, Paleomagnetic constraints on the interpretation of early Cenozoic Pacific Northwest paleogeography, in Nilsen, Tor H., ed., Geology of Upper Cretaceous Hornbrook Formation, Oregon and California: Pacific Section S.E.P.M., v. 42, p. 231-237.

8. **Wells, R. E.**, and Heller, P. L., 1988, The relative contribution of accretion, shear, and extension to Cenozoic tectonic rotations in the Pacific Northwest: Geological Society of America Bulletin, v. 100, p. 324-338.

9. **Wells, R. E.**, 1989, Geologic map of the Cape Disappointment-Naselle River area, Pacific and Wahkiakum Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-1832; one oversize sheet with interpretive explanation, scale 1:62,500.

10. **Wells, R. E.**, 1989, Mechanisms of Cenozoic tectonic rotation, Pacific Northwest convergent margin, U.S.A.: in Kiessel, C. and Laj, C., Paleomagnetic rotations and continental deformation, NATO Advanced Study Institute v. C254, p. 313-325, Kluwer Publishers, Netherlands.

11. **Wells. R. E.**, Simpson, R. W., Bentley, R. D., Beeson, M. H., Mangan, M. T., and Wright, T. L., 1989, Correlation of Miocene flows of the Columbia River Basalt Group from the central Columbia River Plateau to the coast of Oregon and Washington: in Hooper, P., and Reidel, S., eds., Volcanism and tectonism in the Columbia River flood basalt province, Geological Society of America Special Paper 239, p. 113-130.

12. **Wells, R. E.**, and Hillhouse, J. W., 1989, Paleomagnetism and tectonic rotation of the lower Miocene Peach Springs Tuff - Colorado Plateau, Arizona: to Barstow, California: Geological Society of America Bulletin, v. 101, p. 846-863.

13. **Wells, R. E.**, 1989, Origin of the oceanic basalt basement of the Solomon Islands arc and its relationship to the Ontong Java Plateau--Insights from Cenozoic plate motion models: Tectonophysics, v. 165, p. 219-235;

14. **Wells, R. E.**, 1990, Paleomagnetic rotations and the Cenozoic tectonics of the Cascade Arc, Washington, Oregon, and California: Journal of Geophysical Research v. 95, p. 19,409-19,417.

15. Hillhouse, J. W., and **Wells, R. E.**, 1991, Magnetic fabric, flow directions, and source area of the lower Miocene Peach Springs Tuff in Arizona, California and Nevada: Journal of Geophysical Research, v. 96, p. 12,443-12,460.

16. England, P. C., and **Wells, R. E.**, 1991, Neogene rotations and semi-continuous deformation of the Pacific Northwest continental margin: Geology, v. 19, p. 978-981.

17. Ponti, D. and **Wells, R. E.**, 1991, Off-fault ground rupture in the Santa Cruz Mountains, California: Ridge top spreading vs. tectonic extension during the Loma Prieta earthquake: Bulletin of the Seismological Society of America, v. 81, p. 1480-1510 and one oversize sheet, scale 1;36,000.

18. Blakely, R. J., **Wells, R. E.**, Yelin, T. S., Madin, I. P., and Beeson, M. H., 1995, Tectonic setting of the Portland-Vancouver area, Oregon and Washington: Constraints from low-altitude aeromagnetic data: Geological Society of America Bulletin, v. 107, p. 1051-1062.

19. **Wells, R. E.**, Snavely, P. D. Jr., Macleod, N. S., Kelly, M. M., Parker, M. J., Fenton, Johanna, and Felger, Tracey, 1995, Geologic map of the Tillamook Highlands, northwest Oregon Coast Range-a digital database: U. S. Geological Survey Open-File Report 95-670, http://pubs.usgs.gov/of/1995/of95-670/

20. Snavely, P. D., Jr., and **Wells, R. E.**, 1996, Cenozoic evolution of the continental margin of Oregon and Washington: in Rogers, A. and others, editors, Earthquake Hazards in the Pacific Northwest of the United States: U. S. Geological Survey Professional Paper 1560, p. 161-182.

21. Parsons, Tom, Trehu, A. M., Luetgert, J. H., Miller, Kate, Kilbride, F., **Wells, R. E.**, Fisher, M. A., Flueh, Ernst, ten Brink, U. S., and Christiansen, N. I., 1998, A new view into the Cascadia subduction zone and volcanic arc: Implications for earthquake hazards along the Washington margin: Geology, v. 26, p. 199-202

22. **Wells, R. E.**, Weaver, C. S., and Blakely, R. J., 1998, Fore arc migration in Cascadia and its neotectonic significance; Geology, v. 26, p. 759-762.

23. Parsons, Tom, **Wells, R. E.**, Fisher, M. A., Flueh, Ernst, ten Brink, U. S., 1999, Three-dimensional velocity structure of Siletzia and other accreted terranes in the Cascadia fore arc of Washington: Journal of Geophysical Research, v. 104, p. 18,015-18,039.

24. Blakely, R. J., **Wells, R. E.**, Tolan, T.L., Beeson, M. H., Trehu, A. M., and Liberty, L. M., 2000, New aeromagnetic data reveal large strike-slip (?) faults in the northern Willamette Valley, Oregon: Geological Society of America Bulletin, v. 112, p. 1225-1233.

25 **Wells, R. E.**, Jayko, A., Niem, A. R., Black, G., Wiley, T., Baldwin, E., and Molenaar, K. M., Wheeler, K., Givler, R., and DuRoss, C., 2000, Geologic map and database of the Roseburg, Oregon 30' x 60' Quadrangle, Douglas and Coos Counties, Oregon: U.S. Geological Survey Open-File Report OF00-376, 2 sheets and 55 p. pamphlet, scale 1:100,000.

50 **Wells, R. E.**, and Simpson, R. W., 2001, Microplate motion of the Cascadia forearc and implications for subduction deformation; Earth Planets Space, v. 53, p. 275-283.

51 Blakely, R.J., **Wells, R.E**., Weaver, C.S., and Johnson, S.Y., 2002, Location, structure, and seismicity of the Seattle fault zone, Washington: Evidence from aeromagnetic anomalies, geologic mapping, and seismic-reflection data: Geological Society of America Bulletin, v. 114, p. 169-177.

52 **Wells Ray E.**, R. J. Blakely, and C. S. Weaver, 2002, Cascadia microplate models and within-slab earthquakes: in Kirby, S., Wang, Kelin, and Dunlop, S., eds. Intraslab earthquakes in the Cascadia subduction system: Science and Hazards: US. Geological Survey Open File Report OF02-328, p. 17-24.

53 Wang, Kelin, **Wells, R. E.**, Mazzotti, S., Dragert, H., Hyndman, R. D., and Sagiya, T., 2003, A revised 3-D dislocation model of interseismic deformation for the Cascadia subduction zone: Journal of Geophysical Research, v. 108, B1, 2026, doi:10.1029/2001JB001227.

54 **Wells, R. E.**, Blakely, R. J., Sugiyama, Y., Scholl, D. W., and Dinterman, P., 2003, Basin-centered asperities in great subduction zone earthquakes–a link between slip, subsidence, and subduction erosion?: Journal of Geophysical Research, v. 108, B10, 2507, doi:10.1029/ 2002JB002072.

55 Nelson, A.R., Johnson, S.Y., Kelsey, H.M., **Wells, R.E.**, Sherrod, B.L., Pezzopane, S.K., Bradley, Lee-Ann, and Koehler, R. D., III, 2003, Late Holocene earthquakes on the Toe Jam Hill fault, Seattle fault zone, Bainbridge Island, Washington: Geological Society of America Bulletin, v.115, pp.1388-1403.

56 Peter J. Haeussler, Dwight C. Bradley, **Ray E. Wells**, Marti L. Miller, 2003, Life and death of the Resurrection Plate: evidence for an additional plate in the NE Pacific in Paleocene-Eocene time: Geological Society of America Bulletin, v.115, pp.867-880. (*44 Citations, Scopus).*

57 **Wells, R. E.**, 2004, Introduction, in Wells, R.E, ed., The Loma Prieta, California, Earthquake of October 17, 1989 - Geologic Setting and Crustal Structure: U.S. Geological Survey Professional Paper 1550-E, 204 pp and 3 oversize plates.

58 Brocher, T.M., Blakely, R.J., and **Wells, R.E.,** 2004, Interpretation of the Seattle uplift, Washington, as a passive roof duplex: Bulletin of the Seismological Society of America, v.94, no. 4, pp. 1379-1401.

59 Booth, D. **Wells, R.E**. and Givler, R., 2004, Chimney Damage in the Greater Seattle Area from the Nisqually Earthquake of February 28, 2001: Bulletin of the Seismological Society of America, v.94, no.3, pp.1143-1158.

60 Johnson, S.Y. , Nelson, A.R. , Personius, S.F. , **Wells, R.E.** , Kelsey, H.M., Sherrod, B .L., Okumura, Koji, Koehler, Rich, Witter, Robert, Bradley, Lee-Ann, Harding, D.J., 2004, Evidence for late Holocene earthquakes on the Utsalady Point Fault, northern Puget Lowland, Washington: Bulletin of the Seismological Society of America, vol. 94, no. 6, pp. 2299-2316.

61 Blakely, R.J., Brocher, T.M., and **Wells, R.E.**, 2005, Subduction zone magnetic anomalies and implications for hydrated forearc mantle: Geology, Volume 33, pp. 445–448, DOI: 10.1130/G21447.1

62 Butler, R., E. Bishop, C. Ault, Jr., B. Atwater, B. Magura, C. Hedeen, R. Blakely, **R. Wells**, K. Shay, R. Wagner, T. Southworth-Neumeyer, and D. Connor, 2006, Linking Middle School Teachers with EarthScope, EOS Transactions of the American Geophysical Union, Vol. 87, No. 26, p. 257 - 261.

63 **Wells, Ray E.**, Rymer, Michael J., Prentice, Carol S., and Wheeler, Karen L., 2006, Map showing features and displacements of the Scenic Drive Landslide, La Honda, California, during the period March 31, 2005-November 5, 2006: U.S. Geological Survey Open-File Report 2006-1397 [available on the World Wide Web at URL http://pubs.usgs.gov/of/2006/1397/].

64 McCaffrey, R., A.I. Qamar, R.W. King, **R.E. Wells**, Z. Ning, 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, 53 p. supplement.

65 Blakely, R.J., and **Wells, R.E.**, 2008, Potential fields illuminate geologic factors associated with subduction-margin earthquakes: III Simpósio Brasileiro de Geofísica (3rd Symposium of the Brazilian Geophysical Society), Belém, Brazil, November 2008, 3 p. (Extended abstract published in Symposium volume and on CD).

66 Blakely, R.J., Sherrod, B.L., Hughes, J.F., Anderson, M.L., **Wells, R.E.**, and Weaver, C.S., 2009, Saddle Mountain fault deformation zone, Olympic Peninsula, Washington—western boundary of the Seattle uplift: Geosphere, v. 5, p. 105-125, doi: 10.1130/GES00196.1.

67 Wheeler, Karen L., **Wells, Ray E.**, Minervini, Joseph M., and Block, Jessica L., 2009, Geologic map of the Carlton quadrangle, Yamhill County, Oregon: U.S. Geological Survey Open-File Report 2009-1172, scale 1:24,000 and database.

68 **Wells, R.E.**, Niem, A.R., Evarts, R.C., and Hagstrum, J.T., 2009, The Columbia River Basalt Group from the gorge to the sea, *in* O'Connor, J.E., Dorsey, R.J., and Madin, I.P., eds., Volcanoes to Vineyards—Geologic Field Trips through the Dynamic Landscape of the Pacific Northwest: Geological Society of America Field Guide 15, p. 737–774, doi: 10.1130/2009.fl d015(32).

69 Evarts, R.C., O'Connor, J.E., **Wells, R.E.**, and Madin, I.P., 2009, The Portland Basin—a (big) river runs through it: GSA Today, v. 19, no. 9, p. 4–10, doi: 10.1130/GSATG58A.1.

70 Hillhouse, J. W., **R. E. Wells**, and B. F. Cox, 2010, Paleomagnetism of Miocene volcanic rocks in the Newberry Mountains, California: vertical-axis rotation and a polarity transition, in "Overboard in the Mojave, 20 Million Years of Lakes and Wetlands", eds. R. E. Reynolds and D. M. Miller, Desert Studies Consortium, California State University, Fullerton, April, 2010, p. 177-195.

71 Walsh, Ken, Peterson, Gary L., Beeson, Marvin H., **Wells, Ray E.**, Fleck, Robert J., Evarts, Russell C., Duvall, Alison, Blakely, Richard J., and Burns, Scott, 2011, A Tunnel Runs Through It - An Inside View of the Tualatin Mountains, Oregon: U.S. Geological Survey Scientific Investigations Map 3144, one 8 x 3 foot sheet with text, approx. scale 1:1,900. http://pubs.usgs.gov/sim/3144/

72 Blakely, R.J., Sherrod, B.L., Weaver, C.S., **Wells, R.E.**, Rohay, A., Barnett, E. A., and Knepprath, N., 2011, Connecting the Yakima fold and thrust belt to active faults in the Puget Lowland, Washington: Journal of Geophysical Research, accepted Feb 14, 2011.