

Pam Bromley
Environmental Studies 102

THE EFFECT OF ELEVATION GAIN ON SOIL

Samples Collected: March 28-April 1
Content Analyzed: April 13-April 27
Report Submitted: May 1, 1995

The Effect of Elevation Gain on Soil

Introduction:

Does soil change as altitude increases? If so, in what ways? How do the soil horizons differ from one another? Are the changes primarily in soil chemistry, or are organic content and soil texture affected as well? What might cause these changes? In an attempt to find the answer to these questions, I collected soil samples from the east-facing slope of Rocky Mountain, a solid granite monolith at the foot of Pike's Peak, just west of Colorado Springs, Colorado. The consistent exposure, as well as the solid bedrock allowed me to more precisely isolate altitude as the cause for any changes in soil content. I hiked from the bottom of Barr Trail, at 6800', to the summit of the mountain, at 9250'. I collected 14 surface soil samples and dug four soil pits.¹ For a more dramatic example of the possible effect of altitude on soil, I dug a soil pit above timberline on the east slope Pike's Peak.² While in the field, I determined the temperature and soil color of the samples. Once in the lab, I determined the percent loss-on-ignition and the soil texture of the samples from the O/A horizon. I thought these measurements would serve as reasonable indicators of changes in soil content. I also found the pH and the concentrations of exchangeable cations and water-extractable anions of each of the samples. I felt these measurements would serve as good indicators of chemical changes in the soil.³

Materials and Methods:

I collected my samples from Rocky Mountain in as sterile a manner as possible. By using the untouched inside of Zip-loc bags as "sterile gloves," I packed as much of each sample as possible into the bag, trying to avoid touching the soil (and thereby contaminating it). I collected samples from

the O/A soil every 200 vertical feet. I had a total of 13 samples of the surface soil. In addition, every 800 vertical feet, I dug a soil pit until I reached the C horizon. I took samples from both the O/A horizon and the B horizon. Precise soil pit sites as well as surface sample sites are shown on **Map 1**.⁴ I determined the change in elevation using a watch with an altimeter and a topographic map.⁵ I also dug a soil pit on Pike's Peak at 12,250' so that I could compare soil from above timberline to soil from below timberline. The location of this sample site is indicated on **Map 2**.⁶

In the field, I measured the temperature in degrees Fahrenheit of each sample with a probing thermometer, and determined its color using the Munsell Rock Color Chart. In the lab, I tested the pH of the samples with a digital pH meter by making a slurry of the sample and distilled deionized water. I determined the concentrations of the magnesium, potassium, and calcium exchangeable cations by using atomic adsorption spectrophotometry. I also found the concentrations of the water-extractable chloride, fluoride, phosphate, and sulfate anions through ion chromatography.⁷ I determined the percent organic matter in each of the samples by weighing the dry samples, baking them in a 660°C oven for 6 hours to burn off all organic material, and weighing them again.⁸ Finally, I found the texture of the samples from the O/A horizon hydrogravimetrically by using a Boyoucos hydrometer to measure the specific gravity of an agitated mixture of soil, 1 M detergent solution, and distilled water at precise time intervals.

Results &

Discussion:

I found many trends in the data as elevation increased. There were considerable changes in horizon composition, including dramatic differences in soil texture, horizon depth and temperature. I expected more correlation

between soil chemistry and elevation, but I did find subtle changes in the chemical composition of the soil as altitude increased.

As long as it has not been cultivated or eroded, the thickness of a soil horizon can serve as an indicator of its age and maturity.⁹ Rocky Mountain has never been significantly disturbed by humans, which limits the amount of erosion, nor has it ever been cultivated. However, **Figure 1** shows that, as elevation increases, the depth of the B horizon decreases substantially. I feel this can be attributed to the Rocky Mountains being a relatively new geological formation. Thus, they have had little time to develop a mature soil profile. As elevation increases, the soil profile is less mature simply because it has had less time to develop. As a result, it is not surprising that the depth of soil horizons is significantly altered by changes in elevation.

you mean
more and
below
throughout the
thickness
of B-
horizon,
correct?

no!
I think you're
reason is
as for
below...
too harsh conditions, thus thinner soils overall and thinner for each horizon!

The thickness of the O/A horizon is affected in a similar manner. **Figure 2** shows that as altitude increases, the thickness of the O/A horizon also decreases. This is to be expected because much of the O/A horizon is comprised of decomposing or humified organic material.¹⁰ Plant growth generally decreases as altitude increases simply because weather conditions are harsher and the growing season is shorter. As a result, less organic matter is present in the soil, causing the depth of the O/A horizon decreases.

Figure 2 shows a logical relationship between soil horizon depth and elevation gain. Eventually, as altitude increases, the growing season becomes so short and the weather conditions so harsh that no vegetation can survive. Indeed, there is no vegetation on the summit of Pike's Peak, at 14,110 ft. As a result, there is no O/A soil horizon. I feel that the line depicting the relationship between O/A horizon depth and altitude is

reasonably accurate. It intercepts the X axis at 13,600', the approximate elevation at which significant amounts of vegetation disappear. yes!

Percent loss-on-ignition (LOI) is a reasonable estimate of the organic component of soil. **Figure 3** shows that percent LOI of the O/A horizon decreases quite substantially as altitude increases. There are fewer and smaller plants as elevation increases due to the abbreviated growing season and severe weather conditions. Therefore, it is not surprising the percent of organic material in the O/A soil horizon decreases as well.

Nice point
In addition, soil temperature decreased as altitude increased. This is also a reflection of harsher weather at higher elevations. For every 100 foot increase in elevation, there is approximately a 0.27°F drop in air temperature.¹¹ As a result, the temperature of snowfall is lower at higher altitudes. Since the east slope of Rocky Mountain was covered with snow at the time of soil sampling, it is not surprising that temperature of the O/A soil horizon decreased as altitude increased. **Figure 4** illustrates this relationship. For every 100 foot increase in elevation, there was a 0.71°F drop in the soil temperature, over two times greater than the decrease in air temperature. I feel the relatively greater decrease in soil temperature can be attributed to the fact that the ground had not completely thawed at higher elevations.

Temperature differed between soil horizons as well. **Figure 5** shows that the temperature of the B horizon was, on average, significantly higher than that of the O/A horizon. Because there was still snow cover, the O/A horizon was quite cold. This horizon may have insulated B horizon from the colder temperatures of the snow. Due to this same insulation effect, in the summer, I would expect the O/A horizon to have a higher temperature

than the B horizon because it would absorb much of the heat of the summer sun. *Because of the extensive snow cover the ground beneath probably never freezes.*

Elevation gain also seems to affect the texture of the O/A soil horizon. Although the percent clay did not change in a consistent manner, both the percent of sand and silt did change uniformly.

Figure 6 illustrates the decrease in percent sand in the O/A soil horizon due to altitude. In contrast, **Figure 7** shows the increase in percent silt in the O/A soil horizon as altitude increases. This is contrary to what I expected. I thought that, because the soils at higher altitudes are less mature, they would have a larger amount of sand in their composition because the soil would not have had as much time to be worn down into silt-size particles. A possible explanation for this trend is that, on average, weather becomes harsher as altitude increases. Because weathering wears down soil into smaller particles, the harsher weather at higher elevations could result in the decreasing percentage of sand and the increasing percentage of silt. It is conceivable that, at higher elevations, weathering has a greater effect on particle size than soil maturity does.

Although I did not find a consistent relationship between pH and increasing elevation, I was surprised that the pH of my soil samples differed so significantly from the pH of the soil samples that ES 102 collected from the R&B plot.¹² **Figure 8** shows that the pH of soil samples from both the O/A and B horizons of the R&B plot is significantly more acidic than the samples I collected. I believe this difference is due to three factors. First, "in humid regions, soils are acidic."¹³ Williamstown averages over 35 inches of rain a year, and over 30% humidity. In contrast, Colorado Springs is very arid, receiving on average less than 16 inches of rainfall each year, and less than 20% humidity.¹⁴ Second, acid deposition can lower the pH of

soils. Williamstown receives acid precipitation because the prevailing weather pattern carries air pollution from the industrial cities of the Midwest to New England. The sulfates and nitrates in this pollution cause the precipitation to be acidic. Acid precipitation is not yet a critical problem in the West because there is so little industrial pollution. Finally, the difference in pH can also be attributed to soil maturity. The low pH of the soils in the R&B plot indicates that they are in the advanced stage of weathering. The significantly higher pH of the Rocky Mountain soils suggests that they are only in the intermediate stage of weathering.¹⁵

The concentration of ions present in the O/A horizon was much greater than the concentration of ions present in the B horizon. First, the concentration of water-extractable anions differed quite dramatically between soil horizons. For example, **Figure 9** shows the concentration of nitrate (NO_3^-) found in the O/A horizon is almost eight times greater than the concentration of nitrate in the B horizon. I feel the high concentration of nitrate in the O/A horizon is a reflection of horizon composition. Because the chief source of nitrate in soils is organic material,¹⁶ and the O/A horizon consists in large part of organic matter, it is not surprising that O/A horizon has a high concentration of nitrate. Accordingly, the B horizon, which has little organic material, has a low concentration of nitrate.

Figure 10 illustrates a similar relationship with the concentration of sulfate (SO_4^-). The amount of sulfate ions extracted by water from the O/A horizon is over four times greater than the amount extracted from the B horizon. While this disparity is large, it is just half the difference in nitrate concentration between horizons. I believe this is also a reflection of horizon composition. The primary sources of sulfate in soils are gypsum

($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and pyrite (FeS_2).¹⁷ Both of these compounds occur in both the O/A horizon and the B horizon of Pike's Peak granite.¹⁸ Unlike nitrate, I feel the lower concentration of sulfate in the B horizon is not due to the absence of sulfate from the horizon, but rather due to its entrapment in the rock. Because the rock in the O/A horizon has been broken down by weathering, many more of the sulfate ions in the O/A horizon can be extracted by water.

The concentrations of exchangeable cations did not change as dramatically between soil horizons as the concentrations of water-extractable anions did. However, there were significant differences between the average cation content of the O/A horizon and the B horizon. **Figure 11** shows that the average concentration of exchangeable potassium ions in the O/A horizon is over 50% greater than the concentration in the B horizon. **Figure 12** depicts a similar relationship regarding magnesium cations. Neither of these results are surprising. Due to intensive weathering and leaching, most of the exchangeable cations in the B horizon have been removed. In contrast, the O/A horizon still retains these cations in its humus.¹⁹

When Figures 11 and 12 are compared, it becomes apparent that, in both horizons, there is a greater concentration of exchangeable potassium ions than magnesium ions. This is somewhat unusual since most soils have a greater concentration of exchangeable magnesium ions.²⁰ Because much of soil chemistry can be attributed to the chemical makeup of the parent material, I feel that the higher potassium concentration could be a reflection of the chemical composition of the parent material. Mica is quite abundant in Pike's Peak granite, and especially in the weathered O/A soil horizon.²¹ Since mica is a primary source of potassium ions in soils,²² the

relatively large amounts of mica could cause the higher-than-normal potassium ion concentration. Because the amount of potassium is greater than the amount of magnesium in the granite parent material, it is not surprising that there is a relatively greater concentration of exchangeable potassium ions in both soil horizons.

Elevation gain seems to have some effect on the concentration of exchangeable cations present in the O/A horizon. **Figure 13** illustrates that the concentration of exchangeable magnesium ions actually increases slightly as elevation increases. **Figure 14** illustrates a similar relationship with potassium ions. The correlation between these graphs suggests that increasing cation concentration with elevation gain is a bona fide trend. I feel this can be attributed to two factors. First, the amount of vegetation decreases as altitude increases. Fewer plants require fewer total ions to supply their nutritional needs. Therefore, the demand for magnesium ions decreases as elevation increases. The greater number of ions left in the soil results in the higher concentration. Second, soil maturity affects the retention of cations. Weathering of mature soils causes the removal of potassium and magnesium, while weathering of less mature soils does not result in this removal.²³ Because soil maturity usually decreases as elevation increases, more cations are retained in the less mature, higher-elevation soils.

There are many uncertainties in the data I collected for my independent project. First, human error may have caused inaccuracies in the data. I could have easily contaminated the samples while in collecting them the field, while sieving them, and while weighing them. The samples may have also been contaminated by unclean glassware in the lab. In addition, there is a considerable possibility that errors were made in making

measurements. For instance, the altimeter may not have been very accurate. In addition, I may not have given the pH meter enough time to equilibrate to some soil samples, or I may have read the hydrometer incorrectly. Finally, once the data were collected, I may have made errors in recording it. Dilutions may not have been accounted for, or the measurements could simply have been entered incorrectly on the spreadsheet.

Furthermore, there is some imprecision in the methods that I used to collect the data. The altimeter may only be accurate to within 30 vertical feet. The ovens used to burn off moisture and organics may have gone above the requisite temperatures, burning off inorganic material as well as organic material. However, this probably only caused at most a 2% error. The hydrometers are quite precise, reading to the nearest thousandth. The pH meters are probably accurate to within 0.02 pH units. The AAS is a very precise instrument, which is capable of determining cation concentrations to within 1 mg of cation per 1 kg of soil. The depths of the horizons are precise to within 0.5 in because I only recorded the horizon depth to the nearest half-inch.

Because of these factors, I feel it is necessary to estimate the total uncertainty of the measurements. Although I did not perform any duplicate tests of my samples, I performed many of the same tests on my soil samples that the ES 102 class did the soil chemistry lab. Because I used similar methods to analyze my samples, I believe the differences in the data collected from the the duplicate samples of the ES 102 soil chemistry lab are a reasonable estimate of both the human error and the precision of the techniques used to analyze the samples.²⁴ Using the method, I calculated the pH to be precise to within 7% and the cation concentrations to be

precise to within 3%. I found that the percent moisture was precise to 3%, and the percent LOI to 1%. There was somewhat more error concerning particle size. I found the percent sand to be accurate to within 9%, the percent silt to within 5%, and the percent clay to within 6%. I feel the higher degree of imprecision of the percent sand measurement may be a reflection of the hydrometer not having enough time to equilibrate before the specific gravity measurement was taken. The bubbles created on the top of the sample due to shaking it made this reading very difficult to take.

Conclusion:

I found many trends in the data I collected from Rocky Mountain. There are significant differences in the data collected from the soil horizons. First, anion and cation concentrations are both considerably lower in the B horizon than in the O/A horizon. Second, the average temperature of the O/A horizon, at the time of data collection, was much lower than the average temperature of the B horizon. Third, although the pH of the samples I collected did not show any consistent trends regarding either elevation or horizon, it was very different from the soil samples ES 102 collected from the R&B plot.

I believe soil composition does change significantly as altitude increases. First, the depth of the O/A and the B soil horizons both decrease substantially. Second, because snowfall temperature decreases as altitude increases, the temperature of both soil horizons decreases as altitude increases. Third, the amount of organic material decreases because it becomes more difficult for plants to survive at higher altitudes. Fourth, the particle size distribution of the O/A horizon changes as elevation increases. Finally, the concentrations of cations increase as elevation increases.²⁵

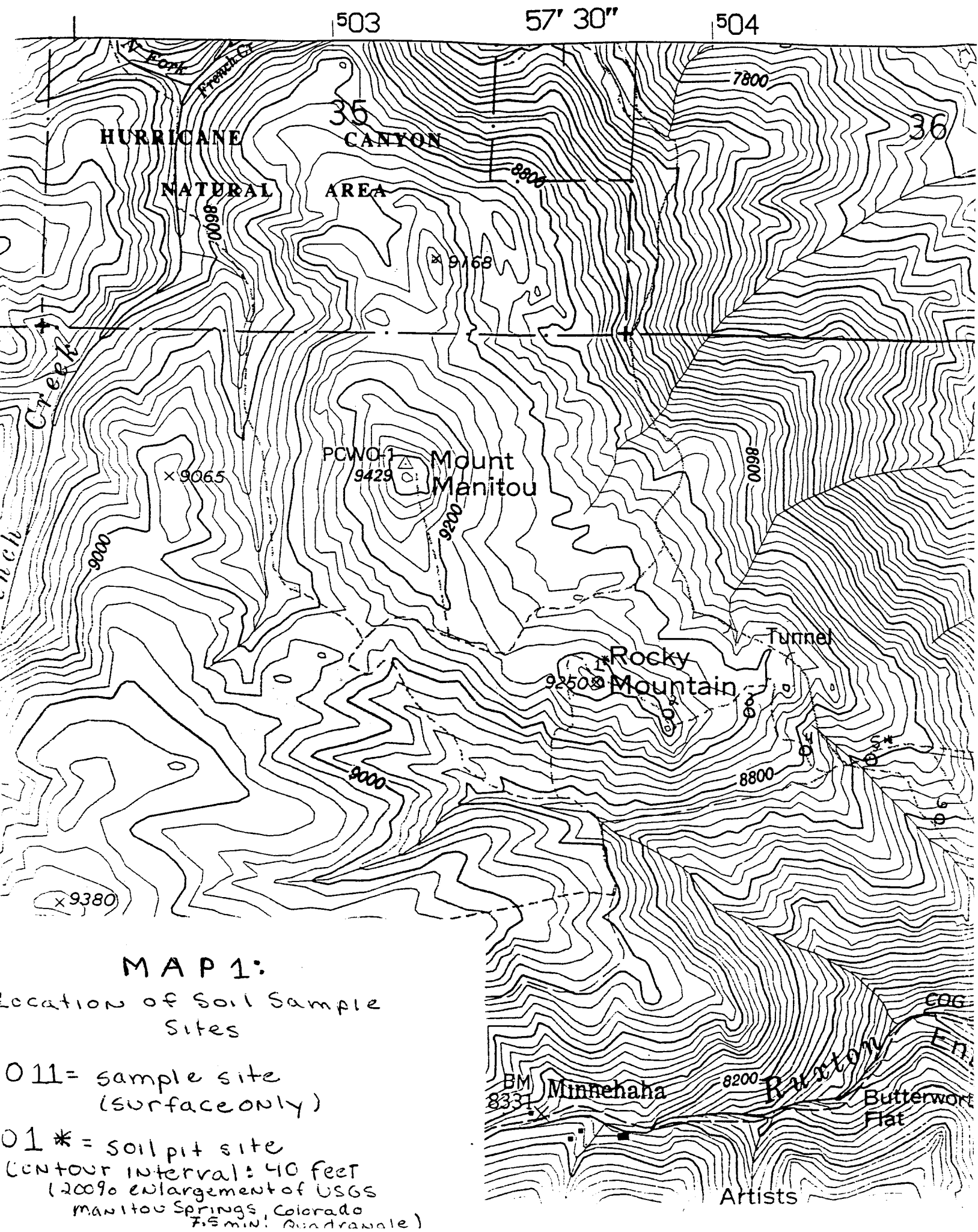
- ¹Thanks to Michael and Rebecca Bromley and my dog Tip for giving up an entire Saturday to help me collect and carry my soil samples.
- ²Thanks to Michael Bromley and Tip for collecting the soil samples from above timberline. I could not do it because it snowed during most of Spring Break.
- ³Thanks to Professor DeSimone for advice regarding the concept of my independent project, and for assistance with soil sampling techniques.
- ⁴Manitou Springs, Colorado, map, (Denver: United States Geological Survey, 1961; revised 1994).
- ⁵Thanks to Ralph Hibbard for letting me borrow his fancy watch for the week.
- ⁶Woodland Park, Colorado, map, (Denver: United States Geological Survey, 1961; revised 1994).
- ⁷Thanks to Professor Thoman for teaching me how to calculate the actual concentrations from the numbers I got from Sandy Brown.
- ⁸Thanks to Sandy Brown for all of her technical assistance and moral support with this aspect of my project. I would have been lost without her.
- ⁹Gilbert Wooding Robinson, Soils: Their Origin, Constitution, and Classification-An Introduction to Pedology, London: Thomas Murby & Co., 1932, p. 50.
- ¹⁰Birkeland, Soils and Geomorphology, "The Soil Profile, Horizon Nomenclature, and Soil Characteristics," Oxford: Oxford Union Press, 1984, p. 7.
- ¹¹Colorado's Front Range, map, (Colorado Springs Gazette Telegraph, June 12, 1994).
- ¹²Thanks to the ES 102-1995 class, TA's and professors for collecting and analyzing the soil samples from the R&B plot.
- ¹³Charles B. Hunt, Geology of Soils: Their Evolution, Classification, and Uses, San Francisco: W.H. Freeman & Co., 1972. p. 167.
- ¹⁴Information Please Almanac, Atlas, and Yearbook, 47th ed., Boston: Houghton Mifflin Co., 1994, p. 392-400.
- ¹⁵Garrison Sposito, The Chemistry of Soils, New York: Oxford University Press, 1989, p. 14.
- ¹⁶Sposito, op. cit., p. 258.
- ¹⁷Hunt, op. cit., p. 258.
- ¹⁸R.W. Blair, Jr., "Weathering and Geomorphology of the Pikes Peak Granite in the Southern Rampart Range, Colorado," Professional Contributions of the Colorado School of Mines: Studies in Colorado Field Geology, Number 8 (1976) p. 69.
- ¹⁹Birkeland, op. cit., p. 6.
- ²⁰Hinrich L. Bohn, Brian L. McNeal, and George A. O'Connor, Soil Chemistry, 2nd ed., New York: John Wiley & Sons, 1985. p. 296.
- ²¹Blair, op.cit., p. 69.
- ²²Sposito, op. cit., p. 8.
- ²³Ibid., p. 14.
- ²⁴Thanks to the students, TA's and professors of ES 102-1995 for testing duplicate samples. I would not have been able to quantify the uncertainties in my data if this had not been done.
- ²⁵Thanks to Jonathan Oakman, Nathan Pleplow, and writing tutor Justin Wright for proof-reading this report.

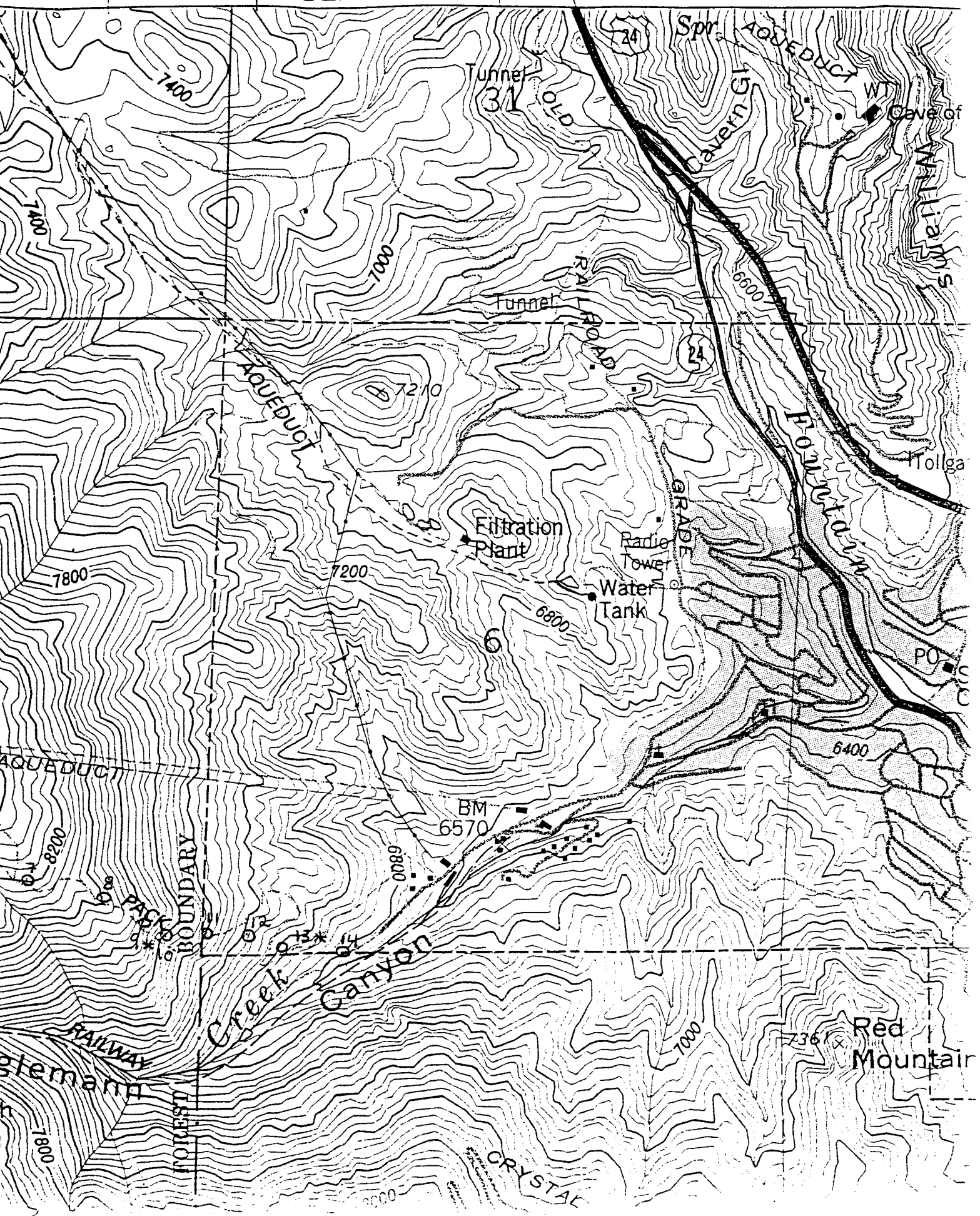
Pam, Each of your sections is clearly & excellently done. You present your results in a logical progression with fine illustrations. In sum, you offer very convincing data for the interpretations you've made. Technically, you ought to have put the error estimates (uncertainty of measurement) in a separate section. Also, footnotes are fine but an alphabetized Bibliography is a MUST.

you really pulled this project off! Congrats!!

PAPER A- → 93

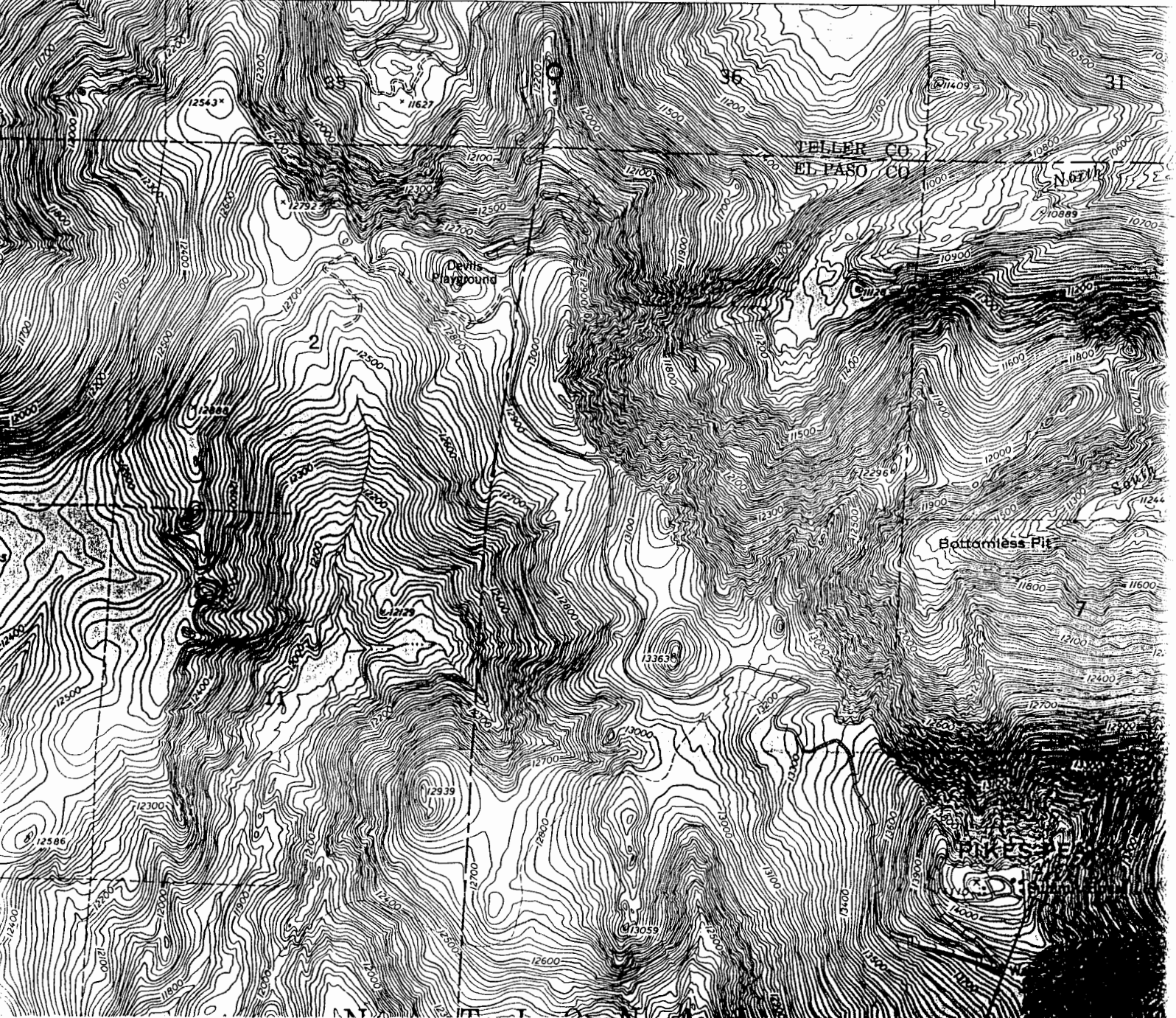
POSTER (Subscores from ID only)	QUAL	A-	} POSTER OVERALL A- → 90
	CONTENT	A	
	GRAPHICS	B+	





UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

492 5' COLORADO SPRINGS 22 MI. 493 CASCADE 11 MI. 494 4961 1 NE (WOODLAND PARK) 495 R 69 W R 68 W 2'30"

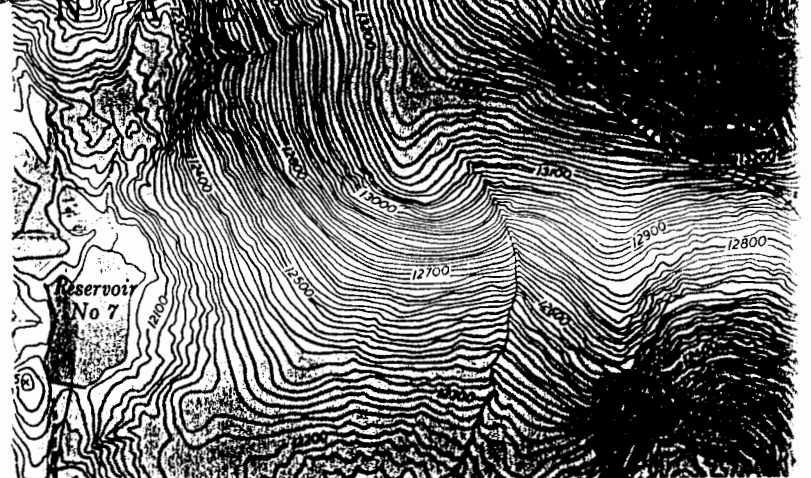


MAP 2:

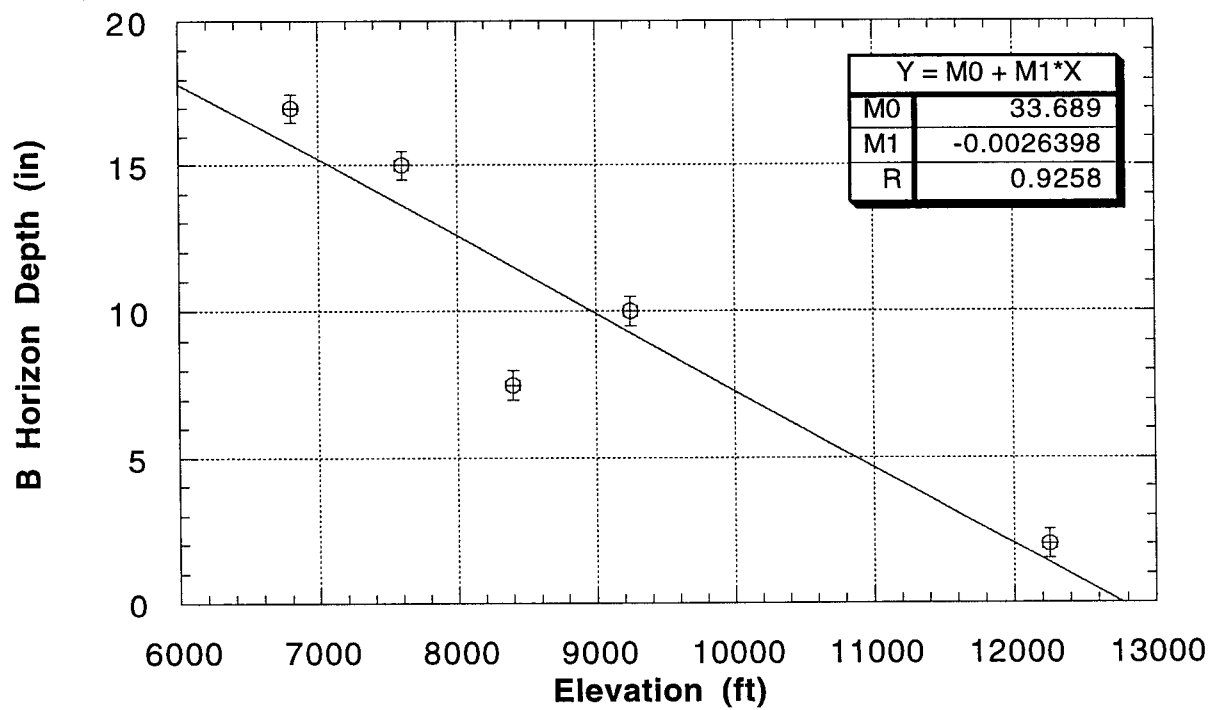
Location of above-
treeline sample site

O = sample site

Contour interval: 20 feet
(100% copy of USGS Woodland
Park, COLORADO 7.5 minute
Quadrawale)



**Figure 1: The Effect of Elevation Gain (ft)
on Depth (in) of the B Soil Horizon**



**Figure 2: The Effect of Elevation Gain (ft)
on Depth (in) of the O/A Soil Horizon**

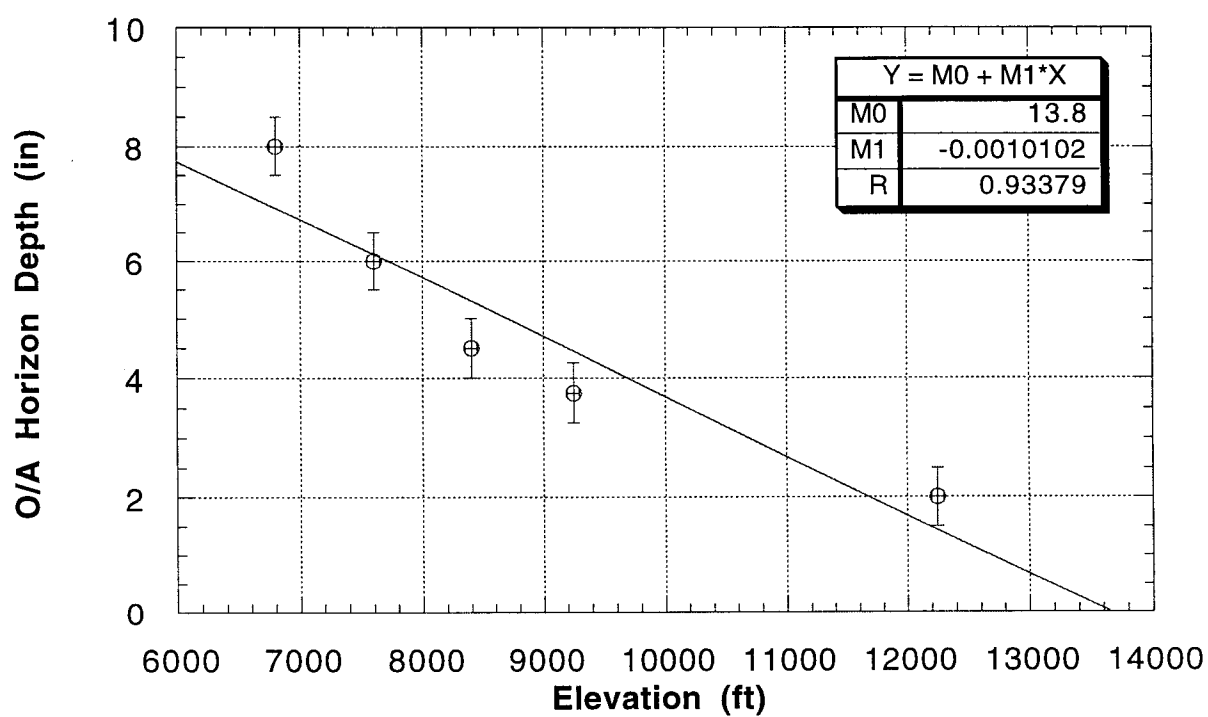


Figure 3: The Effect of Elevation Gain (ft) on the Percent Loss-On-Ignition of the O/A Soil Horizon

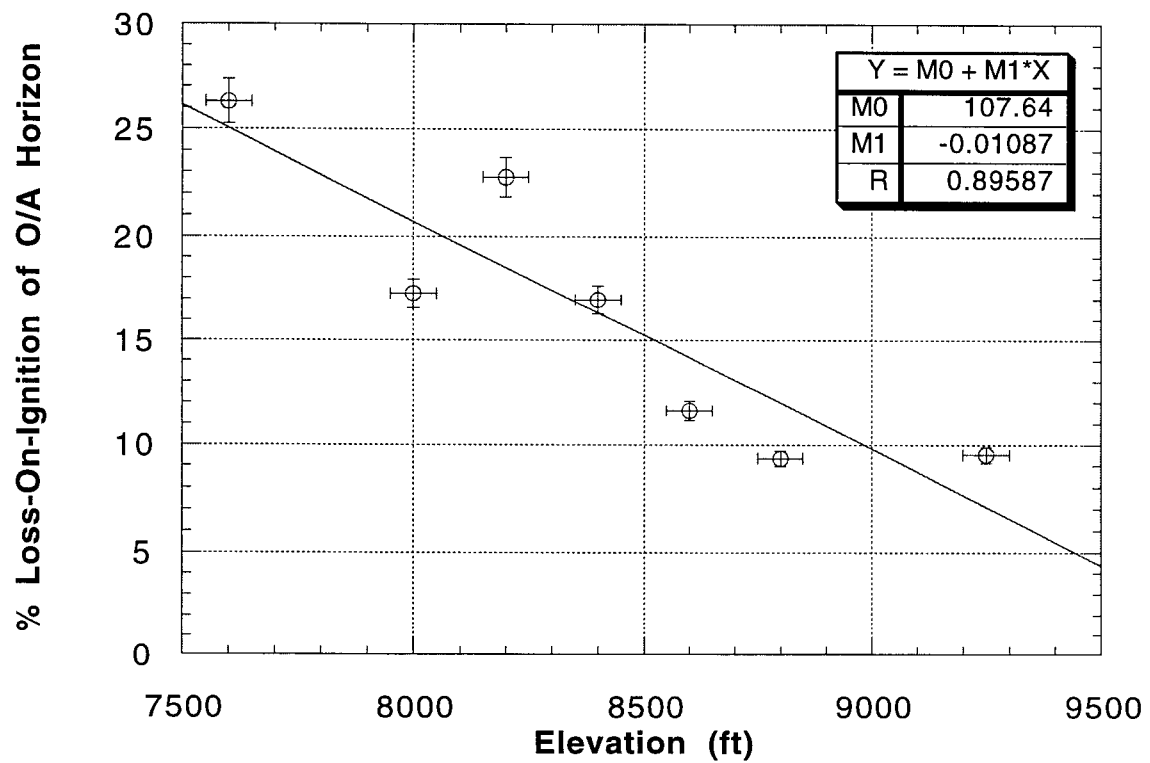
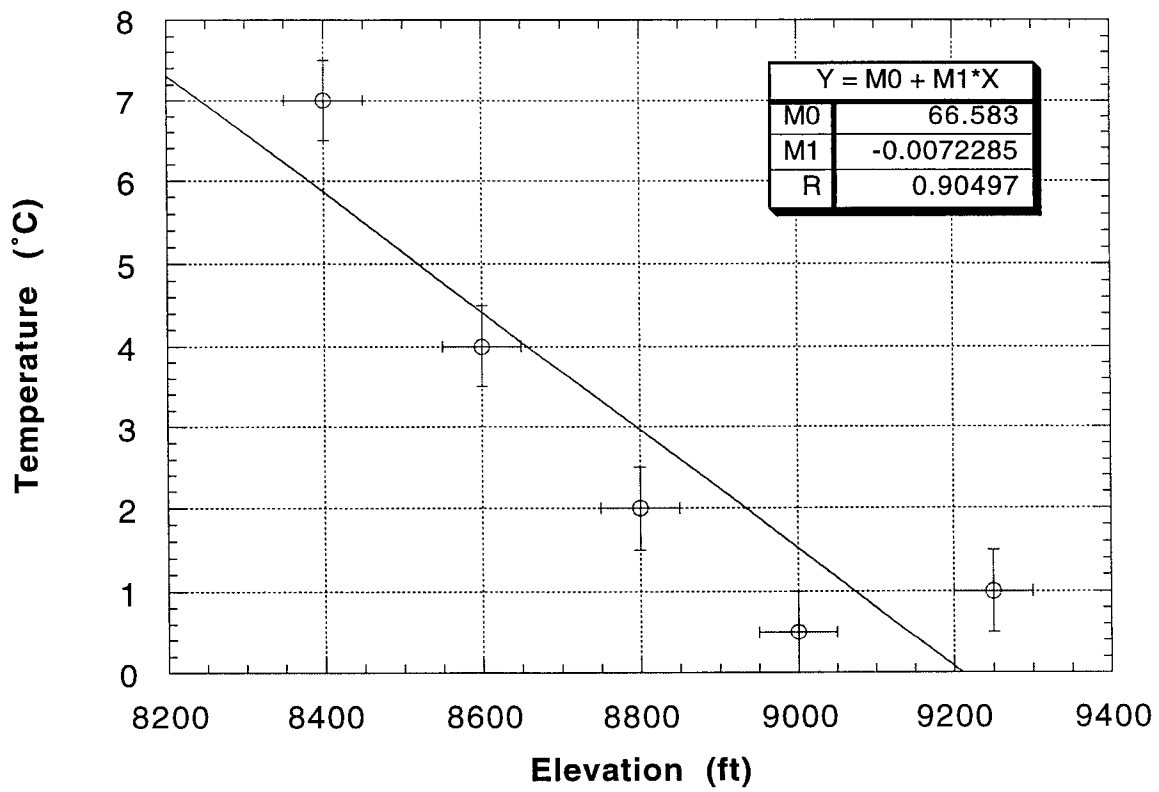
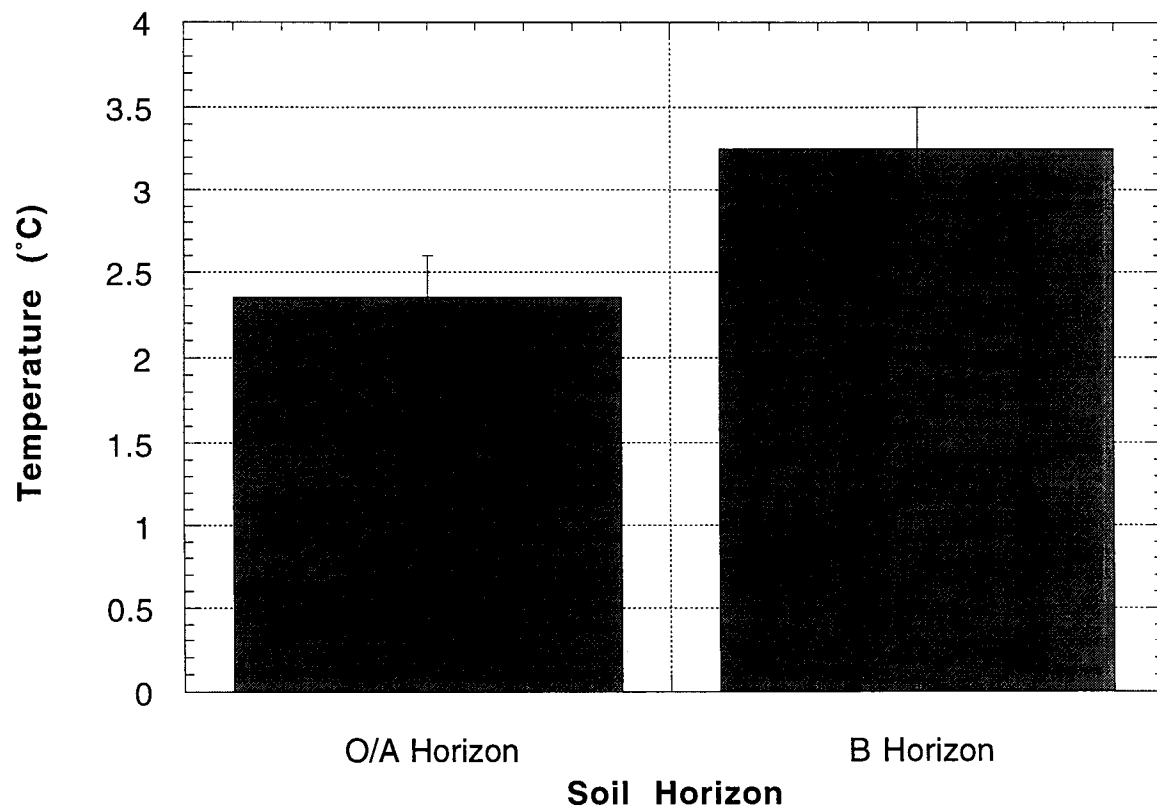


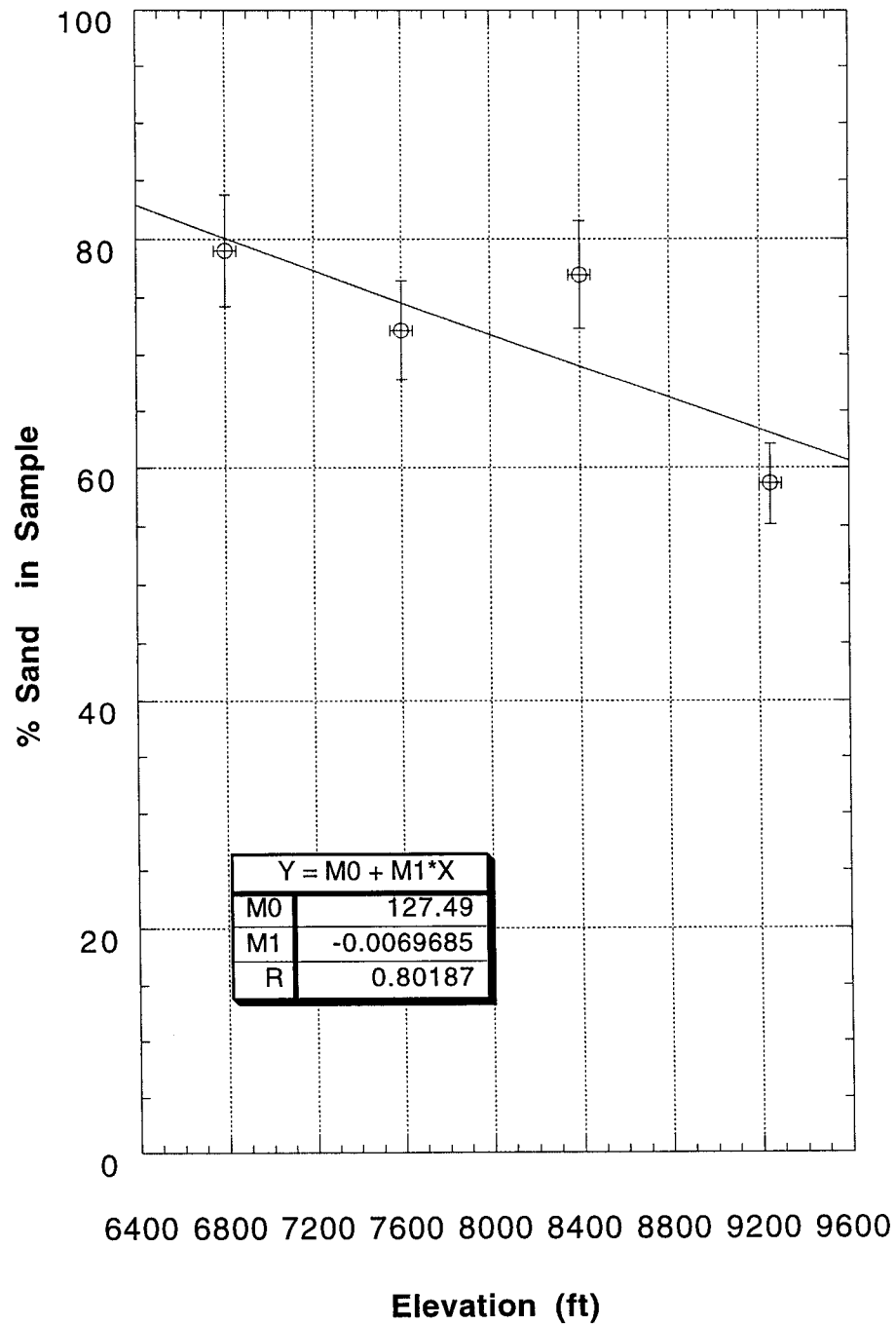
Figure 4: Change in Temperature (°C) of the O/A Soil Horizon as Elevation (ft) Increases



**Figure 5: Average Temperature (°C) of
Soil Horizons on Rocky Mountain**



**Figure 6: The Effect of Elevation Gain (ft)
on Percent Sand in the O/A Soil Horizon**



**Figure 7: The Effect of Elevation Gain (ft)
on Percent Silt in the O/A Soil Horizon**

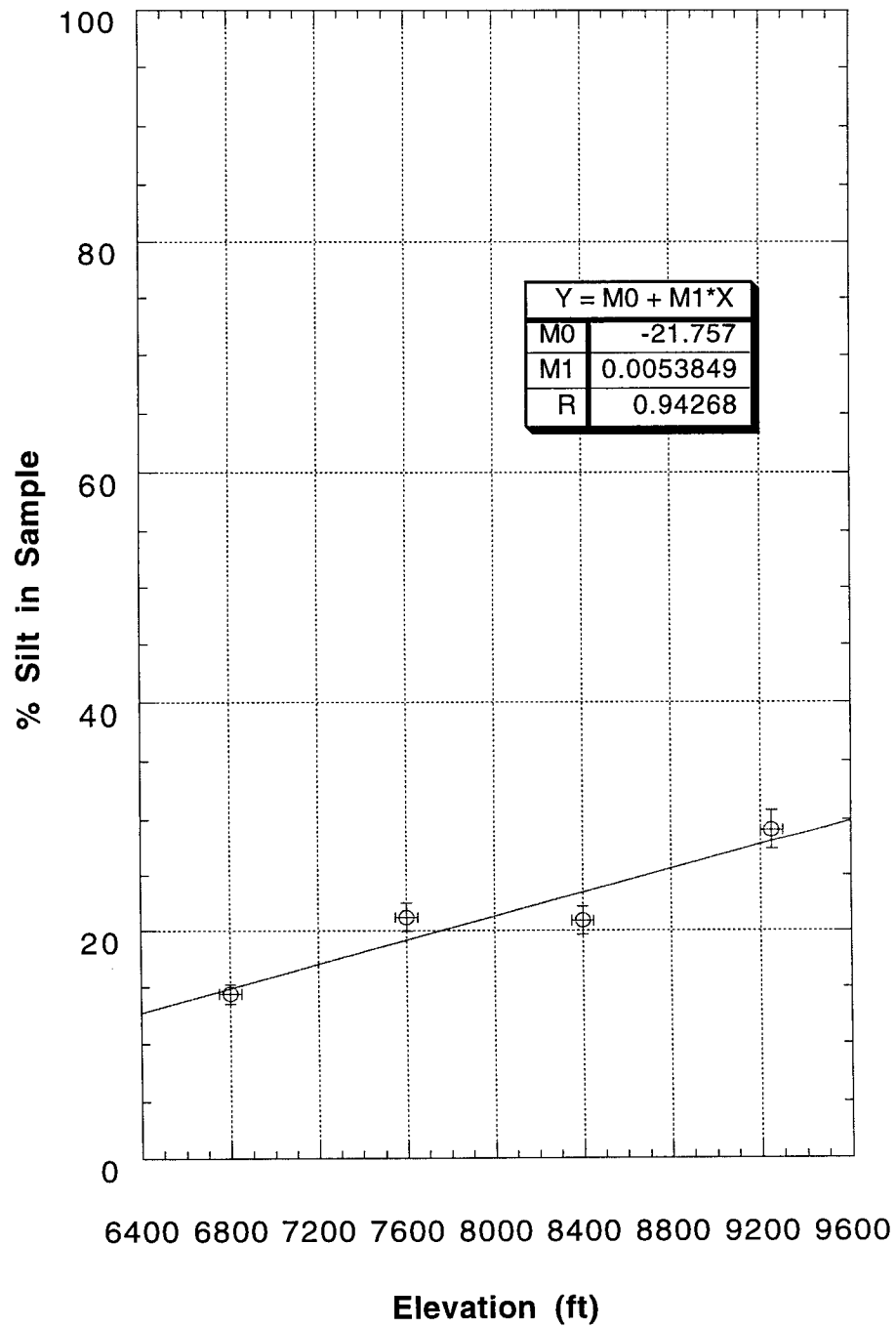
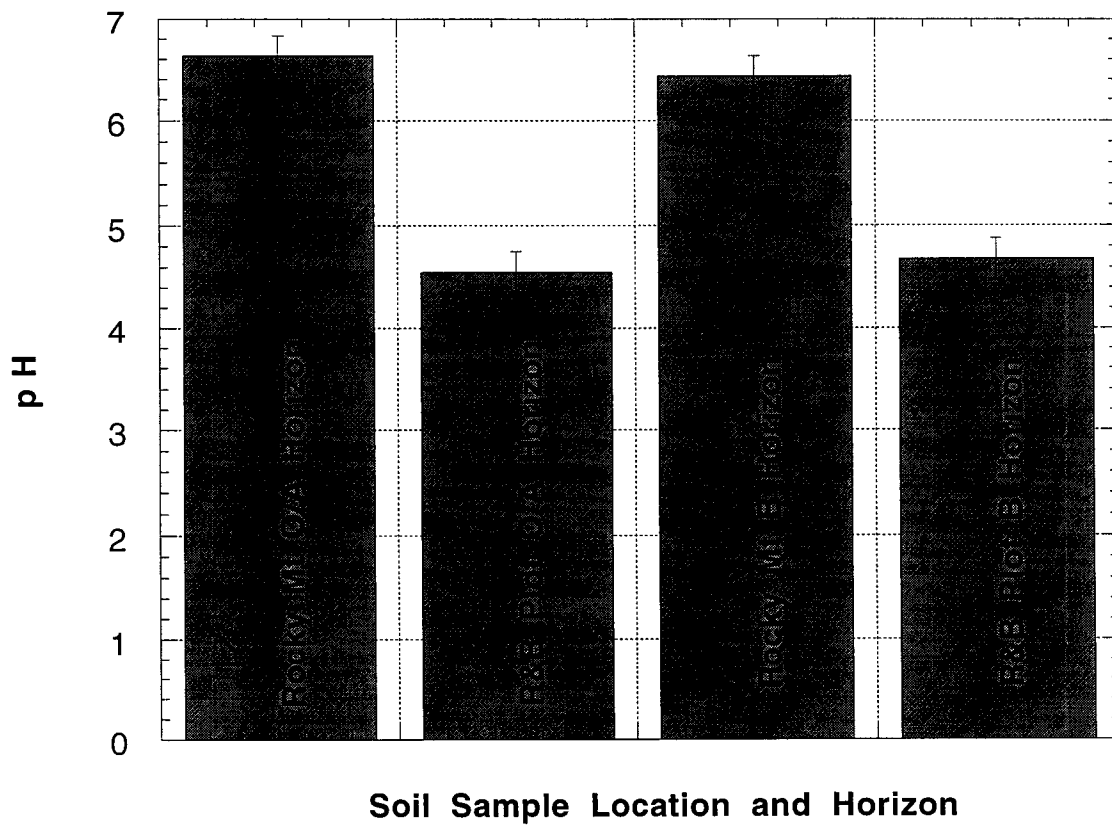
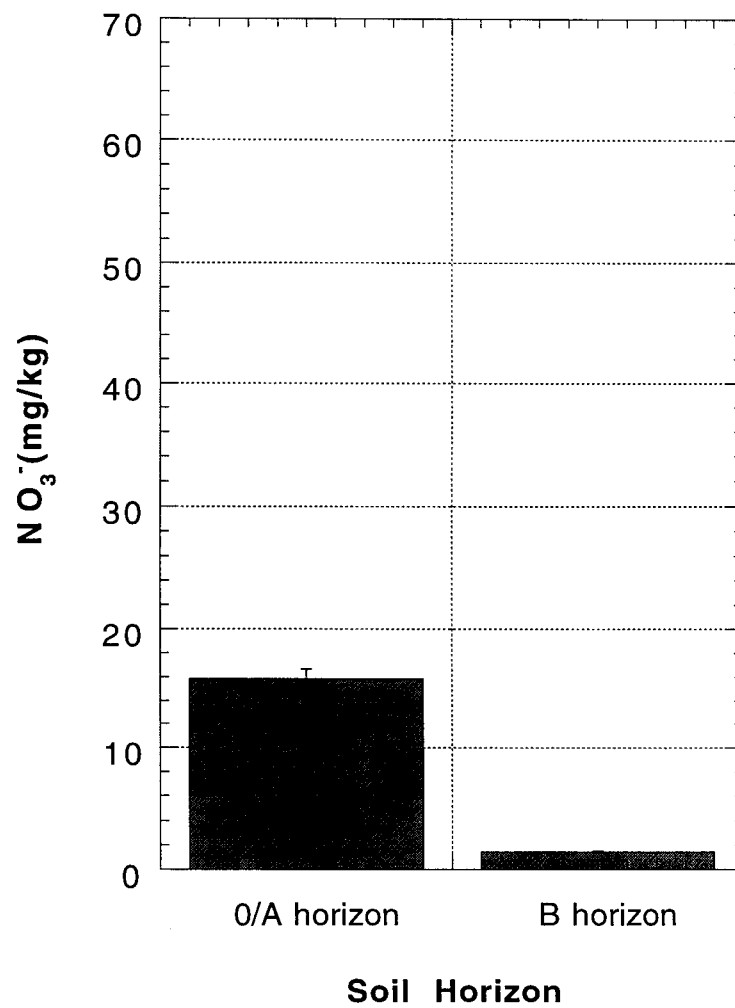


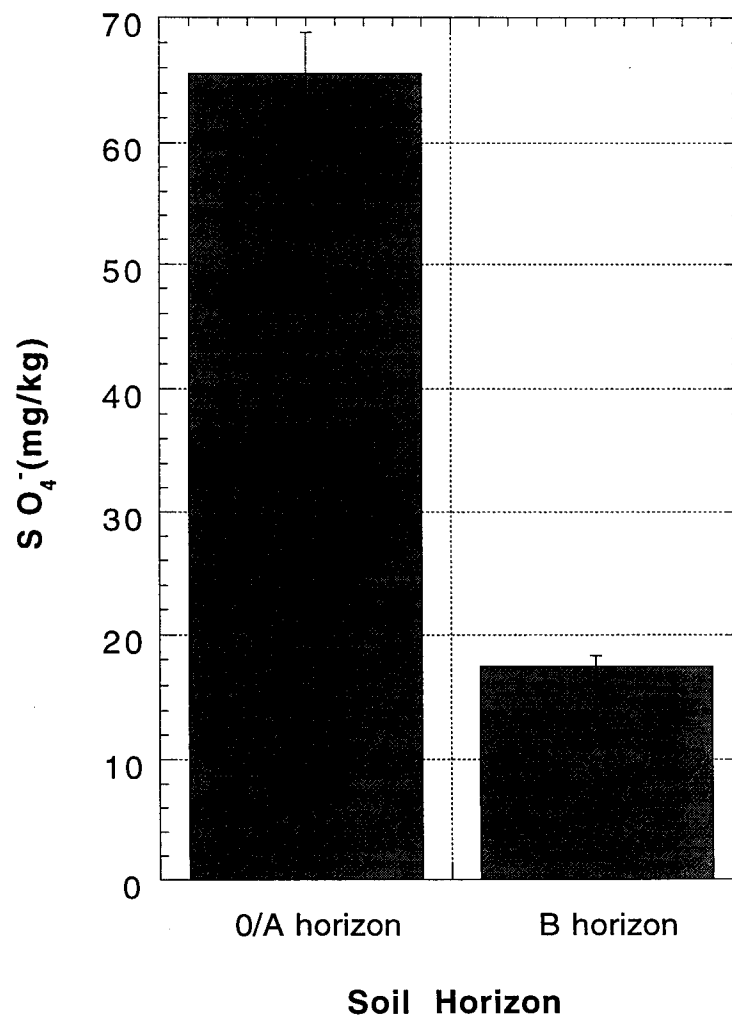
Figure 8: Average pH of Soil Samples from Rocky Mountain and the R&B Plot



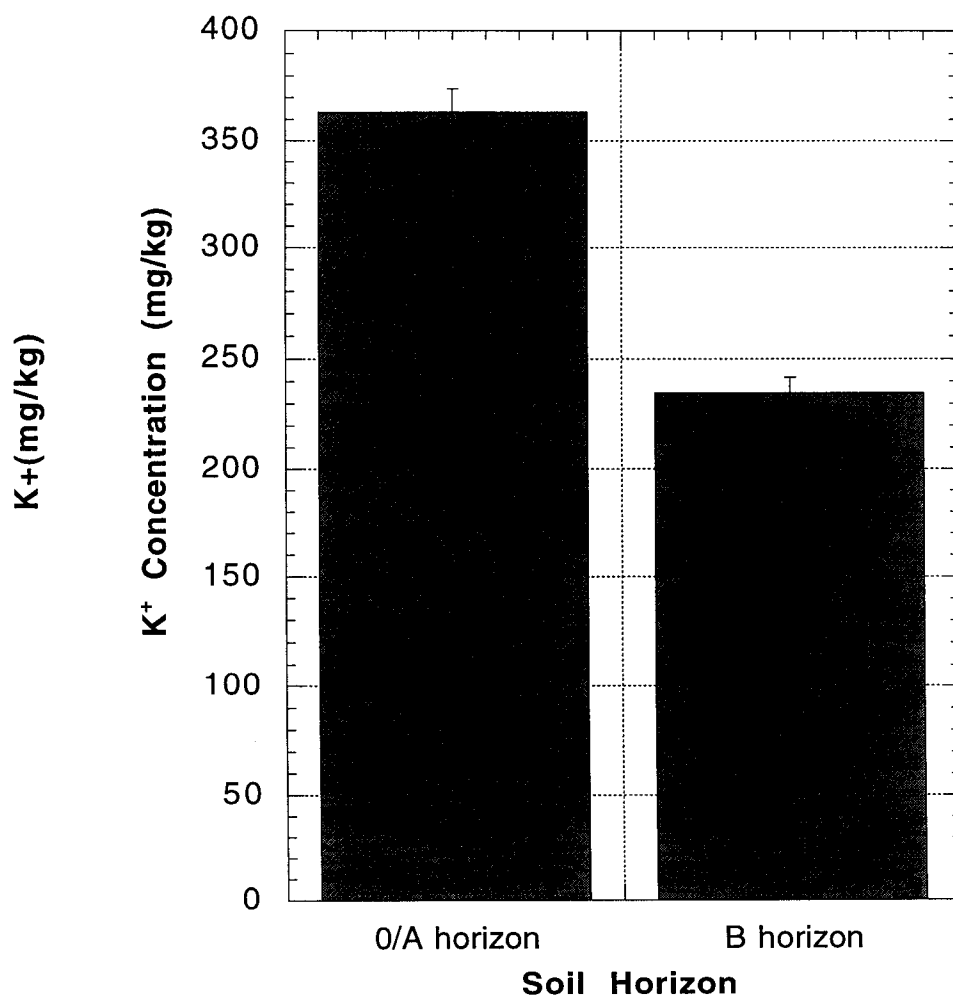
**Figure 9 : Average Concentration
(mg/kg) by Soil Horizon of
Water-Extractable Nitrate (NO_3^-)**



**Figure 10: Average Concentration
(mg/kg) by Soil Horizon of
Water-Extractable Sulfate (SO_4^-)**



**Figure 11: Average Concentration of
Exchangeable Potassium (K^+)
Cations (mg/kg) of Soil Horizons**



**Figure 12: Average Concentration (mg/kg)
of Exchangeable Magnesium (Mg^{++})
Cations of Soil Horizons**

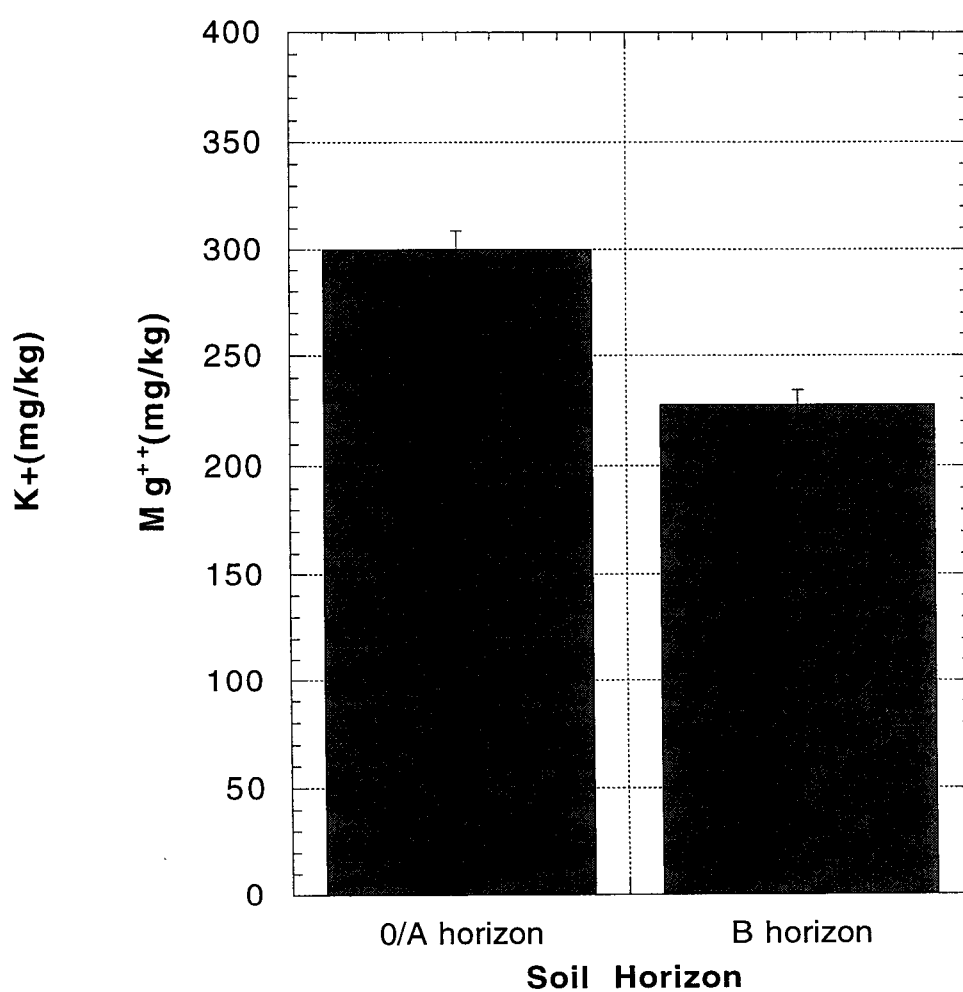


Figure 3: The Effect of Elevation Gain (ft) on Exchangeable Magnesium (Mg^{++}) Ion Concentration (mg/kg) in the O/A Soil Horizon

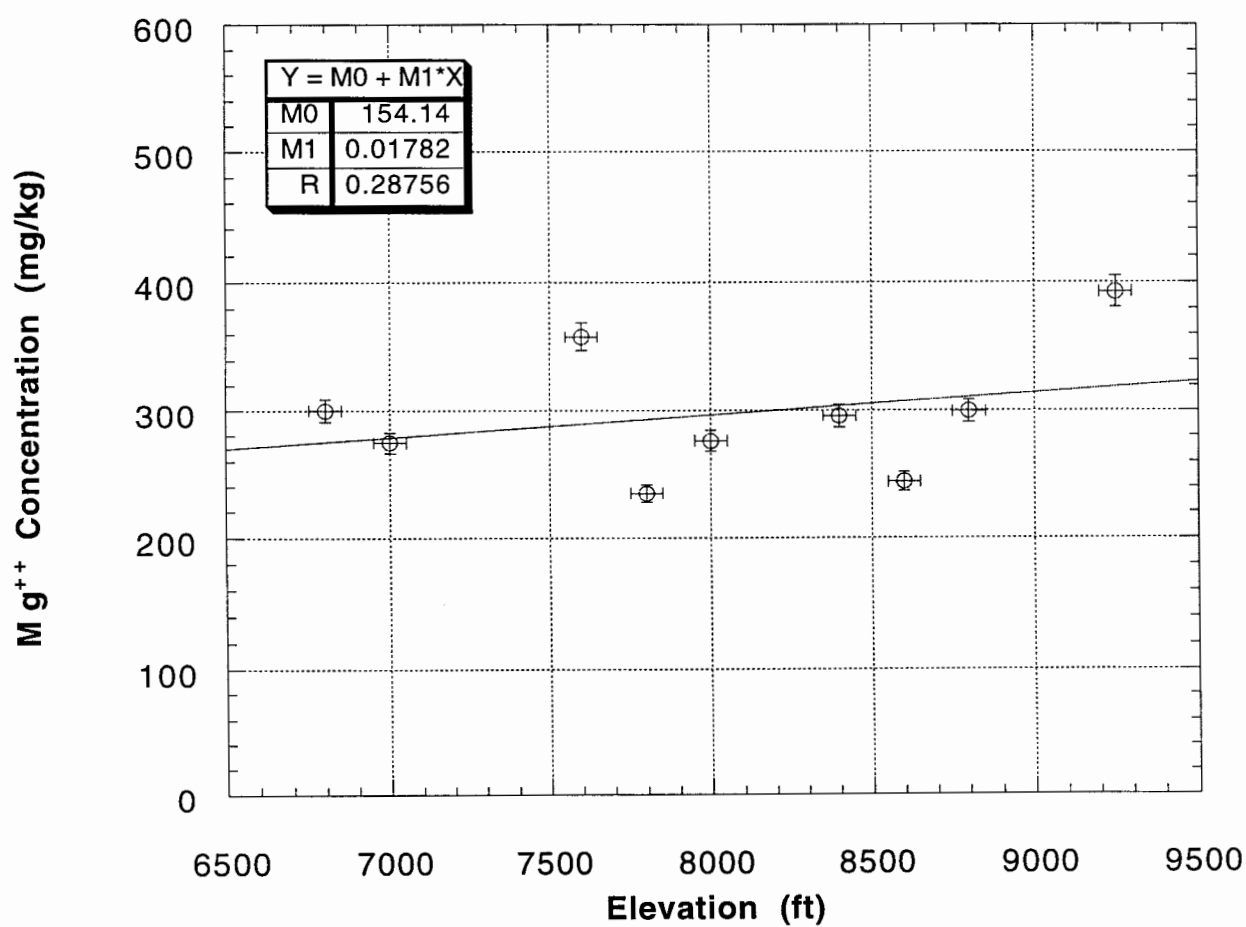


Figure 14: The Effect of Elevation Gain on Exchangeable Potassium (K⁺) Ion Concentration (mg/kg) in the O/A Soil Horizon

