Research Experience for Graduates and Post-Doctoral Researchers

Twenty-nine graduate students and three post-doctoral researchers are involved in research administered through ICS. These students are involved in field research both locally and internationally. Many have presented their research with talks or posters at professional meetings: e.g., American Geophysical Union, Geological Society of America, Seismological Society of America, annual meeting for the Southern California Earthquake Center. In addition to the abstracts presented, ICS graduate students are also involved as authors and co-authors on articles in referred journals.

Highlight of Post-Doctoral Research

Gregor Hillers

Postdoctoral Program, Ralph Archuleta, advisor

The Role of Memory and Feedback Mechanisms on Seismicity Distributions

One of my postdoctoral projects, in collaboration with Prof. R. J. Archuleta (UCSB Crustal Studies) and Prof. J. M. Carlson (UCSB Physics), investigates the effects of memory and feedbacks on earthquake patterns. It is a major goal in seismology to understand the spatial and temporal occurrence of earthquakes, particularly of large, devastating events. However, other than gross estimates averaged over large spatial and temporal domains cannot be made at present. These assessments are primarily based on an extrapolation of past seismicity patterns, under the assumption that the overall properties of the system under consideration, e.g., the fault network in Southern California, do not change over time scales comparable to the extrapolation horizon.

In the past, computer simulations of simple mechanical models have been evaluated and served as a guide to the interpretation of real data. Although the available instrumentation allows a satisfactory monitoring of regional seismicity since the 1960's, this 50-year period covers only a fraction of the `seismic cycle,' i.e., the average occurrence of large(st) earthquakes, which is of the order of hundreds of years. Computer models, on the other hand, allow the generation of synthetic seismicity covering thousands of (model) years. By comparing patterns found in computer generated earthquake distributions to statistics of real earthquake catalogs, scientists can at least estimate which parameters control which aspect of a specific occurrence pattern.

Usually, these `control variables' are held constant during one numerical experiment, and researchers spend a good deal of their time in tweaking these parameters and comparing the corresponding results, thus exploring possible response characteristics of the model. The parameters are kept constant to isolate effects associated with each of these `tuning knobs,' and the time independence is often viewed as a satisfactory approximation to processes that occur in nature over the time intervals considered.

There is, however, a large body of evidence from a variety of field observations, laboratory and numerical experiments, which implies that the properties of a system, that affect its stability substantially, are constantly subject to change, on time scales ranging from sub-seconds to ten thousands of years associated with the passage of a rupture tip and the evolution of tectonic plate margins, respectively. Over these time scales, multiple strength degradation and healing mechanisms in the Earth's crust take place, with the competing tendencies of weakening and strengthening rock and/or fault zone properties. The constant-parameter approach assumes that these effects cancel each other out statistically.

We use a simple mechanical model of an earthquake fault and investigate the effects of relative amplitudes of weakening and healing mechanisms on generated seismicity distributions. The evolution laws, according to which the tuning parameter weaken or heal, have been adopted from results obtained in laboratory experiments focusing on rock surface abrasion and healing as a function of external control variables like slip, time, and temperature. During the numerical experiments, we measure the internal stress or energy of the system, and interpret its temporal evolution as a proxy for the evolution of the system's overall state. All parameters being constant, these functions fluctuate around their long-term average value, which is controlled by the current value of the tuning parameters. Including competing weakening and strengthening effects, however, results in a broad range of non-stationary response statistics (Figure 1). The fluctuations, which are persistent over a wide range of non-extreme parameter choices, imply that extrapolations based on past properties have to be applied cautiously. While these stress or energy fluctuations cannot be observed for real faults, the corresponding statistics of the frequency of occurrence do also show deviations from long-term static behavior.

This study looks at first-order effects in a simplified mechanical representation of an earthquake fault, and the results suggest that the relative effects of memory and feedback mechanisms on rock and fault zone properties probably control seismicity patterns to a significant degree. It implies that subtle changes in recovery processes after earthquakes are relevant for future earthquake nucleation, and that anticipated earthquake occurrences probably should account for these interseismic processes.

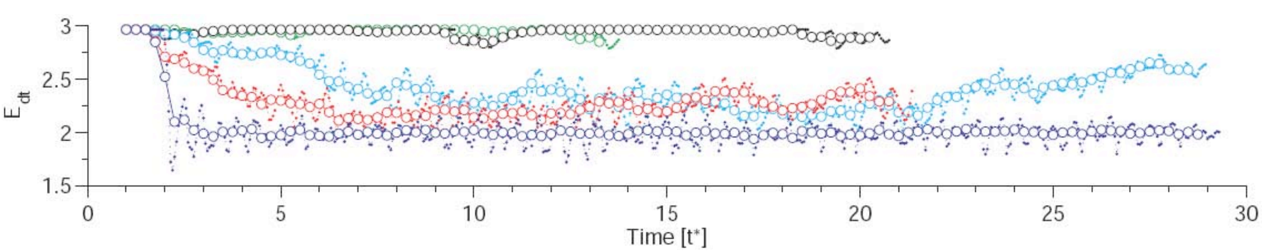


Figure 1 *Typical temporally averaged (dt=[0.1, 0.5]t*-bins) stress or internal energy levels (E) of five systems with variable healing amplitudes and constant weakening effects. Relatively high E-levels correspond to dominating restrengthening effects (black, green), while a relatively low level is characteristic for conditions in which weakening processes prevail (dark blue). While all examples show deviations from the long-term average, the red and light blue curves suggest that a statistically stable state does not exist for the values of competing mechanisms chosen. One time unit t* roughly corresponds to one earthquake cycle.*

Scaling Laws of Earthquakes

Despite the apparent complexity in the earthquake process, it is of basic interest to understand observed scaling relations between fundamental earthquake source parameters, such as fault length *L* and width *W*, average slip *u* during an earthquake of size *M*, and the stress drop *SD*, i.e., the difference in stress on a fault prior to and after the earthquake happened. Knowledge of these interdependencies helps to evaluate the seismic potential of a fault and thus to estimate the potential damages associated with earthquakes on that fault. Recent compilations of empirical *u*-*L* data, however, manifested a paradox between some of the hitherto assumed interrelations between *L*, *W*, *u* and *SD*. Namely, the width *W* of large earthquakes has been assumed to saturate with the width of the seismogenic zone *WZ*, usually interpreted to coincide with the depth extent of background seismicity. This would imply an increase in stress drop *SD* with earthquake size *M*, which is, despite of considerable scatter, assumed to be magnitude independent.

Together with Prof. S. G. Wesnousky (U Reno), we explored the implications of a relaxed lower-seismicity boundary on fundamental scaling relations. We use a quasi-dynamic 3D model of a 2D strike slip fault, developed during my doctorate studies, and compare results from numerical simulations with and without the possibility of slip propagating below *WZ*. Synthetic seismicity from the relaxed case produces statistics compatible with observations, including a constant *SD*-*M* (no increase of stress drop with size) and *u*-*L* scaling, respectively. On the other hand, the model prohibiting deep slip produces an increasing *SD* with earthquake size, which is in apparent conflict with data. Our study, along with a variety of other indirect observations, suggests that a large earthquake continues to grow in the downward direction, but with decreasing growth rates. It is difficult to observe seismic slip unequivocally at these depths (15-20 km) with seismological and geodetic measurements, and it possibly generates frequencies that are longer compared to the seismic frequency band. However, our observations might encourage increased sensitivity to coseismic processes at depth.

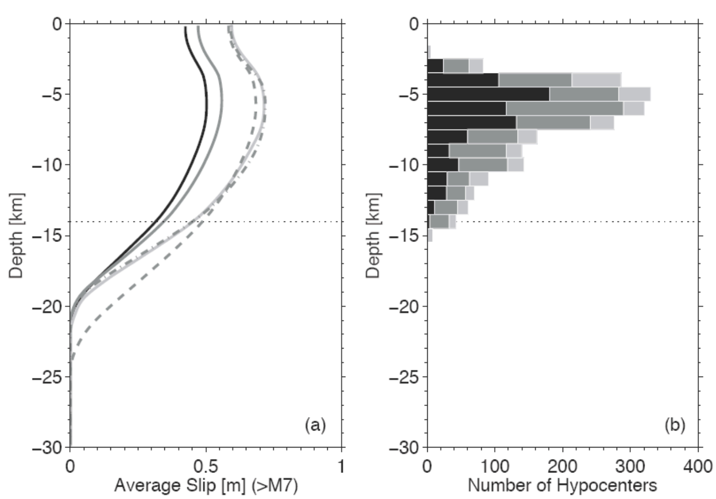


Figure 2 *(a) Averaged slip-depth profiles from models that allows slip to propagate below WZ, indicated by the dotted horizontal line. The amount of slip below -15 km depends on the parameters chosen, but is substantial. (b) Depth distribution of background seismicity in the model, which terminates at WZ. Usually, this type of data is used to estimate the largest vertical extend of earthquakes that occur in a particular region. The juxtaposition to the slip profiles suggests that this assumption is not necessarily justified.*

Efficient Generation of Multiple Rupture Scenarios

One of seismologist's contributions to appropriate building codes is to provide estimates of the ground motions that are expected in the vicinity of an active fault. This usually requires a `tool-chain,' consisting of a (dynamic) source model, the wave propagation effect and the site response, providing the possibility to compute a multitude of different rupture scenarios and subsequent ground motions. It is inherently difficult, however, to automatically produce a large number of rupture models that display observed variability in earthquake source properties. While different approaches seem fruitful and are pursued by a number of research groups, I participate in an effort lead by Dr. P. M. Mai (ETH Zurich), in collaboration with the URS Corp. office in Pasadena, which aims to take a shortcut by using synthetic final slip distributions and to efficiently extract input parameters for dynamic rupture models from them.

A suite of synthetic slip maps, resembling spatial complexity comparable to that of natural earthquakes, are generated by the same 3D quasi-dynamic multi-cycle approach discussed above, in response to variable boundary conditions with different degrees of heterogeneity. Empirical scaling relations are then applied to estimate input parameters for dynamic rupture codes. Preliminary results of this approach suggest that this is a highly efficient method to produce the desired number of event realizations, showing realistic variability. However, the mapping or scaling relations turn out to give satisfactory results---and hence realistic rupture propagation pattern---only during mature parts of the rupture. The scaling breaks down in the nucleation region and in areas where the event stops. This behavior can be understood considering the assumptions that underlie the theoretical scaling estimates. Current and future theoretical and numerical work is directed at a more refined estimate of the mapping functions covering all aspects of rupture, and to extract the governing input parameters to dynamic rupture codes in a more rigorous way.

Cécile Bonnet-Matzinger

Postdoctoral Program, Douglas Burbank, advisor

Interactions between drainage patterns and growing folds (Central Otago, New Zealand)

This postdoctoral project, in collaboration with Douglas Burbank (UCSB Crustal Studies) and Bodo Bookhagen (UCSB Geography), was supported by the Swiss National Science foundation (grant PBFR22-118553).

Introduction

Although a number of previous studies have dealt with the development of folds in sedimentary rocks, the behavior of growing anticlines and their impact on the hydrographic network are less known in bedrock. Our aims are to better understand what control the erosion of actively growing folds affecting basement rocks and to build the erosion surfaces associated with these folds. Our first project was to perform Geographic Information Systems (GIS) analyses simultaneously on two study areas in Tajikistan and New Zealand, while the field work would take place in Tajikistan. The location of the study area at the border with Afghanistan and the very bad wintry climatic conditions in Tajikistan prevented a geological collaboration during this springtime. We decided thus to focus our work on the Central Otago area in New Zealand.

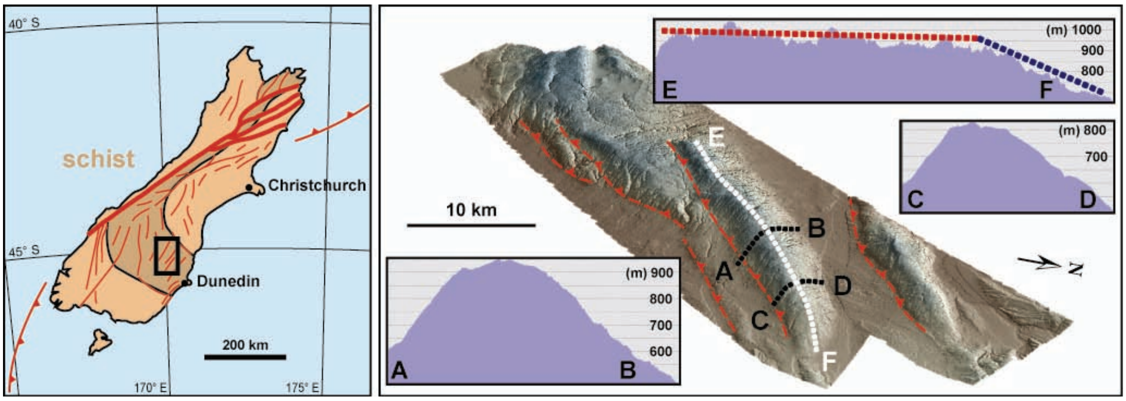


Fig. 1 *Left: structural scheme of South Island, New Zealand. The study zone highlighted by the black rectangle is located in the Central Otago fold and thrust belt. Right: Perspective view of the TOPSAR Digital Elevation Model. The two SE/NW fold cross profiles AB and CD highlight the strong asymmetry of the folds, while the SW/NE fold longitudinal profile EF (length = 26 km) illustrates the flat top of the ridges.*

The Central Otago region is constituted by a flat peneplain surface deformed by late Cenozoic fault-related folds (Fig. 1, left). The successive NE-trending and elongated anticlines developed above still active buried reverse faults have grown probably since 1.5 Ma. Previous studies have shown that despite the slow shortening across the whole Central Otago region, the initial lateral growth of the ranges must have occurred at a faster rate than their present tip extension. One longitudinal and two cross profiles of a fold show the flat top of the ridge reflecting the first stage of fast development of the structures and highlight the strong asymmetry of the ridge (Fig. 1, right). Four factors make Central Otago a particularly favorable region to estimate the erosion rates of the growing folds. 1) The same bedrock underlies the entire study area allowing the comparison of drainage patterns on the different folds. 2) No glaciation has occurred in these ranges so that the geomorphology largely reflects the tectonics. 3) Fold growth and fault propagation styles and rates are fairly well constrained notably by cosmogenic dating. 4) Low rates of erosion in the semi-arid climate permit confident reconstruction of the pre-erosion geometry of the folds. To estimate the erosion rates in the Central Otago region, we have combined field work with a GIS analysis based on a 5-m resolution TOPSAR Digital Elevation Model (DEM).

GIS analysis

The first step of the research project was to acquire data as TOPSAR images and to transform them in an accurately georeferenced Digital Elevation Model usable in a GIS environment. To estimate the eroded volumes of rocks, we clipped either a 75 m or a 125 m wide band on both sides of the drainage lines. A width comprised between 150 and 250 m appeared to be a good average for the numerous channels incising the folds (picture Fig. 2). Then, using a spline function, we filled the remaining topography to obtain an estimated pre-erosion surface. By subtracting the present topography from the two calculated pre-erosion surfaces, we obtained a range of thickness for the eroded rocks (Fig. 2). By comparing some longitudinal profiles along the folds we have observed that the buffer method does not provide the best estimates on the whole study area. As the width of the channels varies in the successive catchments, the buffer sometimes underestimates or overestimates the volume of rocks that have been removed by erosion. A better estimate may be obtained with a method based on the connection of the gentle slopes (slopes of 0 to 10°). After removing the flat slopes corresponding to the stream beds and connecting the gentle slopes at highest topography, we would get a smooth envelope more representative of the pre-erosion initial topography. This work is still in progress.

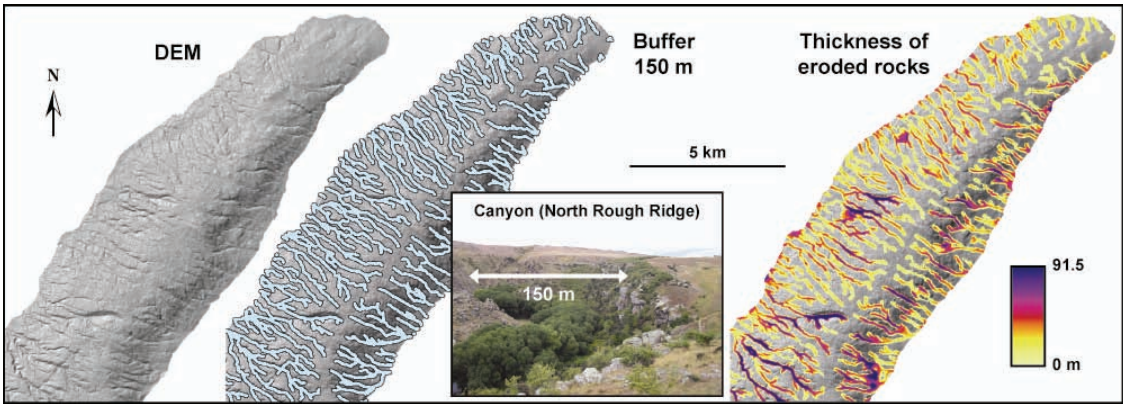


Fig. 2 *On the DEM, we clipped a band on both sides of the drainage lines to represent the rocks eroded along the channels (see picture). Using a spline function, we filled the remaining topography to obtain an estimated pre-erosion surface. By subtracting the present topography from the calculated pre-erosion surface, we obtained an erosion estimate.*

This high-resolution topography analysis provided us qualitative data on the structural and geomorphic evolution of the Central Otago active fold system. However, it also highlighted the need to constrain our evolution model with quantitative data collected in the field to get the rates of folding and uplift, the spatial variations in erosion rates or the controls on the magnitude of channel incision.

Field and lab work

In the field (late April-early May 2008), our aim was to collect detrital sand samples on both sides of the largest ridge of the study area (North Rough Ridge). Due to a surprising lack of running water and sand deposits, we were able to collect only 9 samples along 6 channels. On the western flank of the ridge, the location of sand deposits was restricted to the foot of two very large catchments (39 and 47 km^2). On the eastern flank, the channels show running water along narrow streams (30/40 cm wide; Fig. 3), while the catchments are largely smaller (< 2 km^2). As we have observed in several spots some large potholes in the schist, it seems that there has been much more water in the past. Using differential GPS we surveyed two channels located on the eastern flank of the ridge. The accurate channel profiles obtained from this study allowed us to testify the resolution of the TOPSAR images and the high precision of the radar mapping technique.

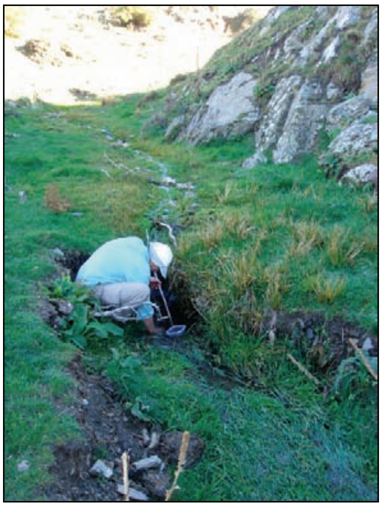


Fig. 3 *Collecting a sample of detrital sand in a stream running on the eastern flank of North Rough Ridge.*

Following the field campaign in Central Otago the 9 collected samples have been processed. The first stages of preparation took place from May to September 2008 in the chemistry lab at the University of California, Santa Barbara (UCSB). The samples were first pre-treated in the rock laboratory. This means washing several times and drying, before being sieved to a grain size (0.25 to 1 mm) for further processing. As this fraction did not provide enough material, we had to crush the pebbles to get more weight. The second step was the quartz cleaning and leeching. The samples were cleaned in a hydrochloric acid bath, then the heavy minerals (among them the quartz) were isolated thanks to a heavy-liquid separation and ultimately, the samples were leeched in a HF/HNO_3 acid mixture. The chemical separation of Aluminum and Beryllium from the quartz fraction of the schist should follow, as well as the dating of the samples.

Results

The drainage pattern is parallel and sometimes dendritic at the head of some catchments. There is no capture and no competition between the streams. The network appears to be juvenile and in a transient state of evolution between the incipient channelization and a more mature geomorphic state. To describe the shape of the basins, we used the form factor obtained by dividing the area of a watershed by the square of its maximal length measured from the mouth. While the circular basins have a form factor close to 1, the long and narrow basins have a form factor close to 0. Most of the watersheds (88 % on a total of 167 basins) have a small to very small form factor (< 0.3) indicating a marked elongated shape (Fig. 4). Due to the shallow slope at the tip of the fold, the basins are less elongated. The homogeneity of the catchment form is another evidence of their simultaneous growth during an initial stage of fold development.

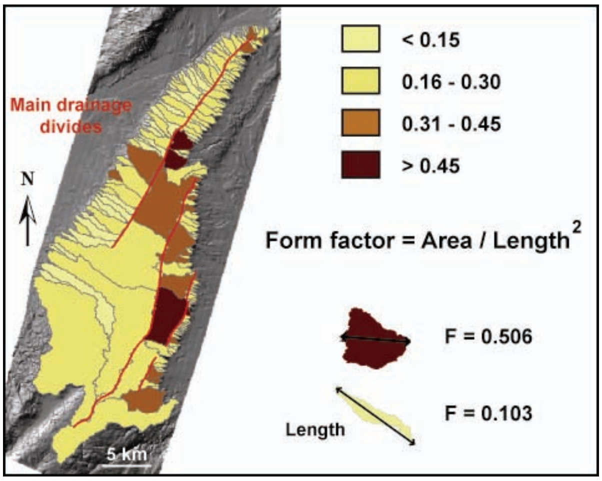


Fig. 4 *The form factor is obtained by dividing the area of a watershed by the square of its maximal length measured from the mouth. The two selected basins illustrate extreme values of form factor. Most of the watersheds have a small form factor (F < 0.3 and represented by a light color) indicating a marked elongated shape.*

To compare the three main folds (North Rough Ridge, Rough Ridge and South Rough Ridge; see location on the DEM Fig. 5), we described the relief, average elevation and mean local relief of their catchments as a function of distance from the NE tip of each fold. The compared catchments are similar: they all reach the main drainage divide and are in an early stage of development. To get the distance of each catchment along the main drainage divide, we have projected perpendicularly the center of gravity of the polygons corresponding to the basins on a line oriented NE/SW representing approximately the fold axis. The relief corresponds to the difference in elevation between the maximal and minimal values in each catchment. It rapidly increases from North to South, i.e. from the tip of the folds to their flat top (top right scheme Fig. 5). The relief along North Rough Ridge (NRR) is higher on its northwestern limb. While Rough Ridge (RR) and North Rough Ridge present a higher average elevation, the more recently developed catchments of South Rough Ridge (SRR) have a lower average elevation. The local relief is the range in elevation values contained within a circular search window (diameter = 250 m in our case). The mean local relief of the catchments located on the eastern flanks of South Rough Ridge and Rough Ridge is higher than the mean local relief of the catchments on both flanks of North Rough Ridge (bottom left scheme Fig. 5). Using geomorphological arguments it was proposed that the major ridges have grown first simultaneously and the smaller frontal ridges such as South Rough Ridge have developed later. The low average elevation of South Rough Ridge in contrast to its high mean local relief is an illustration of its recent development (bottom right scheme Fig. 5).

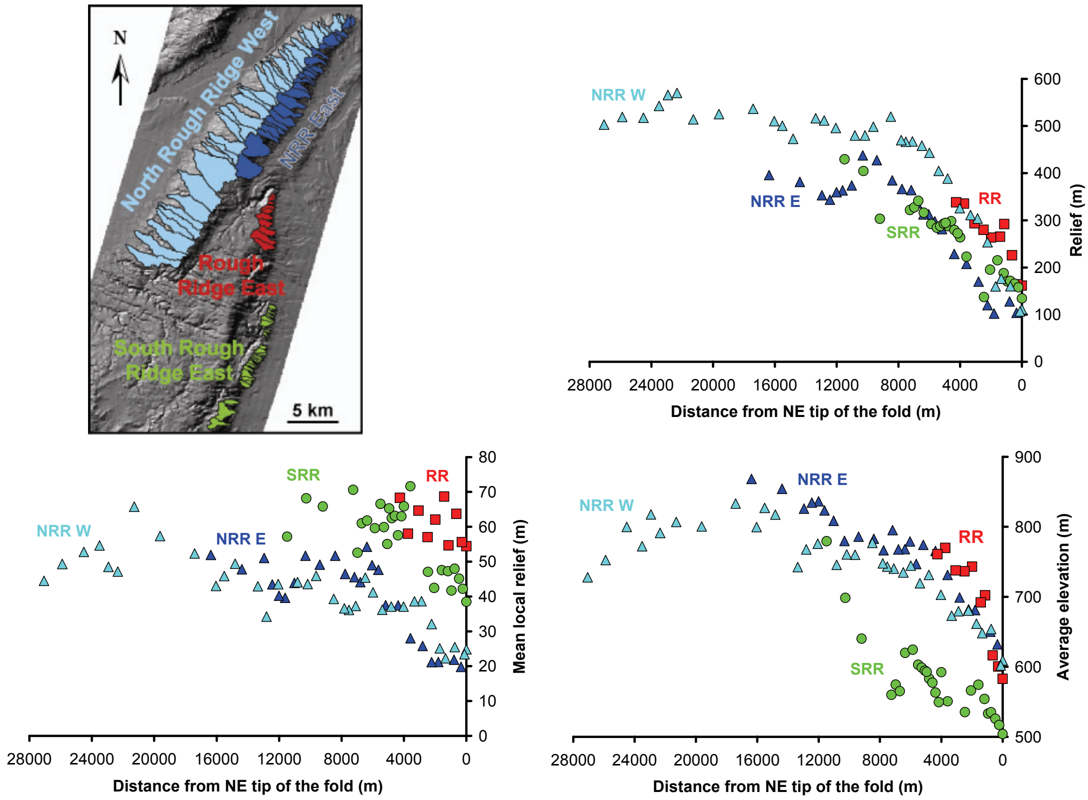


Fig. 5 *The analyzed catchments on North Rough Ridge, Rough Ridge and South Rough Ridge are represented on the DEM of the study zone (top left). We compared the relief (top right), the average elevation (bottom right) and the mean local relief (bottom left) of the catchments as a function of distance from the NE tip of each fold.*

We have focused our work of erosion estimates on the largest fold of the area, North Rough Ridge. The fact that the fold grew rapidly laterally and then slowly vertically along much of its length suggests that the starting time for erosion is similar along most of the fold. For this reason we compared directly mean erosion with both relief and Specific Stream Power instead of talking about erosion rate. The mean erosion is on average lower and more uniformly distributed on the northwestern flank of the ridge. Indeed, even if the relief is high on this flank, since the basins are elongated, the slope is shallower. In active orogens, a number of authors describe an increasing relationship between erosion rate and relief. But in our case, the relationship is weak (Fig. 6, left). The reason may be that in such young folds, the rates of surface erosion and rock uplift did not have enough time to reach equilibrium. The mean Specific Stream Power is the measure of potential energy per unit area acting on the river bed. It integrates the effects of discharge and channel slope and width. The Specific Stream Power increases gradually from the North to the South relative to the increase in relief along the ridge. The very low values of Specific Stream Power coincide with the recently developed tip of the fold. We observe a linear relationship between mean erosion and Specific Stream Power for each catchment (Fig. 6, right). Such a relationship has been observed in other places such as for example in the Himalaya.

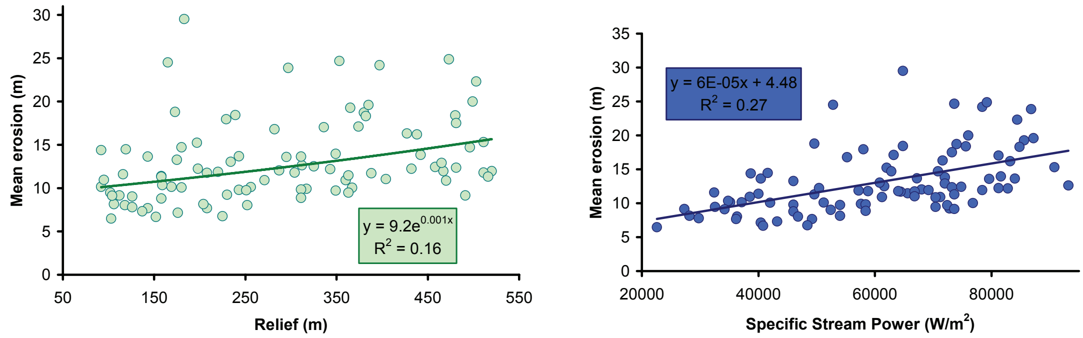


Fig. 6 *Left: The relationship between relief and mean erosion is weak for the catchments located on North Rough Ridge. Right: There is a linear relationship between Specific Stream Power and mean erosion of the catchments.*

Conclusion

The Central Otago region appears to be an ideal place to study the active fault and fold development in basement rocks. It offers a rare case of known starting conditions for erosion unconformity. The good preservation of the unconformity surface allows a realistic estimate of the eroded volumes of bedrock. The low rate of erosion implies that the shape of the ridges reflects tectonic deformation above the underlying faults. The juvenile drainage appears to be in a transient state of evolution and the form of the folds and their catchments indicate a non-episodic growth of the structures. It has been proposed that the major ridges have grown simultaneously during a first stage of development and that the smaller frontal ridges have developed later. We observe that for such a recent fold as for instance South Rough Ridge, the low average elevation of the catchments contrasts with their high mean local relief. There is a linear relationship between Specific Stream Power and erosion but a weak relationship between relief and erosion. We think that this is due to the transient state of the folds that have not reached the equilibrium between surface erosion and rock uplift. The cosmogenic dating of the detrital sand samples collected on both sides of North Rough Ridge should provide an estimate of the erosion rate on the fold. They may be linked with the ages previously measured on quartzites on other folds allowing a comparison between the old major ridges and the smaller frontal ones more recently developed. We may ultimately compare the evolution of the drainage network in the basement rocks of Central Otago with the one in folding Tertiary rocks.

Presentation given by Cécile Bonnet-Matzinger on this research:

"Interactions between drainage pattern and growing folds (Central Otago, New Zealand)", presentation given at the EGU General Assembly 2008 in Vienna (Austria), April 2008.

Highlight of Graduate Student Research

Tomoko Yano
Ph.D Program, Toshiro Tanimoto, advisor

Joint-inversion of ZH ratio and Phase Velocity for Crustal S-wave Velocity Structure in LA Basin

Improving our understanding of seismic S-wave velocity structure of the shallow crust is important for accurate ground motion prediction of each earthquake scenario. Currently, we mainly use SCEC Community Velocity Model (CVM-H) to do this ground motion simulation. However, we attempt to improve S-wave crustal structures in the urban area of Los Angeles basin and its surroundings for more accurate ground motion prediction. We invert for S-wave velocity structures using two kinds of data sets; the ratio between particle motions of vertical and horizontal displacement (ZH ratio) and phase velocities of seismic surface wave such as Rayleigh waves. We found that ZH ratios and phase velocities derived from SCEC Community Velocity Model (CVM-H) is systematically different from observed ZH ratios and phase velocities. Our inversion results showed that most velocity structures need slower S-wave velocity at shallow depth about upper 5 km in depth in order to fit observed ZH ratio and phase velocity. This discrepancy cannot be ignored since slower S-wave velocity at shallow depth is expected to amplify ground motions by a factor of few, although this factor changes from frequency to frequency.

For ZH ratio data, we take advantage of the fact that stable ZH ratios can be obtained between 0.13-0.37 Hz. This relatively long frequency range enables us to observe different patterns depending on local structure. Within this frequency range, ZH ratios show remarkably sharp sensitivities at upper 5km. This means that S-wave velocity structure retrieved by this data contains good S-wave velocity information about upper 5 km.

As for phase velocity measurement, we use Green's functions (source location information) obtained from seismic noise by cross-correlation. This enables us to find phase velocity on paths between every possible pair of stations in southern California. We took advantage of having seismic wave with a strong signal between 0.13-0.2 Hz. For this range of frequency, phase velocity is sensitive down to 20 km.This means that S-wave velocity structure retrieved by this data contains good S-wave velocity information down to 20 km.

Jointly inverting ZH ratios and phase velocities allows us to resolve the entire upper crust while retaining sensitivities at very shallow depth. This method was applied to LA basin area and surroundings with good variance reduction for fitting data. For our future work, we would like to show that our inversion results for the LA basin area require slower S-wave structures than CVM-H at shallow depth.

Richard Lease
Ph.D Program, Douglas Burbank, advisor

≥24km Dextral Shear on the Bristol-Granite Mountains Fault Zone: Successful Geologic Prediction from Kinematic Compatibility of the Eastern California Shear Zone

For regional kinematic compatibility to be a valid boundary condition for continental tectonic reconstructions, there must be tests that validate or invalidate kinematic model predictions. In several reconstructions of western North America, the displacement history of the Mojave block continues to be unresolved. The magnitude of displacement along the Bristol-Granite Mountains fault zone (BGMFZ), the eastern margin of the Eastern California Shear Zone (ECSZ) in the Mojave block, is a key example of a long-standing kinematic prediction that has defied a positive field test until now. The ECSZ is a network of late Neogene and Quaternary right-lateral faults that extend from the Gulf of California north through the Mojave Desert linking Pacific-North America plate motion with Basin and Range extension. This network of faults accounts for ~15 % of post-16 Ma plate transform motion. Geologic estimates of net dextral offset along the Mojave portion of the ECSZ (53±6km) are approximately half that measured to the north in the Owens Valley – Death Valley region (~100±10km). Previous geological estimates of BGMFZ slip range from 0-15 km (Howard and Miller 1992; Brady 1992, 1993). Models of right-lateral displacement based on kinematic compatibility suggest 21-27 km of BGMFZ displacement (Dokka and Travis 1990a; McQuarrie and Wernicke 2005). We map and describe a tuff- and gravel-filled paleovalley offset by the BGMFZ. The orientation of the Lost Marbles paleovalley is constrained by the position of gravel outcrops, provenance, and tuff anisotropy of magnetic susceptibility (AMS). Reconstruction of the paleovalley indicates at least 24 km of post-18.5 Ma dextral offset, confirming a significant, previously undocumented component of dextral slip in the Mojave portion of the ECSZ.

Extrustion vs. convergence? Two-phase late Tertiary growth of the Laji-Jishi Shan, NE Tibet

The northeastern margin of the Tibetan Plateau near Xining, Qinghai Province, China, has a preponderance of curvilinear mountain ranges like the Laji-Jishi Shan where an east-trending segment bends into south-trending segment (or vice-versa). It is debatable whether these curved ranges were created solely by one tectonic regime or are composite structures. Utilizing low-temperature thermochronology to decipher temporal variations in the nature and vergence of range growth provides a time-series of how sustained, far-field Indo-Asian convergence was manifest in northeastern Tibet throughout the Cenozoic. Ostensibly, the Laji-Jishi Shan has the appearance of a pop-up structure at the scale of the entire range. But a closer look at the corner of the range reveals north- and south-vergent thrust faults systematically cut by east- and west-vergent thrust faults. Apatite (U-Th)/He data vary from elevation-invariant ages of ~22 Ma at the northeast corner to elevation-invariant ages of ~8 Ma along the south trending portion of the range. The difference in ages can be explained by initial north-verging compression during early Miocene time that is overprinted by later east- and west- vergent thrusting by at least late Miocene time. Alternatively, the difference in ages reflects greater or longer-lived exhumation along the southern portion of the range compared to the north. This suggests that initial growth

of the Laji-Jishi Shan was perhaps one of the last major expressions in this region of a middle Tertiary phase of predominantly unidirectional deformation that mimicked India-Asia convergence in sense. Later, east-vergent growth of the Laji-Jishi Shan occurred in the Late Miocene, potentially due to lateral extrusion and expansion of the plateau towards the east inducing localized shortening and exhumation.

Duane DeVecchio
Ph.D. Program, Edward Keller, advisor

The Camarillo fold Belt (CFB) in the western Transverse Ranges is composed of several active south-verging folds and reverse faults that pose an unknown hazard to nearly one million people living in the cities of Ventura, Camarillo, Thousand Oaks, and Oxnard as well as those living in the San Fernando, Simi, and Santa Clara River Valleys. Although numerous consulting reports have been generated on some of the known faults, the CFB is the only remaining fold belt between the Los Angeles fold belt and the Santa Barbara fold belt that has not been studied as a unit for the purpose of evaluating potential seismic hazard.

We integrate geologic mapping, GIS-based topographic analyses, Optically Stimulated Luminescence (OSL) and radiocarbon dating and compile previous consulting geologist reports to elucidated the relative timing of deformation on active faults, develop a chronology of deformed surfaces, better constrain the age of the Saugus Formation, and shed light on the landscape evolution in this part of the western Transverse Ranges. New mapping and age dating of the Saugus Formation exposed in the study area indicate that mapped as Saugus strata are an order of magnitude younger than previously thought (20ka vs. 200ka). This has significant implications for the timing and rates of deformation in the study area as well as the seismic hazard. Additionally it calls into question lithostratigraphic correlation of these regionally extensive strata for the purpose of assessing rates of active deformation.

Late Quaternary transpressive deformation in the CFB appears to be predominately controlled by pre-existing Miocene transtensional structures. Some of these structures are oriented parallel to the structural grain (E-W) of the western Transverse Ranges and some are north-striking. East-striking faults accommodate north south contraction with vertical uplift rates as high as 1.6 mm/yr with an interpreted maximum $M_w = 6.4$. North-striking transverse faults locally limit the lateral growth of faults and folds in the CFB. Transverse faults are characterized by changes in the structural style geometry and magnitude of deformation across the faults. Adjacent structural domains are typified by greater structural relief east of the transverse faults and distinct geomorphic changes characterized by greater erosional modification east of the faults. This suggests transverse faults serve as a structural barrier to deformation, but have a finite strength. Locally, late Quaternary structural domains in the CFB and within discrete fold complexes appear to young to the west and south with time.

Radiometric dating of geomorphic surfaces in this part of the western Transverse Ranges suggests the landscape evolution is strongly modulated by global climate change. A regionally extensive erosion surface was beveled on Oligocene to Pleistocene bedrock during Oxygen Isotope Stage 2 (OIS2; 18-26 ka). Preliminary investigations in the Ojai Valley to the north suggest strath cutting during this same interval (Heermance pers. comm.), which may suggest these erosion surfaces characterize a regional geomorphic marker in southern California. Downcutting following the Last Glacial Maximum (LGM; 18 ka) resulted in deep canyons cut through out the study area. Regional aggradation associated with the Pleistocene-Holocene transition resulted in accumulation of as much as 30 m of sediment that back-filled paloecanyons. Loose constraints of the aggradation event suggest deposition occurred between ~15 and 4 ka.

RESEARCH EXPERIENCE FOR UNDERGRADUATES

Twenty-six undergraduate students are involved in research administered through ICS. Four undergraduate students are involved in administrative work through ICS.

Undergraduates worked for the Portable Broadband Instrument Center (PBIC) that provide researchers with year-round access to a "pool" of high-resolution, digital seismic recording equipment. The equipment consists of data recorders, data acquisition systems and sensors. A broad dynamic range of recording is obtained by pairing both weak motion and strong motion sensors with a single recorder. Principal Investigator Jamie Steidl manages the PBIC out of ICS.

NEES@UCSB provides undergraduate students with the opportunity to work with research facilities such as the Garner Valley Field Site and SFSI Structure and the Wildlife Refuge Liquefaction Field Site. Research activities at the field sites include both active shaking at the sites as well as the use of recorded earthquakes and ambient noise to study local site response. The George E. Brown Jr. Network for Earthquake Engineering funded by the National Science Foundation (NEES). Principal Investigator Jamie Steidl manages NEES@UCSB out of ICS. http://nees.ucsb.edu

Garner Valley Field Site and SFSI Structure

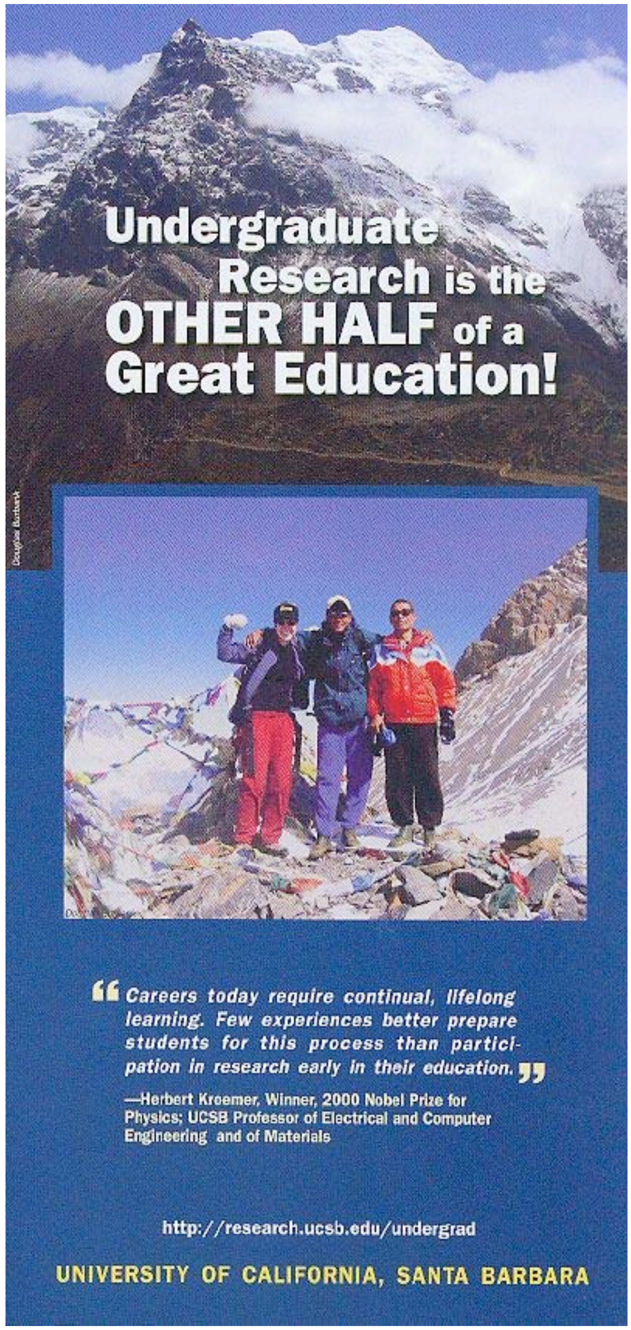

Wildlife Refuge Liquefaction Field Site

UCSB Operated Observatories two engineering seismology array facilities donated to UCSB by the Japanese are currently operated using ICS resources. These arrays are very similar in scope to the NEES observatories. One is located in Southern California near Borrego Springs and the other is located in Central California, near the towns of Salinas and Hollister. These additional arrays provide greater chances for catching a big earthquake in close at a densely instrumented site as they are also located in seismically active areas.

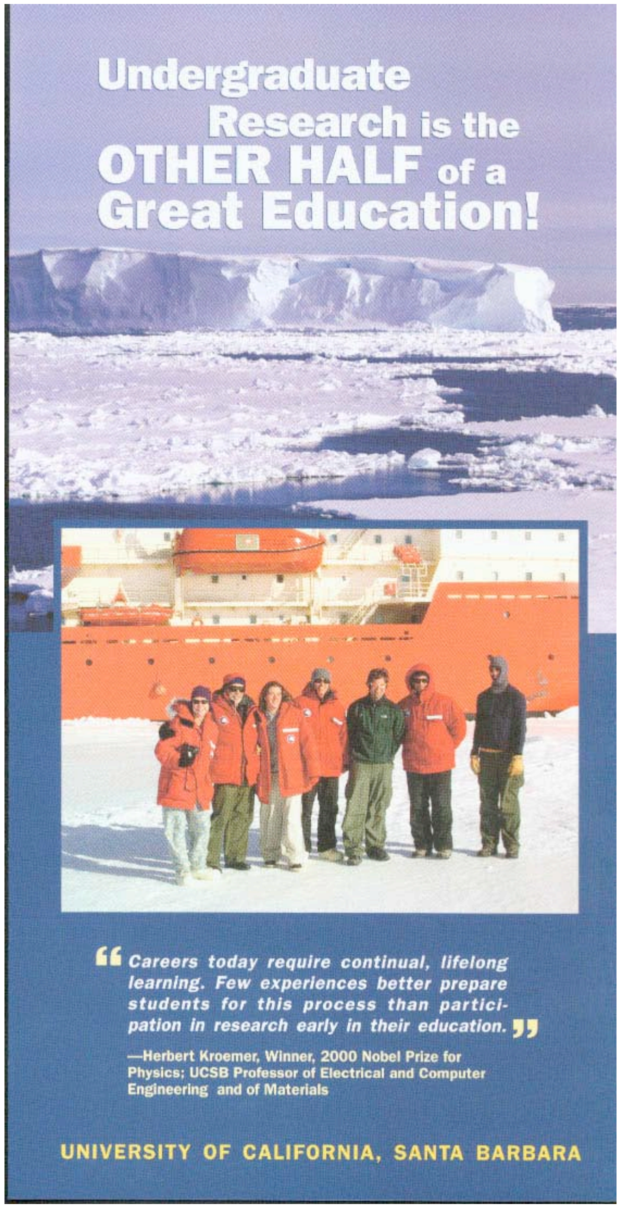

The UCSB Borrego Downhole Array Facility


The UCSB Hollister Earthquake Observatory

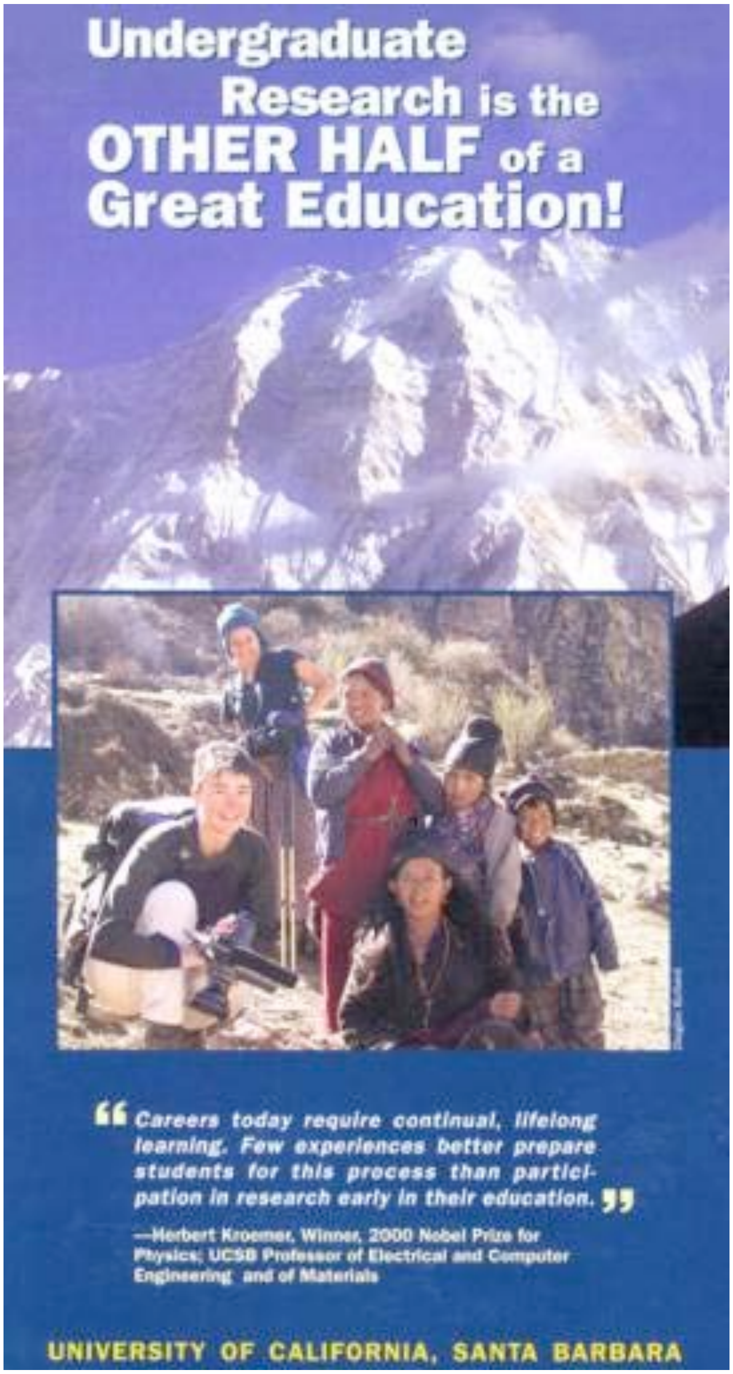
The research projects administered at the Institute have been featured by the Office of Research publication on undergraduate research opportunities brochure from 2002-2005. Covers of the brochure are featured following this page.



Cover: Awesome research Monsoon-drenched Himalayan gorges and wind-swept alpine desert on Tibet’s southern plateau were natural laboratories for undergraduate Karen Vasko in spring 2004. The senior’s research project documented effects of the previous year’s catastrophic flood, which displaced boulders more than 15 feet in diameter. Vasko also was field assistant to Beth Pratt, \a graduate student mentored by UCSB geology professor Douglas Burbank, director of the Institute for Crustal Studies. Burbank leads an eight-university team studying interactions between climate, erosion, and mountain building in the world’s highest mountains. As Vasko helped install devices to monitor river flow, sediment loads, snow melt, and air temperature, she went from tropical rivers to glaciers at 18,000 feet. (Inset: Karen Vasko and two Nepalese assistants reach an alpine pass festooned with prayer flags.)



Cover: Extreme Research Very cool by any measure, a four-week expedition to Antarctica gave five undergrads, two graduate students and their faculty mentor a chance to explore new areas of the ocean floor in the minus 15-degree Antarctic summer of January 2003. Prepping for National Science Foundation-supported research in the coldest, windiest, highest, driest continent on earth included medical exams, full dental tune-ups, and a mandatory geophysics course. Led by Bruce Luyendyk, professor of Geological sciences and principal investigator in UCSB's Institute for Crustal Studies, the research team prepared for drilling from the Ross Ice Shelf that will answer questions about the evolution of the East and West Antarctic ice sheets, Antarctic climate, global sea level, and tectonic history of the West Antarctic rift system.



Cover photo: ***7,8000-Mile Field Trip*** Nepal’s Annapurna mountain range in the Himalayas was junior Michelle Garde’s research lab for eight weeks in spring 2002. Garde (left, in back) was field assistant to Beth Pratt (left, foreground), graduate student working under the supervision of Douglas Burbank, geology professor and director of the Institute for Crustal Studies. Burbank is leading an eight-university team studying inter actions between climate, erosion, and mountain building in the world’s highest mountains. Garde also did her own research, which produced “valuable information on the history of a colossal, 5000-year-old landslide and rates of erosion in this mountainous region,” according to Burbank. (The family in this photo was herding sheep near Tibet where the researchers were camping.)