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Thermobarometry of the Leo Pargil Dome, NW India: Insights into Exhumation of Mid-Crustal Rocks in the Himalaya

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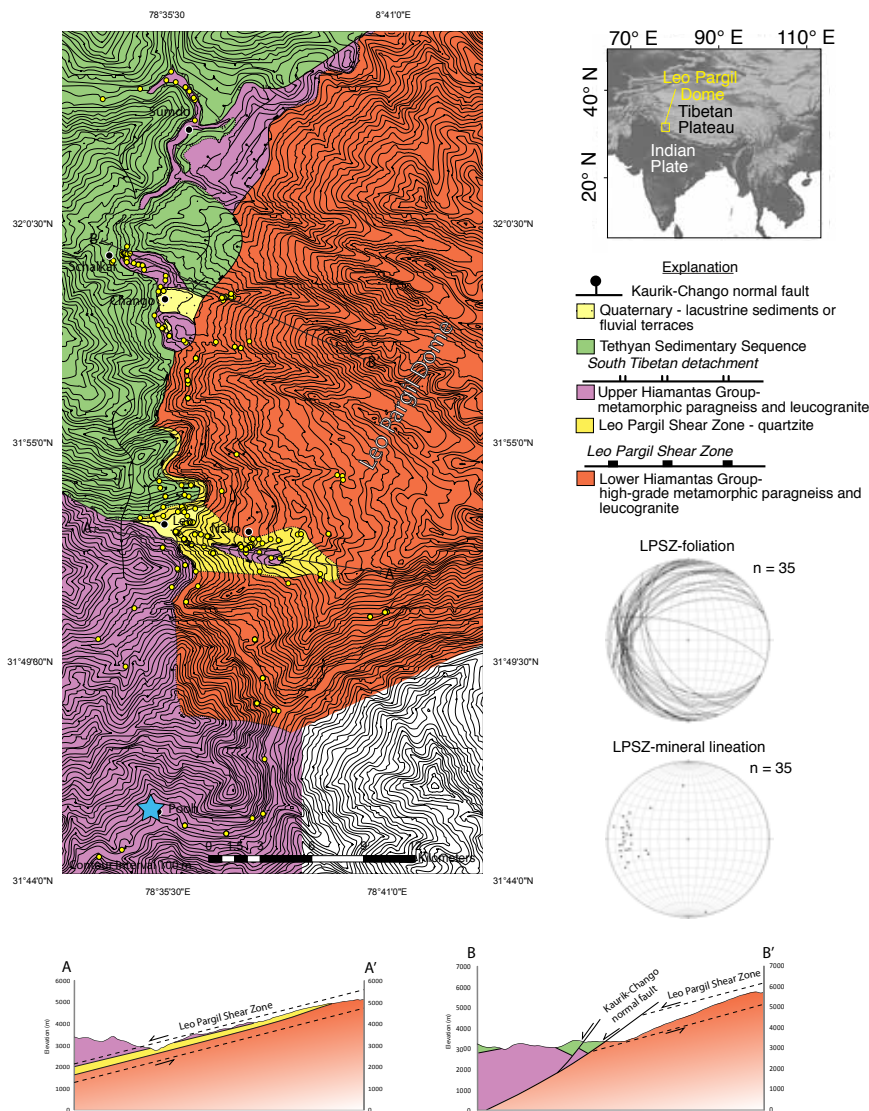
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In the Himalayan orogen, the foreland is dominated by thrust faults, which accommodate north-south crustal shortening associated with continent-continent collision. The interior of the orogen, however, is dominated by east-west extension, which in the highly compressional Himalaya remains a process that is poorly understood. This study aims to improve this understanding by quantifying the exhumation history of metamorphic rocks associated with the Leo Pargil Dome, a prominent extensional feature located on the southern margin of the Tibetan Plateau. By examining extensional features and the exhumation history of associated metamorphic rocks, valuable insights such as the chronology and kinematics of the extensional processes can be understood. Mineral assemblages and the elemental composition of specific minerals record the pressures and temperatures to which rocks have been subjected, allowing direct quantification of exhumation history by thermobarometry. In this study, a sample from the hanging wall of the Leo Pargil shear zone (LPSZ) was analyzed using conventional light microscopy, as well as an electron microprobe. The sample contained quartz, plagioclase, muscovite, biotite, and garnet, with garnets exhibiting prograde compositional zoning, and biotite and muscovite showing homogeneous elemental compositions. Temperature estimates were calculated using garnet-biotite geothermometry, whereas pressure estimates were calculated using garnet-biotite-muscovite-plagioclase geobarometry, with all calculations performed by Geothermobarometry (GTB) computer software. Results indicate that rocks from the hanging wall of the LPSZ were subjected to temperatures ranging from 500 to 635°C and pressures between 6.8 and 9.2 kbar prior to exhumation. Assuming a lithostatic pressure gradient of 3.7 km/kbar, this sample was exhumed from a depth of 25-34 km. The constraint of these pressures and temperatures, as well as an estimated depth from which the sample was exhumed, allows future researchers a better understanding of extensional processes in the Himalayas.

Introduction

Continent-continent collision between the Indian and Asian plates began in the early Eocene (~55 million years ago). North-south-oriented compressional forces (known as crustal shortening) are accommodated by thrust faults on the front side, or the foreland, of the Himalaya. East-west extension dominates, however, in the interior of the mountain chain (known as an orogen) in the Tibetan Plateau. Crustal shortening, and the resulting thrust fault system, is a process that has been extensively studied in the Himalayan orogen (Besse et al., 1984; Schelling and Arita, 1991). By contrast, understanding of extension in the highly compressional tectonic setting of the Himalaya is only in its infancy and

Figure 1. Geologic map and cross section of the Leo Pargil Dome (Langille et al., in prep).



requires further investigation. This study aims to further this understanding by examining the pressure-temperature history of metamorphic rocks of the Leo Pargil Dome, a prominent extensional feature located on the southern margin of the Tibetan Plateau (Fig. 1). Examining extensional features, such as the Leo Pargil Dome and the exhumation history of associated metamorphic rocks, can provide valuable insight into the timing and mechanism of extension.

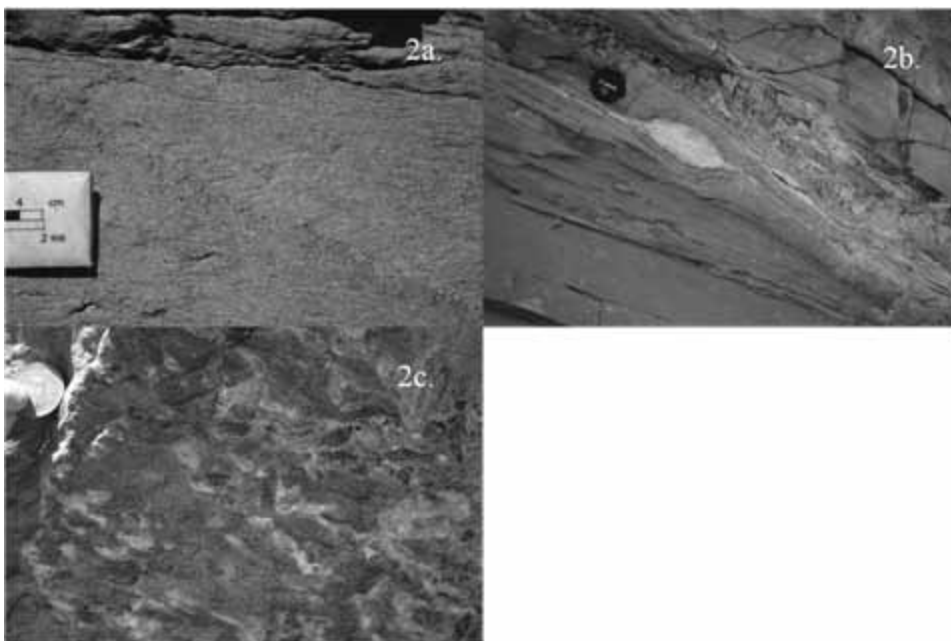
Background

The Leo Pargil Dome was created by the emplacement of granites during crustal melting, which were later brought to the surface (exhumed) by normal faulting (Fig. 1; Langille et al., in prep). The western limb of the dome is bound by the Leo Pargil shear zone (LPSZ), which separates high-grade metamorphic rocks from lower-grade rocks of the Tethyan Sedimentary Sequence (TSS). In the down-dropped side (or hanging wall) of the LPSZ, metamorphic rocks at the base of the TSS (the Hiamanta Group) were subject to poly-phase metamorphism and deformation proximal to the dome. The pressure, temperature and exhumation history of a sample from the hanging wall of the LPSZ is the focus of this investigation.

Petrography

The sample that was analyzed is a pelitic schist with strong lineation formed during ductile deformation (Fig. 2). Visible in thin section are quartz, plagioclase, muscovite, biotite, and garnet. The large garnet grains (known as porphyroblasts), which range from 400 to 1000 μm in diameter, contain inclusions of opaque Fe-oxides and quartz.

Figure 2. Outcrop pictures of a) pelitic schist, b) the Leo Pargil shear zone (LPSZ), and c) the staurolite/kyanite metamorphic assemblage.



Methods

The pressures and temperatures to which rocks have been subjected are recorded in their mineral assemblages. The elemental composition of certain minerals, such as garnet, plagioclase, biotite, and muscovite, can be used to quantify directly the pressures and temperatures of metamorphism (Ferry and Spear, 1978; Ghent and Stout, 1981). Mineral assemblages were first determined using a conventional petrographic microscope. Petrographic analyses were performed in both reflected and transmitted light on a polished thin section cut perpendicular to foliation and parallel to lineation.

A Cameca SX-100 electron microprobe was then used to determine the elemental compositions of a variety of minerals in the sample. Compositional variability was characterized by creating compositional maps (Fig. 4a, b, c) and by using electron backscatter imaging (Fig. 4d). Composition was analyzed along a line transect through a garnet porphyroblast with a $35\ \mu\text{m}$ step size in order to evaluate compositional zoning (Fig. 3).

Compositional data were then related to metamorphic pressures and temperatures using thermobarometry. This technique involves relating the known elemental behavior of minerals under high temperatures and pressures to samples whose temperatures and pressures of deformation are unknown. Temperature estimates were calculated using the garnet-biotite geothermometer developed by Ferry and Spear (1978). Pressure estimates

Figure 3. Compositional map of a line transect across garnet porphyroblast 12. The convex and concave shapes of the elemental curves indicate prograde compositional zoning.

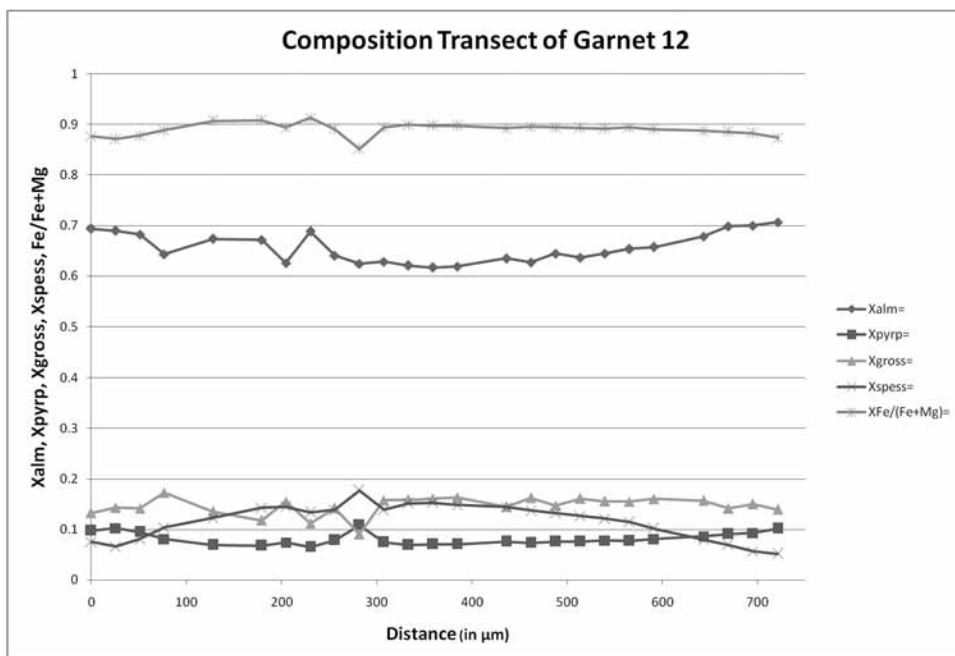
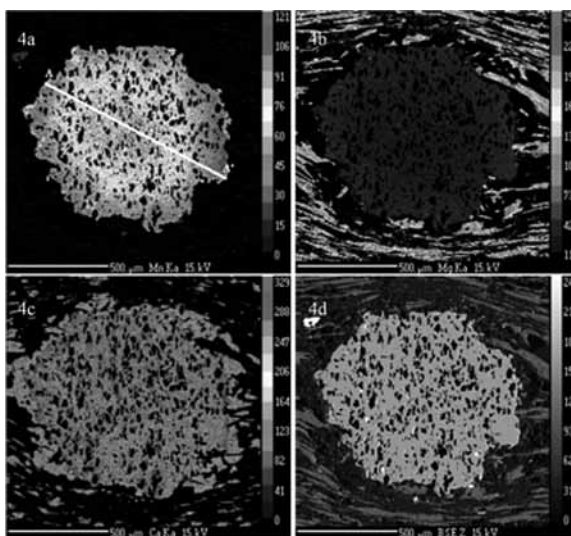


Figure 4. X-ray map of a) Mn, b) Mg, and c) Ca concentrations in a garnet porphyroblast. d) Electron back-scatter image of same garnet porphyroblast showing elemental differentiation.



were calculated using the garnet-biotite-muscovite-plagioclase geobarometer of Ghent and Stout (1981). Both of these calculations were performed using the computer software program GTB (Geothermobarometry). The geothermometer calculates temperatures for a range of fixed pressures, whereas the geobarometer calculates pressures for a range of fixed temperatures. The intersection of the lines generated from each of these methods is used to define the pressure-temperature conditions to which the sample was subjected.

Results

The convex and concave shapes of the elemental concentration curves (Fig. 3) indicate that garnet 12 is compositionally zoned, particularly with respect to Fe and Mn. As the center of the porphyroblast is approached, the concentration of almandine (Fe) garnet decreases systematically, whereas a systematic increase in the concentration of spessartine (Mn) garnet is observed. Plagioclase was also analyzed for elemental composition, and exhibited a range from 50 to 60% albite, which is the Na-bearing feldspar (Fig. 5). The elemental compositions of both biotite and muscovite were shown to be homogeneous throughout the sample (Fig. 6, 7).

Thermobarometry calculations indicate that this sample of the hanging wall of the LPSZ was subjected to metamorphic temperatures between 500 and 625°C and metamorphic pressures between 6.8 and 9.2 kbar (Fig. 8). Assuming a lithostatic pressure gradient of 3.7 km/kbar (Chambers et al., 2009), this sample was exhumed from a depth of 25-34 km.

Figure 5. Compositional range of plagioclase in the Leo Pargil shear zone (LPSZ) hanging wall sample. The majority of grains contained between 50 and 60% albite.

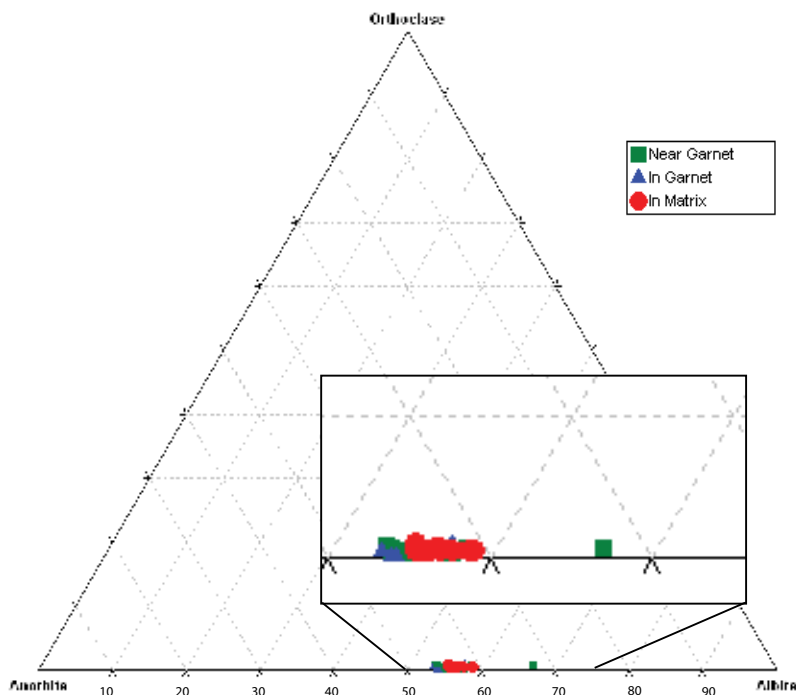


Figure 6. Elemental composition of muscovite grains near garnet porphyroblasts. The horizontal nature of the lines for each element indicates that muscovite composition is homogeneous throughout the sample.

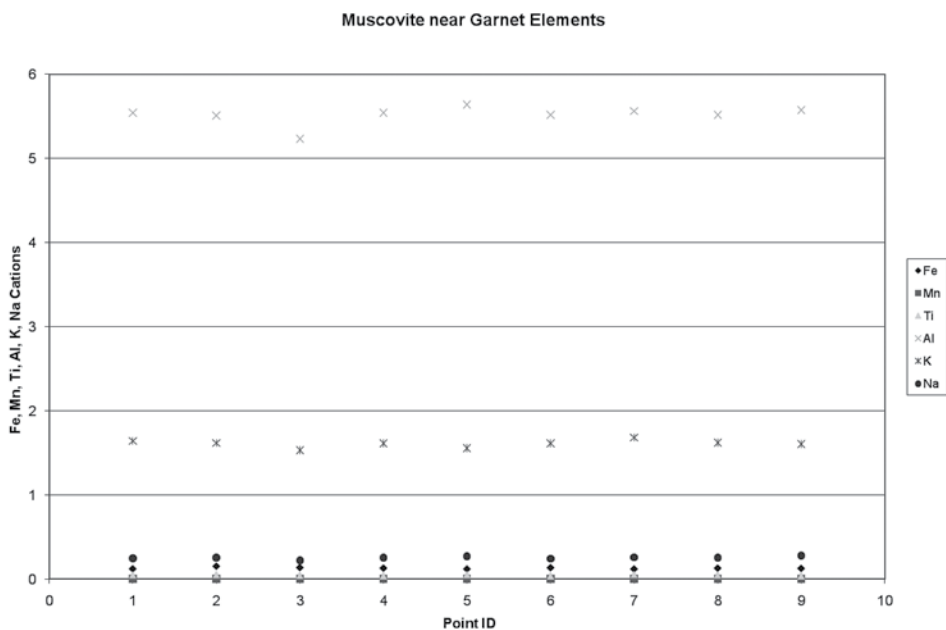


Figure 7. Elemental concentrations of Ti, and Al + Si in the octahedral site of biotite. The tight grouping of points indicates that biotite composition is homogenous throughout the sample.

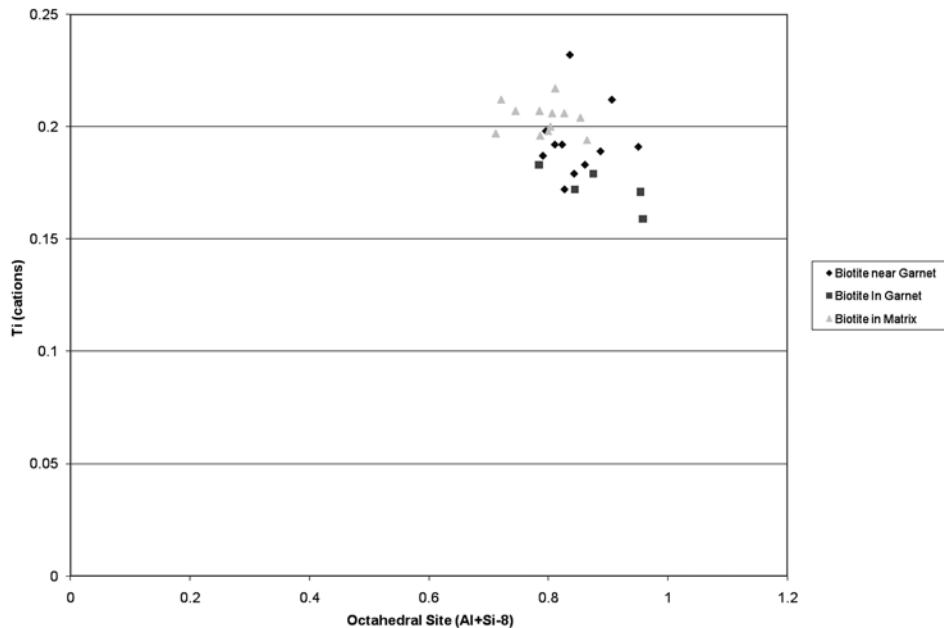
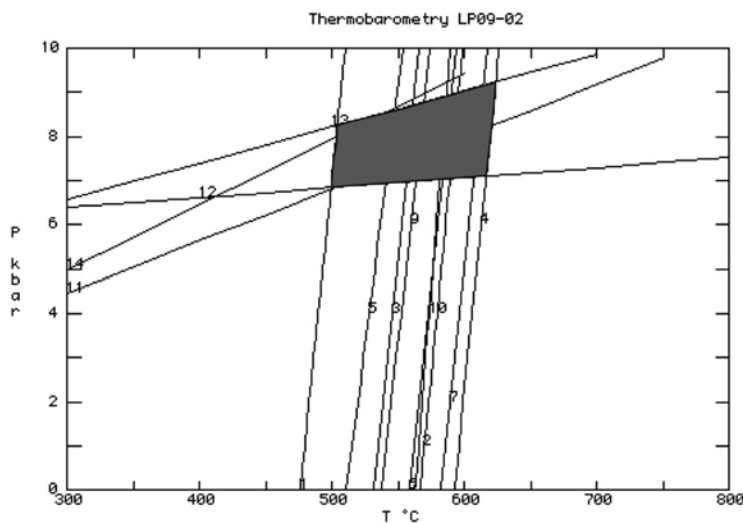


Figure 8. Pressure-temperature (P-T) estimates for the Leo Pargil shear zone (LPSZ) hanging wall sample. Lines were generated using the computer software Geothermobarometry (GTB; <http://ees2.geo.rpi.edu/MetaPetaRen/Software/software.html>). Blue shaded region shows the intersection of P-T estimates that defines the metamorphic conditions to which the sample was subjected. Vertical lines represent various geothermometry models, whereas horizontal lines represent various geobarometry models.



Discussion/Conclusions

In an attempt to constrain the exhumation history of the Leo Pargil Dome, a sample of pelitic schist from the hanging wall of Leo Pargil shear zone (LPSZ) was analyzed using thermobarometry. The sample contains quartz, muscovite, biotite, plagioclase, Fe-oxides, and garnet, with garnet porphyroblasts exhibiting prograde zoning indicative of growth during the early stages of crustal thickening. Using garnet-biotite geothermometry and garnet-biotite-muscovite-plagioclase geobarometry, metamorphic temperatures and pressures were calculated to range from 500-625°C and from 6.8-9.2 kbar, respectively. Given a lithostatic pressure gradient of 3.7 km/kbar, hanging wall rocks currently exposed at the surface of the LPSZ were exhumed from a depth of 25-34 km, below the transition between brittle and plastic behavior in continental crust (brittle-ductile transition). This is in good agreement with visual evidence of ductile deformation in the samples analyzed.

These data constrain pressure-temperature conditions prior to the onset of exhumation of the Leo Pargil Dome. These hanging wall pressure-temperature estimates, when combined with existing data from the footwall of the LPSZ, as well as new ages obtained using U-Th-Pb geochronology (Leech and Sas, 2006), have the potential to provide new insights into crustal thickening and extension on the southern margin of the Tibetan Plateau and throughout the Himalayan orogen.

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About the Author

Nicholas C. Costello graduated from the University of Tennessee in 2010 with a degree in Earth and Planetary Sciences. Nicholas transferred to the University of Tennessee in the fall of 2006 and entered the Department of Earth and Planetary Sciences as a freshman. He became involved in the department as a regular attendee at monthly Geo-Club meetings. He was also the Roller Hockey Club president from 2008 to 2010, leading the team to two regional tournament victories. Nicholas began a research project in structural geology, one of his passions, with Dr. Micah J. Jessup in the spring of 2009. The project involved studying microtectonic and extensional features in the Himalayas. While at Tennessee, Nicholas had the opportunity to present his research both at the annual Sigma Xi student competition and at the Exhibition for Undergraduate Research and Creative Achievement.

About the Advisors

Dr. Micah J. Jessup is an associate professor in the Department of Earth and Planetary Sciences at the University of Tennessee. His primary research interests involve integrating field- and lab-based structural geology with metamorphic geology, geochronology, thermochronology, and isotopic geochemistry to test aspects of the tectonic evolution of orogenic systems. Some examples of his recent and ongoing collaborative projects in the Himalayas, Tibet, and Colorado include the quantification of the kinematic evolution of shear zones, the exhumation migmatite-cored domes during orogen-parallel extension, and the interplay between focused denudation and exhumation. He has served as a research mentor to numerous undergraduates and is proud to have seen several continue their success in graduate school and beyond.

Jackie Langille received a Bachelor's of Science degree in Geology in 2006 from Idaho State University in Pocatello, Idaho. Then, she completed her Master's thesis at Central Washington University in Ellensburg, Washington, where she received a Master's of Science degree in 2008. She is now in her third year of her Ph.D. degree at the University of Tennessee in the Earth and Planetary Sciences Department and is expected to graduate in June 2012. While at the University of Tennessee, Jackie has focused her research on two mountain ranges in the Himalaya that were exhumed by extensional faults, including the Leo Pargil dome, NW India.