PLANT COMPOSITION ON FOUR BASALT FLOWS AT EL MALPAIS NATIONAL MONUMENT, NEW MEXICO

THESIS

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By

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In the beginning was an idea containing two key elements: lava and vegetation. Thanks to the enthusiasm and support of my outstanding committee members, Dr. Earl (Chair), Dr. Butler, and Dr. Fonstad. They helped transform this idea into a study of scientific merit and without a doubt a wonderful educational experience. I would like to express my deep appreciation to Dr. Butler for his biogeographic expertise and continual positive attitude. Without the much-needed help from Dr. Fonstad regarding the analysis of my field data, I would still be floating among regressions. And finally, I am indebted to Dr. Earl's continual support in this research from the beginning to the end. Dr. Earl's geographic wisdom and wonderful spirit has made working with him an endless joy that has led me to regard Dr. Earl as being one of the most important mentors in my life.

This research has truly been a collaborative effort. I cannot express how integral the wide knowledge and support has been of Jeff Wilson, a fellow graduate student. He accompanied me on every trip to New Mexico and made collecting the field data a possibility. As well, he provided innumerable versions of editorial support and most importantly emotional support, especially when the research looked its bleakest. Lisa Chism, my dear friend from Colorado, also made collecting the data a possibility. I have an overwhelming sense of gratitude for her strong arms and amazing sense of humor. As well, an equally important field collector was Bill Manderson (Uncle Billy) who drove all the way from San Diego, California, to spend a week with me out on the treacherous lava flows collecting data and weathered the rather slow town of Grants, New Mexico. I am

always happiest when I am spending time with my family and it was such a gift to be able to share my research with my endlessly curious and outdoorsy Uncle.

Finally, I would like to thank my mother, Nancy Manderson, and her husband, Bill Coats, for their support. Since the beginning of my educational career, my mother has had high expectations for my intellectual life. Through her example as bright, beautiful, and strong female, higher education seemed to be a natural and acquirable goal, though I do not think that either one of us would have dreamt that it would have included vegetation and lava. Lesson 1123, "Geographical directions are not always straight."

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CHAPTER 1

INTRODUCTION

According to Thomas T. Veblen, (1989) biogeography has evolved since the 1950's due to four important influences: " (1) stimulus provided by a few influential faculty in leading geography departments, (2) attraction of ecologically oriented students by the environmental movement of the late 1960s and 1970s, (3) incorporation of ecological perspectives (e.g., Odum 1959) into geographical curricula in the 1960s, and (4) general resurgence of physical geography beginning in the 1970s" (30-1). This evolution has allowed geographers and ecologists to collaborate and ask new questions pertaining to aspects of vegetation dynamics. Vegetation dynamics is the study of the processes and patterns of changes in community composition and structure over time (Pickett and White 1985, Veblen 1989). Geographical biogeographers research vegetational changes that occur through space as well. "In most of these studies, the objective is to relate changes in community parameters such as composition, structure, and physiognomy to variation in the physical environment" (Veblen 1989, 34). Spatial scale varies from stand-scale to global scales.

For this research, I will examine vegetation composition and morphology on four distinct basalt flows at El Malpais National Monument, New Mexico (Figure 1.1). Little research has been done on the differences in species composition on basalt lava flows at

El Malpais National Monument, New Mexico. Understanding how life grows on flows is fundamental to understanding the changes in vegetation over time and space. This research will explain vegetation characteristics on four different and distinct basalt flows. Therefore, there is an element of both space and time. I will develop an understanding of vegetative spatial variability on basalt flows of different ages.

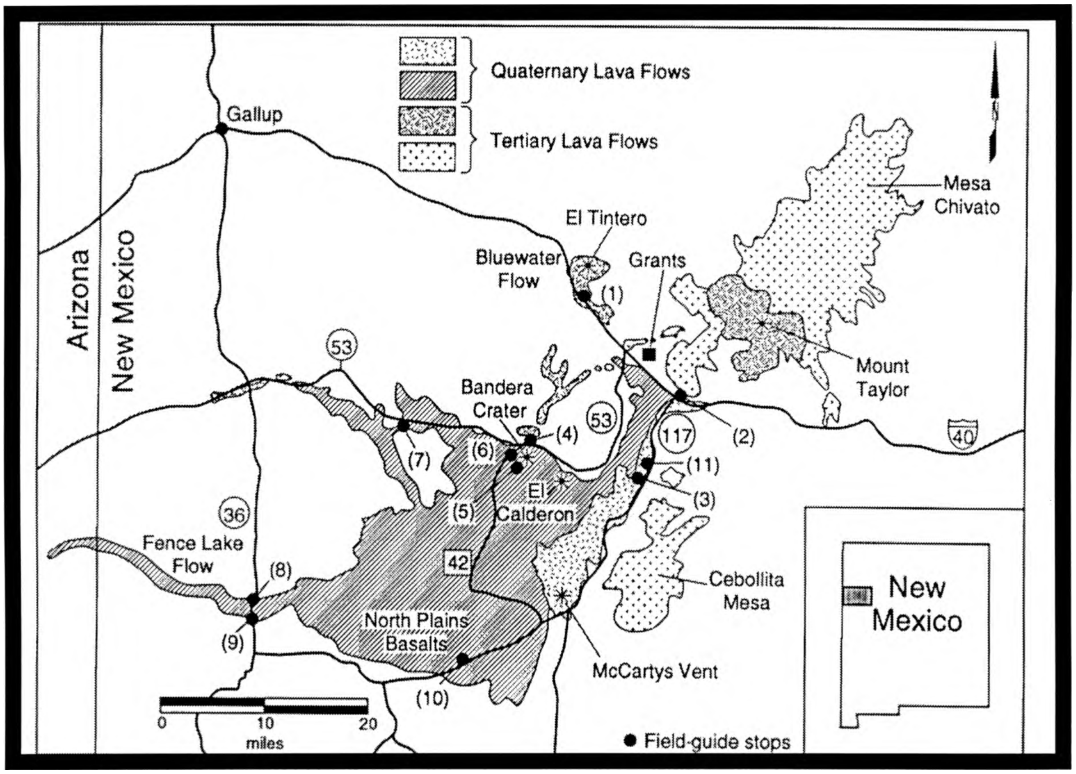


Fig. 1. Location map of El Malpais National Monument encircled by New Mexico Highways 36, 53 and 117 (Laughlin et al. 1999).

Significance of the Research

El Malpais has proven to be an excellent site for scientific study. Though Bleakly (1997) described, classified, and mapped the vegetation and flora of El Malpais, there was little focus on the variations of vegetation habitats on different ages of flows. This study will enhance our understanding of spatial variability of vegetation, and could add to the knowledge we have of the lava flows at El Malpais. "More than most sciences, biogeography helps us to understand and appreciate the living environment that we experience every single day" (MacDonald 2002, 1).

CHAPTER 2

LITERATURE REVIEW

Theoretical applications for this research will consist of vegetation succession paradigms established by the founder of classical succession theory, F. E. Clements in 1916. Succession describes how disturbances change geomorphic and biological environments. Primary succession occurs when plants and animals develop on a previously uninhabited surface, such as a volcanic island. Secondary succession occurs when a biological environment restores itself from a disturbance such as a flood (MacDonald 2002).

> Clementsian successional theory was an equilibrium viewpoint in its assumption that successional change necessarily progressed towards the development of a stable vegetation type in equilibrium with the regional climate. It was deterministic by postulating that the development of the climax was as orderly and as predictable as the life history of an individual organism (Glenn-Lewin et al. 1992, 3).

According to the "Clementsian model", age of the site is an important factor regarding vegetation development. The "Tolerance model", "Inhibition model", and "Random models" are alternative proposed models of succession (MacDonald 2002). Even though the "Clementsian model" has been criticized by Henry A. Gleason (1927) and Arthur G. Tansley (1935) as simplistic, the age of site has proven to be an important control on density and species. As lava flows weather, they will provide more suitable habitats for plants and a greater diversity of species.

Hans Jenny (1941), a soil scientist, also viewed ecology in a temporal paradigm. As a Darwinian, Jenny applied evolution to soil development and formation resulting in a factor-function paradigm similar to the Davisian erosion cycle and the Clementsian succession system. Jenny developed five controls for soil formation. "For constant climate, organisms, parent material, and topography, Jenny asserted that the soil profile is 'solely a function of time': $S=f(time)_{cl,o,r,p}$ " (Osterkamp and Hupp 1996, 431).

Background of Study Site

El Malpais, located in west central New Mexico, is an area of intense physical contrast. It is a land of ancient fire and year round ice. The Monument is comprised of areas with dense vegetation contrasted with locations where vegetation is so sparse that it has been compared to the moon. El Malpais, literally meaning "the bad country," has long been known as a laboratory for natural history.

The Native Americans that first lived on this land experienced terrain similar to what is present today. The rain, snow, and wind over time have had relatively little erosive effect on the rugged flows. The prehistoric Pueblo people and their descendents, the Acoma and Zuni people, and the later-arriving Navajos, adapted to the environment and revered these intense surroundings.

> One example of the many oral traditions associated with the area is the Acoma Pueblo epic of a ruthless gambling Kachina and his twin sons, who blinded him so he would not destroy their people. Black lava blood flowed from the Kachina's eyes, ruining all that lay in its path. As it cooled, it solidified into serpentine ropes and cresting waves of black rock,

> producing ice caves where water could be found year-round for the Acoma tribe and their animals (Mabery et al. 1999, 5).

"As early as the 1930s portions of the lava flows were proposed as a National Monument to preserve their scientific value" but it would not be until 1987 that it was actually established as El Malpais National Monument and Conservation Area (Mabery et al. 1997, 5). In 1938, biologists, ecologists, and geologists under R.L. Nichols of the U.S. Department of Agriculture published reports on the year-round ice caves and lava flow features. A.W. Hatheway and A.K. Herring were commissioned by NASA to study the lava tubes and their similarity to lava caves on the moon. In the 1980s, the National Monument became the focus of integrated scientific study (Mabery et al. 1997).

El Malpais National Monument is located just south of Grants, New Mexico. The flows are part of the Zuni-Bandera volcanic field, which includes approximately 100 volcanoes dating from the Quaternary. The Zuni-Bandera volcanic field is centrally located in the Jemez lineament, which extends from central Arizona to northeastern New Mexico and is a significantly weak zone from which volcanoes have periodically erupted for the past 16 million years (Laughlin et al. 1993).

El Malpais lava flows represent the youngest volcanic activity in the larger Zuni-Bandera field (Mabery et al. 1999, Laughlin et al. 1993). This volcanic activity is the product of larger plate tectonic motions affecting most of the Southwest. Much of this igneous activity is caused by the North American plate overriding the East Pacific Rise. "This sliding motion, coupled with the opening of the Gulf of California during the past 5 million years, caused most of the western United States to be stretched to one and a half times its original size. This stretching not only pulled the Colorado Plateau west, it pushed the plateau upward as hot, plastic rock from the mantle rose beneath this enormous block of continental crust" (Mabery et al. 1999, 8).

Within the monument, three distinct volcanic episodes have been identified, the oldest eruptions occurred between 500,000 and 750,000 years ago (Mabery et al. 1999; Laughlin et al. 1993). The majority of these older flows are located in the southwestern region of the monument and their source vents can no longer be found due to erosion or layering by younger volcanic rock.

From 100,000 to 200,000 years ago, the second period of intense eruptive activity occurred, dating the cone and the flow of El Calderon to around 115,000 years ago. The third pulse of volcanic activity occurred 16,000 years ago. Within this period, closely spaced eruptions of Cerro Candelaria, Twin Craters, Lost Woman Crater, and Lava Crater occurred. The much younger McCartys flow from the third pulse dates from 3,000 years ago and younger, which suggests that volcanic activity is still a possibility (Mabery et al. 1999). McCarty's, Bandera, Twin Craters, and El Calderon are the flows of interest for this paper (Fig. 2).

Fig. 2. Images of McCartys, Bandera (top), Twin Crater, and El Calderon(bottom) lava flows at El Malpais National Monument (Bill Manderson 2002).

El Malpais contains four major groups of volcano features: basalt cones, cinder cones, shield volcanoes, and composite or stratovolcanoes (Mabery 1999; Laughlin et al. 1993). McCarty's is the youngest basalt flow of the Zuni-Bandera volcanic field extending for thirty-five miles and is characterized as a typically vesicular, porphyritic basalt dominated by plagioclase feldspar (Laughlin et al.1993). McCartys is a shield volcano with a small crater that is not easily identifiable. The chemical properties of the flow resulted in a relatively high 51.58% SiO_2 content. Most of the lava is characterized as being a typical ropy pahoehoe with collapse features, large pressure ridges, and lava blisters (Mabery et al. 1999).

Bandera lavas are both aa and pahoehoe surfaces. Aa flows are thick viscous lava that cooled quickly and broke into chunks or irregular blocks. Bandera's lavas are characterized as nepheline normative, holocrystalline, microporphyritic, and vescular. Chemically, Bandera was tested as having 44.47% SiO_2 content and an Al_2O_3 content of 15.22% (Laughlin et al. 1993).

Twin Craters is a characterized by differentiated plagioclase and olivine (Cascadden et al 1997). Twin Craters is located in the center of the Zuni-Bandera volcanic field and erupted, in geologic terms, over a short period of time and in a limited area. Cascadden et al. (1997) explored the possibility that Twin Crater might be related to Cerro Candelaria, Lost Woman Crater, and Lava Crater. "The spatial and temporal proximity of the four vents would tend to suggest that they are genetically related in some way (i.e. that they are all created by similar processes, from similar sources, and can be expected to have undergone similar histories)" (56) Twin Craters is a cinder cone comprised of channelized aa and tube-fed pahoehoe (Mabery et al. 1999).

El Calderon, the oldest of the lava flows, began with eruptions of scoria that ranged in composition from alkalic to transitional to tholeitic. Subalkaline (tholeitic) flows followed the scoria eruptions and eventually breached the northeast margin of the cinder cone (Cascadden et al. 1997). El Calderon is a composite volcano, which is the largest type of volcano made of alternate layers of cinder, ash, and lava. The lava flows of El Calderon are aa flows followed by pahoehoe eruptions (Mabery et al. 1999).

When assessing vegetation growth and patterns it is essential that the climate of the area be referred to and reviewed. "Biologists have long recognized that the general structure of the atmosphere is the dominant factor controlling the distribution of biomes on this planet" (Neilson 1986, 26). During the late Tertiary, a double rain shadow developed over the New Mexico area and other surrounding Southwestern states. This rain shadow has caused a decrease in precipitation so much that the state receives an average of 75 percent sunshine annually and has an arid to semi arid climate (NMSU 2002). Albuquerque, the nearest large city to the Monument, averages 230 mm (9 in) of precipitation a year. The mean temperature and precipitation for El Malpais National Monument were compiled from five local station readings of the New Mexico Climate Normals from the period of 1971-2000. El Malpais mean temperature resulted in 10.2 °C (50.3 °F) with a mean precipitation of 347 mm (13.66 in) a year. El Malpais is classified as being part of the Southwest Uplands, which consists of two vegetative zones. These zones are the pinyon-juniper belt (Upper Sonoran Zone), roughly from 1370 m (4,500 ft) to 1980m (6,500 ft) in elevation and the ponderosa pine-Gambel oak belt (Transition Life Zone), roughly from 1980om (6,500 ft) to 2440m (8,000 ft) in elevation (Elmore 1976).

Bleakly 's (1997) study provides a comprehensive classification and identification of the vegetation and flora of El Malpais. "...in most respects the plant life of the monument actually is more similar to that found in regional mountain ranges than to that in the Colorado Plateau" (Bleakly 1997, 113). Carroll and Morain (1992) organized El Malpais into four plant communities: (1) mixed-conifer woodland, (2) shrub/conifer, (3) grass or grass/shrub, and (4) barren to sparse grass/ shrub. The vegetation map (Fig. 3) displays where the plant communities are located.

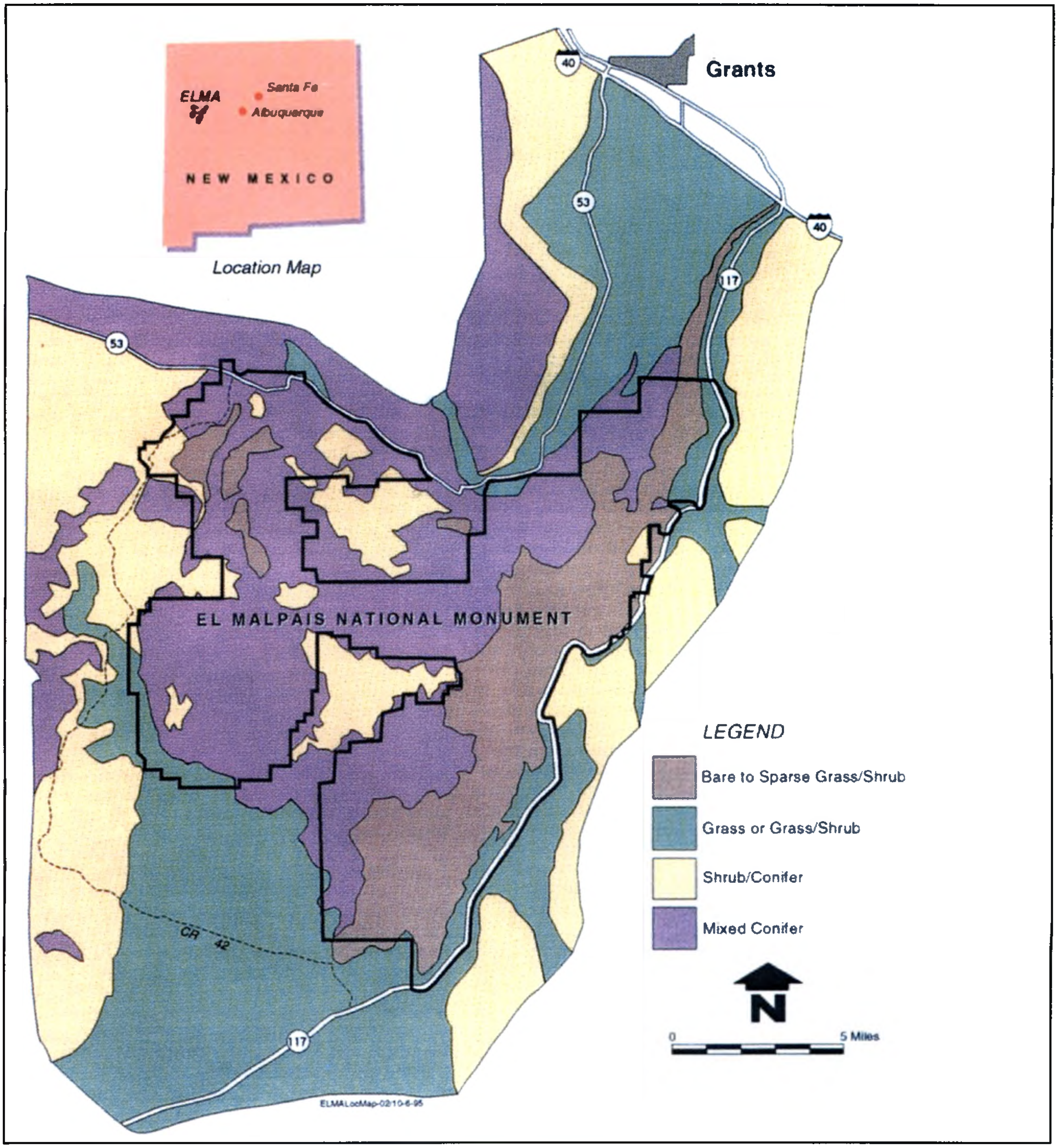


Fig. 3. Vegetation map of El Malpais (Bleakly 1997).

The four flows studied along the Zuni-Acoma trail are classified as bare to sparse grass/shrub, as well as mixed conifer. Bleakly and his team found that plant density was low on the flows. However, when the possible growth sites were taken into account plant density was found to be at its maximum. Another important find was the unique characteristics of the basalt. Basalt traps more moisture than the grasslands and allows conifers to grow their long roots in cracks and soil-covered depressions. The basalt surface causes the area to sustain growth similar to those in mountain environments, although the flows are found at low elevations. "Lava is not absorbent, so runoff moves down through the heavily fractured surface into areas of high moisture, low evaporation, and cool temperatures. These are suitable growth conditions for deep-rooted plants such as conifers, but not shallow-rooted plants such as grasses and annuals" (Bleakly 1997, 116).

Further, much of the lava is too young or unstable to support abundant vegetation. Stunted and twisted conifers are found along the McCarty's and Bandera flows. Bleakly (1997) also found that the type of flow affected vegetation growth. Aa lava, which is typically rough and loose, does not support much vegetation while pahoehoe lava is smooth and often ropy, allowing vegetation to live in a more stable condition (Mabery 1999). Bleakly (1997) found that cinders behave similarly to sedimentary soils and may contain more water below the surface. "This may explain the presence of alligator juniper (*Juniperus deppeana)*, a species that requires more water than other junipers (Dick-Peddie 1993), only on cinders in the monument area" (Bleakly 1997, 118). The "edge effect" is another interesting aspect of the lava in relation to vegetation growth.

Along the boundaries between lava flows and between lava flows and surrounding grass/scrublands, denser vegetation is present due to capture of runoff (Bleakly 1997).

The first comprehensive study on the flora of El Malpais of the distinctive environments on the lava flows was published in *Ecological Monographs* (Lindsay 1951, Grissino-Mayer et al. 1997). Lindsay extensively studied the relationship between substrate material and tree growth. He found that the habitats on the flows were unique in species diversity, finding various trees, shrubs, mosses, and algae. Lindsay discovered forests of old-aged trees such as Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), piñon (*Pinus edulis*), and a range of juniper species (*Juniperus* spp.) that managed to exist to great ages on little soil (Grissino-Mayer et al. 1997). Both Grissino-Mayer et al. (1997) and Lindsay (1951) hypothesized, "…that the porous nature of the lava acts as a reservoir that traps and holds moisture from winter snowmelts and summer monsoonal rainfall. Ice caves that occur throughout the Malpais provide evidence that the lava may act as a special type of aquifer" (Grissino-Mayer et al.,155).

Grissino-Mayer et al. (1997) used Lindsay's studies of the rare, old-age conifers and attempted to understand Native American migratory patterns in relationship to climatic change in the American Southwest that would be apparent in the tree rings of the conifers. It was found that the trees reached great ages. On the Bandera flow, trees were found to have an average age of 600 years and it is thought that El Malpais proper has some Douglas-fir trees that are more than 1,000 years. Grissino-Mayer et al. (1997) were able to reconstruct climate due to abundant remnant wood from 28 trees that had tree-ring sequences dating to prior to 1000 AD.

Other climatic studies have been performed on the year round ice caves that are found in lava tubes of El Malpais (Dickfoss et al. 1997). “Ice caves are restricted to areas that have sub-zero winter temperatures, but not necessarily a mean annual temperature below zero (Henderson, 1933; Blach, 1970). Conceivably, some of these caves could contain Pleistocene ice; cave ice was dated to 3000 yrs BP in Romania’s Ghetarul de la Scarisvara” (Bogli 1980, 227, and Dickfoss et al 1997, 91). Northup and Welbourn (1997) performed a study on the lava-tube ecology, finding environments from moss gardens to a variety of cave-adapted and noncave-adapted invertebrates. Scientists such as Laughin and WoldeGariel (1997) have also studied the ages of the Zuni-Bandera volcanic field. Absolute ages have proven difficult to determine. Different dating techniques have been used on the flows such as radiometric or cosmogenic, argon 40-argon 39, carbon 14, Helium 3, Chlorine 36, and uranium series disequilibrium resulting in the age estimates used for this research. Absolute ages for each of the flows have been determined. McCarty, the youngest flow of the monument, has been found to have an average age of 2,450 years BP. Bandera has a minimum age of 3,166 to 10,500 years BP. Twin craters is 15,800 and El Calderon dates approximately 115,000 yeas BP (Laughlin et al. 1993; Mabery et al 1999).

CHAPTER 3

METHODOLOGY

Hypotheses

I expect to find a correlation between the age of the basalt flow and vegetation. As the age of the flow increases, I expect the density, cover, and frequency of vegetation to increase as well. In short, the age of flow partially determines the amount and types of vegetation.

I am also interested in understanding the geomorphic differences of the flows. I will study the surface complexity of each flow to determine if the flows are significantly different from one another. I expect that as the age of flow increases the surface complexity will decrease and allow for a more stable environment for vegetation growth.

The independent variables are the ages of the four basalt flows. The dependent variables are density, cover, frequency, importance, and fractal dimensions of the flows. Density, cover, and frequency are all measured in relative amounts and will be determined by the Random Quadrat method as well as the Line Interception method (Barbour et al. 1987; Canfield 1939). Barbour (1987) and Greg-Smith (1983) define density as the measure of rooted plants per unit area. Relative density is the percent of total plant density in comparison to the density of one species. Cover or coverage "is the percentage of quadrat area beneath the canopy of a given species" (Barbour 1987, 191).

Relative cover is the percentage of a species relative to the percentage of total plant cover. "**Frequency** is the percentage of total quadrats that contains at least one rooted individual of a given species" (Barbour 1987, 193). Moreover, "**Importance** refers to the relative contribution of a species to the entire community" (Barbour 1987, 194). A resultant importance value (IV) can be reached by summing relative cover, relative density, and relative frequencies (Barbour 1987).

Surface complexity is a scale-dependent measure of the surface length in relation to the straight length. C= surface (length)/straight (length). The straight length is 50 meters and the surface length is the 50 meters of the transect tape that is reduced in length because of the flow morphology. The ratio between the two determines the amount of surface complexity. As the surface complexity decreases, the ratio becomes closer to one. A ratio of one would be a completely smooth surface. I am using the surface complexity as a measure of fractal geometry of vertical cross-section profiles to develop an understanding to the surface topography of the lava flows (Commito and Rusignuolo 2000).

Figure 4 is a model of my research design that displays the correlation between age, surface complexity, and vegetation. In this analysis, I will need to address the possibility of multicollinearity. As well, it is necessary to account for the influence of other factors or the possibility for different determining factor at finer or larger scales.

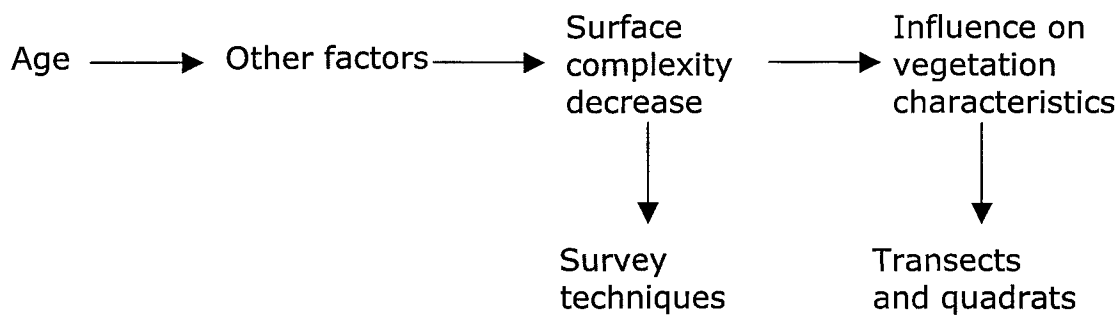


Fig. 4. Research design model.

Source of Data

I collected data in the field from El Malpais National Monument, New Mexico on two different occasions, November 2001 and March 2002. One trip served as a reconnaissance study of the area while the second trip consisted of collecting the needed data. I used the Random Quadrat method, the Line Interception method, and Surface Complexity measure method.

Transects: Four 50 meter long tapes were placed along each flow starting at the generated point that was given a geographic location and navigated to with the aid of a GeoExplorer GPS unit. As well, I randomly generated the azimuth for the transect direction. At every five meters starting at zero, the presence or lack of vegetation was recorded. I recorded if there is lava only, lava with vegetation, soil with no vegetation, or soil with vegetation.

Quadrats: Along the transects, stratified random distances were generated for the location of two 1 meter quadrats and two 10 meter quadrats. The quadrat method allows the researcher to estimate cover, density, and frequency (Barbour 1987). With the data from these quadrats, I estimated the percentages of vegetation and classified the different types of vegetation present. This allowed me to determine relative density, cover frequency, and importance rank (Barbour 1987) (Fig. 5).

McCarty's: Flow 1 Transect 1

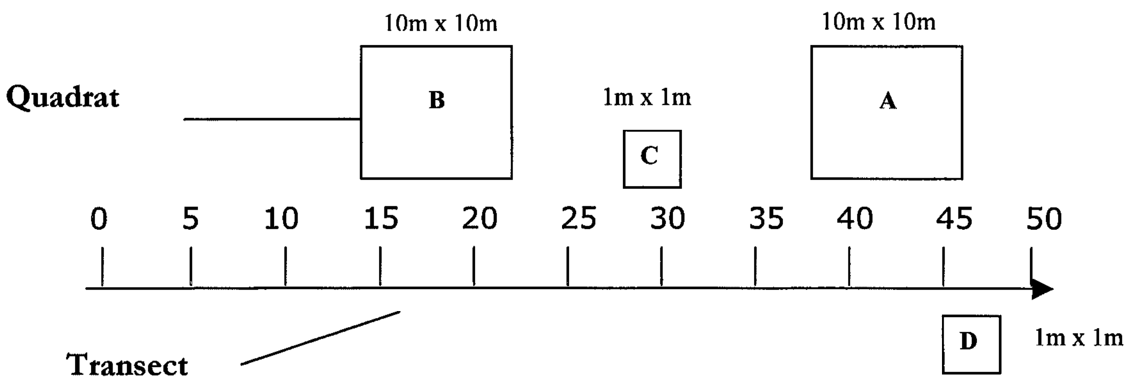


Fig. 5. Transect with four quadrates randomly placed. The left and the right side will also be randomly determined.

Surface Complexity: In the field I took elevation measurements at every five meters along the randomly generated transects with a leveler and stadia rod (Fig. 6). These elevations were calculated and then compared to the straight length.

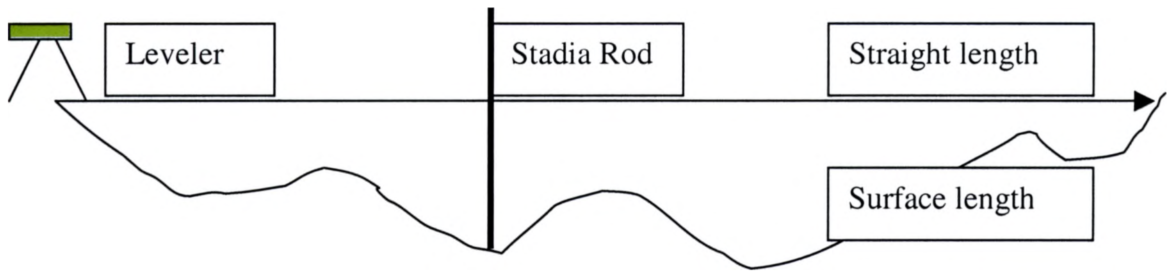


Fig. 6. Straight length versus surface length of 50m transect.

I analyzed the results of the Transect and Quadrat measurements to determine if there is a significant relationship between each flow. To determine the relationship between age and plant density, I used simple linear regression. To analyze the transect measurements I recorded the percentage for each flow of the presence of vegetation and the presence or absence of soil.

As well, I used descriptive statistics and comparative tables to describe and analyze the relationships between the flows. I analyzed and graphed the ratios of the surface complexity through a regression analysis in Excel.

In summary, Figure 7 displays the field sampling design for my analysis of El Malpais.

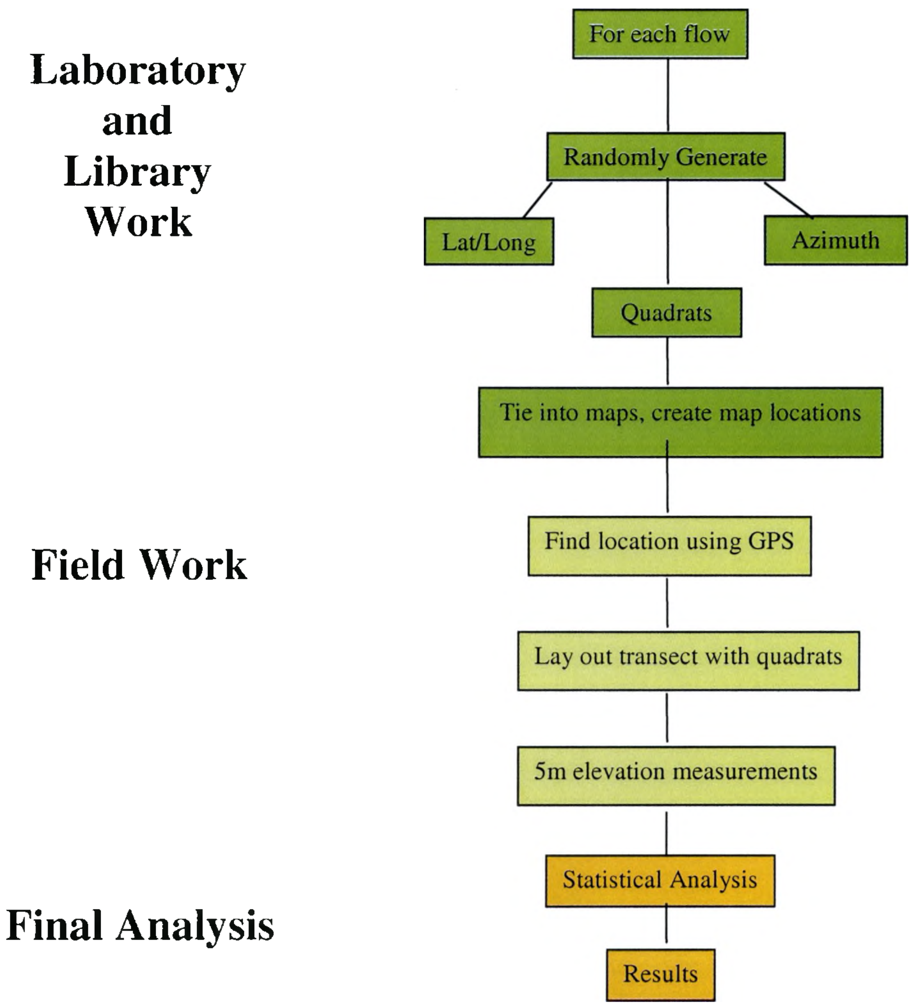


Fig. 7. Field Sampling design.

CHAPTER 4

ANALYSIS OF THE DATA

Introduction

This chapter expands and clarifies the relationship between the age of the basalt flows and vegetation characteristics through statistical analysis and other quantitative techniques. This chapter is organized into three different sections: The first section is an examination of the data from the Random Quadrat Method, the second section is an analysis of Transect measurements, and the third section is an inspection of Surface Complexity ratios.

Random Quadrat Method

Along each transect four quadrats were randomly placed; two quadrats were 10mx10m and two quadrats were 1mx1m. Different sizes were necessary so that all of the species of the flows could be categorized and analyzed. The quadrats in the field were assigned a general percentage of plant coverage. Through regression analysis, the relationship between vegetation coverage and age of the flows was compared. According to figure 8 there is an r square of 0.2664 which demonstrates a positive linear relationship, showing that age does have an important role in determining the amount of vegetation present on the flows. However, the result also suggests that in the natural the result also suggests that in the natural world other factors contribute to vegetation growth rather than solely age. Therefore, the 26% is an accurate reflection of the actual relationship between age and vegetation; other factors must be involved as well.

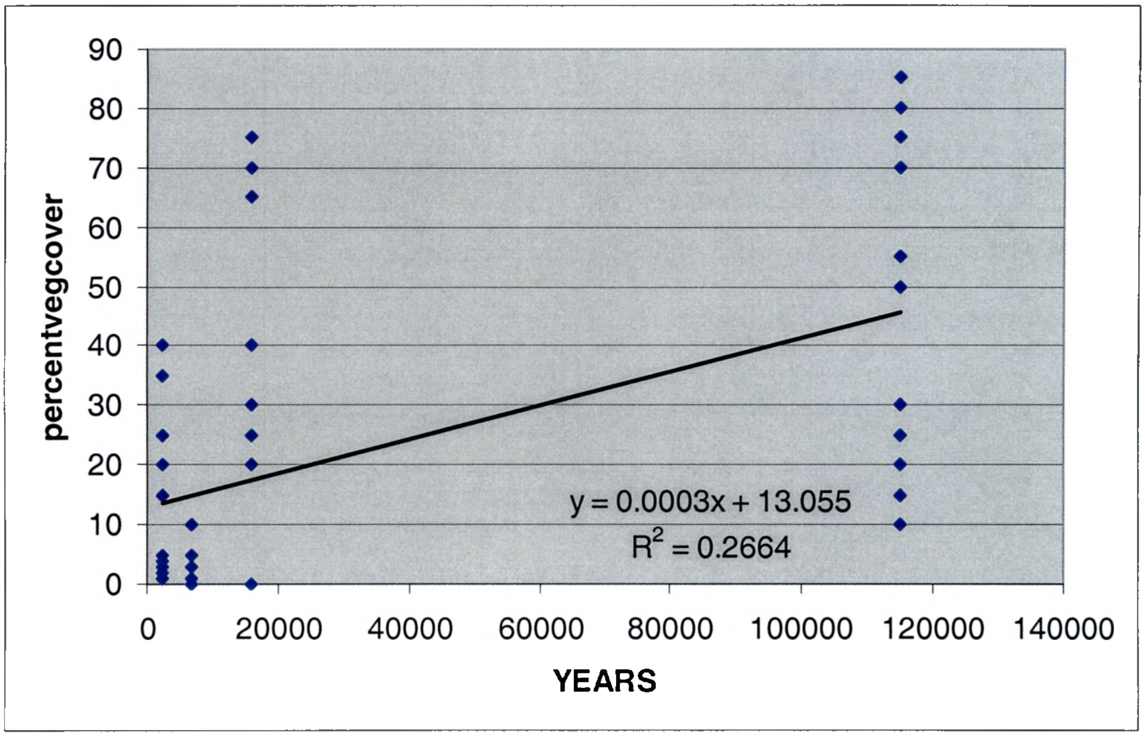


Fig. 8. Regression of percentage vegetation cover in relation to age of the flow.

Figure 4.1 indicates that the youngest flow, McCarty's, has a higher amount of vegetation cover than the second youngest flow, Bandera. This can be attributed to two factors. The first being, the type of lava on the second flow is aa (see Chapter 2), an environment that is more difficult for vegetation to grow upon than the younger McCarty's flow which is characterized by pahoehoe lava. The second contributing factor is that the transect locations for Bandera were closer to the crater than the younger McCarty's flow. However, the general trend is that as the age of the flows increases the percent coverage of vegetation increases as well. McCartys has a large amount of quadrats that were recorded as 10% or less covered by vegetation and did not have any quadrats that had more than 40% cover. Twin Craters and El Calderon continued a linear increase in vegetation cover.

Flow Characteristics

For each quadrat on each flow, relative cover, absolute density and relative density were calculated (Appendix 1). Included is an example of a 1x1 meter quadrat (Fig. 9). On the flows, grasses grow in little clumps or bundles and are regarded as one plant. A frequency table was then generated which represents plant group for each flow and how they correspond to the other flows (Table 1). Plants were generalized into simplified plant groups of grass, juniper, pine, cactus, oak, shrub, and squawbush. Grass is the most frequent plant group for each flow. One hundred and sixty five plants of grass were found in quadrats on the McCartys flow, which accounts for 59.8% of total plant frequency, while seven grasses were identified on the Bandera flow resulting in 38.9%

total frequency. Five hundred and twenty three plants of grass were identified on Twin Craters with 87.6% frequency, and 1036 plants of grass on El Calderon which represents 96.4% of plant frequency. The frequency of grass increases as the age of the flows increase. While grass frequency increases, pine, juniper, and shrub frequency decrease with age. Oaks are most frequent on the Twin Crater flows. Vegetation plant group diversity is highest among the youngest flow, McCartys, and the third oldest flow, Twin Craters. Actual vegetation presence is higher among the two older flows, Twin Craters and El Calderon.

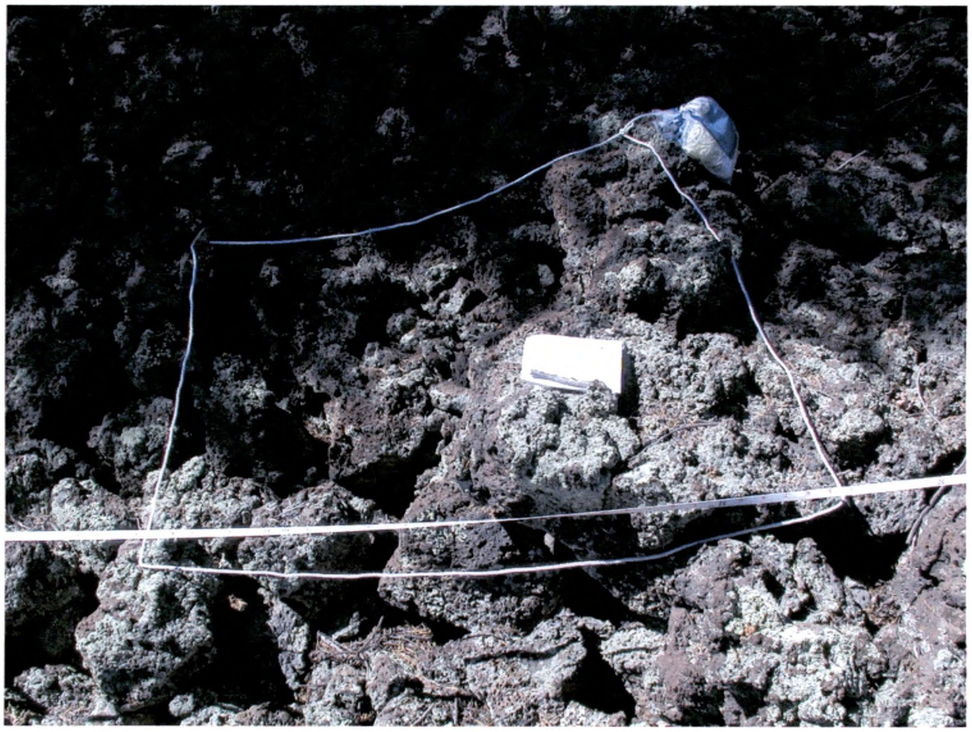


Fig. 9. 1x1 meter quadrat on Twin Crater (Bill Manderson, 2002).

TABLE 1

Comparison of vegetation absolute frequency (relative frequency)

Plant Groups	McCartys	Bandera	Twin Crater	El Calderon
Grass	165 (59.8%)	7 (38.9%)	523 (87.6%)	1036 (95.9%)
Juniper	16 (5.8%)	2 (11.1%)	36 (6%)	31 (2.9%)
Pine	12 (4.3%)	1 (5.6%)	5 (0.8%)	1 (0.1%)
Cactus	12 (4.3%)	0 (0%)	6 (1%)	7 (0.6%)
Oak	1 (0.4%)	0 (0%)	15 (2.5%)	0 (0%)
Shrub	66 (23.9%)	8 (44.4%)	9 (1.5%)	5 (0.5%)
Squawbush	4 (1.4%)	0 (0%)	3 (0.5%)	0 (0%)
Total Species	276	18	597	1080

Importance Values

The summation of relative cover, relative density, and relative frequency determines the plant group's Importance Values (IV) for each flow. The range for any plant group is between 0 and 300. It is possible to have two similar IVs while the plant group contains significantly different values for relative cover, density, and frequency. Through the analysis of Table 2-5, the most important plant group is grass. As the age of the flows increase the IV increases as well. The only flow that was not recorded as having an IV rank for grass as 1 is the Bandera flow. Pine was recorded as having an IV rank of 1 on the Bandera flow. The IVs for the plant group grass were McCartys (170), Bandera (185.7), Twin Crater (237.1), and El Calderon (258.8). The plant group Juniper was present on every flow and was recorded as having an IV rank of 4 on both the two younger flows, McCartys and Bandera, and an IV rank of 3 on the two older flows, Twin Crater and El Calderon. The plant group Pine has IV ranks of 6, 1, 6, and 4, going from youngest flow to the oldest. The plant group Cactus was ranked a 7 for both McCartys and Twin Craters and was not present on Bandera, however for the oldest flow Cactus had an IV rank of 2. Oaks were present and ranked high in importance for McCartys (3) and Twin Craters (2), however Oaks were not present on either Bandera or El Calderon. The plant group shrubs showed a negative linear decrease. As the flows aged, the IV rank decreased from an IV of 2 for McCartys to a 3, 4, and then 5 for the oldest flow. The final plant group, squawbush, had an IV rank as 5 for both McCartys and Twin Craters but was not present on either Bandera or El Calderon again displaying there was a higher diversity of plant groups on McCartys and Twin Craters.

TABLE 2

McCartys Plant Group Importance Values

Plant Group	R/ Cover	R/ Density	R/ Frequency	IV	IV rank
Grass	42.3	67.9	59.8	170	1
Juniper	43.3	20.5	5.8	69.6	4
Pine	17.9	5.8	4.3	28	6
Cactus	5.0	9.2	4.3	18.5	7
Oak	57.0	25.0	0.4	82.4	3
Shrub	35.0	24.8	23.9	83.7	2
Squawbush	18.5	9.6	1.4	29.5	5

TABLE 3

Bandera Plant Group Importance Values

Plant Group	R/ Cover	R/ Density	R/ Frequency	IV	IV rank
Grass	71.8	75.0	38.9	185.7	2
Juniper	40.0	18.3	11.1	69.4	4
Pine	100	100	5.6	205.5	1
Cactus	0	0	0		
Oak	0	0	0		
Shrub	58.3	65.8	44.4	168.5	3
Squawbush	0	0	0		

TABLE 4

Twin Crater Plant Group Importance Values

Plant Group	R/ Cover	R/ Density	R/ Frequency	IV	IV rank
Grass	62.0	87.5	87.6	237.1	1
Juniper	30.0	8.4	6.0	44.4	3
Pine	10.3	1.9	0.8	13.0	6
Cactus	2.7	2.3	1.0	6.0	7
Oak	34.7	13.1	2.5	50.3	2
Shrub	21.0	8.1	1.5	30.6	4
Squawbush	10.0	4.7	0.5	15.2	5

TABLE 5

El Calderon Plant Group Importance Values

Plant Group	R/ Cover	R/ Density	R/ Frequency	IV	IV rank
Grass	77.7	84.7	96.4	258.8	1
Juniper	28.5	4.4	2.9	35.8	3
Pine	15.0	1.0	0.1	16.1	4
Cactus	10.3	27.8	0.7	38.8	2
Oak	0	0	0		
Shrub	5.0	0.5	0.5	6.0	5
Squawbush	0	0	0		

Transect Analysis

Analysis was performed on the data acquired from the transects. At every five meters on each transect, presence or absence of vegetation was recorded as well as presence or absence of soil. To determine the differences between the flows, a table of percentage vegetation and percentage soil for each flow was created. In general, the amount of vegetation and soil presence increases as the age of the flows increase. However, the second flow is markedly different from the other three flows. There was almost no vegetation or soil presence recorded. This difference is attributed to the transects' proximity to the crater and because the flow was of aa lava. The youngest flow and the second oldest flow were the most similar in vegetation presence yet; they differed in reference to soil presence. Soil presence was higher on the Twin Craters flow, which is the older lava flow. Moreover, the oldest flow was almost 100% vegetation and soil presence. It can be concluded that age is a significant determinate of vegetation while taking in account that proximity to the crater and type of lava also significantly influences vegetation growth.

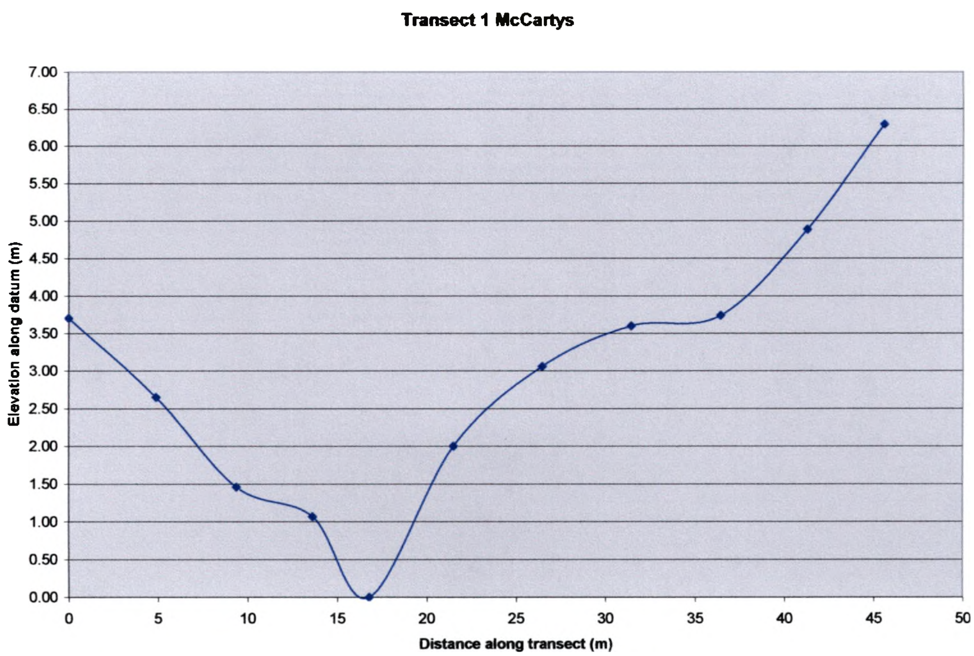
TABLE 6

Transects Percentage of Vegetation and Soil

Transects	% Vegetation	%Soil
McCartys	54.5	6.8
Bandera	6.8	2.3
Twin Craters	61.4	61.4
El Calderon	100	100

Surface Complexity

At every five meters elevation measurements were recorded along a fifty meter transect. Because the transect was placed along the surface of the flow the actual distance was less than a perfectly straight 50 meters. For each transect, the measured distance was divided by the actual distance of 50 meters. (Appendix 2) Table 2 compares the ratios on each transect and provides an averaged total for each flow. As the surface complexity of the flow decreases, the ratio becomes closer to one, meaning that the measured distance is closer to 50 meters and the topography is less fragmented. Table 2 illustrates this trend. Surface complexity decreased as the flows matured in age. The found total means for surface complexity were 0.897 for McCartys, 0.956 for Bandera, 0.977 for Twin Craters, and 0.995 for El Calderon. Figures 10-17 display the graphed transects. The flow morphology differences are apparent when examining the graphs while accounting for scale differences between the graphs.



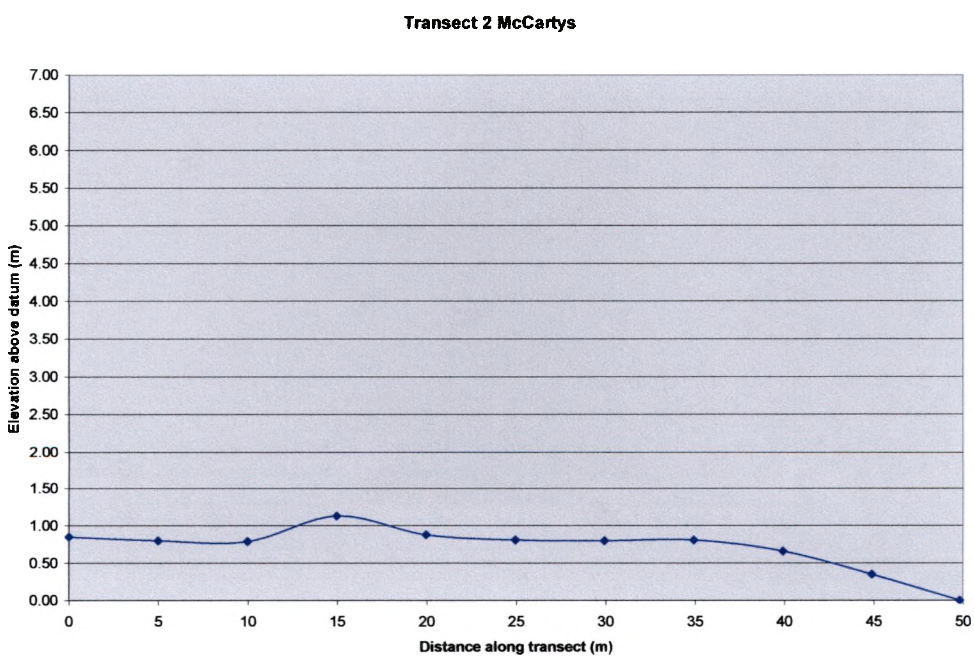
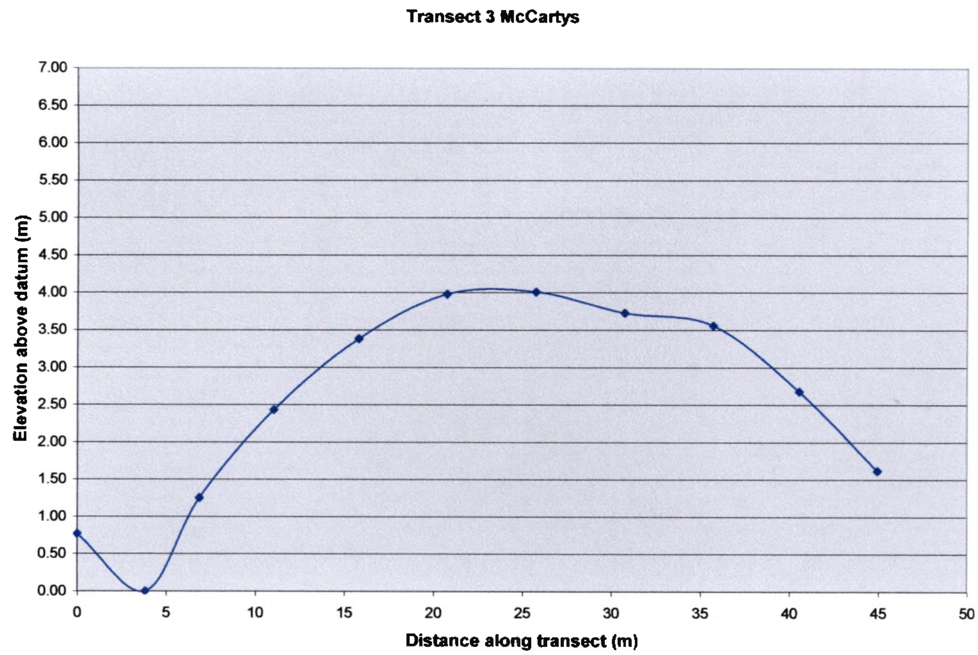


Fig. 10. McCartys Transects 1 and 2.



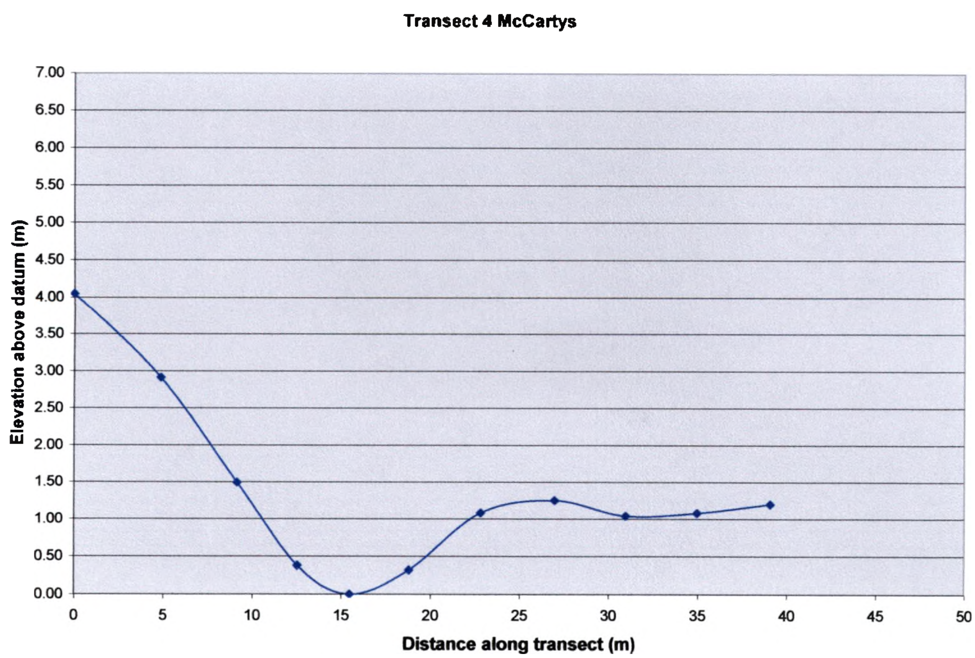
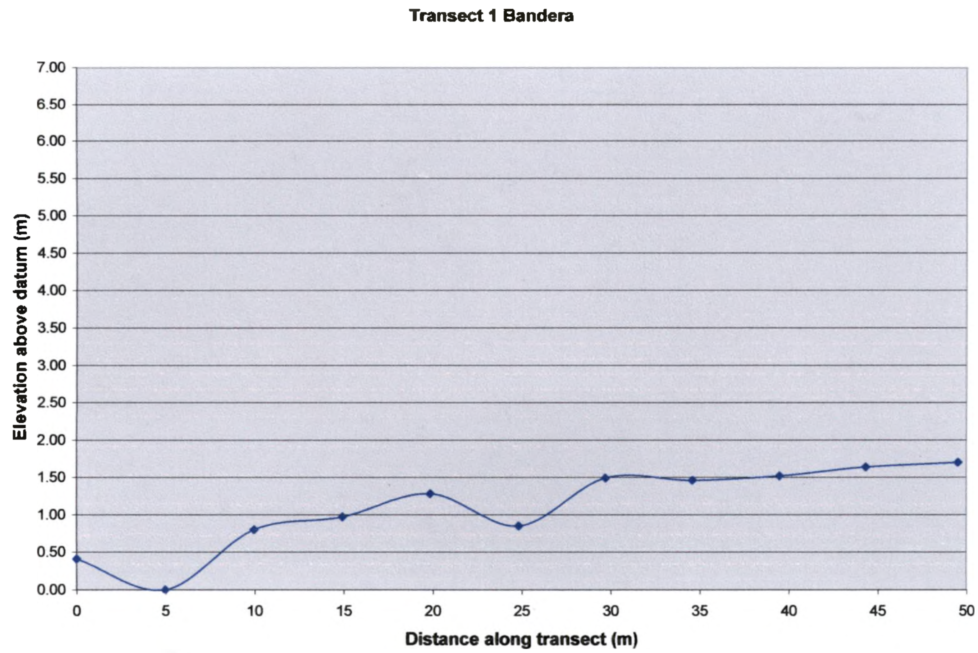


Fig. 11. McCatrys Transects 3 and 4.



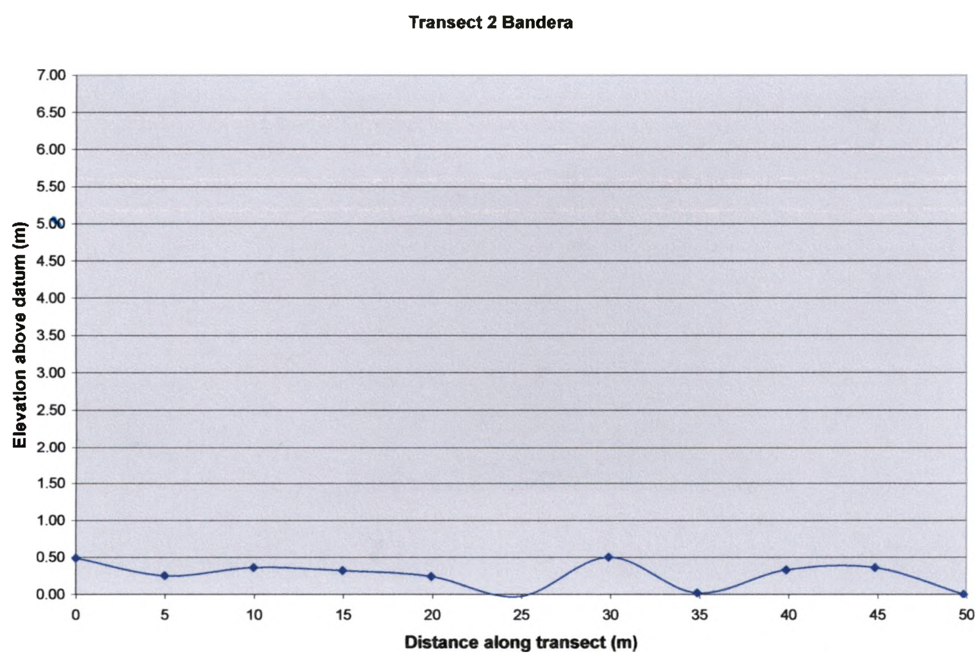
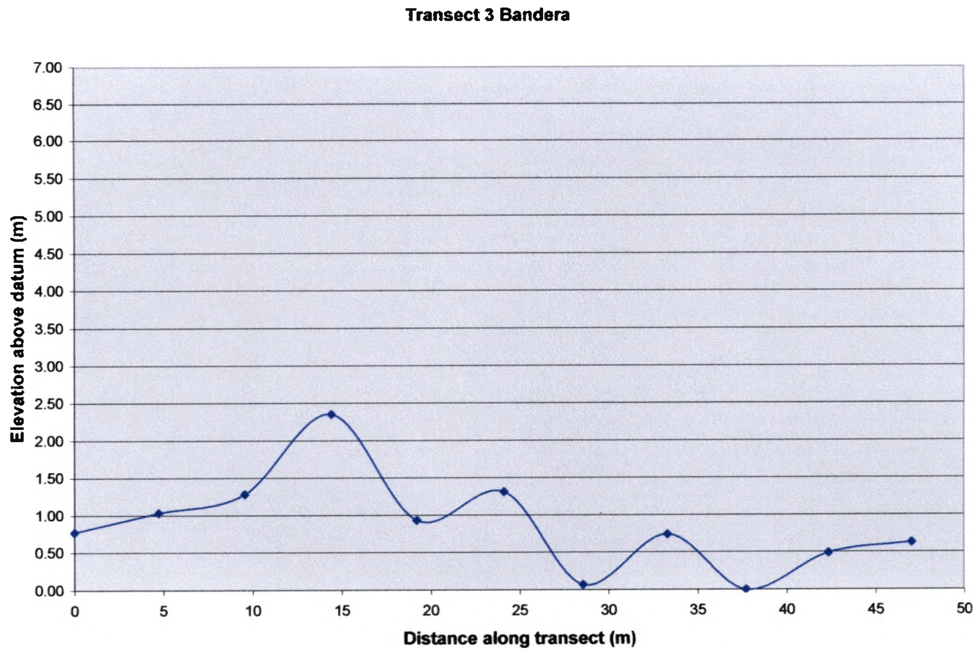


Fig. 12. Bandera Transects 1 and 2.



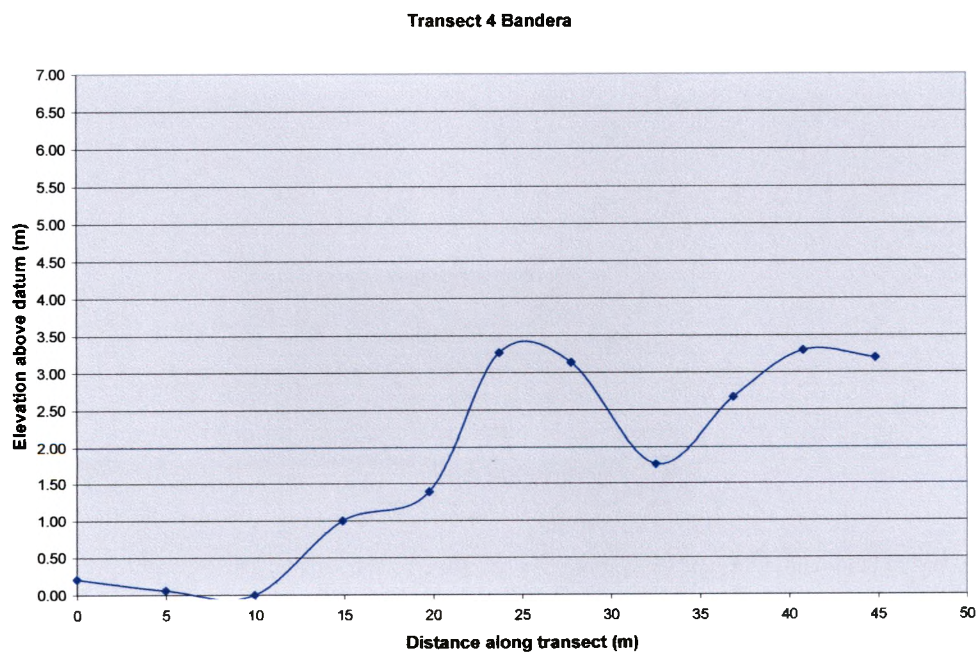
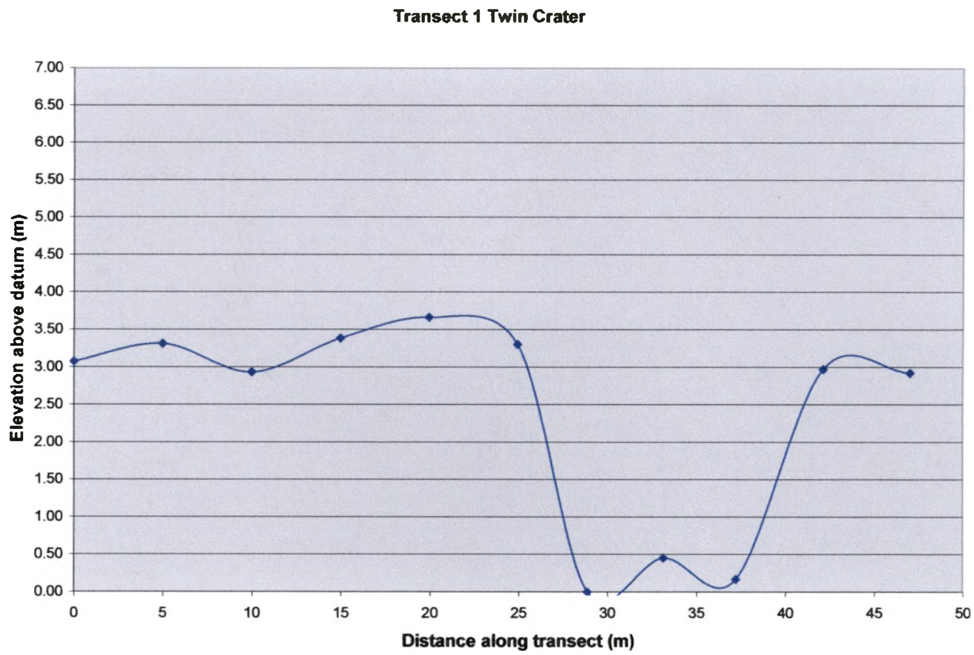


Fig. 13 Bandera Transects 3 and 4.



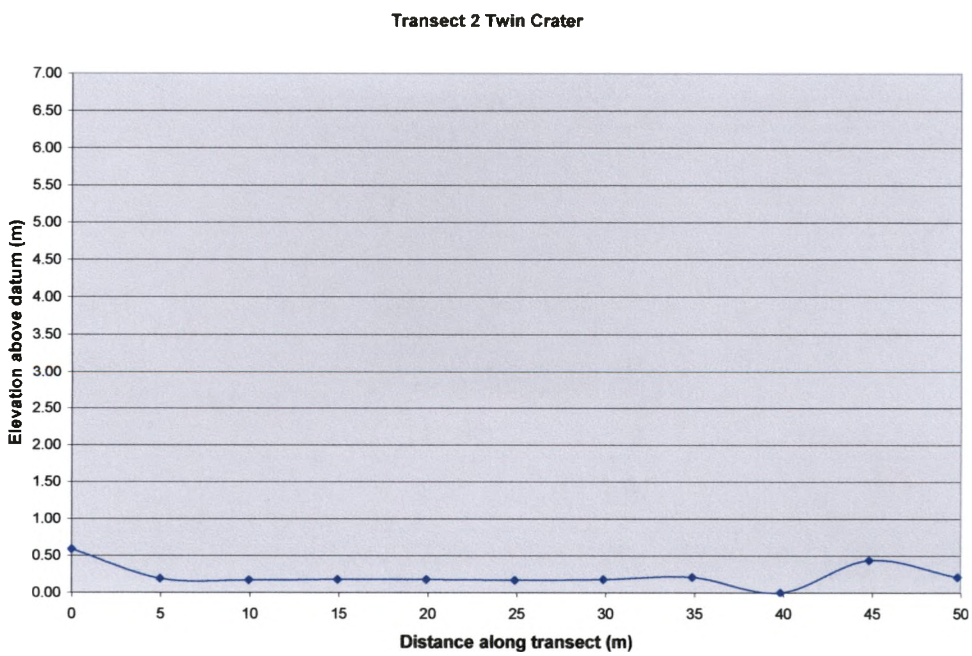
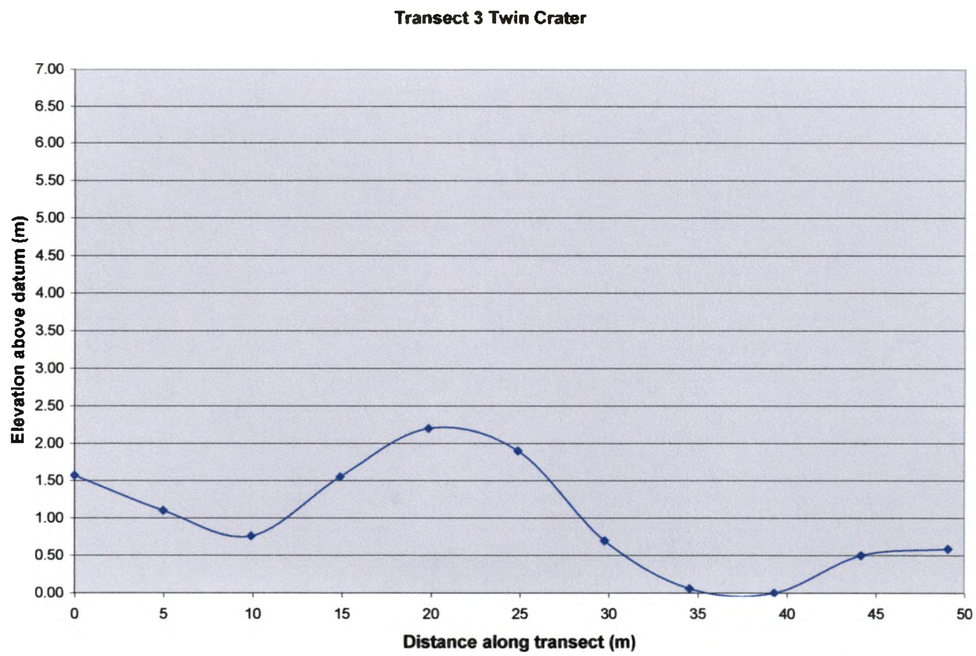


Fig. 14. Twin Crater Transects 1 and 2.



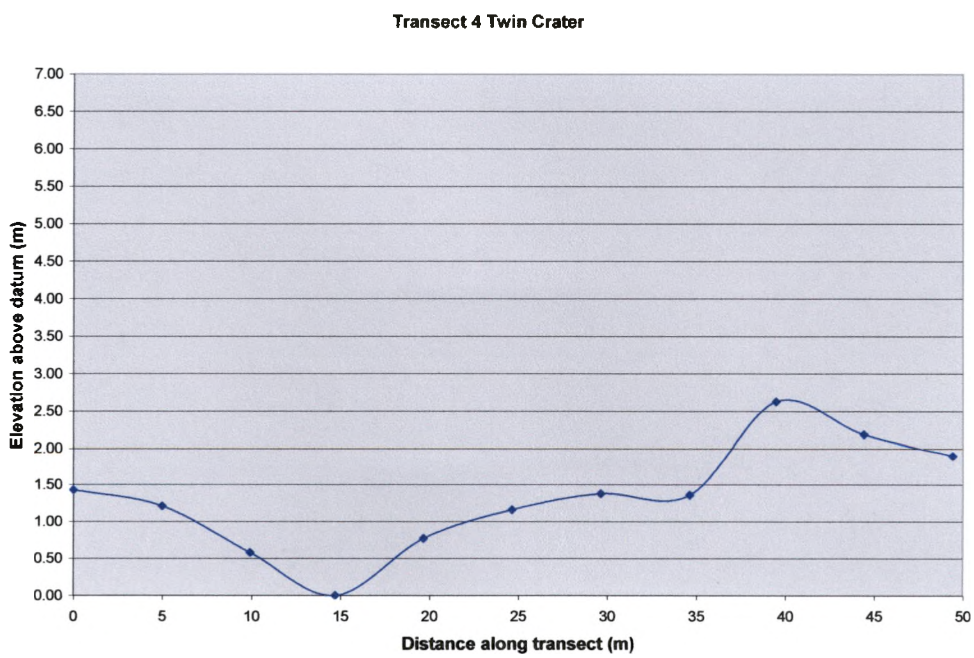
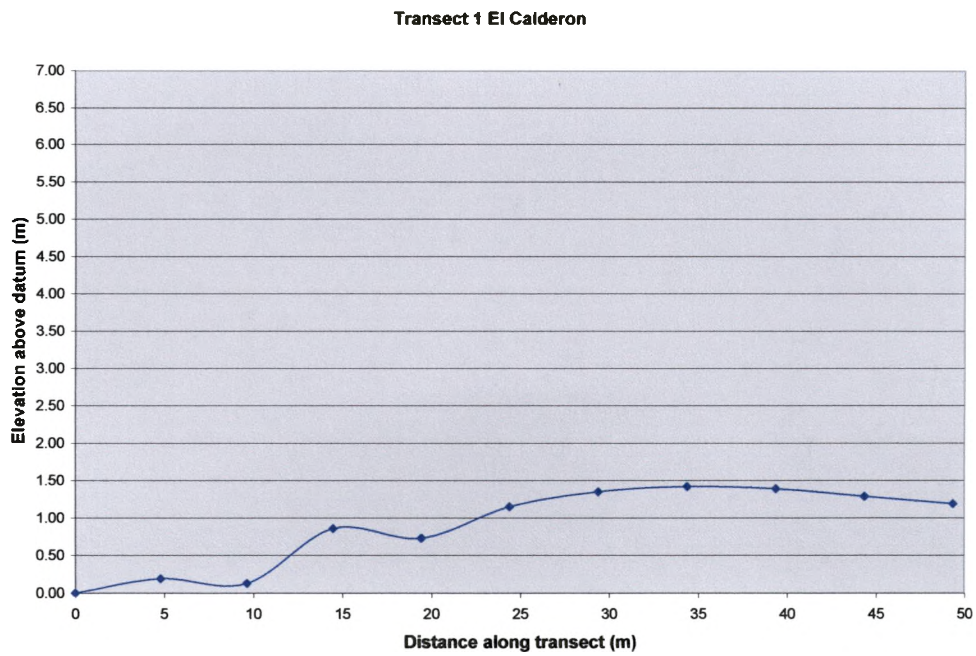


Fig. 15. Twin Crater Transects 3 and 4.



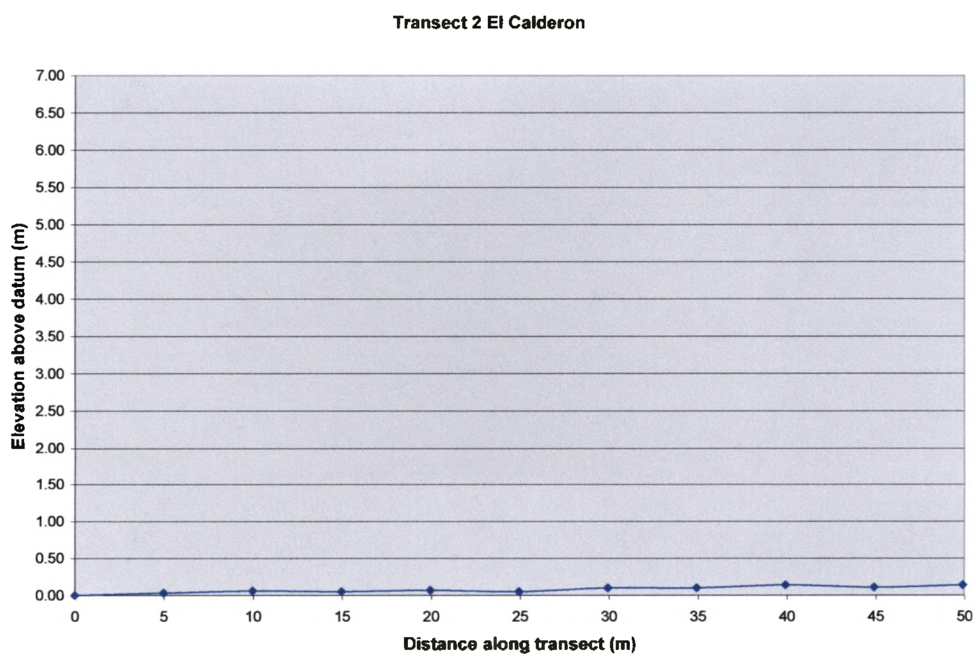
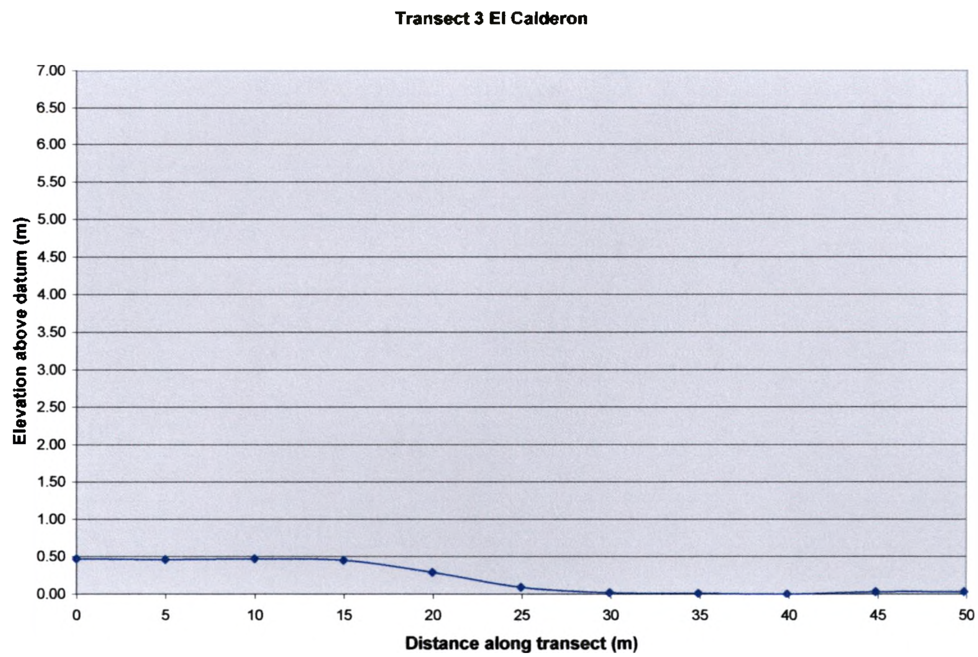


Fig. 16. El Calderon Transects 1 and 2.



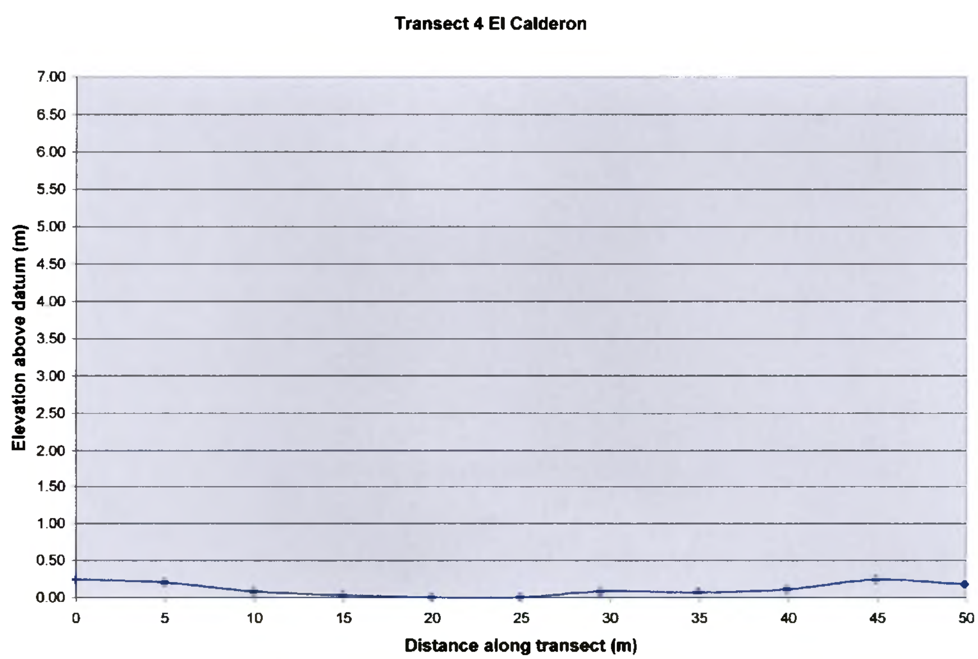


Fig. 17. El Calderon Transects 3 and 4.

TABLE 7

Surface complexity summary

McCartys	Bandera	Twin Craters	El Calderon
0.9114	0.9902	0.9402	0.9868
0.9964	0.9968	0.9964	0.998
0.899	0.9408	0.9814	0.9972
0.7816	0.8972	0.988	0.9982
Total Averages			
0.897	0.956	0.977	0.995

Results

Through varied forms of analysis, the data provide strong evidence that age is an important influence on vegetation growth. Vegetation cover increases as the age of the flow increases. The frequency of vegetation for the grass species increased as the flow increased in age. Density and cover also increase with age while plant diversity was not found to be linear. There was a higher number of individual plants on the first and third flow. Transect analysis provided support for the relationship between vegetation presence and age. Finally, surface complexity also exemplifies that as the age of the flow increases the morphology of the flow decreased in complexity.

CHAPTER 5

DISCUSSION OF THE RESULTS AND CONCLUSION

Random Quadrat Results

A positive linear relationship of 26% was determined between the percentage of vegetation cover of each quadrat and the age of the flows. Bandera had a lower plant cover than McCartys, which is attributed to its proximity to the crater and flow type. Yet, in general, there is a strong relationship between the age of the flows and the amount of vegetation cover present reflecting the reality of a natural habitat.

Frequency and Importance Value Results

Grass frequency increase with the age of the lava flows however similar to vegetation cover, Bandera had a lower recording than McCartys which is actually the youngest flow. Once more, this can be attributed to Bandera's closeness to the crater and the lack of vegetation found on each Bandera transect. When examining vegetation frequency, it appears that there is a possible frequency competition between grass and pine, juniper, and shrubs. As the flows increase in age, the grass frequency increases and the pine, shrub, and juniper frequency decreases.

The Importance Values (IVs) for grass were found to be a linear increase as the age of the flow increased. Grass IV for McCartys was 170 which was lower than

Bandera's IV of 185.7. This is significant because it is the first finding where Bandera typically reflects its age. The IVs found other plants groups to be less linear. Yet, similarly to the frequency results, it did appear that the IV of shrubs decreased with age while junipers were rather consistently important on each flow. The IVs of pines conflicted with their frequency results. While pine frequency decreased with age, the IV for McCartys was a six, which is the second lowest IV. Bandera's IV was recorded as a one, which is the highest IV, Twin Crater's IV was a six and El Calderon was a four. Due to the calculations for the IVs, it is possible to acquire a high frequency for a plant group and then a low IV. Another trend that was discovered is that McCartys and Twin Craters resulted similarly regarding IVs. Such as the pine group, or the Squawbush group was found to be a five for both flows and was not present on either Bandera or El Calderon. This result is possible because Bandera acts more as the youngest flow due to its proximity to the crater and therefore has less plant vegetation. As well, El Calderon, because it is the oldest flow, has become dominated by the grass plant group and therefore has lower plant group diversity. McCartys and Twin Craters had higher plant group diversity; all plant groups were present on both flows.

Chorological influences on plant vegetation are undoubtedly present. However, it is also apparent from the results that other factors influence plant vegetation growth on the lava flows. In reference to the hypothesis, general plant cover increased with age. Density, frequency, and cover per flow increased depending upon which plant group was examined. The grass plant group resulted the most uniformly to the hypothesis because of their increase with age.

Transect Analysis

The resulting data for the transects showed that age is not the only factor influencing vegetation growth, however it does have an important impact. The percentage of vegetation and soil did increase with age accounting for Bandera's unique location and lava type. In addition, it was found that on the two older flows where vegetation was present soil was also present while on the youngest flow, McCartys, vegetation presence did not necessarily predict soil presence. Soil presence can be attributed to time influences on the surface of the flow. As the age of the flow increases, the opportunity for soil creation and deposition is greater. Where soil presence was recorded, the amount of soil was minimal. Only a thin layer of soil was on the lava. Some scientist have hypothesized that the available soil is mostly eolian deposits from the nearby sandstone bluffs. However, soil accumulation did increase with the age of the flows, which suggests that the breakdown of the surface contributes to vegetation growth.

Surface Complexity

This research indicates that as the age of the flow increased the surface complexity decreased. This finding was in agreement with the hypothesis. As the surface complexity decreased, plant cover increased, in particular, the plant group grass increased in frequency. The plant group pines, shrubs, and junipers seemed to be more successful on the younger flows that had a higher surface complexity. It appears that as the surface complexity decreased and more soil accumulated the vegetation types reflected closer surrounding vegetation at that latitude rather than the younger flows, which had more mountainous type of vegetation. This is similar to what Bleakly (1997) discovered in his classification research of the flora and fauna of El Malpais.

Limitations of the Research

It is apparent from the results that other factors influence vegetation growth rather than just age. Other variables that research should consider include climatic variables and lava composition. To have a better understanding of the dynamics of vegetation growth more data and research is needed on each of the flows. The relationship between plant growth and surface complexities needs to be examined at different scales. Scale is an important variable that warrants addressing in future research. It is also important to be aware that there is possible cross correlation between the surface complexity decrease and temporal influences. Though there are different possible lines of causality, the most fitting and significant is the chorological influences on the vegetation. In the natural world there are many active variables however, according to the research in this study, it is apparent that time has a large influence on vegetation growth.

Other Temporal Vegetation Research

Temporal research has been applied to the vegetation studies of numerous Quaternary volcanic features. Researchers have found that as the plants grow back on the newly formed island time is the most significant influence on vegetation but that organics and parent material also influence the amount and types of vegetation (Frederiksen et al. 2001). This supports my findings at El Malpais, New Mexico. Since available research on the National Monument has little knowledge of the differences regarding plant growth on the flows, this research is an important beginning for future projects.

Conclusion

As William Stafford so eloquently expresses in his poem *Great is Earth our home*, this research has allowed me to enhance and deepen my relationship with the Earth as I *celebrate the weeds in the fields*. The seasons of time have had an important effect on the plant characteristics of El Malpais National Monument, New Mexico. While the results of the research have made it clear that other variables influence plant characteristics, it is also obvious that time has had a significant role in plant development. With this knowledge and hopefully inspiration for further knowledge, let us *sing in the wind.*

Weeds

What's down in the earth
comes forth in cold water,
in mist at night, in muttering
volcanoes that ring oceans
moving strangely at times.

And in autumn all the fields
witness forth: power there
where roots find it, rooms
delved silently and left
for the dark to have.

Up and down all highways
weed flags proclaim,
"Great is Earth our home!"
as we slip our hand
into winter's again.

Great is Earth our home.
Great is the sky.
And great are weeds in the fields.
We celebrate earth and air
as we sing in the wind.

-William Stafford (1994: 10)

APPENDIX I
INDIVIDUAL FLOW DATA

Quad	Name of Flow	Plant Group	Actual Cover (%)	Relative Cover (%)	Actual Desnsity	Relative Density (%)
10mQ1T1	McCartys	juniper	1	100	1	100
10mQ2T1	McCartys	juniper	18.2	70	2	7.7
		sage	2.6	10	1	3.8
		squawbush	3.9	15	3	11.5
		grass	0.26	5	20	76.9
1mQ1T1	McCartys	squawbush	2.86	22	1	7.7
		grass	10.14	78	12	92.3
1mQ2T1	McCartys	grass	2	100	2	100
10mQ1T2	McCartys	sage	20.16	72	18	64.3
		grass	7.84	28	10	35 7
10mQ2T2	McCartys	pinon pine	4.3	10	1	2.3
		long pine	4.3	10	1	2.3
		juniper	12.9	30	3	6.9
		sage	8.17	19	6	13.9
		grass	12.9	30	30	69.8
		cactus	0.43	1	2	4.7
1mQ1T2	McCartys	oak tree	2.28	57	1	25
		grass	1.72	43	3	75
1mQ2T2	McCartys	juniper	3.15	35	1	11.1
		sage	2.43	27	1	11.1
		grass	2.97	33	5	55.6
		grass	0.5	5	2	22.2
10mQ1T3	McCartys	pine	5.1	30	1	5.9
		juniper	6.8	40	2	11.8
		shrubs	3 4	20	4	23 5
		grass	1.7	10	10	58.8
10mQ2T3	McCartys	pine	4.62	42	2	18.2
		juniper	5.28	48	2	18.2
		grass	1.1	10	7	63.6
1mQ1T3	McCartys	grass	2	100	2	100
1mQ2T3	McCartys	grass	1	100	1	100
10mQ1T4	McCartys	pinon pine	13.57	23	5	8.5
		long pine	2.9	5	1	1.7
		juniper	11.2	19	4	6.8
		grass	23.6	40	40	67.8

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Quad	Name of Flow	Plant Group	Actual Cover (%)	Relative Cover (%)	Actual Desnsity	Relative Density (%)
		cactus	1 8	3	4	6.8
		shrubs	5.9	10	5	8.5
10mQ2T4	McCartys	pine	2.9	5	1	1.8
		juniper	2.3	4	1	1.8
		sage	32.5	57	30	56.6
		cactus	2.3	4	5	8.8
		grass	17.1	30	20	35.1
1mQ1T4	McCartys	cactus	0.72	12	1	16.6
		grass	1.4	23	4	66 6
		sage	3.9	65	1	16.6
1mQ2T4	McCartys	grass	1	100	1	100
10mQ1T1	Bandera	no vegetation				
10mQ2T1	Bandera	pine	1	100	1	100
1mQ1T1	Bandera	no vegetation				
1mQ2T1	Bandera	no vegetation				
10mQ1T2	Bandera	shrubs	2.6	51	4	80
		juniper	2.5	49	1	20
10mQ2T2	Bandera	juniper	1.9	31	1	16.6
		sage	1.9	32	1	16.6
		grass	2.2	37	4	66.7
1mQ1T2	Bandera	no vegetation				
1mQ2T2	Bandera	no vegetation				
10mQ1T3	Bandera	shrubs	2	100	1	100
10mQ2T3	Bandera	shrubs	1.5	50	2	66.7
		grass	1.5	50	1	33.3
1mQ1T3	Bandera	no vegetation				
1mQ2T3	Bandera	no vegetation				
10mQ1T4	Bandera	grass	1	100	1	100
10mQ2T4	Bandera	grass	1	100	1	100
1mQ1T4	Bandera	no vegetation				

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Quad	Name of Flow	Plant Group	Actual Cover (%)	Relative Cover (%)	Actual Desnsity	Relative Density (%)
1mQ2T4	Bandera	no vegetation				
10mQ1T1	TwinCraters	juniper	25.6	40	9	14.1
		pine	1.9	3	1	1.6
		ponderosa	2.6	4	1	1.6
		grass	27.5	43	50	78.1
		squawbush	6.4	10	3	4.7
10mQ2T1	TwinCraters	pinon pine	4	10	1	2.5
		juniper	16	40	4	10
		shrub	8	20	5	12.5
		grass	12	30	30	75
1mQ1T1	TwinCraters	pine overhar	0 3	30		
1mQ2T1	TwinCraters	juniperoverh	0.3	30		
10mQ1T2	TwinCraters	juniper	12	20	4	6.7
		oak tree	6	10	1	1.7
		pine	6	10	1	1.7
		grass	36	60	54	90
10mQ2T2	TwinCraters	pine overhar	7.5	10	1	1.4
		grass	67.5	90	70	98.6
1mQ1T2	TwinCraters	grass	30	100	30	100
1mQ2T2	TwinCraters	grass	18	100	18	100
10mQ1T3	TwinCraters	juniper	3.15	45	7	5.9
		grass	57.2	52	110	92.4
		cactus	0.06	3	2	1.7
10mQ2T3	TwinCraters	sage		22	4	3.6
		juniper		30	6	5.5
		grass		43	97	88.2
		cactus		5	3	2.7
1mQ1T3	TwinCraters	no vegetation				
1mQ2T3	TwinCraters	grass	12	100	12	100
10mQ1T4	TwinCraters	juniper	9	25	4	11.1
		oak tree	15.5	43	6	16.6
		long pine	1.8	5	1	2.8
		grass	9.7	27	25	69.4

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Quad	Name of Flow	Plant Group	Actual Cover (%)	Relative Cover (%)	Actual Desnsity	Relative Density (%)
10mQ2T4	TwinCraters	oak tree	19.4	51	8	21.1
		juniper	3.8	10	2	5.3
		cactus	0.8	2	1	2.6
		grass	14.1	37	27	71.1
1mQ1T4	TwinCraters	no vegetation				
1mQ2T4	TwinCraters	no vegetation				
10mQ1T1	El Calderon	juniper	11.2	62	2	11.1
		big cactus	2.7	15	1	55
		cactus	2.3	13	5	27.8
		grass	1.8	10	10	55.6
10mQ2T1	El Calderon	pine	14.7	15	1	1
		juniper	19.6	20	4	4.1
		grass	63.7	65	93	4.9
1mQ1T1	El Calderon	grass	10	100	10	100
1mQ2T1	El Calderon	grass	6	100	6	100
10mQ1T2	El Calderon	grass		85	120	97.6
		junipers		15	3	2.4
10mQ2T2	El Calderon	grass		80	140	97.2
		junipers		20	4	2.8
1mQ1T2	El Calderon	grass	35	100	35	100
1mQ2T2	El Calderon	grass	10	100	10	100
10mQ1T3	El Calderon	junipers		10	2	1.7
		grass		90	118	98.3
10mQ2T3	El Calderon	junipers		10	3	1.7
		cactus		3	1	0.6
		grass		17	40	22.9
		grass		70	130	74.7
1mQ1T3	El Calderon	grass	12	100	12	100
1mQ2T3	El Calderon	grass	22	100	22	100
10mQ1T4	El Calderon	juniper		66	5	7.5
		grass		34	62	92.5

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INDIVIDUAL FLOW DATA

Quad	Name of Flow	Plant Group	Actual Cover (%)	Relative Cover (%)	Actual Desnsity	Relative Density (%)
10mQ2T4	El Calderon	juniper		25	8	3.8
		shrubs		5	1	0.5
		grass		70	200	95.7
1mQ1T4	El Calderon	grass	20	100	20	100
1mQ2T4	El Calderon	grass	8	100	8	100

APPENDIX II
TRANSECT SURFACE COMPLEXITY

TRANSECT	FLOW	X	Y		X	Y
1	MCCARTY	0	0		0	3.7
1	MCCARTY	4 89	-1.05		4.89	2.65
1	MCCARTY	9 36	-2.24		9.36	1.46
1	MCCARTY	13.61	-2.63		13.61	1.07
1	MCCARTY	16.79	-3.7		16.79	0
1	MCCARTY	21.49	-1.7		21.49	2
1	MCCARTY	26.45	-0.64		26.45	3.06
1	MCCARTY	31.44	-0.1		31.44	3.6
1	MCCARTY	36.43	0.04		36 43	3.74
1	MCCARTY	41.29	1 187		41.29	4.887
1	MCCARTY	45.57	2.59	0.9114	45.57	6.29
2	MCCARTY	0	0		0	0.85
2	MCCARTY	4.99	-0.05		4.99	0.8
2	MCCARTY	9.98	-0.06		9.98	0.79
2	MCCARTY	14.97	0.28		14 97	1.13
2	MCCARTY	19.96	0.03		19.96	0.88
2	MCCARTY	24.95	-0.04		24.95	0.81
2	MCCARTY	29.94	-0.05		29 94	0.8
2	MCCARTY	34.93	-0 04		34.93	0 81
2	MCCARTY	39.92	-0.19		39.92	0.66
2	MCCARTY	44.89	-0.5		44.89	0.35
2	MCCARTY	49 82	-0.85	0.9964	49.82	0
3	MCCARTY	20 75	-3.21		0	0.77
3	MCCARTY	16.92	-3.98		3.83	0
3	MCCARTY	13.89	-2.73		6.86	1.25
3	MCCARTY	9 71	-1.55		11.04	2.43
3	MCCARTY	4.96	-0.6		15.79	3.38
3	MCCARTY	0	0		20.75	3.98
3	MCCARTY	4.99	0.03		25.74	4.01
3	MCCARTY	9.98	-0.25		30.73	3.73
3	MCCARTY	14.96	-0.42		35.71	3.56
3	MCCARTY	19.79	-1.3		40.54	2.68
3	MCCARTY	24.2	-2.36	0.899	44.95	1.62
4	MCCARTY	0	0		0	4.05
4	MCCARTY	4.87	-1.14		4.87	2.91
4	MCCARTY	9.16	-2.56		9.16	1.49
4	MCCARTY	12.55	-3.67		12.55	0.38
4	MCCARTY	15 48	-4 05		15 48	0
4	MCCARTY	18.81	-3.73		18.81	0.32
4	MCCARTY	22.83	-2.97		22.83	1.08
4	MCCARTY	26.97	-2.8		26.97	1.25
4	MCCARTY	30.96	-3.01		30.96	1.04
4	MCCARTY	34.98	-2 97		34.98	1.08
4	MCCARTY	39.08	-2.85	0.7816	39.08	1.2
1	BANDERA	0	0		0	0.41
1	BANDERA	4.98	-0 41		4.98	0
1	BANDERA	9.96	0.39		9 96	0.8
1	BANDERA	14.92	0.56		14.92	0.97

APPENDIX II
TRANSECT SURFACE COMPLEXITY

TRANSECT	FLOW	X	Y		X	Y
1	BANDERA	19.84	0.87		19.84	1.28
1	BANDERA	24.82	0 44		24.82	0.85
1	BANDERA	29.7	1.08		29.7	1.49
1	BANDERA	34.59	1.05		34.59	1.46
1	BANDERA	39.47	1.11		39.47	1.52
1	BANDERA	44.32	1.23		44 32	1 64
1	BANDERA	49.51	1.29	0.9902	49.51	1.7
2	BANDERA	0	0		0	0.49
2	BANDERA	4.99	-0.24		4.99	0.25
2	BANDERA	9.98	-0 13		9.98	0.36
2	BANDERA	14.97	-0.17		14 97	0.32
2	BANDERA	19.94	-0.25		19.94	0.24
2	BANDERA	24.91	-0.52		24 91	-0.03
2	BANDERA	29.9	0 01		29.9	0.5
2	BANDERA	34 88	-0.47		34 88	0.02
2	BANDERA	39.87	-0.16		39.87	0.33
2	BANDERA	44.86	-0.13		44.86	0.36
2	BANDERA	49.84	-0.49	0.9968	49.84	0
3	BANDERA	0	-1.58		0	0.77
3	BANDERA	4.74	-1.32		4.74	1.03
3	BANDERA	9.56	-1.07		9.56	1.28
3	BANDERA	14 44	0		14.44	2.35
3	BANDERA	19.23	-1.42		19.23	0.93
3	BANDERA	24.12	-1.04		24 12	1.31
3	BANDERA	28.57	-2 28		28 57	0.07
3	BANDERA	33.3	-1 61		33 3	0.74
3	BANDERA	37.71	-2.35		37.71	0
3	BANDERA	42.35	-1.86		42.35	0.49
3	BANDERA	47.04	-1.72	0.9408	47.04	0.63
4	BANDERA	0	0		0	0 21
4	BANDERA	4.99	-0 15		4 99	0.06
4	BANDERA	9.98	-0.21		9.98	0
4	BANDERA	14.92	0.79		14.92	1
4	BANDERA	19.78	1.18		19.78	1.39
4	BANDERA	23.73	3.06		23.73	3.27
4	BANDERA	27.78	2.93		27.78	3.14
4	BANDERA	32.53	1.55		32.53	1.76
4	BANDERA	36.88	2.46		36.88	2.67
4	BANDERA	40.81	3.09		40.81	3.3
4	BANDERA	44.86	2.99	0.8972	44.86	3.2
1	TWINCRATER	0	0		0	3.07
1	TWINCRATER	4.99	0 24		4 99	3.31
1	TWINCRATER	9.98	-0.14		9.98	2.93
1	TWINCRATER	14.97	0.31		14.97	3.38
1	TWINCRATER	19.94	0.59		19.94	3.66
1	TWINCRATER	24.93	0.23		24.93	3.3
1	TWINCRATER	28.88	-3 07		28.88	0
1	TWINCRATER	33.14	-2.62		33.14	0.45

APPENDIX II
TRANSECT SURFACE COMPLEXITY

TRANSECT	FLOW	X	Y		X	Y
1	TWINCRATER	37.21	-2.9		37 21	0.17
1	TWINCRATER	42.11	-0 1		42.11	2.97
1	TWINCRATER	47.01	-0 15	0.9402	47.01	2.92
2	TWINCRATER	0	0		0	0.59
2	TWINCRATER	4.98	-0.4		4.98	0.19
2	TWINCRATER	9.96	-0.42		9 96	0 17
2	TWINCRATER	14.94	-0.41		14 94	0.18
2	TWINCRATER	19.92	-0.41		19.92	0.18
2	TWINCRATER	24.9	-0.42		24.9	0.17
2	TWINCRATER	29.88	-0 41		29.88	0 18
2	TWINCRATER	34 87	-0 38		34.87	0.21
2	TWINCRATER	39.84	-0.59		39.84	0
2	TWINCRATER	44.83	-0.15		44.83	0.44
2	TWINCRATER	49 82	-0.38	0.9964	49 82	0.21
3	TWINCRATER	0	0		0	1.57
3	TWINCRATER	4.98	-0.47		4.98	1.1
3	TWINCRATER	9.91	-0.81		9.91	0.76
3	TWINCRATER	14.9	-0.02		14 9	1.55
3	TWINCRATER	19.86	0.63		19.86	2.2
3	TWINCRATER	24.89	0.33		24.89	1.9
3	TWINCRATER	29.77	-0.87		29.77	0.7
3	TWINCRATER	34.54	-1.51		34.54	0.06
3	TWINCRATER	39.29	-1.57		39.29	0
3	TWINCRATER	44.17	-1.07		44.17	0.5
3	TWINCRATER	49.07	-0.98	0.9814	49 07	0.59
4	TWINCRATER	0	0		0	1.43
4	TWINCRATER	4 99	-0.22		4.99	1.21
4	TWINCRATER	9.92	-0.85		9.92	0.58
4	TWINCRATER	14.71	-1.43		14.71	0
4	TWINCRATER	19.67	-0.66		19.67	0 77
4	TWINCRATER	24 66	-0 27		24 66	1.16
4	TWINCRATER	29.65	-0.05		29.65	1.38
4	TWINCRATER	34.64	-0.07		34 64	1.36
4	TWINCRATER	39.49	1 2		39.49	2.63
4	TWINCRATER	44.43	0 76		44.43	2.19
4	TWINCRATER	49.41	0.47	0.9882	49.41	1.9
1	ELCALDERON	34.37	-1.42		0	0
1	ELCALDERON	29.58	-1.23		4.79	0.19
1	ELCALDERON	24.73	-1.29		9.64	0.13
1	ELCALDERON	19.9	-0.56		14.47	0.86
1	ELCALDERON	14.93	-0.69		19.44	0.73
1	ELCALDERON	9 98	-0.27		24 39	1.15
1	ELCALDERON	4.99	-0.07		29 38	1.35
1	ELCALDERON	0	0		34.37	1.42
1	ELCALDERON	4.99	-0.03		39.36	1.39
1	ELCALDERON	9.98	-0 13		44.35	1.29
1	ELCALDERON	14.97	-0.23	0.9868	49.34	1.19
2	ELCALDERON	0	0		0	0

APPENDIX II

TRANSECT SURFACE COMPLEXITY

TRANSECT	FLOW	X	Y		X	Y
2	ELCALDERON	4.99	0.03		4.99	0.03
2	ELCALDERON	9.98	0 06		9.98	0.06
2	ELCALDERON	14 97	0.05		14.97	0 05
2	ELCALDERON	19.96	0.07		19 96	0.07
2	ELCALDERON	24.95	0.05		24.95	0.05
2	ELCALDERON	29.94	0.1		29 94	0.1
2	ELCALDERON	34.93	0.1		34.93	0.1
2	ELCALDERON	39.92	0.14		39.92	0.14
2	ELCALDERON	44.91	0.11		44.91	0.11
2	ELCALDERON	49.9	0 14	0.998	49.9	0.14
3	ELCALDERON	0	0		0	0.47
3	ELCALDERON	4.99	-0.01		4.99	0.46
3	ELCALDERON	9.99	0		9.99	0.47
3	ELCALDERON	14.98	-0.02		14 98	0.45
3	ELCALDERON	19.97	-0.18		19 97	0.29
3	ELCALDERON	24.96	-0.38		24.96	0.09
3	ELCALDERON	29.94	-0.45		29.94	0.02
3	ELCALDERON	34.92	-0.46		34.92	0.01
3	ELCALDERON	39.9	-0.47		39.9	0
3	ELCALDERON	44.88	-0.44		44.88	0.03
3	ELCALDERON	49.86	-0.44	0.9972	49.86	0.03
4	ELCALDERON	0	0		0	0.24
4	ELCALDERON	4.99	-0.04		4 99	0.2
4	ELCALDERON	9.98	-0.16		9.98	0.08
4	ELCALDERON	14.97	-0.21		14 97	0.03
4	ELCALDERON	19 96	-0 24		19.96	0
4	ELCALDERON	24.95	-0.24		24.95	0
4	ELCALDERON	29.44	-0.16		29.44	0.08
4	ELCALDERON	34.93	-0.17		34.93	0.07
4	ELCALDERON	39.92	-0 13		39.92	0.11
4	ELCALDERON	44.92	0		44.92	0.24
4	ELCALDERON	49.91	-0.06	0.9982	49.91	0.18

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