

TRACE ELEMENT CYCLING IN GRAND CANYON NATIONAL PARK

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ABSTRACT: Thirteen sites in the Grand Canyon National Park have been studied in an effort to define the variables that affect natural trace element levels in Gutierrezia sarothrae (snakeweed). The plant density was measured at each site and the vegetation was classified according to the scheme of Brown and Lowe (1974). Samples of Gutierrezia sarothrae, water and soil were collected at each site and analyzed for major anions and cations and the trace elements of zinc, iron, copper and manganese. The chemical data was then analyzed to determine statistically significant correlations between trace element levels in the sample of Gutierrezia sarothrae and local geological, hydrological and soil parameters. The sites chosen for this study include: Hance, Cottonwood, Pipe, Garden, Horn, Salt, Monument, Hermit and Boucher Creeks from the South Rim and Bright Angel, Tapeats, Thunder and Deer Creeks from the North Rim.

The earth is an isolated heavenly body that interacts with other objects of the solar system only through gravitational forces and receives energy from the stars in the form of electromagnetic radiation. Matter is not exchanged with other objects and the earth's mass has been constant throughout its 4.5 billion year existence. The form of matter on the earth has changed quite dramatically as the earth aged, however, leading to the formation of our oceans, land masses, atmosphere, and life as we know it. This study was an investigation of the movement of chemical elements between the lithosphere, hydrosphere, and biosphere, and attempts to determine what natural factors dictate trace element levels in Gutierrezia sarothrae in a pristine environment. In addition to providing an insight into trace element cycling, the data obtained will be extremely valuable for future studies in assessing "significant deterioration" of the environment in a Class I area and in evaluating the chemical impact of old mining operations on a pristine environment.

The Grand Canyon is a mile deep chasm cut through the Kaibab plateau in northern Arizona by the Colorado River. The unique geological features of the Grand Canyon combined with its remoteness from large metropolitan and industrial centers have resulted in maintenance of its pristine condition. Meteorological studies conducted

from 1973 through 1976 support this statement and also indicated that there was a minimum of exchange between air within the canyon walls and that above the canyon rim. Trace element levels in the waters, soils and plants of the Grand Canyon, then, should be governed exclusively by natural factors except for those areas disturbed by old mining operations or recent human activities.

EXPERIMENTAL

The sites chosen for this project included: Hance Creek, Cottonwood Creek, Pipe Creek, Garden Creek, Horn Creek, Salt Creek, Monument Creek, Hermit Creek and Boucher Creek from the south rim. The north rim sites included: Deer Creek, Tapeats Creek, Thunder River and Bright Angel Creek. The location of these water sources is shown in Figure 1. The sampling sites were all located near the normal hiking trails which provided access from the rim of the Grand Canyon.

On site geological determinations included percent grade, faulting, amount and direction of exposures, soil type, erosional characteristics and localized mineral deposits. Field samples included soil taken from the same location as the Gutierrezia sarothrae samples and random collections of parent rock material. Parent rock materials were also collected from all formations within the canyon to complete a vertical analysis.

Upon return to the laboratory soil samples were split for chemical and geological analysis. Geological determinations included multiple sieving to determine the percent composition by size and x-ray diffraction analysis of the clay fraction (less than 63 μm) to determine clay minerals (Warshaw and Roy, 1961; Reeves and Brooks, 1978). Rock samples were analyzed for mineral content using thin sections and petrographic microscopy (Heinrich, 1965).

Chemical determinations of soil samples included sulfates, carbonates, pH, percent water and percent organic components. Sulfate concentrations were measured turbidimetrically using barium sulfate precipitation (Black, et. al., 1964). This method is considered accurate to 1 ppm and the detection limit is 1 ppm. Carbonate concentrations were determined by adding 3N HCl to an accurately weighed sample until all carbon dioxide had been given off and the sample remained at a constant weight (Black, et. al., 1964). Moisture content was determined by weight difference after the sample was dried at 100° C for 24 hours. Organic content was similarly determined by drying at 400° C for 24 hours. The soil pH was measured in the field using packaged reagents (Hellige, Inc.) and published procedures.

At each creek site, a series of ten line-intercepts were used to sample the representative vegetation (Smith, 1966). For each intercept, a steel tape was stretched thirty feet at about twenty foot intervals. A total of three hundred feet, including both overstory and understory of perennial shrubs and annual grasses, were recorded. Both sides of the creek were sampled. Each plant occurring on the intercept was recorded as to genus, species, amount of cover, and number

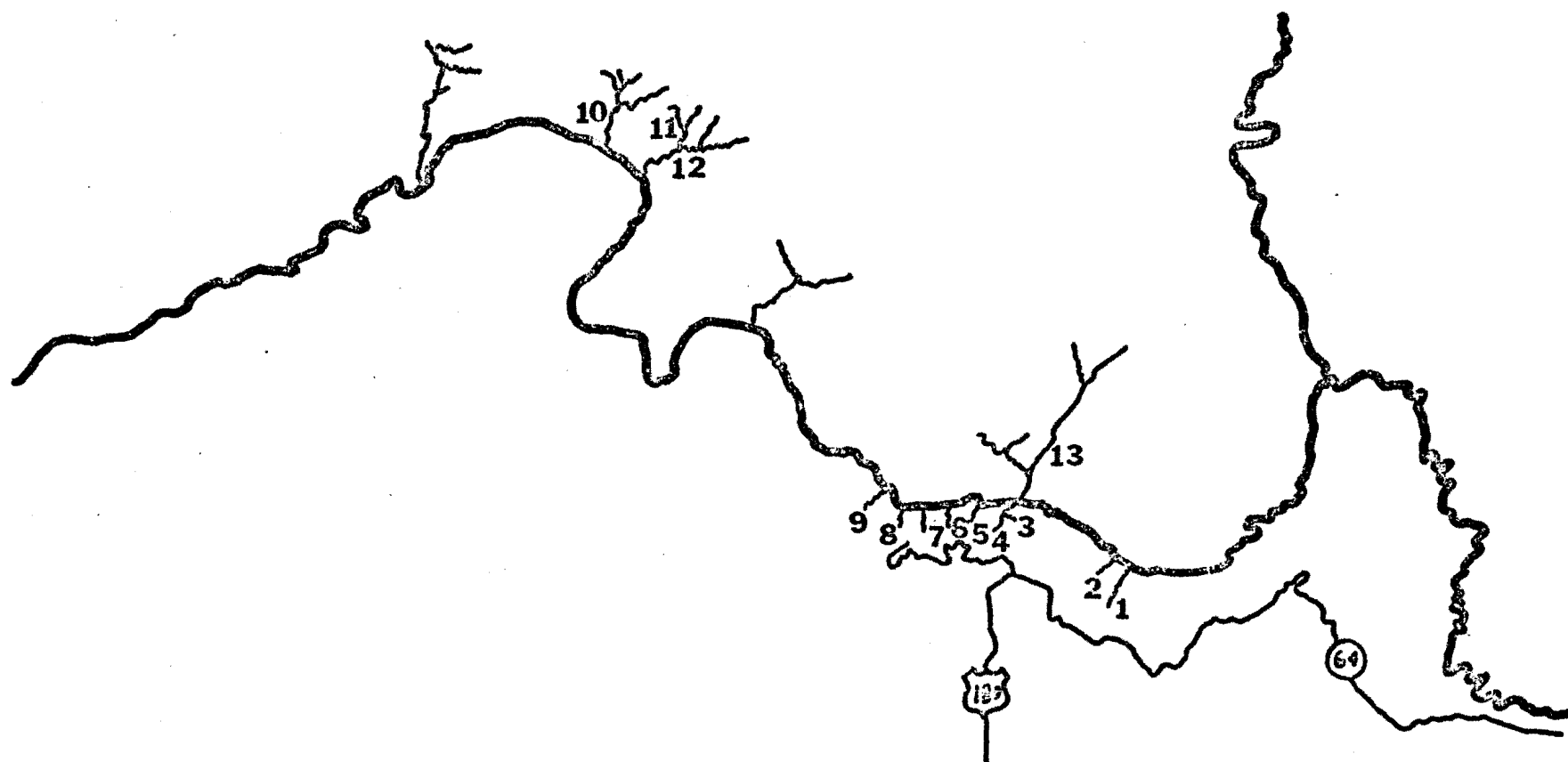


Figure 1. Map of the Grand Canyon Showing the Sites Used for This Project.
1) Hance Creek; 2) Cottonwood Creek; 3) Pipe Creek; 4) Garden Creek; 5) Horn Creek; 6) Salt Creek; 7) Monument Creek; 8) Hermit Creek; 9) Boucher Creek; 10) Deer Creek; 11) Thunder River; 12) Tapeats Creek; 13) Bright Angel Creek.

of occurrences. Bare ground was recorded as well. From this data frequency, relative density, relative frequency, relative dominance, importance values, percent vegetational cover, and percent total cover were established for each species at each site (Tables 2, 3 and 4).

Community classifications were designated for each site according to the Brown and Lowe (1974) system of vegetational classification (Table 5).

In addition, samples of snakeweed (Gutierrezia sarothrae) and Mormon tea (Ephedra viridis) were collected at each site for future laboratory analysis. To prevent accidental contamination of the samples during handling and transport, rubber gloves were used to collect and place the plants in Zip-loc plastic bags.

To prepare the plants for laboratory analysis the snakeweed samples were divided into plants to be oven dried and ground into a homogeneous sample, and plants to be divided into roots, stems, and leaves and ground and dried separately. Mormon tea samples were dried and ground into homogeneous samples.

Any plant that could not be readily identified in the field was collected and identified in the Deaver Herbarium, Northern Arizona University, by Dr. James M. Rominger.

The following statistical tests were used to interpret the data (Phillips, 1959).

Frequency -
$$\frac{\text{Number of samples of occurrence of the species}}{\text{Number of samples measured}}$$

This is a measure of the degree of evenness of distribution of a species throughout the site sampled.

Relative Frequency -
$$\frac{\text{Number of samples of occurrence of the species}}{\text{Number of samples of occurrence of all species}} \times 100$$

This test shows in what percentage of the samples each species is found in relation to the total samples of occurrence of all species.

Relative Density -
$$\frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

This test gives the percentage of abundance numerically of each species in a given area.

Relative Dominance -
$$\frac{\text{Total basal area of the species}}{\text{Total basal area of all species}}$$

This test shows which species covers the greatest percentage of the total area.

Importance Value - The sum of relative density, relative frequency, and relative dominance. The importance value determines which species are most vigorous, numerous, and common within a given area.

Trace metal analysis of plant, soil and water samples was done by atomic absorption spectrophotometry using standard procedures (Perkin Elmer, 1976). Plant samples were dried at 70°C and ground in a Wiley-Mill to pass through a 60-mesh screen. The ground plants were dried at 70°C for 12 hours, and then weighed (1.0 g) to the nearest 0.1 mg and ashed at 500°C for 12 hours. The material remaining from the ashing was dissolved in a mixture of mineral acids (5 mls of HNO₃ and 5 mls of a ternary acid solution consisting of 1 part H₂SO₄, 2 parts HClO₄ and 5 parts HNO₃), heated gently for 1 hour, cooled and quantitatively transferred to a 50.0 ml volumetric flask. Aliquots of this solution were then taken to prepare samples for analysis by the method of standard additions (Perkin-Elmer, 1976). All solutions were used as quickly as possible, usually within the day, and only stored in acid washed polyethylene containers. All glassware used was class A volumetric glassware, and was washed with Aqua Regia and rinsed with double distilled water before use. A Perkin-Elmer model 306 atomic absorption spectrophotometer was used for all trace metal analysis. Standard flame procedures were used when possible, and a model 5000 Graphite Furnace Atomizer was employed for samples with sub part-per-million values for the metal of interest. The numbers obtained from the atomic absorption spectrophotometric analysis are considered accurate to at least 1%.

DISCUSSION

Geological Studies

Geological conditions of the Grand Canyon provide the fundamental basis for chemical trends. The geological structure determines the erosional characteristics, including surface and subsurface flows. The Colorado River flows perennially, however, many of the small tributaries flow in a direct response to precipitation and runoff within the canyon area. Recharge of these aquifers takes place in highly permeable areas, including the Kaibab Limestone and Coconino Sandstone, which are large enough to receive proportionally greater amounts of precipitation (Johnson and Sanderson, 1968; Metzger, 1961; Huntoon, 1974; Foust, et. al., 1979).

The movement of groundwater, and ultimately surface water, is largely responsible for dissolution of mineral components and the release of associated metal complexes to the soil and aqueous environments. Many mineral associated metal ions have been listed in Table 1 and would contribute to the trace metal movement and availability within the Grand Canyon.

A brief geological analysis of the thirteen sites sampled in this investigation has been included to assist in determining drainage systems and possible groundwater movement. The effects of this movement upon the natural trace element composition of each creek basin can be seen in later analysis.

Table 1. Common Minerals With Associated Microelements

Mineral	Structure	Associated Microelement
Azurite ¹	$\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$	Copper
Biotite ²	$\text{K}(\text{Mg}, \text{Fe})_3(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$	Iron
Chalcocite ¹	Cu_2S	Copper
Chalcopyrite ¹	CuFeS_2	Copper, Iron
Chlorite ²	$(\text{Mg}, \text{Fe})_3(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2(\text{Mg}, \text{Fe})_3(\text{OH})_6$	Iron
Chrysocolla ¹	$\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$	Copper
Cumingtonite ²	$(\text{Mg}, \text{Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$	Iron
Epidote ²	$\text{Ca}_2(\text{Al}, \text{Fe})\text{Al}_2\text{O}(\text{SiO}_4)(\text{Si}_2\text{O}_7)\text{OH}$	Iron
Glauconite ²	$(\text{K}, \text{CaNa})_{1-.5}(\text{Fe}, \text{Mg}, \text{Al})_2(\text{SiAl})_4(\text{OH})_2$	Iron
Goethite ¹	FeOOH	Iron
Hematite ¹	Fe_2O_3	Iron
Hornblende ²	$(\text{Ca}, \text{Na})_{2-3}(\text{Mg}, \text{Fe}, \text{Al})_5\text{Si}_6(\text{Si}, \text{Al})_2\text{O}_{22}(\text{OH})_2$	Iron
Magnetite ¹	Fe_3O_4	Iron
Malachite ¹	$\text{Cu}_2(\text{OH})_2\text{CO}_3$	Copper
Rhodochrosite ¹	MnCO_3	Manganese
Siderite ²	FeCO_3	Iron
Smithsonite ¹	ZnCO_3	Zinc
Sphalerite ¹	ZnS	Zinc

1) Mortvedt, et. al. 1972

2) Breed and Roat 1976

Cottonwood Creek

Cottonwood Creek is located on the South Rim of the Grand Canyon. This drainage defines the western boundary of Horseshoe Mesa.

The rock unit exposed in the sampling area is Bright Angel Shale. The Bright Angel Shale is Cambrian in age. It is composed of a mixture of mudstones and fine grained sandstones. The overlying rock units, which form the cliffs outlining the basin, are Muav Limestone and Redwall Limestone. These are dated as Cambrian and Mississippian, respectively. These units are composed of both limestones and dolomites.

Weathering in this area is moderate due to the semi-arid climate of the region. Limestone and sandstone units form prominent cliffs and the shaley units form benches.

Structurally this area is interesting because the Grandview-Phantom Monocline runs through the area. This flexural folding has caused local faulting in the area. This faulting has controlled the location of the spring that feeds Cottonwood Creek. The folding has caused normal faulting in the more competent sandstone units producing a rotated graben structure. The spring reaches the surface through one of these fault zones.

The water present in this system has become available by infiltration and percolation of surface water into the overlying sandstone and limestone units. The normal faulting provides an avenue of escape for groundwater in the area.

There is no evidence of mineralization in this area. The slopes defining this drainage in the Bright Angel Shale are 26° on the North, 23° on the West, and 23° on the South.

X-ray diffraction analysis of the clay size fraction of the soil samples revealed particles of quartz, calcite, dolomite, albite, and two clay minerals; illite and kaolinite.

Rock samples collected at the site were taken out of the Bright Angel Formation and were composed of about 95% quartz grains, 2% glauconite, 1% detrital muscovite, and 2% inarticulate brachiopod shell fragments cemented by a calcite cement.

Hance Creek

Hance Creek is located on the South Rim of the Grand Canyon. This drainage defines the eastern boundary of Horseshoe Mesa.

The sampling site occurred at the contact between the Bright Angel Shale and the Tapeats Sandstone. The Bright Angel Shale and Tapeats Sandstone are both Cambrian in age. The Bright Angel shale is a mixture of mudstones and fine grained sandstones while the Tapeats is a coarse to medium grained sandstone forming massive cliffs.

The spring in this drainage is controlled by the contact of these two units. The Tapeats is a tightly cemented sandstone that does not allow infiltration and percolation of ground water. The water moving in the alluvial sand and gravel in the Hance drainage reaches the surface when the water table meets the Tapeats.

This drainage is one that exhibits an enormous discharge of surface water during parts of the year. This is evidenced by large boulders, wide drainage, and poorly sorted alluvium forming the banks along the creek.

Although there is no immediate evidence of mineralization in Hance Creek, there has been some mining on Horseshoe Mesa for copper in the past. On top of the mesa there are large deposits of azurite and malachite which undoubtedly wash down into Hance Creek and affect the trace element abundance of copper in the area. The slopes in this area are formed by Bright Angel Shale outcrops. These slopes are 22° on the east side of the drainage and 23° on the west side.

X-ray diffraction analysis of the clay size fraction of the soil samples showed quartz, albite, calcite, dolomite, kaolinite and illite.

Bright Angel Creek

Bright Angel Creek is located in the Inner Gorge of the Grand Canyon. The creek itself runs down from the North Rim. The Bright Angel Canyon is controlled by a very large fault running NE and extends from the South Rim to the North Rim. The Vishnu Schist is the rock unit exposed in this area and is composed of metamorphosed sedimentary and minor volcanic materials deposited about two billion years ago. The rocks show a wide compositional range from impure quartzite to mafic amphibolite with mica schist being the most common. This rock unit is dated as being from the Older Precambrian.

Weathering is moderate in the inner canyon area. The schist forms cliff units that are being weathered in place.

Bright Angel Creek has its source about eight miles up the canyon from the sampling site. This creek is also spring fed coming from Roaring Springs. This spring is controlled by the contact of the Muav Limestone and the Bright Angel Shale. The upper part of the Bright Angel Shale consists of a shale that does not allow infiltration of ground water and the water exits to the surface.

The immediate slope that the plant samples were taken from is 60° . This is directly under a vertical cliff of Vishnu Schist. The west side of the creek is also a vertical cliff of Vishnu. There is not much alluvium present in the drainage due to the constant flow and high discharge.

X-ray diffraction analysis of the clay size fraction of the soil samples revealed quartz, albite, calcite, dolomite, illite and kaolinite.

Thin section studies of rock samples in the area included quartz, muscovite, chlorite, biotite, hornblende, epidote, cummingtonite, and orthoclase.

Pipe Creek

Pipe Creek is located on the South Rim of the Grand Canyon. This drainage cuts through the Vishnu Schist and carries a small amount of water year round. The source of this creek was undeterminable due to high cliffs making it impassable.

Weathering is moderate in this area. The walls of the canyon are composed of Vishnu Schist that is weathering in place. There is no evidence of faulting or mineralization in the area. The slope measurements are 55° on the north side and 70° on the south side of the creek. X-ray diffraction analysis of the clay size fraction of the soil samples showed quartz, albite, calcite, dolomite, kaolinite, and illite.

Garden Creek

Garden Creek is located on the South Rim of the Grand Canyon. The rock units exposed at this sampling site were Tapeats Sandstone and Vishnu Schist. The Tapeats Sandstone is a coarse to medium grained sandstone that is Cambrian in age. The Vishnu Schist is a metamorphosed sedimentary and volcanic material that is Pre-Cambrian in age. The contact between the two of them represents the Great Unconformity.

The spring that feeds this creek is located at Indian Gardens. This area has been altered by the presence of man. Located near the spring is a Ranger Station, corral, pumphouse, and picnic area.

The Tapeats Sandstone forms massive cliffs in the area through which Garden Creek flows. This creek appears to be of fairly constant discharge as there is no evidence of flood deposits in the area.

Weathering is moderate in the area due to the semi-arid climate of the Colorado Plateau. There is no evidence of mineralization in the area. The sample site is bounded by a 37° slope to the north and a 35° slope on the south. X-ray diffraction analysis of the clay size fraction of the soil samples show quartz, calcite, albite, illite, and kaolinite.

Tapeats Creek

Tapeats Creek is located on the North Rim of the Grand Canyon. The rock unit exposed at this sampling site is the Shinumo Formation. This formation is Pre-Cambrian in age. The Shinumo Formation is predominantly a sandstone with a large quartzite unit. Weathering in this area is moderate due to the semi-arid climate. The resistant Shinumo forms massive cliffs in this area.

Tapeats Creek forms from Tapeats Spring which is about eight miles above the sampling site. This spring emerges at the contact of the Muav Limestone and Bright Angel Shale. Surface water on the North Rim percolates into the overlying rock units and is channeled into the Redwall and Muav Limestone by means of a fault system. The impermeable shale of the Bright Angel shale does not allow infiltration and the water discharges out of a solution cave in the Muav near the contact with the shale unit. This water moves very rapidly through the overlying sediments and is not in contact with the rock units for as long a time as the slow moving percolating water on the South Rim.

There is no evidence of any mineralization in the immediate area of study. The slopes defining this drainage are 60° on the west and vertical on the east. The clay size fraction of the soil samples were analyzed by x-ray diffraction and revealed quartz, albite, calcite, dolomite, illite and kaolinite. A sample of Shinumo was analyzed in thin sections and was composed entirely of rounded quartz grains with overgrowths. An iron-oxide stain was present between some of the grains.

Thunder River

Thunder River is located on the North Rim of the Grand Canyon. The rock unit exposed at the sample site is Shinumo. The Shinumo Formation is a sandstone with a large quartzite unit and is Pre-Cambrian in age.

Thunder River is fed by a spring that is fault controlled. The fault is part of the same system that is responsible for Tapeats Spring and Deer Spring. The actual effluence of water occurs at the Muav - Bright Angel contact. The discharge of Thunder River Spring is greater than that of Tapeats or Deer. Very little alluvium is present in this drainage due to the constant flow and high rate of discharge. Faulting is evident at Thunder Spring thus explaining the location of the spring. Some offset is discernible in the Redwall Limestone.

No mineralization is present in this area. Slope measurements in the immediate sampling area are 60° on the north slope and 10° on the south slope. X-ray diffraction analysis of the clay size fraction of the soil samples reveal quartz, albite, calcite, dolomite, siderite, illite and kaolinite.

Deer Creek

Deer Creek is located on the North Rim of the Grand Canyon. The rock outcrop in this area is Quaternary alluvium from landslides, slump blocks, and rock falls.

Deer Creek is fed by two springs both emerging at the Muav - Bright Angel contact. The only spring affecting the sample area is Deer Spring. Deer Spring is controlled by a fault that is part of the

same system of Thunder River and Tapeats Creek. Surface water on the North Rim is able to infiltrate and percolate into the sandstone and limestone units. Once into these units the fault system makes an easy avenue of travel for the water. The water then emerges in areas where the fault meets the Muav - Bright Angel contact.

The area above Deer Spring, Surprise Valley, is an area where an enormous amount of slumping has occurred in the Redwall Limestone. These slump blocks extend into Deer Creek drainage and rock outcrops are covered with this alluvium. There is no evidence of mineralization in this area. The slope to the east of the sampling site is 27° . X-ray diffraction analysis of the clay size fraction of the soil samples taken show quartz, calcite, dolomite, illite and kaolinite.

Boucher Creek

Boucher Creek is located on the South Rim of the Grand Canyon. The sampling site is located at the contact between the Tapeats Sandstone and the Vishnu Schist, the Great Unconformity. The Tapeats is Cambrian in age and is composed of a coarse to medium grained sandstone. The Vishnu is Pre-Cambrian in age and is composed of metamorphosed sedimentary and volcanic material. The origin of the creek was not determined, but most likely occurs at the Bright Angel - Tapeats contact as do most of the springs on the South Rim. Evidence of faulting is present in the area. This fault runs SW-NE and Boucher Canyon follows the fault.

An old abandoned mine is present in the Vishnu Schist directly below the sampling site. This mine was owned and operated by Louis Boucher in the early 1890's. Small amounts of azurite and malachite are located near the mine and were the source of copper for early mining operations.

Slope measurements taken in the immediate vicinity of the sample site are 33° to the north, 35° to the south and 30° to the east. X-ray diffraction analysis of the clay size fraction of the soil sample revealed particles of quartz, illite and kaolinite.

Hermit Creek

Hermit Creek is located on the South Rim of the Grand Canyon. The rock unit exposed at the sampling site is the Tapeats Sandstone. The Tapeats is Cambrian in age and is a coarse to medium grained sandstone. Weathering in this area is moderate due to the semi-arid climate of the Colorado Plateau with the Tapeats Sandstone forming massive cliffs in the area.

The origin of Hermit Creek was not determined, but it is most likely at the Bright Angel - Tapeats contact. There is no evidence of faulting or mineralization in the area. Slope measurements in the area are 23° on the north and 90° on the south side of the sampling site. X-ray diffraction analysis of the clay size fraction of the soil samples show quartz, calcite, illite, and kaolinite.

Monument Creek

Monument Creek is located on the South Rim of the Grand Canyon. This sampling site is located at the contact between the Tapeats Sandstone and the Vishnu Schist. The spring in this drainage is formed from water percolating from above layers into thick accumulations of alluvium. The water emerges out of the alluvium when it encounters the resistant and impermeable Vishnu Schist.

The drainage above the spring is large and evidence of seasonal flooding is present. Large boulders and thick accumulations of unsorted alluvium demonstrate the occasional flooding. There is no evidence of faulting in the area.

On the underside of resistant layers of Tapeats Sandstone localized heavy accumulations of halite crystals (NaCl) are present. Slope measurements in this area are 30° to the east and 22° to the west. X-ray diffraction analyses of the clay size fraction of the soil samples show particles of quartz, calcite, dolomite, illite and kaolinite.

Salt Creek

Salt Creek is located on the South Rim of the Grand Canyon. The sampling site is located at the Tapeats Sandstone and Vishnu Schist contact. The Tapeats Sandstone is Cambrian in age and is composed of a coarse to medium grained sandstone. The Vishnu Schist is Pre-Cambrian in age and is composed of metamorphosed sediments and minor volcanics. Salt Creek is fed by a spring that flows out of alluvial sand and gravel when it encounters the resistant and impermeable Vishnu Schist.

Weathering is moderate in this area due to the semi-arid climate of the region. Limestone and sandstone units form prominent cliffs while the shaley units form benches.

Salt Creek drainage shows evidence of flooding during parts of the year. The drainage is full of poorly sorted alluvium and large boulders. Slope measurements in the immediate area of study are 30° on the west side of the drainage and 40° on the east side. X-ray diffraction analyses of the clay size fraction of the soil samples show quartz, calcite, dolomite, siderite, illite, and kaolinite.

Horn Creek

Horn Creek is located on the South Rim of the Grand Canyon. The rock unit exposed at the sampling site is Tapeats Sandstone. The Tapeats is Cambrian in age and is composed of coarse to medium grained sandstone.

Horn Creek is intermittent and only flows in the spring and after periods of heavy precipitation. The spring that feeds Horn Creek is variable in its location of origin. The spring emerges at different locations depending on how much water is in the subsurface, which is

alluvial sand and gravel. There is no evidence of any faulting or any mineralization in the area. The slope measurements in the area are 30° to the east and 25° to the west.

X-ray diffraction analyses of the clay size fraction of the soil samples show particles of quartz, calcite, illite and kaolinite.

Botanical Studies

The floral environment of the Grand Canyon National Park is very uniform. A narrow, moist riparian zone of each creek bed is flanked by a broad semi-arid mixed shrub-grass community. In sampling the immediate watershed vegetation for each creek, line intercepts were taken through both communities and the results were combined. The line intercept measured shrubby overstory and herbaceous understory simultaneously in each community. As a result, an excessively generous vegetation cover total was recorded (Table 2). A 10 - 20% reduction in total vegetation cover for each site would give a more accurate estimate of the actual vegetation cover. However, it should be noted that due to an unusually moist winter and spring in northern Arizona in 1979, there resulted a lush display of annual grasses, dominated by red brome (Bromus rubens) and 6-weeks fescue (Festuca octoflora). This thick cover of annual grasses contributed to the very high vegetation cover percentages recorded at all sites.

Table 3 compares the overstory shrub cover and importance value for each site. Gutierrezia sarothrae (snakeweed) was classed as a shrub in this survey and any plants with greater or lesser degree of woodiness were classed as shrubs or herbs respectively. For each site the three leading shrubs are ranked according to percent cover and importance value. Table 4 lists a summary of the total cover of all sites for the top ten shrubs and their respective importance values, indicating the obvious choices for chemical studies to be snakeweed and Mormon tea or joint fir (Ephedra viridis).

Using the Arizona System for Natural and Potential Vegetation by Brown and Lowe (1974), two basic community classifications apply at each site. The streamside zone best fits the Mixed Scrub Community (342.43) of the Riparian Scrub, while the semi-arid hillside zone most closely approximates the Mixed Scrub Community of the Great Basin Desert Scrub. The Riparian Scrub Community (342.43) was usually dominated by seep willow (Baccharis glutinosa) and catclaw (Acacia greggii). The Great Basin Desert Mixed Scrub Community was dominated by joint fir and snakeweed. The expected blackbush (Coleogyne ramosissima) and shadscale (Atriplex confertiflora) were completely absent at all sites studied though both are present on the adjacent Tonto Plateau. The determination of which community dominated the sample data was primarily a function of the relative width of the Riparian Scrub Community. Table 5 summarizes the community classification to the fifth digit for each site.

Table 2. Percent Vegetation Cover

Site	% Vegetation*
Deer	83.7
Salt	77.5
Horn	76.7
Hermit	71.9
Thunder	70.8
Garden	69.0
Monument	68.1
Boucher	66.4
Pipe	65.8
Tapeats	64.3
Cottonwood	63.0
Hance	55.8
Bright Angel	54.3

* Includes overlap of overstory and understory

Table 3. Dominant and Important Shrubs

Site	Dominants % cover	Importance value
Cottonwood	Gutierrezia sarothrae Fallugia paradoxa Chrysothamnus nauseosus	Gutierrezia sarothrae Ephedra viridis Fallugia paradoxa
Hance	Fallugia paradoxa Gutierrezia sarothrae Ephedra viridis	Gutierrezia sarothrae Fallugia paradoxa Ephedra viridis
Bright Angel	Ephedra viridis Baccharis emoryi Baccharis glutinosa	Ephedra viridis Baccharis glutinosa Baccharis emoryi
Pipe	Ephedra viridis Acacia greggii Baccharis emoryi	Ephedra viridis Acacia greggii Baccharis emoryi
Garden	Ephedra viridis Vitis arizonica Bernardia incana	Ephedra viridis Gutierrezia sarathrae Bernardia incana
Thunder	Ephedra viridis Fallugia paradoxa Encelia farinosa	Ephedra viridis Gutierrezia sarothrae Encelia farinosa
Tapeats	Ephedra viridis Encelia farinosa Prosopis juliflora	Ephedra viridis Encelia farinosa Gutierrezia sarothrae
Deer	Gutierrezia sarothrae Baccharis glutinosa Ephedra viridis	Gutierrezia sarothrae Ephedra viridis Baccharis glutinosa
Boucher	Ephedra viridis Baccharis glutinosa Gutierrezia sarothrae	Ephedra viridis Baccharis glutinosa Gutierrezia sarothrae
Hermit	Baccharis glutinosa Ephedra viridis Gutierrezia sarothrae	Gutierrezia sarothrae Ephedra viridis Baccharis glutinosa
Monument	Gutierrezia sarothrae Acacia greggii Ephedra viridis	Gutierrezia sarothrae Acacia greggii Ephedra viridis
Horn	Fallugia paradoxa Lycium andersoni Chrysothamnus nauseosus	Gutierrezia sarothrae Fallugia paradoxa Lycium andersoni
Salt	Rhus trilobata Baccharis Glutinosa Gutierrezia sarothrae	Gutierrezia sarothrae Baccharis glutinosa Rhus trilobata

Table 4. Total Cover and Importance Value of Ten Major Shrubs (3900 Ft)

Shrub	Cover (ft)	Importance Value
Ephedra viridis	376.5	349.4
Gutierrezia sarothrae	262.5	308.2
Fallugia paradoxa	159.4	157.6
Baccharis glutinosa	152.3	135.8
Acacia greggii	128.0	130.9
Rhus trilobata	95.2	65.5
Lycium andersoni	80.7	79.4
Chrysothamnus nauseosus	66.2	58.3
Baccharis emoryi	34.7	34.9
Vitis arizonica	21.4	16.5

Table 5. Classification of Sites by Community Type

Boucher	Mixed Scrub Community (~~324.23~~)
Bright Angel	(342.43)
Deer	340 Scrubland Formation
Hermit	342 Temperate Scrubland
Pipe	342.4 Riparian Scrub
Salt	342.43 Mixed Scrub Community
Cottonwood	Mixed Scrub Community (362.17)
Garden	
Hance	
Horn	360 Desert Scrub Formation
Monument	326 Temperate Desert Scrub
Tapeats	362.1 Great Basin Desert Scrub
Thunder	362.17 Mixed Scrub Community

Table 12. Concentration Factors

Element	Soil Available µg/g	<u>Gutierrezia</u> Homogenous Sample µg/g	Concentration Factor	<u>Gutierrezia</u> Leaves µg/g	Concentration Factor	Concentration Factor (Kale leaves ¹)
Copper	3.23	11.22	3.47	20.31	6.29	27.5
Iron	2.42	288.36	119.16	344.60	142.40	120
Manganese	4.45	31.85	7.16	70.49	15.84	45.8
Zinc	1.78	18.88	10.61	36.22	20.35	41

¹Bowen, 1966.

does not appear to be a deficiency in the Gutierrezia or Ephedra species.

Table 12 indicates the concentration factors found when analyzing copper, iron, manganese and zinc in the available soil fraction and homogenous Gutierrezia samples and Gutierrezia leaf samples. For comparison the concentration factor of the same elements by kale leaves as reported by Bowen (1966) is shown.

The concentration factors are lower for the Grand Canyon for copper, manganese and zinc. However, these factors may be low because the available metal concentration are higher than that required by the plant species. This may be true for copper and zinc whereas manganese does appear to be limiting.

CONCLUSION

The study of the movement of trace metals between the biosphere, hydrosphere and lithosphere is a complex, challenging problem. This project has provided the groundwork for future studies by showing significant correlations between trace metal levels in minerals, soils, waters and plants. Although several significant results have been described, many questions remain unsolved and can only be answered by further research.

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PURPOSE

The purpose of this study was to determine the representative vegetation of thirteen sites in Grand Canyon National Park; to classify each site to community; and to collect plant samples for chemical analysis.

The vegetation data provided a means by which plant density and community diversity could be compared between sites. Evidence of outside community disturbances were associated with some of the study areas.

Date ?

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SITE DESCRIPTIONS

The thirteen side canyons chosen for the study were Boucher, Hermit, Monument, Horn, Salt, Garden, Pipe, Cottonwood, and Hance Creeks on the south rim; and Bright Angel, Tapeats, Thunder, and Deer Creeks on the north rim.

Pipe, Bright Angel, and Cottonwood are the only sites not found where the creeks cut through the Tapeats sandstone formation, ca. 4000 feet. Pipe Creek is located in the Vishnu schist formation at an elevation of ca. 3000 feet. Bright Angel is located in the inner canyon schist at an elevation of about 2200 feet.

The various slope angles and exposures of the sites are shown in Table 1.

Table 1. Slope and exposure of the 13 collecting sites in the Grand Canyon.

Boucher	Northeast	30°	Southwest	33°
Hermit	Northeast	23°	Stream	0°
Monument	West	20°	Stream	0°
Horn	East	38°	West	32°
Salt	East	40°	West	30°
Garden	East	27°	West	35°
Pipe	North	55°	South	70°
Cottonwood	East	23°	West	26°
Hance	East	22°	West	23°
Bright Angel	East	60°	Stream	0°
Tapeats	North	32°		
Thunder	East	32°	West	32°
Deer	East	30°	West	0°

MATERIALS AND METHODS

At each creek site, a series of ten line-intercepts were used to sample the representative vegetation (Smith, 1966). For each intercept, a steel tape was stretched thirty feet at about twenty foot intervals. A total of three hundred feet, including both overstory and understory of perennial shrubs and annual grasses, were recorded. Both sides of the creek and the creek itself were sampled. Each plant occurring on the intercept was recorded as to genus, species, amount of cover, and number of occurrences. Bare ground was recorded as well. From this data frequency, relative density, relative frequency, relative dominance, importance values, per cent vegetational cover, and per cent total cover were established for each species at each site (Tables 2 and 4). Index of uncertainty (H') and evenness (J') values were determined for each site to provide an indication of diversity between sites (Table 3).

Community classifications were designated for each site according to the Brown and Lowe (1974) system of vegetational classification (Table 9).

In addition, samples of snakeweed (Gutierrezia sarothrae) and Mormon tea (Ephedra viridis) were collected at each site for future laboratory analysis. To prevent accidental contamination of the samples during handling and transport, rubber gloves were used to collect and place the plants in zip-loc plastic bags.

To prepare the plants for laboratory analysis the snakeweed samples were divided into plants to be oven dried and ground into a homogeneous sample, and plants to be divided into roots, stems, and leaves and ground and dried separately. Mormon tea samples were dried and ground into homogeneous samples.

Any plant that could not be readily identified in the field was collected and identified in the Deaver Herbarium, Northern Arizona University, by Dr. James M. Rominger.

The following statistical tests were used to interpret the data (Smith, 1966).

Frequency----- $\frac{\text{Number of samples of occurrence of the species}}{\text{Number of samples measured}}$

This is a measure of the degree of evenness of distribution of a species throughout the site sampled.

Relative Frequency-- $\frac{\text{Number of samples of occurrence of the species}}{\text{Number of samples of occurrence of all species}} \times 100$

This test shows in what percentage of the samples each species is found, in relation to the total samples of occurrence of all species.

Relative Density---- $\frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$

This test gives the percentage of abundance numerically of each species in a given area.

Relative Dominance-- $\frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$

This test shows which species covers the greatest percentage of the total area.

Importance Value---The sum of relative density, relative frequency, and relative dominance. The importance value determines which species are most vigorous, numerous, and common within a given area.

Index of Uncertainty (H')--This test will show the amount of diversity within a community and is calculated using a pi log pi table and the relative density.

Evenness (J')----- $\frac{H'}{H'_{\max}}$

This is another measure of total diversity between communities. A high J' value is an indication of great diversity.

Table 2. Per cent Vegetation Cover for each Site*

<u>Site</u>	<u>% Vegetation Cover of total length</u>
1. Deer.....	83.7%
2. Salt	77.5%
3. Horn	76.7%
4. Thunder	70.8%
5. Hermit	71.9%
6. Garden	69.0%
7. Monument	68.1%
8. Boucher	66.4%
9. Pipe	65.8%
10. Tapeats	64.3%
11. Cottonwood	63.0%
12. Hance	55.8%
13. Bright Angel	54.3%

* These percentages should be reduced by 10-20% to compensate for overlap of overstory and understory.

Table 3. Table of J' Values for each Site.

<u>Site</u>	<u>J' value</u> *
1. Monument	.838
2. Salt	.823
3. Hermit	.773
4. Bright Angel	.766
5. Garden	.762
6. Horn	.743
7. Cottonwood	.653
8. Hance	.606
9. Boucher	.599
10. Deer	.582
11. Pipe	.572
12. Tapeats	.528
13. Thunder	.431

* A higher J' value indicates higher species diversity.

Table 4. Frequencies of Major Species for Entire Study

<u>Shrubs & Forbs</u>		<u>Frequency</u>
<i>Ephedra viridis</i>	13 of 13 sites	100%
<i>Sphaeralcea grossulariae-</i> <i>folia</i>	13 of 13 sites	100%
<i>Gutierrezia sarothrae</i>	12 of 13 sites	92.3%
<i>Acacia greggii</i>	12 of 13 sites	92.3%
<i>Fallugia paradoxa</i>	9 of 13 sites	69.2%
<i>Baccharis glutinosa</i>	9 of 13 sites	69.2%
<i>Opuntia phaeacantha</i>	8 of 13 sites	61.5%
<i>Chrysothamnus nauseosus</i>	7 of 13 sites	53.8%
<i>Lycium andersonii</i>	6 of 13 sites	46.2%
<i>Rhus trilobata</i>	5 of 13 sites	38.5%
<i>Baccharis emoryi</i>	2 of 13 sites	15.4%
<i>Vitis arizonica</i>	1 of 13 sites	7.7%
<i>Cladium californicum</i>	1 of 13 sites	7.7%
 <u>Grasses</u>		
<i>Bromus rubens</i>	13 of 13 sites	100%
<i>Festuca octoflora</i>	11 of 13 sites	84.6%
<i>Sitanion longifolium</i>	7 of 13 sites	53.8%
<i>Bromus arvensis</i>	2 of 13 sites	15.4%
<i>Bromus tectorum</i>	2 of 13 sites	15.4%

Discussion:

At each site, a moist, riparian zone of rather narrow width was flanked by a broader, hillside zone of an arid mixed shrub-grass community. In an effort to sample the immediate watershed vegetation for each creek, the line intercepts were taken through both type of communities and the results were combined. Usually a maximum of two hours was available for sampling due to the rigorous schedule required to visit these remote sites on foot. As a result the line intercept was the most efficient method but a greater total distance measured would have been desirable. The line intercept measured shrubby overstory and herbaceous understory simultaneously in each community. As a result, an excessively generous vegetation cover total was recorded. (Table 2). A 10-20 percent reduction in total vegetation cover for each site would give a more accurate estimate of the actual vegetation cover. However it should be noted that due to an unusually moist winter and spring in northern Arizona in 1979, there resulted a lush display of annual grasses; dominated by red brome (Bromus rubens) and 6-weeks fescue (Festuca octoflora). This thick cover of annual grasses contributed to the very high vegetation cover percentages recorded at all sites. One would not expect this high cover in subsequent years or even later in the season.

Table 5 has been prepared to compare separately the overstory shrub cover and the understory herbaceous cover for each site. Snakeweed was classed as a shrub in this survey and any plants with greater or lesser degree of woodiness were classed as shrubs or herbs respectively. For each site, the three leading shrubs and herbs are ranked according to percent cover and Importance Value. A listing of plant names corresponding to the acronyms of Table 5 is given in Table 6. Also a summary of total cover for all sites combined for the top ten shrubs and herbs along with their respective Importance Values is given in Tables 7 and 8.

Using the Arizona System for Natural and Potential vegetation by Brown and Lowe(1974), two basic community classifications apply at each site. The streamside zone best fits the Mixed Scrub Community (342.43) of the Riparain Scrub, while the arid, hillside zone most closely approximates the Mixed Scrub Community of the Great Basin Desert Scrub. The Riparian Scrub Community (342.43) was usually dominated by seep willow (Baccharis glutinosa) and catclaw (Acacia greggii). The Great Basin Desert Mixed Scrub Community was dominated by Mormon Tea or joint fir (Ephedra viridis) and snakeweed (Gutierrezia sarothrae). The expected blackbrush (Coleogyne ramosissima) and shadscale (Atriplex confertifolia) were completely absent at all of our sites though both are present on the adjacent Tonto Plateau.

An attempt is made to determine which community dominated our sample data for each site. This decision was determined primarily by the relative width of the Riparian Scrub Community. Table 9 summarizes the community classification to the 5th digit for each site.

Table 5. Dominant and Important Shrubs & Herbs for each Site *

Site	Dominants by % Cover		Importance Value	
	Shrub/Herb		Shrub / Herb	
Cottonwood	Gusa	Brar	Gusa	Brar
	Fapa	Brru	Epvi	Brru
	Chna	Enfr	Fapa	Enfr
Hance	Fapa	Brru	Gusa	Brru
	Gusa	Feoc	Fapa	Feoc
	Epvi	Enfr	Epvi	Plpu
Bright Angel	Epvi	Brru	Epvi	Brru
	Baem	Moss	Bagl	Moss
	Bagl	Eqla	Baem	Eqla
Pipe Springs	Epvi	Brru	Epvi	Brru
	Acgr	Feoc	Acgr	Feoc
	Baem	Arlu	Baem	Stni
Garden Creek	Epvi	Brru	Epvi	Brru
	Viar	Brte	Gusa	Brte
	Bein	Brri	Bein	Feoc
Thunder River	Epvi	Brru	Epvi	Brru
	Fapa	Feoc	Gusa	Feoc
	Enfa	Erfl	Enfa	Erfl
Tapeats	Epvi	Brru	Epvi	Brru
	Enfa	Feoc	Enfa	Feoc
	Prju	Amin	Gusa	Amin
Deer Creek	Gusa	Brru	Gusa	Brru
	Bagl	Feoc	Epvi	Feoc
	Epvi	Brri	Bagl	Brri
Boucher	Epvi	Brru	Epvi	Brru
	Bagl	Muas	Bagl	Muas
	Gusa	Spgr	Gusa	Spgr
Hermit	Bagl	Clca	Gusa	Brru
	Epvi	Tyla	Epvi	Muas
	Gusa	Muas	Bagl	Clca
Monument	Gusa	Feoc	Gusa	Brru
	Acgr	Brru	Acgr	Feoc
	Epvi	Enfr	Epvi	Stni
Horn	Fapa	Feoc	Gusa	Feoc
	Lyan	Brru	Fapa	Brru
	Chna	Spgr	Lyan	Spgr
Salt	Rhtr	Arlu	Gusa	Brru
	Bagl	Brru	Bagl	Feoc
	Gusa	Feoc	Rhtr	Arlu

* See Table 6 for complete names for abbreviations used.

Table 6. Scientific names abbreviated in Table 5.

<u>Shrubs</u>		<u>Herbs</u>	
<u>Acronym</u>	<u>Scientific Name</u>	<u>Acronym</u>	<u>Scientific Name</u>
Acgr	Acacia greggii	Amin	Amsinckia intermedia
Baem	Baccharis emoryi	Arlu	Artemisia ludoviciana
Bagl	Baccharis glutinosa	Brar	Bromus arvensis
Bein	Bernardia incana	Brri	Bromus rigidus
Chna	Chrysothamnus nauseosus	Brru	Bromus rubens
Enfa	Encelia farinosa	Brte	Bromus tectorum
Epvi	Ephedra viridis	Clca	Cladium californicum
Fapa	Fallugia paradoxa	Enfr	Encelia frutescens
Gusa	Gutierrezia sarothrae	Eqla	Equisetum laevigatum
Lyan	Lycium andersoni	Erfl	Erigeron flagellaris
Prju	Prosopis juliflora	Feoc	Festuca octoflora
Rhtr	Rhus trilobata	Muas	Muhlenbergia asperifolia
Viar	Vitis arizonica	Plpu	Plantago purshii
		Spgr	Sphaeralcea grossulariaefolia
		Stni	Stellaria nitens
		Tyla	Typha latifolia

Table 7. Total Cover and Importance Values of Ten Major Shrubs for all sites combined (3900' measured)

<u>Shrub</u>	<u>Cover (ft.)</u>	<u>Importance Value</u>
<i>Ephedra viridis</i>	376.5	349.4
<i>Gutierrezia sarothrae</i>	262.5	308.2
<i>Fallugia paradoxa</i>	159.4	157.6
<i>Baccharis glutinosa</i>	152.3	135.8
<i>Acacia greggii</i>	128.0	130.9
<i>Rhus trilobata</i>	95.2	65.5
<i>Lycium andersoni</i>	80.7	79.4
<i>Chrysothamnus nauseosus</i>	66.2	58.3
<i>Baccharis emoryi</i>	34.7	34.9
<i>Vitis arizonica</i>	21.4	16.5

Table 8. Total Cover and Importance Values of Ten Major Herbs for all sites combined (3900' measured)

<u>Herb</u>	<u>Cover(ft)</u>	<u>Importance Value</u>
<i>Bromus rubens</i>	360.2	814.4
<i>Festuca octoflora</i>	137.6	339.9
<i>Sphaeralcea grossulariaefolia</i>	67.3	115.9
<i>Bromus arvensis</i>	40.4	36.2
<i>Encelia frutescens</i>	35.1	58.1
<i>Cladium californicum</i>	32.5	25.4
<i>Opuntia phaeacantha</i>	30.9	48.6
<i>Sitanion longifolium</i>	25.8	62.1
<i>Bromus tectorum</i>	19.4	36.1
<i>Erigeron flagellaris</i>	6.1	8.6

Table 9. Classification of Sites by Community Type to 5th Digit

Boucher

Bright Angel

MIXED SCRUB COMMUNITY (342.43)

Deer

340 Scrubland Formation

342 Temperate Scrubland

Hermit

342.4 Riparian Scrub

342.43 Mixed Scrub Community

Pipe

Salt

Cottonwood

MIXED SCRUB COMMUNITY (362.17)

Garden

360 Desertscrub Formation

Hance

362 Temperate Desertscrub

362.1 Great Basin Desertscrub

Horn

362.17 Mixed Scrub Community

Monument

Tapeats

Thunder

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