MODERN POLLEN DISTRIBUTION AS RELATED TO VEGETATION COMMUNITIES AND ELEVATION IN THE GRAND CANYON, ARIZONA

by

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ABSTRACT

Twenty-five surface soil samples were collected and analyzed for their pollen content from a traverse across the Grand Canyon, Arizona. In an attempt to relate the modern pollen distribution to the vegetation in the Canyon, five principal vegetation communities were described ranging from a mixed coniferous forest (elev. 2515 m) to a desert shrub community (elev. 760 m) near the Colorado River.

The modern pollen distribution of most major plant communities is distinctive despite the over-representation of wind-blown coniferous pollen, especially *Pinus*, at lower elevations in the Canyon. The woodland and forest communities are characterized by greater than 50 percent *Pinus* pollen. Relatively high frequencies of Compositae and *Ephedra* pollen dominate the desert shrub community.

INTRODUCTION

An important part of plant geography deals with the variations in vegetation patterns through time. Understanding the nature of vegetation changes and deducing their causes has been largely dependent on the reconstruction of past plant communities through macrofossil analysis. Palynology, the study of pollen and spores, is one important tool which can be used in the reconstruction of fossil vegetation.

The nature of past vegetation at a given site can be empirically determined by relating the modern pollen distribution to the vegetation community surrounding the site (Davis, 1969; Martin, 1963). Once this relationship is understood, changes in the composition of vegetation communities through time may be deduced from the assemblages of pollen grains preserved in the stratigraphic section.

The problem is to establish spatial variations in the surface pollen distribution as related to the vegetation communities and elevation in the Grand Canyon, Arizona. The results should provide a basis for the evaluation of glacial and postglacial pollen records in the Grand Canyon area. In addition, the results of this study will be compared to other selected modern pollen studies in the Southwest to determine the consistency of elevational and zonal associations.

Several studies comparing the modern pollen distribution with vegetation communities and elevation have been conducted in the Southwest (Adam, 1965; Bent and Wright, 1963; Dixon, 1962; Hevly, 1964; Hevly, Mehringer and Yokum, 1965; Maher, 1963; Martin, 1963; Mehringer, 1967; Potter and Rowley, 1960). Most of these studies were undertaken to establish a modern base for the paleoecological interpretation of fossil pollen data. These studies have described various methods for sampling the modern pollen rain, and all have established some degree of correlation between the surface pollen and the vegetation communities.

The Grand Canyon is an area of high vertical relief (Figure 1) and the vegetation is characterized by a wide variety of ecological responses. The morphology of the Canyon suggests a closed depositional basin for pollen derived from source areas at higher elevations. Nearly all previous modern pollen studies have been conducted in relatively open alluvial areas or along traverses over the slopes of mountain ranges. A modern pollen study has never been conducted across such a unique topographic feature as the Grand Canyon.

Four previous palynological studies have been conducted in the general area of the Grand Canyon (King, 1971; Martin, pers. comm.; Martin, Sabels and Shutler, 1961; Schwartz, Lange and de Saussure, 1958). King's (1971) study consists of a traverse of surface pollen samples collected along the Colorado River from Lee's Ferry to Diamond Creek, a distance of 365 kilometers. The study was initiated to provide background data for interpreting fossil pollen profiles in the Canyon. The results indicate the modern pollen distribution closely correlates with changes in vegetation and geomorphology along the River.

In a study of Tse-an Kaetan Cave in Cremation Canyon, Anderson in Schwartz *et al*. (1958) found a high relative abundance of *Abies* and *Picea* pollen in the cave sediments, but no radiocarbon control is available. The most significant feature of Martin's fossil data is the high frequency of Artemisia in deposits dated around 12,000 years B.P.

Figure 1. The Grand Canyon, Arizona.

THE PHYSICAL SETTING

The Grand Canyon is located in northwestern Arizona approximately 96 kilometers north of the town of Williams, via U.S. Highway 64. The principal area of study is located in the Grand Canyon National Park, from the area commonly known as the South Rim across the Canyon to the North Rim (Figure 2).

Physiography

The Grand Canyon is part of the Colorado Plateau, and is a broad, uplifted asymetrical arch underlain by highly resistant Permian limestones (Strahler, 1944). The Grand Canyon gorge was formed by the erosive action of the Colorado River through thousands of feet of sediment. The Colorado River has dissected the area into two high, flat plateaus: the Kaibab, known as the North Rim, and the Coconino to the south.

The Kaibab Plateau is the higher of the two with an elevation ranging from 2280-2800 meters. The terrain generally consists of rounded valleys of gentle slope not more than 90-120 meters deep.

The Coconino Plateau or South Rim is the southward extension of the Kaibab Plateau and ranges from 1820-2280 meters in elevation. The Plateau is characterized by very

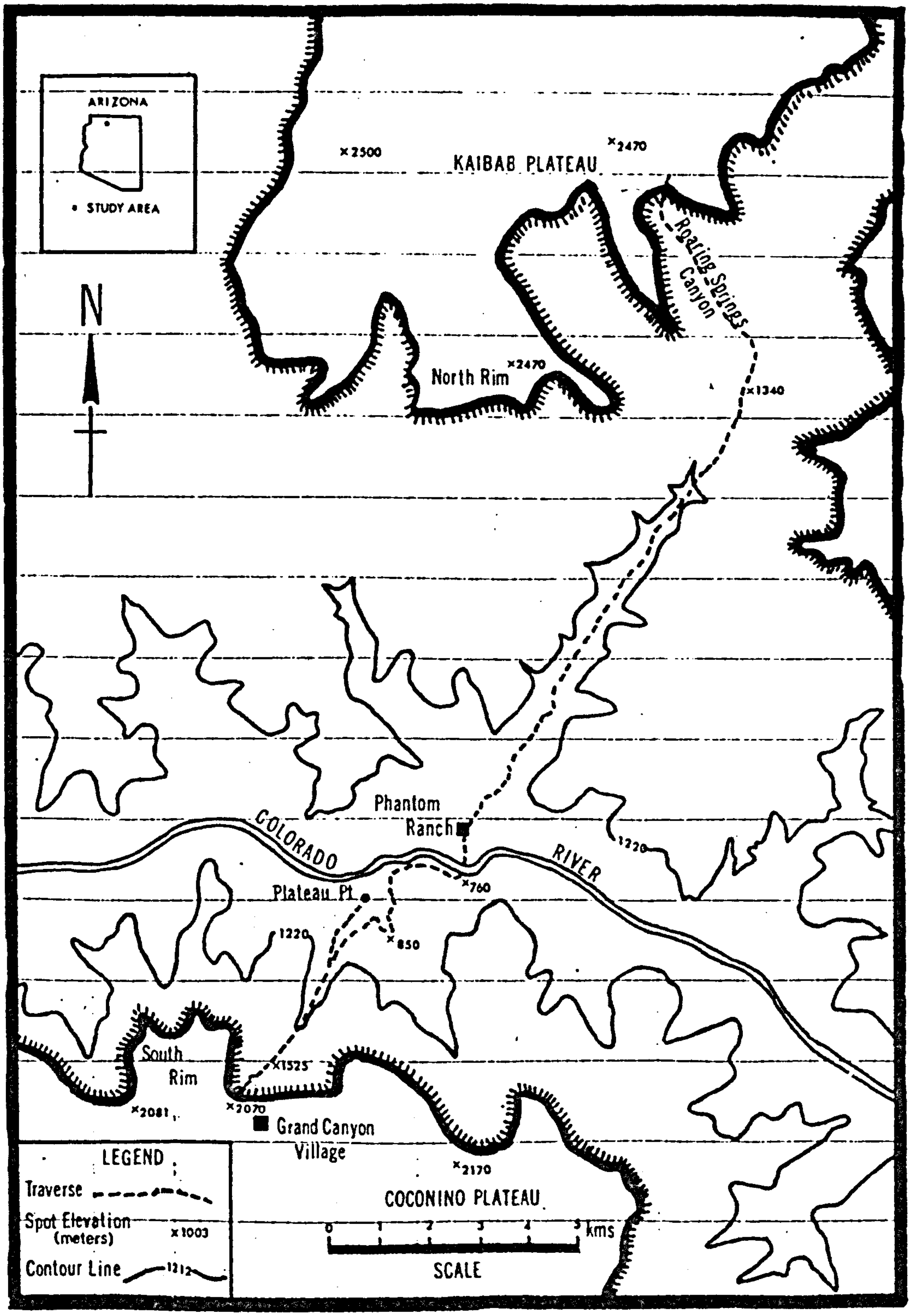

Figure 2. Map of the Study Area.

little relief and a generally southerly slope. The inner canyon is an area of extremely rugged relief characterized by deep narrow canyons and towering erosional remnants. The Canyon itself is asymetrical in form with the North Rim being nearly twice as far from the Colorado River as the South Rim.

In the study area the elevation on the North Rim is about 2530 meters. The South Rim is approximately 2135 meters, and the Colorado River at Phantom Ranch is about 760 meters above sea level. The length of the traverse across the Canyon, via the Bright Angel and North Kaibab trails, is approximately 40 kilometers.

Climate

The average annual precipitation recorded at the Bright Angel Ranger Station on the North Rim is approximately 635 millimeters. Average annual precipitation in the Inner Gorge at Phantom Ranch is about 254 millimeters, and the amount at the Park Headquarters on the South Rim is approximately 406 millimeters (Green and Sellers, 1964; Bennett, 1969).

The greatest amounts of precipitation at the Grand Canyon are generally received during the summer and winter seasons with the spring and fall being relatively dry. Summer precipitation is generally derived from locally intense thundershowers. Winter precipitation is usually related to mid-latitude storm cells. At the rims of the Canyon winter precipitation usually occurs in the form of snow with yearly accumulations of greater than 3.8 meters on the Kaibab Plateau.

A strong temperature gradient exists between the Canyon rims and bottom (Table 1). The average annual temperature on the North Rim is 6.1^{o} C., with temperatures at the bottom averaging 20.6^{o} C. An intermediate value of 9.4^{o} C. is recorded at the South Rim (Green and Sellers, 1964).

Because of the tremendous variation in relief in the Canyon, a straight line temperature-precipitation relationship between the rims and bottom is impossible and estimating intermediate amounts is, at best, hazardous.

Wind information is not available for the Grand Canyon area; however the highest annual velocities for Arizona have been recorded at Prescott, Flagstaff, and Winslow. Flagstaff is the closest recording station to the Grand Canyon with a general prevailing wind direction from the southwest. The frost free periods in the Grand Canyon area, roughly approximating the plant growing season, are 101 days on the North Rim, 331 days in the Inner Canyon, and 148 days on the South Rim (Green and Sellers, 1964).

Table 1. Temperature Data for the Grand Canyon Area.*

	South Rim (Elev. 2100 m)	Phantom Ranch (Elev. 760 m)	North Rim (Elev. 2560 m)
January average	1.7	7.8	3.3
July average	20.6	33.3	16.7
Annual average	9.4	20.6	6.1
Lowest recorded	-28.9	-7.2	-31.7
Highest recorded	36.7	48.9	32.8

*Temperatures are in degrees centigrade. (After Green and Sellers, 1964.)

Vegetation

The plant communities in the Grand Canyon range from spruce-fir forests distributed on the higher slopes of the Kaibab Plateau to a desert shrub community at the lower elevations along the Colorado River. The vegetation communities in this area of the Grand Canyon have been described by several workers (Bennett, 1969; Clover and Jotter, 1944; Martin, n.d.; Merkle, 1952; 1954; 1962; Merriam, 1890; Rand, 1958; Rasmussen, 1941). Nearly all of these studies have been conducted on either the North Rim, the South Rim, or the Canyon bottom. Rand (1958) described the vegetation communities across the Canyon, but her study is too broad for palynological interpretations.

In this study the descriptions of the plant communities in the Grand Canyon are based on the previously published studies, and the author's observation of the vegetation along the trails across the Canyon. The descriptions are by no means a complete list of species and were based on apparent local plant dominance. Nomenclature follows Kearney and Peebles (1960).

With increasing elevation five principal plant communities are recognized: desert shrub community (Bennett, 1969; Clover and Jotter, 1941; Martin, n.d.), juniper shrub savannah, pinyon-juniper woodland (Merkle, 1952), oak woodland, and mixed coniferous forest (Merkle, 1962). Other vegetation communities present in this area of the Canyon, but not directly related to the study, include ponderosa pine parkland present at higher elevations on the Coconino and Kaibab plateaus and a spruce-fir forest distributed above 2650 meters on the North Rim (Merkle, 1954).

The desert shrub community is situated below approximately 1220 meters in the Canyon. The vegetation in this area is characterized by low, woody species of desert shrubs (Martin, n.d.). In general the vegetation is dominated by catclaw acacia (Acacia greggi) and Mormon tea (Ephedra, sp.) which are commonly found distributed together. Both E. nevadensis and E. torreyana are present in the desert community. Yucca (Yucca baileyi) and agave (Agave utahensis) are commonly present with numerous cacti (Opuntia sp.). Other common shrubs include Fallugia paradoxa, Rhus sp., Encelia farinosa, and Atriplex sp. The herbaceous vegetation consists of various grasses, composites, and legumes.

The vegetation on the Tonto Shelf (elev. 1160 meters) on the south side of the Canyon is characterized by an almost pure blackbrush (Coleogyne ramosissima) community with Yucca, catclaw, Ephedra sp., agave and cacti. Riparian communities found along the Colorado River and major tributaries in this area include cottonwood (Populus fremontii), willow (Salix sp.), salt cedar (Tamarix pentandra), desert almond (Prunus fasciculata), and seep willow (Baccharis sp.).

Above the desert shrub community is the juniper shrub savannah, which extends to an approximate upper altitudinal limit of 1525 meters on either side of the Canyon. The community is dominated by two species of juniper (Juniperus utahensis and J. scopulorum). In addition this community is characterized by a heterogeneous mixture of xerophytes reflecting the low soil moisture and high temperatures of this area (Rand, 1958). These plants include hoptree (Ptelea pallida), currant (Ribes inebrians), squawbush (Rhus trilobata) and redbud (Cercis occidentalis) and oak (Quercus sp.). Other shrubs include Fallugia paradoxa, Philadelphus microphyllus, Prunus fasciculata, Gutierrezia sp., Chrysothamnus sp., Ephedra sp., Artemisia sp., Yucca sp., Agave sp., and Opuntia sp. The herbaceous elements in this community are grasses, small composites, legumes, and mallows. Chenopods are locally distributed in disturbance environments along tributary drains.

The pinyon-juniper woodland is distributed between 1675-2185 meters elevation in this area of the Canyon, but it is best developed between 1830-2135 meters. Merkle (1952) placed the altitudinal range of this community between 1980-2225 meters on the Coconino Plateau, but the pinyon-juniper association extends well below the South Rim. This community also occurs in scattered stands on open and south-facing slopes above 2440 meters on the North Rim.

The community is composed of pinyon pine (*Pinus edulis*) and juniper (*Juniperus* sp.) with varying amounts of gambel oak (*Quercus gambelii*). Subdominant shrubs consist of *Chrysothamnus* sp., fernbush (*Chamaebatiaria millefolium*), and *Gutierrezia* sp. (Merkle, 1952). Other shrubs present in this community include *Ephedra viridis*, cliffrose (*Cowania mexicana*), sagebrush (*Artemisia tridentata*), and *Opuntia* sp. The herbaceous vegetation consists primarily of grasses and small composites. Below the rims of the Canyon other important elements of the pinyon-juniper community are manzanita (*Arctostaphylos* sp.), mountain mahogany (*Cercocarpus* sp.), currant, mahonia (*Berberis fremontii*), rose (*Rosa* sp.) and buckbrush (*Ceanothus* sp.). Douglas fir (*Pseudotsuga taxifolia*) is locally distributed below the rims on mesic, north-facing slopes.

A ponderosa pine (*Pinus ponderosa*) community is distributed above 2135 meters on the South Rim and in scattered locations on the North Rim. Merkle (1962) has divided the community into two units: ponderosa pine-sagebrush community and ponderosa pine-grassland.

An oak woodland largely replaces the pinyon-juniper association in Roaring Springs Canyon on the north side of the Canyon. This community has an altitudinal range between 1525-2130 meters in this canyon. The oak woodland is a response to apparently more mesic conditions due to cold air drainage in this narrow, northwest trending canyon. The vegetation is characterized by dense stands of gambel oak with varying amounts of hop-hornbeam (Ostrya knowltoni) and New Mexico locust (Robinia neomexicana). Other shrubs in this association include silktassel (Garryea flavescens), buckbrush, cliffrose, Rosa sp., and mahonia. Pinyon pine and juniper are locally present in this community but are most abundant at lower elevations and on more zeric south-facing slopes. Ponderosa pine and Douglas fir are locally present in the oak woodland, and generally confined to north-facing slopes above 2130 meters elevation. The herbaceous vegetation in the oak woodland consists of abundant grasses and numerous small compositae.

Above 2880 meters elevation in Roaring Springs Canyon is a mixed coniferous forest of ponderosa pine, white fir (Abies concolor), Douglas fir, and aspen (Populus tremuloides).

The mixed coniferous forest occurs in mesic localities on the North Rim, but is less widely distributed than the spruce-fir forests which are present at the higher elevations. Other important woody plants in the mixed coniferous forest include minor amounts of gambel oak and New Mexico locust, pygmy juniper (J. communis), hop-hornbeam, and cliffrose. The herbaceous vegetation consists primarily of grass, small composites and forbs.

METHODOLOGY

Localities and Sampling Procedure

Modern pollen samples in the Southwest have been collected from lake sediments, cave fills, moss polsters, atmospheric pollen samplers, and the sediment from cattle tanks. Most of these methods are inapplicable in the Grand Canyon, and surface soil samples were selected. These samples were used to determine the relation between the modern pollen distribution to vegetation communities and elevation. The field work was conducted during June, 1970; the laboratory processing and analysis were done during the following fall and winter.

Twenty-five surface soil samples were collected along a traverse originating on the South Rim near Grand Canyon Village and terminating on the North Rim near Bright Angel Point. The traverse roughly follows the trace of the Bright Angel fault. All sampling locations were reached via the Bright Angel and North Kaibab trails. Supplementary surface soil samples were collected at two sites on the Kaibab and Coconino Plateaus, some distance from the rims of the Canyon.

The soil surface samples within the Canyon were collected at vertical intervals of approximately 150 meters. The elevation intervals were determined by means of a

U.S.G.S. topographic map at a scale of 1:62,500, and checked against a pocket altimeter. The sites were selected some distance from the trails to avoid any cultural disturbance in the plant communities and in the surface pollen represented. Samples were also collected from areas of exposed ground in an attempt to assess the significance of long distance transport.

To avoid any gross over-representation of a particular pollen species at a site, the surface soil samples were collected using a modified version of the multiple subsample technique (Hevly, Mehringer, and Yokum, 1965). This method consisted of collecting 10-20 subsamples of surface soil at some interval (5-10 paces), in an area 30-40 meters square. Each subsample consisted of a pinch of surface sediment placed in a clean plastic bag and thoroughly mixed with the other subsamples collected from the site. The above collecting procedure could not always be regidly adhered to, as the number of subsamples, sampling interval, and site area varied due to precipitous conditions in the local terrain.

The general composition of the local dominant vegetation was noted at each site, and unknown plant species were collected and later identified. No attempt was made to classify the local vegetation by any phytosociological parameters. Slope was measured at each site by means of a clinometer, and other site features such as location, exposure, and general soil characteristics were noted.

Pollen Extraction

The extraction of the surface soil samples was done at the Laboratory of Paleoenvironmental Studies of the Department of Geosciences, University of Arizona. The extraction procedure utilized generally followed the standard HCL and HF digestion technique used for alluvial sediments (Martin et al., 1961; Mehringer, 1967). This process removes carbonates, silicates, and other inorganic material from the surface samples. Acetolysis was used to remove non-resistant organic material from the samples (Erdtman, 1943). Following the extraction procedure a drop of the relatively pure pollen matrix was mounted in glycerine and basic fuchin stain on a glass slide. The excess pollen residue derived from the extraction was placed in glass vials and stored. Table 2 shows the complete sequence utilized in the extraction procedure.

Pollen Analysis

The pollen recovered were identified and tabulated using a Zeiss binocular microscope at 640X. The more difficult identifications were made under anisole oil immersion. Pollen identifications were made at the generic level wherever possible, however generic pollen determinations of many of the plant families in the Southwest are not

Table 2. Extraction Procedure for Southwestern Alluvial Pollen Samples.*

Approx. 50 g. of sediment
HCL swirl, 750 ml. beaker
#100 mesh brass screen
HCL swirl, 250 ml. beaker
transfer to test tube
10-15% HCL
25-30% HCL
H_2O wash
50% HF, 24 hour stand
70% HF, 24 hour stand
70% HF, 30 minutes in boiling H_2O bath
2 boiling H_2O washes
20% HNO_3, 10 minutes stand
2 boiling H_2O washes
Acetolysis
2 boiling H_2O washes
conc. HCL (37%), 2 minutes in boiling H_2O bath
2 boiling H_2O washes
5-7% NAOH, 2-3 minutes in boiling H_2O bath
H_2O washes until decant is clear
transfer to vial
mount on slides

*After Mehringer, 1967.

possible. No attempt was made to identify the pollen types of *Pinus*, *Juniperus*, and *Quercus* past the generic level.

"Cheno-ams" refer to various genera in the family Chenopodiaceae indistinguishable from the genus *Amaranthus* of Amaranthaceae. Grass pollen was not identified below the family level. The pollen of the subfamilies Liguliflorae and Tubiflorae in the Compositae are morphologically distinct, and the latter subfamily was divided into two artificial pollen types: high- and low-spine Compositae (Hevly, Mehringer, and Yokum, 1965).

Low-spine Compositae are generally wind-pollinated and include members of the tribe Ambrosieae, while the high-spine Compositae are generally insect-pollinated and include such genera as *Encelia*, *Zinnia*, and *Helianthus*. The pollen of the genus *Artemisia* is distinct from that of the Compositae.

The pollen of *Ephedra* was separated into two artificial groupings: *E. torreyana*- and *E. nevadensis*-type as proposed by Martin (1963) and Hevly *et al.* (1965). In the Grand Canyon the *E. torreyana*-type contains only that species while the *nevadensis*-type includes both *E. viridis* and *E. nevadensis*.

Two hundred pollen grains were counted on each slide. No pollen types observed were excluded from the sum. Pollen counts of each site were plotted in an attempt to illustrate the relationship of the modern pollen to the vegetation communities and elevation along the traverse (Figure 3). The relative frequency of the pollen types recovered are presented in Appendix 1.

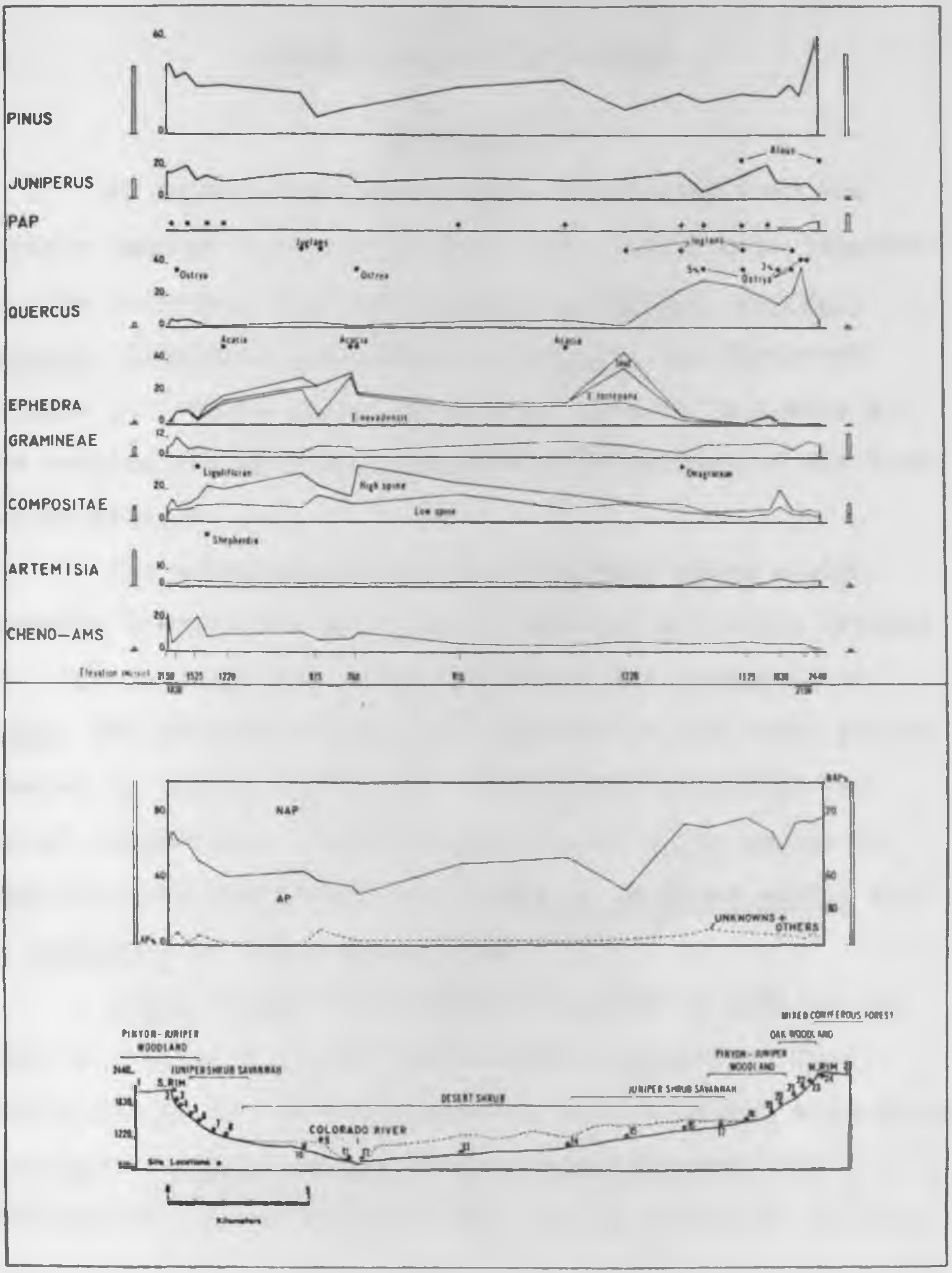

Figure 3. Modern Pollen Spectra of the Grand Canyon, Arizona.

MODERN POLLEN DISTRIBUTION

Analysis

Of thirty-five pollen types identified from the surface samples collected in the Grand Canyon area (Appendix 1), the principal ones are: *Pinus*, *Juniperus*, *Quercus*, *Ephedra*, Graminae, Compositae, *Artemisia*, and Cheno-ams (Figure 3). These pollen types were present in nearly all the samples and accounted for nearly 90 percent of the total pollen present.

The arboreal pollen (AP) frequency shows a high positive correlation when plotted against elevation (Figure 4). The AP frequency largely reflects the abundance of *Pinus*, and generally exceeds 60 percent of the total pollen present in samples collected in woodland, parkland, and forest communities. High frequencies of *Pinus* appear to coincide with the general distribution of *Pinus edulis* and *P. ponderosa* in these communities.

Pinus is well represented (10-34%) in most of the samples collected in the desert shrub community. This effect points to the importance of long distance, wind blown transport of *Pinus* pollen, and strongly suggests the presence of relatively poor local pollen producers in this community.

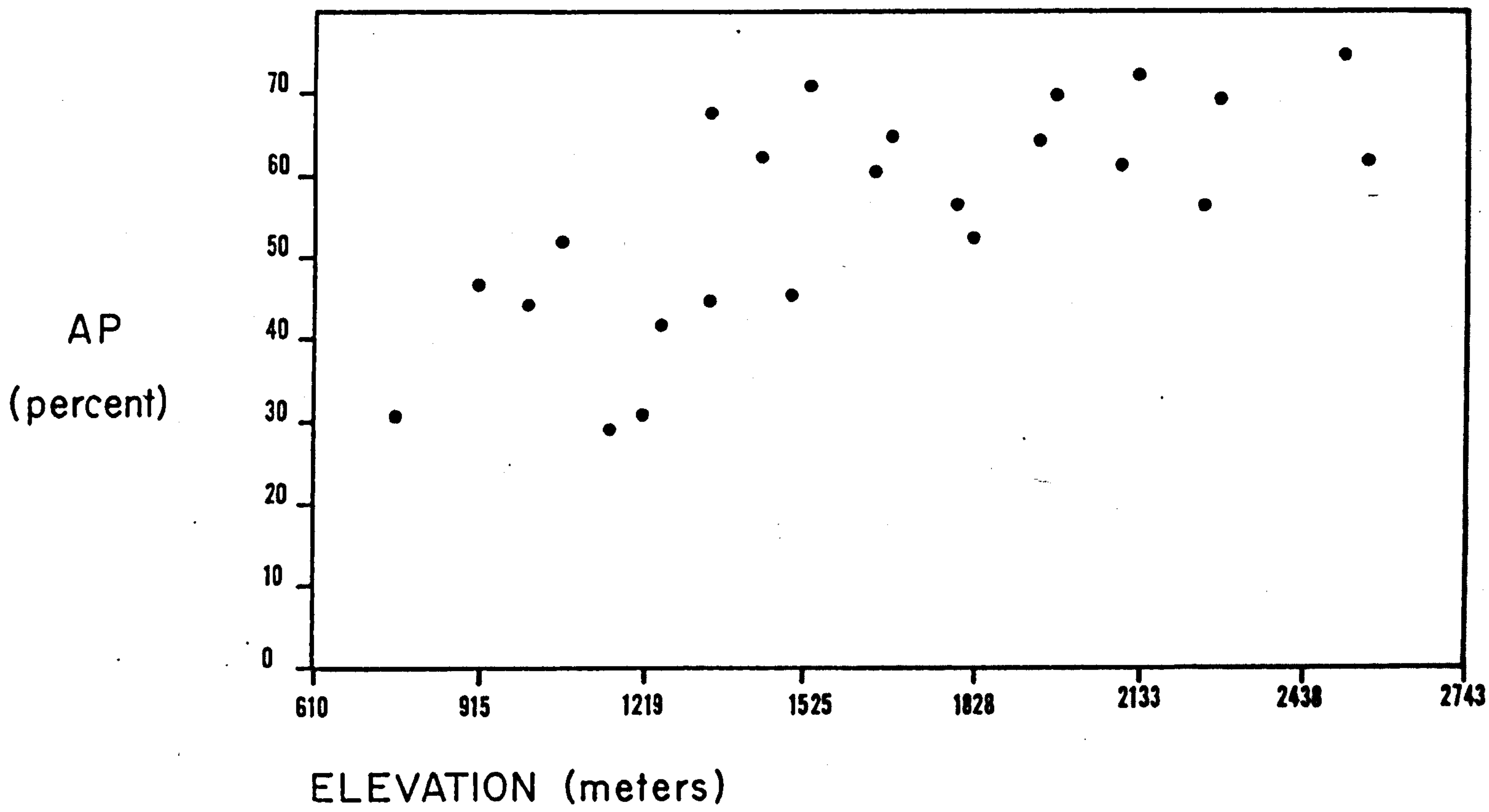

Figure 4. Relationship of Arboreal Pollen Frequency to Elevation.

The lowest percentage of _Pinus_ (10%, N = 400) was found in the sample collected at Plateau Point at an elevation of 1160 meters on the south side of the Canyon. The _Pinus_ values obtained from surface samples collected approximately 150 meters above and below this site averaged about 27 percent. The relatively sharp decrease of _Pinus_ at Plateau Point may possibly be explained by the topographic position of the site or in terms of local vegetation characteristics.

Plateau Point, on the Tonto Shelf, overlooks the steep escarpment of the Inner Gorge of the Colorado River. The Tonto Shelf is a narrow surface of relatively little relief occasionally cut by side canyons leading into the inner canyon.

The general physical features of the Plateau suggest the possibility of differential heating between the areas of exposed flat surfaces and the side canyons. If this effect were present, convectional updrafts would result over much of the Shelf during the day. Cold air drainage during the night would be directed down the side canyons and away from the exposed surfaces. Because _Pinus_ pollen is highly bouyant and subject to wind transport, the deposition of _Pinus_ at Plateau Point may be significantly reduced by adverse wind patterns. In addition the deposition of _Pinus_ may be affected through the exposed nature of the Point with respect to strong inner canyon winds.

The vegetation at Plateau Point is characterized by a relatively closed community of blackbrush, with *Ephedra torreyana*, *Yucca* sp., and other elements of the desert shrub community. The large population of exclusively non-arboreal pollen producers may be controlling the relative abundance of *Pinus* drifting in from the upper slopes and rims. The relative frequency of NAP is high (61.4%), and most of these types are relatively less bouyant or are insect-pollinated. The aerodynamics of these pollen types, combined with the low slope declivity of the site, and the closed nature of the vegetation may retard both wind transport and slope wash movement of the local non-arboreal pollen types from the area.

Several factors or combinations of factors appear to be limiting the frequency of *Pinus* on Plateau Point. Future studies in either this area of the Canyon, or in areas of similar geographic nature may profit by utilizing absolute pollen frequencies or employing closer spaced sampling procedures.

Other coniferous pollen sporadically present in the surface samples include *Picea*, *Abies*, and *Pseudotsuga* (PAP). These types were grouped because their combined relative abundance generally never exceeded 1 percent of the total pollen present. *Pseudotsuga* had the most limited distribution, and was found only at the site collected at 1950 meters on the south side and between 1980-2515 meters on the north side. The distribution of this large, heavy pollen type tends to reflect the local occurrence of Pseudotsuga taxifolia on the more mesic north-facing slopes of both rims. The presence of a single Picea pollen grain recovered in a sample collected near the Colorado River and the isolated occurrences of Abies pollen in the desert shrub community further demonstrate long distance, wind transport in the Canyon. The highest frequencies of PAP pollen were found distributed in and directly below the mixed coniferous forest community reflecting the nearness and composition of this community.

The highest frequencies of oak pollen were found distributed above 1525 meters elevation in the pinyon-juniper woodland on the south side of the Canyon, and between 1220-2130 meters on the north side. Small amounts of Quercus (app. 5%) in the pinyon-juniper woodland suggest the presence of Quercus gambelli, which is a subdominant element in this community. High frequencies of oak pollen (up to 38%) on the north side apparently reflect the increasing presence of generally closed stands of Q. gambelli and its hybrids in the narrowing, more mesic, northwest trending Roaring Springs Canyon. In this canyon the relative abundance of oak pollen sharply declines near the ecotone between oak woodland and the mixed coniferous forest.

A sharp decrease in Quercus pollen, accompanied by an abrupt increase in the relative abundance of high-spine Compositae, occurs at 1830 meters elevation in Roaring Springs Canyon. The sample was collected in a relatively open pinyon-oak association distributed on a southwest-facing slope. The pollen and vegetation data at this site suggest that the more xeric slope exposure may be influencing the relative frequency of local non-arboreal pollen producers.

The presence of up to 5 percent Ostrya pollen in the oak woodland suggests the presence of Ostrya knowltoni which is a local subdominant in this community. Five Juglans (walnut) pollen grains were found in samples collected between 1220-1980 meters elevation on the north side of the Canyon. These pollen grains are of interest as the closest known source area for this type is located in Havasu Canyon approximately 65 kilometers west of the deposition area (MacDougall, 1947). Its occurrence here may indicate a local source somewhere on the north side of the Canyon.

The distribution of Juniperus is somewhat uniform throughout the surface samples. In general Juniperus reaches its maximum abundance in the pinyon-juniper woodland and juniper shrub savannah communities. Because of the difficulties encountered in the identification of juniper pollen, the distribution and relative frequency of this type may be somewhat unreliable.

The pollen recovered from the samples collected in the desert shrub community is largely dominated by non-arboreal species. The principal types found in this area are *Ephedra* and Compositae pollen. The distributions of these types seem to reflect closely the plant species present at lower elevations.

The highest frequencies of *Ephedra torreyana*-type occur in the samples collected at Plateau Point on the south side of the Canyon, and at 1200 meters elevation on the north side. The abundance of *E. torreyana*-type is low for most samples collected in the desert shrub community, and is present in trace amounts above 1500 meters on both sides of the Canyon. The distribution of *E. nevadensis*-type is more consistent, gradually increasing in abundance with decreasing elevation from the rims.

The presence of four acacia polyads in samples distributed in the desert shrub community reflects the occurrence of *Acacia greggi*. Cat claw acacia is insect pollinated, and produces large, heavy polyads which have a limited distribution.

Low-spine Compositae pollen is evenly distributed throughout the traverse with the highest frequencies found in the desert shrub community. Changes in the relative abundance of this type may reflect variations in the abundance of *Franseria* sp. The frequency of high-spine Compositae is greatest in samples collected adjacent to the Colorado River, and decreases with increasing elevation. The abundance of high-spine Compositae pollen near the River is probably related to the local distribution of *Encelia farinosa*, *Brickellia* sp., and *Baccharis* sp. in this area. High-spine Compositae pollen on the upper slopes of the Canyon appears to be related to the prevalence of *Chrysothamnus* sp. and *Gutierrezia* sp., both subdominants in the juniper shrub savannah and the pinyon-juniper woodland.

The pollen of Gramineae, Cheno-ams, and *Artemisia* is characterized by relatively low frequencies generally uniformly distributed throughout most of the samples. Gramineae pollen is more abundant near the rims of the Canyon and, surprisingly, in the desert shrub community. This distribution suggests abundance of grass present on the cooler, more mesic upper slopes. The higher frequencies of Gramineae in the desert shrub community may point to the relatively poor local pollen production of many of the desert species.

An abundance of Cheno-am pollen was noted at 1493 meters on the south side of the Canyon. This sampling site was collected near a small floodplain of Garden Creek, and apparently reflects the disturbed nature of the site.

The relative frequency of *Artemisia* pollen never exceeded 5 percent abundance in the samples collected in the

Canyon, but increased to nearly 23 percent on the Coconino Plateau in a ponderosa pine-sagebrush community. These data seem to suggest a relatively limited dispersion for *Artemisia* pollen in the Canyon.

Consistency of the Data

The results of the present study are compared below with other selected surface pollen studies in the Southwest to determine the general trends of findings. The studies selected for comparison with the Grand Canyon data were chosen from their similar elevational and zonal relationships.

In a study of southeastern Arizona, Martin (1963) indicated the frequency of arboreal pollen increases in woodland and parkland localities, and non-arboreal and herbaceous pollen generally dominated the lower shrub and grassland communities. The frequency of *Pinus* was highest in samples collected above 1800 meters elevation. High frequencies of *Pinus* from desert areas reflected regional mixing from the montane forest sources, and suggested the poor local pollen production of many desert species. The lower desert areas were generally characterized by high frequencies of Cheno-ams and high- and low-spine Compositae pollen.

In a study of the Las Vegas Valley, Mehringer (1967) found a close geographic correlation between the modern pollen composition and the local vegetation communities. The study indicated desert areas were largely dominated by both low-spine Compositae and Cheno-am pollen. The presence of *Pinus* was significant in desert areas and was interpreted by Mehringer to be the result of the sparse vegetation cover and locally poor pollen producers.

Woodland communities were dominated by high *Pinus*, *Juniperus*, and *Artemisia* values closely reflecting the distribution of these plants.

In Hevly's study (1964) in northeastern Arizona, the modern plant communities were characterized by a succession of pollen types with an increasing relative abundance of arboreal pollen with elevation. Woodland, parkland, and forest communities were sharply separated from the lower elevation communities by more than 50 percent arboreal pollen. The forest and woodland communities were characterized by between 50-80 percent *Pinus* pollen with varying amounts of *Abies*, *Picea*, *Pseudotsuga*, and *Quercus* pollen. Below the woodland areas Cheno-am and Compositae pollen increased in abundance in the grassland and desert communities. Graminae pollen was more abundant in the desert areas than in the grasslands, and Hevly suggested this was probably due to the poor local production of the desert species.

The relationship of the surface pollen to vegetation communities and elevation in the Grand Canyon area appears to be in general agreement with the results of the above studies. The abundance of arboreal pollen types in forest and woodland communities closely compares with those found in the other areas. The distribution of non-arboreal pollen types in the study area appears to be related to local distributions of plants in the Canyon. Compared with the other studies, the most significant anomaly in the Grand Canyon data is the low frequency of Cheno-ams in the desert shrub community. This effect may point to an actual lower abundance of these plants growing in the area due to unfavorable habitats.

SUMMARY AND CONCLUSIONS

The modern pollen distribution in the Grand Canyon suggests a close geographic relationship between the vegetation communities and elevation despite the local overrepresentation of coniferous pollen, especially *Pinus*, in the desert areas. Relatively high frequencies of arboreal pollen (50-70%), mainly *Pinus*, dominate the surface samples collected in woodland and forest communities. The presence of oak pollen between 5-15 percent in the woodland samples suggests the close proximity of *Quercus gambelii*. Higher frequencies of *Quercus* pollen appear to characterize a relatively closed oak woodland. Sporadic occurrences of *Picea* and *Abies* pollen in the desert samples suggest wind transport, but the highest frequencies of these types occur in and near the mixed coniferous borders.

The juniper shrub savannah community appears to be characterized by somewhat variable frequencies of *Juniperus* pollen and high frequencies of high-spine Compositae pollen. The lower desert shrub community is dominated by the high relative abundance of *Ephedra* and Compositae pollen. Variations in the abundance of Compositae pollen appears to indicate local changes in the vegetation associations.

Pinus appears to be significantly overrepresented in most of the samples collected from the desert areas. This effect may point to the presence of locally poor pollen producers in the area, and suggests the lower canyon is acting as a huge depositional trap for arboreal pollen drifting in from sources on the upper slopes and rims.

The occurrence and distribution of Acacia polyads in the surface samples suggests this pollen type is a relatively good indicator of the desert communities, a feature not reported by Martin (1963) or Hevly et al. (1965) in southern Arizona.

Sharp variations occurring within relatively homogeneous pollen zones appear to suggest local differences in pollen production related to slope exposure and the topographic position of the site.

While it presents unusual opportunity for atmospheric mixing of pollen, the Grand Canyon study shows a pattern of change with elevation in accord with other modern pollen studies made across similar vegetation communities in the Southwest. Major variations in the relative pollen counts appear to be due to local compositional differences in the plant communities.

The pollen data in the Canyon suggest the wind-pollinated type, Artemisia, is especially limited in dispersion. The high frequencies of this pollen type in pre-12,000 B.P. deposits at Ramparts and Stanton caves suggest Artemisia was growing in abundance at these sites.

APPENDIX 1

MODERN POLLEN FREQUENCIES IN THE GRAND CANYON, ARIZONA

Site No.	Vegetation	Elevation (meters)	Slope	Exposure	Pinus	Picea	Abies
	Park Entrance Sta.						
1	Ponderosa-Sagebrush	2255	0^o	Open	42.0		
	South Rim						
2	Pinyon-Juniper	2103	0^o	Open	43.0		
3	Pinyon-Juniper	1950	40^o	NW	43.0		
4	Pinyon-Juniper	1798	45^o	NW	35.0		
5	Ecotone	1645	50^o	N	38.0		.5
6	Juniper Shrub Savannah	1493	20^o	N	29.5		
7	Juniper Shrub Savannah	1340	25^o	W	29.5		
8	Ecotone	1250	0^o	Open	30.0		
	Plateau Pt.						
9	Desert Shrub	1160	0^o	Open	10.0		
10	Desert Shrub	1005	35^o	NE	25.5		
11	Desert Shrub	777	35^o	S	16.0		
12	Desert Shrub	762	10^o	S	16.5		
13	Desert Shrub	915	40^o	N	29.0		

Site No.	Pseudosuga	Juniperus	Quercus	Ephedra torr.	Ephedra nev.	Ephedra undif.	Salix	Rhamnaceae	Berberis ?	Betulaceae
1		12.0	2.5		1.0					
2		17.0	1.0			.5				
3	.5	16.0	4.5	.5	1.5			1.5	.5	
4		17.0	4.0		6.5					
5		20.5	5.0	.5	6.0	2.0				.5
6		11.0	3.5	.5	3.0		.5			
7		14.0	1.0	1.0	6.5	4.0				
8		10.0	1.0	2.0	12.5	3.5				
9		15.0	3.3	18.3	5.5					
10		15.5	3.0	1.5	21.5	5.5				
11		13.5	1.5	2.0	29.5					
12		10.0	1.5	.5	19.0					.5
13		13.0	4.0	2.0	11.0					

Site No.	Fraxinus	Juglans	Acacia	Populus	Alnus	Acer	Saxifragaceae	Gramineae	HS Compositae	LS Compositae	Artemisia
1								6.0	2.0	6.5	22.5
2								5.0	4.0	4.0	.5
3								6.5	6.0	6.5	.5
4								12.0	1.5	7.0	1.0
5								5.5	3.0	7.5	4.0
6								6.0	4.5	9.5	3.0
7								5.5	12.0	10.0	3.5
8			1.0					3.5	9.5	10.5	2.5
9	.25	.25						6.3	6.0	16.0	2.3
10		.5						3.0	21.5	8.5	2.0
11			1.5					6.0	4.0	10.5	2.0
12			.5					3.5	24.0	10.5	2.0
13								6.5	7.5	16.5	2.5

Site No.	Cheno-am	Liguliflorae	Eriogonum	Umbelliferae	Polygonaceae	Polemoniaceae	Opuntia	Shepherdia	Onagraceae	Yucca
1	2.0		2.0	.5						
2	22.5		.5	1.0						
3	5.0		1.0		3.5					
4	7.5			1.0						
5	3.5			1.5	.5					
6	21.0	.5			1.0					
7	9.0		1.0					.5		
8	11.0						.5			
9	7.5									
10	12.0				.5					
11	8.0			.5						
12	7.5									
13	4.5									

Site No.	Nyctaginaceae	AP	NAP	Unknowns etc.
1		56.5	41.5	4.0
2		61.0	38.5	.5
3		64.0	30.5	5.5
4		56.0	36.6	7.5
5		60.0	39.0	1.0
6		45.0	48.0	6.0
7		44.5	52.0	3.5
8		41.5	58.0	.5
9		28.8	61.4	9.8
10		44.0	55.5	.5
11		32.5	64.0	3.5
12		28.5	68.8	3.0
13	.5	46.5	50.5	3.0

Site No.	Vegetation	Elevation Meters	Slope	Exposure	Pinus	Picea	Abies
14	Desert Shrub	1067	5^o	W	34.0	.5	
15	Desert Shrub	1220	0^o	W	15.5		
16	Ecotone	1340	10^o	W	26.0		
	Roaring Springs						
17	Mesic Community	1432	20^o	SW	20.0		.5
18	Pinyon-Juniper Oak Woodland	1525	35^o	E	25.0		
19	Ecotone	1676	40^o	E	24.0		
20	Oak Woodland	1830	30^o	SW	23.5		1.5
21	Oak Woodland	1980	50^o	E	31.0		.5
22	Oak Woodland	2135	50^o	SE	22.0		.5
23	Ecotone	2286	35^o	SE	37.0	.5	1.5
	North Rim						
24	Mixed Coniferous Forest	2515	0^o	Open	61.0	3.0	2.5
	Meadow, Kaibab Plateau						
25	Spruce-Fir Forest	2560	0^o	Open	50.0	4.0	6.5

Site No.	Pseudotsuga	Juniperus	Quercus	Ephedra Torr.	Ephedra nev.	Ephedra undif.	Salix	Rhamnaceae	Berberis ?
14		11.0	4.5	1.5	12.0		1.0		
15		12.5	1.5	20.5	14.5	10.0	1.0		
16		17.0	23.5	2.0	3.0			1.0	
17		4.5	31.5	.5	2.0				
18		14.0	25.0		1.0		1.5		
19		21.5	17.0	.5	5.0				
20		10.0	14.0		1.5				
21	1.5	9.5	21.0		1.0				
22	1.0	9.0	38.0		.5				
23	3.0	10.0	16.0		1.0			1.5	
24	.5	3.5	25.0	.5	.5		.5		
25	.5	2.0	2.0	.5					

Site No.	Betulaceae	Fraxinus	Juglans	Acacia	Populus	Alnus	Acer	Saxifragaceae	Gramineae
14				1.0					10.0
15			.5		.5				7.5
16			.5		1.0				2.5
17	5.0				.5				8.5
18	1.0		1.0		.5	1.5	1.0		8.0
19					.5				8.5
20	3.0				.5		.5		8.0
21	3.5	1.0	.5						5.5
22	.5				1.0				8.0
23	.5					.5		.5	10.0
24					1.5	1.0			8.0
25					.5				15.0

Site No.	HS Compositae	LS Compositae	Artemisia	Cheno-am	Liguliflorae	Eriogonum	Umbelliferae	Polygonaceae	Polemoniaceae	Opuntia
14	9.0	8.0	2.5	3.5			.5			
15	1.0	10.5	.5	6.0			1.0			
16	5.0	6.0	1.0	5.5			1.5	.5		.5
17	2.0	4.5	5.0	5.0			.5	.5		
18	3.5	3.0	.5	6.0			.5	1.0		
19	3.0	5.0	3.0	5.0			.5			
20	10.5	9.5	5.0	5.0			1.0	1.0		
21	2.0	5.5	2.5	4.5				2.0		
22	1.5	4.5	3.0	5.0				1.0		
23	3.0	5.0	3.5	2.5			1.0			
24	2.0	3.5	4.0	1.5			.5		.5	
25	6.0	5.0	1.5	1.5				1.0	1.0	

Site No.	Shepherdia	Onograceae	Yucca	AP	NAP	Unknowns etc.
14				51.5	46.5	2.0
15			.5	30.5	67.0	2.5
16		.5		67.5	26.5	6.0
17				62.0	28.5	9.5
18				70.5	22.0	7.5
19				64.5	31.5	4.0
20				52.0	42.0	6.0
21				69.5	25.0	5.5
22				72.0	24.0	4.0
23				69.0	22.5	6.5
24				75.5	20.5	4.0
25				61.5	37.5	1.0

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