Statement of Research & Teaching Interests

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Research

My main research interests lie in understanding active deformation and brittle failure of the earth’s lithosphere in seismic and volcanic provinces and its impact on society. Accordingly, I plan to focus my studies on fields that have application in advancing our understanding of geologic hazards. During my graduate and postdoctoral studies I have begun several such projects with this in mind. Though these interests are broad, I plan to primarily focus on several aspects of each. Specifically, in earthquake zones, I am most interested in studying: lithospheric forcing; factors that define earthquake fault parameters (e.g., geometry, coupling and temporal variations in seismicity); along with other parameters that control the recurrence of large events. In volcanic regions, I am interested in exploring magmatic and rheologic controls on ground deformation and volcanic seismicity such as tremors and volcano-tectonic earthquakes. In studying these regions I plan to utilize a broad spectrum of geophysical tools including, seismometers, tiltmeters, Global Positioning System (GPS) technologies, and synthetic aperture radar interferometry (InSAR). These tools are useful over a range of frequencies; from low (to zero) frequency geodetic ground deformation to high frequency earthquake rupture activity.

Earthquake recurrence at the New Madrid seismic zone:

Between 1811 and 1812 there were several devastating earthquakes along the Mississippi river valley of the central United States. This region, now called the New Madrid seismic zone, is still seismicly active, generating dozens of $M = 2$ earthquakes each year. Thus, assessing the causes of deformation and better estimating the recurrence of large events are necessary for determining earthquake hazard in the region. As a part of my PhD thesis, I, along with Seth Stein (thesis advisor at Northwestern University) and several other colleagues, utilized GPS geodetic measurements from across the seismic zone and found minimal long range tectonic motion across the region [1]. Additionally, my reexamination of continuous GPS results away from the seismic zone and across the stable North American plate found less than 1 mm/yr of differential plate motion; consistent with local results. Thus, there appears to be little or no resolvable plate-wide motion driving seismic activity. With the maximum allowable horizontal slip accumulation from my study, and assuming 100% seismic release of geodetic strain, the recurrence interval for “New Madrid style” $M = 8$ earthquakes, with 5-10 m slip, would be 2,500-5,000 years. This is significantly greater than the 500-1,000 years previously estimated from the earthquake frequency-magnitude distribution and the ~500 year recurrence interval found from recent paleoseismic studies. My GPS results are also consistent with my reevaluation of the earthquake frequency-magnitude distribution, and the general lack of fault-associated topography. These data may also be consistent with the paleoseismic evidence of a large event every 500 years if the 1811-12 earthquakes and earlier events were considerably smaller (low $M = 7$) and recurring every 500-1000 years. Smaller $M = 7$ events are also consistent with recent earthquake intensity studies for the 1811-12 series.

Reducing the size of the largest earthquakes has considerable effects on predicted seismic hazard in New Madrid. Because these results suggest either considerably smaller or less frequent large earthquakes in the region, colleagues from Impact Forecasting L.L.C. (a natural hazards assessment firm for insurance companies) and I explored the effects that these parameters, along with several predicted ground shaking models, have on predicted hazard at various frequencies [3]. We found that modest changes in these parameters can significantly affect predicted ground accelerations, thus demonstrating considerable uncertainties in seismic hazard from the New Madrid
seismic zone. In the future, I would like to further explore other geologic evidences that are used to support rapid recurrence of large earthquakes in the NMSZ (e.g., controls on maximal extent of earthquake liquefaction in the central US, and the existence of disproportionally frequent “characteristic earthquakes” from paleoseismic records as compared to recorded seismicity).

Volcano deformation:

Ground deformation measured across a volcanic edifice can be used to obtain information on the magmatic “plumbing systems” at depth, and if available in a timely manner, may also be useful for eruption warning. Most crustal and volcano deformation models published to date assume that the earth’s crust behaves as a perfectly elastic solid. While elastic half-space models fit a variety of deformation data, this rheology is an oversimplification, and may be inadequate for volcanoes. Crustal material approximates elastic behavior only at temperatures cooler than the brittle-ductile transition. However, in active volcanic regions, magma at relatively shallow crustal depths can significantly heat and hydrate otherwise brittle shallow crust causing it to act as a viscous or viscoelastic solid, thus significantly influencing the surface deformation field.

I am collaborating with Timothy and Jacqueline Dixon (University of Miami) on a project to better determine the geometric and rheologic constraints for surface deformation at Long Valley Caldera (LVC) in east-central California. The LVC was formed 760,000 years ago in a massive caldera forming eruption creating the Bishop Tuff. The region has experienced seismicity and surface deformation well above background levels since 1979, with the most recent phase of unrest occurring in late-1997. During this latest period of unrest, a seemingly “steady-state” inflation rate of about 1 cm/yr grew exponentially over a few months to a rate of more than 10 cm/yr before decaying back to the background inflation rate. Using mathematical and numerical modeling that include the effects of viscoelasticity on deformation from a variable pressure source, we have been able to characterize the recent deformation more realistically than with a purely elastic model [4]. Though this work shows the necessity for considering viscoelastic behavior on ground deformation at highly silicic volcanoes, many parameters still need to be better defined.

Further numerical modeling of the deformation at Long Valley, along with a GPS pilot study at the Valles Caldera, are the focus of my current postdoctoral fellowship at Los Alamos National Laboratory. By improving our understanding of individual physical parameters and how they control surface deformation, my work can be incorporated into more precise forecasts of hazards from potentially active volcanoes. With recent improvements in both GPS and Synthetic Aperture Radar interferometry (InSAR) technologies, this field of volcano geodesy is sure to grow and I am very pleased to have become a part of this small, but rapidly growing group.

Volcano seismology:

During the 1997 inflation episode at Long Valley Caldera (discussed above), the “South Moat”, an area adjacent to the region of inflation, experienced massive seismic swarm activity with 4 large earthquakes ($M > 4.5$) occurring concurrent with peak dome inflation [4]. Currently, little is known about the relationship between seismicity and dome growth, though it is possible that the activity is caused by fluid pressure changes. Learning more about this relationship is useful since geodetic monitoring could therefore become an effective tool for short-term forecasting of some larger earthquakes in volcanic regions.

I have worked briefly with Peter Malin (Duke University) to help resolve low frequency trailers in the many smaller earthquakes from the 1997 episode. It is believed that these are due to harmonic oscillations of fluid filled cracks and tubes near a dike intrusion [5]. By identifying harmonic signals from fluid activity, it may be possible to observe magma migration (necessary information for eruption prediction). Several recent studies have gone further by exploring the temporal and spatial dependence of seismicity on pore pressure and rheology at active volcanoes. During periods of increased seismicity, this information can also unveil areas where increasing temperatures from magma influx may change physical rock properties. Although my experience in this field has been limited, I am eager to incorporate volcano seismology into my research plan as I believe it well compliments studies of volcanic deformation from magma migration and may aid in the identification of regions where brittle elastic deformation prevail.
"Tsunami earthquake" detection:

"Tsunami earthquakes" are large shallow oceanic events characterized by slow-source fault rupturing which yield significant deficiency in high-frequency energy. Because of this, these rare events often generate large tsunamis that are not predicted by normal real-time tsunami detection algorithms. Since the deployment of a global network of digital seismometers there have been three such events (Nicaragua, 1992; Java, 1994; Peru, 1996).

Along with Emile Okal (Northwestern University), I have worked to develop real-time approximations of earthquake energy release for use in identifying these destructive events. We developed an algorithm to estimate the seismic energy radiated from an earthquake at teleseismic distances (between 30° and 90°) by calculating the energy still present in the generalized P wave train. We calculated this energy ($E$) for 124 globally distributed earthquakes ($M_0 > 10^{25}$ dyn-cm) and compared it with the published seismic moment ($M_0$). We found that high-frequency energy released by known "tsunami earthquakes" were deficient by as much as two orders of magnitude from an average large oceanic event [6]. Since the slow-source rupture that defines "tsunami earthquakes" is likely caused by properties of the individual subduction zone in which they occur, we examined smaller events from regions of large "tsunami earthquakes" and found little spatial correlation [7]. However, this may be due to the short time scale in which we have examined the regions. It is possible that future earthquakes that rupture the same segment of fault as an earlier "tsunami earthquake" may also generate large tsunamis. I am currently proposing to further this work by incorporating a study of current microseismicity, not recorded teleseismically, to better determine this relationship.

Characterizing shallow subduction processes:

Most of the world’s great earthquakes occur along the active portion of the thrust interface at subduction zones. Basic seismological properties about plate coupling across these regions, termed seismogenic zones, are not well understood. These regions are difficult to study because they often occur offshore. However, The Nicoya Peninsula in Costa Rica, a ophiolite complex, lies directly over an active seismogenic zone, making it perfect for such a study.

With Susan Schwartz (UCSC) and Tim Dixon (University of Miami), I have developed a more complete image of the seismogenic zone in Costa Rica using both on/off-shore passive seismic arrays and GPS geodesy. Over the span of the 18 month seismic deployment, we recorded several thousand small earthquakes ($M < 4$) occurring beneath the peninsula. I located many of these events using a high resolution three dimensional localized velocity model, and relative relocation techniques, to better determine seismogenic structure. Although interplate seismicity is present from 10 to 40 km depth, I have found that most events concentrate along a narrow band between 14 to 22 km starting about 60 km land-ward of the trench. This activity, which best defines the upper limit of the seismogenic zone has a significant jump in earthquake depth with events in the south starting about 8-10 km and not beginning until about 20 km depth in the north. I found that these events are coincident with a change in type and temperature of the incoming plate and is likely controlled by changes in the thermal and physical structure of the down-going slab [8].

During the seismic campaign, a large normal faulting outer-rise earthquake occurred just south of our network. This event has raised several ideas about the state of stress of the down-going slab and how it effects seismogenic zone coupling. There are still many questions to be answered about near-surface subducting plate interactions here that we plan to further explore using data from this experiment (i.e., role of sedimentary diagenesis, effects from subducted seamounts, metamorphic reactions and aseismic creep in earthquake distributions). With Dr. Schwartz, I am currently writing proposals to continue exploring these questions and to also look into changes in the seismogenic zone as it extends northward to Nicaragua, the site of a large "tsunami earthquake" in 1992.

References

Teaching

I am excited by the opportunity to develop undergraduate and graduate courses, and begin the process of mentoring graduate students. I am committed to seeing that students utilize computer technology and available geologic and geophysical Internet resources and obtain geophysical field experience wherever appropriate.

While at Northwestern University, I had the opportunity to become a graduate student delegate to the Earth System Science Education Program of the Universities Space Research Association (ESSE/USRA). I have also had the opportunity to be a teaching assistant eight times for six different undergraduate courses. These courses include several different introductions to earth science (Physical Geology, Global Environmental Change, Planetary Geology, and Plate Tectonics), an introduction to geophysics for majors, and an intensive earth physics course for Northwestern’s Interdisciplinary Science Program. Most recently, I taught an introduction to solid earth geophysics called "The Dynamic Earth" at UC Santa Cruz to about 40 undergraduates.

Philosophy

From my experiences as a teaching assistant and lecturer, I have begun to formulate various ideas about what is necessary to develop courses that both engage and instruct students in science. I have learned that one of the challenges in teaching science at the undergraduate level is that students are not uniformly interested in the topics being discussed and are not all focused in becoming scientists as I was. Students in any one class generally maintain a wide range of interests; from those who are highly science-oriented to those whose energies lie elsewhere, yet are there to fulfill scientific distribution requirements mandated by the school. Oftentimes, students who look to fulfill distribution requirements will choose geological science courses as alternatives to chemistry or physics because they may consider geology as an easier alternative (of course, this is not necessarily the case). Mixing these students with others who are taking the course because of genuine interest in the material can create highly diverse classes. To best teach in such a class, I believe an instructor must be aware of this diversity and learn to engage all the students. An instructor may be tempted to focus instruction towards those students who are science-minded and most likely to continue in either geology or another science major, while leaving other students to either struggle or become bored with the course material. In doing so, I feel the instructor both alienates a significant portion of the class and ensures a lower future enrollment. I believe that at the introductory level,


attention must be made to actively engage all students, striving to educate not just the science-minded, but the class as a whole. I consider it important for my students to leave with, if nothing more, an understanding of the utility of science in interpreting our natural environment and the processes that control the earth. With this information at hand, the students may, in the future, be better able to make decisions in their lives, as consumers, parents and professionals.

Course Development and Potential Contributions

I am aware that, in general, most students entering into college and even graduate school in geology are lacking in many needed computer skills, and that few programs within geology departments do much to introduce students to such computer resources. Thus, I have recently been able to get a new undergraduate course accepted for instruction by UC Santa Cruz. The course, “Introduction to Scientific Computation”, is a first or second year undergraduate course aimed to teach students the basics of using a computer and the Internet for scientific research. The course is designed to focus on learning to use available electronic resources for researching articles, acquiring data, processing and visualizing data as well as disseminating information over the Internet for others. The course will introduce students to online geologic resources, networking, UNIX basics, using Matlab or similar programs for processing and visualizing data, and HTML for creating scientific online resources. The applications used in this course need to change with technological advances, but learning to use the computer as a scientific tool is fundamental to a good modern scientific undergraduate education.

Upon arrival into a new department, I feel that I would be qualified to teach a variety of courses at both the undergraduate and graduate levels. These include introductory courses in physical geology, geophysics, geologic hazards, and plate tectonics. Also at the undergraduate level, I can teach more advanced courses in geodynamics, structural geology and earthquake seismology and physical volcanology. Courses I can teach at the graduate level include deformation modeling, and advanced topics courses in geophysical volcanology, seismology, and geodynamics.

Though my career interests lie mainly in performing high quality geophysical research, I also genuinely enjoy teaching and understand the fundamental necessity of building solid undergraduate and graduate programs. In the effort to train aspiring scientists and to educate students, I hope that I will be able to incorporate teaching into my research projects in a way that is advantageous to the department, my research and my students’ education.