Course Outline and Reading List - GEOL 701(i) - Western US Tectonic Framework
Fall 2012

Expectations

Course will consist of reading 2-4 papers per week with students presenting the papers orally in class. Students are expected to 1) do the reading, 2) formulate questions about the reading, and 3) articulate those questions during class time. Participation element of grading will follow from performance in these three categories.

The required paper will take the form and style of a proposal, written to the NSF to request funding for research activities. This document will provide a brief synthesis of a topic, suggest a course of action that must be taken to answer research questions on the topic. 15 pages maximum, not including references (which are required). Budgets need not be developed in detail but project should be realistic and attainable for 'reasonable' costs. If you are familiar with NSF proposal structure, this means that only the Project Description and References need to be done. Figures are allowed and can be very helpful to communicate project context.

The class will participate in a peer-review of these proposals. Each class member will review one of the proposals submitted by their classmates, randomly assigned by the instructor. Reviewers will know the identity of proposal authors, but authors will not know the identity of their reviewers. Review will address both NSF criteria 1) Intellectual Merit and 2) Broader Impacts and the total will be less than on page. Comments should convey a constructive critique of the merits of the project. Do not engage in detailed editing of the proposal as you would as a manuscript reviewer. Rather, focus on the clarity of the presentation, value of the research, and likelihood of the project to be successful.

The reading list will be initiated by instructor and developed over the term by the students and instructor. There is no final.

Course is graded 40% participation 50% final paper, 10% review.

Course structure

Overview: Geologic History and Provinces of the Western United States (4 weeks)

Provinces/Features
- San Andreas Fault system
- Coast ranges, Transverse Ranges, Peninsular Ranges
- Great Valley
- Great Basin
- Cascadia
- Modoc Plateau
- Columbia River basalts

The OWL (Olympic - Wallowa Lineament)
Colorado Plateau
Mendocino Triple junction
Rocky Mountains
Yellowstone

Concepts of the Cordillera
Thrusts, Ridges, Transforms, Subduction
Forearcs, backarcs, transgressions
Triple junction migration
Volcanic arcs
Sr ratio >.706 line
Major Western US orogenies
Antler
Sonoma
Nevadan
Sevier
Laramide

Seismic Structure & Tectonic History (3 weeks)
Inferring structure from seismology
Techniques:
Receiver functions, P to S conversions
tomography,
anisotropy,
splits,
surface waves,
ambient noise
The Moho and its definitions
Lithosphere/Asthenosphere boundary
Upper mantle structure
Mantle flow: delaminations, drips, blobs, curls, rolls, and tacos

Discussion of Topics for Papers/Proposals
Discuss as a group, and individually with Bill
Will set up meeting times week before.

Geodetic Measurement: Cases (3 weeks)
San Andreas Fault - Central California
San Andreas Fault System - Northern California
San Andreas Fault System - Southern California
- Discussion of comparison between geologic and geodetic slip rates
Cascadia
- Discussion of relative importance of temporary elastic vs. permanent deformation
Colorado Plateau
- Rotation, Rigidity and the Rio Grande Rift

Great Basin/Walker Lane
Baja California?

Dynamic Framework (3 weeks)
Topography, isostasy and gravity
Dynamic topography
San Andreas Fault - weak or strong?
Coherence and admittance between gravity and topography
Strength
Viscosity
Stress

Week 14 Reserved catch up and topics revealed.

Reference List

Atwater, T., (1970), Implications of plate tectonics for Cenozoic tectonic evolution for Western North America, *Geological Society of America Bulletin*, *81*, 3513-3536.

Atwater, T., and J. Stock (1998), Pacific-North America plate tectonics of the Neogene southwestern United States; an update, *International geological Review*, *40*, 5, 375-402.

Also see Tanya's animations at:
at:http://emvc.geol.ucsb.edu/1_DownloadPage/Download_Page.html#WNATectGeolHist

Burchfiel, B. C., D. S. Cowan, and G. A. Davis (1992), Tectonic overview of the Cordilleran orogen in the western U.S., in *The Cordilleran Orogen: conterminous U.S.: The Geology of North America, Volume G-3, Decade of North America Geology*, edited by B. C. Burchfiel, et al., pp. 407-480, Geological Society of America, Boulder.

Berglund, H. T., A. F. Sheehan, M. H. Murray, R. Mousumi, A. R. Lowry, S. R. Nerem, and F. Blume (2012), Distributed deformation across the Rio Grande Rift, Great Plains, and Colorado Plateau, *Geology*, *40*, 1, doi:10.1130/G32418.1, 23-26.

Colgan, J. P., and C. D. Henry (2009), Rapid middle Miocene collapse of the Mesozoic orogenic plateau in north-central Nevada, Int. Geol. Rev., 51(9–11), 920–961, doi:10.1080/00206810903056731

Cox, A., and R. B. Hart (1986), *Plate Tectonics: How it Works*, 392 pp., Blackwell Scientific Publishing, Brookeline Village, MA.

DeCelles, P. G. (2004), Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western USA, *American Journal of Science*, *304*, 105-168.

Dickinson, 2002, The Basin and Range Province as a composite extensional domain, *International Geology Review,* Vol. 44, 2002, p. 1–38.

Dickinson, 2009, Anatomy and global context of the North American Cordillera, *Geological Society of America Memoirs* 2009;204;1-29 doi: 10.1130/2009.1204(01).

Dilek, Y., and E. M. Moores (1999), A Tibetan model for the early Tertiary western United States, *Journal of the Geological Society*, *156*, 929-941.

Dixon, T. H., S. Robaudo, J. Lee, and M. C. Reheis (1995), Constraints on present-day Basin and Range deformation from space geodesy, *Tectonics*, *14*, 755-772.

Dixon, T. H., M. Miller, F. Farina, H. Wang, and D. Johnson (2000), Present-day motion of the Sierra Nevada block and some tectonic implications for the Basin and Range province, North American Cordillera, *Tectonics*, *19*, 1-24.

Dokka, R. K., and C. J. Travis (1990), Role of the Eastern California Shear Zone in Accommodating Pacific-North-American Plate Motion, *Geophysical Research Letters*, *17*, 1323-1326.

Dokka, R. K., and C. J. Travis (1990), Late Cenozoic Strike-Slip Faulting in the Mojave Desert, California, *Tectonics*, *9*, 311-340.

Egger, A., E. Miller, Evolution of the northwestern margin of the Basin and Range: The geology and extensional history of the Warner Range and environs, northeastern California, *Geosphere;* June 2011; v. 7; no. 3; p. 756–773; doi:10.1130/GES00620.1.

England, P., G. A. Houseman, and L. J. Sonder (1985), Length scales for continental deformation in convergent, divergent, and strike-slip enviornments: Analytical and approximate solutions for a thin viscous sheet model, *Journal of Geophysical Research*, *90*, B5, 3551-3557.

Fay, N., and E. Humphreys (2006), Dynamics of the Salton block: Absolute fault strength and crust-mantle coupling in Southern California, *Geology*, *34*, 261-264.

Fay, N., and E. D. Humphreys (2008), Forces acting on the Sierra Nevada block and implications for the strength of the San Andreas fault system and the dynamics of continental deformation in the western United States, *Journal of Geophysical Research*, *113*.

Faulds, J. E., C. D. Henry, and N. H. Hinz (2005), Kinematics of the northern Walker Lane: An incipient transform fault along the Pacific-North American plate boundary, *Geology*, *33, doi:10.1130/G21274.1*, 505-508.

Flesch, L.M., Holt, W.E., Haines, A.J., & Shen-Tu, B., Dynamics of the Pacific-North America plate boundary in the western United States, *Science* **287**, 834 (2000).

Flesch, L. M., W. E. Holt, A. J. Haines, L. X. Wen, and B. Shen-Tu (2007), The dynamics of western North America: stress magnitudes and the relative role of gravitational potential energy, plate interaction at the boundary and basal tractions, *Geophysical Journal International*, *169*, 866-896.

Forsyth, D. W., and S. Uyeda (1975), On the relative importance of the driving forces of plate motion, *Geophysical Journal of the Royal Astronomical Society*, *43*, 163-200.

Foy, T. Andrew; Frankel, Kurt L.; Lifton, Zachery M.; Johnson, Christopher W.; Caffee, Marc W. Distributed extensional deformation in a zone of right-lateral shear: Implications for geodetic versus geologic rates of deformation in the eastern California shear zone-Walker Lane, *Tectonics*, Vol. 31, No. 4, TC4008 http://dx.doi.org/10.1029/2011TC002930

Friedrich, A. M., B. P. Wernicke, N. A. Niemi, R. A. Bennett, and J. L. Davis (2003), Comparison of geodetic and geologic data from the Wasatch region, Utah, and implications for the spectral character of Earth deformation at periods of 10 to 10 million years, *Journal of Geophysical Research*, *108(B4), 2199, doi:10.1029/2001JB000682*.

Gao, W., S. P. Grand, W. S. Baldridge, D. Wilson, M. West, J. Ni, and R. C. Aster (2004), Upper mantle convection beneath the central Rio Grande rift imaged by P and S wave tomography, *Journal of Geophysical Research*, *109*, B03305, doi:10.1029/2003JB002743.

Hammond, W. C., and W. Thatcher (2004), Contemporary tectonic deformation of the Basin and Range province, western United States: 10 years of observation with the Global Positioning System, *Journal of Geophysical Research*, *109, B08403, doi:10.1029/2003JB002746*.

Hammond, W. C., and W. Thatcher (2005), Northwest Basin and Range tectonic deformation observed with the Global Positioning System, 1999-2003, *Journal of Geophysical Research*, *110, B10405, doi:10.1029/2005JB003678*.

Hammond, W. C., G. Blewitt, and C. Kreemer (2011), Block modeling of crustal deformation of the northern Walker Lane and Basin and Range from GPS velocities, *Journal of Geophysical Research*, *doi:10.1029/2010JB007817*.

Hearn, E. H., and E. D. Humphreys (1998), Kinematics of the southern Walker Lane Belt and motion of the Sierra Nevada block, California, *Journal of Geophysical Research*, *103*, 11, 27,033-027,049.

Henry, C. D., McGrew, A. J., Colgan, J. P., Snoke, A. W., and Brueseke, M. E., (2011), Timing, distribution, amount, and style of Cenozoic extension in the northern Great Basin, in Lee, J., and Evans, J. P., eds., Geologic Field Trips to the Basin and Range, Rocky Mountains, Snake River Plain, and Terranes of the U.S. Cordillera: Geological Society of America Field Trip Guide 21, p. 27–66.

Henry, C. D. (2009), Uplift of the Sierra Nevada, California, *Geology*, *37*, 6, doi: 10.1130/focus062009.1, 575-576.

Hildebrand, R. S., 2009, Collision catalyzes cordilleran orogeny*, in* Did Westward Subduction Cause Cretaceous–Tertiary Orogeny in the North American Cordillera?, Geological Society of America Special Paper 457, p 71., Boulder, CO, USA.

Humphreys, E., K. G. Dueker, D. Schutt, and R. B. Smith (2000), Beneath Yellowstone: Evaluating plume and nonplume models using teleseismic images of the upper mantle, *GSA Today*, *10*, 12.

Humphreys, E. D., E. Hessler, K. G. Dueker, G. L. Farmer, E. Erslev, and T. Atwater (2003), How Laramide-Age hydration of North American lithosphere by the Farallon slab controlled subsequent activity in the western United States, *International geological Review*, *45*, 575-595.

Humphreys, E. D., and D. D. Coblentz (2007), North America dynamics and western U.S. tectonics, *Reviews of Geophysics*, *45*.

Humphreys, E., and B. Schmandt (2011), Looking for mantle plumes, *Physics Today*, *64*, 8, 34-39.

Jones, C. H., J. R. Unruh, and L. J. Sonder, 1996, The role of gravitational potential energy in active deformation in the southwestern United States, *Nature*, *381*, 37-41.

Jones, C. H., G. L. Farmer, and J. Unruh (2004), Tectonics of Pliocene removal of lithosphere of the Sierra Nevada, California, *Geological Society of America Bulletin*, *116*, 11-12, 1408-1422.

Jordan, T.H., Composition and development of continental tectosphere, *Nature, v. 274*, p 544-548.

Karato, S., and P. WU (1993), Rheology of the Upper Mantle - a Synthesis, *Science*, *260*, 5109, 771-778.

Kreemer, C. & Hammond, W.C., 2007, Geodetic constraints on areal-changes in the Pacific-North America plate boundary zone: What controls Basin and Range extension, *Geology* v. 35, doi: 10.1130/G23868A.1, p 943.

Kreemer, C., G. Blewitt, and R. Bennett (2010), Present-day motion and deformation of the Colorado Plateau, *Geophysical Research Letters*, *37*.

Kreemer, C., G. Blewitt, and W. C. Hammond (2010), Evidence for an active shear zone in southern Nevada linking the Wasatch fault to the Eastern California shear zone, *Geology*, *38*, 475-478.

Lachenbruch, A. H., and J. H. Sass (1978), Models of extending lithosphere and heat flow in the Basin and Range province, in *Cenozoic Tectonics and Regional Geophysics of the Western Cordillera, Memoir 152*, edited by R. B. Smith and G. P. Eaton, pp. 209-250, Geological Society of America, Boulder, Colorado.

LaMaskia, T. A. (2012), Detrital zircon facies of Cordilleran terranes in western North America, *GSA Today*, *22*, 3, doi:10.1130/GSATG142A.1, 4-11.

Levander, A., B. Schmandt, M. S. Miller, K. Liu, K. E. Karlstrom, R. S. Crow, C. T. A. Lee, and E. D. Humphreys (2011), Continuing Colorado plateau uplift by delamination-style convective lithospheric downwelling, *Nature*, *472*, 7344, 461-U540.

Levander and Miller, 2012, Evolutionary Aspects of Lithosphere Discontinuity Structure in the Western U.S., *Geochem. Geophys. Geosyst*., Vol. 13, Q0AK07 http://dx.doi.org/10.1029/2012GC004056

Long, M. D., C. B. Till, K. A. Druken, R. W. Carlson, L. S. Wagner, M. J. Fouch, D. E. James, T. L. Grove, N. Schmerr, and C. Kincaid (2012), Mantle dynamics beneath the Pacific orthwest and the generation of voluminous back-arc volcanism, *Geochem. Geophys. Geosyst*., 13, Q0AN01, doi:10.1029/2012GC004189.

Lowry, A. R., N. M. Ribe, and R. B. Smith (2000), Dynamic Elevation of the Cordillera, western United States, *Journal of Geophysical Research*, *105*, 23,371-323,390.

Lowry, A. R., and R. B. Smith (1995), Strength and rheology of the western U.S. Cordillera, *Journal of Geophysical Research*, *100*, 17,947-917,963.

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*, *169*, 1315-1340.

Meade, B. J., and B. H. Hager (2005), Block models of crustal motion in southern California constrained by GPS measurements, *Journal of Geophysical Research*, *110*, B03403, doi:10.1029/2004JB003209.

McKenzie, D., and J. Jackson (1983), The Relationship between Strain Rates, Crustal Thickening, Paleomagnetism, Finite Strain and Fault Movements within a Deforming Zone, *Earth and Planetary Science Letters*, *65*, 182-202.

McKenzie, D., F. Nimmo, J. A. Jackson, P. B. Gans, and E. L. Miller (2000), Characteristics and consequences of flow in the lower crust, *Journal of Geophysical Research*, *105*, B5, 11029-11046.

Molnar, P. (1992), Brace-Goetze strength profiles, The partitioning of strike-slip and thrust faulting at zones of oblique convergence, and the stress-heat flow paradox of the San Andreas Fault, in *Fault Mechanics and transport properties of rocks*, edited, Academic press, ltd.

Oldow, J. S. (1984), Evolution of a late Mesozoic back-arc fold and thrust belt, northwestern Great Basin, U.S.A, *Tectonophysics*, *102*, 1-4, 245-274.

Oldow, J. S. (2003), Active transtensional boundary zone between the western Great Basin and Sierra Nevada block, western U.S. Cordillera, *Geology*, *31*, 1033-1036.

Popov, A.A., S.V. Sobolev, and M.D. Zoback, 2012, Modleing evolution of the San Andreas Fault system in northern and central California, *Geochem. Geophys. Geosyst*., 13, Q08016, doi:10.1029/2012GC004086.

Reheis, M. C., and T. L. Sawyer (1997), Late Cenozoic history and slip rates of the Fish Lake Valley, Emigrant Peak, and Deep Springs fault zones, Nevada and California, *GSA Bulletin*, *109*, 280-299.

Roy, M., J. K. MacCarthy, and J. Selverstone (2005), Upper mantle structure beneath the eastern Colorado Plateau and Rio Grande rift revealed by Bouguer gravity, seismic velocities, and xenolithe

data, *Geochemistry Geophysics Geosystems*, *6*, 10, Q10007, doi:10.1029/2005GC001008.
Schmandt, B., and E. Humphreys Seismically imaged relict slab from the 55 Ma Siletzia accretion to the northwest United States, *Geology*, *39*, 2, 175-178.
Schmandt, B., and E. Humphreys, 2010, Complex subduction and small-scale convection revealed by body-wave tomography of the western United States upper mantle, *Earth and Planetary Science Letters*, *297*, 3-4, 435-445.
Schmalzle, G., T. Dixon, R. Malservisi, and R. Govers (2006), Strain accumulation across the Carrizo segment of the San Andreas Fault, California: Impact on laterally varying crustal properties, *Journal of Geophysical Research*, *111, B05403, doi:10.1029/2005JB003843*.
Schwartz, D. P., and K. J. Coppersmith (1984), Fault behavior and characteristic earthquakes; examples from the Wasatch and San Andreas fault zones, *Journal of Geophysical Research*, *89*, 7, 5681-5698.
Shen-Tu, B., W. E. Holt, and J. A. Haines (1998), Contemporary kinematics of the western United States determined from earthquake moment tensors, very long baseline interferometry, and GPS observations, *Journal of Geophysical Research*, *103*, B8, 18,087-018,117.
Shen-Tu, B., W. E. Holt, and J. A. Haines (1999), Deformation kinematics in the western United States determined from Quaternary fault slip rates and recent geodetic data, *Journal of Geophysical Research*, *104*, B12, 28,927-928,955.
Silver, P. G, and W. E. Holt (2002), The mantle flow field beneath western North America, *Science*, *295*, 1054-1057.
Silver, P. G., and W. W. Chan (1991), Shear wave splitting in sub-continental mantle deformation, *Journal of Geophysical Research*, *96*, 16,429-416,454.
Silver, P. G., 1996, Seismic anisotropy beneath the continents: Probing the depths of Geology, *Ann. Rev. Earth Planet. Sci., 24,* 385-432.
Snoke, A. W., (2005), Southern Cordillera, in Selley, R. C., Cocks, L.R.M., and Plimer, I. R., eds., Encyclopedia of Geology, v. 4: Academic Press, p. 48–61.
Stewart, J. H. (1988), Tectonics of the Walker Lane Belt, western Great Basin; Mesozoic and Cenozoic deformation in a zone of shear, paper presented at Rubey colloquium on Metamorphism and crustal evolution of the Western United States, Los Angeles, CA, 1988.
Surpless, B. (2008), Modern strain localization in the central Walker Lane, western United States: Implications for the evolution of intraplate deformation in transtensional settings, *Tectonophysics*, *457*, 3-4, 239-253.
Svarc, J. L., J. C. Savage, W. H. Prescott, and M. H. Murray (2002), Strain accumulation and rotation in western Oregon and southwestern Washington, *Journal of Geophysical Research*, *107, doi:10.1029/2001JB000625*.
Thatcher, W., G. R. Foulger, B. R. Julian, J. L. Svarc, E. Quilty, and G. W. Bawden (1999), Present-day deformation across the Basin and Range province, western United States, *Science*, *283*, 1714-1718.
Townend, J., and M. D. Zoback (2004), Regional tectonic stress near the San Andreas fault in central and southern California, *Geophysical Research Letters*, *31*, 15, -.
Unruh, J. R. (1991), The Uplift of the Sierra-Nevada and Implications for Late Cenozoic Epeirogeny in the Western Cordillera, *Geological Society of America Bulletin*, *103*, 11, 1395-1404.
Unruh, J. R., J. Humphrey, and A. Barron (2003), Transtensional model for the Sierra Nevada frontal fault system, eastern California, *Geology*, *31*, 4, 327-330.

Wallace, R. E. (1984), Patterns and timing of late quaternary faulting in the Great Basin province and relation to some regional tectonic features, *Journal of Geophysical Research*, *89*, B7, 5763-5769.
Wallace, R. E. (1987), Grouping and migration of surface faulting and variations in slip rates on faults in the Great-Basin Province, *Bulletin of the Seismological Society of America*, *77*, 3, 868-876.
Wang, K., and J. He (1999), Mechanics of low-stress forearcs: Nankai and Cascadia, *Journal of Geophysical Research*, *104(B7)*, 15,191-115,205.
Wang, K., T. Mulder, G. C. Rogers, and R. D. Hyndman (1995), Case for very low coupling stress on the Cascadia subduction fault, *Journal of Geophysical Research*, *100*, B7, 12,907 - 912,918.
Wells, R. E., C. S. Weaver, and R. J. Blakely (1998), Fore-arc migration in Cascadia and its neotectonic significance, *Geology*, *26*, 8, 759-762.
Wells, R. E., and R. W. Simpson (2001), Northward migration of the Cascadia forearc in the northwest U.S. and implications for subduction deformation, *Earth Planets Space*, *53*, 275-283.
Wernicke, B. P., and K. J. Snow (1998), Cenozoic tectonism in the central Basin and Range: Motion of the Sierran-Great Valley block, *International geological Review*, *40*, 403-410.
Wernicke, B. P., A. M. Friedrich, N. A. Niemi, R. A. Bennett, and J. L. Davis (2000), Dynamics of plate boundary fault systems from Basin and Range Geodetic Network (BARGEN) and Geologic Data, *GSA Today*, *10*, 11, 1-7.
Wernicke, B. P., J. L. Davis, R. A. Bennett, J. E. Normandeau, A. M. Friedrich, and N. A. Niemi (2004), Tectonic Implications of a dense continuous GPS velocity field at Yucca Mountain, Nevada, *Journal of Geophysical Research*, *109*, B12404, doi:10.1029/2003JB002832.
Wesnousky, S. G. (2005), Active faulting in the Walker Lane, *Tectonics*, *24*, TC3009, doi:10.1029/2004TC001645.
Wesnousky, S. G., A. D. Baron, R. W. Briggs, J. S. Caskey, S. J. Kumar, and L. Owen (2005), Paleoseismic transect across the northern Great Basin, *Journal of Geophysical Research*, *110, B05408, doi:10.1029/2004JB003283*.
Wesnousky, S. G., J. Bormann, C. Kreemer, W. C. Hammond, and J. N. Brune (2012), Neotectonics, geodesy, and seismic hazard in the Northern Walker Lane of Western North America: Thirty kilometers of crustal shear and no strike-slip?, *Earth and Planetary Science Letters*, *doi:10.1016/j.epsl.2012.02.018*.
West, M., J. Ni, W. S. Baldridge, D. Wilson, R. C. Aster, W. Gao, and S. P. Grand (2004), Crust and upper mantle shear wave structure of the southwest United States: Implications for rifting and support for high elevation, *Journal of Geophysical Research*, *109, B03309, doi:10.1029/2003JB002575*.
Wilson, D., R. C. Aster, M. West, J. Ni, S. P. Grand, W. Gao, W. S. Baldridge, S. Semken, and P. Patel (2005), Lithospheric structure of the Rio Grande rift, *Nature*, *433*, 851-855.
Zandt, G., and E. Humphreys (2007), Toroidal Mantle Flow Through the Western U.S. Slab Window, *Nature*.
Zoback, M. L., R. E. Anderson, and G. A. Thompson (1981), Cainozoic Evolution of the state of stress and style of tectonism of the Basin and Range province of the western United States, *Philosophical transactions of the royal astronomical Society A*, *300*, 407-434.
Zoback, M. L. (1989), State of stress and modern deformation of the northern Basin and Range Province, *Journal of Geophysical Research*, *94*, B6, 7105-7128.