THE GEOMORPHIC IMPACTS OF

MARMOTS IN GOTHIC, COLORADO

THESIS

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This thesis is dedicated to John Thomas Kizer (1978 – 2003), a good friend of mine who was taken from those he loved while I was writing this thesis. This manuscript was submitted on November 21, 2003.

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CHAPTER I

INTRODUCTION

Marmots (Genus *Marmota)* are burrowing mammals that excavate complex burrow systems in alpine environments around the world. Marmots act as geomorphic agents and thereby contribute to erosion and sediment transfer in the alpine environments in which they live. This research, based within the field of environmental geography, seeks to quantify how much sediment is excavated by yellow-bellied marmots (*Marmota flaviventris*) (Figure 1.1) by using basic field methods. This research also examines if marmots' excavations contribute to landslides, rockfalls, or other geomorphic processes by examining the question "are marmots a significant component of the slope debris cascade"? The research also provides qualitative descriptions of environmental conditions (slope aspect, steepness, burrow opening shapes) found at marmot burrows.

Chapter 1 of this thesis is divided into five sections that provide an overview of this topic. The first section describes the significance of the research and why this research is useful for environmental geographers. The second section deals with the research questions posed for this study. Limitations of the research are considered in the third section, while concepts and terms associated with the research are discussed in the fourth section. Finally, a reader's guide to the thesis is presented as the final section of this chapter.

Fig. 1.1. Photograph of a yellow-bellied marmot (*Marmota flaviventris*)

Significance of the Research

This research is significant because it provides the first quantification of soil excavation by marmots in the United States. The amount of sediment excavated by marmot burrowing is not well understood and "very few quantitative data exists on the actual amount of sediment removed from marmot burrows and subsequently eroded" (Butler 1995, p128). Therefore, understanding the quantity of sediment redistributed by marmots in an alpine environment will enable researchers to gain further knowledge of alpine ecology and the role marmots play in these ecosystems.

Another reason why this research is significant is because the effects of burrowing on a landscape are widespread. Broad tunnel complexes created by marmots affect geomorphic process because digging bioturbates sediment above and below the surface, leads to the formation of mounds from sediment that has been rearranged by animals, and may produce unique landforms (Butler 1995). Mammalian burrowing results in the rearrangement and deposition of soil that creates unique geomorphic conditions which may also affect vegetation cover above the burrows (Butler 1995; Del Moral 1984). The existence of burrowing mammals on slopes also has a geomorphic impact that influences slope development and slope stability. Marmot burrows are a common sight at elevations above 2900 m in the Elk Mountains of Colorado, and are therefore important components of landform development.

The impact of burrowing by marmots effects alpine landscapes in direct and indirect ways. Directly, they (1) destroy vegetation by digging up rooting systems, (2) bring subsurface soils to the surface during the process of excavation, (3) degrade the stability of slopes by excavating beneath large rocks, (4) change the concentration and density of subsurface material by exposing it to weathering processes on the surface, (5) physically move soil, gravel, and rocks down slope during burrow creation (Price 1971) and (6) they create large mounds of sediment on the surface. Indirectly, marmots (1) rearrange nutrients by changing soil properties at the surface, (2) change plant communities by burying some plants, which enables other plants to initiate primary succession, and (3) compact extruded soil on the surface and presumably on the floors of their tunnels, both of which may adversely affect infiltration capacity (Price 1971).

Finally, this research is significant due to a lack of prior research in this field. Even though marmots have been studied extensively in the United States, little research exists on actual volumes of sediment removed (Butler 1995). Sediment movement by marmots has been studied by Russian soil scientists in the Eastern Pamirs; however their research was conducted on the red marmot (*Marmota caudate*), which occupies a slightly different habitat than the yellow-bellied marmot (Tadzhiyev and Odinoshoyev 1987). The research conducted in that study is quite different from this research, and they did not actually quantify the amount of sediment displaced. Scientists have also studied the geomorphic impact of other mammals, like bears, beavers, arctic ground squirrels, pocket gophers, and wombats; however, a review of zoogeomorphic literature did not produce any previous research conducted on the yellow-bellied marmot. A lack of research on this topic merits further investigation.

Research Questions

This paper addresses four research questions:

1. Can sediment excavation by quantified using standard field methods? If so, how much sediment do yellow-bellied marmots move during one summer season?

2. Does marmot excavation affect slope stability and integrity?

3. Do marmots move a significant amount of sediment compared to bears, ground squirrels, pocket gophers, or other small mammals?

4. Do marmot burrows occur at all azimuths in equiprobability?

Hypotheses:

Ho: Sediment removal by marmots cannot be quantified by using standard field methods.

H^1: Sediment removed by marmots can be quantified by using standard field methods.

Another hypothesis concerning marmots' role in natural hazards will also be investigated.

Ho: Marmot burrows have no affect on landslides, rockfalls, or other geomorphic processes that may affect human beings.

H^1: Marmot burrows have an affect on landslides, rockfalls, and other geomorphic processes that may affect human beings.

A hypothesis examining marmot's contribution to erosion processes when compared to other animals is also tested.

Ho: Marmots have little impact on erosion when compared to other mammals like bears, porcupines, ground squirrels, and voles.

H^1: Marmots have a great deal of impact on erosion when compared to other mammals like bears, porcupines, ground squirrels, and voles.

The hypothesis concerning the idea that all burrows occur in equiprobability follows.

Ho: Marmot burrows occur at all azimuths in equiprobability.

H^1: Marmot burrows do not occur at all azimuths in equiprobability.

Limitations of the Research

The research presented in this thesis is limited for a variety of reasons. The major limitation to this research is that the data do not account for all of the sediment excavated by marmots. The research cannot account for the total volume excavated because it is believed that marmot burrows are probably larger than the measurements taken in this study. As burrow systems are complex underground systems, knowing their subsurface extent is impossible to determine without destroying marmot habitat or exercising live capture methods. Therefore, this research presents an underestimate of sediment excavated from the system.

This research is also limited because it does not explain all of the geomorphic and biogeographic impacts that marmots have on alpine ecosystems. Marmots affect the landscape in a myriad of ways and sediment movement is only one component of their effects. Evidence is presented in this thesis that suggests marmots play a role in landslides and rockfalls; however, this thesis does not attempt to conclude that marmots are the only factors contributing to slope failure in the study areas. This research does not make any conclusions about the impacts of marmot burrows on plant community diversity and rates of succession around burrowing sites.

Major Concepts and Terms Associated with the Research

Various concepts and terms are associated with this research. The following section explains some unfamiliar concepts and terms to the reader.

Geomorphology

Geomorphology is a science that examines the form and shape of landforms and how they change. Geo, from the Greek word geo, means Earth, while morph, from the Greek word morphe, means shape or form. When combined with ology, or the study or science of, the word geomorphology clearly means the study of the Earth's shapes and forms. Geomorphology is mainly studied by geologists and geographers, and the science has both geographic and geologic roots. Major paradigms within the field of geomorphology include the dynamics of landform development and the evolution of slope formation (Friend et al. 2000).

Zoogeomorphology

Zoogeomorphology examines the role animals play in landscape development. The science seeks to quantify the changes and alterations, mainly geomorphic, that specific organisms make upon the land. It is a relatively new scientific field that is still in the initial stages of development. Pioneered by scientists like George Malanson, Larry Price, and David Butler, zoogeomorphology is "fundamental to a thorough understanding of Earth-surface processes and landforms" (Butler 1995, p3). Animals' manipulations of their environment and the effects these processes have on soil cover, substrate, flora, and sediment movements are the main focus of zoogeomorphology. Understanding marmots' interactions with their environment should provide some valuable information on alpine geomorphology and should contribute to the field of zoogeomorphology.

Threshold Theory

This research will be based in threshold theory, which is based on equilibrium theory. In physical geography, threshold theory states that processes occur at equilibrium, with very little change occurring in the system until a breaking point is reached. At this breaking point, or threshold, change occurs and the system adapts to the change. In this research, the role marmots play in the alpine ecosystem is investigated. As marmots excavate all season long, marmots may continue to excavate a site until a threshold point is reached, thus forcing them to begin excavation in another site.

Threshold levels that are exceeded due to marmots will lead to changes in the system, such as landslides and rockfalls. The idea of a geomorphic threshold relates to the idea that landscapes act as complete systems. If sediment is removed from the system, a slope's integrity may be compensated, causing a catastrophic event like a landslide or rockfall (Wilkerson 2001). These events permanently alter a landscape, forcing all properties of that system to adjust and respond accordingly.

Formulas Used to Calculate Volume of Sediment Excavated

During field work, marmot burrows were classified into basic geometric shapes such as triangles, ovals, rectangles, and squares. Formulas used for all volume calculations can be found in chapter 4. When volume calculations began, it became apparent that some of the rectangles were improperly labeled in the field and should have been labeled trapezoids, as burrows with four irregular sides have a trapezoidal shape rather than a rectangular shape. Trapezoids are four sided quadrilaterals with one pair of parallel sides while rectangles have two pairs of parallel sides. Therefore, rectangles with one pair of parallel sides were reclassified as trapezoids during data processing to account for this discrepancy.

Reader's Guide to this Thesis

The following chapters are organized into sections that deal with particular aspects of this thesis. Chapter two presents a review of the literature that is relevant to this thesis. Chapter three provides a site description, as well as a map of Gothic, Colorado. Methods of data analysis are presented in chapter four. Chapter five documents the results of the field work conducted in June, 2003. Chapter six explores the research questions in a discussion format while chapter seven presents avenues for future research and contributions of the research.

CHAPTER II

LITERATURE REVIEW

Current literature on the geomorphic impacts of marmots is limited; however, a great deal has been written on marmots' biology and natural history. This chapter is designed to inform the reader about marmots' life history characteristics with attention given to their daily habits. This chapter also contains several sections detailing relevant literature that has been written on marmots in the last sixty years.

The idea behind geomorphic thresholds is discussed in the first section of this chapter. The second section details marmot's life history patterns, while the third section introduces some literature that has been written on the structure of marmot burrows. The final section addresses previous geomorphic work done on other mammals.

Theoretical Framework

Landscapes act as systems, therefore; debris flow cascades, like landslides, are portrayed in terms of geomorphic thresholds events that modify a system due to quick and abrupt alterations of properties within the system (Ritter et al. 1999). Rockfalls, landslides, slumps, and other debris flows are set in motion by unexpected changes in a structure during which a threshold is surpassed (Wilkerson 2001). These unforeseen changes often occur due to the addition of variables (i.e. rain, snow, or wind), or when a variable such as soil or bedrock, is extricated from the system. In other words, internal and external geomorphic controls may lead to unstable slopes and slope failure (Schmidt and Beyer 2002). As soil and substrate are reorganized within a landscape, certain properties of the landscape system will become altered. Excavation of soil beneath bedrock may contribute to the weakening of some rock types and may cause small scale landslides and/or rockfalls to occur. Burrowing mammals, including marmots, may therefore weaken certain rock types to the point at which a threshold is reached and the system fails. When the threshold event occurs, a landscape is permanently altered to the point that it cannot be reconstructed or reorganized (Wilkerson 2001).

Geomorphic Thresholds

The concept of geomorphic thresholds is one of the anchors of General Systems Theory. The idea of thresholds, first described in 1973 by S.A. Schumm, proposes that equilibrium conditions controlled by weather patterns and other external forces can be thrown into a state of disequilibrium if certain controlling factors are modified (Ritter et al. 1999). One can also conceptualize the idea of thresholds by thinking of a system that fluxes between states of equilibrium and disequilibrium. For example, Ritter and colleagues (1999) suggest that four traits can be used to characterize geomorphic thresholds: (1) they are exposed by changes in morphology that prohibit a landform from returning to its pre-existing condition prior to another catastrophic event; (2) the landform exhibits a fresh equilibrium condition that is a result of the disruptive event; (3) the incident is dependent upon time and space; and (4) they can be recognized by the paradigms used to describe geomorphology. The aforementioned ideas have been introduced to most geomorphic systems and some believe that the threshold theory symbolizes the structural framework of contemporary geomorphology (Ritter et al. 1999).

Natural History of Marmots

Yellow-bellied Marmots are well-studied animals that live in colonies at high elevations above 2900 m in areas that have few trees and shrubs. Colonies refer to marmots in the same social group. Colonies are arranged into multiple harems, which include at least one adult female capable of reproducing along with their young. Territorial males are also associated with each harem (Armitage 1965; Svendsen 1974).

After hibernating during the winter, marmots emerge from their burrows in late April or early May, depending upon the arrival of spring (Armitage 1991). Shortly after emerging from the melting snow pack, marmots begin to forage and to construct new burrows. Marmots usually construct burrows beneath large rocks on steep mountain sides or in the middle of large meadows surrounded by trees, rivers, boulders, or herbaceous plants. Marmots also dig burrows beneath large bushes, willow trees, and smaller rocks. Some burrows even occur along natural cracks and crevices in large, exposed pieces of bedrock. Large boulders above burrows are used to look out for predators and for sun bathing (Blumstein et al. 2001; Tyser 1980). Research has shown that marmots dig numerous burrows in an area to reduce the likelihood of predation (Blumstein et al. 2001). For example, yellow-bellied marmots tend to avoid wide open meadows for burrows due to encroachment by badgers and other predators. Burrows serve three main purposes: as a home or nest, for hibernation, and for shelter from predators. If predators encroach upon a marmot's habitat, the animal will quickly move to the nearest flight burrow, which has only a single entrance. Marmots prefer however, to retreat to a nesting burrow, which usually has multiple entrances (Armitage 1991).

Marmot density tends to conform to the scattered patches of forest and meadow vegetation that occur in mountainous areas in the western United States (Armitage 1991; Svendsen 1976). Geology and the underlying substrate appear to play major roles in determining ideal habitats for marmots. Svendsen (1976) found that marmots do not make burrows beneath flat (5-10 cm thick) sedimentary rocks that are less than 40 cm in diameter because these rocks are too small to burrow beneath. He also found that in areas where suitable habitat exists, marmots have excavated almost every rock during the lifetime of the colony (Svendsen 1976). Understanding the relationship between marmots and different rock strata will help to determine why marmots excavate in some areas, but not in others.

Yellow-bellied marmots have an average burrow density of 4.3 burrows per home range (Armitage 1975; Svendsen 1974). Svendsen (1976), however, claims that in an area only 0.85 ha large, 78 marmot burrows existed in multiple stages of use, with only four to six being used regularly. The large differences reported by Svendsen in different years may indicate a superior habitat existed in that area or it could be indicative of different terms used to describe the average number of burrows per home range. Perhaps the averages reported in Table 2.1 refer only to burrows in use, thereby explaining this large discrepancy. Another explanation relates to marmot density; larger populations have more burrows while smaller populations require fewer burrows. Home ranges of social groups average 0.1-7.2 ha while average home range size is about 3.65 ha (Armitage 1975; Svendsen 1974). Burrow density numbers are similar to those of

Table 2.1. Marmot Burrow Densities

Species	Burrow density[a]	Home range area (ha)[b]	$\bar{x}$ area (ha)[c]	References
M. camtschatica	1.5–2.1	13.0	13.0	Mosolov & Tokarsky (1994)
M. monax	3.6–6.4	0.6–1.3	0.95	Henderson & Gilbert (1978); Ferron & Ouellet (1989); Swihart (1991); Meier (1992)
M. flaviventris	4.3	0.1–7.2	3.65	Svendsen (1974); Armitage (1975, 1988)
M. olympus	6.1–26.5	2.0–8.7	5.35	Barash (1973); Wood (1973); Blumstein 1999
M. baibacina	10–45	2.1–3.6	2.85	Pole & Bibikov (1991); Rogovin (1992)
M. sibirica	16–37	1.7	1.7	Seredneva (1991); Rogovin (1992)
M. caligata	32	13.8–20.5	17.15	Holmes (1979); Blumstein 1999
M. marmota	34.3–46.9	0.7–5.0	2.85	Arnold (1993); Perrin & Allainé (1993), Perrin et al. (1993), Allainé et al. 1994, Bel et al. (1995); Sala et al. (1996); Herrero et al. (1997)
M. caudata	35.4	0.6–7.0	3.8	Davydov (1991); Blumstein 1998, Blumstein & Arnold (1998) unpubl. data
M. bobac	94.1, core area	0.7–1.5	1.1	Savchenko & Ronkin (1997); Blumstein, unpubl. data
M. vancouverensis	148.4, core area	3.0	3.0	Heard 1977, this study

[a]Total number of main and escape burrows in marmot home ranges. [b]Average social group home range, when reported. In the case of multiple studies, we report the total range. [c]Average home range size, or midpoint of the range.

Note: This table was not created for this study and the term "this study" refers to Blumstein et al., 2001.
Source: Blumstein, Daniel T., Janice C. Daniel and Andrew A. Bryant. 2001. Anti-predator behavior of Vancouver Island marmots: Using congeners to evaluate abilities of a critically endangered mammal. *Ethology* 107: 1-14.

other marmot species in the world like *M. camatschatica* and *M. monax*, but are much smaller than other species like *M. sibrica* and *M. olympus* (Armitage 1991; Blumstein et al. 2001).

Marmots spend 72 to 84% of their day in their burrows, 7 to 16% foraging, and 8 to 12% resting above ground (Armitage 1991). Overall, they spend about 80% of their life in a burrow, which provides them with shelter from the harsh environmental conditions in which they exist. Burrows also serve as safe havens from predators, nurseries for young, and a place to avoid social interactions. More importantly however, burrows function as a place to hibernate in the winter, which accounts for roughly 60% of the overall subterranean life of a marmot (Svendsen 1974). Different burrows are selected for different tasks, as each burrow provides marmots with different features (Svendsen 1974; Armitage 1991). Therefore, burrows are perhaps the most important feature in a marmot's life.

Although little research has been conducted on the effects marmots have on a landscape, one study has been conducted on the Olympic Marmots' (*M. olympus*) effect on subalpine vegetation structure and species composition. Roger Del Moral's 1984 study found that marmots' impact on drier areas is more intense than on wet soils, even though marmot density is higher near moist soils. The study also found that marmots manipulate the quality of the ecosystem by eating plants that are appetizing and pleasant while refraining from consuming less palatable plants. The study concludes that vegetation structure would likely change in a dramatic fashion if marmots were removed from the landscape. The plants are therefore controlled by the grazing pressures placed upon them by Olympic Marmots (Del Moral 1984). Similar pressures are likely to be found in the yellow-bellied marmot communities found near Gothic, Colorado.

Structures of Marmot Burrows

Previous research done on yellow-bellied marmot burrows revealed little about the amount of sediment excavated on a per year/unit basis. Svendsen's 1974 research attempted to document the shape and structure of marmot burrows, which proved to be a difficult, if not impossible, task. Dissecting marmot burrows that are dug out beneath numerous rocks, or within fissures in larger rocks, is "physically impossible" (Svendsen 1974, p. 490). Therefore, Svendsen attempted to excavate five burrows completely, in areas where it was possible, by digging them out of the ground. He found that main passage ways were between 3.8 and 4.4 m long, with burrow openings extending 0.6 m down before sloping upwards, at a depth of 0.4 to 0.6 m below the surface. Svendsen notes that marmot nests often lie at higher elevations than burrow opening, as tunnels are built upwards in order to mirror the slope of the hillside (Svendsen 1974). Figure 2.1 demonstrates Svendsen's drawings of the tunnels he excavated. Results from this study also indicate that large rocks positioned at the opening of the burrows, as well as within the passageways themselves, act as support structures that help to maintain the integrity and structural support of the burrow. Thick root mats also act as support structures as the roots prevent gravel, small rocks, and alluvium from entering the burrow (Svendsen 1974).

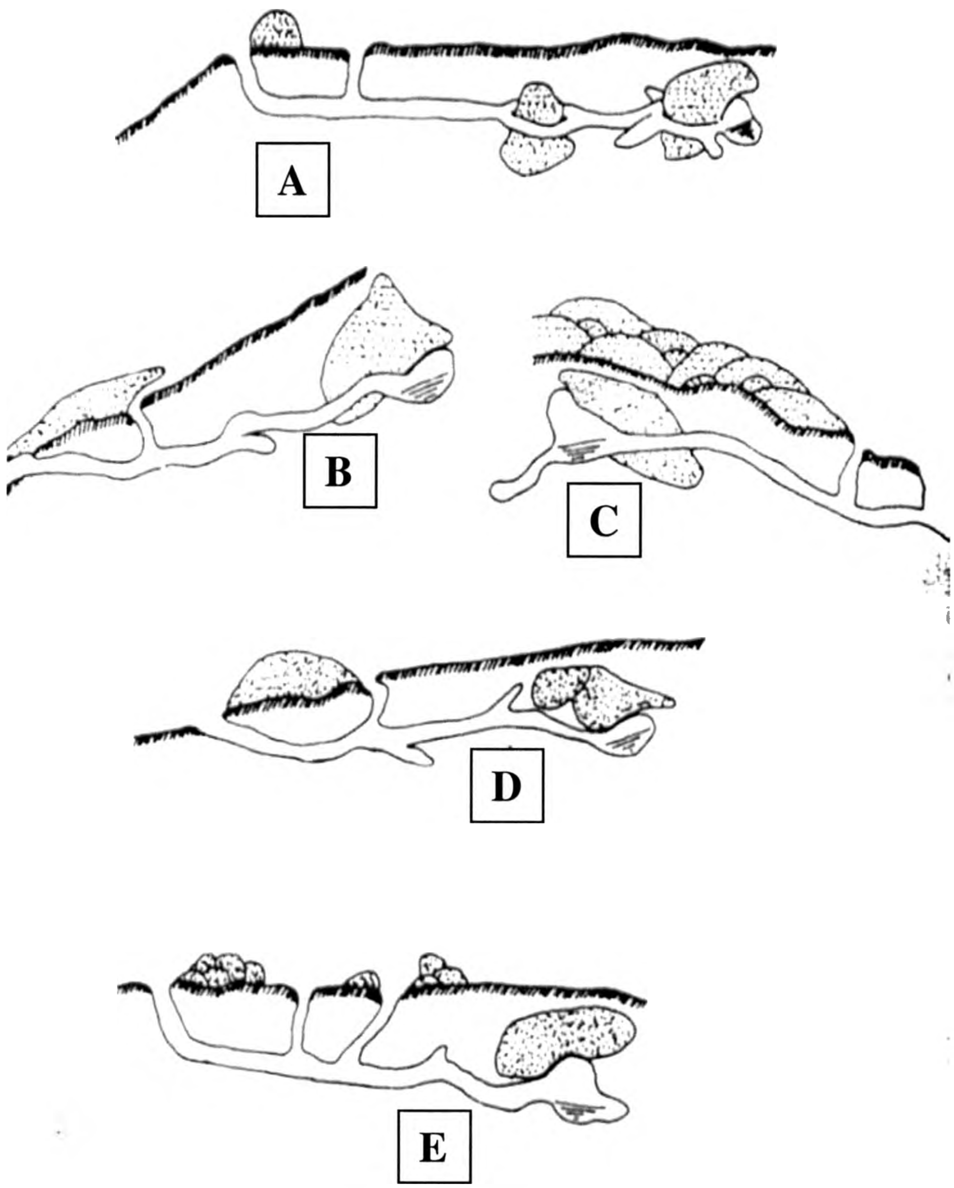


Fig. 2.1. Diagram of marmot tunnels excavated by Svendsen, 1976. A, B, C, D, and E are all different tunnel structures found by Svendsen's 1976 research.
Source: Svendsen, Gerald E. 1976. Structure and location of burrows of yellow-bellied marmot. *The Southwestern Naturalist* 20: 487-94.

Zoogeomorphic Work on Other Animals

Over the last thirty years, many researchers have undertaken studies on how mammals affect geomorphic processes on a landscape. Ground squirrels, wombats, voles, pocket gophers, porcupines and moles are some of the burrowing mammals that have been investigated to examine the effects of burrowing on local geomorphology (Alkon and Whittaker 1989; Gutterman et al. 1990; Imeson 1976, Price 1971; Smith and Gardner 1985; Thorn 1978; and Yair and Rutin 1981). Most of these studies conclude that small burrowing animals are certainly geomorphic agents, and many animals play more important roles in sediment transport and slope processes than previously thought. Arctic ground squirrels for example, are believed to excavate about 8 tons of sediment per acre per year in the Ruby Range mountains of the Yukon Territory (Price 1971), whereas Thorp (1949) found that Colorado prairie dogs excavate between 196 and 235 tons of sediment per acre per year (7926 and 9512 tons/km^2 per year). While exact measurements of sediment displaced have not been quantified, pocket gophers in Colorado have also been shown to change local morphology. Evidence shows that a strong correlation exists between collapsing tunnel structures and the formation of small terracettes, which are a unique morphological feature found mainly in alpine environments (Thorn 1978).

Butler (1992) found that individual grizzly bears in Glacier National Park, Montana, displace about 6.8 m^3 of sediment annually. Broken down, they displace 1 m^3 searching for small mammals, 1.5 m^3 by digging for plants like glacier lily, and 4.3 m^3 of sediment by creating winter dens. Butler's research goes on to estimate that over 136,000

m^3 of sediment has been rearranged by grizzly bears activities over a one-hundred year period (Butler 1992).

Alkon and Whittaker (1989) found that the crested porcupines of the Negev desert, Israel, are also agents of erosion. On an annual basis, porcupines in this locality have been found to move 0.35 m^3 for every 1000 m^2 of surface area. A table of previous work on sediment movement by mammals can be found in Table 2.2.

TABLE 2.2

Comparison of Sediment Movement by Mammals.

Animal	Sediment Displaced	Area	Time	Location	Author
Arctic ground squirrel	0.0378 metric tons	1 km^2	1 year	Ruby Range, Yukon Territory	Price, 1971
European ground squirrel	0.23 - 0.44 m^3	1 km^2	1 year	Czechoslovakia	Turcek, 1963
European mole	0.01 m^3	1 km^2	1 year	Czechoslovakia	Turcek, 1963
Continental field vole	0.0056 - 0.028 m^3	1 km^2	1 year	Czechoslovakia	Turcek, 1963
Grizzly bears	1350 m^3	entire park	1 year	Glacier National Park, Montana	Butler, 1992
Porcupines	0.35 m^3	1 km^2	1 year	Negev Desert, Israel	Alkon and Whittaker, 1989
Pocket gopher	0.39 - 0.58 metric tons	1 km^2	1 year	Colorado Front Range	Thorn, 1978
Pocket gopher	1.1 - 1.45 metric tons	1 km^2	1 year	Wasatch Plateau, Utah	Ellison, 1946
Yellow bellied marmots	2.69 m^3	1 km^2	1 year	Gothic, Colorado	Plaster, 2003
* Some data is presented in metric tons, others in cubic meters. Two different measurements are given.					
* * 1 metric ton= 1000 kilograms					

CHAPTER III

SITE DESCRIPTION

Gothic, Gunnison County, Colorado, is located in a pristine, montane, U-shaped valley about thirty miles north of Gunnison, Colorado, in the Elk Mountains (Figure 3.1). This research was conducted in the areas surrounding the Rocky Mountain Biological Laboratory (RMBL) in the East River Valley of the Upper Gunnison Basin (UGB), about 16 – 17 kilometers north of the ski resort town of Crested Butte.

Climate

The research was conducted in the Elk Mountains, which receive more precipitation in the winter than the summer due to the large mountains that tend to receive large winter storms. Climate data from Crested Butte, Colorado, is used in this study as it is one of the oldest weather stations in the UGB. The station is located near the lower end of the subalpine zone. Climate data containing 104 years of study (1894-1997) is presented (Table 3.1).

Average January temperatures are -11.0° C with a range of -29.0° C to 4.8° C. Average July temperatures are 13.8° C, with a range of -3.2° C to 27.6° C. Average snowfalls are 476 cm, with a range of 112 cm to 919 cm (United States Department of Agriculture 2001).

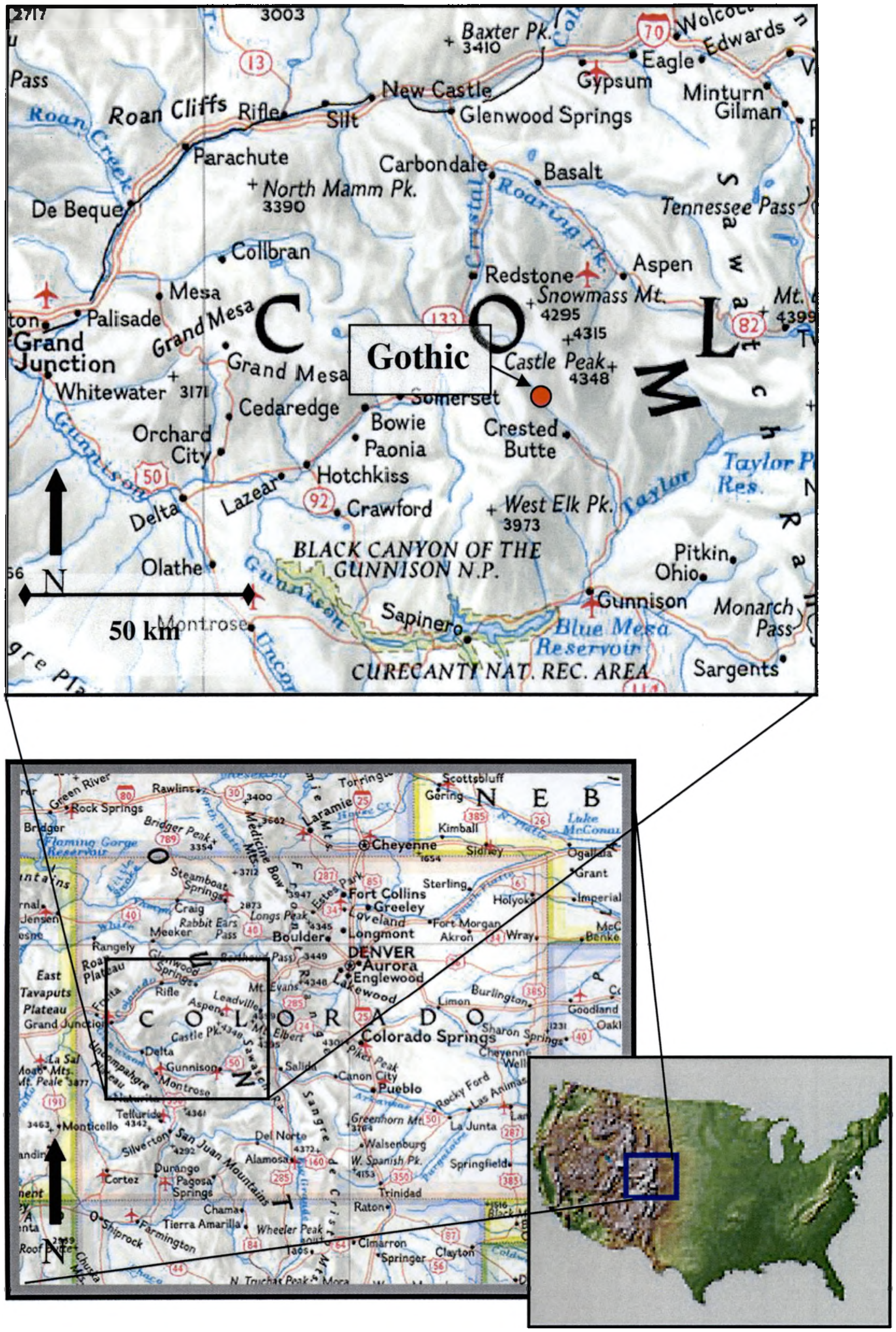


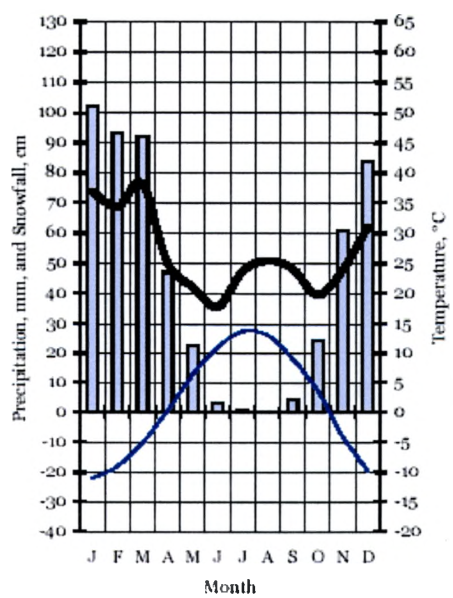
Fig. 3.1. Map of Gothic, Colorado, and vicinity.

TABLE 3.1

Crested Butte Climatic Data (1894-1997).

Quantity	Min	Mean	Max
Yearly Temp. °C	-12.3	1.4	14.1
January Temp. °C	-29.0	-11.0	4.7
July Temp. °C	-3.2	14	27.6
Absolute Temp. °C	-43.8		35
Yearly Precipitation. mm	127	622	2367
January Precipitation. mm	0	74	366
July Precipitation. mm	0	48	140
Yearly Snowfall, cm	112	476	919

Averages	Jan	Feb	Mar	Apr	May	Jun	
Temperature, °C	-11.1	-9.1	-5.2	0.3	6.3	10.9	
Precipitation, mm	74	69	77	50	42	36	
Snowfall, cm	102.1	93.5	91.9	47	22.6	3.3	
	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature, °C	13.8	13.1	9.1	3.6	-4.1	-9.8	1.4
Precipitation, mm	48	51	48	40	48	62	6223
Snowfall, cm	0.5	0	4.1	24.4	60.7	83.8	476



Source: United States Department of Agriculture. 2001. Ecological types of the Upper Gunnison Basin: vegetation-soil-landform-geology-climate-water land classes for natural resource management. Technical report R2-RR-2001-01, p. 59.

Geology

The United States Forest Service describes the UGB as being located inside the Central and North Central Highlands Sections of the Southern Rocky Mountain Open-Woodland-Coniferous Forest-Alpine Meadow Province (United States Department of Agriculture 2001). The U.S. Forest Service describes these lands as containing high elevation granitic laccoliths which have a north-south trend associated with them. Sharply dipping sedimentary rocks like sandstones and shales border the exposed granite in many of the precipitous U-shaped valleys. A wide variety of geologic shapes and surfaces characterize most of the large peaks due to periods of glaciation within recent geologic history. Glaciers have eroded the granitic peaks over time, which has resulted in the deposition of various landform features at the base of the valleys. Most of the sedimentary rocks located in the study area are Mesozoic and Tertiary shales and sandstones surrounded by Tertiary granitic laccoliths that have been intruded into the Mancos shale. The Maroon formation, consisting of late Paleozoic conglomerates and sandstones, flank the eastern portion of the Gothic study area (United States Department of Agriculture 2001). A map of the geology of the area can be found Figure 3.2.

Soils

Throughout the study area, soils are of a similar nature. Most soils are sandy loams that contain a variety of rock sizes. Small pebbles and medium to large boulders are found in the soil, which are remnants of erosion processes (Svendsen 1976). Svendsen (1976), using obsolete Davisian terminology, described the mountains as being

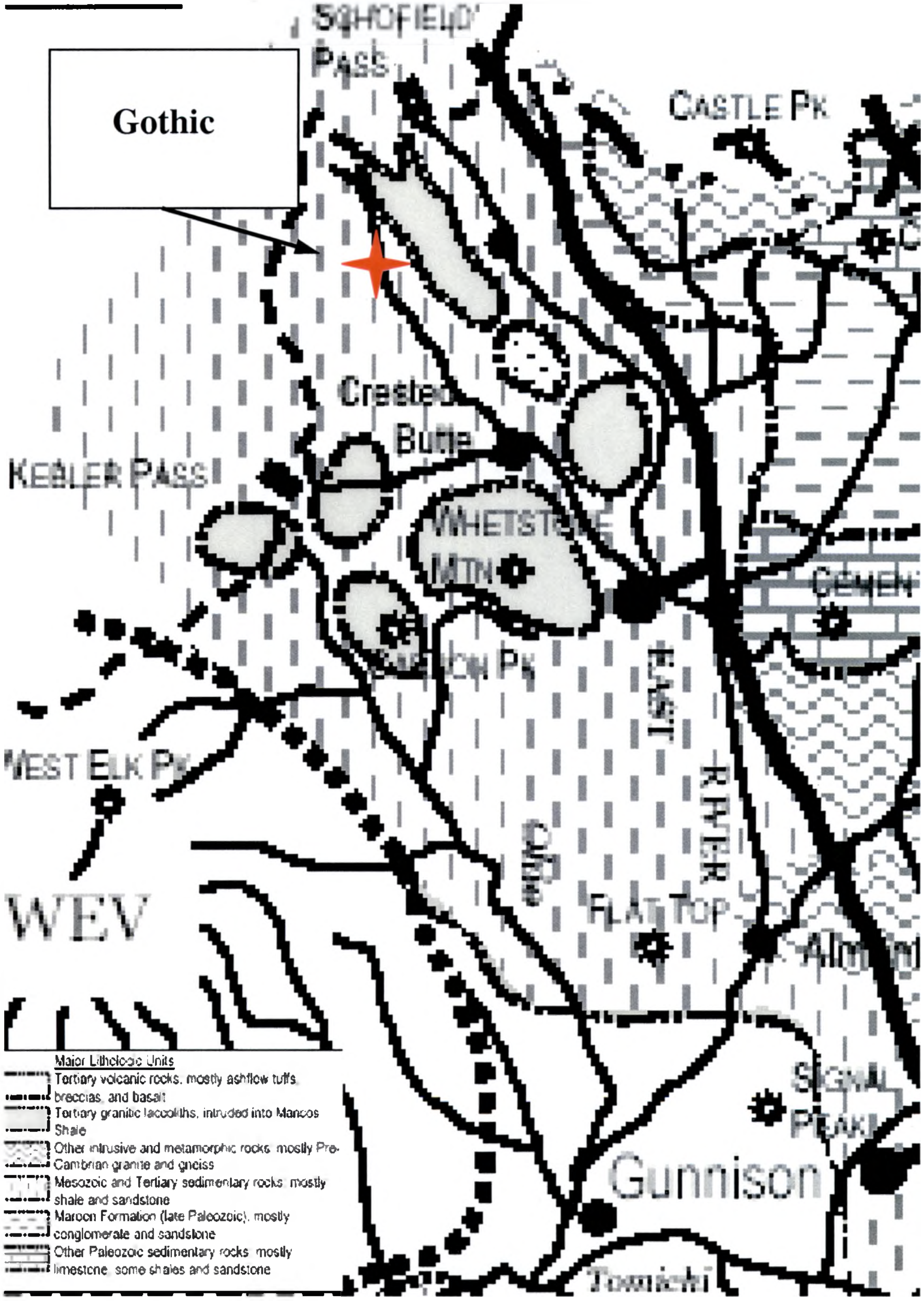


Fig. 3.2. Geologic map of Gothic and vicinity.
Source: United States Department of Agriculture. 2001. Ecological types of the Upper Gunnison Basin: vegetation-soil-landform-geology-climate-water land classes for natural resource management. Technical report R2-RR-2001-01, p. 12.

"in an early mature stage of the erosion cycle and the soil formed from the erosion processes" (Svendsen 1976, p. 490), contains about 50-70% sand, 30-50% silt, 15-20% clay. Soils are very porous and surface water drains off very quickly due to the steep slopes on which marmots burrow (Svendsen 1976).

Vegetation Zones

The research conducted for this paper took place in the subalpine and montane life zones of the Gunnison National Forest. Although there is a good deal of elevational overlap between the two zones, both zones are typically characterized by specific elevations depending on their azimuth. The subalpine zone occurs between 2960 m and 3600 m (9,700' -11,800') on north and east facing slopes while it occurs between 3080 m and 3750 m (10,100'-12,300') on south and west facing slopes. The soil temperature regime is cryic, whereas the soil moisture regime ranges from mostly udic to some ustic. The subalpine zone is characterized by subalpine fir, Englemann spruce, aspen, lodgepole pine, Douglas fir, bristlecone pine, mountain big sagebrush, Thurber fescue, planeleaf willows, Wolf willows, and Idaho fescue. The lower areas of the subalpine zone are dominated by large patches of Douglas fir, subalpine fir, and quaking aspen. Riparian areas tend to be dominated by short woody plants such as planeleaf willow, Wolf willow, and bog birch, especially in the upper portions of the subalpine zone. The riparian areas of the lower portions of the subalpine zone are often characterized by blue spruce, Engelmann spruce, thinleaf alder, blue willows, and serviceberry willow (Johnston et al. 2001).

The montane zone is lower in elevation than the subalpine zone, and is dominated by Douglas fir, ponderosa pine, bristlecone pine, Arizona fescue, aspen, big sagebrush, Saskatoon serviceberry, and blue and serviceberry willows. The montane zone generally has a frigid soil temperature regime while the soil moisture regime ranges from udic above to ustic lower. The montane elevations on north and east facing slopes range from 2770 m to 3260 m (9,100' – 10,700') while elevations are slightly higher on south and west facing slopes, which range from 2860 m to 3380 m (9,400' – 11,100') (United States Department of Agriculture 2001).

Plant Communities Associated with Yellow-Bellied Marmots

In the East River Valley of Colorado, marmot habitats are dominated by different plants depending upon slope and substrate. In open grassland areas, the *Festuca thuberi* community dominates, with grasses like *Festuca, Bromus*, and *Poa* being the dominant grasses. Other plants associated with these habitat areas are *Viguera multiflora, Senecio crassulus, Lomatium simplex, Vicia americana, Linum lewisii, Potentilla fructiosa, Potentilla gracilis, Artemisia tridentate, Taraxacum officinale,* and *Erigeron speciosus* (Svendsen 1974). On steeper slopes, more woody plants persist, including *Heracleum lanatum, Aquilegia coerulea, Thalictrum fendleri, Veratrum californicum, Delphinium barbeyi,* and *Phacelia heterophylla* (Svendsen 1974). At higher elevations, *Erythronium grandiflorum* (glacier lily) is also common, especially near Schofield Pass and Emerald Lake. *Potentilla pulcherrima* (cinquefoil) is common in open grasslands as well as steeper slopes, but is less common at elevations above 3200m. *Seriphidium tridentatum* (sagebrush) is also present in the valley, especially near the ridges along the riverside.

CHAPTER IV

METHODS OF ANALYSIS USED IN THE RESEARCH

The research will utilize proven field methods and statistical analyses to answer the following research questions: (1) can sediment excavation by marmots be quantified using standard field methods? If so, how much sediment do yellow-bellied marmots move during one summer season? (2) does marmot excavation affect slope stability and integrity? (3) do marmots move a significant amount of sediment compared to bears, ground squirrels, pocket gophers, or other small mammals? (4) do marmot burrows occur at all azimuths in equiprobability?

The methods employed to examine these research questions include field methods, geometry, geomorphology, and statistics.

Field Methods

Standard field methods include the use of basic geometry to determine the volume of sediment removed from each site (Butler 1995). Measurements of burrow length were taken using a standard measuring tape. Marmot burrow sizes, which have measurable dimensions along a cross section, can be calculated by using geometric volume formulas that correspond to the shape of the burrow. This approach has been successfully completed by Thorn (1978) in an analysis of pocket gopher's role as a geomorphic agent in Colorado. As burrows are found in the field, the shape and structure of the burrow were characterized as having either an oval, triangular, or rectangular shape. The length of the sides of each burrow was measured so that volume calculations could be completed once field work was complete. A probe was used to measure the depth of each burrow (Figure 4.1). For this research, a standard Stanley measuring tape was inserted into a burrow and the depth of the burrow was recorded. The tape was pushed further and further into the burrow, until tension was felt, indicating that the back wall of the burrow had been hit. In almost all cases, the probe did not extend to the furthest point of the burrow because burrows are not completely straight and have bends within them. It is important to recognize that all probe depths are underestimates of total burrow depth, and volume calculations are therefore underestimates of the total sediment displaced.

Volume Calculations

Oval burrows, often found in loose soil, were examined by measuring the length and the height of the burrow, followed by the depth of the burrow. The volume was then calculated by the formula: volume = (4/3)(pi) abc, where a, b, and c are the distances from the center to the edge on each axis (Marquis 2003). For burrow measurements, L1 (a) is the height of the burrow, L2 (b) is the length of the burrow, and Probe Depth (c), is the depth of the burrow. A data table containing all volume results from oval burrows can be found in Appendix 1.

Triangular shaped burrows (Figure 4.2), usually found between sharp, angular rocks, were assigned four lengths. The three sides of a triangle were measured, followed

Fig. 4.1. Photograph of probe measurements.

Fig. 4.2. Photograph of a triangular shaped burrow.

by a measurement of the depth of the burrow using the probe. As each side of the triangle had different lengths, standard triangle formulas that use height of the triangle were insufficient to calculate volume. Therefore, Heron's formula for triangle volume was used. This formula states that the area of a triangle can be calculated by taking the square root of s*(s-a)*(s-b)*(s-c), where s = (a + b + c)/ 2. Likewise, a is the length of side a, b is length of side b, and c is the length of side c. The volume of each triangular shaped burrow is then calculated by multiplying the probe depth of the burrow by the area of the triangle (Wilson 1986). A data table containing all volume results from triangular shaped burrows can be found in Appendix 1.

Finally, all other burrows were characterized as rectangular, even though very few of these burrows were true rectangles by definition. Most of the rectangular burrows were trapezoidal, or four sided figures that have four unequal lengths. Most rectangular burrows fell into this trapezoid category. For the burrows that were true rectangles, the formula V= L*W*H was used to discover volumes. In this scenario, L is burrow length, W represents burrow width, and H is burrows depth. Note that the true rectangular burrows have two equal lengths and two equal heights while the trapezoid-shaped figures have four unequal sides. For the trapezoid calculations, a more complicated formula was used that accounts for all sides being unequal. This formula is (a + c) / 4 *(a-c), multiplied by the square root of (a – b + c + d) *(a - b - c + d) *(a -b + c-d) *(a + b + c-d). In this case, a is the length of the longest side of the trapezoid, b is the second longest side, c is the third longest side, and d is the shortest side (Yi Jie 2003). After trapezoid areas were calculated, they were multiplied by the probe depth to determine the volume of the burrow. Appendix 1 shows the volume calculations for rectangular shaped burrows.

Once volume calculations had been made for all burrows, it was essential to understand how much sediment was rearranged on a per unit basis. For each site, a volume calculation was made that explains how much sediment was excavated based on the amount of area surveyed. This was done by drawing rectangles around each study area on a USGS 1: 24000 topographic map and measuring the area of the rectangle. Therefore, the results yielded sediment moved per unit area or m^3/km^2.

Sediment Weighs

Another experiment designed by the researcher to understand the weight of sediment removed by marmot burrows involved the use of a scale and a plastic bag. In the field, certain marmot diggings were found that were fresh and had been excavated within the past year. These diggings were very conspicuous because they have not been eroded very much and still looked like fresh diggings (Figure 4.3). When these mounds of sediment were discovered, they were weighed by placing all of the soil and rocks into a plastic bag and subsequently placed onto a scale. Prior to each sediment weigh, the scale was checked for accuracy by placing an object of known weight upon the scale. In almost every case, multiple weighs were necessary to weigh the entire pile of excavated sediment. All of the sediment was weighed until all loose, excavated material had been removed from the mound. Figure 4.4 documents the same mound as seen in Figure 4.3, after the sediment weigh was completed. As diggings of this type were rare, nine trials were completed at numerous study sites throughout the Gothic Valley.

Fig. 4.3. Sediment mound prior to sediment weigh.

Fig. 4.4. Sediment mound after sediment weigh was completed.

Sediment Fence

A new field method that was employed during this research was the collection of sediment removed by marmot digging activities. This was done by placing a tarp outside of the digging area that was designed to collect soil material removed by marmots. Finding a burrow that was actively being excavated was necessary in order to do this (Figure 4.5). A sediment fence was constructed outside of a marmot burrow that was being actively excavated (Figure 4.6). A tarp was then placed just below the burrow and was secured to the fence in order to trap all of the soil excavated by the marmots. The sediment fence was placed just below a road to insure that material moved down slope by processes not involving marmots were excluded from the study. The road acted as a conduit for material that could have otherwise ended up on the tarp. After one week, the site was visited to check up on the progress of the experiment. After one more week, the sediment was then weighed and returned to the area where the tarp was. For a control, a second sediment fence was built ten feet from the main experiment, just beneath a burrow that was not being actively excavated (Figure 4.6). The control fence was built in the same way, with the same slope angle and environmental conditions. This method is a new method developed by the researcher and presented formidable problems that will be discussed in the results section.

Geomorphology

To investigate the role marmot burrows play in slope processes, careful notes were taken in areas where slope failures may have occurred in the vicinity of marmot burrows. When slumps, rockfalls, or landslides were encountered near known marmot

Fig. 4.5. Mound of sediment prior to installation of sediment fence.

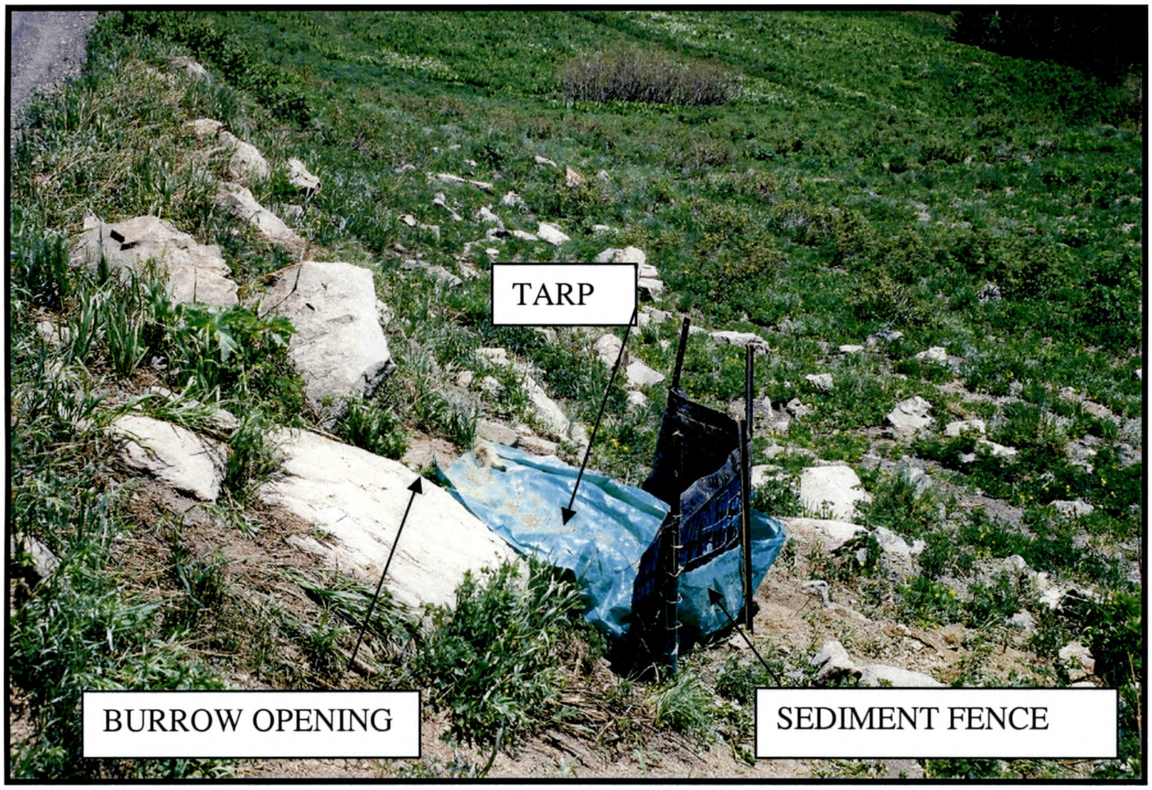


Fig. 4.6. Sediment Fence.

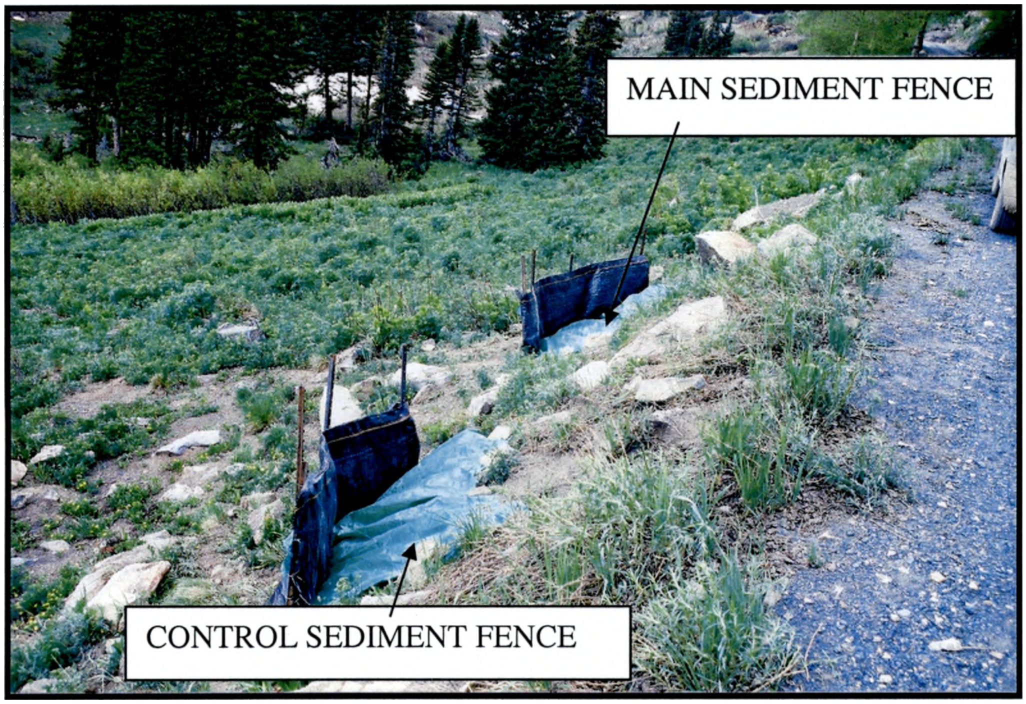


Fig. 4.7. Sediment fence and control.

burrows, a variety of measurements were taken on the size, shape, structure, and age of the event. Rock types were also examined to see if correlations between rock type and slope failure exist. All slope failure events were examined to determine if the actions were true threshold-crossing events that represent changes in the system from states of equilibrium to states of disequilibrium (Ritter et al. 1999). Extensive photographs were also taken of the area to document events. Finally, consultations were made with University of Texas geologist Matthew Davis to determine if a landslide had occurred due to marmot activity.

Marmot's sediment movement compared to other animals

In order to investigate the third question that examines how much sediment marmots move compared to other mammals in alpine environments, a comparison of relevant research was required. A table was designed that demonstrates the roles different mammals play in sediment displacement (Table 2.2). All data from previous studies was standardized to compare and contrast how much sediment was moved down slope per unit area. For the research, sediment displaced in cubic meters per square kilometer will be used to demonstrate relationships between animals and sediment movement.

Statistics

Finally, statistics were used to calculate for equiprobability of marmot burrows occurring at all azimuth directions. In the field, azimuths were recorded for all marmot burrows surveyed (Appendix 4). A Rayleigh Test for Circular Uniformity was used in order to test the question: "do marmot burrows occur at all azimuths in equiprobability?" This type of statistical test was used to test a hypothesis concerning populations (burrow azimuths) based on a circular scale (Zar 1974). The hypothesis for this test was:

Ho: $p=0$ (the population is distributed around the circle uniformly)

Ha: $p\neq0$ (the population is not distributed around the circle uniformly)

As burrow azimuth data occur in a circular pattern, it is important to use a statistical test that allows one to compensate for values which occur from 1-360. The Rayleigh test poses the question "how big must a sample r be to signify, with assurance, a nonuniform population distribution?" "Rayleigh's R" is acquired by using the formula:

$$R = nr,$$

and "Rayleigh's z" can be used to test the null hypothesis, which states that there is not a population mean direction:

$$z = R^2/n\,.$$

In this scenario, r is a measure of concentration that has no units, but varies from 0 to 1. A r value of 0 signifies too much dispersion to indicate a mean angle while r values closer to 1 indicate that the most of the data is focused around a mean direction. The sample size is denoted by n. If the Null Hypothesis (Ho) is rejected by the test, then it is determined that there is a mean population direction. However, if the Null Hypothesis is not rejected, and the alternative hypothesis is accepted, then there is no direction mean, signifying that burrow azimuths are distributed uniformly around the circle (Zar 1974). One caveat of this procedure is that "even if there in no mean direction (i.e., the circular distribution is uniform), a random sample still might display a calculable mean" (Zar 1974, p316-7).

Another aspect of the Rayleigh test is the mean angle. The sample size of 203 burrows, described as a_1 through a_n, has a mean angle of $\bar{a}$, which is an estimate of the mean angle of the population (Zar 1974).

The population in this case is all of the burrows' azimuths sampled during the course of field work. The mean angle was tested by the formula:

$$X = \frac{\sum_{i=1}^{n} \cos a_1}{n}$$

and

$$Y = \frac{\sum_{i=1}^{n} \sin a_1}{n}$$

Next, it was necessary to find r (which is not a correlation coefficient in this case):

$$r = \sqrt{X^2 + Y^2}$$

If r was found to equal zero, then the mean angle was unable to be determined, and the test concludes that there was no mean direction (Zar 1974).

CHAPTER V

RESULTS

This chapter examines the role marmots play as geomorphic agents by analyzing the data obtained from field research conducted in and around Gothic, Colorado, in June 2003. This chapter is designed to answer each of the four research questions in a clear and concise manner with attention to visual evidence of the zoogeomorphic impact of marmots. Section one presents results on the general characteristics of burrows. Section two examines the amount of sediment displaced by marmots while section three investigates the possibility that marmots contribute to slope failure processes. The fourth section compares marmot's sediment movement to those of other animals. The fifth section explores whether or not marmot burrow azimuths are distributed uniformly around a circle. The final two sections explain the results of the sediment fence and sediment weighs conducted.

General Characteristics of Marmot Burrows and Study Sites

Marmot burrows were found at numerous locations throughout the Gothic Valley. Burrows were found on slopes ranging from 2° to 33°, with a mean of 18.6° and a standard deviation of 8. Burrows were sampled at elevations ranging from 2751.4 m to 3161.7 m (9027' to 10373'), a range of 410.3 m (1346'). The mean elevation for all study sites was 2963 m (9721'). The standard deviation for all elevations was 87.5 m

(287'). Burrows were found at almost every azimuth possible, with a range of 5° to 360°, representing 98.6% of all azimuths (Appendix 2). Thirty-one study sites were examined. Some sites had as few as two burrows surveyed, while other study sites, like Sandstone (site # 30), had forty-two measurable burrows. A table of all field data can be found in Appendix 3. Also located in the appendices (Appendix 4), the reader can find a brief overview of each study site, including rock types, plant types, and other notable features associated with the site.

Results from this thesis project indicate that marmots dig burrows in a variety of habitats throughout the Elk Mountains of Colorado. Most burrow openings found amongst talus blocks tend to be angular and contain sharp three or four sided figures. This research characterized these types of burrows as triangular, rectangular, and trapezoid shaped. These angular burrows typically occurred on steeper slopes due to the presence of large, angular rocks. Average sizes for triangular shaped burrows were 19.7 cm by 21.0 cm by 18.8 cm by 89.8 cm deep (7.75" by 8.3" by 7.4" by 35.5"). Triangular shaped burrows accounted for 37% of all burrows sampled. Average rectangular burrows were 19.9 cm by 20.0 cm by 19.9 cm by 17.8 cm by 162.6 cm deep (7.8" by 7.9" by 7.8 by 7" by 64" deep) and these burrows accounted for 5% of all burrows sampled. Trapezium shaped burrows made up 18.4% of all burrows sampled and they averaged 26.1 cm by 12.4 cm by 18.8 cm by 14.6 cm by 91.5 cm deep (10.3" by 4.9" by 7.4" by 5.7" by 36.0" deep). Burrow data can be found in table 5.1.

Oval burrows were found more often in sediment that had been deposited in lower, flatter areas, often at the bottom of a valley. The availability of loose sediment

TABLE 5.1

Comparison of Average Burrow Sizes.

	Triangle	Rectangle	Trapezoid	Oval
Length 1 (cm)	19.7	19.9	26.1	25.1
Length 2 (cm)	21	20	12.4	22.4
Length 3 (cm)	18.8	19.9	18.8	--
Length 4 (cm)	--	17.8	14.6	--
Probe Depth	89.8	162.6	91.5	105.9
% of burrows	37.5	5	18.5	39

enables marmots to construct a round burrows that mimics the contours of the marmots' body shape. These burrows are typically larger than the angular burrows and accounted for 39% (77 out of 200) of all burrows measured in the study. Average sizes for oval burrows were 25.1 cm wide by 22.4 cm wide by 106 cm deep (9.9" by 8.8" by 41.7").

Volume of Sediment Displaced

In order to calculate the amount of sediment displaced per unit area, study areas were measured using National Geographic seamless USGS topographic maps, available on CD-ROMs. Throughout field work, GPS locations of every marmot study site were entered into a database that stored the locations. A map showing some of the prominent study sites overlaid onto the USGS topographic map is found in Figure 5.1. Following completion of field work, the amount of surface area was calculated by using the distance (measuring) tool in the map program. Small boxes were drawn around each study area that included all burrows surveyed as well as a 5 m buffer zone around each burrow. The results presented here are estimates of the area around burrow sites; therefore, the data on the surface area surveyed do not account for burrows that were not measured, or satellite burrows that may have been obscured by vegetation. During data screening for outliers, some outliers were found that were excluded from the volume measurements. They were excluded due to irregularities found amongst certain burrows. Therefore, even though over 200 burrows were sampled, only 200 burrows were included in this portion of the analysis.

During the course of field work, 200 individual burrows were measured, encompassing an area of 0.264 km^2. Results from volume calculations indicate that the total volume of sediment displaced by the 200 burrows was 15.7 m^3. When 15.7 is divided by .264, we find that marmots displaced a total of 59.7 m^3 per square kilometer. It is important to recognize that this number represents an area of land that assumes a very high density of marmot burrows, which is certainly not the case in Colorado. There were no areas of the study site that had densities of 200 burrows per 0.264 km^2. However, these numbers are important because they show the potential zoogeomorphic effect of marmots in a localized area.

In one particular area that is not included in the main study of 200 burrows, marmots were found to have an even higher degree of impact on local geomorphology. In the River South study site (Figure 5.2), site # 27, some very interesting geomorphic conditions were found that shows that marmot burrows in loose sediment can lead to the formation of a karst-like topography (Figure 5.3). In this area, marmot excavations probably weakened the loose riparian sediments along the sides of the East River, resulting in the collapse of large areas of sediment. Sizes of the holes were recorded using the same volume calculations used for oval burrows, as the openings in the ground had oval shapes. In this area, marmot activity has led to the displacement of 3.7 m^3 in 0.034 km^2. In a larger area with similar geologic conditions, marmots could potentially account for 109.5 m^3/ km^2 (3.7 m^3 / 0.034 km^2) of sediment displacement in a highly localized area. This research does not claim that marmots can have this type of effect in all locations. In fact, this particular area is quite unique due to the loose sediments deposited by flooding events. Therefore, marmots can potentially displace up 110 m^3/ km^2; however, this scenario is unlikely because marmot density rarely, if ever, is high enough to account for such large amounts of sediment movement.

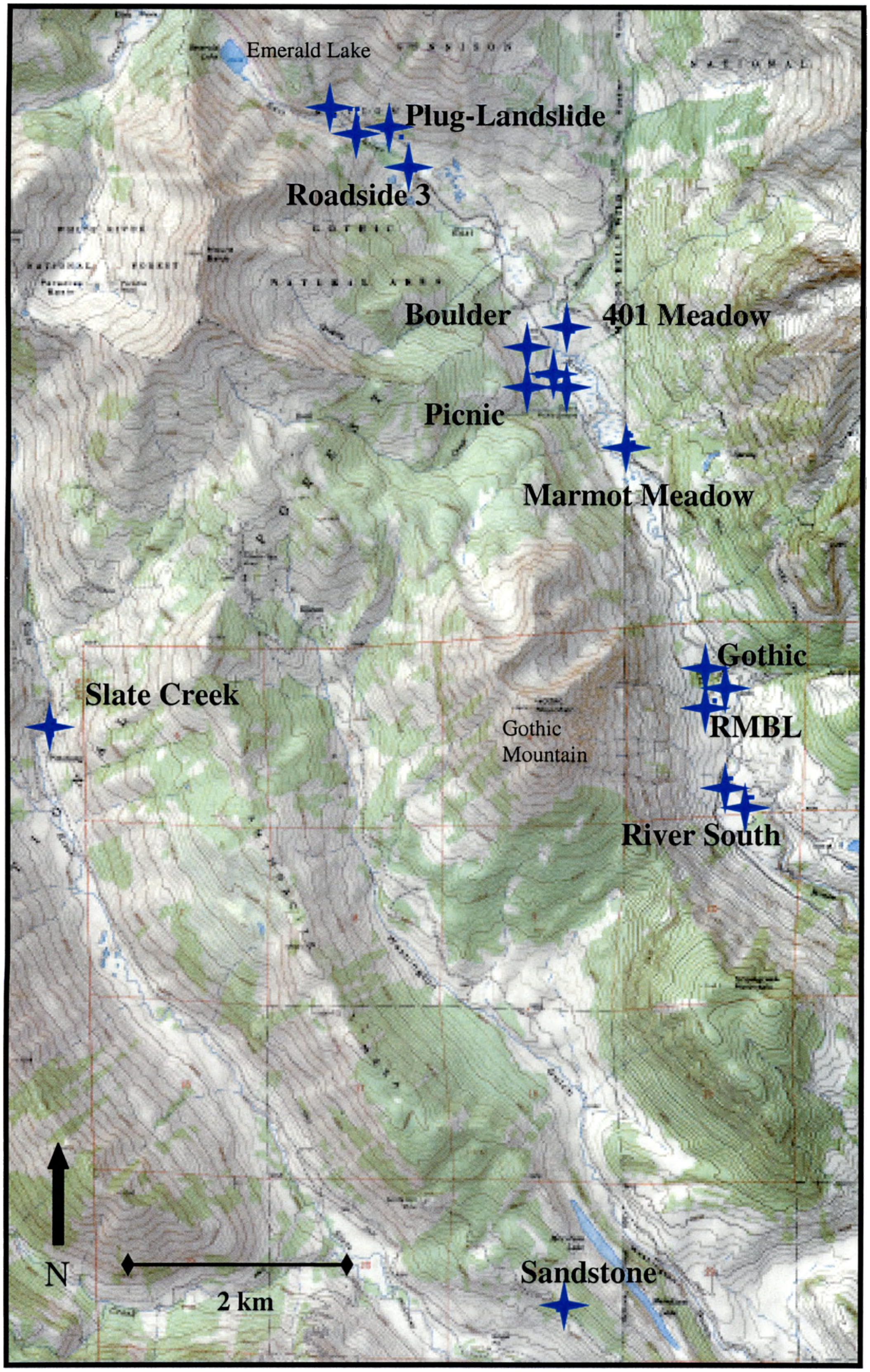


Fig. 5.1. Locations of prominent study sites. Note that some study sites are close together and therefore one star may indicate more than one study site.

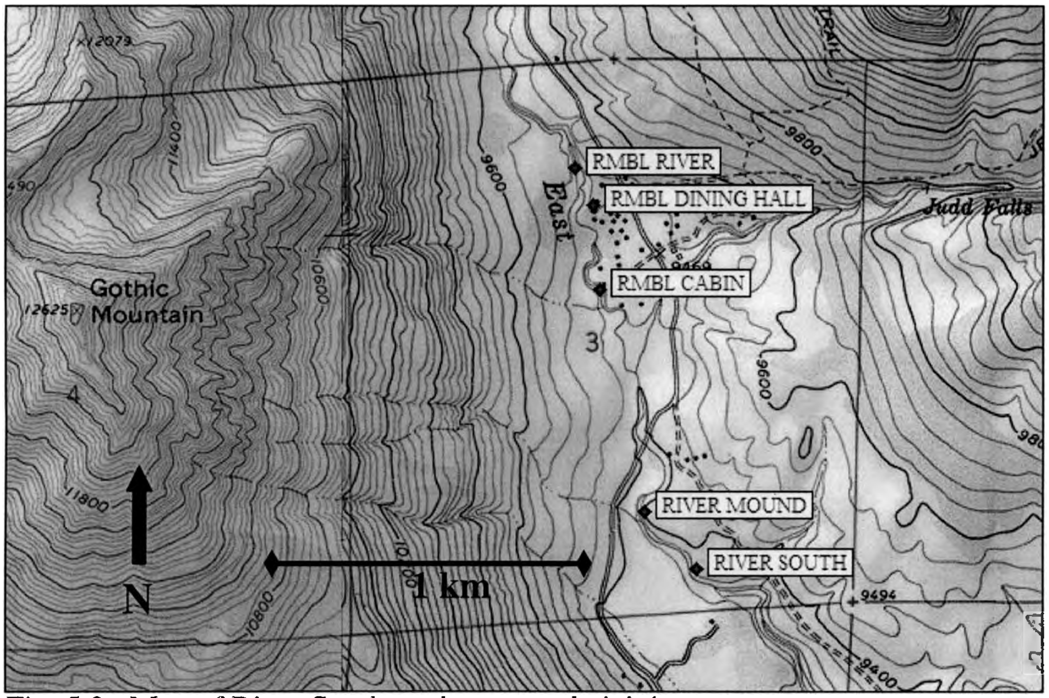


Fig. 5.2. Map of River South study area and vicinity.

Fig. 5.3. Large holes found at River South study site.

Marmots' Impact on Slope Failure

Although this research question has the least amount of evidence to support any strong conclusions, it was found that marmots probably contribute to small scale landslides and/or slope failures. Two sites were found that demonstrate evidence of these processes.

At site #25, Plug Landslide, a small slump (Figure 5.4) was found in an area of high marmot activity and density. The slump was discovered when the researcher went to measure the size of some burrow openings, only to discover that a mass wasting event had occurred in the same area.

Fractures present in the granodiorite/quartzite bedrock had enabled marmots to create burrow systems within the rock, a scenario that was not common in the study area. It appears that marmots had been living in this area for hundreds, if not thousands of years, as the site was favorable for marmot habitat. Large fields of glacier lily, a marmot food source, exist just above the area of the highest burrow density. Large boulders and outcrops, which are favored by marmots as sunning spots, are also present throughout this area. Therefore, it is assumed that marmots had excavated in this area for many years.

The landslide discovered here had two marmot burrows located at the bottom of the landslide, which suggests that burrows existed there prior to the slope failure event. At an elevation of 3138 m (10,295'), this study area was subjected to extreme winter temperatures and high amounts of snowfall. The research suggests that marmots' burrowing activities weakened the underlying bedrock, especially within the fractures.

Fig. 5.4. Small landslide at Plug-Landslide study site.

Years and years of heavy snowfall placed pressure on the area, and eventually the slope horizon failed, exposing marmot's burrows beneath the surface.

One interesting fact about the burrows being exposed is that they were significantly larger than any other burrows seen during the research. The landslide exposed burrows that are normally not seen, and the cavity was large enough for a person to lie down in. Even though the actual burrow below the landslide had been vacated, desiccated fecal material within the burrow provides evidence of earlier occupation. An alternative view of the mass wasting event is shown in Figure 5.5. The drawing in Figure 5.6 shows the cross section of the burrows while Figure 5.7 shows a map view of the landslide.

Perhaps this landslide would have occurred without marmot activity; however, marmot activity in the immediate vicinity of the landslide provides evidence that marmots may be a contributing factor to the instability of the slope. It is possible that marmot activity could have led to a threshold crossing event, which changed the system from a state of equilibrium to one of disequilibrium.

The second site of considerable interest is site #27, Sandstone. One of only two study sites investigated outside of the Gothic Valley, Sandstone is an area of intense marmot activity located two valleys west of the Gothic Valley in the Slate Creek Valley. Located at 2751 m, (9027') the area is slightly lower, and thereby drier than site # 25. The area is characterized by sagebrush, buttercup, Indian paintbrush, blue phlox, holly grape, cinquefoil, daisy, and monkshood.

Fig. 5.5. Photograph of landslide at Plug-Landslide location.
Researcher is pointing to the two burrow locations.

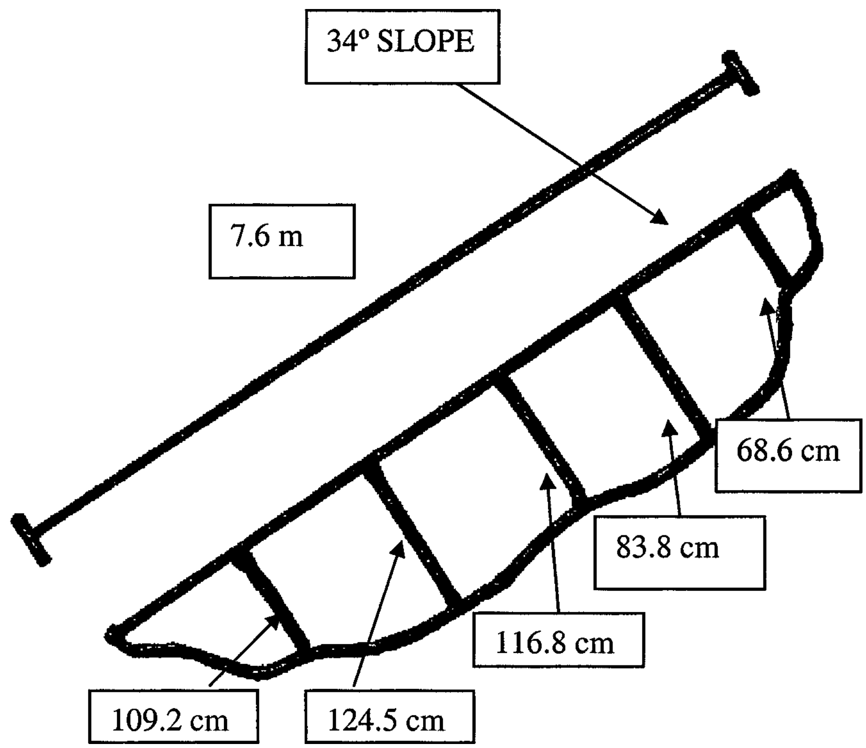


Fig. 5.6. Cross section of landslide. Figure not drawn to scale.

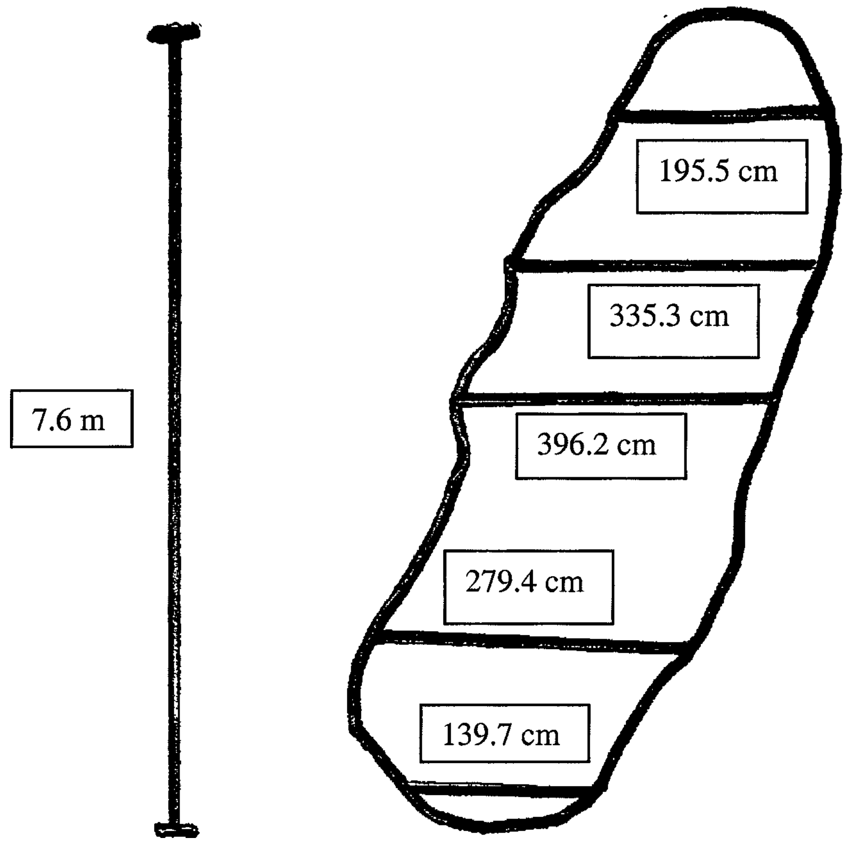


Fig. 5.7 Map view of landslide. Figure not drawn to scale.

Forty-two burrows were measured in this locality, which is essentially a sandstone ridge that is about ten meters wide by 300 meters long. Sandstone outcrops line the west side of the ridge with exposed sandstone ranging in height from 0.5 m to 3 m. Numerous burrows line the west side of the ridge, with a few scattered escape burrows along the top and east sides of the ridge. The landslide found here is very large: debris extended 20-25 m downslope and 2-5 m across slope. It appeared that it had occurred within the last two years as succession was still in its primary stages because: (1) no lichens were growing on any of the freshly exposed rocks, (2) very few plants were living on the rocks, and (3) fresh sandstone exposures showed no signs of weathering.

The rock in this area was thinly bedded, medium grained sandstone with numerous scour surfaces and channel forms. Most rock layers had thicknesses of less than 25 cm (10"), and the sands show evidence of bioturbation. Burrows within the rock were horizontal and ran between fractures in the rock. Most likely the rocks are hummocky cross bedded sandstones, which are high energy-storm deposits from terrestrial (not coastal) environments. Therefore, these sandstones weather massively. Joint planes cut through the rocks, which is where most of the larger burrows were found. Numerous small scale collapses around burrows were also found.

Evidence for the landslide being related to marmot activity lies within the fact that burrows were found in joint planes immediately adjacent to the whole landslide. Also, large sandstone blocks are being rafted down slope, which were underlain by burrows. Therefore, it appears that marmots' repeated digging activities into the rock fractures probably contributed to weaker joint plane surfaces, which eventually produced a landslide. Photos of the landslide can be seen in Figures 5.8, 5.9, and 5.10. Evidence from the photos demonstrates that a large amount of material was moved downslope as a result of the landslide.

Other evidence of marmots' role as geomorphic agents in this area are small trails that marmots create by trampling small plants. These trails (Figure 5.11) were evidenced elsewhere as well, however, the short shrubs made marmot trails easier to see here. Finally, evidence was found that shows scrape marks from marmot claws on the rock surfaces near the landslide. These scrapes are seen in Figure 5.12.

Marmot's sediment movement compared to other animals

The results from this study indicate that marmots have a profound effect on the landscape. While marmots do not displace as much sediment as small mammals like pocket gophers, they rearrange more sediment than animals such as the European mole (Table 2.2). European moles, for example, are capable of displacing 0.01 m^3/ km^2 while European ground squirrels are capable of displacing 0.23 -0.44 m^3/ km^2. This study indicates that marmots are capable of displacing up to 2.8 m^3/ km^2, which is significantly more than either European animal. Pocket gophers appear to have the largest geomorphic impact of any of the small mammals. They are capable of moving between 0.39 -1.45 metric tonnes/ km^2, depending upon the location of the research. One metric ton weighs 1000 kilograms. Unfortunately, comparisons between metric tons and cubic meters are impossible to make; however, one can see that pocket gophers are capable of displacing very large amounts of sediment. Likewise, a comparison between grizzly bears and marmots is difficult because the bears' sediment displacement has been reported over an area the size of Glacier National Park. Therefore, comparing sediment movement from one square kilometer and thousands of square kilometers does little in reporting the differences between sediment displaced per unit area.

Fig. 5.8. Large landslide at Sandstone study site.

Fig. 5.9. Alternative view of landslide at Sandstone study site.

Fig. 5.10. Alternative view of landslide at Sandstone.

Fig. 5.11. Small trails made my marmots at Sandstone. Trails are on top of the ridge.

Fig. 5.12. Small scrape marks made by marmots.

Statistics

Results from Rayleigh's Test for Circular Uniformity reveal that there is no preferred burrow azimuth orientation. The original hypotheses were:

Ho: p=0 (the population is distributed around the circle uniformly)

Ha: p≠0 (the population is not distributed around the circle uniformly)

A *z* value of 0.7268 was found, and in Rayleigh's z table (Zar 1974 - table B.34), z.05, 200 = 2.992. A *z* value of 0.73 is lower than 2.9, which indicates that the Null hypothesis should be accepted and the alternative hypothesis should be rejected. Therefore, there is no preferred burrow orientation.

A mean angle was also found by using Rayleigh's Test for Circular Uniformity. A mean angle of 235° was found using table D.35 of Zar's 1974 edition of *Biostatisitcal Analyses*. When examining the table, two values are used (cosine and sine of a) which correspond to different azimuths on a compass. The cosine of "a" is -0.82, while the sine of "a" was found to be -0.58. These two values on the chart indicate that the mean angle is 235°, signifying that the average burrow orientation is in a south-southwest trend.

Sediment Fence

The sediment fence experiment, in which a sediment fence was built in order to trap sediment removed from marmot burrowing, was a failure. A sediment fence was installed at the Roadside 3 location on June 11, 2003, and remained there until June 30, 2003. (Figures 4.3, 4.4) The tarp was 7' long and it took one and one-half hours to construct. There are a variety of explanations that explain reasons for the failure. The sediment fences did not trap any sediment that could have been weighed. Both the control, and the fence set up beneath current burrowing, produced negligible amounts of sediment that can not be considered data.

There are two main reasons why the experiment probably did not work. (1) The fence was not constructed until mid June, a time when most burrowing work has already been completed. Although burrowing was occurring prior to the placement of the fence, it is difficult to determine whether or not the burrowing was completed or not. Therefore, the marmot could have already completed burrowing for the year when the fence was installed. (2) The construction of the sediment fence could have altered the behavior of the marmot so that it felt uncomfortable returning to the burrow, which would have forced the marmot to halt burrowing. After the fence was constructed, the researcher watched the marmot approach the burrow with extreme caution, similar to a human being peering over a cliff. The marmot approached the fence, rose up on its' hind legs, and surveyed the fence for about five minutes. The marmot then turned around, walked three feet away, came back, and repeated the same thing. Clearly, the marmot was deeply disturbed by the construction of the fence and was very apprehensive about going back into the burrow. Therefore, the sediment fence experiment probably did not work because the marmot's behavior was altered to the point that its' daily habits were modified as a result of the sediment fence.

Sediment Weighs

During the course of fieldwork, sediment excavated by marmot burrowing activity was weighed. Each "sediment weigh" consisted of a series of individual weighs which were designed to enable the researcher to weigh all of the sediment found in mounds located at burrow entrances. Every burrow in the field area that was being actively excavated was weighed except for two burrows located in the Marmot Meadow study area. These mounds of sediment were not weighed due to concern for current biological studies being undertaken in this area.

During each individual "sediment weigh," it is probable that 100% of the sediment pile was not weighed. Reasons for this are as follows: (1) erosion had taken place on some of the mounds and therefore some rocks and/or sediment were moved into vegetated areas downslope, (2) small grains of sediment were not able to be sorted from the vegetated areas and were not part of the sediment weigh.

Results from nine "sediment weighs" indicate that the average pile weighed 45.7 kilograms (100.8 lbs) with a range of 9.75 kg to 80.3 kg (21.5 lbs -177 lbs). Only three trials were necessary to calculate the lightest weigh (9.75 kg), which is burrow #2 from the River Mound study site, while sixteen trials were required for the heaviest burrow (80.3 kg), which is burrow #4 from the 401 Meadow. A table of all "sediment weighs" can be found in table 5.2.

While data from the sediment weighs cannot be used to calculate the volume of sediment displaced, this data can be used to help obtain a rate of sediment rearrangement on a yearly basis. A rate of excavation is determined by examining how many burrows are actively being excavated per year. This study found nine active burrows out of 203 total burrows. This gives a rate of 4.4 burrows per 100. Roughly 4.4% of all burrows in the study area are undergoing active excavation. Although more studies over longer periods of time would be needed to verify this rate, this research shows that one can expect an active excavation rate of about 4-5% in this area of Colorado.

TABLE 5.2

Sediment Weight Measurements.

			Trial # (All weights reported in kilograms)																
Site Name	Burrow #	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
River Mound	1	6/4/2003	5.9	6.12	4.58	5.53	4.99	5.53	3.67	1.95									38.3
	2	6/4/2003	4.31	3.4	2.04														9.75
401 Meadow	6	6/11/2003	3.99	3.76	2.72	4.49	2.27	2.72	3.63	4.08	1.81	2.49	2.72						34.7
	8	6/11/2003	3.63	2.27	2.72	5.9	2.63	4.31	4.63	3.63	7.71	5.9							43.3
	4	6/11/2003	3.63	4.54	3.18	2.95	4.08	2.63	3.72	4.99	5.44	7.48	6.58	4.31	5.9	7.03	5.22	8.62	80.3
Roadside 3	1	6/12/2003	3.86	6.35	6.8	5.44	6.58	4.54	5.9										39.5
Willow Tree	1	6/23/2003	1.81	4.31	2.72	5.67	4.08	6.35	4.76	4.08	8.16	2.72							44.7
Slate River	1	6/24/2003	4.76	4.54	7.26	4.99	6.12	6.58	5.44	3.63	2.27								45.6
Sandstone	19	6/28/2003	6.35	6.8	4.99	9.98	7.26	5.22	5.44	4.99	2.72	4.99	1.81	6.8	4.76	3.63			75.7

Average sediment weigh = 45.7 kg.

CHAPTER VI

DISCUSSION OF RESULTS

This chapter aims to provide some discussion of the results found in this study. The first portion of this section reiterates some of the findings concerning the general characteristics of marmot burrows. The second section discusses the total volumes displaced, with some ideas about how this data could be projected over time. Marmots' impacts on slope failure are described in the third section while the fourth section discusses the preferred slope aspect for burrows. Finally, the usefulness of the sediment trap is described.

Marmot burrows were sampled on slopes ranging from 2° to 33° and burrows were found facing azimuths ranging from 5° to 360°. Average sizes for triangular shaped burrows were 19.7 x 21.0 x 18.8 x 89.8 cm deep and average sizes for trapezoid shaped burrows were 26.1 x 12.4 x 18.8 x 14.6 x 91.5 cm deep. Rectangular burrows averaged 19.9 x 20.0 x 19.9 x 17.8 x 162.6 cm deep whereas oval shaped burrows averaged 25.1 x 22.4 x 105.9 cm deep. Trapezoidal shaped burrows accounted for 18.4% of all burrows sampled, while rectangular, oval, and triangular shaped burrows accounted for 5%, 38.3%, and 37.3%, respectively, of all burrows measured. Burrows were sampled at elevations ranging from 2750 m to 3160 m, with a mean elevation of 2960 m for all study sites.

Results indicate that yellow-bellied marmots (*Marmota flaviventris*), are capable of displacing up to 59.7 m^3 per square kilometer in a highly localized area. As noted in the previous chapter, this number represents potential sediment displacement and does not imply that marmots actually move 59.7 m^3/ km^2. In fact, marmots displace much less sediment than 59.7 m^3/ km^2 per year. Individual displacement per burrow averaged 0.079 m^3. One aim of this research is to determine a rate of sediment displacement by marmots in the Elk Mountains of Colorado. Therefore, it is necessary to make some conjectures about possible rates using data from the sediment weighs and from the volumes of sediment displaced.

Over the course of the research, sediment weighs were conducted on nine burrows which were actively being excavated. The researcher assumes that all burrows undergoing excavation were active during the 2003 field season. The researcher also assumes that all active burrows in the study areas were surveyed because active burrow excavations are very prominent features of a marmot colony. As seen in Figure 6.1, large mounds of sediment pile up in front of a burrow that is being actively excavated. These features are severely deformed, eroded, and weathered, even after one winter. Therefore, it is possible to verify that all burrows that were being actively excavated were in fact, surveyed.

Next, we assume that the rate of burrow excavations is 9 excavations for every 203 burrows. This gives us a rate of 0.044 excavations per burrow. In other words, roughly 4.5% of all burrows surveyed are actively being excavated. Assuming that all burrows contribute an equal amount of sediment, we can assume that 4.5% of the

Fig. 6.1. Photograph of fresh marmot diggings underneath a willow tree.

sediment displaced was from the current field season. So, if 4.5% of the total sediment displaced is from the 2003 season, we can obtain a rate of displacement per year per km^2 by taking 4.5% of 59.7 m^3/km^2. Using this method, we find that yellow-bellied marmots displace about 2.69 m^3/km^2/year.

Assuming that marmot burrowing activity is relatively constant over time, some number can be projected that may illustrate marmots' effect on a landscape over time. Over a ten year period, marmots may be capable of displacing up to 26.9 m^3/km^2 and 269 m^3/km^2 over a one-hundred year period. Over the course of a thousand years, these figures balloon to 2690 m^3/km^2. This research does not attempt to say that marmots have moved this amount of sediment, but that marmots are certainly capable of having a dramatic effect on erosion processes in an alpine environment. These results cannot be expected in all areas of Colorado at all elevations or in other alpine environments where marmots are found. As marmot density changes along with elevation, climate, available moisture, and ecosystem type, marmot's effect on sediment movement will also change. Marmot density is both site specific and species specific (Table 2.1). In fact, marmot burrow density can range from 1.5 burrows/ hectare to 46.9 burrows/ hectare depending on the species (Blumstein et al. 2001). Therefore, the numbers presented in this research can only be expected in areas of Colorado that have similar burrow densities and environmental and elevational conditions.

One of the most fascinating results of this research is the idea that yellow-bellied marmots can contribute to mass wasting processes like landslides and rock falls. Visual inspections of two study sites indicate that two independent mass wasting events occurred in areas where marmot burrows are present. Although it is very difficult to claim that marmots caused the landslides, the research indicates that marmot activity may have contributed to these processes. If this is indeed true, this would be the first case in which animals have been known to accelerate mass wasting events in an alpine environment. While the researcher is hesitant to state that marmots cause landslides, the research indicates that marmot burrowing may play a role in these processes. Most likely, large amounts of wet, heavy snowfall in alpine environments also contribute to these processes. In order to explore this idea further, more research needs to be done that examines how marmots are actually weakening the rocks that they burrow beneath and how this process works in concert with other weathering processes. Research must also be conducted to explore how marmots may force a system into disequilibrium by crossing a threshold boundary that causes a mass wasting event.

Results from the Rayleigh Test for Circular Uniformity indicate that there is no preferred burrow orientation. As burrows occur at almost all azimuths, marmot burrows are probably constructed in areas where digging is easiest in that particular area. The mean burrow azimuth is 235°, which indicates that more marmot burrows occur on southwesterly exposures than would be expected from a completely random distribution (Svendsen 1976). Svendsen (1976) also found that yellow-bellied marmot burrows do not occur at all azimuths in equiprobability. His study found that 48% of all burrows occurred at azimuths between 180° and 270°. This thesis found that 38.8% of all burrows occurred between 180° and 270°. Reasons for such discrepancies between data sets are likely due to different sample sizes; Svendsen only sampled 33 burrows while this study sampled 203 burrows.

CHAPTER VII

CONTRIBUTIONS AND FINAL REMARKS

This research contributes to different geographic fields of study, including the field of zoogeomorphology and threshold theory. This research has contributed to the field of zoogeomorphology by providing the first quantitative analysis of sediment movement by marmots. One major goal of the field of zoogeomorphology is to quantify actual amounts of sediment that is excavated and subsequently eroded by animals. Zoogeomorphology seeks to examine the roles animals play in earth surface processes, including the creation of landforms, as well as the erosion, transportation, and deposition of sediment (Butler 1995).

The research suggests that marmots can have profound effects on local geomorphology, especially in areas where marmot density is high. Studying the geomorphic role played by marmots contributes to the field of zoogeomorphology because this research examines the effect that marmots have on local geomorphology. This thesis has proved that marmots certainly play a role in sediment transport, erosion, and deposition. Marmots have also been shown to create new landforms as a result of their daily activities.

This thesis also provides some useful methods of analysis for future research. For example, this research suggests that sediment fences are not useful techniques for imposition of such devices. The sediment fence used for this research was a dismal failure and modifications to this method should be made prior to future studies of this type.

The research also reveals that sediment displacement by marmots can indeed be quantified, especially when one uses the proper volume formulas to calculate sediment removed. Marmots are capable of moving at least 2.69 m^3/ km^2 in the Elk Mountains of Colorado, which is a significant amount of movement over the course of one year.

Future Research Suggestions

In terms of future research in this field, it is important for zoogeomorpholgists to recognize the need for standardization across all scales of measurement. Perhaps the largest problem in this study involved the complexities associated with determining the zoogeomorphic impact of animals that were studied in different ways. Future studies of a similar nature should seek to report the amount of sediment displaced in m^3/ km^2, rather than metric tonnes per hectare. Unless future studies standardize how results are reported, comparisons between different animals will continue to pose a major challenge to those wishing to continue studies in zoogeomorphology.

Final Remarks

How will the field of zoogeomorphology change over time? What other animals can be studied that can provide zoogeomorpholgists with a better understanding of animals' role in geomorphic processes? How can zoogeomorphic studies be improved to increase the accuracy of our measurements? These are questions that lie at the forefront of zoogeomorphology. These are the questions that will be answered by future scientists wishing to gain a more thorough understanding of animals and the roles they play in the manipulation of landscapes. In order for these questions to be answered however, we must, as a society, seek to protect those environments in which these animals exist. Future studies can not persist unless human beings make a more concerted effort to protect the natural landscapes that are home to these animals.

APPENDIX 1

Volume calculations for all burrows.

Site Name	Burrow #	Burrow Shape	Volume (in³)	Volume (cm³)	Volume (m³)
Aspen	2	R(Trapezoid)	1067	17220.313	0.017220313
Slate Creek	4	R(Trapezoid)	2738.352607	44194.27272	0.044194273
Upper Picnic	3	R(Trapezoid)	1205.568862	19456.67586	0.019456676
Upper Picnic	5	R(Trapezoid)	4944.050097	79792.02451	0.079792025
Upper Upper Picnic	6	R(Trapezoid)	6897.892341	111325.0845	0.111325084
401 Meadow	1	R(Trapezoid)	3651.755263	58935.67819	0.058935678
401 Meadow	8	R(Trapezoid)	2037.424764	32881.99827	0.032881998
Roadside 3	2	R(Trapezoid)	12354	199381.206	0.199381206
Lower Picnic	3	R(Trapezoid)	1211.713926	19555.85106	0.019555851
Lower Picnic	4	R(Trapezoid)	6124.553555	98844.16983	0.09884417
Lower, Lower Picnic	1	R(Trapezoid)	15460.25837	249513.1098	0.24951311
Lower, Lower Picnic	3	R(Trapezoid)	321.8312982	5194.035322	0.005194035
Lower, Lower Picnic	7	R(Trapezoid)	6468.279627	104391.5649	0.104391565
Lower, Lower Picnic	9	R(Trapezoid)	838.686473	13535.56099	0.013535561
N. Marmot Meadow	1	R(Trapezoid)	7961.880745	128496.7933	0.128496793
N. Marmot Meadow	4	R(Trapezoid)	424.6694487	6853.740232	0.00685374
N. Marmot Meadow	8	R(Trapezoid)	7129.193628	115058.056	0.115058056
N. Marmot Meadow	13	R(Trapezoid)	292.1341462	4714.752985	0.004714753
N. Marmot Meadow	16	R(Trapezoid)	354.3727215	5719.221352	0.005719221
N. Marmot Meadow	17	R(Trapezoid)	1196.052256	19303.08737	0.019303087
N. Marmot Meadow	19	R(Trapezoid)	1258.114434	20304.70885	0.020304709
River South	4A	R(Trapezoid)	4567.430452	73713.76007	0.07371376
Quartzite	6	R(Trapezoid)	16757.60587	270451.0012	0.270451001
Quartzite	8	R(Trapezoid)	3254.714461	52527.83669	0.052527837
Sandstone	5	R(Trapezoid)	576	9296.064	0.009296064
Sandstone	6	R(Trapezoid)	1900.703028	30675.44617	0.030675446
Sandstone	11	R(Trapezoid)	7249.510203	116999.8452	0.116999845
Sandstone	20	R(Trapezoid)	3374.974963	54468.72093	0.054468721
Sandstone	21	R(Trapezoid)	880	14202.32	0.01420232
Sandstone	23	R(Trapezoid)	1048.686679	16924.75431	0.016924754
Sandstone	24	R(Trapezoid)	6646.97946	107275.6015	0.107275601
Sandstone	26	R(Trapezoid)	2543.570669	41050.68703	0.041050687
Sandstone	27	R(Trapezoid)	555.6077753	8966.953886	0.008966954
Sandstone	34	R(Trapezoid)	48790.7708	787434.2499	0.78743425
Sandstone	37	R(Trapezoid)	762.2080429	12301.2756	0.012301276
Sandstone	41	R(Trapezoid)	1292.481715	20859.3624	0.020859362
Sandstone	42	R(Trapezoid)	3622.028617	58455.91985	0.05845592
Old Road	1	Rectangle	560	9037.84	0.00903784
Old Road	2	Rectangle	2065.5	33335.1045	0.033335105
Willow Tree	1	Rectangle	5390	86989.21	0.08698921
Mid Picnic	2	Rectangle	11136	179723.904	0.179723904

APPENDIX 1, CONTINUED.

Site Name	Burrow #	Burrow Shape	Volume (in³)	Volume (cm³)	Volume (m³)
Lower, Lower Picnic	11	Rectangle	1995	32197.305	0.032197305
River South	3	Rectangle	1456	23498.384	0.023498384
Sandstone	8	Rectangle	2047.5	33044.6025	0.033044603
Sandstone	16	Rectangle	464	7488.496	0.007488496
Sandstone	7	Rectangle	4704	75917.856	0.075917856
Spruce Mound	1	Oval	9311.680626	150281.2136	0.150281214
Spruce Mound	5	Oval	570.1990667	9202.442737	0.009202443
Tree Fall	1	Oval	6342.09017	102354.9933	0.102354993
Plug	1	Oval	1558.229956	25148.27327	0.025148273
Plug	2	Oval	1497.492498	24168.03143	0.024168031
Rock Talus	1	Oval	2488.730431	40165.62042	0.04016562
Slate Creek	5	Oval	1121.548577	18100.67249	0.018100672
Slate Creek	7	Oval	1105.840614	17847.16167	0.017847162
Slate Creek	10	Oval	204.2035225	3295.64065	0.003295641
Mid Picnic	5	Oval	1044.579557	16858.46948	0.016858469
401 Meadow	2	Oval	1659.15362	26777.08028	0.02677708
401 Meadow	3	Oval	3887.720909	62743.92776	0.062743928
401 Meadow	4	Oval	867.8649707	14006.47276	0.014006473
401 Meadow	5	Oval	3764.151598	60749.64264	0.060749643
401 Meadow	7	Oval	1121.548577	18100.67249	0.018100672
401 Meadow Hillside	1	Oval	1252.448271	20213.26265	0.020213263
401 Meadow Hillside	2	Oval	706.072949	11395.31132	0.011395311
Boulder	2	Oval	2722.713633	43941.87533	0.043941875
Boulder	8	Oval	431.9689899	6971.547528	0.006971548
Lower, Lower Picnic	4	Oval	813.6724974	13131.86044	0.01313186
RMBL River	1	Oval	1031.653213	16649.8512	0.016649851
RMBL River	2	Oval	1193.314335	19258.90005	0.0192589
RMBL River	3	Oval	798.0954338	12880.46221	0.012880462
RMBL River	4	Oval	447.6769532	7225.058348	0.007225058
RMBL River	5	Oval	7263.362216	117223.4028	0.117223403
RMBL River	6	Oval	646.6444879	10436.19539	0.010436195
RMBL River	7	Oval	894.1758091	14431.10338	0.014431103
RMBL River	8	Oval	1869.247629	30167.78749	0.030167787
RMBL Dining	1	Oval	748.7462492	12084.01572	0.012084016
RMBL Dining	2	Oval	452.3893422	7301.111593	0.007301112
RMBL Cabin	1	Oval	2563.539606	41372.9657	0.041372966
RMBL Cabin	2	Oval	5034.598578	81253.38644	0.081253386
Marmot Meadow	1	Oval	673.8716243	10875.61414	0.010875614
Marmot Meadow	2	Oval	990.4852589	15985.44159	0.015985442
Marmot Meadow	3	Oval	268.6061719	4335.035009	0.004335035
Marmot Meadow	6	Oval	1091.376198	17613.72046	0.01761372
N. Marmot Meadow	5	Oval	209.4395103	3380.144256	0.003380144
N. Marmot Meadow	12	Oval	439.8229716	7098.302938	0.007098303
N. Marmot Meadow	14	Oval	1143.539726	18455.58764	0.018455588

APPENDIX 1, CONTINUED.

Site Name	Burrow #	Burrow Shape	Volume (in³)	Volume (cm³)	Volume (m³)
N. Marmot Meadow	20	Oval	1596.419942	25764.62145	0.025764621
N. Marmot Meadow	23	Oval	446.6952055	7209.213921	0.007209214
N. Marmot Meadow	24	Oval	1735.729941	28012.94552	0.028012946
River South	2A	Oval	1256.637062	20280.86554	0.020280866
River South	5A	Oval	3418.052808	55163.95426	0.055163954
River South	6A	Oval	9424.777962	152106.4915	0.152106492
River South	7	Oval	15268.1403	246412.5163	0.246412516
River South	8	Oval	846.6592203	13664.23316	0.013664233
River South	9	Oval	427.6493	6901.832053	0.006901832
River South	10	Oval	42223.00527	681437.082	0.681437082
River South	11	Oval	2082.87593	33615.53463	0.033615535
River South	12	Oval	2477.669406	39987.10655	0.039987107
River South	13	Oval	4851.142657	78292.59133	0.078292591
River South	14	Oval	967.6105374	15616.26646	0.015616266
River South	15	Oval	4104.490802	66242.37706	0.066242377
River South	17A	Oval	934.6238146	15083.89374	0.015083894
River South	18A	Oval	572.5552612	9240.46936	0.009240469
River South	19	Oval	494.800843	7985.590805	0.007985591
River South	20	Oval	311.0176727	5019.51422	0.005019514
River South	21	Oval	626.2241357	10106.63133	0.010106631
Plug Landslide	1	Oval	8326.791329	134386.0853	0.134386085
Plug Landslide	2	Oval	17799.08588	287259.447	0.287259447
Quartzite	1	Oval	498.4660344	8044.74333	0.008044743
Quartzite	3	Oval	697.6953686	11260.10555	0.011260106
Quartzite	7	Oval	1068.141502	17238.73571	0.017238736
Sandstone	4	Oval	502.6548246	8112.346215	0.008112346
Sandstone	9	Oval	678.5840133	10951.66739	0.010951667
Sandstone	10	Oval	368.6135381	5949.053891	0.005949054
Sandstone	12	Oval	791.6813488	12776.94529	0.012776945
Sandstone	13	Oval	1191.187215	19224.57046	0.01922457
Sandstone	15	Oval	262.0611872	4229.405501	0.004229406
Sandstone	17	Oval	299.4984997	4833.606286	0.004833606
Sandstone	30	Oval	1182.024236	19076.68915	0.019076689
Sandstone	32	Oval	384.8451001	6211.015071	0.006211015
Sandstone	33	Oval	1187.914722	19171.7557	0.019171756
Sandstone	35	Oval	1503.252085	24260.9854	0.024260985
Sandstone	39	Oval	795.870139	12844.54817	0.012844548
Sandstone	40	Oval	216.7698931	3498.449305	0.003498449
Snowbank	1	Triangle	3045.069184	49144.37155	0.049144372
Aspen	1	Triangle	1151.974867	18591.72238	0.018591722
Aspen	2	Triangle	4003.21809	64607.93676	0.064607937
Slate Creek	3	Triangle	58756.71137	948274.5648	0.948274565
Slate Creek	6	Triangle	13194.0104	212938.1338	0.212938134
Slate Creek	8	Triangle	8364.811479	134999.6925	0.134999692

APPENDIX 1, CONTINUED.

Site Name	Burrow #	Burrow Shape	Volume (in³)	Volume (cm³)	Volume (m³)
Slate Creek	9	Triangle	2024.121094	32667.29033	0.03266729
Upper Picnic	1	Triangle	2087.596736	33691.72373	0.033691724
Upper Picnic	2	Triangle	4232.173909	68303.05472	0.068303055
Upper Picnic	4	Triangle	385.934002	6228.588858	0.006228589
Upper Picnic	6	Triangle	5734.380155	92547.16132	0.092547161
Upper Picnic	8	Triangle	48299.06831	779498.6635	0.779498664
Mid Picnic	1	Triangle	23814.4058	384340.6951	0.384340695
Mid Picnic	4	Triangle	32485.62212	524285.4554	0.524285455
Upper Upper Picnic	1	Triangle	2333.013675	37652.5077	0.037652508
Upper Upper Picnic	2	Triangle	5134.330891	82862.96625	0.082862966
Upper Upper Picnic	3	Triangle	12996.87353	209756.5419	0.209756542
Upper Upper Picnic	4	Triangle	5168.527008	83414.85739	0.083414857
Upper Upper Picnic	5	Triangle	1442.497834	23280.47254	0.023280473
Upper Upper Picnic	7	Triangle	1074.636714	17343.56193	0.017343562
401 Meadow	6	Triangle	4718.750554	76155.9152	0.076155915
Roadside 3	1	Triangle	9124.682712	147263.2543	0.147263254
Boulder	1	Triangle	3782.090618	61039.16048	0.06103916
Boulder	3	Triangle	11057.38229	178455.0928	0.178455093
Boulder	4	Triangle	3960	63910.44	0.06391044
Boulder	5	Triangle	6372.894535	102852.1449	0.102852145
Boulder	6	Triangle	1223.246851	19741.98093	0.019741981
Boulder	7	Triangle	1836.749847	29643.30578	0.029643306
Lower Picnic	1	Triangle	9196.384164	148420.444	0.148420444
Lower Picnic	2	Triangle	19458.26803	314036.9877	0.314036988
Lower Picnic	5	Triangle	2719.659604	43892.58635	0.043892586
Lower Picnic	6	Triangle	2093.134128	33781.09169	0.033781092
Lower Picnic	7	Triangle	11803.2973	190493.4152	0.190493415
Lower Picnic	8	Triangle	1031.558843	16648.32816	0.016648328
Lower, Lower Picnic	2	Triangle	1949.050989	31455.7339	0.031455734
Lower, Lower Picnic	6	Triangle	4999.811871	80691.96379	0.080691964
Lower, Lower Picnic	8	Triangle	4681.95944	75562.1434	0.075562143
Lower, Lower Picnic	10	Triangle	3090.199099	49872.72325	0.049872723
Lower, Lower Picnic	12	Triangle	4364.768035	70442.99132	0.070442991
Lower, Lower Picnic	13	Triangle	3810.675531	61500.49239	0.061500492
Lower, Lower Picnic	14	Triangle	568.75	9179.05625	0.009179056
Marmot Meadow	4	Triangle	9300.519515	150101.0845	0.150101084
Marmot Meadow	5	Triangle	1574.784231	25415.4427	0.025415443
N. Marmot Meadow	2	Triangle	3883.580822	62677.11088	0.062677111
N. Marmot Meadow	3	Triangle	4950.99321	79904.07942	0.079904079
N. Marmot Meadow	6	Triangle	7763.554687	125296.0091	0.125296009
N. Marmot Meadow	7	Triangle	25147.8976	405861.9194	0.405861919
N. Marmot Meadow	9	Triangle	6550.325305	105715.7001	0.1057157
N. Marmot Meadow	10	Triangle	2259.35555	36463.73922	0.036463739

APPENDIX 1, CONTINUED

Site Name	Burrow #	Burrow Shape	Volume (in³)	Volume (cm³)	Volume (m³)
N. Marmot Meadow	11	Triangle	3051.384931	49246.30141	0.049246301
N. Marmot Meadow	15	Triangle	819.029914	13218.32378	0.013218324
N. Marmot Meadow	18	Triangle	2128.51191	34352.05371	0.034352054
N. Marmot Meadow	21	Triangle	1968.75	31773.65625	0.031773656
N. Marmot Meadow	22	Triangle	8963.472499	144661.4827	0.144661483
River South	16	Triangle	2368.021702	38217.50225	0.038217502
Quartzite	2	Triangle	10520.72568	169793.9917	0.169793992
Quartzite	4	Triangle	2910.338254	46969.94907	0.046969949
Quartzite	5	Triangle	3099.515367	50023.0785	0.050023079
Quartzite	10	Triangle	27885.48009	450043.7632	0.450043763
Quartzite	11	Triangle	11893.82588	191954.4558	0.191954456
Sandstone	1	Triangle	6595.649475	106447.1869	0.106447187
Sandstone	2	Triangle	2327.436358	37562.49538	0.037562495
Sandstone	3	Triangle	25781.69758	416090.8173	0.416090817
Sandstone	14	Triangle	948.75	15311.87625	0.015311876
Sandstone	18	Triangle	814.5870119	13146.61979	0.01314662
Sandstone	19	Triangle	2100	33891.9	0.0338919
Sandstone	22	Triangle	4895.994457	79016.45453	0.079016455
Sandstone	25	Triangle	684	11039.076	0.011039076
Sandstone	28	Triangle	6066.620627	97909.1903	0.09790919
Sandstone	29	Triangle	1272.792206	20541.59341	0.020541593
Sandstone	31	Triangle	5086.531462	82091.53126	0.082091531
Sandstone	36	Triangle	1701.378265	27458.54382	0.027458544
Sandstone	38	Triangle	910.1333436	14688.64203	0.014688642

APPENDIX 2

Site characteristics.

Site Name	Burrow Number	Latitude	Longitude	Elevation (m)	Azimuth (°)	Slope Angle (°)
River Mound	1	N 38° 57' .8"	W 106° 59' 20.3"	2875	NA	8
Spruce Mound	1	N 38° 56' 56.2"	W 106° 59' 15.0"	2868	NA	2
Spruce Mound	5			2868	NA	2
Tree Fall	2			3159	170	14
Snowbank	1	N 39° 00' 20.8"	W 107° 01' 52.5"	3146	220	14
Old Road	1	N 39° 00' 18"	W 107° 01' 54.0"	3141	280	3
Old Road	2			3141	60	3
Willow Tree	1	N 39° 00' 19.7"	W 107° 01' 51.2"	3159	225	10
Plug	1	N 39° 00' 17.0"	W 107° 01' 44.9"	3130	60	33
Plug	2			3130	130	33
Plug	3			3130	140	33
Aspen	1	N 38° 58' 40.7"	W 106° 59' 58.3"	2953	280	6
Aspen	2			2953	275	6
Aspen	3			2953	290	6
Rock Talus	1	N 38° 57' 13.8"	W 107° 03' 42.0"	2954	310	7
Slate Creek	1	N 38° 58' 43.3"	W 106° 59' 58.9"	2864	220	26
Slate Creek	2			2864	270	26
Slate Creek	3			2864	50	26
Slate Creek	4			2864	245	26
Slate Creek	5			2864	75	26
Slate Creek	6			2864	315	26
Slate Creek	7			2864	265	26
Slate Creek	8			2864	18	26
Slate Creek	9			2864	224	26
Slate Creek	10			2864	280	26
Upper Picnic	1	N 38° 58' 57.6"	W 107° 00' 39.2"	3027	60	25
Upper Picnic	2			3027	60	25
Upper Picnic	3			3023	60	25
Upper Picnic	4			3023	60	25
Upper Picnic	5			3020	72	25
Upper Picnic	6			3020	65	25
Upper Picnic	7			3020	75	25
Upper Picnic	8			3020	70	25
Mid Picnic	1	N 38° 58' 58.0"	W 107° 00' 38.4"	3009	42	22
Mid Picnic	2			3010	90	22
Mid Picnic	3			3010	20	22
Mid Picnic	4			3010	20	22
Mid Picnic	5			3010	170	22
Upper Upper Picnic	1	N 38° 58' 59.1"	W 107° 00' 40.0"	3038	131	14

APPENDIX 2, CONTINUED.

Site Name	Burrow Number	Latitude	Longitude	Elevation (m)	Azimuth (°)	Slope Angle (°)
Upper Upper Picnic	4	N 38° 58' 59.1"	W 107° 00' 40.0"	3038	110	14
Upper Upper Picnic	5			3038	27	14
Upper Upper Picnic	6			3038	25	14
Upper Upper Picnic	7			3038	35	14
401 Meadow	1	N 38° 59' 39.7"	W 107° 00' 21.7"	2969	220	4
401 Meadow	2			2967	181	4
401 Meadow	3			2961	178	4
401 Meadow	4			2953	15	4
401 Meadow	5			2950	87	4
401 Meadow	6			2950	172	4
401 Meadow	7			2950	121	4
401 Meadow	8			2949	110	4
401 Meadow Hillside	1	N 38° 59' 39.7"	W 107° 00' 21.7"	2946	280	17
401Meadow Hillside	2			2946	331	17
Roadside 3	1	N 39° 00' 13.8"	W 107° 01' 35.7"	3104	201	25
Roadside 3	2			3104	200	25
Boulder	1	N 38° 59' 07.0"	W 107° 00' 39.8"	2986	120	17
Boulder	2			2986	7	17
Boulder	3			2986	68	17
Boulder	4			2982	52	17
Boulder	5			2981	35	17
Boulder	6			2980	37	17
Boulder	7			2976	51	17
Boulder	8			2976	114	17
Lower Picnic	1	N 38° 58' 54.4"	W 107° 00' 36.6"	3002	45	15
Lower Picnic	2			2999	15	15
Lower Picnic	3			2999	108	15
Lower Picnic	4			2999	53	15
Lower Picnic	5			2999	32	15
Lower Picnic	6			2989	45	15
Lower Picnic	7			2991	59	15
Lower Picnic	8			2981	134	15
Lower, Lower Picnic	1	N 38° 58' 54.0"	W 107° 00' 36.0"	2978	61	21
Lower, Lower Picnic	2			2978	15	21
Lower, Lower Picnic	3			2978	30	21
Lower, Lower Picnic	4			2978	85	21

APPENDIX 2, CONTINUED.

Site Name	Burrow Number	Latitude	Longitude	Elevation (m)	Azimuth (°)	Slope Angle (°)
Lower, Lower Picnic	5	N 38° 58' 54.0"	W 107° 00' 36.0"	2978	14	21
Lower, Lower Picnic	6			2971	96	21
Lower, Lower Picnic	7			2971	333	21
Lower, Lower Picnic	9			2971	10	21
Lower, Lower Picnic	10			2971	100	21
Lower, Lower Picnic	11			2971	65	21
Lower, Lower Picnic	12			2971	70	21
Lower, Lower Picnic	13			2971	130	21
Lower, Lower Picnic	14			2971	141	21
RMBL River	1	N 38° 57' 37.0"	W 106° 59' 29.4"	2902	210	17
RMBL River	2			2902	190	17
RMBL River	3			2902	220	17
RMBL River	4			2902	210	17
RMBL River	5			2902	250	17
RMBL River	6			2902	268	17
RMBL River	7			2902	199	17
RMBL River	8			2902	282	17
RMBL Dining	1	N 38° 57' 33.3"	W 106° 59' 28.4"	2898	44	1
RMBL Dining	2			2898	225	1
RMBL Cabin	1	N 38° 57' 24.3"	W 106° 59' 27.1"	2895	335	18
RMBL Cabin	2			2895	256	18
Marmot Meadow	1	N 38° 58' 41.5"	W 107° 00' 00.5"	2938	194	10
Marmot Meadow	2			2938	246	10
Marmot Meadow	3			2938	330	10
Marmot Meadow	4			2938	61	10
Marmot Meadow	5			2938	165	10
Marmot Meadow	6			2938	240	10
N. Marmot Meadow	1	N 38° 58' 43.2"	W 107° 00' 00.8"	2940	294	10
N. Marmot Meadow	2			2940	11	10
N. Marmot Meadow	3			2940	245	10
N. Marmot Meadow	4			2940	210	10

APPENDIX 2, CONTINUED.

Site Name	Burrow Number	Latitude	Longitude	Elevation (m)	Azimuth (°)	Slope Angle (°)
N. Marmot Meadow	5	N 38° 58' 43.2"	W 107° 00' 00.8"	2940	170	10
N. Marmot Meadow	6			2940	10	10
N. Marmot Meadow	7			2940	176	10
N. Marmot Meadow	8			2940	173	10
N. Marmot Meadow	9			2940	28	10
N. Marmot Meadow	10			2940	240	10
N. Marmot Meadow	11			2940	193	10
N. Marmot Meadow	12			2940	193	10
N. Marmot Meadow	13			2940	321	10
N. Marmot Meadow	14			2940	325	10
N. Marmot Meadow	15			2940	80	10
N. Marmot Meadow	16			2940	284	10
N. Marmot Meadow	17			2940	320	10
N. Marmot Meadow	18			2940	5	10
N. Marmot Meadow	19			2940	12	10
N. Marmot Meadow	20			2940	147	10
N. Marmot Meadow	21			2940	240	10
N. Marmot Meadow	22			2940	312	10
N. Marmot Meadow	23			2940	182	10
N. Marmot Meadow	24			2940	109	10
River South	1A	N 38° 56' 55.3"	W 106° 59' 14.2"	2871	45	15
River South	1B			2871	45	15
River South	2A			2871	135	15
River South	2B			2871	135	15
River South	3A			2871	184	15
River South	3B			2871	184	15
River South	4A			2871	255	15
River South	5A			2871	89	15

APPENDIX 2, CONTINUED.

Site Name	Burrow Number	Latitude	Longitude	Elevation (m)	Azimuth (°)	Slope Angle (°)
River South	5B	N 38° 56' 55.3"	W 106° 59' 14.2"	2871	89	15
River South	6A			2871	100	15
River South	6B			2871	100	15
River South	7			2871	265	15
River South	8			2871	32	15
River South	9			2871	100	15
River South	10			2871	283	15
River South	11			2871	281	15
River South	12			2871	101	15
River South	13			2871	24	15
River South	14			2871	40	15
River South	15			2871	40	15
River South	16			2871	40	15
River South	17A			2871	50	15
River South	17B			2871	50	15
River South	18 A			2871	20	15
River South	18 B			2871	20	15
River South	19			2871	20	15
River South	20			2871	20	15
River South	21			2871	290	15
Plug Landslide	1	N 39° 00' 17.7"	W 107° 01' 45.0"	3138	133	33
Plug Landslide	2			3138	144	33
Quartzite	1	N 39° 00' 20.1"	W 107° 01' 45.0"	3162	163	33
Quartzite	2			3162	173	33
Quartzite	3			3162	207	33
Quartzite	4			3162	180	33
Quartzite	5			3162	360	33
Quartzite	6			3162	240	33
Quartzite	7			3162	225	33
Quartzite	8			3162	245	33
Quartzite	9			3162	245	33
Quartzite	10			3162	305	33
Quartzite	11			3162	183	33
Sandstone	1	N 38° 54' 12.0"	W 107° 00' 51.7"	2751	260	26
Sandstone	2			2751	260	26
Sandstone	3			2751	245	26
Sandstone	4			2751	234	26
Sandstone	5			2751	268	26
Sandstone	6			2751	251	26
Sandstone	7			2751	220	26
Sandstone	8			2751	220	26
Sandstone	9			2751	223	26
Sandstone	10			2751	260	26
Sandstone	11			2751	275	26

APPENDIX 2, CONTINUED.

Site Name	Burrow Number	Latitude	Longitude	Elevation (m)	Azimuth (°)	Slope Angle (°)
Sandstone	12	N 38° 54' 12.0"	W 107° 00' 51.7"	2751	315	26
Sandstone	13			2751	47	26
Sandstone	14			2751	274	26
Sandstone	15			2751	255	26
Sandstone	16			2751	230	26
Sandstone	17			2751	224	26
Sandstone	18			2751	261	26
Sandstone	19			2751	220	26
Sandstone	20			2751	170	26
Sandstone	21			2751	238	26
Sandstone	22			2751	122	26
Sandstone	23			2751	157	26
Sandstone	24			2751	284	26
Sandstone	25			2751	180	26
Sandstone	26			2751	234	26
Sandstone	27			2751	205	26
Sandstone	28			2751	250	26
Sandstone	29			2751	265	26
Sandstone	30			2751	220	26
Sandstone	31			2751	278	26
Sandstone	32			2751	244	26
Sandstone	33			2751	267	26
Sandstone	34			2751	195	26
Sandstone	35			2751	225	26
Sandstone	36			2751	146	26
Sandstone	37			2751	193	26
Sandstone	38			2751	172	26
Sandstone	39			2751	198	26
Sandstone	40			2751	250	26
Sandstone	41			2751	289	26
Sandstone	42			2751	275	26

APPENDIX 3

Original Measurements. Note: measurements have been converted to metric units.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
Spruce Mound	1	Oval	45.72	33.02			193.04
Spruce Mound	5	oval	27.94	11.43			55.88
Tree Fall	1	Oval	43.18	24.13			190.5
Snowbank	1	Triangle	15.875	17.78	12.7		101.6
Old Road	1	Rectangle	12.7	17.78			40.64
Old Road	2	Rectangle	10.795	22.86			137.16
Willow Tree	1	Rectangle	13.97	50.8			124.46
Plug	1	Oval	20.32	30.48			78.74
Plug	2	Oval	13.97	40.64			82.55
Aspen	1	Triangle	17.78	22.86	7.62		116.84
Aspen	2	Triangle	13.97	17.78	15.24		121.92
Aspen	3	Rectangle	20.32	22.86	15.24	15.24	92.71
Rock Talus	1	Oval	24.765	33.02			95.25
Slate Creek	1	Rectangle	50.8	114.3			104.14
Slate Creek	2	Rectangle	8.89	11.43	15.24	10.16	132.08
Slate Creek	3	Triangle	34.29	27.94	33.02		147.32
Slate Creek	4	Rectangle	7.62	17.78	12.7	15.24	116.84
Slate Creek	5	Oval	30.48	8.89			129.54
Slate Creek	6	Triangle	25.4	33.02	21.59		73.66
Slate Creek	7	Oval	27.94	15.24			81.28
Slate Creek	8	Triangle	29.21	25.4	25.4		38.1
Slate Creek	9	Triangle	29.21	15.24	17.78		59.69
Slate Creek	10	Oval	7.62	12.7			66.04
Upper Picnic	1	Triangle	52.705	38.735	35.56		71.12
Upper Picnic	2	triangle	15.24	22.86	13.335		73.66
Upper Picnic	3	Triangle	21.59	24.13	12.7		81.28
Upper Picnic	4	Rectangle	25.4	10.16	12.7	11.43	92.71
Upper Picnic	5	Triangle	13.97	13.335	7.62		43.18
Upper Picnic	6	Rectangle	8.89	21.59	15.24	17.78	147.32
Upper Picnic	8	Triangle	7.62	34.29	17.78		58.42
Upper Picnic	9	Triangle	16.51	10.16	9.525		33.02
Upper Picnic	10	Triangle	40.64	44.45	16.51		203.2
Mid Picnic	1	Triangle	33.02	22.86	34.29		81.28
Mid Picnic	2	Rectangle	30.48	40.64			147.32
Mid Picnic	3	Square	22.86	10.16			104.14
Mid Picnic	4	Triangle	30.48	35.56	18.415		177.8
Mid Picnic	5	Oval	24.13	17.78			76.2
Upper Upper Picnic	1	Triangle	20.32	21.59	12.7		50.8

APPENDIX 3, CONTINUED.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
Upper Upper Picnic	2	Triangle	21.59	19.05	16.51		79.375
Upper Upper Picnic	3	Triangle	33.655	24.13	20.32		91.44
Upper Upper Picnic	4	Triangle	17.78	19.05	20.32		75.565
Upper Upper Picnic	5	Triangle	13.97	16.51	10.16		86.36
Upper Upper Picnic	6	Rectangle	8.89	16.51	17.78	12.7	74.93
Upper Upper Picnic	7	Triangle	8.89	17.145	16.51		63.5
401 Meadow	1	Rectangle	21.59	12.7	17.78	19.05	73.66
401 Meadow	2	Oval	31.75	16.51			99.06
401 Meadow	3	Oval	25.4	34.29			139.7
401 Meadow	4	Oval	16.51	19.05			86.36
401 Meadow	5	Oval	35.56	16.51			200.66
401 Meadow	6	Triangle	16.51	17.78	12.7		149.86
401 Meadow	7	Oval	22.86	17.78			86.36
401 Meadow	8	Rectangle	20.955	15.24	16.51	20.32	102.235
401 Meadow Hillside	1	Oval	20.32	16.51			116.84
401 Meadow Hillside	2	Oval	19.685	15.24			73.66
Roadside 3	1	Triangle	13.97	33.02	25.4		132.08
Roadside 3	2	Rectangle	7.62	8.89	38.1	55.88	30.48
Boulder	1	Triangle	10.16	22.86	24.13		100.33
Boulder	2	Oval	33.02	12.7			203.2
Boulder	3	Triangle	24.13	26.67	12.7		176.53
Boulder	4	Triangle	12.7	15.24	17.78		139.7
Boulder	5	Triangle	24.13	12.7	19.05		154.94
Boulder	6	Triangle	13.97	20.32	17.78		27.94
Boulder	7	Triangle	12.7	16.51	13.97		76.2
Boulder	8	Oval	13.97	12.7			76.2
Lower Picnic	1	Triangle	20.955	30.48	20.32		81.28
Lower Picnic	2	Triangle	21.59	34.29	23.495		129.54
Lower Picnic	3	Rectangle	24.13	13.97	14.605	21.59	76.2
Lower Picnic	4	Square	17.145	8.89	19.05	17.145	63.5
Lower Picnic	5	Triangle	24.13	25.4	10.16		66.04
Lower Picnic	6	Triangle	15.24	19.05	17.145		45.72
Lower Picnic	7	Triangle	26.67	14.605	27.94		125.73
Lower Picnic	8	Triangle	16.51	13.97	8.89		78.74
Lower, Lower Picnic	1	Rectangle	24.13	9.525	21.59	16.51	116.84

APPENDIX 3, CONTINUED.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
Lower, Lower Picnic	2	Triangle	11.43	19.05	21.59		55.88
Lower, Lower Picnic	3	Square	10.795	8.89	8.89	12.7	58.42
Lower, Lower Picnic	4	Oval	17.78	15.24			93.98
Lower, Lower Picnic	5	Square	11.43	13.97			60.96
Lower, Lower Picnic	6	Triangle	16.51	17.78	21.59		85.09
Lower, Lower Picnic	7	Rectangle	8.89	8.89	21.59	22.86	76.835
Lower, Lower Picnic	8	Triangle	15.24	19.05	17.78		97.79
Lower, Lower Picnic	9	Rectangle	16.51	15.24	24.13	11.43	53.34
Lower, Lower Picnic	10	Triangle	17.78	17.78	22.86		45.72
Lower, Lower Picnic	11	Rectangle	38.1	8.89			96.52
Lower, Lower Picnic	12	Triangle	21.59	19.05	20.32		50.8
Lower, Lower Picnic	13	Triangle	16.51	19.05	17.78		71.12
Lower, Lower Picnic	14	Triangle	11.43	7.62	12.7		81.28
RMBL River	1	Oval	31.75	16.51			61.595
RMBL River	2	Oval	20.955	21.59			82.55
RMBL River	3	Oval	16.51	17.78			85.09
RMBL River	4	Oval	11.43	24.13			50.8
RMBL River	5	Oval	60.96	43.18			86.36
RMBL River	6	Oval	16.51	24.13			50.8
RMBL River	7	Oval	14.605	22.86			83.82
RMBL River	8	Oval	21.59	17.78			152.4
RMBL Dining	1	Oval	16.51	25.4			55.88
RMBL Dining	2	Oval	22.86	10.16			60.96
RMBL Cabin	1	Oval	22.86	21.59			162.56
RMBL Cabin	2	Oval	46.99	41.91			80.01
Marmot Meadow	1	Oval	15.24	16.51			83.82
Marmot Meadow	2	Oval	12.065	22.86			112.395
Marmot Meadow	3	Oval	11.43	24.13			30.48
Marmot Meadow	4	Triangle	22.86	24.13	19.05		85.09

APPENDIX 3, CONTINUED.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
Marmot Meadow	5	Triangle	20.32	21.59	12.7		34.29
Marmot Meadow	6	Oval	12.7	18.415			146.05
N. Marmot Meadow	1	Rectangle	5.08	19.05	16.51	15.24	93.98
N. Marmot Meadow	2	Triangle	17.78	16.51	13.97		106.68
N. Marmot Meadow	3	Triangle	15.24	17.145	16.51		124.46
N. Marmot Meadow	4	Rectangle	15.875	16.51	12.7	14.605	63.5
N. Marmot Meadow	5	Oval	12.7	12.7			40.64
N. Marmot Meadow	6	Triangle	17.78	24.13	25.4		71.12
N. Marmot Meadow	7	Triangle	27.305	27.94	25.4		109.22
N. Marmot Meadow	8	Rectangle	22.86	21.59	13.97	40.64	246.38
N. Marmot Meadow	9	Triangle	22.86	12.7	21.59		128.27
N. Marmot Meadow	10	Triangle	13.97	11.43	12.7		139.7
N. Marmot Meadow	11	Triangle	19.05	20.32	8.89		139.7
N. Marmot Meadow	12	Oval	15.24	17.78			50.8
N. Marmot Meadow	13	Rectangle	15.24	20.32	19.05	13.97	137.16
N. Marmot Meadow	14	Oval	16.51	15.24			142.24
N. Marmot Meadow	15	Triangle	7.62	20.32	22.86		46.99
N. Marmot Meadow	16	Rectangle	8.89	9.525	19.685	20.32	59.69
N. Marmot Meadow	17	Rectangle	13.97	16.51	22.86	10.16	160.02
N. Marmot Meadow	18	Triangle	13.97	15.24	22.225		64.77
N. Marmot Meadow	19	Rectangle	6.35	25.4	20.32	7.62	41.91
N. Marmot Meadow	20	Oval	13.335	29.21			128.27
N. Marmot Meadow	21	Triangle	13.97	16.51	15.24		63.5
N. Marmot Meadow	22	Triangle	16.51	33.02	26.035		81.28

APPENDIX 3, CONTINUED.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
N. Marmot Meadow	23	Oval	8.255	15.875			106.68
N. Marmot Meadow	24	Oval	16.51	25.4			129.54
River South	1A	Oval	25.4	40.64			139.7
River South	2A	Oval	15.24	20.32			127
River South	3A	Square	17.78	10.16			132.08
River South	4A	Rectangle	17.78	15.24	40.64	71.12	93.98
River South	5A	Oval	20.32	43.18			121.92
River South	6A	Oval	63.5	38.1			121.92
River South	7	Oval	30.48	68.58			228.6
River South	8	Oval	17.78	26.67			55.88
River South	9	Oval	13.97	22.86			41.91
River South	10	Oval	91.44	81.28			177.8
River South	11	Oval	21.59	22.86			132.08
River South	12	Oval	17.78	33.02			132.08
River South	13	Oval	21.59	25.4			276.86
River South	14	Oval	30.48	17.78			55.88
River South	15	Oval	30.48	24.765			170.18
River South	17A	Oval	12.7	17.78			129.54
River South	18 A	Oval	11.43	22.86			68.58
River South	19	Oval	17.78	22.86			38.1
River South	20	Oval	30.48	13.97			22.86
River South	21	Oval	33.02	10.16			58.42
Plug Landslide	1	Oval	22.86	24.13			472.44
Plug Landslide	2	Oval	44.45	26.67			469.9
Quartzite	1	Oval	21.59	20.32			35.56
Quartzite	2	Triangle	25.4	27.94	13.97		129.54
Quartzite	3	Oval	16.51	12.7			104.14
Quartzite	4	Triangle	11.43	21.59	22.86		68.58
Quartzite	5	Triangle	15.24	10.16	17.78		160.02
Quartzite	6	Rectangle	14.605	15.24	39.37	33.02	150.495
Quartzite	7	Oval	10.16	25.4			129.54
Quartzite	8	Rectangle	10.16	7.62	33.02	25.4	81.28
Quartzite	9	Triangle	30.48	25.4	19.05		48.26
Quartzite	10	Triangle	27.94	17.78	30.48		190.5

APPENDIX 3, CONTINUED.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
Quartzite	11	Triangle	22.86	20.32	21.59		111.76
Sandstone	1	Triangle	27.94	12.7	20.32		172.72
Sandstone	2	Triangle	15.24	15.24	20.32		58.42
Sandstone	3	Triangle	55.88	21.59	40.64		101.6
Sandstone	4	Oval	20.32	10.16			76.2
Sandstone	5	Rectangle	12.7	17.78	10.16	10.16	40.64
Sandstone	6	Rectangle	7.62	10.16	30.48	27.94	142.24
Sandstone	7	Rectangle	26.67	17.78			162.56
Sandstone	8	Rectangle	26.67	7.62			165.1
Sandstone	9	Oval	30.48	11.43			60.96
Sandstone	10	Oval	27.94	10.16			40.64
Sandstone	11	Rectangle	12.7	20.32	27.94	38.1	218.44
Sandstone	12	Oval	20.32	17.78			68.58
Sandstone	13	Oval	17.78	33.02			63.5
Sandstone	14	Triangle	8.89	16.51	20.32		58.42
Sandstone	15	Oval	8.89	16.51	20.32		55.88
Sandstone	16	Rectangle	10.16	10.16	10.16	10.16	73.66
Sandstone	17	Oval	27.94	10.16			33.02
Sandstone	18	Triangle	12.7	12.7	15.24		40.64
Sandstone	19	Triangle	10.16	25.4	10.16		71.12
Sandstone	20	Rectangle	15.24	7.62	15.24	12.7	104.14
Sandstone	21	Rectangle	10.16	10.16	17.78	12.7	101.6
Sandstone	22	Triangle	15.24	20.32	22.86		76.2
Sandstone	23	Rectangle	20.32	22.86	10.16	15.24	35.56
Sandstone	24	Rectangle	17.78	20.32	10.16	15.24	93.98
Sandstone	25	Triangle	7.62	17.78	20.32		48.26
Sandstone	26	Rectangle	22.86	25.4	10.16	10.16	35.56
Sandstone	27	Rectangle	35.56	25.4	15.24	10.16	71.12
Sandstone	28	Triangle	25.4	30.48	12.7		93.98
Sandstone	29	Triangle	13.97	16.51	10.16		76.2
Sandstone	30	Oval	26.67	12.7			109.22
Sandstone	31	Triangle	21.59	19.05	25.4		48.26
Sandstone	32	Oval	26.67	12.7			35.56
Sandstone	33	Oval	69.85	13.97			38.1
Sandstone	34	Rectangle	40.64	39.37	17.78	14.605	68.58
Sandstone	35	Oval	55.245	13.97			60.96
Sandstone	36	Triangle	13.97	20.32	13.97		58.42
Sandstone	37	Rectangle	16.51	15.24	22.86	22.86	49.53
Sandstone	38	Triangle	10.16	11.43	25.4		40.64
Sandstone	39	Oval	48.26	10.16			50.8
Sandstone	40	Oval	22.86	10.16			29.21

APPENDIX 3, CONTINUED.

Site Name	Burrow Number	Field Classification	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Length 4 (cm)	Probe Depth (cm)
Sandstone	41	Rectangle	12.7	15.24	10.16	14.605	60.96
Sandstone	42	Rectangle	13.97	15.24	24.765	27.94	58.42

APPENDIX 4

Site Name	Site Description (Rock type and plants)
River Mound	Large Boulders (white grano-diorite), aspen, typical grasses (larkspur, white sweet pea, monument plant, corn husk lily), mule's ear, holly grape, 30 m above river
Spruce Mound	Large boulders, finely bedded shale, large spruce tree
Tree Fall	Finely bedded shale, large spruce (fallen), willow, typical grasses
Snowbank	White grano-diorite with veins, snow below burrow, willows, not much vegetation
Old Road	Intrusive white granite w/ quartz and pyrite seams, rocky area in middle of meadow with typical grasses and glacier lily
Willow Tree	Underneath a willow tree
Plug	Very rocky, white granite with quartz intrusions and quartz crystals, regular woody plants, glacier lily
Aspen	Sandstone rocks with conglomerates, meadow beneath aspen trees
Rock Talus	Rocky meadow, cinquefoil plants
Slate Creek	Prominent ridge, blocky weathering pattern fractured into polygonal blocks. Lithology: granodiorite, badly weathered, amphibole clasts prominent on weathered surfaces, albite has undergone serricitic diagenesis. Burrowing site similar to quartzite study site in that marmots utilize heavily fractured nature of the rock and explore key areas of weakness to create burrows. Sediment in fractures fills are likely opening mode exhumation fractures. Granodiorite is intrusive and a likely first order contibutant to tertiary topography. Site is in a glacial valley and located on one of the near vertical terraced cliff faces. Numerous abandoned burrows evidenced by small depressions and chaotic collapse structure in the granodiorite talus, typical grasses (larkspur, showy daisy, cutleaf daisy, white sweet pea, monument plant, corn husk lily, Bromus sp., sneezeweed, aspen, Indian paintbrush), typical bushy plants, spruce.

APPENDIX 4, CONTINUED.

Site Name	Site Description (Rock type and plants)
Upper Picnic	Rocky, steep slopes, volcanic breccia with quartz, calcium Feldspar
Mid Picnic	Same as upper picnic, with typical grasses, woody plants, larkspur
Upper, Upper Picnic	Rocks covered in lichens, many woody plants
401 Meadow	Limestone or dolomite with quartz intrusions and large crystals, located in a meadow at bottom of valley, just above river, dandelions, larkspur, white sweet pea, corn husk lily, typical grasses, some woody plants
401 Meadow Hillside	Same as 401 meadow, steeper
Roadside 3	White grano-diorite, steep, typical grasses, typical bushy plants, aspen
Boulder	Same as lower picnic, more elderberry
Lower, Lower Picnic	Same as lower picnic, more elderberry
RMBL River	Soft siltstone, steep slope, large spruce trees, most burrows beneath trees, little ground cover
RMBL Dining	Edge of concrete pad, open meadow, excavated 1-2 years ago, spruce, elderberry, Bromus sp., dandelion, cinquefoil
RMBL Cabin	Steep slope, large spruce trees, elderberry, lupen, larkspur, dandelions, cinquefoil, buffalo grass
Marmot Meadow	Embricated sandstone, large boulders
N. Marmot Meadow	Embricated sandstone, large boulders, felspathic, lithic conglomerates, clasts 2-3 cm, rounded conglomerates, Bromus sp., aspen grove, buffalo grass, cinquefoil, false King Solomon seal

APPENDIX 4, CONTINUED.

Site Name	**Site Description (Rock type and plants)**
River South	Interbedded siltstones and shales, granodiorite boulders, huge holes (almost karst-like), mules ear, blue phlox, sagebrush, wild rose, holly grape, granodiorite boulders
Plug Landslide	Slump- landslide area, granodiorite-quartzite contact between 2 different lithologies, debris from landslide is from igneous intrusion, large debris flow, igneous rocks buried at depth
Quartzite	3 burrows excavated down into vertical fractures perpendicular to primary bedding, glacier lily, corn husk lily, cinquefoil, sumac, willow, buffalo grass
Sandstone	Thinly bedded, medium grained sandstone with numerous scour surfaces and channel forms, thickness of 10', sands show evidence of bioturbation- horizontal burrows. Nautaloid clasts present in rock strata. Joint planes cut through sites of large burrows, numerous small scale collapses around burrows. Burrows in joint planes immediately adjacent to whole landslide. Joint block being rafted down slope underlain by burrows. Marmot trails exist in substrate. Small, unsuccessful marmot burrows into finer grained siltstones. Sagebrush, sagebrush buttercup (*Ranunculus glaberrimus*) Indian paintbrush (*Castilleja sp.*), blue phlox, holly grape, cinquefoil, daisy, monks head

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