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Impacting Earthquake Science and Geoscience Education: Educational Programming to Earthquake Relocation

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IMPACTING EARTHQUAKE SCIENCE AND GEOSCIENCE EDUCATION:
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Dedication

To my husband and daughters, without their support I would not be where I am today.

In memory of my mom and dad, Ruby and Francis Pataluna

IMPACTING EARTHQUAKE SCIENCE AND GEOSCIENCE EDUCATION: EDUCATIONAL PROGRAMMING TO EARTHQUAKE RELOCATION

by

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DISSERTATION

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But most of all my family. "We" started this endeavor in 2004. It has been a long journey with a lot of hurdles but with their love, support, and encouragement we accomplished what we set out to do..................I share this degree them!

Abstract

This dissertation is comprised of four studies: three related to research on geoscience education and another seismological study of the South Island of New Zealand. The geoscience education research is grounded in 10 years of data collection and its implications for best practices for recruitment and retention of underrepresented minority students into higher education in the geosciences. The seismological component contains results from the relocation of earthquakes from the 2009 Dusky Sound M_w 7.8 event, South Island, New Zealand.

In recent years, many have cited a major concern that U.S. is not producing enough STEM graduates to fit the forecasted economic need. This situation is exacerbated by the fact that underrepresented minorities are becoming a growing portion of the population, and people in these groups enter STEM careers at rates much smaller than their proportion of the populations. Among the STEM disciplines the Geosciences are the worst at attracting young people from underrepresented minorities. This dissertation reports on results the Pathways program at the University of Texas at El Paso Pathways which sought to create a geoscience recruitment and training network in El Paso, Texas to increase the number of Hispanic Americans students to attain higher degrees and increase the awareness of the geosciences from 2002-2012. Two elements of the program were a summer program for high school students and an undergraduate research program conducted during the academic year, called PREP. Data collected from pre- and post-surveys from the summer program showed statistically significant positive changes in attitudes towards the geosciences. Longitudinal data shows a strong positive correlation of the program with retention of participants in the geoscience pipeline.

Results from the undergraduate research program show that it produced far more women and minority geoscience professionals than national norms. Combination of the institutional data,

focus groups results, and career outcomes strongly suggest the program cultivated an environment in which not only were students expected to enter graduate school, but they were successful in pursuing a graduate degree and entering the geoscience workforce. The third study was a critical incident study conducted to develop a taxonomy for geoscience recruitment at the more pre-college age. Analysis of 20 interviews with undergraduate geoscience majors produce an independent taxonomy with many similarities to a previous study garnered from interviews with geoscience professionals. Use of the taxonomy in program design will enhance the effectiveness of the recruitment of underrepresented minorities to major in the geosciences and enter careers in the geosciences.

New Zealand is one the most seismically active places in the world. July 15th, 2009 Dusky Sound, South Island, New Zealand encountered a M_w 7.8 earthquake. In order to gain insight into partitioning of the slip on the subduction zone, a relocation study from the 2009 events was performed. Using the software program *hypoDD*, events were relocated and formed 4 major clusters. Results from the relocation indicate that 1) the events are all located above the subduction interface; 2) the events appear to have occurred in a transitional zone between the Australian and Pacific plates; and 3) the northernmost cluster appears to have partially filled a seismic gap between the 2009 Dusky Sound event and a previous event in 2003.

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Chapter 1: Introduction

The research presented in this dissertation spans from geoscience recruitment and retention- from high school to undergraduate levels - to modeling of earthquakes in the southern island of New Zealand. With such variation within the subject content each chapter is independent and has been written in publication format.

Chapters 2, 3, and 4 pertain to the recruitment and retention of students into the Geosciences. A major challenge in STEM education in the United States today is recruitment of students from underrepresented minorities. There is a significant need for developing new strategies for attracting and retaining a more diverse population of students within the geosciences.

Chapter 2 presents results from ten years of data from pre- and post-surveys collected during a summer high school science program, held at the University of Texas at El Paso (UTEP), and confirms the positive influences such programs have in recruiting students into STEM (science, technology, engineering, mathematics) majors in college. Short-term indicators show statistically significant positive changes in student attitudes towards science and the geosciences. Long-term indicators show that 55% of the participants remain in the geoscience pipeline and 20% either are or were geoscience majors in college.

Chapter 3 - The overall goal was to mentor students through an undergraduate degree in geosciences and prepare them for graduate education. This chapter presents qualitative and quantitative statistics on a non-traditional research experience for undergraduates (REU) held at

UTEP from 2002 – 2012. From experience in educating minority undergraduates at UTEP we have found that a majority of our undergraduate student population must work outside the university while attending college in order to finance their education. Any opportunity to remain on campus to "work" at an activity related to a future career will both be highly sought after and contribute to student success. Thus with successful funding from the National Science Foundation (NSF) the department was able to support 59 students. Statistics on the 59 participants: 6 are currently enrolled in a PhD program; 21 have graduated with a Master's degree; 10 are currently enrolled in a Master's program; 7 are in the undergraduate program; 8 are employed in STEM careers; and 7 we are unsure of. We have been very successful in cultivating an environment in which not only do students expect to enter graduate school on completing a B.S., but they also choose to overcome traditional cultural ties to home and leave El Paso to pursue their graduate education.

Chapter 4 - With the objective of providing concrete and useful information for individuals developing programs for inspiring interest in the Geosciences among pre-college students and trying to increase the number of freshman Geoscience majors, the purpose of this study was to investigate why students decided to major in the geosciences using the critical incident technique designed by John Flanagan (Flanagan, 1954). Since we were investigating why a student choose the geosciences we recruited student participants from the UTEP Geological Sciences department. Twenty interviews were conducted. Of the twenty, 18 were undergraduates and 2 were graduate students. Taxonomy has been developed from the critical incidents. It was determined that 90% of the participants stated college level class was a critical incident in there major choice. Another major critical incident was that the participant had some

pre-college interest in science, such as rock collections or other geo-related hobbies and that they were influenced by the Geosciences from some form of pre-college program participation such as our Pathways Summer High School Camp. Thirty five percent of the participants stated that family involvement was a crucial component in their decision. Students at a younger age are/can be exposed at some level to the geosciences through various means and having parental support can reinforce college decisions later in life.

Within Chapter 5 the research moves from geoscience recruitment and retention to earthquake relocation.

Chapter 5 - On July 15th, 2009 UTC the largest magnitude earthquake (Mw 7.8) to affect New Zealand in over 70 years occurred in Dusky Sound, a fiord located in the southwest corner of the South Island of New Zealand. To better determine how this region of the South Island transitions between non-partitioned oblique subduction and a slip partitioned convergent margin we relocated aftershocks of the Dusky Sound 2009 sequence using *hypoDD*. These relocations will be used to aid in the selection of event pairs for a larger scale study of stress drop variations using the Empirical Greens Function technique. This research is fundamental to improving the New Zealand seismic model for seismic hazard.

Chapter 2: Pathways to the Geosciences Summer High School Program: A Ten Year Evaluation

2.1 ABSTRACT

The high demand for scientists and engineers in the workforce means that there is a continuing need for more effective strategies to increase student completion in STEM (Science, Technology, Engineering, and Mathematics) majors. The challenge lies not only in finding and enacting effective strategies to increase students' completion of STEM degrees but also in recruiting students to these disciplines, especially those from underrepresented minority groups. This article presents results from ten years of data from pre- and post-surveys collected during a summer high school science program and quantifies the positive influences such programs have in recruiting students into STEM majors in college. These results are distinctive because they come from a long-running program that specifically targeted high school students of Hispanic American origin and the field of geosciences. Each summer, from 2002-2012, UTEP (University of Texas at El Paso) operated a two-week summer program, called Pathways To the Geosciences, designed to expose Hispanic American high school students to content and careers in the geosciences. The short-term goal of the program was to introduce the students to the geosciences and to inform them of the possibilities of the geosciences as a college major and career choice. The long-term goal was to form a pipeline from the summer program to the UTEP geology undergraduate and graduate programs. Short-term indicators show statistically significant positive changes in student attitudes towards science and the geosciences. Long-term indicators show that 55% of the participants remain in the geoscience pipeline and 20% either are or were geoscience majors in college. This high retention rate far exceeds the 2010 national

averages.

2.2 INTRODUCTION

The high demand for scientists and engineers in the workforce means that there is a continuing need for more effective strategies to increase student completion in STEM (Science, Technology, Engineering, and Mathematics) majors, allowing them to enter the workforce to enjoy successful careers in these STEM disciplines. The challenge lies not only in finding and enacting effective strategies to increase students' completion of STEM degrees but also in recruiting students to these disciplines, especially those from underrepresented minority groups. Here we use the National Science Foundation's (NSF) definition of underrepresented groups, which includes African Americans, Hispanic Americans, Native Americans, Native Pacific Islanders, Native Alaskans, and persons with disabilities.

Among the STEM disciplines, the geosciences is a relatively small field in terms of numbers of students and professionals. Knowledge in basic geoscience fields, however, is essential to enhancing many areas of modern society, including the discovery and development of energy resources and sustaining the global environment. In 2008, underrepresented minorities comprised 23% of all enrolled students and 16% of all graduates from four-year universities, while less than 10% of geosciences graduates at all degree levels were underrepresented minorities (Gonzalez and Keane, 2012). In 2010, less than 1% of Bachelor's degrees awarded in STEM came from the Earth, Atmospheric, and Ocean Sciences (NSF, 2013). Within that grouping only 5% of the degrees were awarded to Hispanic Americans. In fact, at 8% the geosciences confer the lowest percentage of Bachelor's degrees to underrepresented minorities

compared with all other science and engineering fields, which averaged ~12 % in 2010 (NSF, 2013).

A decision to pursue a STEM major is a longitudinal process that begins during secondary education and carries into post-secondary studies (Wang, 2013). Thus, summer programs are a common strategy for increasing interest in and recruitment to STEM careers among K-12 students. From 2002 – 2012, the Department of Geological Sciences at The University of Texas at El Paso (UTEP) was supported by two grants from NSF's Opportunities for Enhancing Diversity in the Geosciences (OEDG) program. Two primary goals were met by these grants: 1) to increase the number of Hispanic American students who attain Bachelor's, Master's, and Doctoral degrees in the geosciences and then enter geoscience careers and 2) to increase awareness of the geosciences as an important and relevant scientific discipline with many career opportunities. Because El Paso County has a population that is 81% Hispanic and because UTEP is one of the largest Hispanic-Serving Institutions (HSI) in the United States, UTEP has a distinct advantage in recruiting minority students into STEM fields. In Fall 2013, UTEP had an enrollment of ca. 23,000 students, of which 78% were Hispanic. At UTEP, 84% of the student body comes from the El Paso region, thus reflecting the demographics of the dominantly Hispanic community that the university serves.

With UTEP having a large attendance from local students and a high Hispanic population, exposure to the geosciences at the high school level is imperative. Nationally, the geosciences are rarely required after middle school. Geology and environmental science classes are offered at the high school level, but only as electives. Specifically in the El Paso area there are over 40 high schools, however within the last ten years three or four have ever offered a geosciences course. Even though El Paso is in Texas, it lies far from the petroleum producing

regions of the state. Few professionals in the community pursue careers in the geosciences. Without the geosciences summer program many students would not be aware of the field as a career choice.

The purpose of this article is to report on 10 years of data collected from a two-week summer program designed to expose high school students from groups underrepresented in STEM to the geosciences under the auspices of the NSF grants. The short-term goal of the program was to introduce students, with a strong interest in STEM, to the geosciences and to give them insight into the possibilities the geosciences have as a college major and career choice. The long-term goal of our summer program was to form a pipeline to the UTEP geology undergraduate program and eventually to the graduate program.

Here we describe the impact the geosciences program had on the participants with regards to attitudes and retention in the geoscience pipeline.

2.3 BACKGROUND

The research literature contains many articles on the results of summer science programs (i.e., Atwater et al., 1999; Knox et al., 2003; Bischoff et. al., 2008), but we were *unable* to find any articles on programs that aligned closely with the UTEP program. Thus the main features of our summer enrichment program including its two week span, its focus on the geosciences, and its targeted recruitment of Hispanic American, freshman level high school students appear to be unique. By contrast, many articles reported on residency programs or on programs that operated from 4 to 8 weeks in length, targeted juniors and/ or seniors, and were focused on general science (scientific methods, perception of science), biological sciences or were engineering

specific.

Nevertheless, the outcomes of all these summer science programs are in agreement: summer science programs are an effective strategy for increasing students' awareness of the sciences and demonstrating the positive effects that these types of programs have on the students' attitudes towards science (Heinze *et al*., 1995). For example, an evaluation of a high school summer science program at the University of Rochester indicated that student attendance at the Summer Science Academy had a positive influence on their performance in advanced science courses, as well as their decision to participate in other science programs, and their desire to pursue a career in the sciences (Markowitz, 2004).

Knox et al. (2003) reported that science outreach initiatives allow students, who already have an interest in science, to interact with like-minded peers. Moreover, the camaraderie of such programs cannot be under-estimated. Roberts and Wassersug (2009) compared students that participated in original scientific research while in high school with students whose first research experience did not occur until college and found the high school students were more likely to both enter and maintain careers in science. This result is consistent with the work of Crisp et al. (2009) who show that students bring pre-college characteristics to college, such as high school experiences, that influence their college experience and chosen major.

In a meta-analysis, conclusions from Russell et al. (2007) suggested that even though many types of undergraduate research experiences fuel interest in STEM careers and lead to higher degrees, there is no formulaic combination of activities that optimizes the research opportunity uniquely for specific racial/ethnic minorities. The key element is the inculcation of enthusiasm – the earlier the better. Attention should be given to fostering the STEM interests of elementary and high school students and providing REUs for college freshmen and

sophomores.

2.4 PROGRAM DESCRIPTION

Beginning June 2002 and lasting for 10 years, the faculty of the Department of Geological Sciences at UTEP led a summer outreach program, called “Pathways to the Geosciences” (henceforth Pathways), designed to enhance awareness of the geosciences among local high school students. The program was designed to give participants an introduction to 1) a broad spectrum of the geosciences ranging from environmental geology and satellite image analysis to structural geology and geophysics, 2) career opportunities in the geosciences, and 3) the college application process including financial considerations. Each session was limited to fifteen high school students. In addition to the recruitment of the students, three high school teachers were recruited to attend the program(s). Teachers were recruited to help bring the geosciences into the high school classrooms. The program was held each summer for a two-week period, Monday through Friday, from 8:00 AM to 3:30 PM. Some years the program was offered in 2 two-week sessions, while in other years, due to funding limitations and faculty/staff availability, the program was only offered in 1 two-week session. During each two-week session, participants engaged in a variety of field and laboratory projects located in and around UTEP and the broader El Paso region (Table 1). Pre- and post-surveys were administered to measure the influences of the camp on the participants.

2.5 RECRUITMENT AND SELECTION OF STUDENTS

Originally our Pathways summer program targeted students who were either entering their junior or senior year of high school in the fall semester following the summer program year and who already had an interest in science. The junior year was targeted for two specific reasons. First, this tends to be the age when most high students are seriously considering college and career choices. The original goal was to have a measurable influence on those choices through the summer program. Second, there was an interest in demonstrating the feasibility of establishing a pipeline between the high schools and the geological and environmental sciences at UTEP and other universities within a relatively short period of time (Miller et al., 2007).

In 2005, the junior/senior level criterion was changed. Reviews of our pre- and post-surveys showed that by the time students were juniors, many of them were already very set in their career and college choices. Although they enjoyed the program, there was little indication that the students would consider changing their college major to the geosciences, at least in the short term. This was surprising since anecdotally we know that it is not unusual for students to change their major once they are actually enrolled. Among our own Department's undergraduate majors, most had changed their initial major before majoring in the geosciences and it was not uncommon that these students actually change majors multiple times. College majors tend to be tailored to a specific degree program (classes) and may direct the student towards a particular career or graduate study within that specific major. However, it is not unusual for students to change their college major throughout their college experience (Leach & Patall, 2013; Porter & Umbach, 2006).

Based on these observations, we modified our participant selection preference to students who had completed their freshman year of high school, beginning in the summer of 2005. Our

reasoning was twofold: first, local high school teachers that we were working with us indicated that students in this age group were still very opened minded towards different career paths and college majors compared to junior and seniors. Second, completion of the freshman year assured that the participants would still have had enough basic math and science background to benefit from the program.

Students were recruited through various means including: 1) contacting science facilitators (district level staff charged with overseeing science curriculum and professional development of teachers) in the El Paso area school districts; 2) contacting the science directors at many of the local high schools directly; 3) via the Pathways program web page (which is no longer maintained); and 4) advertising within Education Service Center - Region 19 (www.ecs19.net), the educational service center for 12 local public school districts. Region 19's main goal is to aid teachers and administrators in their role as educators of children. This organization acts as a link between the districts and charter schools within the region and the Texas Education Agency (TEA) in Austin.

A significant effort was made to recruit excellent candidates. Mid-spring of each year, the Pathways Program Coordinator (T. Carrick) met with each of the district science facilitators and provided them with posters and brochures advertising the Pathways program, as well as applications. If time was available at these meetings, a short presentation about the summer program was also given. The science facilitators in turn distributed the materials to representatives from each of the high schools during their regular monthly meeting with science department directors, chairs, or heads. Letters were sent directly to science department heads describing the program and providing them with the applications, posters, and brochures. Another recruitment tool was the Pathways Program web page, where students were able to read

about the program and download the application form. Typically, by mid-April most of the area high schools had posters and brochures, and the applications for the students.

Students were selected for the program based on several criteria: grade level (freshman year completed), grade point average, teacher recommendation, and a written narrative on why the student was interested in attending the program and what they hoped to gain from the experience. Participant selection was completed by mid-May of each year. Each participant selected was promised a small stipend in exchange for completion of the program.

2.6 PROGRAM ACTIVITIES

The El Paso region provides a natural setting for exploring geoscience topics and environmental issues. The region is located at the southern end of the Rio Grande Rift, the City of El Paso surrounds the Franklin Mountains, and it lies within the great Chihuahuan Desert. Because of these major features, geology is very prominent locally with features such as fault scarps, rift basin and range topography, volcanoes and volcanic features, and desert landscapes that are highly visible and accessible. In addition, because of its location on the border with Mexico, the El Paso area shares many environmental challenges with our border city, Ciudad Juarez. In turn, many of the activities in the Pathways program were chosen to highlight the local geologic and environmental setting and take advantage of the participants' natural curiosity about their surroundings (Table 1).

The Pathways program was not only designed to give students exposure to a broad range of topics in the geosciences, it was also aimed at fostering interactions with many different geoscientists as role models. Since geology is not taught in many of the local high schools, we

sought to expose the students to a broad range of geoscience concepts and to demonstrate how many of these concepts were subsets of more familiar classes such as biology, chemistry, and physics. The geoscience concept within the subsets of these other basic sciences was a significant part of professional development for teacher participants. Pathways exposed the teachers to the geoscience concepts and later worked with the teachers to incorporate the program activities into their own science curriculum/classrooms. An important consideration when preparing the activities was that the content met several of the required state education science standards – the Texas Essential Knowledge and Skills (TEKS) (Texas Education Agency, 2010). (http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html)

Another goal of the Pathways program was exposure to a variety of role models within the geosciences. Within one two-week program session, students would take part in approximately 10 different activities. A different faculty member usually led each of the activities with the assistance of several graduate and undergraduate students. The participants were thus able to meet a larger number of geoscientists, in various stages of their careers and with diverse backgrounds. Over the course of the program the faculty included several underrepresented minorities: 3 Hispanic, 1 Native American, 1 disabled, and 3 women. Graduate students included both Hispanic and Asian minorities, as well as women.

Field-based and hands-on *activities* and *projects* that promoted critical thinking and inquiry-based learning were incorporated into the program, reinforcing the basic concepts of the scientific method. A typical *activity* (Table 1) would encompass a simple experiment or demonstration that typically took less than a few hours. Some examples the participants really enjoyed: simulating plate boundaries with Oreo cookies; "Mentos in Diet Coke" demonstration as an example of a gas-driven eruption; or an off campus trip to the local water treatment or

desalinization plant. *Projects* would be more elaborate. A typical *project* would include a full day of fieldwork: mapping and collecting samples, and perhaps a second day for processing samples, data reduction, and discussion. This type of exercise allowed participants to carry out a *project* from beginning to end, to reflect on what was accomplished, and on how the process could be improved in the future (Miller et al., 2007).

2.7 METHODS

To assess the effectiveness of the summer program as a strategy for contributing to the national pipeline for geoscientists, we administered surveys to participants that were designed to elicit short- and long-term indicators of the likelihood that participants would enter or be retained in the geoscience pipeline. Our methodology builds upon the geoscience pipeline model for underrepresented groups of Levine et al. (2002) and Fuhrman et al. (2004) which propose that while retention in the STEM career path is critical, a number of other factors, including parental support, exposure to geoscience classes, experiences in the outdoors, experiencing extraordinary geosciences events, taking introductory geosciences courses, accessibility of geoscience faculty, and participation in informal interactions and social activities in a geoscience department, all increase the likelihood that an individual will choose a geoscience career path. Working with American Institutes for Research, (independent evaluation group from the NSF OEDG program) pre- and post-participation surveys were designed to collect demographic data and data about students' knowledge and attitudes towards the sciences and geosciences, as well as their educational plans. After each daily activity, data were also collected to enable formative evaluation and improvement of program activities. Another series of surveys was administered annually after participation, to assess the permanency of changes associated with participation, as

well as to determine students' major and career plans (Miller et al., 2007).

The pre- and post-participation surveys asked for participants to respond to a series of statements on science, geoscience, college attendance, major, and future STEM course taking plans. For each statement, responses were provided in the form of a 5-point Likert-scale. For analytic purposes, responses were treated as interval data. For example, in some questions, participants were asked to indicate the extent to which they agreed with statements such as "the geosciences are interesting." For analyses, responses were assigned the following values: strongly disagree = 1; disagree = 2; don't know = 3; agree = 4; strongly agree = 5.

For each statement or question, mean responses and standard deviations were calculated. In addition, when identical items were asked in the pre- and post-participation surveys, both parametric (Paired-Samples T-Test) and non-parametric tests (Wilcoxon signed ranks tests) were performed to determine if there was any statistically significant change in the means of the participants' pre- and post- responses. If there was a statistically significant change in the means, an effect size calculation (Cohen's d) was also performed.

2.8 RESULTS

The Pathways program ultimately introduced 245 high school students to the geosciences between 2002 – 2012. In the fall of 2003, the pre- and post-surveys were redesigned to elicit more precise responses from attendees. Because of this, the short-term indicators from the 2002 program data were not used in this study. Therefore, the statistical analysis sample number (*n*) was 230. Long-term indicators, specifically the college tracking data, from the 2002 cohort are included in this study.

Demographics – Demographic data (Table 2) were collected during the summers from 2003 – 2012. During this time frame there were 16 summer program sessions that took place with a total of 230 participants. Of those 230 participants, a little over half were female (52%). More than three-quarters (78%) were Hispanic. Because of the demographics of the El Paso area population, we were successful in recruiting a high number of under-represented minorities to the program without any extra effort.

Academic Background – Participants were well prepared in mathematics and the sciences. In mathematics, 99% had taken Algebra 1, 71% had taken geometry, and several had taken Pre-calculus (Table 3). In the sciences, 73% had taken Biology and 34% had taken Chemistry. A small percentage (5%) of the participants had already taken a geoscience course. This particular statistic was not surprising since the majority of the area high schools do not offer a geosciences course. According to Levine et al. (2002), having an academic background characterized by high- level of preparation in math and science is diagnostic of students in the geoscience pipeline and suggests that this group has a higher likelihood of being retained in the pipeline.

Long-term College Plans – To assess whether the summer program had any positive effect on the participants' long-term plans for college, several questions addressed the likelihood that the participants would attend college (Table 4) and the likelihood that they would take a range of STEM courses while in college (Table 5). In reviewing the individual case summaries, the pre-surveys showed 99.57% of the participants planned on attending college; the post-survey showed 100% planned on attending college.

When asked, "I will attend the University of Texas at El Paso" (Table 4) there was a statistically

significant change: *t (df = 229) = -4.703 p < .000 and an effect size of 0.25.* The pre-survey question had a mean response of 2.57 while the post-survey had a mean of 2.75. This positive response to attending UTEP may be a result of several factors. First, participation in the summer program exposed the participants to the professors and graduate students, and the university campus. Many students had never been on the UTEP campus or exposed to a college classroom with a university professor. Second, the students attended a half-day session on college recruitment, financial aid, scholarships, and academic opportunities at UTEP. Many of the students commented that this session was very helpful. Learning what is required for college enrollment (SAT, ACT, GPA), the application process (when to begin, where to go), and information on financial aid (what is available, FAFSA) before their junior year made them feel more prepared.

Third, anecdotal reports suggest that many high school students have a bias against UTEP because: a) it is their hometown university and students prefer to leave home, and b) disappointing as it may sound, some local teachers speak negatively about UTEP and encourage students to leave the El Paso area and attend other institutions. We believe that being on the UTEP campus, having been exposed to the UTEP college environment, and experiencing UTEP for *themselves* made an impact on their overall attitudes.

Another statement "I will attend a community college" had a statistically significant change of *t (df = 229) = -2.154, p = 0.032* with a mean of 1.95 and 2.04 pre- and post-survey respectively. We believe that this result stems from presentation of content related to the cost of attendance at a major 4-year university versus a community college, the benefits of the community college (smaller class size, class availability, faculty/student interaction) students realized this was another viable option.

Statistically significant changes occurred in the likelihood that the participant would study specific STEM courses in college (Table 5). This was a surprising result. Since participants were already well prepared in mathematics and the sciences, we were expecting little change between the pre- and post-surveys. Having an increase in the likelihood of taking STEM classes in college indicates more enthusiasm about the sciences, which may lead to an increased likelihood of selecting a STEM major. Our view is that as long as our participants choose a STEM major they remain in the geoscience pipeline.

When asked on the post-survey "After participating in Pathways would you like to become a geoscientist?" 24% responded "yes", 68% responded "maybe", and only 0.08% responded "no". Thus, 92% of the participants either indicated that they would like to become a geoscientist or were at least considering the option at the close of the program.

Attitudinal Changes – Data on changes in attitude toward science and geoscience were also collected from the surveys to develop short-term indicators of whether participation in the Pathways program increased the likelihood of retention in the geoscience pipeline (Table 6). These data show significantly positive changes in attitudes towards the geosciences. Within the geosciences, participants more strongly agreed that the geosciences are:

- "interesting" t (df = 228) = -8.413, p = < .001, effect size 0.67;
- "fun" t (df = 228) = -11.282, p = < .001, effect size 0.90;
- "useful" t (df = 228) = -6.002, p = < .001, effect size 0.51;
- "well paid" t (df = 198) = -17.226, p = < .001, effect size 1.46;
- "respectable career" t (df = 198) = -7.471, p = < .001, effect size 0.61,

after participation in the program. We attribute the large positive change in response to the "the

geosciences are well paid" statement to a brochure (THECB and TEA, 2002) that shows geoscientists have the fourth highest paying job (among those listed) in Texas. When choosing a college major, potential earnings in that field are a significant factor (Montmarquette et al., 2002).

Changes in attitudes towards the sciences were also positive changes. There was a statistically significant change when responding to "I am good at science", t (df = 228) = -2.181, p = .030, effect size 0.13 and for "I am interested in science" t (df = 228) = -3.929, p = .000, effect size 0.24.

In response to the statement "Science is "boring", $\bar{X}_{pre}$ = 1.603, $\bar{X}_{post}$ = 1.533, we saw a decrease moving the average response closer to a scale of 1, "Strongly Disagree". For the statement "If I had a choice, I would not study science at school", $\bar{X}_{pre}$ = 1.699, $\bar{X}_{post}$ = 1.585, there is a decrease in the average response moving closer to a scale of 1, "Strongly Disagree". Based on these results, the Pathways program clearly made a positive impact on the participant's attitudes towards both the geosciences and science.

Retention in the Geoscience Pipeline – To determine whether participants stayed in the geoscience pipeline, an annual survey was sent to all of the participants. Two different surveys were mailed: 1) a survey for students that were college age eligible and 2) a survey for current high school students. From the initial pilot program in 2002 through 2012, 206 of the 245 participants graduated from high school and were college eligible. Of these 206 participants 86 responded to the college aged survey. This was an overall return rate of 42% on the surveys. In addition, we were able to find a number of participants that have matriculated at UTEP. Of these 86 responses, 100% were in college. Of these participants 45% were enrolled at UTEP and 19%

were enrolled at the El Paso Community College (EPCC) (Table 7). Additional statistics from Doser and Villalobos (2013) indicate that since the summer of 2008 over 20 students have entered the A.S. in Geological Science program at EPCC, with about 10 students continuing to UTEP's B.S. program and 2 currently in graduate programs. This suggests a pipeline from the high schools to UTEP and EPCC is feasible.

Of these 86 participants, 55% were in the geoscience pipeline, measured by a choice of STEM discipline as a college major, and 20% became geoscience majors (Table 8). Among that 20%, one participant completed their MS degree in Geology and two are currently enrolled in Masters in Geology programs, one at UTEP and one at the University of Arizona. This result exceeds national norms. For example, national data from 2010 shows 32% of all Bachelor's degrees that were awarded in science and engineering disciplines, less than 1% was in Earth Sciences (NSF, 2013). In addition, of the 86 respondents 75% say they will definitely or probably take a geology course in college. These longitudinal survey results show a positive correlation of the Pathways program with retention of participants in the geoscience pipeline.

2.9 CONCLUSIONS

The Pathways to the Geosciences Summer Program proved to be a very effective strategy for inspiring interest in and recruitment into the geosciences among Hispanic-American high school students with a strong interest and ability in math and science. Data from our program's pre- and post-surveys showed statistically significant positive changes in attitude towards science, more specifically the geosciences. Longitudinally, the data show a positive correlation of the Pathways program with retention of participants in the geoscience pipeline.

Some of the key elements from the Pathways program that we believe contributed to its success were: 1) the local, accessible geology that surrounds the El Paso region; 2) exposure on and to the UTEP campus; and 3) the interaction between the participants and UTEP faculty and graduate students, many of whom were Hispanic origin. Most K-12 students never have an opportunity to directly interact with university faculty.

Furthermore, for the academic year 2012/2013, nine Pathways program alumni were enrolled in the geosciences curriculum at UTEP. Of those nine students, one is currently a Masters student and will be continuing her graduate education in a PhD program at the University of Hawaii. It is also worth mentioning that not included in our reported statistics is a participant from the 2002 program who earned her Masters degree in the geosciences (from the University of Arizona) and is currently employed by ExxonMobil.

The UTEP Pathways program has had a direct and measurable impact on Hispanic American community. Whereas Hispanic Americans comprise a growing portion of the U.S. population, they complete degrees at half the rate as the population as a whole, and they major in geoscience at less than half the rate that they major in most other science and engineering fields (NSF, 2013). The Pathways program described here has proven to be a very effective recruitment strategy for improving the likelihood that Hispanic Americans will enter a geoscience career path. This is important to the health and balance of the geoscience field, and for many areas of modern society including discovery and development of energy resources, natural hazards mitigation, and sustaining the global environment.

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Table 2.1 List of Typical Program Activities/Projects

	Activity(ies)/Project
Day 1 *El Paso Geology* (on and off campus)	• observation skills • analogue modeling • hike along Transmountain Rd in El Paso • analog building of the Franklin Mountains
Day 2 *"Search for the Pipe"* (off campus)	• measuring conductivity • measuring resistivity • measuring gravity • using GPR
Day 3 *Mt Cristo Rey/Fossils* (off campus)	• day trip Mt Cristo Rey, NM • dinosaur footprints • Structures/faults/folds/laccolith contact • Fossil collecting
Day 4 *Local Water Treatment* (off campus)	• visit to local waste water treatment plant • visit to local desalinization plant
Day 5 *Geophysics* (on campus)	• Intro. To geophysics, seismic waves and earthquakes • Convection cells/viscosity • Looking at the ocean floor • "Journey to the Center of the Earth"
Day 6 *Seismic Refraction* (on and off campus)	• Field trip for seismic refraction experiment to look for the water table • Laying the geophones for the experiment • Collecting data from the geophones • data analysis
Day 7 *Volcanoes* (on campus)	• Volcanoes discussion • "Mentos" eruption experiment • Viscosity/lava • Monitoring a volcano experiment
Day 8 *Plate Tectonics* (on campus)	• Earth's Structure • Mapping earthquakes • Plate Tectonic Maps • Edible Plates with Oreos • Tsunamis
Day 9 *CSI:UTEP* (on campus)	• Geology Circus • Density • Forensics and structure • Topographic profiles
Day 10 *Wrap up day* (on campus)	• Careers for Geoscientists video and discussion • UTEP College recruitment, financial aid... • Swimming pool fun

Table 2.2 Participant Demographics

2003- 2012 Cohorts	No. Participants (n=230)	% Participants
Gender		
Male	111	48%
Female	119	52%
Grade Level		
Entering 10th grade in the fall	99	43%
Entering 11th grade in the fall	94	41%
Entering 12th grade in the fall	37	16%
Race/Ethnicity		
African American	4	1.7%
Asian	8	3.5%
Hispanic	179	78%
Native American	1	.4%
Pacific Islander	2	.8%
White	33	14.3%
Other	3	1.3%

Table 2.3 Participant Academic Background

2003 - 2012 Cohorts	No. Participants (n=230)	% Participants
High School Mathematics Courses Taken		
Algebra I	228	99%
Algebra II	104	45%
Geometry	164	71%
Pre-Calculus	27	12%
Calculus	2	1%
High School Science Courses Taken		
Biology	167	73%
Chemistry	77	34%
Physics	34	15%

Table 2.4. Likelihood of Attending College

Statements	**Pre-Participation <u>Average</u> Response Mean**	**Post-Participation <u>Average</u> Response Mean**	**Effect Size**
2003 - 2012 Cohort			
I will attend UTEP.	2.57	2.75**	0.25
I will attend a university other than UTEP.	3.08	3.05	
I will attend a community college	1.95	2.04*	0.10

NOTES: 1 = I will definitely not attend, 2 = I will probably not attend, 3 = I will probably attend, 4 = I will definitely attend.
* Indicates statistically significant $p < .05$.
** Indicates $p < .001$. Effect size: 0.2 small; 0.5 medium; 0.8 large

Table 2.5. Likelihood of Studying STEM Fields in College

Field	**No. Participants**	**Pre-Participation <u>Average</u> Response Mean**	**Post-Participation <u>Average</u> Response Mean**	**Effect Size**
2003 – 2012 Cohort				
Physics	229	2.82	3.12**	0.40
Chemistry	229	2.89	3.10**	0.25
Computer science	227	2.72	2.85*	0.15
Mathematics	228	3.23	3.47**	0.29
Engineering	229	2.95	2.93	
Biology	228	2.94	3.04	
Geosciences	229	2.89	3.10**	0.33

NOTE: 1 = will definitely not study, 2 = Will probably not study, 3 = Will probably study, 4 = Will definitely study.
* Indicates statistically significant $p < .05$.
** Indicates $p < .001$. Effect size: 0.2 small; 0.5 medium; 0.8 large

Table 2. 6. Participant Attitudes Toward Science and Geoscience

Statements	Pre-Participation Average Response Mean	Post-Participation Average Response Mean	Effect Size
2003 – 2012 Cohorts			
I am interested in science	4.38	4.52**	0.24
I am good at science.	4.01	4.11*	0.13
Science is boring.	1.60	1.53	
Science is a hard subject.	2.78	2.66	
If I had a choice, I would not study science at school.	1.70	1.59	
I have always been interested in science.	3.93	3.99	
The geosciences are interesting.	4.12	4.48**	0.67
The geosciences are fun.	3.84	4.41**	0.90
The geosciences are important.	4.14	4.56**	0.68
The geosciences are hard.	3.05	3.06	
The geosciences are useful.	4.22	4.52**	0.51
Geoscientists are well paid.	3.34	4.38**	**1.46**
Geoscience is a respectable career.	4.15	4.53**	0.61

NOTE: 1 = Strongly Disagree, 2 = Disagree, 2.5 = I don't know, 3 = Agree, 4 = Strongly Agree.
* Indicates statistically significant $p < .05$.
** Indicates $p < .001$. Effect size: 0.2 - small; 0.5 - medium; 0.8 - large

Table 2.7. College Attendance of Program Participants

	No. Respondents (n=86)	% Respondents
Attending UTEP	39	45%
Attending EPCC	16	19%
Attending another 4 year college	31	36%

Table 2.8. Declared College Major of Program Participants

	No. Respondents (n=86)	**% Respondents**
Engineering	13	15%
Geology	17	20%
Science	17	20%
Other	39	45%

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Chapter 3: Pathways Research Experience Program (PREP): A non-traditional research experience for undergraduates (REU) in the Geosciences

3.1 INTRODUCTION

A major challenge in science, technology, engineering and math (STEM) education in the United States today is recruitment and retention of students especially those from underrepresented minorities. The President's Council of Advisors on Science and Technology (PCAST) (PCAST, 2012) stated that less than 40% of the students that intend to major in STEM actually complete the degree. The United States is not producing enough STEM graduates to fit the forecasted economic need. Within the next ten years there will be a need for approximately 1 million more STEM college graduates than expected based on the current norms. The United States needs to increase the number of awarded STEM undergraduate degrees by about 34% annually over current rates (PCAST, 2012). Even with undergraduates' renewed interest in majoring in STEM, bachelor's degree completion rates in these areas remain persistently low, especially among underrepresented minority students (HERI, 2010). It is imperative that higher education institutions do more to improve the educational accomplishments of underrepresented minorities in STEM fields (Perna et al., 2010). An interesting note, the number of STEM majors, from first year through graduation, expands rather than shrinks. Amongst students who graduate within six years of enrollment, the numbers who start with a non-STEM major but graduate with a STEM degree is greater than the numbers who start in a STEM major and graduates with a non-STEM degree (Salzman, 2013).

Among the STEM disciplines, the geosciences are a relatively small field in terms of numbers of students and professionals. American Geosciences Institute (AGI) reported for 2013 there was an enrollment in the geosciences of 27,591 undergraduate students and ~ 10,000 graduate students. Employment rates for 2012 record 296,963 employed as Geoscientists in the United States (Wilson, 2014). Knowledge in basic geoscience fields, however, is essential to enhancing many areas of modern society, including the discovery and development of energy resources and sustaining the global environment. Two key populations must be considered as the United States looks to build the future geosciences workforce and optimize worker productivity: the nation's youth and its growing underrepresented minority (URM) community (Velasco and Velasco, 2010).

In 2008, underrepresented minorities comprised 23% of all enrolled students and 16% of all graduates from four-year universities, while less than 10% of graduates at all degree levels were underrepresented minorities in the geosciences (Gonzalez and Keane, 2012). In 2010, less than 1% of bachelor's degrees awarded in STEM came from the Earth, Atmospheric, and Ocean Sciences (NSF, 2013) and within that only 5% of these STEM degrees were awarded to Hispanic Americans. In 2010, only 12% of bachelor's degrees in geosciences were conferred on underrepresented minorities, the lowest of all other science and engineering fields (NSF, 2013).

Factors that are known to improve recruitment and retention in STEM are mentoring (at all age levels, from K -12 teachers , university faculty , career geoscientists); addressing financial needs and concerns; developing partnerships between K -12 institutions and universities; middle school and high school programs; informational distribution about the STEM and careers within the community; and lastly the involvement in undergraduate research programs(URP) (Hearn, 1987; Russell, 2005; Huntoon and Lane, 2007; Miller et al. 2007; Serpa et al. 2007; O'Connell,

2011; Mundy, 2013). In the geosciences the summer high school programs and the REUs have been very successful in the recruitment and retention in STEM(Seymour et al. 2003; Lopatto, 2004, 2007, 2010; Hunter et al., 2007; Miller et al., 2007; Russell, 2007; Serpa et al. 2007; Blake et al., 2013; Eagan et al, 2013). Important factors for REUs: they can provide students with mentoring, enhance the educational experience in the sciences, increase research skills, provide students with access to professional networks, assist in financial needs, increase intentions to pursue STEM related graduate programs, socialize students (connections with faculty, graduate students, and other peers in their STEM field) and overall enhancement of the overall educational experience.

Here we report on 10 years of practices, data and results from an undergraduate research program (URP) conducted by the Department of Geological Sciences at The University of Texas at El Paso (UTEP) supported by two grants awarded from the National Science Foundation (NSF) Opportunities for Enhancing Diversity in the Geosciences (OEDG) program. The UTEP program, termed "PREP" (Pathways Research Experience Program) was distinctive in three ways. First, the program was conducted throughout the academic year, by contrast to the summer-only timing of most such programs. For this reason we refer to it as "non-traditional". Designated as a Doctoral/Research Intensive University by the Carnegie Foundation, UTEP is also a Hispanic Serving Institution (HSI) of 23,000 students, which serves a population that in 2013 was 84% Hispanic. Thus, the program was distinctive in that its participants were 2) dominantly Hispanic, and 3) attending a regional university with a large research portfolio, as well as a significant population of masters and doctoral students.

Our results show that the non-traditional approach to a research experience correlates well with high retention of students in the geoscience pipeline. Over 10 years, 71% of the

students who participated in the program were retained in the Geoscience or STEM pipeline in that they received a bachelor's degree, entered a career in geoscience and/or entered and/or completed a graduate degree. Further, First Time in College (FTIC) PREP students graduated an average of a year earlier than their peers. PREP participants who entered UTEP as transfer students graduated more than a semester earlier than their peers on average. Finally, PREP students graduated with an average GPA of 3.31 compared to 3.12 for their peers, a significant difference. We conclude with thoughts on the key aspects of the program that led to its success. Among these are those common to other REU programs such as mentoring and research guidance while with our non-traditional REU there was financial support for the fall and spring semesters, a program coordinator, additional funding for supplies and travel, and a sense of security remaining at home.

3.2 THE LANDSCAPE OF UNDERGRADUATE RESEARCH PROGRAMS IN STEM

Undergraduate Research Programs have long been recognized as effective mechanisms for deepening creativity and critical thinking among undergraduate students (www.cur.org).) as well as propelling participants to graduate school. Funding for such programs has long been a priority of several federal funding agencies, seeking to increase the number of students who enter STEM fields and go on to research careers(www.cur.org)

A typical URP takes place during the summer months and may provide a stipend. Funding can be provided by National Science Foundation, Department of Energy, NASA, and Jet Propulsion Lab to name a few. Students become aware of programs in several manners: departmental postings, mentors and academic advisors, from peers, and through their own search. Students are encouraged to apply for an URP outside of their home institution. This

allows the student to appreciate a different perspective on research and begin networking (meeting new faculty and peers). The application process begins in the spring typically requires an application packet that will contain transcripts, letters of recommendations and short narratives from the student. Focusing on academic research, networking, and mentoring, an URP prepares students for future graduate research training. Many URPs focus not only on the research but teaching students the fundamentals for abstract writing, presentation skills, but provides mentoring from faculty and graduate students. However, the drawbacks are very few programs invite students back for multiple years and very few take place during the academic year.

Over the years, many studies have presented documented benefits of URPs (e.g. Seymour, et al., 2003; Hunter, et al., 2007; Lopatto, 2007; Hurtado, et al., 2010; Adetunji, et al., 2012; Eagan, et al., 2013; Graham, et al., 2013; Webber, et al., 2013). Overall, a URP experience has indeed proven to be successful in increasing the likelihood of undergraduates staying in the STEM field.

Other levels of success within REUS and ORPS have been documented. In a study by Hunter et al., (2007) they state undergraduate research experiences may produce other benefits such as reducing minority students' sense of marginalization and promoting their integration into the STEM community; enabling students to make meaningful contributions to the field; and socializing students to the norms of science and science careers.

In a long-term study, Lopatto (2007) found that undergraduate research enhances the educational experience of science undergraduates, attracts and retains talented students to careers in science, and acts as a pathway for minority students to begin science careers. He also stated the study showed an overwhelming majority of students reported that their research experience

either maintained or increased their interest in postgraduate education (Lopatto, 2007). Eagan et al. (2013) indicate that participation in an URP significantly improves students' probability of indication of plans to enroll in a STEM graduate program.

Findings from Russell et al., (2007) suggest that hands-on research is a factor believed to inspire undergraduate students in pursuing advanced degrees and careers in STEM. However their conclusions suggest that even though many types of undergraduate research experience fuel interest in STEM careers and higher degrees there is no formulaic combination of activities that optimizes the research opportunity. The key element is inculcation of enthusiasm – the earlier the better.

Weidman (1989) suggests for relationships and interactions between students and faculty. Researchers have found this relationship particularly relevant for underrepresented minority students, as more frequent interactions with faculty among the students corresponds with significantly higher degree aspirations (Carter, 2002; Maton, Hrabowski, & Schmitt, 2000). Webber et al., (2013) also support the notion of positive benefits for student success as well as advantages for faculty who serve as mentors to undergraduate students in research programs.

Lastly, Carrero-Martinez (2011) notes we need to reconsider the method that is taken in developing a diverse, talented STEM workforce. There needs to be a more "two-way-bridge" between institutions. Many institutions recruit underrepresented minorities for their summer REU program but are not sending or encouraging their students to apply for REUs at the minority serving institutions.

Documentation, of non-traditional academic year programs, especially those targeted at underrepresented minority students, like the UTEP program are relatively rare, but we did find three similar programs in the literature. These are the Meyerhoff Scholarship Program housed at

the University of Maryland, Baltimore County, a CREST (Cooperative Remote Sensing Science and Technology) an REU program awarded to the New York City College of Technology (City Tech), and C-MORE (Center for Microbial Oceanography: Research and Education) Scholars Program University of Hawaii at Manoa (UHM)).

The Meyerhoff Scholarship Program housed at the University of Maryland, Baltimore County is a very successful on-campus, academic year research in the pursuit of STEM Ph.D. (Carter et al., 2009). The program has been in effect for over 20 years and since 2009 has successfully graduated more than 550 STEM majors. Meyerhoff is oriented primarily toward African Americans, is an on-campus, academic year research opportunity and requires their students to obtain summer research internships as well. Carter et al. (2009) state that their program overall increased the probability of pursuing a STEM Ph.D. program associated with participation in on-campus, academic year research is substantial.

The CREST REU program at New York City College of Technology (City Tech) is a year around program, 9 weeks during the summer, 3 weeks in the fall and three weeks in the spring. The NSF CRST REU program provides state-of-the-art satellite and ground-based remote sensing basic research experiences and STEM academic and research advancement opportunities for underrepresented students in STEM at CUNY (Blake, et al., 2013). The program is composed of the following three primary components: (1) Structured Learning Environments: Preparation and Mentorship,(2) Student Support and Safety Nets, and (3) Vision and Impetus for Advancement. Outcomes state the program has a 100% STEM retention rate for its REU scholars.

C-MORE Scholar Programs housed at UHM is a program more closely aligned to UTEP's PREP. The program is an undergraduate research experience offered during the academic year, has three levels of awards (trainee, intern, and fellow), require community outreach, monthly meetings, and support a student symposium. Gibson and Bruno (2012) describe the program as being dedicated to advancing the emerging field of microbial oceanography, and its areas of research include microbial biodiversity, metabolism, and energy flow; the role of microbes in climate variability; and ecosystem modeling. The program is based on the cohort model, enabling undergraduates to begin building collaborations and developing a peer support group, which can be a critically important factor in student success. Although still a young program (when comparing to Meyerhoff) C-MORE has produced favorable results in retaining students in STEM (Gibson and Bruno, 2012).

3.4 The Pathways Research Experience Program at UTEP

3.4.1 University Setting

Located in far west Texas along the borders of New Mexico and Mexico, UTEP is a regional Minority Serving Institute (MSI), one of the largest Hispanic-Serving Institutions (HSI) in the United States, and is designated as one of the state's "Emerging Tier One" universities by the Texas Higher Education Coordinating Board. El Paso County has a population that is ~82% Hispanic giving UTEP a distinct advantage in recruiting minority students into STEM fields. For the Fall 2013 enrollment there were ca. 23,000 students, of which 78% were Hispanic. Of the ca. 23,000, 19,696 were undergraduates. At UTEP, 84% of the student body comes from the El

Paso region, thus reflecting the demographics of the dominantly Hispanic community that the university serves. In addition ~50% are first-generation college students.

UTEP offers 71 bachelor's, 76 master's and 20 doctoral degrees. The Department of Geological Sciences was the first department, in the universities history, to offer a doctoral degree. The department functions in a Research I setting and has a very longstanding history for success in both the Masters and Doctoral programs. The faculty consists of 14 male and 7 female, 12 professors, 5 assistant professors, 3 associate professors, 1 lecturer, research staff and visiting professors.

Although the university has many different opportunities it faces a lot of challenges in student success: 86% of beginning students receive financial aid; 62% beginning students have submitted SAT scores; 30% have submitted ACT scores; the average SAT was ~950; graduation rates based on the period from 2005 – 2012 - 10% graduated in 4 years, 37% graduated in 6 years and 45% graduated in 8 years; and graduation rates from 2007 – 2013 - 12 % in 4 years and 39% in 6 years. On average UTEP has transfer student from the local community college of ~1460 students a year.

The faculty of the UTEP Department of Geological Sciences had all these attributes in mind when it first contemplated proposing an undergraduate research program as a component of a submission to the National Science Foundation's (NSF) Opportunities for Enhancing Diversity in the Geosciences (OEDG) program. For example, the low graduation rates and long time to degree correlate strongly with the fact that the majority of the UTEP undergraduate student population work outside the university while attending college in order to finance their education. Any opportunity (e.g. funded research) to remain on campus to "work" on an activity related to a future career would both be highly sought after and contribute to student success.

Students would spend more time on campus, which would then result in more interaction among other undergraduates, graduate students, and faculty. This in turn develops a greater sense of belonging to a community of geoscientists.

With these hypotheses is mind, UTEP proposed a *non-traditional* URP which provided financial support to UTEP students in exchange for participation in a research program located at the university for the length of an academic year. That program, PREP, was supported from 2002 – 2012 through two grants from the NSF OEDG program. Over that time period, the program provided financial support that enabled 59 students to conduct research with a faculty mentor, participate in professional development workshops, and be enculturated to the geosciences community. The overall goal was to mentor students through an undergraduate degree in geosciences and prepare them for graduate education.

3.4.2 Participant Recruitment, Selection, and Financial Support

Recruitment to the program was conducted each year through distribution of flyers and announcements in undergraduate geoscience classes, in the Environmental Sciences coordinators office, in each of the department offices within the College of Science, and in other strategic areas throughout the campus. Faculty and the program coordinator also announced the availability of the program in all undergraduate classes in Geology and Environmental Science. Students submitted an application package that consisted of a statement of purpose, a résumé, a transcript, at least one letter of recommendation, and a series of questions related to research, personal goals, etc. to the program coordinator. In addition, the student packet provided a list of possible research mentors. Students were required to select a mentor and a possible research topic. Submission deadlines were typically set within the first few weeks of the semester.

Selection of the participants normally took place at the beginning of the Fall semester, although occasionally students were added in the spring semester depending on availability of funds. A committee consisting of two faculty members from the department of Geological Sciences, the Director of the Environmental Sciences Program, one faculty member from the College of Science from outside of Geological Sciences, and the program coordinator selected the participants. In choosing applicants from the pool for acceptance, committee members focused on factors such as likelihood the student could/would succeed in the program (insight from letters of recommendation), geoscience courses taken, review of core requirements such as math and other science courses (grades, where they lacking courses, etc.), and responses from questions on the applications. Unlike many REU programs, we encouraged applications from first and second year students.

The number of participants selected was dependent upon funding. Our initial group encompassed seven students. Some years participating faculty had additional funding from their grants and would support a student half-time and PREP would support the other half, allowing PREP to fund more students. In a typical semester, 7-9 student participants were enrolled in the program. On average the participants remained in the program with support for at least 2 years (Figure 1). To remain in the program participants were required to: be enrolled as full-time students (12 credit hours), be enrolled in classes that led to a STEM degree, making progress towards a degree in science, conduct research, maintain a 3.0 GPA, attend weekly group meetings, participate in PREP outreach activities, and submit monthly reports on their research progress to the program coordinator.

Financial support from the program consisted of a stipend of \$760/month, \$600 per year in travel funds, and \$400 per semester for materials and supplies for research for each

participant. Throughout the program we experienced persistent challenges with the student's financial aid package and the ability to actually award the PREP stipend. A student's financial aid package is always highly individualized and confidential matter. Students who could not accept awards often confided in the program coordinator that they were unable to accept the PREP stipend because they had already accepted other grants or loans. Sometimes the student would be able to accept a portion of the stipend. We interpreted these difficulties as evidence that very few of the participants had either the family or personal means to finance college without grants and loans: an indirect indicator of their socio-economic status. None of this is surprising given UTEP's students demographics. Fortunately, many students chose to remain in the program without receiving a stipend from PREP. When preparing their financial aid for subsequent years, some students anticipated receipt of the PREP stipend allowing them to receive the full PREP amount. This phenomenon also allowed us to stretch our NSF funding over that many more students.

As might be expected for a program that spanned ten years, practices in recruitment, selection, and financial support evolved over time, as we adapted to our students needs to assure their success. For example, although we began by requiring a GPA of 3.0 for admission to the program, in practice, we did admit a number of students with GPAs below 3.0. Long experience at UTEP had taught us that GPA is not always the best indicator of whether a student will be successful. If an existing participant's GPA fell below 3.0 we did not necessarily drop them from the program. Instead, we worked with the student to understand the reasons for the lower grades. In addition, we worked with the research mentor to reduce the student's research commitment and to make more time for their course work. In every case, the participants who were given this consideration were able to successfully raise their GPA.

Another change that occurred over time was we became more willing to accept students with more limited coursework in the major. Initially, preference was given to students that were classified as juniors or seniors in their major. The thought was that the student who had already completed several introductory science and math courses as well as some foundation courses in their major would be more likely to succeed in the major. This policy is clearly reflected in Figure 2 which shows that more than half of the students were in their junior year when they entered PREP. As the program progressed, however, we decided to "take a chance" and see if we could foster students that had no or very little course work in their major. Of the twelve students that were admitted into the program as lower level undergraduates we successfully graduated eight.

3.4.3 Program Activities and Expectations

In return for their stipends, PREP participants were expected to a) conduct research with a faculty mentor, b) attend weekly professional development activities led by the program coordinator and faculty members, c) take part in Pathways outreach activities, and d) present their research at a variety of internal and external venues. Here we explain how these expectations unfolded in practice.

Student research covered a wide range of geoscience topics including: paleontology, structural geology, hydrogeology, environmental geology, seismology, and geomicrobiology. Nineteen faculty members were involved as research mentors. Of these faculty 5 were female, 14 were male, 2 Hispanic, 1 Asian, 1 Native American and 15 white/other. Students were asked to approach faculty prior to acceptance into the program so they would have a general idea of their research topic. Some students worked alongside graduate students while other students

conducted their research independently. Funds were available to each student ($400 a semester) to cover any required materials and/or supplies required for their research

Throughout the academic year, program participants attended weekly cohort meetings led by a UTEP faculty member and the program coordinator. The goals of the meeting were to provide professional development to support the students' research and career aspirations, and to build a geoscience "community" among the participants. Topics for the meeting were generally selected by the faculty and program coordinator; however students would occasionally suggest topics. Other departments on campus, such as the library or graduate school, were delighted to get involved with the program. The choice of topics was tied to the flow of events for the academic year. For example, in the fall we commonly covered: an overview and orientation to the program; research skills (a library visit), since we found many students were not familiar with how to search for journals, articles, etc.; graduate school presented the processes involved in applying for graduate school; and PowerPoint and presentation skills were discussed to help prepare them for the required end of semester research presentation. Whereas in the spring we covered topics such as leaning Adobe Illustrator; writing a scientific abstract; and applying for summer internships (Table 1). We also took time in the meetings for each participant to share where they were with respect to their research, and their overall experiences with how things were progressing in their classes, exams, preparing for upcoming events, etc. By sharing their experiences, good or bad, with their peers, participants came together as a cohort and developed a shared identity as "PREP students".

Participants were expected to take part in outreach activities as part of the overall goal of our NSF grants to create a geoscience network in El Paso. This requirement was also designed to develop a sense of efficacy as geoscience leaders and to inculcate the value of volunteer

scientific outreach to the community as a geoscience professional. Participants were expected to participate in at least 2 such activities in a semester. Typical outreach activities included: engaging in our departments annual Earth Science Week, judging of K – 12 science fair projects within the local school districts, and presenting geological concepts at local elementary schools. In addition, PREP participants assisted in hosting local school field trips in the geology department. It was not uncommon to have over 200 elementary students in the department during these events.

An expectation to present their research results at a variety of venues throughout the year served to develop presentations skills in the participants and as extra motivation to make measurable progress in their research as they balanced work on research with course work during the semester. In general most participants experienced a progression from presenting to their peers, to presenting at internal forums at UTEP, to presenting at national meetings.

At the end of the Fall semester each participant was required to give an oral presentation related to their research. Their audiences were the PREP participants, UTEP faculty, and the program coordinator. Presentations were fashioned after a typical oral presentation at a Geological Society of America or American Geophysical Union annual meeting. Each presentation was evaluated (anonymously) by each member of the audience (see appendix). Copies of these written evaluations were returned to each student and their faculty mentor. This presentation event allowed students to present in a more “friendly” environment before an actual meeting and receive important feedback from their peers.

In mid-spring students presented their research at the department’s Annual Student Research Colloquium. The colloquium is organized and facilitated by the graduate students within the department. PREP participants were required to present their research in either an oral

presentation or poster format. Many students commented that this experience made them feel more confident and comfortable with the possibility of presenting at a major annual conference. Students were awarded prizes (first, second, and third place) for best oral presentation and best poster. It was not at all uncommon for PREP students to be awarded at least one of the three places. Comments from external judges stated how impressed they were with the overall presentation skills and research level of the PREP students.

Students presented their research results at national meetings including the Annual Meetings of the Geological Society of America, Society for the Advancement of Chicanos and Native Americans in the Sciences (SACNAS), American Geophysical Union, as well as local research expos conducted at UTEP. Travels funds, $600 per year, were available for these meetings. Approximately 45% of the PREP students were able to present their research at external meetings or conferences. Typically these students had more than 3+ semesters in the program. All 59 students presented their research at the annual UTEP Department of Geological Sciences Student Research Colloquium at least once.

Participants were highly encouraged to apply for summer internships. Since PREP was an *untraditional* REU it gave the students an opportunity to apply for summer REUs or internships. Each participant was encouraged to apply to a minimum of three programs. The summer programs were not a requirement of the program, however the students were very enthusiastic about the possibility of a summer internship with most being successful in obtaining a summer research experience. Many of the participants (34%) were selected to attend summer REUs and several of the students participated for two or more summers. This is a major benefit to a *non-traditional* academic-year REU.

3.5 RESULTS

To assess the impact of the program, we analyzed 12 years of quantitative data on the program participants, and all other students enrolled in UTEP's undergraduate Geological Sciences majors and Environmental Sciences majors as well as qualitative data in the form of surveys and focus groups. The quantitative data make a compelling case that participation in PREP substantially increased student success and the likelihood that they would attend graduate school. The qualitative data give important insight into what and how aspects of the program helped move students toward these career goals.

3.5.1 Student Data

In order to discover if academic and career outcomes for the PREP participants differed substantially from their peers, we analyzed 12 years (2000-2012) of demographic and outcome data for all students enrolled in undergraduate programs in Geological Sciences and Environmental Science at UTEP. Our data set included, gender and ethnicity, first generation in college, first time in college (FTIC), transfer status, grade point average (GPA), graduate rates, and time to degree. The data were obtained from the Center for Institutional Evaluation, Research and Planning at UTEP.

Review of the demographic data shows for PREP participants compared to that for undergraduate majors in Geological and Environmental Sciences shows that the two groups were similar in terms of ethnicity, status as first generation in college, and entry status, but substantially different with respect to gender (Table 2). Both groups were over 60% Hispanic and over 20% White Non-Hispanic. International comprised more than 9%, compared to ca. 2% for the PREP participants. This is not surprising as our selection process for PREP participants

favored citizens and permanent residents, in deference to our support from the NSF. At UTEP, most undergraduates who are international students are Mexican in origin, mainly from Ciudad Juarez, El Paso’s sister city on the border. Both groups were comprised of a little over 30% of students who self-declared as “First Generation in College”. Our experience with UTEP students suggests that this number is probably an under-estimate of the actual percentage of students who were first generation. Finally, both groups contained similar percentages of transfer students at ca. 40%. At UTEP, the vast majority of transfer students come from El Paso Community College (EPCC).

With respect to gender, the PREP participants were 64% female to 36% male which differs substantially from the group of majors, which was comprised of 52% female and ~48% male (Table 3). This result came as surprise, as we made no conscious effort to favor women over men in the selection process. In fact, 41% of the PREP participants were Hispanic female, compared with Hispanic males, and White Non-Hispanic males and females who each comprised ca. 15% of the PREP participants. From the undergraduate majors 36% were Hispanic female, 27% Hispanic male compared with 8% White Non-Hispanic female and 15% White Non-Hispanic male. As a result, the program had particularly strong impact on attracting Hispanic women into the Geosciences.

Analysis of time-to-degree data for PREP participants compared undergraduate majors shows that the PREP participants took much less time to obtain their degrees (Table 3). On average, PREP participants completed their degrees 6-9 months sooner than the group of undergraduate majors (Table 3) regardless of gender, ethnicity, entry status or status as first generation in college. PREP participants who were also first generation in college completed their degrees more 15 months sooner than their peers. Those who entered as transfer students

completed their degree more than 13 months sooner than their peers in the department. Across the board, female students completed their degrees 6 months to a year earlier than their male counterparts.

Analysis of GPA data for PREP participants compared to the group of undergraduate majors shows that PREP participants completed their degrees with an average GPA that was 0.2 higher on average than that of their peers (Table 3). PREP participants who were also first generation in college graduated with GPAs that were 0.27 higher on average than peers with the same entry status. PREP participants who were transfer students graduated with a GPA that was 0.29 higher than their peers who entered college as freshman. PREP participants also entered the program with an initial average GPA of 3.17 and graduated with an average GPA of 3.31. Unfortunately, we do not have comparable data for the departmental majors. Across the board, female students completed their degree with somewhat higher GPAs than their male counterparts.

3.5.2 Degree and Career Outcomes

Analysis of Bachelor degree data reveals that 88% of the PREP students earned a bachelors degree (49 BS, 2 BIS, 1 BA) while only 84% of the undergraduate majors obtained a bachelors degree. With respect to no degree obtained, 18% of the undergraduate majors had not obtained a degree while 12 % of the PREP students (at the time of this writing) had not obtained an undergraduate degree. Of the 52 PREP participants that earned a bachelors degree, 34 were from the Geological Sciences. Among these 34, 28 completed a masters degree. This means that 82% of the PREP participants with a degree in Geological Sciences continued on for a masters degree. There are 11 Ph.D. students within the PREP participants' cohort. Of these 11,

3 were awarded the NSF Graduate Research Fellowship. Statistically 39% of the participants who attained a masters degree went on for their Ph.D.

When examining the career outcome: 27 participants are currently employed within the STEM field. This cohort includes: 16 female, 11 male, 16 Hispanic, 11 Other, 10 bachelors degrees, and 17 master degrees. It is a difficult task keeping track of the students once they have graduated and entered the workforce. What data we have indicates that participants took up initial employment within the oil and gas industry, environmental firms, mining, and academia. Oil and gas industry employs the largest at37%, 10% within academia, 15% within the environmental field, 7% in mining, and 19% in other fields such as USGS, National Forest Service, etc.

3.5.3 Survey and Focus Group Data

As part of both formative and summative evaluation of the program, we collected qualitative data using surveys and focus groups. Participants were given written surveys when they first entered the program and when they exited the program (Appendix A). Focus groups sessions were conducted in between entrance to and exit from the program. Throughout the length of the program we would amend the program format based on information collected by means of the evaluations.

From the First-Time Participant questionnaires*:* When asked about plans after graduating with a bachelor's degree 94% said they would enter a graduate program right after graduation and 6% said they planned to work before entering a graduate or professional program. When asked, "Ten years from now how likely is it that you'll be working in the geosciences field" 88%

were very likely; 6% were moderately likely; and 6% not likely at all. When asked "Ten years from now how likely you'll be working in a career in the sciences" 76% were very likely and 24% were moderately likely.

Information gathered from the Exit questionnaires*:* participants had very positive attitudes towards: a) furthering their education in science; b) continuing on to graduate school, and c) continuing on to a career in geosciences/sciences over the next ten years. When asked in the exit evaluations "Has the research experience encouraged you to further your education in the sciences?" a response of yes or no, 100% of the participants marked "yes". There were explanations such as "The research made me feel more comfortable with my development as a student because it was very challenging and reassuring" or "This research experience motivated me" or "When you do research you start asking yourself many questions that encourage yourself to keep learning more. I believe that learning is a never-ending process".

The last question asked "Ten years from now, how likely is it that: a) you'll be working in the geosciences field and b) you'll be working in a career in the sciences". The response choices were rated on a scale from 1 - 4 (4 = very likely, 3 = moderately likely, 2 = not so likely, and 1 = not likely at all). Ninety-four percent responded with 4(very likely) on (a) and (b) and 6% with 3(moderately likely) for (a) and (b).

Common themes related to both needed changes and the impact of the program on participants are evident from the facilitators notes from the focus groups. The recurring themes were: cohort meetings, financial support, career plans, and additions to the program.

Meetings –Initially the program required participants to meet bi-monthly with the program PIs and the program coordinator. Based on comments from evaluations, there was a

significant need to meet more frequently and with a more diverse topic agenda. The program went from bi-monthly meetings to weekly meetings.

Financial Support - Many participants commented the financial support eliminated the need for outside employment. Financial support allowed the participants more time to concentrate on classes, enabled full time enrollment, thus leading to a quicker time to degree, and the opportunity to be involved in research.

Career Plans - Many participants commented before participating in the program there was no consideration for graduate school however comments such as: “now not only considering an M.S degree but a Ph.D. as well”. One participant stated “I am not only considering graduate school, but am “gung-ho” about it”.

Additions to the Program – When asked what they would add to the program the many responded with more students and more funding.

One last comment from the facilitator “the ease with which the students articulately described their research was very impressive”. After having conducted several of the focus groups the facilitator recognized improvements within the cohort that had been in the program more than one semester. It was mentioned students had a better command of the technical language and were more comfortable when asked to explain their research.

3.6 DISCUSSION

Whereas, our data on GPA, time-to-degree, and career outcomes strongly suggest that PREP participants are enjoying more success than their undergraduate peers. it is the result from the focus groups and surveys that point to likely causes for this extra success. Key elements

appear to be the mix of financial support, mentoring, and professional development activities provided by PREP.

When reviewing the demographic data we were surprised to see that PREP participants were 64% female to 36% male and 41% of the female were Hispanic. There was no consciences effort to recruit more females than males into the program. One thought may be, within the Hispanic culture family is an important factor. Perhaps the females were more attracted to "a sense of belonging" within a group. Weekly meetings brought the PREP participants together for discussions and guidance. The PREP participants formed strong bonds amongst the group.

To increase the GPA, maintain it, and conduct scientific research is a huge accomplishment. Comments from the focus group indicated that belonging to a group provided them with support both mentally and emotionally. Being able to have discussions with your peers (about research, classes, fatigue, etc.) and knowing they understood what you are experiencing was a huge component. Having peers, weekly meetings to share their concerns, and financial support lessened their worries and allowed them to focus more on school and research. One student commented "I was able to do research while in school and not need to have a job. This allows me to complete school sooner".

Time-to degree was shorter than the departmental major. Again the financial support arose repeatedly in the focus groups. Financial support allowed them to spend more time on campus, time to focus on studies, and the ability to take more classes. These qualities alone can lead to a faster time-to-degree. It was also mentioned that the mentors, PIs, and the program coordinator always had time to meet and speak with the participants about many topics such as courses to take and when to take a certain course. Although there are undergraduate advisors, there was a personal connection between the participants, the PIs, the mentors, and the program

coordinator. As one stated “they cared”. The surprising fact was that the First-Generation participants completed their degree 15 months sooner than the departmental majors. Although we were not aware of which participant was a First-Generation some thoughts from the focus and survey data support once again come into mind: financial support, belonging to a group, mentoring, and having PIs and a program coordinator that understood what the participants were dealing with and could relate to. There is a sense of belonging and support.

Most significant were the overall statistics from our program and the comparison of national data from NSF degrees granted (Tables 4 and 5). Sixty-five percent of the PREP cohort received a bachelors degree in the Geological Sciences. Departmentally 50% of the students received a degree in the Geological Sciences. When looking at graduate degrees (we have no comparison data for departmental majors) nationally only ~35% of students that obtained their bachelors degree continued on to the masters level. From the PREP cohort 82% of students that received a bachelors degree in the Geological Sciences went on for a masters degree. The PREP program generated about 47% more in masters degrees than the national average. Finally comparing the Ph.D. nationally ~51% whom obtained a masters degree continued on for a Ph.D. while the PREP number, not as significant, with 39% continuing on for a Ph.D.

3.7 CONCLUSIONS

The PREP cohort (59) has generated 11 potential Ph.Ds, 28 masters, and 49 bachelors degrees in the geosciences/environmental sciences and 27 careers in the oil and gas industry, environmental consulting, and academia. Statistically the PREP program has recruited and retained 71% of the participants into the geoscience pipeline. We attribute this success to the program directors’ ability to create an environment in which not only do students expect to enter

graduate school on completing a bachelor's degree, but they also choose to overcome traditional cultural ties to home and leave El Paso to pursue their graduate education.

Based on our quantitative and qualitative data we *know* that an academic year REU has significant advantages over summer REUs and that the academic year program have the capacity to generate more underrepresented minorities who enter the geosciences and later take up careers in the field. With the success of PREP, the Meyerhoff Scholarship Program, the REU at NYC, and the C-MORE Scholars Program more REU programs *should* consider an academic year experience.

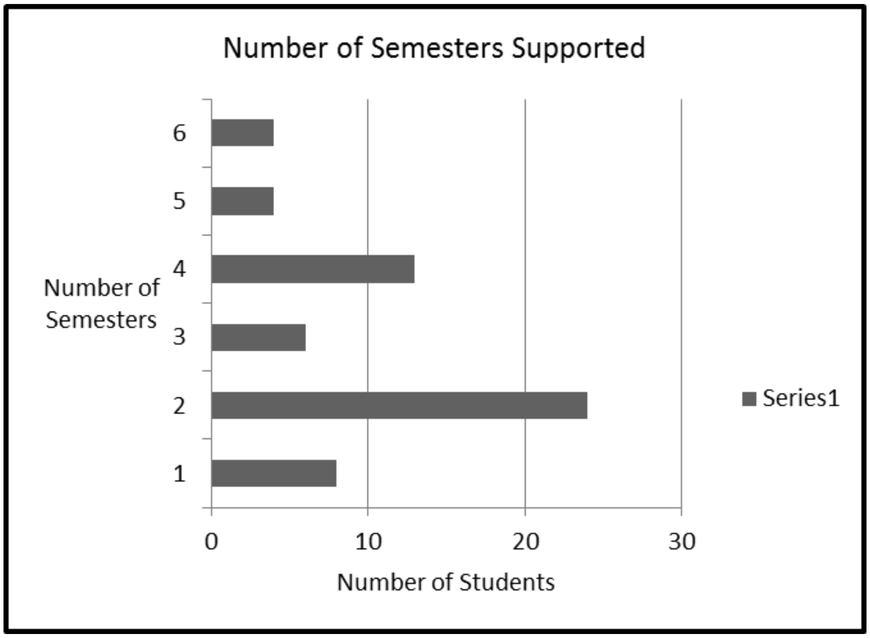

Figure 3.1. Histogram of the number of semesters students were supported in the program.

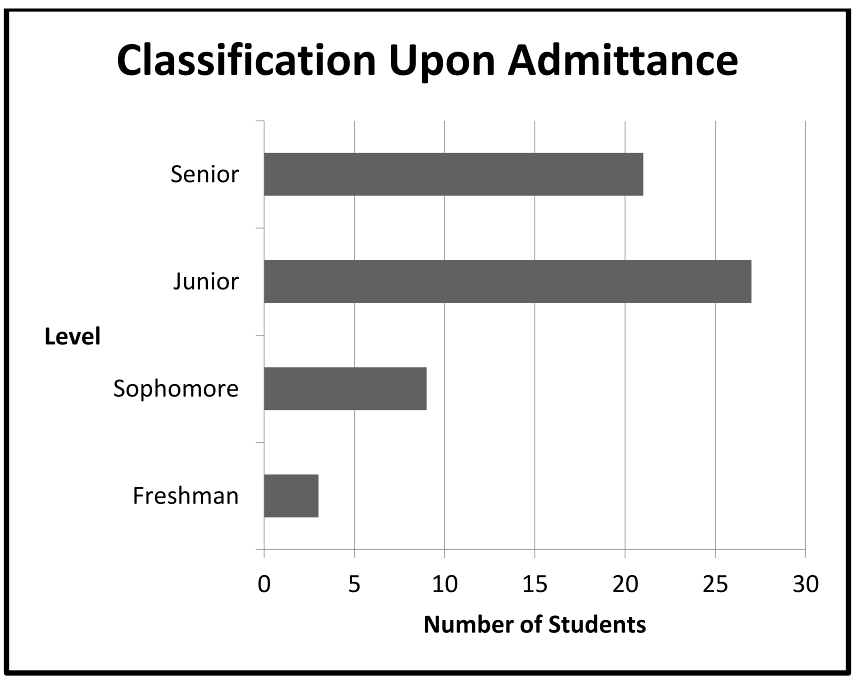

Figure 3.2. Histogram of the level of classification at which students were admitted into PREP.

Table 3.1. Weekly Meeting Topics

Fall Semester	**Spring Semester**
Orientation/expectations of the program	How to write a scientific abstract
Internship presentations – students present their summer research	Presentation Skills – posters
How to Write a Proposal	How to – Adobe Illustrator
Applying for the NSF Graduate Research Fellowship	Poster layout in Adobe Illustrator
Writing an NSF Proposal	How to get the most out of a professional meeting
Research Skills/Visit to the Library	How to write a resume
Presentation from Graduate School-applying for graduate school(s)	Applying for summer internships
How to apply to graduate schools	How to get the most from a summer internship
Presentation Skills – oral/PowerPoint	Calendars – Time management
How to – PowerPoint	Interviewing skills
Students oral/ppt presentations of their research	Mock interviews
	Career Services presentation

TABLE 3.2. Comparison of demographics between the PREP students and the Departmental (non-PREP) students.

2002 – 2012 PREP Participants	No. of Participants	% Participants	2002 -2012 Departmental Participants	No. of Depart. Participants	% Depart. Participants
Gender					
Male	21	35.6%	Male	115	47.9%
Female	38	64.4%	Female	125	52.1%
Race/Ethnicity					
Hispanic	34	57.6%	Hispanic	151	65%
White non-Hispanic	17	28.8%	White non-Hispanic	55	21.1%
Two or more	0		Two or more	0	
Native American	0		Native American	0	
Asian	2	3.4%	Asian	4	1.1%
International	6	10.2%	International	27	11.7%
Black	0		Black	0	
unknown	0		unknown	2	1.1%
Gender/Race/Ethnicity					
Hispanic Female	24	40.7%	Hispanic Female	87	36.3%
Hispanic Male	10	16.9%	Hispanic Male	64	26.7%
White Non-Hispanic Female	9	15.3%	White Non-Hispanic Female	19	7.9%
White Non-Hispanic Male	8	13.6%	White Non-Hispanic Male	36	15.0%
Two or more races Female	0	0.0%	Two or more races Female	0	0.0%
Two or more reaces Male	0	0.0%	Two or more reaces Male	0	0.0%
Native American Female	0	0.0%	Native American Female	0	0.0%
Native American Male	0	0.0%	Native American Male	0	0.0%
Asian American Female	2	3.4%	Asian American Female	2	0.8%
Asian American Male	0	0.0%	Asian American Male	2	0.8%
International Female	3	5.1%	International Female	15	6.3%
International Male	3	5.1%	International Male	12	5.0%
Black Non-Hispanic Female	0	0.0%	Black Non-Hispanic Female	0	0.0%
Black Non-Hispanic Male	0	0.0%	Black Non-Hispanic Male	0	0.0%
Unknown Female	0	0.0%	Unknown Female	1	0.4%
Unknown Male	0	0.0%	Unknown Male	1	0.4%
First Generation College					
	16	27.1%		81	33.8%
First-Time College versus Transfers					
First-Time	33	56%	First-Time	125	52.1%
Transfers	23	39%	Transfers	101	42.1%
Overall GPA					
Overall GPA	52	3.31	Overall GPA	202	3.12

TABLE 3.3. Comparison of degree outcomes between the PREP students and the Departmental (non-PREP) students.

Demographic Category	**PREP Participants**					**Undergraduate Majors**			
	Degrees Granted - Geological Sciences	*Degrees Granted - Other*	*Average Time to Degree*	*GPA*	*No Degree*	*Degrees Granted - Geological Sciences*	*Degrees Granted - Other**	*Average Time to Degree*	*GPA*
Total	34	18	5.17	3.31	7	101	101	5.98	3.12
Gender									
Female	20	13	4.91	3.34	5	34	65	5.74	3.17
Male	14	5	5.59	3.26	2	67	36	6.23	3.07
Race/Ethnicity									
Hispanic	17	13	5.43	3.22	5	58	68	5.91	2.85
White Non-Hispanic	13	3	5.11	3.37	1	33	16	6.15	3.01
Two or more	0	0	0	-	0	0	0	-	-
Native American	0	0	0	-	0	0	0	-	-
Asian American	1	1	4.33	3.42	0	1	3	4.67	3.14
International	3	2	4.40	2.96	1	9	14	5.46	2.90
Black Non-Hispanic	0	0	-	-	0	0	0	-	-
Unknown	0	0	-	-	0	0	0	6.17	-
First Generation in College									
Total	10	3	4.64	3.38	3	31	33	6.02	3.11
Female	4	1	4.69	3.32	2	10	21	6.52	3.08
Male	6	2	4.50	3.42	1	21	12	6.06	3.10
Entry Status									
Total FTIC	20	8	5.91	3.19	5	49	57	6.14	3.11
Female	13	6	5.92	3.20	4	23	39	5.94	3.18
Male	7	2	5.89	3.19	1	26	18	6.42	3.01
Total Transfer	13	8	3.92	3.48	2	47	39	4.59	3.19
Female	7	6	3.47	3.54	1	11	24	4.25	3.20
Male	6	2	4.58	3.39	1	36	15	4.86	3.17

Table 3.4. Participant demographics and STEM involvement

	Total		Male	%	Female	%	Hispanic	%	Other	%
Participants	59		21	36%	38	64%	42	71%	17	29%
Education										
Bachelor’s degree	52		20	38%	32	62%	35	67%	17	33%
MS degree	28		16	57%	12	43%	19	68%	9	32%
In a PhD program	11		3	27%	8	73%	9	81%	2	19%
In a MS program	2		-	-	2	100%	-	-	2	100%
In an UG program*	2		1	50%	1	50%	2	100%	-	-
Career Outcome										
STEM Career**	27		12	44%	15	56%	17	63%	10	37%
Other Careers/Unknowns	17		2	12%	15	88%	15	88%	2	12%

* as of December 2013

** 71% have remained in the STEM pipeline

Table 3.5. PREP Statistics compared to the NSF 2010 Statistics

BS Degree	%	MS Degree	%	PHD Degree	%
NSF total number of degrees					
1,668,227*		698,528**		48,069***	
NSF number of Science and Engineering degrees					
525,374	31%	139,926	20%	33,141	69%
NSF number of Earth/Atmospheric/Ocean Sciences degrees(EAOS)					
4802	0.9%	1677	1.2%	864	2.6%
PREP students in degreed in Geological Sciences (n=34)					
34/52	65%	28/34	82%	11/28	39%

*Total number of bachelor's degrees awarded in all fields (NSF, 2013)
** Total number of master's degrees awarded in all fields (NSF, 2013)
***Total number of doctoral degrees awarded in all fields (NSF, 2013)

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Chapter 4: Why Did You Decide to Become a Geoscience Major: A Critical Incident Study for the Development of Recruiting Programs for Inspiring Interests in the Geosciences among Pre-College Students

4.1 INTRODUCTION

Data from the 2014 AGI Status of the Geoscience Workforce implies that within the geosciences fewer bachelors (less than 8%), Masters (~5%) and Ph.D.(~3%) degrees have been awarded to under-represented students than in any other science and engineering field (Wilson, 2014). Thus the Geosciences clearly need effective strategies for attracting and retaining a more diverse population of students. It should be noted that this is not entirely surprising because it is usually a “found major” in college. That is students don’t often encounter it as a stand-alone field and/or career option until that time, in large part because the geosciences are rarely taught in high school.

Over the last 10 years, concerted efforts have been made by a number of groups to determine the primary factors that lead to successful recruitment and retention of students to geoscience programs in higher education (e.g. Levine et al., 2007; Serpa et al., 2007; Huntoon and Lane, 2007; Hoisch et al., 2010; Baber et al., 2010). Broadly, this activity has been referred to as understanding the factors that influence the “geoscience-pipeline”, with data being collected from geoscience professionals, geoscience graduate students and undergraduate majors.

In 2007, Levine et al., (2007) proposed an initial geoscience pipeline model that was grounded in a review of literature on factors that influenced underrepresented minorities’ choice of science, technology, engineering, and mathematics (STEM) majors and careers. They refined their initial model for use in the geosciences through a series of critical incident (CI) interviews, that focused on behaviors that influenced their subjects, who were either geoscience professionals or graduate students in the geosciences, to enter or leave the field. The critical

incident technique is a tool developed by Robert Flanagan for observing human behavior. This technique consists of methods and procedures in data collection for identifying significant experiences that influenced an individual's decisions or actions (Flanagan, 1954). The technique is effective in identifying events that either attracted or deterred students from pursuing an education in the geosciences (Levine et. al., 2007, Hoisch et al., 2010). The product of the approach is a taxonomy of incidents derived from summarizations of interview data. Levine et al.'s (2007) taxonomy defines four categories of indicators conducive to retaining students in the geoscience pipeline (Figure 1).

Subsequently, a number of investigators working on diversity in the geosciences have used this model to help define strategies for successful recruitment and retention of minorities within their programs (Baber, et al., 2010, Haller, et al., 2010, Hoisch, et al., 2010). Several authors have found that the Levine et al. taxonomy is a good working model but that it needs to be expanded. For example, Baber et al. (2010) make the case that the taxonomy would benefit from the addition of a framework for self-efficacy..

As part of the UTEP Pathways program, we conducted our own critical incident study, with 20 UTEP students as subjects. Our study had two goals: 1) to develop a taxonomy for designing geoscience recruitment programs in the pre-college population, and 2) to discover if there were substantial difference between our taxonomy and that of Levine et al. (2007), that could be traced to our dominantly minority population of subjects. Here we document the results of that work.

4.2 METHODOLOGY

Since we were investigating why a student chose the geosciences we recruited student participants from the UTEP Geological Sciences department. We interviewed twenty students of whom 18 were undergraduate students and 2 were graduate students. Participants in the interviews were 45% male, 55% female, 65% minority (dominantly Hispanic).

To develop an interview protocol, 2 UTEP faculty members and 1 staff member were trained in the critical incident technique by Dr. Roger Levine from American Institute of Research (AIR). The two faculty members were co-Principal Investigators (PIs) on the grant and the staff member was the grant coordinator. With the help of Dr. Levine we designed a set of open-ended interview questions. These questions were accompanied by a "probe" protocol, which was comprised of a series of a follow up questions designed to stimulate the subject to relay stories about specific events or situations that played a significant role in their selection of a geoscience major. For example, following the protocol of Levine et al., 2007 the interviewer asks questions (i.e. "What is your current major", "When did you decide to major in (subject), "Why did you decide to major in (subject)") and probes that are designed to stimulate the provision of specific situations and events that played a critical role in the selection of a geoscience major (i.e. "Tell me more" "What do you like about geoscience?") Depending on the interviewee's responses the interviewer might probe for further information. Sample incidents are provided in Figure 2.

Each interview began with a standard introduction designed by AIR. The interviewer would introduce themselves, and state that we were interested in finding out why and how students choose their college majors. The interviewee was told this study is part of our NSF grant to find out why students choose geoscience majors. The students were instructed that the

interview would take about 30 minutes of their time. We advised them that everything they said was strictly confidential and we made sure that they understood that they did not have to answer questions they were uncomfortable with and that their cooperation was voluntary. We also informed the students that the interview would be taped to ensure accurate reporting and again were advised that no one other than the investigators would listen to the recording. Once the student had agreed to the conditions of the interview and was comfortable the open-ended question and 'probe' portion of the interview began. Typically, an interview lasted about 30 minutes.

Analysis of the interviews was performed with the aid of Audacity, a free software program for audio editing and recording. Audacity gave us the capacity to stop, rewind, fast forward, or return to a specific point in the interview efficiently. It also enhanced the sound/tone of the recordings compared to the original cassette tapes. In reviewing the recordings I listened for specific behaviors or events for critical incidents. These events or situations were each written up as a "critical incident". It is important to keep in mind that "critical" means the incident was crucial to the outcome and "incident' is an observable, specific behavior. In this case, I was looking for critical incidents comprised of a specific behavior that was responsible for or influenced an individual's choice to major in the geosciences. As a critical incident was established, the details were noted on a generic critical incident form comprised of three questions: 1) What led up to the situation? 2) What happened? What did (you/person) do? and 4) (If not obvious) How did this lead to your decision (not) to major geoscience.) (Figure 2). The initial count of critical incidents was 92.

After defining the initial set of critical incidents, I met with Dr. Levine and his staff at AIR to review the incidents. With guidance from Dr. Roger Levine, Carmen Sussman-Martinez,

and two other staff members from AIR our first step was to review the initial critical incidents for validity. According to Butterfield, et al., (2009) there are 9 ways to validate the critical incidents. Among these is tape recording the interviews, so you have the participant's actual words, placing incidents into categories by an independent evaluator, and independent extraction of the critical incidents. In this study, the validity of an incident was defined on the basis of whether the team members from AIR agreed that a proposed incident was indeed critical. After extensive review with the AIR team, a total of 157 were eventually identified. A possible limitation of this study is that we did not pursue other statistical methods for determining validity.

The ultimate goal was to use the critical incidents to develop a taxonomy for designing possible recruitment programs for the *pre-college* population. Once the number of critical incidents was finalized, we split into two groups to categorize the 157 critical incidents into broader groupings. Each group was given an identical set of incidents. For example, through discussion, one group came up with a category for "Outdoor Experiences" that contained critical incidents that involved hiking and camping. So Outdoor Experiences became a major category and hiking and camping became minor or subcategories. If we were not able to place a critical incident into a category or subcategory the incident was left as its own (sub) category.

After each group had completed their initial taxonomy the two groups met to share their categories and subcategories. We then worked together, looking at the similarities and differences among the two to build a final taxonomy.

Taxonomy developed (Table 1) has two major categories: Formal Exposure and Informal Exposure to the Geosciences as well as a number of subcategories. The major categories were chosen based on the premise that the taxonomy was to be designed for pre-college age students.

The two major categories were based on the types of settings where students learned about or were exposed to the geosciences. The first, “formal exposure” refers to organized programs such as school, church, and Boy Scouts, and camps, whereas an “informal exposure” refers to private or family life, and things done outside of school and organized programs. The subcategories are then closely tied to actual critical incidents. Under Informal Exposure we defined 4 categories and 11 subcategories. Under the Formal Exposure we defined 7 categories and 18 subcategories. Because we realized that some of the critical incidents we had collected could occur in both formal and informal settings, we created a third combined major category designated as “formal and informal”. This major category consists of 2 additional categories, 5 subcategories and 1 sub-subcategory (Table 1.

To demonstrate that the taxonomy was viable, an independent evaluator was given the original 157 critical incidents. Normally, it is sufficient to assess viability by having an independent evaluator categorize a small subset (~25%) of the incidents into a proposed taxonomy. In this case, the evaluator decided to attempt to associate all the critical incidents with the categories/subcategories in the taxonomy. Of the 157 critical incidents s/he placed 149 into the proposed taxonomy (Table 1). S/he then suggested that we create 2 new subcategories: geoscience friends and high school level classes. It is not unusual to add subcategories each time an independent evaluator reviews the taxonomy. According to Dr. Levine taxonomy are always “works in progress”.

4.3 DISCUSSION

By examining the overall population of critical incidents, we discovered that some types of incidents occurred more often than others among the people that we interviewed. For example, 90% of the participants stated that a college level class was a critical incident in there major choice. Another 55% of the participants had some sort of pre-college experience related to geoscience, such as collecting rocks, other geoscience-related hobbies, or participation in a pre-college program such as the UTEP Pathways Summer High School Program. For 35% of the participants, family influences were a crucial components to their decision. As an example, one participant had one parent who supported and one did not support geosciences as a career. The participant took this a challenge to prove the parent, who did not support the geoscience major, wrong. Another example of a positive family influence was a participant had grown up in California. They had recollections of earthquakes and speaking with their dad about "What was that" When is this going to happen again?." They shared a rock collection. "Dad" encouraged the participant to "explore and find out more".

Our taxonomy aligns wells with more than half of the subcategories in the Levine et al taxonomy (Figure 1). Similar subcategories include Familial Factors, Geoscience awareness, Outdoor experiences, mentors, and careers. Three particular subcategories from the Levine et al. taxonomy that we did not encounter were Encounters with Racism, Ethnic cultural values and socialization, and Economy. This could be a result of the differences in the sample groups. Overall we were surprised at the similarities between the two taxonomies since Levine et al. focused was on career paths while our taxonomy was developed for recruitment programs for the *pre-college* population.

4.4 CONCLUSIONS

That our taxonomy and the Levine et al. taxonomy share so many subcategories is significant for fully understanding the geoscience pipeline. The Levine et al. taxonomy was a first effort at defining a taxonomy for the geosciences and was based on interviews with people who were already geoscience professionals, 29% of whom were minority. By contrast, 90% of the participants in our study were undergraduates and 65% were minority. We were able to develop a separate taxonomy from a very different sample group yet still have more than 70% of the taxonomy similar. This adds support to other studies that have indicated that the Levine et al. taxonomy seems to be effective as a practical tool.

Our taxonomy point to a number of effective ways for increasing pre-college interest in the geosciences. For example development of summer programs, at the middle school and the high school level should be considered. There needs to be an outreach component to the local schools (bringing students in for "Geoscience Fairs", tours, etc.) to increase their awareness of the geoscience content. Within Texas, the curriculum change that allows a geosciences course to be taken as a core science elective in the high school creates an excellent opportunity for Texas universities/community colleges to develop a strong working relationship in the development of hands-on labs to be incorporated into the course and recruitment opportunities.

Introductory college classes are also critical for recruitment. 90% of the participants stated that a college level class was a critical incident in there major choice. Several mentioned high school courses attributed to the major choice.

Finally, there were three subcategories that our critical incident study did not encounter as the Levine et al.: Encounters with Racism, Ethnic cultural values and socialization, and Economy. This could be a result of the differences in the sample groups.

Whereas, the critical incidents technique is not a new approach, applying it to the geosciences is. Since our study was completed a few additional studies (e.g. Houlton, 2010, and Stokes, et al., 2014), have applied the technique to the geosciences. Future work could include a comparison of these critical incidents studies to look for common themes and differences. In addition, our study could be extended by reviewing of our own critical incidents for themes that may be tied to gender and ethnicity.

With our taxonomy in place, we believe our model will be successful in contributing to the recruitment of underrepresented minorities into the geosciences.

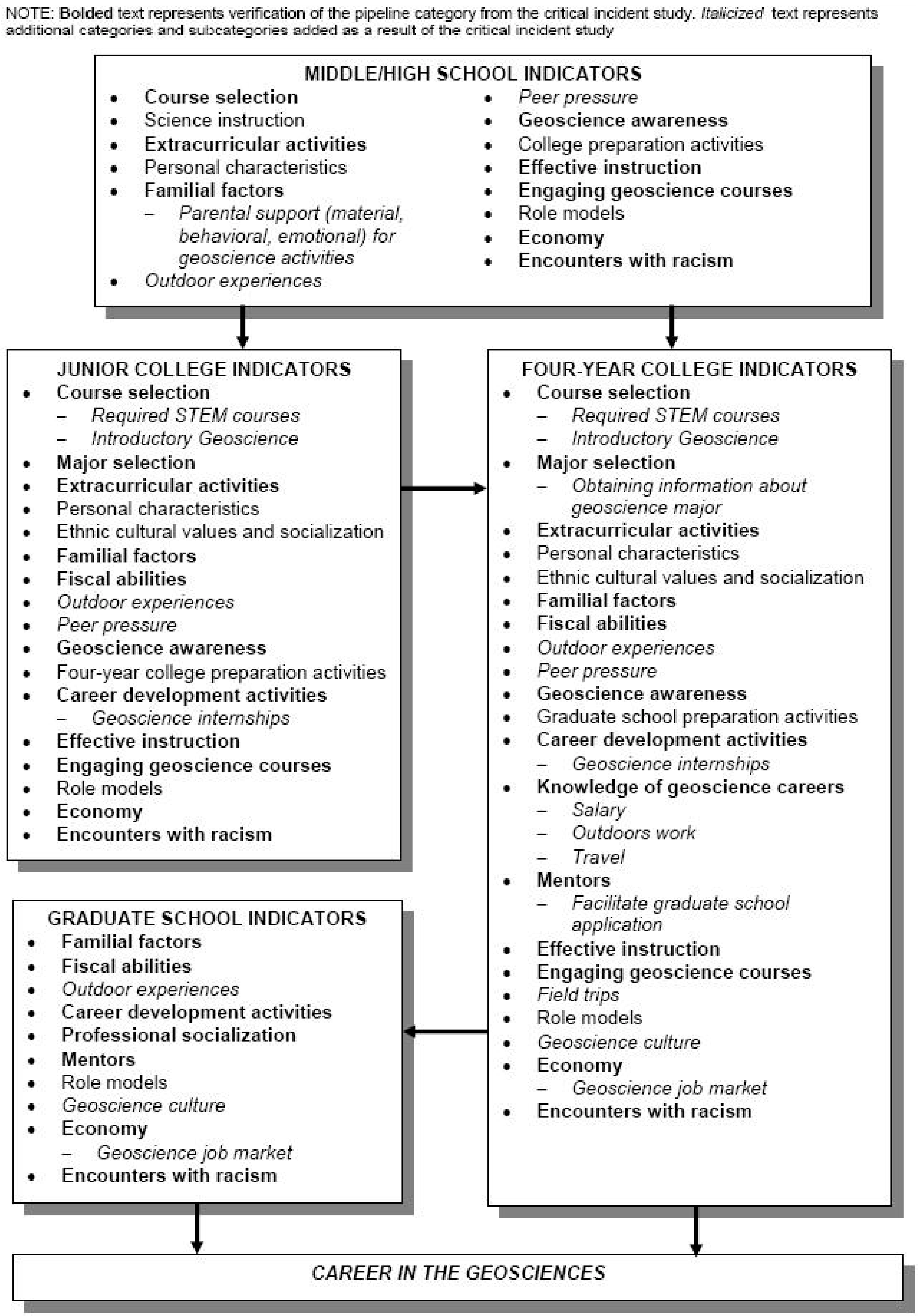

Figure 4.1. The Geoscience Career Pipeline Mode from Levine, et.al., 2007

Incident #1		Incident # 2
1. **What led to the situation?** *My parents always exposed me to the natural world: going hiking, camping – those were our family vacations growing up.*		**1. What led to the situation?** *It goes back to the 5th grade when I learned about the rock cycle.*
2. **What happened? What did (you/person) do?** *In my senior year of high school, when I really started thinking about what I wanted to major in, I realized that I wanted to major in Geology.*		2. **What happened? What did (you/person) do?** *I wrote a report on the rock cycle that was 2 pages long. The requirement was ½ page.*
		3. (If Not Obvious) How did this lead to your decision (not) to major in geoscience? *It was my first exposure to geology.*

Figure 4.2. Samples of critical incidents.

Table 4.1. UTEP Pathways Taxonomy

Informal Exposure to Geoscience

1) Outdoors Experiences
   a) Enjoying the outdoors
   b) Hiking
   c) Camping
   d) Exposure to geological phenomena
2) Family Involvement
   a) Family trips
   b) Family support
   c) Family role models
   d) Scientists in the family
3) Learning about science careers
4) Interest in science content
   a) Collecting rocks, minerals, or other geo-related hobbies
   b) Appreciation of geoscience
   c) Appreciation of geological artifacts

Formal Exposure to Geoscience

1) Academic experiences
   a. College level classes
   b. Elementary School level classes
   c. Middle School-level classes
   d. Outdoor labs
   e. Research experiences
   f. Field work/trips
   g. Hands-on experiences
   h. Did not like other STEM fields
2) Program participation
   a. Pathways*
   b. Metals**
   c. Cub and Boy scouts
3) Faculty support and validation
   a. Emotional support
   b. Academic support
4) Geoscience community
   a. Individual attention
   b. Smaller class size
   c. Forming relationships with grad students/professors
5) Good performance in geoscience classes

6) Characteristics of geosciences
    a. Practicality of the field
    b. Dynamic nature of the field
7) Funding/scholarships available

Formal and Informal
1) Media
    a. Movies
    b. Posters
    c. Science-focused events
2) Learning about careers in science
    a. Learning about geoscience careers
    b. Learning about benefits of geoscience careers
        i. Financial incentives

* Pathways was a two week summer program for high school students and teachers designed to introduce the geosciences and their connections with other sciences such as biology, chemistry, and physics held at UTEP.

** The **METALS Program** was an opportunity for older high school students to be exposed to the Environmental and Earth Sciences in preparation for a college experience.

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Chapter 5: Relocating Earthquakes of the 2009 Dusky Sound, South Island, New Zealand Sequence

5.1 ABSTRACT

On July 15th, 2009 UTC the largest magnitude earthquake (M_w 7.8) to affect New Zealand in over 70 years occurred in Dusky Sound, a fiord located in the southwest corner of the South Island of New Zealand. The 2009 sequence was the southernmost in a series of seven $M_w > 6$ earthquakes occurring over an 11 year period, including an M_w 7.2 event in 2003. The 2009 mainshock created fewer landslides and radiated relatively little high frequency energy compared with the 2003 mainshock, although both occurred on the plate interface, suggesting the 2009 mainshock had a lower stress drop. GPS studies indicate slip along the plate interface in the 2009 mainshock was highly oblique, in contrast to the region located north of the 2009 sequence where slip is partitioned into trench normal thrusting along the subduction interface and strike-slip faulting along the Alpine fault within the Pacific plate. After relocation of aftershocks from the 2009 sequence using *hypoDD* there is a better understanding on how this region of the South Island transitions between non-partitioned oblique subduction and a slip partitioned convergent margin. The relocations will aid in the selection of event pairs for a separate study of stress drop variations using the Empirical Greens Function technique.

5.2 INTRODUCTION

New Zealand's active tectonics is dominated by the oblique convergence of the Pacific plate and the Australian plate, which produces earthquakes, volcanoes, active geological deformation, and steep terrain (Figure 1). This tectonic setting is what makes New Zealand one

of the most seismically active countries in the world with more than 15,000 earthquakes ($M_L \geq 2$) located per year (Petersen et al., 2011) (Figure 2).

On July 15th, 2009 the largest earthquake in New Zealand since 1931, M_w 7.8, occurred at Dusky Sound within the Puysegur subduction zone (Figure 3). The M_w 7.8 earthquake ruptured the plate boundary interface between the subducting Australian plate and the overlying Pacific plate, with the deeper end of the rupture underlying the coast of Fiordland. This event appears to be one of the better recorded shallow (ca. 12 km) subduction thrust earthquakes and could be evaluated because of the recent deployment of seismographs and a continuous GPS network in Fiordland as part of the GeoNet project run by GNS Science (http://www.geonet.org.nz). This was the only major subduction interface earthquake event that has occurred in New Zealand's historical record. In contrast to many subduction zones with oblique subduction, where the slip in major earthquakes is partitioned into more-or-less pure thrust earthquakes on the subduction interface and strike-slip earthquakes in the backarc, the Dusky Sound mainshock is a case where the majority of the slip on the subduction interface was not partitioned. Slip occurred at shallow depth west of the strike-slip Alpine Fault undergoing contraction about normal to subduction zone (Beavan, et al., 2010). The most interesting aspect of this earthquake was the radiation of only a small amount of seismic energy and its slow release.

To better determine how this region of the South Island transitions between non-partitioned oblique subduction and a slip partitioned convergent margin I relocated aftershocks events from the Dusky Sound 2009 sequence using HypoDD (Waldhauser and Ellsworth, 2000). These relocations will be used to aid in the selection of event pairs for a larger scale study of stress drop variations using the Empirical Greens Function technique. Once good quality EGFs

are obtained, the next step will to be to obtain estimates of stress drop variation in the Dusky Sound earthquake sequence.

5.3 TECTONICS OF NEW ZEALAND

The country of New Zealand straddles the obliquely convergent Australian–Pacific plate boundary giving rise to a diverse and complicated tectonic setting (Figure 1). In the North Island subduction of the Pacific plate to the west beneath the Australian plate is accommodated by the Hikurangi Trough. The increasing thickness of the Pacific plate leads to cessation of subduction south of ~ 43° (Reyners and Robertson, 2004). South of 44°, the direction of subduction flips, with the Australian plate being subducted to the east along the Puysegur Trench.

A series of right-lateral strike-slip faults link the two subduction zones. In the northern South Island this strike-slip motion is accommodated by the Marlborough fault system, which in turn, transfers right-lateral strike-slip motion to the Alpine fault (Doser et al., 1999) (Figure 1). The Alpine Fault is a continental transform fault that accommodates around two-thirds to three-quarters of the total plate motion in the central South Island (Norris and Cooper, 2001, 2007; Cox et al., 2008). Beginning just north of Arthur's Pass (the southern end of the Marlborough fault system) the Alpine fault goes off-shore at the latitude of Milford Sound (Sutherland and Norris, 1995). It has been proposed that the Alpine Fault exists because the continental crust of the Australian plate is too buoyant to subduct. Thus the inherited Eocene rift boundary with Eocene and Oligocene oceanic crust has become the locus of active deformation that connects slip on the subduction interface with the up-dip intracontinental plate boundary (Sutherland et al., 2000, Beavan et al., 2010). The interaction of the southern Alpine fault with the relatively

young Puysegur trench is poorly understood (Doser, et al., 1999) and is the location of this research.

The Puysegur or Fiordland subduction zone (Figure 2) is a young and intriguing subduction zone but extremely complicated in nature. It includes a regional transition from subduction of oceanic crust to transcurrent deformation and oblique continental collision (Eberhart-Phillips & Reyners, 2001). There are not many places on Earth where it is possible to study an active, growing, and isolated subduction zone. Results from a thermochronologic study done by Sutherland et al. (2009) state subduction initiated around 25 Ma in Fiordland. It is believed that the region may currently be in the uplift stage after subduction initiation (House et al., 2002). Structural transitions from subduction systems to transform faults on obliquely convergent plate boundaries are often poorly surveyed or over-looked. However, detailed tectonic studies of such transitions are necessary to clearly identify the modalities of transfer of relative plate motion from the transform plate boundary to subduction interface (Lamarche and Lebrun, 2000).

Because motion between the Australian and Pacific plate on the South Island is oblique, strike-slip faulting along the Marlborough fault system accommodates the lateral component of plate motion, while high angle reverse faulting in the Buller Region accommodates the compressional component of motion. Further to the south, less slip partitioning occurs, with the North Alpine and Jacksons Bay fault systems displaying a mix of strike-slip and high-angle reverse faulting. In between the Southern Alps and Fiordland, the Alpine fault becomes a nearly pure strike-slip fault, still accommodating the majority of plate motion. Still further south in the Fiordland region compressional motion is taken up through subduction of the Australian plate along the Puysegur Trench, but at least some component of strike-slip motion appears to be

occurring on the offshore extension of the southern Alpine fault. The Alpine Fault can be traced offshore from Milford Sound to the southwest where it aligns with the southeastern edge of Resolution Ridge at the frontal Puysegur subduction thrust (Delteil et al., 1996; Barnes et al., 2005; Beavan et al., 2010). There is a sharp connection between two segments of the plate boundary that is controlled by the position of inherited structures in the down going plate, in line with the transform segment of the plate boundary and it appears to be accommodated by tearing of the subducting plate. The tearing would facilitate the abrupt transfer of plate motion from the subduction interface to the transform fault (Lebrun et al., 2000). In summary, it appears that the regional transition from subduction of oceanic crust to transcurrent deformation and oblique continental collision (Eberhart-Phillips and Reyners, 2001) is occurring within Fiordland.

5.4 SEISMICITY OF THE SOUTHERN ISLAND

New Zealand is one of the most seismically active places in the world (Figure 3). The Alpine fault and the Marlborough fault system dominate most of the recent and historic seismicity of the South Island, and most of the seismicity is shallow ($\leq$ 33 km) except at the northern end of the South Island (Ristau, 2013). However, within the past decade, it is the Fiordland region, to the south, that has been the most seismically active of all New Zealand (Figures 4 and 5).

Thrust faulting is the dominant mechanism of seismicity in the Fiordland region. Moving south towards the Puysegur Trench, however, there is change from thrusting to strike-slip motion. Strike-slip motion becomes the dominant mechanism of deformation approaching the Macquarie Ridge Complex (MCR). Many researchers conclude that the MCR fault zone is an

incipient subduction zone, with oblique motion corresponding to the transition from lateral (strike-slip) motion.

Doser et al. (1999) separate the South Island of New Zealand into four areas based on earthquakes and tectonics: the Buller region; the central South Island; the Fiordland region; and the Puysegur Bank/Solander trench region south of the South Island. For this research, our interests are within the Fiordland region.

Initiation of large earthquakes in the Fiordland region in the past ~15 years began with an M_w 7.2 earthquake on August 21, 2003 that occurred along the plate interface (McGinty and Robinson, 2007) at ~45.1°S (Figure 2). The 2003 Fiordland earthquake (M_L 7.0, M_w 7.2) was the largest shallow earthquake to occur in New Zealand for 35 years (Reyners et al. 2003; McGinty and Robinson, 2007). Using data recorded by portable seismometers, the 2003 Fiordland earthquake was determined to have probably occurred on the plate interface between the Australian and Pacific plates (McGinty and Robinson, 2007). The aftershocks are diffuse and do not distinguish between the two possible main shock fault planes suggested by its GCMT solution, with one plane corresponding to subduction interface thrusting and the other corresponding to steeply seaward dipping reverse faulting. The distinction is important for calculating the induced stress changes on the overlying Alpine Fault which has a history of very large earthquakes, the last possibly in 1717. The Harvard CMT solution fault plane that is consistent with low angle thrust faulting on the plate interface can explain, using static stress calculations, the unusual aftershock distribution if most of the slip occurred near the bottom, shoreward edge of the aftershocks (McGinty and Robinson, 2007). This sequence was followed by several M_L>6 events in 2007 and 2008 located to the north and south of the 2003 main-shock.

Based on historical events (from 1981 to 1962) analyzed by Doser et al. (1999), none of the large (M>6) Fiordland region events appears to have occurred at the shallow part of the plate interface. Rather they appear to have been associated with complex deformation within both the subducted and the overlying plates (Fry et al., 2010). Yet, within the last 30 years there have been a series of earthquakes that are interpreted as shallow interplate thrust events. These events surround the 2009 Dusky Sound earthquake rupture zone, suggesting that this latest event (2009) has filled a gap in interplate slip along the subduction zone (Fry et al., 2010) (Figure 5).

The M_w 7.8 Dusky Sound event occurred on the subduction interface on July 15, 2009 (Figure 6.). The earthquake ruptured about an 80 km long section of the subduction interface (Beavan et al., 2010). Based on a detailed slip-time distribution study of the earthquake rupture by Fry et al. (2010), they are confident the earthquake involved thrusting on the shallow part of the plate interface. In addition, stress calculations predict that the mainshock loaded the southernmost Alpine fault by about 2 bars.

Seismic recordings of the Dusky Sound mainshock show very little high-frequency content (Fry et al., 2010). Comparisons of waveforms of the 2003 and 2009 events indicate the 2003 event was much richer in high frequency energy, more widely felt, and created more landslides (Reyners, 2009), suggesting a higher stress drop.

When compared to other worldwide events of similar magnitude the Dusky Sound mainshock generated very little damage. There has been no evidence, as of yet, for rupture of the Alpine fault or activation of other strike-slip faults during this event. The Dusky Sound mainshock appears to be a case where the majority of the subduction interface slip is not partitioned. This is in contrast to many other subduction zones undergoing oblique subduction

where the slip in major earthquakes is partitioned into more-or-less pure thrust earthquakes on the subduction interface and strike-slip earthquakes in the backarc (Beavan et al., 2010).

5.5 DATA

Data used in this research was obtained from the New Zealand GeoNet (NZGN), the New Zealand Earthquake Catalog and personal communication with Dr. John Ristau from GNS Science. The NZGN is a strongly integrated data collection and analysis system consisting of national and regional-scale sensor networks (Petersen et al., 2011). The network was developed for “public good” in enhancing New Zealand’s ability to respond to and prepare for natural hazards. The network consists of 111 regional seismic network stations that are generally equipped with short-period seismometers, 149 continuously recording GPS (cGPS) monuments, 222 strong-motion accelerograph stations, 14 tsunami gauges, and various volcano and landslide surveillance instruments located throughout New Zealand (Petersen et al., 2011) (Figure 1). The backbone of the NZGN is the New Zealand National Seismograph Network (NZNSN). The NZNSN consists of 49 stations equipped with broadband seismometers and strong-motion sensors. The network is designed to record a complete catalog of shallow earthquakes of magnitude 3 or greater and deeper events of magnitude 3.5 or greater originating in New Zealand. This research utilized 19 stations (Table 1). Of the 19 stations 5 are considered “good stations” proving low noise level for all three components across the entire frequency band analyzed and wind conditions (Petersen et al., 2011).

The New Zealand Earthquake Catalog contains more than 15,000 earthquakes that have occurred in New Zealand. The catalog can be searched using the Quake Search accessible via the GeoNet website (www.geonet.org.nz). Waveform data are available and can be queried and

downloaded using a Java client on the user's computer, which processes these data and files in MiniSEED (only waveform data of Standard Exchange of Earthquake Data), SAC (Seismic Analysis Code), or plain text formats. I selected 138 events from the catalog for the 2009 Dusky Sound earthquake sequence that spanned a time frame from July 15, 2009 – September, 09, 2011. These events were selected based on criteria from prior work by Dr. John Ristau (date?) and other researchers in New Zealand.

5.6 METHODOLOGY

Earthquake relocation was accomplished by using the double-difference technique developed by Waldhauser and Ellsworth (2000). The double-difference algorithm, known as hypoDD, solves for event hypocenters and origin times using differential travel-time data from catalog phase picks and/or waveform cross correlations. It does so by minimizing the residuals between the observed and theoretical travel times (double differences) for pairs of earthquakes by adjusting the vector difference between the hypocenters. The relocated hypocenters are determined by solving the double-difference equation for all hypocentral pairs at all stations. Relocating events with hypoDD results in precise relative locations and reduces error between events. Results from both synthetic-data and real-data studies show that relative errors are reduced by a factor of ∼2 using catalog arrival times alone and are reduced by a further factor of ∼5–10 if cross-correlation data are also used (Waldhauser and Ellsworth, 2000).

Earthquake relocation with hypoDD is a two-step process. The first step involves the analysis of catalog phase data and/or waveform data to derive travel time differences for pairs of earthquakes using the algorithm Ph2dt. In the second step, the differential travel time data from step one is used to determine double-difference hypocenter locations. This process, carried out

by hypoDD solves for hypocentral separation after insuring that the network of vectors connecting each earthquake to its neighbors has no weak links that would lead to numerical instabilities (Waldhauser, 2001).

To apply double-difference relocation to catalog arrival times requires preprocessing of data to calculate the differential travel times for event pairs. This was done by using a software program developed by Boulder Real Time Technologies (BRTT) called Antelope. Antelope is an integrated collection of programs for data collection and seismic data analysis. The seismic waveform data were downloaded from the GeoNet website under Applications and Data; Earthquake Resources; Continuous Waveform Buffer. After the data were downloaded I used the dbloc2 command in Antelope to pick P and S wave arrivals. Approximately 5244 P and S arrivals were chosen for the 138 events.

Once I had picked P and S wave arrivals for the earthquakes I transformed my P- and S-phase data into input files for hypoDD using Ph2dt. Ph2dt searches the P- and S-phase data for event pairs with travel time information at common stations and subsamples these data in order to optimize the quality of the phase pairs and the connectivity between the events. The ph2dt program approximates the event pairs, links, nearest neighbors, and eventually entire clusters containing events and their location relative to every other event in the cluster (Waldhauser, 2001). The input parameters for ph2dt are summarized in the appendix along with the values I used for my analysis.

Once Ph2dt is successfully run, the next step is to select parameters for running hypoDD. The critical parameters I used for my analysis are listed in the appendix and they included a velocity model of 4.4, 6.0, 6.5, 8.1 and 8.65 km/s with depths of 0.0, 0.5, 12.0, 33.0 and 100 km; a maximum separation of 10 km; and the minimum number of observations was set for 1.

5.7 RESULTS

From the original 138 events, only 103 events met the necessary criteria for hypoDD to attempt relocation (Figure 9). Of those 103 events, 92 could actually be relocated (Figure 10). Overall, the mean shift in latitude when comparing the hypoDD located events with the relocated events was 0.016 ° to the south; the mean shift in longitude was 0.001° to the east; and the mean shift in depth was + 0.04 km (Figure 11).

Using a MAXSEP of 10km, a total of 103 events were grouped into clusters. A total of 13 clusters were obtained. Six clusters contained 35, 27, 12, 7, 4, and 4 events, respectively with the remaining seven clusters containing only 2 events each (Table 2).

5.8 DISCUSSION

Data collected and processed from the NZGN resulted in picking P- and S-wave arrivals for 138 events of which 92 were actually relocated. The results of the relocation produced 13 clusters. From these clusters I concentrated on 4 clusters: cluster 1 with 35 relocations; cluster 2 with 27 relocations; cluster 3 with 11 relocations and cluster 4 with 7 relocations. The other clusters had less than 5 events, thus I felt examination of them would not produce reliable results (Figure 12).

I compared our hypocenter locations to structural cross sections determined by Malservisi et al. (2003) based Figure 13. I focused on projecting our hypocenter clusters (denoted by ellipses) on to cross sections A-A’ and B-B’ since they were closest to the clusters. A-A’ strikes in the direction of plate convergence and the ellipses indicate that all events occurred above the plate interface (Figure 13a). B-B’ strikes perpendicular to A-A’ and indicates that the

boundary between the Australian and Pacific plate is not clearly defined at this latitude. The clusters all occur within this diffuse region between the two plates.

Examining the centroid moment tensor focal mechanisms for events within each cluster revealed the following: Cluster 1, located to north of the initial rupture, was predominantly reverse oblique with some strike-slip mechanisms. Cluster 2, to the south, was predominantly reverse oblique with a number of either high angle reverse or low angle thrusting events. Cluster 3, surrounding the initial event, revealed mostly reverse oblique mechanisms and cluster 4, to south, had normal oblique mechanisms. Overall, the largest percentage(~60%) of the focal mechanisms appear to be reverse oblique indicating there is no apparent partitioning of slip as seen further north with partitioning between thrusting along the subduction interface and strike-slip motion along the Alpine fault.

Beavan et al. (2010) modeled slip during the 2009 Dusky Sound mainshock based on GPS and InSAR (interferometric synthetic aperture radar) observations (Figure 14). They found all slip in the 2009 mainshock occurred along the subduction interface with no indication of rupture along the Alpine fault. That is, slip was not partitioned between convergence along the subduction interface and strike-slip motion on the Alpine fault. However, Beavan et al. (2010) believe that Coulomb stress changes from movement on the subduction interface have brought a 100km long offshore portion of the Alpine Fault closer to failure.

I compare the location of our epicenters to the mainshock slip model in Figure 14. Clusters 1 through 3 occurred in regions that slipped < 3 m during the mainshock, but cluster 4 appears to have occurred in a region that slipped 2 – 4 meters (Figure 14). This suggests that most aftershocks were in regions where slip was low in the mainshock; regions where post-mainshock stresses would have been higher and led to additional fault slip. Although it appears

cluster 4 may have occurred in an area of greater slip, it is possible that the cluster is not well located since it is the farthest distance from the shore. It is also possible that the slip model is poorly resolved because this portion of the fault rupture zone is located far from the GPS and InSAR observations

Referring to figure 6, note that cluster 1 events fall within a seismic gap between the 2009 M_w 7.8 Dusky Sound event and the 2003 M_w 7.2 event. This seismicity may have further loaded the stress along offshore portion of the Alpine fault system, supporting the conclusions of Beavan et al., (2010).

I plan to further examine how the stress field evolved during the Dusky Sound sequence through use of Coulomb failure modeling (e.g. Robinson, 2002) and examination of the temporal and spatial variation of aftershock focal mechanisms. This analysis will be key to determining whether the aftershocks also contributed to stress loading of the Alpine fault or may have partially relieved the stress increase caused by the mainshock. In addition, the locations will be used to identify event pairs for determination of stress drop variations using the empirical Greens function technique.

5.9 CONCLUSIONS

Results from the relocations of events occurring in the Dusky Sound region from July 15, 2009 – September 2011 indicate:

- the events are all located above the subduction interface.

- the events appear to have occurred in the transitional zone between the AUS/PAC plate
- the northernmost cluster appears to have partially filled a seismic gap between the 2009 M_w 7.8 Dusky Sound event and the 2003 M_w 7.2 event.

5.10 AKNOWLEDGEMENTS

This work was made possible by funding from NSF award 1113703. I would also like to thank Drs. John Ristau and Stephen Bannister from GNS Science in New Zealand for their support and encouragement.

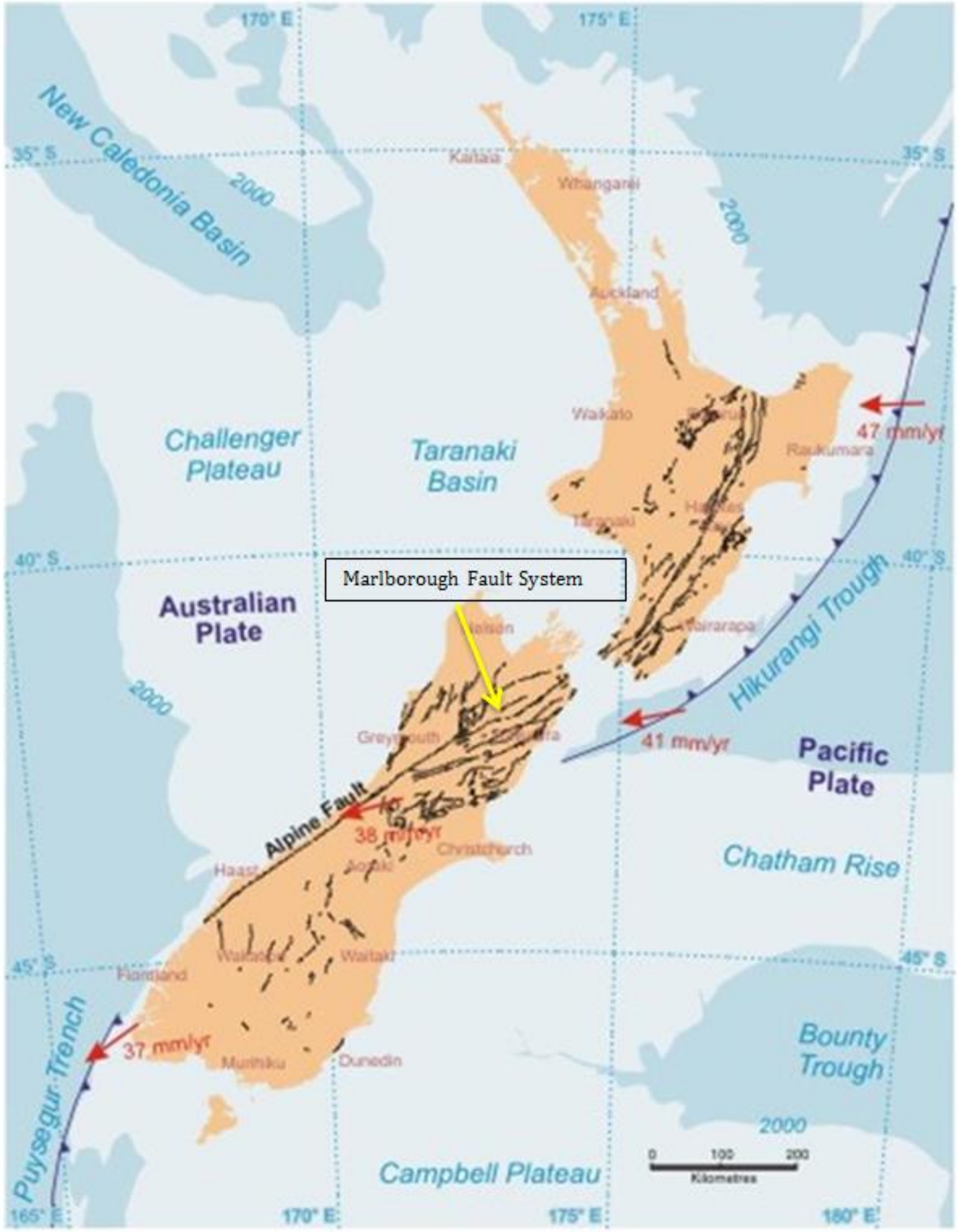

Figure 5.1. Tectonics of New Zealand.

In the Northern Island the Pacific plate is subducting beneath the Australian Plate while in the south Southern Island the Australian Plate is subducting beneath the Pacific plate. Red arrows indicate how the direction and rate of plate motion changes. The Marlborough fault system and Alpine fault systems connect the northern subduction zone with the southern subduction zone.

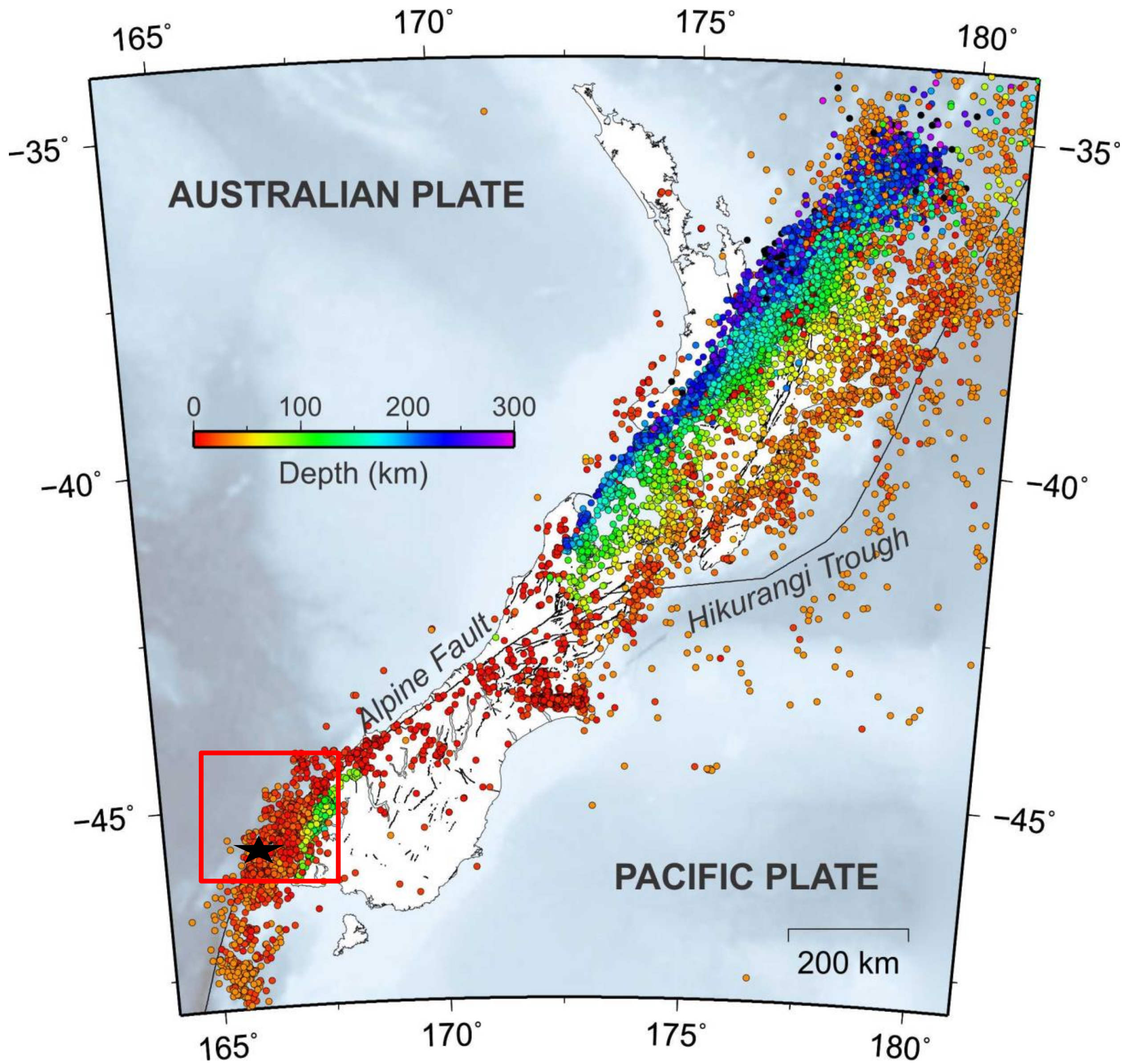

Figure 5.2. Seismicity map of New Zealand.

Representative seismicity of New Zealand with specific dates unknown. Red box indicates proposed study area. Black star indicates Dusky Sound. Modified from GNS New Zealand (http://info.geonet.org.nz/display/geonet/About+GeoNet; last accessed 7/05/2014).

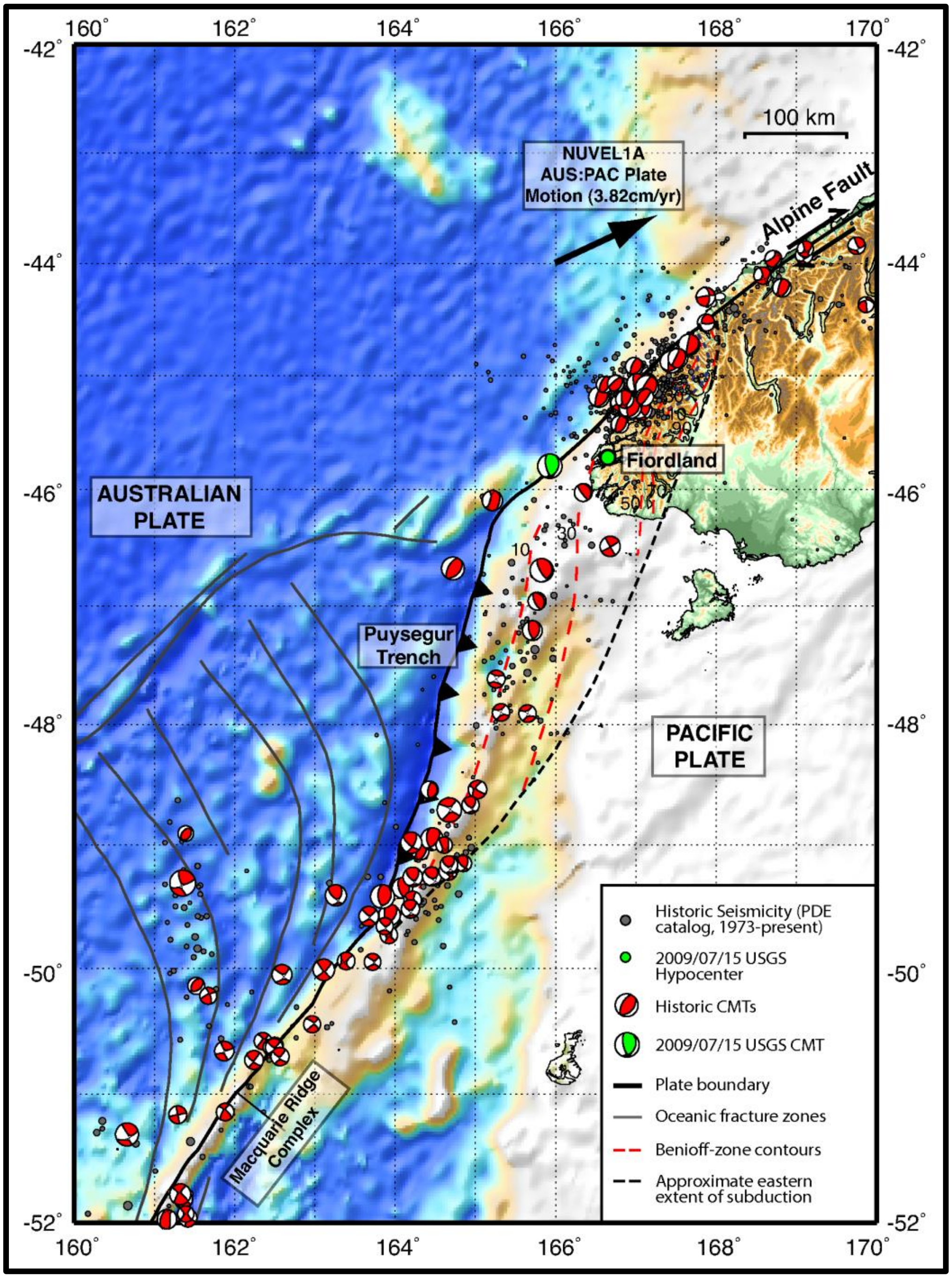

Figure 5.3. Seismicity map from 1973 to present.

The 2009 July 15th 7.8 Mw Dusky Sound earthquake is shown in green In the Fiordland region the mechanisms are predominantly thrust with strike-slip motion increasing towards the south. (from USGS http://earthquake.usgs.gov/earthquakes/eqinthenews/2009/us2009jcap/#summary).

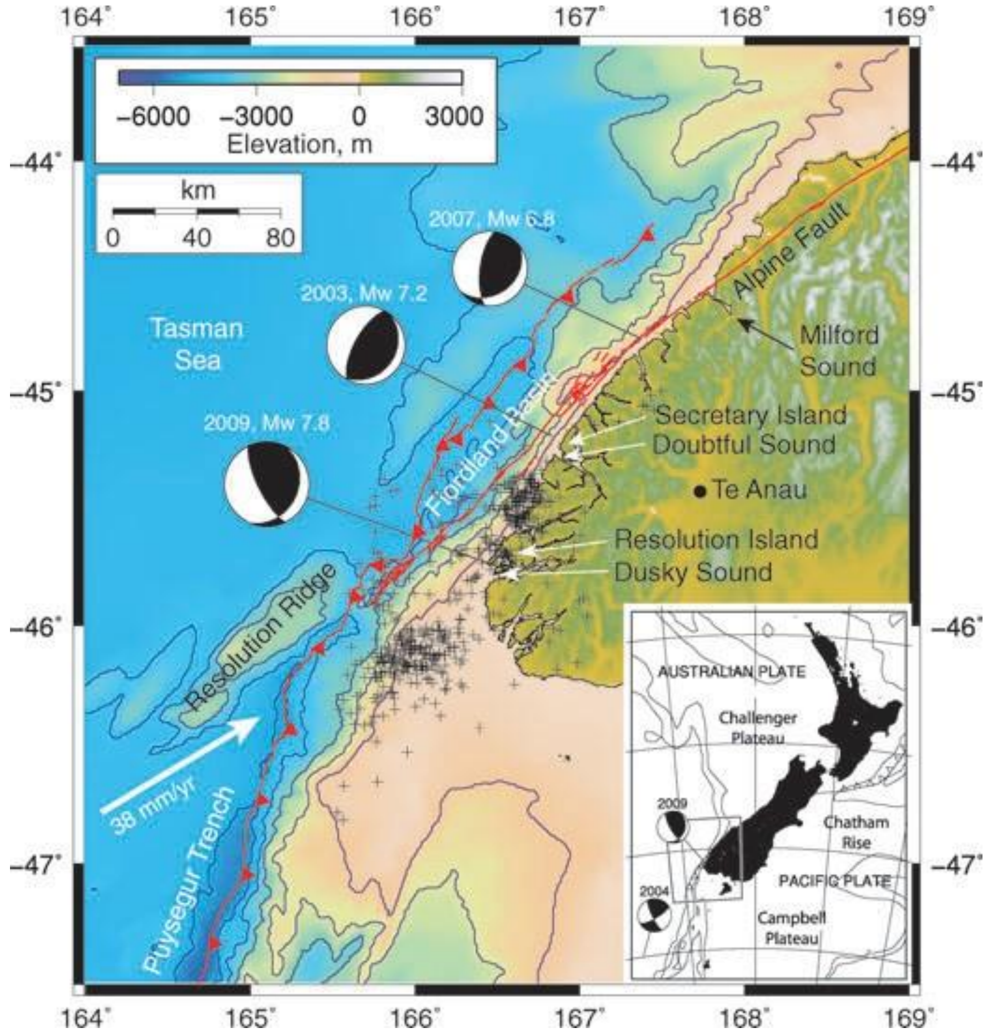

Figure 5.4. Location map and tectonic setting of the Fiordland region, inset showing the regional setting.

Global CMT focal mechanism solutions are shown for the 2009 Dusky Sound earthquake (plotted at its GeoNet epicentral location) and for other earthquakes. Crosses show GeoNet preliminary locations for M > 3.5 aftershocks from 2009 July 15–2010 February 28. Red lines indicate the Puysegur subduction thrust (in south) and Fiordland Basin frontal thrust (Delteil et al. 1996; Barnes et al. 2002); the offshore Alpine Fault (Barnes et al. 2005) (in north) and the onshore Alpine Fault (Sutherland et al. 2006). The white arrow shows the present-day relative plate motion from Beavan et al. (2002); the MORVEL (DeMets et al. 2010) plate motion model has the same rate with a direction 4◦ closer to north. Resolution Ridge is the southernmost extension of the continental Challenger Plateau. Bathymmetric contours are plotted from 1000–5000 m in 1000 m increments. (From Beavan et al., 2010)

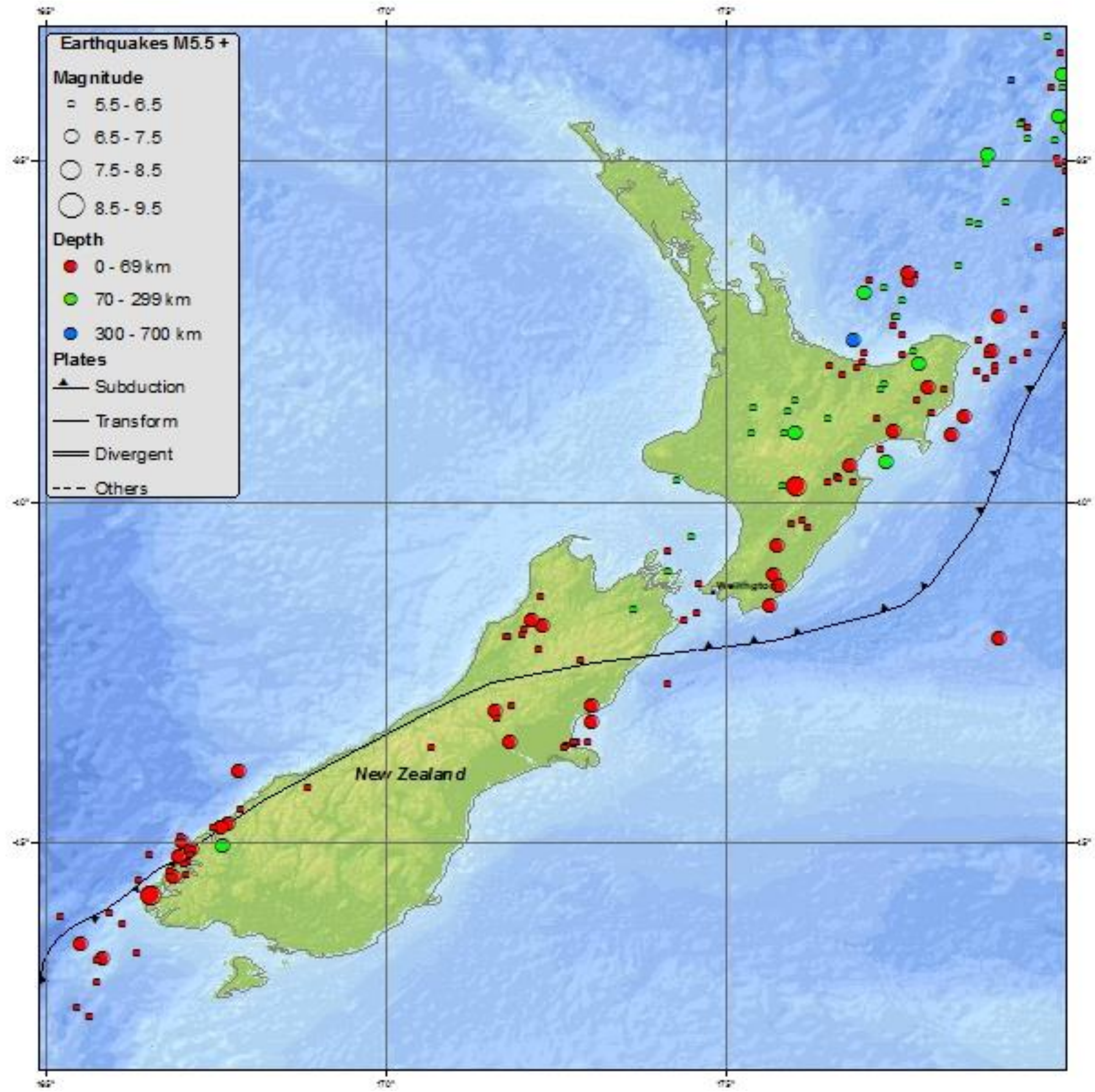

Figure 5.5. Seismicity map of New Zealand from 1900 to March 2012.

Earthquakes are M 5.5 and higher. Note the occurrence of many events at the southwestern end of the South Island. Modified from USGS. (http://earthquake.usgs.gov/earthquakes/world/new_zealand/seismicity.php; last accessed 7/05/2014)

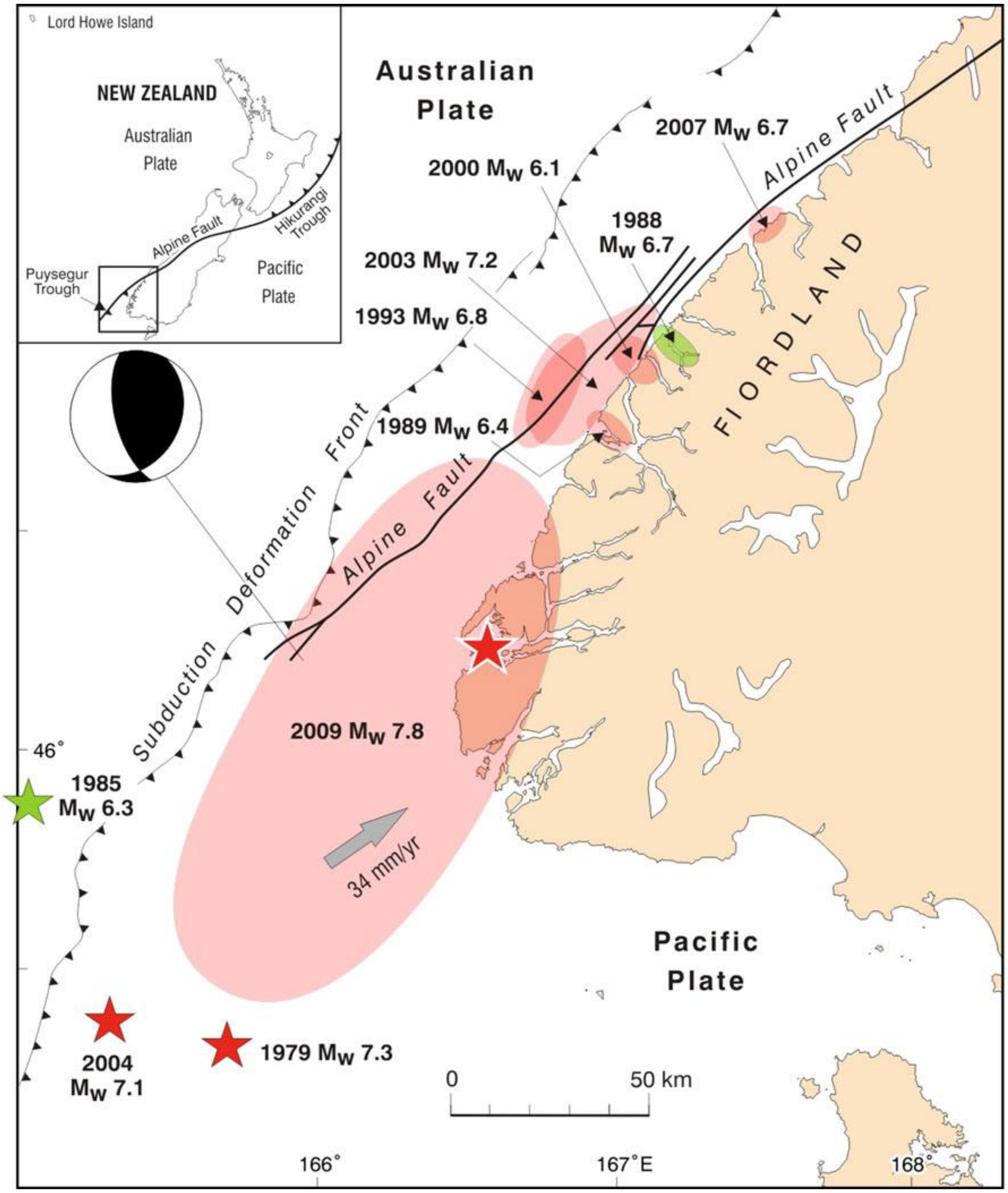

Figure 5.6. Tectonic setting of the 15 July 2009 Fiordland earthquake.

The large pink area shows the estimated rupture area based on the distribution of aftershocks, the red star indicates the epicenter location, and the focal mechanism illustrates the USGS centroid moment tensor solution. Also shown are the locations of previous large earthquakes in this region since 1979; pink is used to denote events interpreted as interplate and green for events interpreted as intraslab. The gray arrow represents the velocity of the Australian plate relative to the Pacific plate. The inset figure shows the location of the Fiordland region with respect to the larger scale tectonic setting of New Zealand, adapted from Fry et al. (2010).

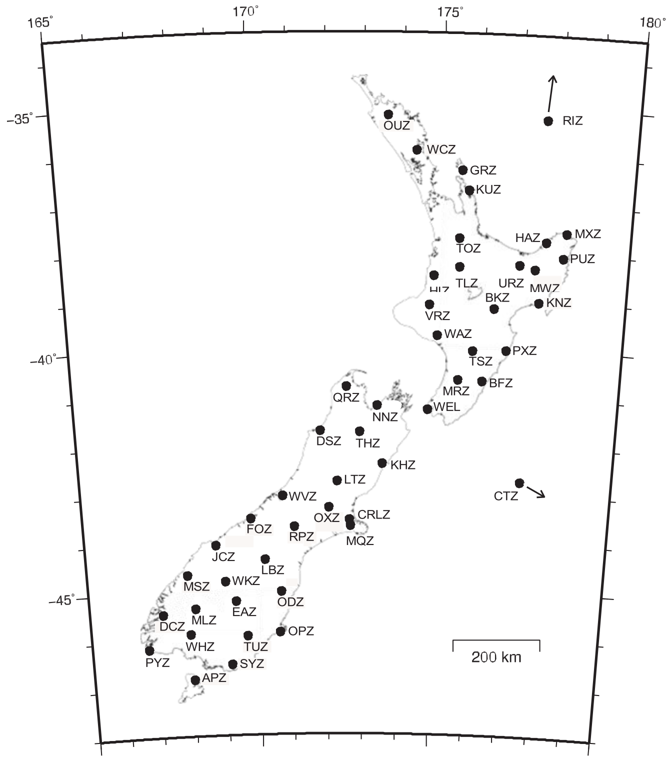

Figure 5.7. Locations of the current (as of May 2010) NZNSN stations.

Each station is equipped with a broadband seismometer and a strong-motion sensor. The recorded data are transferred to the GeoNet data centers in near real time. (Petersen et al., 2011)

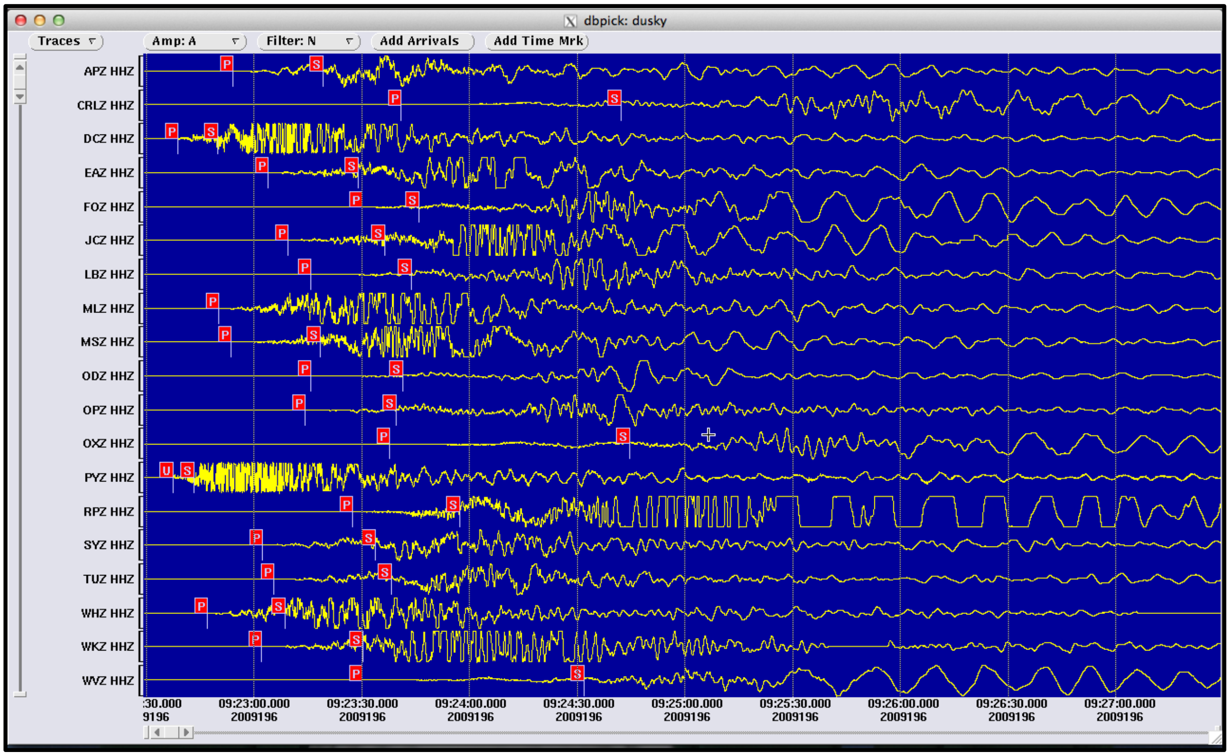

Figure 5.8. Computer display of waveforms.

This shows representative P and S waveform data as displayed by the Antelope dbloc2 software.

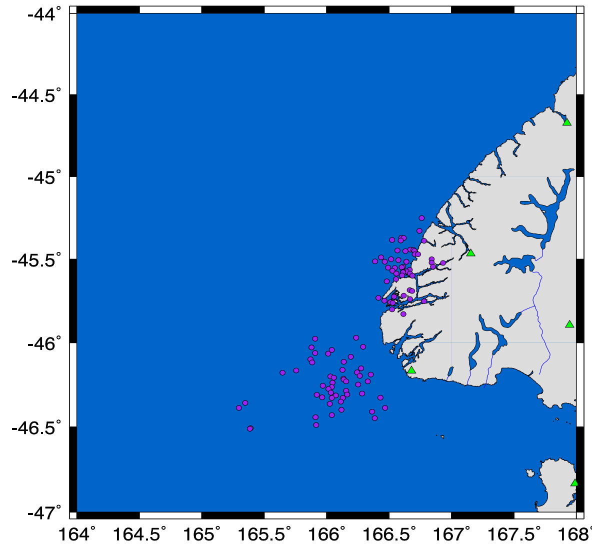

Figure 5.9. Initial events suitable for relocation.

These are the initial 103 events from the hypoDD.loc file

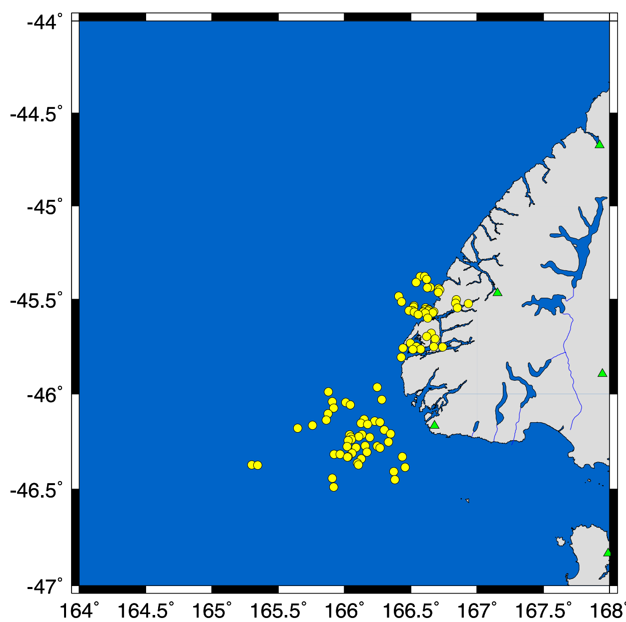

Figure 5.10. Relocated events.

Shows events relocated by hypoDD (in hypoDD.reloc file).

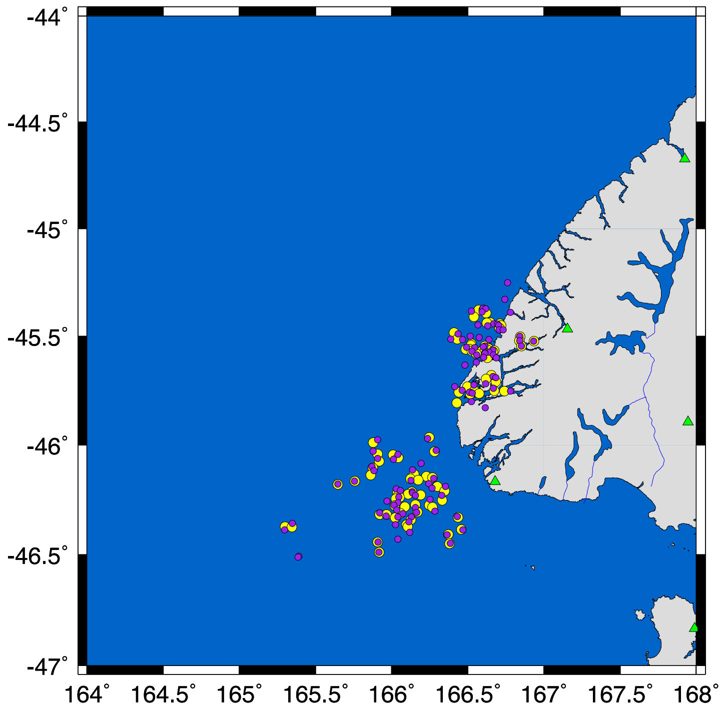

Figure 5. 11. Comparison of initial and relocated events.

Located (purple) and relocated (yellow) events by hypoDD

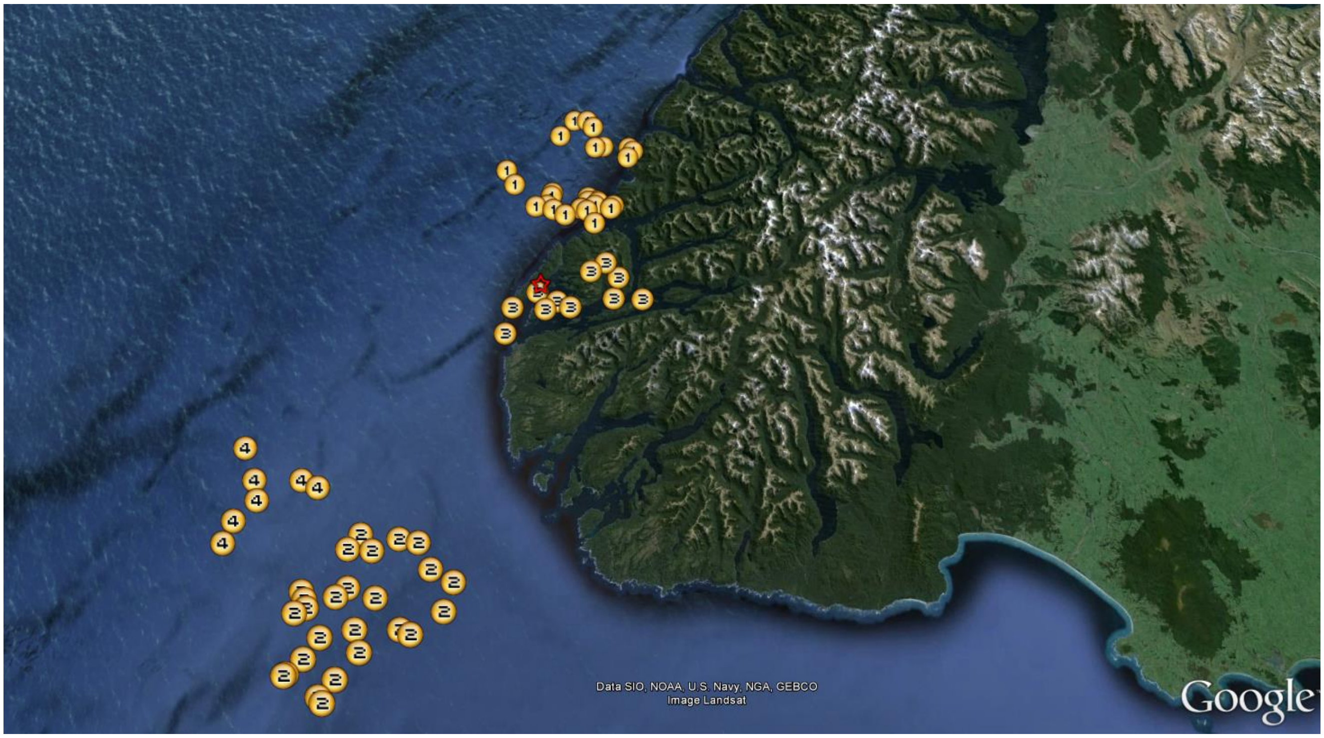

Figure 5.12. Four largest relocated clusters.

Numbers refer to clusters. The red star indicates the 2009 Mw 7.8 Dusky Sound event.

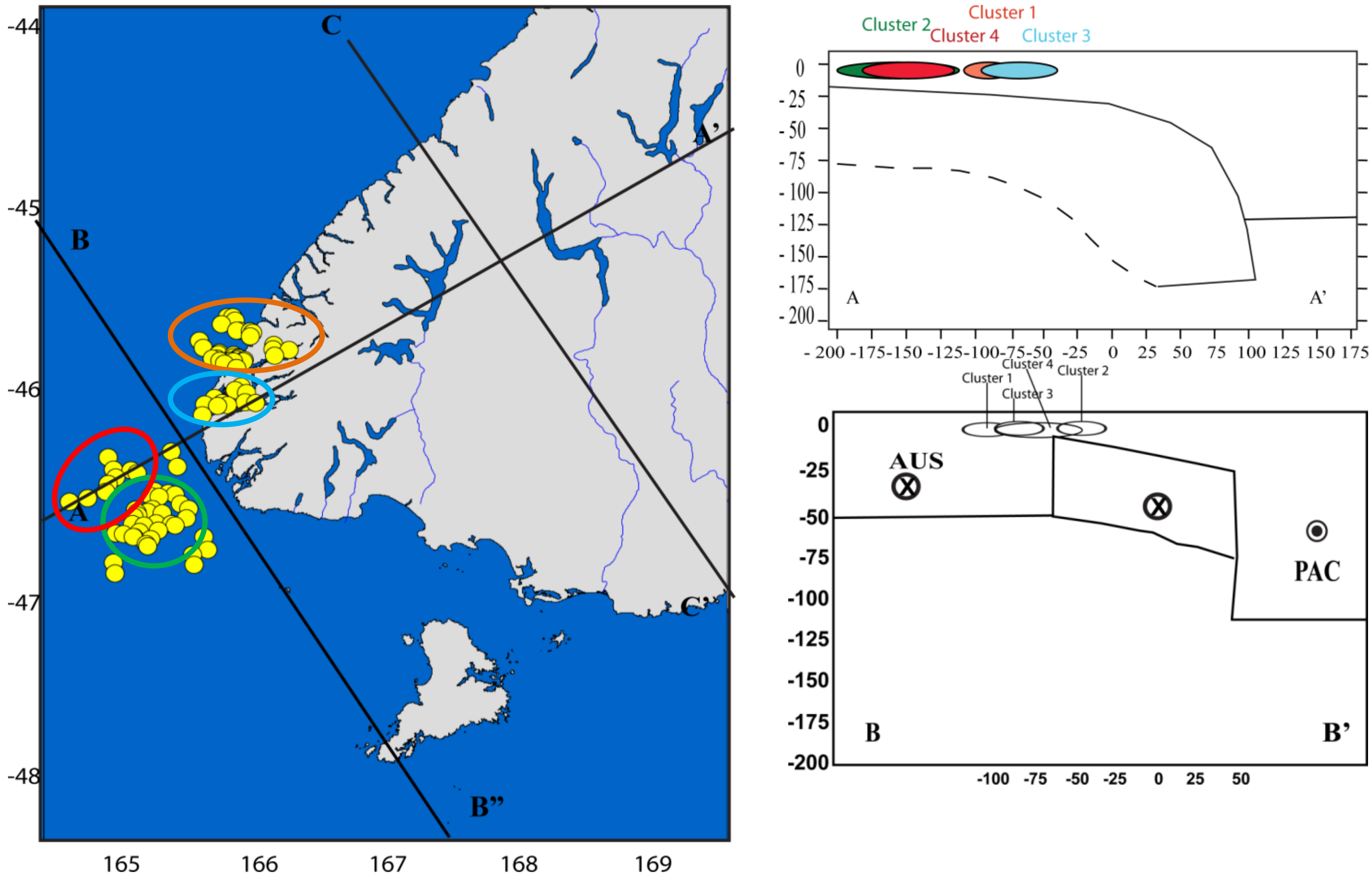

Figure 5.13. Cross section view of the Fiordland subduction zone.

Modified from Malservisi et al. (2003) with clusters 1, 2, 3, and 4. (left) map view of the area, (top right) vertical cross section running parallel to the direction of plate convergence (section A-A') and (bottom right) vertical cross section B-B' running perpendicular to A-A'. Symbols indicate the Pacific plate (PAC) is moving out of the plane of the cross section (towards viewer) and the Australian plate (AUS) is moving into the plane of the cross section (away from viewer).

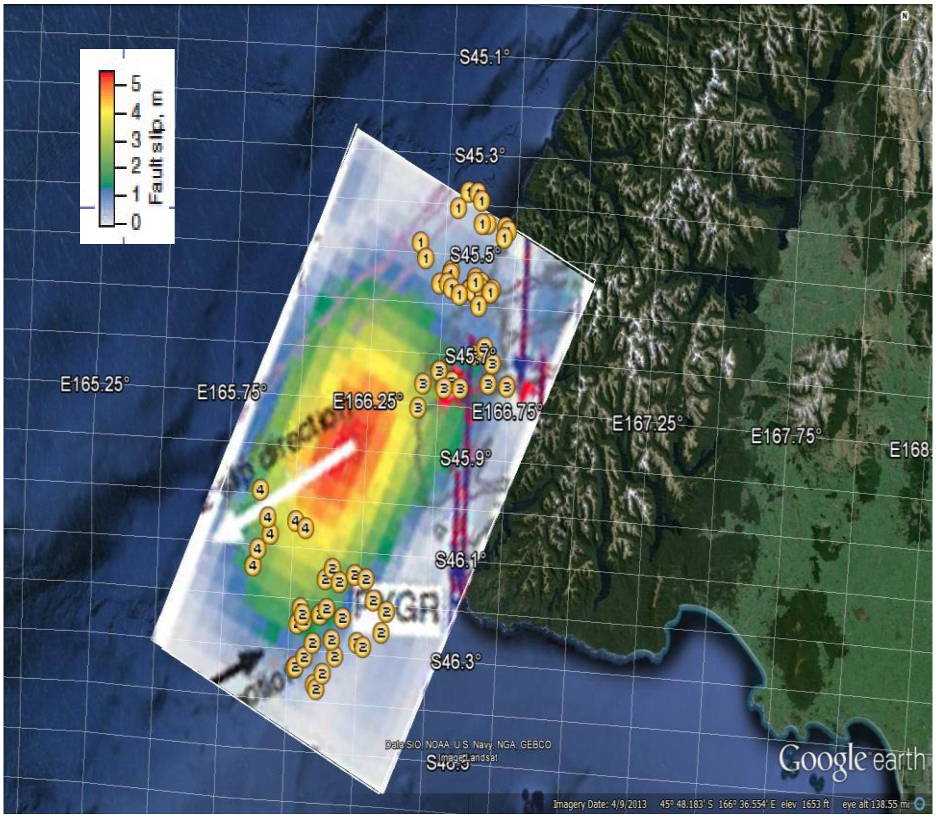

Figure 5.14. Comparison of aftershocks to slip.

Slip during the 2009 mainshock as determined from modeling of GPS and InSAR data by Beavan et al., (2010) with clusters 1, 2, 3, and 4 superimposed on the model. Vertical colored bars show GPS observation points. White arrow shows direction of slip during the mainshock. Note the arrow indicates oblique slip on the subduction interface.

Table 5.1. New Zealand National Seismograph Network Stations

Stations are listed in order of geographical order from north to south.

Code	Station Name	Latitude	Longitude	Altitude (m)
WVZ	Waitaha Valley	-43.0764	170.7361	75
OXZ	Oxford	-43.3259	172.0383	360
FOZ	Fox Glacier	-43.5655	169.6886	10
CRLZ	Canterbury Ring Laser	-43.57641	172.6231	55
RPZ	Rata Peaks	-43.7192	171.0539	412
JCZ	Jackson Bay	-44.0750	168.7853	1072
LBZ	Lake Benmore	-44.3872	170.1842	423
MSZ	Milford Sound	-44.6753	167.9275	90
WKZ	Wanaka	-44.8285	169.0176	564
ODZ	Otahua Downs	-45.0453	170.6444	270
EAZ	Earnscleugh	-45.2327	169.3082	320
MLZ	Mavora Lakes	-45.3481	168.1728	640
DCZ	Deep Cove	-45.4678	167.1542	50
OPZ	Otago Peninsula	-45.88596	170.59768	375
WHZ	Wether Hill Road	-45.8939	167.9467	320
TUZ	Tuapeka	-45.9561	169.6322	110
PYZ	Puysegur Point	-46.1678	166.6806	277
SYZ	Scrubby Hill	-46.5385	169.1388	52
APZ	Stewart Island	-468334	167.9888	601

Table 5.2. Clusters, original number of events per cluster, final number of events clustered, the mean latitude/longitude, and the mean depth change.

	Original # in cluster	Relocated # in cluster	Mean Latitudinal shift	Mean Longitudinal shift	Mean Depth shift
Cluster 1	35	28	0.0157539° S	-0.01289° W	0.100
Cluster 2	27	26	0.0046108° N	0.00257° E	0.068
Cluster 3	12	11	0.0026257° N	-0.00445° W	0.049
Cluster 4	7	7	-0.0083287° S	-0.00109° W	-0.643
Cluster 5	4	4	-0.0004887° S	-0.00075° W	-0.024
Cluster 6	4	2	-0.0128237°S	0.00171° W	1.779
Cluster 7	2	2	-0.0000080° S	0.00000°	0.000
Cluster 8	2	2	-0.0000065° S	0.00000°	0.000
Cluster 9	2	0	NO RELOCATION		
Cluster 10	2	2	0.0000630° N	0.00000°	0.000
Cluster 11	2	2	-0.0000190° S	-0.00002° W	0.000
Cluster 12	2	2	-0.0000075° S	-0.00027° W	0.000
Cluster 13	2	2	-0.0001100° S	-0.00003° W	-0.017

5.12 REFERENCES

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Appendix

Appendix A - Chapter 3 – Surveys

First-time Participant

Section I. Demographics

1. Which of the following best describes you? You may check more than one box.

African-American	❑
Hispanic or Latino	❑
Native American	❑
Pacific Islander (Guamanian, Samoan, etc.)	❑
Asian	❑
White	❑

Other (Please specify): ______________________________________

2. Please check one box to indicate your **gender:**

Male	❑
Female	❑

3. Please check one box to indicate your **major:**

Pre-Science	❑
Biological Sciences	❑
Chemistry	❑
Environmental Sciences	❑
Geological Sciences	❑
Physics	❑

Other (Please enter your major.): ____________________________

4. Please check one box to indicate your **classification:**

Freshman	❑
Sophomore	❑
Junior	❑
Senior	❑

5. Please check one box to indicate how many **science courses** you took in **high school**.

   1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Other ❑ (Please, indicate how many): ___________

6. Please check one box to indicate how many **college science courses** you have taken.

   1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Other ❑ (Please, indicate how many): ___________

7. What **mathematics courses** have you taken in college? Please check one box on each line.

		Yes	**No**
a.	Math 0310 Introductory Algebra	❑	❑

b.	Math 0311 Intermediate Algebra	❑	❑
c.	Math 1508 Pre-Calculus	❑	❑
d.	Math 1312 Calculus II	❑	❑
e.	Math 1411 Calculus I	❑	❑
f.	Other mathematics courses: ________________________________		

8. What sparked your interest in the geosciences?

Please explain.

9. Please check one box to indicate the number of semester(s) you have received **Pathways** or **other research stipend** support:

   1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Other ❑ (Please, indicate how many): __________

Section II. Research Experience

10. Please name your current faculty mentor:
    ____

11. Please name your current project or its title:
    ____

12. Please check one box on each line to indicate the option that best describes **your interest in**:

	Extremely interested	**Very** interested	Interested	**Moderately** Interested	**Slightly** interested	**Not** interested **at all**
a. your research topic.	❑	❑	❑	❑	❑	❑
b. research in general at this current time.	❑	❑	❑	❑	❑	❑

13. What do you find interesting about your research topic?

14. In general, what do you find interesting about doing research?

15. What do you hope to gain or learn from your research experience?

16. What concerns or recommendations do you have?

17. Please check one box to indicate how likely it is that you will participate in an external research experience in the fall of 2003?

0% ❑ 10% ❑ 20% ❑ 30% ❑ 40% ❑ 50% ❑ 60% ❑ 70% ❑ 80% ❑ 90% ❑ 100% ❑

18. Please check one box on each row to indicate your plans after graduating with a bachelor's degree:

	Yes	No
a. I plan to enter a graduate program (Masters or Doctorate) to continue my research interests in geosciences right after graduation.	❑	❑
b. I plan to enter a professional program (e.g., medical school, MBA, law school) right after graduation.	❑	❑
c. I plan to enroll in a graduate or professional program while working.	❑	❑
d. I plan to work before entering a graduate or professional program.	❑	❑
e. I plan to work right after graduation.	❑	❑

19. Please check one box to indicate how likely it is that you will go to graduate school:

0% ❑ 10% ❑ 20% ❑ 30% ❑ 40% ❑ 50% ❑ 60% ❑ 70% ❑ 80% ❑ 90% ❑ 100% ❑

20. If you were to go to graduate school, what would you major in?

Please explain why.

21. If you were to go to graduate school, how would you pay for your education? Please check one box on each line.

		Yes	No
a.	By working.	❑	❑
b.	Through financial support from family or friends.	❑	❑
c.	Through a scholarship.	❑	❑
d.	Through a loan.	❑	❑
e.	Through fellowships.	❑	❑
f.	Through teaching assistantships.	❑	❑
g.	Through research assistantships.	❑	❑

h.	Other (Please describe.): ______________________________________

Section III. Pathways Stipend Process

22. Who told you about the Pathways Research Stipend?

23. Did you work with your professor or mentor to develop your application?
    Yes ❑ No ❑

24. Before applying, did you know about the demands of an undergraduate research experience?
    Yes ❑ No ❑

25. Do most of the students in your major know about the Pathways Research Stipends?
    Yes ❑ No ❑

26. Please check one box on each line to indicate if you expected that your research experience in the Pathways program would provide you with **opportunities to**:

		No
a. serve as a mentor.	❑	❑
b. receive mentoring.	❑	❑
c. gain a better understanding of the research process.	❑	❑
d. enhace your knowledge of your discipline.	❑	❑
e. improve your laboratory skills.	❑	❑
f. gain in-depth knowledge about your research topic.	❑	❑
g. have contact with other researchers in your field.	❑	❑
h. participate in a research group.	❑	❑
i. present at regional or national conferences.	❑	❑
j. improve your time management skills.	❑	❑
k. co-author a research publication.	❑	❑
l. conduct research.	❑	❑
m. have career opportunities.	❑	❑
n. receive assistance in applying to a graduate program.	❑	❑
o. Other: ____		

27. How important were each of the following in your decision for participating in the Pathways program? Please check one box on each line.

	Very important	Moderately important	Slightly important	Not important at all
.. It provides an opportunity to work in the geosciences.	❑	❑	❑	❑
b. It provides an opportunity to make new friends.	❑	❑	❑	❑
c. It provides an opportunity to learn research skills.	❑	❑	❑	❑
d. It provides a research stipend.	❑	❑	❑	❑
e. It provides an opportunity to improve laboratory skills.	❑	❑	❑	❑
f. It provides an opportunity to gain in-depth knowledge about your research topic.	❑	❑	❑	❑

28. Ten years from now, **how likely is it that**:

	Very likely	**Moderately** likely	**Not so** likely	**Not** likely **at all**
a. you'll be working in the geosciences field?	❑	❑	❑	❑
b. you'll be working in a career in the sciences?	❑	❑	❑	❑

Please explain your answers to questions 29 a-b.

30. What other activities or presentations would you like to see added to the program to help enhance your undergraduate research experience?

Exit Survey

Start Date: ________ / ________
Month Year

Exit Date: ________ / ________
Month Year

29. Please write your social security number: ________________________

30. Which of the following best describes you? You may check more than one box.

African-American	❑
Hispanic or Latino	❑
Native American	❑
Pacific Islander (Guamanian, Samoan, etc.)	❑
Asian	❑
White	❑

Other (Please specify): ______________________________________

31. Please check one box to indicate your **major:**

Pre-Science	❑
Biological Sciences	❑
Chemistry	❑
Environmental Sciences	❑
Geological Sciences	❑
Physics	❑

Other (Please enter your major.): ___________________________

32. Please check one box to indicate your **classification:**

Freshman	❑
Sophomore	❑
Junior	❑
Senior	❑

33. Please check one box to indicate how many **college science courses** you have taken.

1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Other ❑ (Please, indicate how many): ___________

34. What **mathematics courses** have you taken in college? Please check one box on each line.

		Yes	No
a.	Math 0310 Introductory Algebra	❑	❑
b.	Math 0311 Intermediate Algebra	❑	❑
c.	Math 1508 Pre-Calculus	❑	❑
d.	Math 1312 Calculus II	❑	❑
e.	Math 1411 Calculus I	❑	❑
f.	Other mathematics courses: ___________________________________		

35. Please check one box to indicate the number of semester(s) you have received **Pathways** or **other research stipend** support:

1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Other ❑ (Please, indicate how many): ___________

36. Please name your faculty sponsor:

____

37. Please name his/her department:

____

38. Please write how often you met with your faculty sponsor:

____

39. Please name your current project or its title:

____

40. Please briefly describe the research project you were involved with.

41. What impact did your research experience have on you?

Please explain.

42. Were you able to relate your academic studies to any aspect of your research experience?

Yes ❑ No ❑

14 a) If yes, please explain how.

14 b) If not, please explain why.

43. Has the research experience encouraged you to further your education in the sciences?

Yes ❑ No ❑

15 a) If yes, please explain how.

15 b) If not, please explain why.

44. What were the best aspects of your research experience?

Please explain.

45. Please check one box on each line to indicate your satisfaction with the following aspects of Pathways program:

	Extremely satisfied	**Very** satisfied	Satisfied	**Moderately** satisfied	**Slightly** satisfied	**Not** satisfied **at all**
a. the application process.	❑	❑	❑	❑	❑	❑
b. finding a mentor.	❑	❑	❑	❑	❑	❑
c. finding a topic.	❑	❑	❑	❑	❑	❑
d. the monthly meetings.	❑	❑	❑	❑	❑	❑
e. faculty involvement.	❑	❑	❑	❑	❑	❑
f. your research mentor.	❑	❑	❑	❑	❑	❑
g. your research project.	❑	❑	❑	❑	❑	❑
h. your overall experience with the Pathways Program.	❑	❑	❑	❑	❑	❑

Please write any comments about your responses to questions 17 a-h. **Your honest reactions and suggestions make a difference for future improvements.**

46. Please check one box on each line to indicate your reasons for leaving the Pathways program.

	Yes	**No**
a. Personal reasons.	❑	❑
b. Complications with your financial aid package.	❑	❑
c. You found an alternate source of financial support.	❑	❑
d. You are changing your major.	❑	❑

e.	You are graduating.	❑	❑
f.	Other reason(s) (Please describe.): ______________________________		

Please explain your responses to questions 18 a - f.

47. If you could change the Pathways program in any way, how would you change it?

48. Please check one box on each row to indicate your plans after graduating with a bachelor's degree:

	Yes	No
a. I plan to enter a graduate program (Masters or Doctorate) to continue my research interests in geosciences right after graduation.	❑	❑
b. I plan to enter a professional program (e.g., medical school, MBA, law school) right after graduation.	❑	❑
c. I plan to enroll in a graduate or professional program while working.	❑	❑
d. I plan to work before entering a graduate or professional program.	❑	❑
e. I plan to work right after graduation.	❑	❑

49. Please check one box to indicate how likely it is that you will go to graduate school:

0% ❑ 10% ❑ 20% ❑ 30% ❑ 40% ❑ 50% ❑ 60% ❑ 70% ❑ 80% ❑ 90% ❑ 100% ❑

50. If you were to go to graduate school, what would you major in?

Please explain why.

51. If you were to go to graduate school, how would you pay for your education? Please check one box on each line.

Yes No

a.	By working.	❑	❑
b.	Through financial support from family or friends.	❑	❑
c.	Through a scholarship.	❑	❑
d.	Through a loan.	❑	❑
e.	Through fellowships.	❑	❑
f.	Through teaching assistantships.	❑	❑
g.	Through research assistantships.	❑	❑
h.	Other (Please describe.): ____		

52. Ten years from now, **how likely is it that**:

	Very likely	**Moderately** likely	**Not so** likely	**Not** likely **at all**
a. you'll be working in the geosciences field?	❑	❑	❑	❑
b. you'll be working in a career in the sciences?	❑	❑	❑	❑

Please explain your answers to questions 24 a-b.

25. What other activities or presentations would you like to see added to the program to help enhance your undergraduate research experience?

Thanks for your help.

Appendix B - Chapter 5

Input parameters:

```
ph2dt.inp - input control file for program ph2dt
* Input station file:
station.dat
* Input phase file:
phase.dat
*MINWGHT: min. pick weight allowed [0]
*MAXDIST: max. distance in km between event pair and stations [400]
*MAXSEP: max. hypocentral separation in km [10]
*MAXNGH: max. number of neighbors per event [10]
*MINLNK: min. number of links required to define a neighbor [8]
*MINOBS: min. number of links per pair saved [8]
*MAXOBS: max. number of links per pair saved [20]
*MINWGHT MAXDIST MAXSEP MAXNGH MINLNK MINOBS MAXOBS
   0      1000     10     137    2       1     19
```

Input parameters for *hypoDD*:

```
* RELOC.INP:
*--- input file selection
* cross correlation diff times:
dt.cc
*
*catalog P diff times:
dt.ct
*
* event file:
event.dat
*
* station file:
station.dat
*
*--- output file selection
* original locations:
hypoDD.loc
* relocations:
hypoDD.reloc
* station information:
hypoDD.sta
* residual information:
hypoDD.res
* source paramater information:
*hypoDD.src

*
*--- data type selection:
```

```
* IDAT:  0 = synthetics; 1= cross corr; 2= catalog; 3= cross & cat
* IPHA: 1= P; 2= S; 3= P&S
* DIST:max dist [km] between cluster centroid and station
* IDAT   IPHA   DIST
    2     3     1000
*
*--- event clustering:
* OBSCC:    min # of obs/pair for crosstime data (0= no clustering)
* OBSCT:    min # of obs/pair for network data (0= no clustering)
* OBSCC  OBSCT
     0     2
*
*--- solution control:
* ISTART:   1 = from single source; 2 = from network sources
* ISOLV:     1 = SVD, 2=lsqr
* NSET:              number of sets of iteration with specifications following
*  ISTART  ISOLV  NSET
    2       2      2
*
*--- data weighting and re-weighting:
* NITER:             last iteration to used the following weights
* WTCCP, WTCCS:               weight cross P, S
* WTCTP, WTCTS:               weight catalog P, S
* WRCC, WRCT:          residual threshold in sec for cross, catalog data
* WDCC, WDCT:                 max dist [km] between cross, catalog linked pairs
* DAMP:             damping (for lsqr only)
*       ---  CROSS DATA ----- ----CATALOG DATA ----
* NITER WTCCP WTCCS WRCC WDCC WTCTP WTCTS WRCT WDCT DAMP
  5      -9     -9   -9   -9   10.0  1.0    3   9   20
  5      -9     -9   -9   -9   0.5   0.1   0.5  9   18
*--- 1D model:
* NLAY:              number of model layers
* RATIO:    vp/vs ratio
* TOP:               depths of top of layer (km)
* VEL:               layer velocities (km/s)
* NLAY  RATIO
   5   1.73
* TOP
0.0  4.0  15.0  35  100.0
* VEL
4.4  6.0  6.5  8.1  8.65
*
*--- event selection:
* CID:        cluster to be relocated (0 = all)
* ID:  cuspids of event to be relocated (8 per line)
* CID
    0
* ID
```

Vita

Tina L. Carrick was born in Buffalo, New York in November of 1957. The younger of two children of Francis and Ruby Pataluna, she graduated from Kensington High School, Buffalo, New York, in 1975. After marrying her husband, David, she relocated to El Paso, Texas in 1977. After working for Texas Commerce Bank for 10 years and having 4 beautiful daughters she returned to school. In fall of 1993 she entered the University of Texas at El Paso (UTEP) and received her B.S. in Geological Sciences in 1999. In August of 1999 she entered the masters program at UTEP completing her degree in Geological Sciences in Structure in 2002. She was hired in 2002 to be the program coordinator for the *Pathways to the Geosciences* grant and the Geological Sciences departmental Graduate Student Coordinator at UTEP as well as adjunct faculty at the El Paso Community College (EPCC). In 2004 she began the Ph.D. program while working in the department and teaching at the EPCC. Future plans may include working with Dr. Steve Harder at the National Seismic Source Facility, adjunct faculty at EPCC, and as an outside consultant for evaluations.

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This thesis/dissertation was typed by Tina L. Carrick.