THE CLIMATES OF UNKAR DELTA AND SOUTH RIM, GRAND CANYON, ARIZONA, 1967
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The Climates of Unkar Delta and South Rim, Grand Canyon, Arizona

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Objective: This preliminary report attempts to relate the Unkar Delta, North Rim and South Rim climates. The climatic relations, present Grand Canyon plant ecology and palynological evidence allow for a reconstruction of 12th Century climate conditions.

Methods: The data of the modern climate has been derived from weather observations. These data were gathered from stations at Grand Canyon Village, North Rim Headquarters, Lees Ferry, Phantom Ranch and Unkar Delta.

The statistical reliability of each station varies in accordance with their respective lengths of record:

South Rim:	60 years
North Rim:	12 years
Lees Ferry:	40 years
Phantom Ranch:	12 years
Unkar Delta:	less than 1 year

All stations except Unkar are a part of the regular U.S. Weather Bureau net in Arizona. Unfortunately, only the South Rim and Lees Ferry stations have long enough records to be treated statistically (1). The South Rim, Lees Ferry and Phantom Ranch stations are operated on a year around basis, the other two are not.

Because only a partial record is available from Unkar Delta, a satisfactory correlation with a long established station was necessary to construct a year long climate for Unkar Delta. Coefficients of correlation for temperature, relative humidity, and precipitation were calculated between Unkar Delta and various

Weather Bureau stations.

Coefficients of Correlation for
Arithmetic Mean Temperatures

Unkar vs. Lees Ferry	r = 0.801	D = 64.2
Unkar vs. South Rim	r = 0.666	D = 44.4
Unkar vs. Phantom Ranch	r = 0.409	D = 16.7

Lees Ferry data offered the best fit and was used throughout the calculations for the extension of the Unkar Delta data beyond the short period of observation (May 20 through June 19, 1967). The low correlation between Phantom Ranch and Unkar Delta serves to point out the well known vagarities of Southwestern climates.

Similar calculations were made for humidity and mean daily temperature derived by integration of areas under hygrothermograph curves, and precipitation. In all cases the coefficient of correlation was so low as to be meaningless. Lacking other choice, I have used the Lees Ferry data for precipitation and relative humidity directly and with reluctance. There may be significant errors in the Unkar projections as a result, even though these data seem to be in fair agreement.

Relative humidities from the Lees Ferry data have been converted to vapor pressure deficits (VPD) using projected Unkar temperatures. The absolute humidities of Lees Ferry and Unkar Delta should be quite similar, differing only in temperature. The resultant VPD's have been used to calculate the evaporation rate at Unkar (See Table 1.).

The hygrothermograph data taken at Unkar in the Summer of 1967 was put to good use in determining the true mean values of temperature and humidity. Even a brief look at the charts will show that the means derived from the maxima and minima do not bear a close relationship to the means derived by integrating the areas under the hygrothermograph curves. The coefficient of correlation between the arithmetic means for temperature and the integrated means from the hygrothermograph curves was found to be only 0.418 (D = 17.5). In other words, only 17.5% of the record was influenced by common factors. Lack of such records at Lees Ferry prevents an attempt at correlation between Unkar and that station.

These integrated means are given in Table 2. They are usually lower than the arithmetic means indicating that the maxima occur as sharp peaks, skewing the results upward.

Using the correlation of temperatures between the 1967 Unkar data and that published for Lees Ferry (2), curve-fitting equations were derived for the mean arithmetic maxima, minima, and means for temperature. The equations derived were used to project the observed Unkar temperatures for the entire year. The results from the maximum and minimum equations were found to contain systematic errors such that they did not equal the results derived from the equation for the mean temperatures. Corrections were applied and the results given in Table 3 are correct and accurate. This systematic error was no doubt introduced because of the necessarily short period of observation at Unkar Delta, giving rise to a large 'moment of torque'. This difficulty can probably be cleared up through increased observation in the future.

<u>The 1967 Data</u>: The data was not split by month, contrary to the usual practice, rather it was treated as an entire unit. Thus a larger number of observations could be included in a reporting unit giving greatly improved statistical reliability.

By calculation (from Lees Ferry data), the mean Unkar temperatures were 4.4° F. cooler than normal during the May-June observation period. A discrepancy of this magnitude has an 85% chance of occurrence (3). This is large enough not to seriously effect the conclusions drawn from the data since the normal dispersion is great.

Rainfall during this period was also atypical. There were 600% more occurrences and about 60% more quantitatively than normal. The same comments apply to abnormal rainfall as to temperatures. Rainfall is typically very unpredictable in the Southwest.

The Unkar arithmetic mean temperature was well on the way toward the predicted July high of 92.2° F. The May-June mean was 78.2° F., about equal to that at Tucson. The integrated mean for this period was 75.2° F., 3.0° cooler.

The moisture evaporated from the river and carried by the prevailing south-westerly winds over the Delta modified to a great extent the VPD normally expected in a desert area. This river evaporation together with the unexpectedly large modifications caused by the precipitation (See Fig. 1.) cause a much better (lower) VPD than would normally be expected and a consequent improvement of growing conditions for plants. The mean Unkar VPD was only 0.613 in. Hg compared to 0.65 in. Hg which was the minimum for the same period at Tucson. The Tucson mean would therefore be higher than the Unkar Mean. This indicates more desirable evapotranspiration at Unkar than Tucson, a good agricultural area.

Similar temperature and precipitation deviations from normal were found on the South Rim of Grand Canyon. Temperatures were 4.5° below normal and rainfall was higher. The predicted precipitation was 0.53 in., 1.33 in. fell instead (251% above normal). There were four incidents of more than 0.10 in. (266% above normal).

The North Rim data is not available at this time and will be included in a future report.

Long Term Data: The May-June Unkar data for temperature was correlated with the Lees Ferry data and a straight line fitted to the correlation. A single equation was calculated

$$(Y = 0.846X + 9.63;\ Y = \text{Lees Ferry},\ X = \text{Unkar Delta})$$

to extend the correlation through the remaining ten months of the year. The Lees Ferry data was taken from Arizona Climate (4). See Fig. 3

Although the coefficient of correlation for the above data was acceptable ($r = 0.801$) and the standard error of estimate was only $\pm$ 3.13° F. at 68% ($\pm$ 6.13 at 95%), the projection may be in serious error, particularly during the colder months. Until further observations are available from Unkar, the January through March and October through December temperatures should be treated with caution since they may be too low.

The temperature extremes on the Delta are greater than either the North or South Rims (for North Rim data see Table 3). In part this may be an effect caused by the interception of solar insolation by the steep south wall of the Inner Gorge, the light and reflective color of the Unkar Delta soil, and the lack of vegetation. Less heat is therefore stored in the Unkar region than on the North or South Rims. The difference in reflectance has been calculated for the following substances (5):

Albedo (percent) of Various Surfaces for Total Solar Radiation, with Diffuse Reflection

Light sand dunes	30 - 60
Sandy soil	15 - 40
Meadows and fields	5 - 20
Forest soil	7 - 10
Water, lakes, etc.	3 - 10

Inspection of these figures shows at once that less heat is stored in the Unkar region than in the more or less forested North and South Rims, even though the solar insolation in places exposed to the sun would be the same (650 langleys per day or 95 B.t.u. per $ft.^2$ hr. in June and 300 langleys per day or 46 B.t.u. per $ft.^2$ hr. in January). This relatively high solar insolation causes rapid heating of absorptive objects, regardless of what the air temperature happens to be. Even in the coolest months on the Delta a person standing in the sun could be fairly comfortable in lightweight dark clothing so long as the wind were not blowing. Even moderate winds would cause rapid cooling of the skin.

The environmental stresses on man caused by the high summer temperatures would be more serious than those caused by cool winters on the Delta. The continuous hot dry winds throughout the summer add to the heat stress already high because of high air temperatures, high insolation, and rapid evaporative loss. Hot wind does not cause cooling through evaporative heat loss because this effect is more than compensated for by increased heat stress due to the removal of the envelope of conditioned atmosphere next to the relatively cooler skin. (6) Thermal stress is highest in July when the mean maximum temperature is over 106° F. This type of climate makes vigorous activity impractical from noon until sundown.

The importance of substantial buildings on Unkar Delta cannot be over emphasized as a means of avoiding the hot summer. Stone or earthen structures have low thermal conductivity, particularly in the case of the sunken kiva. I would speculate therefore that the first structures to be built on the Delta for summer occupancy were not made of brush, etc. If temporary structures were erected, they were probably intended for use at other times of the year.

Another possible refuge from high summer temperatures would be in Unkar Canyon, where cold air drainage from the North Rim and reduction of solar insolation by shading, would greatly lower heat stress, just as it does at Phantom Ranch (See Table 5).

The growing season on Unkar Delta is much longer than on either of the rims because of the higher mean temperatures. The Unkar climate is better for agriculture as a result. Corn grows best when minimum night temperatures are above 50° F. There are 158 such days (May 3 to October 7) on the average at Unkar, but only 43 such days per year occur on the high, cold North Rim. The shorter growing season on the North Rim would allow for planting only one crop; two could be grown with ease at Unkar.

Today a tremendous number of *Zea* hybrids have been developed so that corn can be grown in most situations from tropical to sub-arctic areas. Grand Canyon inhabitants may have used different hybrids on the North Rim and in the Inner Canyon, but I doubt it. For one thing, new hybrids would take an appreciable amount of time to produce and test. Therefore I think that the corn grown on the North or South Rims was the same variety, at least at first, as that later grown in the Inner Canyon. Modern hybrids mature after 120 days in the tropics down to a minimum of 60 days in mid-Canada. Certainly one of the shorter maturing varieties was used on the North Rim.

The hot dry air found in the Inner Canyon during the summer would mean high VPD's generally prevailing during the growing season. The mean maxima in July are 1.759 in. Hg. Evapotranspiration would be high and evaporative loss from the hot porous soil rapid. About 12.89 in. of free standing water (See Table 1) would evaporate during this month with an average wind velocity of 10 mph. Coarse textured soil absorbs several times as much heat as a fine textured one. Therefore water loss from the sandy Unkar soils would be correspondingly great. Under these conditions, water stress for plants would be acute by 6 pm. Irrigation of cultivated crops is absolutely necessary. The time after sundown would be the most efficient for irrigation. The soil is cooler and the evening hours offer the best time for the heavy labor of carrying water from the river or check dams.

Rainfall for the Inner Canyon and the South Rim follows similar distribution patterns but differs in amount. It is at a maximum amount during the growing season. Neither place has sufficient rainfall (about 6 in. during the season) to raise corn without irrigation or means of catchment. Distribution is weakly bimodal with the modes falling in March and August for the South Rim and February and August at Unkar. In order for rainfall to be directly useful to plants, enough must fall at one time to allow the soil to reach field capacity at the root zone. For the coarse textured Unkar soils, 0.1 in. of precipitation would be required. On the South Rim, where the soil is finer in texture, about 50% more would be needed. On the average this condition is met by 12 storms at Unkar and 8 on the South Rim during the growing season.

The North Rim climate provides enough rainfall for Zea cultivation without irrigation (about 6 in.). But areas with shallow soil would have to be avoided for agricultural purposes to prevent surface leaching of nutrients, waterlogging of the soil, and subjection of corn plants to damping off due to poor drainage. Rainfall distribution is more erratic here than in the canyon or on the South Rim. Peaks of precipitation are found in March, April, and December with lows in February, June, and September. Maximum precipitation occurs in December rather than in August (See Fig. 2).

VPD's give a rough estimate of the water evaporated at a given temperature and pressure. The atmospheric pressure changes are of little importance and can be ignored. Temperature has a major effect on evaporation rates as does wind. The evaporating power of water reaches a maximum between 4 pm and 7 pm and decreases until sunrise the following day, whereupon it gradually builds up again. The effects of air movement are predictable. A doubling of the amount of wind about doubles the evaporation rate of free standing water. The effect of wind on the rates of water loss in plants is less predictable.

Winds generally increase water loss in plants. But violent wind causes the stomata to close (probably through irritability), cutting water loss. The point at which this happens depends upon sunlight intensity, osmotic balance, and wind velocity. Wind effect

High VPD's usually mean rapid water loss by plants and rapid depletion in the upper soil layers. On days when the mean VPD is more than 0.300 in. Hg, plants will feel distress if the soil is drier than 1/4 field capacity. Irrigation is then required to maintain good growth.

The evapotranspiration rates at Unkar are two to three times greater than on the South Rim. This disparity is larger when compared to the North Rim. The exact VPD data are not known at this time for the North Rim.

Both the Inner Canyon and the South Rim have summer dominant precipitation patterns at the present time. The daily record kept in May and June at Unkar indicates the importance of this regimen for agriculture. The effect is two-fold: the first is obvious; most of the precipitation falls in a useful form to plants, namely rain, at a time when temperatures are high enough for it to be used. The second effect is the lowering of the VPD's. Even traces of rain, too small to be measured, cause a marked decrease in the VPD, although no additional moisture is available in the root zone. (See Fig. 1) This lowers water loss in plants, enabling longer periods to pass without irrigation, although it does not improve the osmotic balance significantly in plants already under stress.

The physiology of Zea has been extensively studied throughout the world because of the immense economic value of this plant. Unfortunately, little has been done with the hybrids used by Southwestern Indians for dryland farming. Indications are that good growth requires minimum temperatures above 50° F. for 60 or more days and effective moisture equivalent to 6 in. rainfall to achieve reasonable yields of 25 to 50 bu/acre. Therefore irrigation is required at all prospective agricultural sites on the South Rim and in the Inner Canyon.

Calculations of the area of catchment required to provide this amount of water per acre are instructive:

Place	In. reqd. in excess of ppt.	Catchment area/acre under cult.	Gallons
South Rim			
1 crop	2.40	.34 acre	65,165
Unkar			
1 crop	4.03	.58 acre	109,478
2 crops	11.03	1.58 acre	299,435

Catchment figures were calculated assuming that no water was evaporated or soaked into the soil prior to delivery to the plants. In practice the catchment areas would be much larger.

Timing of irrigation is important. After germination until flowering, less water is required for good yields. From tassel formation until the ears are half ripe, optimum water is necessary for good yield. Drought or wilting at this point will lower yields by 50% or more.

Consequences of Migration: Prior to 1050 AD the North Rim climate was probably unlike that found today. Summer rainfall was reduced to levels below present ones. The magnitude of this difference cannot be assessed at this time and must await future palynological investigation. (See Appendix) Temperatures may have been about two or three degrees lower than at present, shortening the already short growing season for Zea. In spite of favorable moisture and good soil fertility, corn farming would have been a difficult and chancey proposition. Growth might have been weak, the plants subject to damping off fungus and insect attack, and yields low. I would guess that North Rim inhabitants were dependant upon hunting and gathering, owing to a lack of robust agriculture. The winter-dominant precipitation and cold soil would favor growth of a dense spruce-fir-yellow pine forest. Clearing of land for agricultural use must have been a major undertaking with primitive tools. Podzolic soil, associated with this type of forest, would not be very favorable for corn cultivation although it would be all right for cucurbits.

There are several drainages and springs near the edge of the Walhalla Plateau that would be attractive sites for check dams. The growing season would be longer in this area but some irrigation would be required to make the land yield good crops.

Unkar Delta was even more unattractive than the North Rim before 1100 AD. Midsummer temperatures were probably a little lower than now and evaporative water loss was possibly not quite as high. But little or no rain fell in the summer and twice as much water would have to be carried to the plants than is the case now. Aside from such phreatophytic plants as mescuite, Unkar Delta was probably barren of vegetation except for a few struggling patches of annual grasses and forbs, (weeds)

About 1100 the summer rainfall started. On the Walhalla Plateau this effect would be less important than in the Inner Canyon or the South Rim because precipitation was still heavy and permanent sources of water were available. Also the winter to summer shift may have been less pronounced; today the winter precipitation is still heavier there than in the summer, quite the opposite of the South Rim or Unkar Delta.

Temperatures may have risen slightly at this time. At any rate the forests on the South Rim became more open as probably did those on the North Rim. I cannot say if this recession was due to temperature changes or if they were caused solely by the decrease of the winter precipitation that favors tree growth. Forest recession did not leave a void. On the North Rim the dense spruce-fir forest would have receded and been replaced with yellow pine and oaks. On the South Rim the yellow pine-oak forest would have been replaced with pinyon, juniper and oak.

An often overlooked effect of summer rainfall on primitive agriculture is the more violent summer storms can cause widespread destruction to check dams and cleared fields through enhanced erosion. This may have been another cause for inhabitants to seek greener pastures elsewhere.

Unkar Delta would be suitable for agriculture after 1100. The summer precipitation would cause erosion difficulty but since the soil is porous and less rain was falling, such problems would not have been as severe. Enhanced summer precipitation may have allowed some of the excess alkali probably extant before 1100 to leach out of the soil, making it better farmland. There were no fields to be cleared and a ready supply of sand was available for top dressing the fields. This latter is important for cutting down of evaporative moisture loss from the soil and decreasing the runoff through higher percolation rates. The longer growing season was (no doubt) of great interest, as mentioned earlier. A further comment about the advantages of growing two crops is in order at this point.

Throughout the southwest summer precipitation is very local in nature and variable in quantity. Figures for average precipitation are relatively meaningless to farmers here because the one sigma deviations for precipitation are often greater than 1/2 the mean. See Fig. 2 The ability to grow two crops must have given the Unkar people greater security in case rainfall was below normal during a portion of the growing season. In fact, it was a hedge against any type of agricultural calamity.

As a result of moving from either of the rims to Unkar Delta, I see the following changes taking place in the way the prehistoric inhabitants lived: 1) development of a society only partially dependent on agriculture to one that was heavily dependent on it, 2) development of intensive agriculture, 3) development of irrigation practices due to #2, 4) dependence on the dwellings and the kiva as shelter in the summer and during the daytime rather than in winter or at night, and 5) development of at least some traits tending to prolong the pioneer and consolidation phases of the migration. You will note that on the average someone had to haul about 700 five-gallon jars of water per day from check dams or the river to water each acre of corn. Certainly this would call for some community action and organization. Even if all or almost all irrigation was by means of rainfall catchment, considerable labor would be needed to maintain terraces and check dams. In short, a migration from the Rims would have necessitated extensive and intensive cultural changes fully comparable to moving from the North Rim of Grand Canyon to the Tucson area.

Literature Sited

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Table 1.

Relationship Between Evaporation and Precipitation

	UNKAR			SOUTH RIM		
	Evap.	Pptn.	Diff.	Evap.	Pptn.	Diff.
January	1.02	0.38	-0.64	0.21	1.44	+1.23
February	1.61	0.47	-1.14	0.30	1.60	+1.30
March	2.89	0.49	-2.40	0.59	1.33	+0.74
April	5.31	0.39	-4.92	1.06	0.86	-0.20
May	8.58	0.31	-8.27	1.76	0.65	-1.11
June	11.61	0.24	-11.37	2.30	0.40	-1.90
July	12.89	0.73	-12.16	2.65	1.95	-0.70
August	11.11	1.18	-9.93	2.27	2.25	-0.02
September	8.80	0.51	-8.29	1.75	1.60	+0.15
October	5.30	0.42	-4.88	1.09	1.16	+0.07
November	2.21	0.39	-1.82	0.44	0.94	+0.50
December	1.13	0.44	-0.69	0.23	1.63	+1.40
Mean	6.17	0.50	-5.67	1.27	1.32	+0.05
Total	72.45	5.95	-66.50	15.21	15.81	+0.60

All figures given in inches.

Evaporation calculated from: -V = c(VPD); where c is a constant derived to account for the increased evaporation due to wind. Wind velocity at Unkar is assumed to average 0.5 m sec^{-1} throughout the year. Mean wind velocity at ground level on the South Rim is assumed to be lower because of tree and brush cover (0.1 m sec^{-1}).

Table 2.

Unkar Delta

Date	Temperature Max.	Temperature Min.	Temperature $\bar{X}$	Temperature Int.$\bar{X}$	Relative Humidity Max.	Relative Humidity Min.	Relative Humidity Int.$\bar{X}$	VPD Min.	VPD Max.	VPD Int.$\bar{X}$	Pptn.
5/24	92	79	85.5	79.2	85	20	38.6	0.100	1.212	0.614	0.28
25	83	66	74.5	72.2	80	28	51.0	0.148	0.820	0.388	0.16
26	86	62	74.0	74.8	70	24	40.2	0.168	0.953	0.526	t
27	84	63	73.5	70.9	64	30	46.2	0.248	0.823	0.424	0.10
28	86	60	73.0	75.2	-	-	-	-	-	-	-
29	85	67	76.0	84.3	-	16	-	-	-	-	t
30	78	63	70.5	65.9	88	31	51.0	0.059	0.668	0.317	0.16
31	79	54	66.5	73.2	95	14	43.0	0.021	0.860	0.467	t
6/1	82	61	71.5	73.6	37	10	21.7	0.200	1.058	0.661	-
2	92	62	77.0	79.2	44	12	20.1	0.314	1.293	0.800	
3	89	67	78.0	80.2	34	16	22.1	0.639	1.158	0.805	
4	95	67	81.0	75.4	86	28	52.6	0.097	0.847	0.412	0.21
5	92	63	77.5	89.3	84	8	34.1	0.093	1.269	0.951	
6	88	68	78.0	77.6	22	11	17.7	0.539	1.189	0.803	
7	91	61	76.0	77.6	37	13	20.9	0.341	1.278	0.764	
8	92	72	82.0	80.6	27	7	15.2	0.578	1.282	0.940	
9	90	61	75.5	78.0	27	10	14.9	0.395	1.241	0.810	
10	89	71	80.0	77.6	22	11	21.3	0.334	1.189	0.764	
11	81	66	73.5	74.6	35	25	30.9	0.420	0.854	0.604	t
12	85	71	78.0	69.0	35	21	26.5	0.514	0.900	0.537	
13	76	68	72.0	62.2	52	30	37.3	0.332	0.634	0.377	0.01
14	83	63	73.0	63.4	49	26	32.5	0.296	0.843	0.380	
15	91	61	76.0	67.2	48	21	31.3	0.282	1.160	0.440	
16	93	67	80.0	71.4	41	18	27.3	0.393	1.204	0.559	t
17	109	67	88.0	78.3	36	1	15.7	0.427	2.500	0.813	
18	96	71	83.5	74.1	58	22	34.5	0.393	1.509	0.559	
$\bar{X}$	90.1	66.7	78.2	75.2	52.3	18.4	31.1	0.330	1.114	0.613	1.12

Table 3.

	UNKAR[1]			SOUTH RIM[2]			NORTH RIM[3]			Unkar Zea Da	S.R. Zea Day	N.R. Zea Da	Unkar ppt.	S.R. ppt.	N.R. ppt.
	$\bar{X}$ max.	$\bar{X}$ min.	A. $\bar{X}$	$\bar{X}$ max.	$\bar{X}$ min.	A. $\bar{X}$	$\bar{X}$ max.	$\bar{X}$ min.	A. $\bar{X}$						
Jan.	44.0	19.4	31.7	40.7	18.1	29.4	35	12	23.5	0	0	0	0.38	1.44	3.79
Feb.	54.8	27.0	40.9	44.7	21.0	32.9	39	09	24.0	0	0	0	0.47	1.60	3.51
Mar.	65.8	36.1	50.9	51.1	25.2	38.3	46	19	32.5	0	0	0	0.49	1.33	3.82
Apr.	77.1	47.4	62.3	60.1	32.3	46.4	52	25	38.5	0	0	0	0.39	0.86	1.94
May	88.9	59.9	73.2	69.8	39.1	54.5	62	34	48.0	28	0	0	0.31	0.65	1.31
June	100.0	68.0	84.2	81.0	46.9	64.0	74	41	57.5	30	6	5	0.24	0.40	1.02
July	106.5	77.9	92.2	84.3	54.1	69.2	77	47	62.0	31	31	31	0.73	1.95	1.55
Aug.	103.0	78.4	88.9	81.5	52.8	67.1	74	46	60.0	31	31	7	1.18	2.25	3.57
Sept.	96.5	64.3	80.4	76.2	46.9	61.6	69	39	54.0	30	0	0	0.51	1.60	1.23
Oct.	80.1	48.5	64.3	64.5	36.1	50.3	59	31	45.0	7	0	0	0.42	1.16	1.55
Nov.	59.7	31.1	45.4	51.9	26.4	39.2	46	25	35.5	0	0	0	0.39	0.94	1.37
Dec.	46.3	21.8	34.1	43.0	19.8	31.4	40	14	27.0	0	0	0	0.44	1.63	3.88
$\bar{X}$ =	76.9	48.0	62.4	62.4	34.9	48.6	56.1	28.5//total		157	68	43	5.95	15.81	28.54

1/ Projection by correlation with Lees Ferry, temperature and precipitation.

2/ From *Arizona Climate*, temperature and precipitation.

3/ From 10 year averages supplied by the National Park Service, temperature and precipitation.

4/ Number of days with a 50% chance of having minimum temperatures above 50° F.

Table 4

Unkar and Phantom Ranch Compared

Month	Unkar[1] Temp.	Unkar[1] Ppt.	Phantom Ranch[2] Temp.	Diff.	Ppt.	Diff.
January	31.7	0.38	46.0	+14.3	0.55	+0.17
February	40.9	0.47	51.0	+10.1	0.69	+0.22
March	50.9	0.49	58.0	+ 7.1	0.66	+0.17
April	62.3	0.39	72.5	+10.2	0.38	-0.01
May	73.2	0.31	74.5	- 1.3	0.22	-0.09
June	84.2	0.24	86.0	+ 1.8	0.38	+0.14
July	92.2	0.73	92.5	+ 0.3	0.78	+0.05
August	88.9	1.18	87.5	- 1.4	1.22	+0.04
September	80.4	0.51	83.0	+ 2.6	0.43	-0.08
October	64.3	0.42	72.5	+ 8.2	0.49	+0.07
November	45.4	0.39	50.0	+ 4.6	0.52	+0.13
December	34.1	0.44	39.5	+ 5.4	0.46	+0.02

1/ Data from Table 3.
2/ Data from Data, Precipitation and Temperature, Grand Canyon National Park. National Park Service, Grand Canyon National Park. 1965.

Fig 1.

VPD & Precipitation - Unkar 5/24-6/18

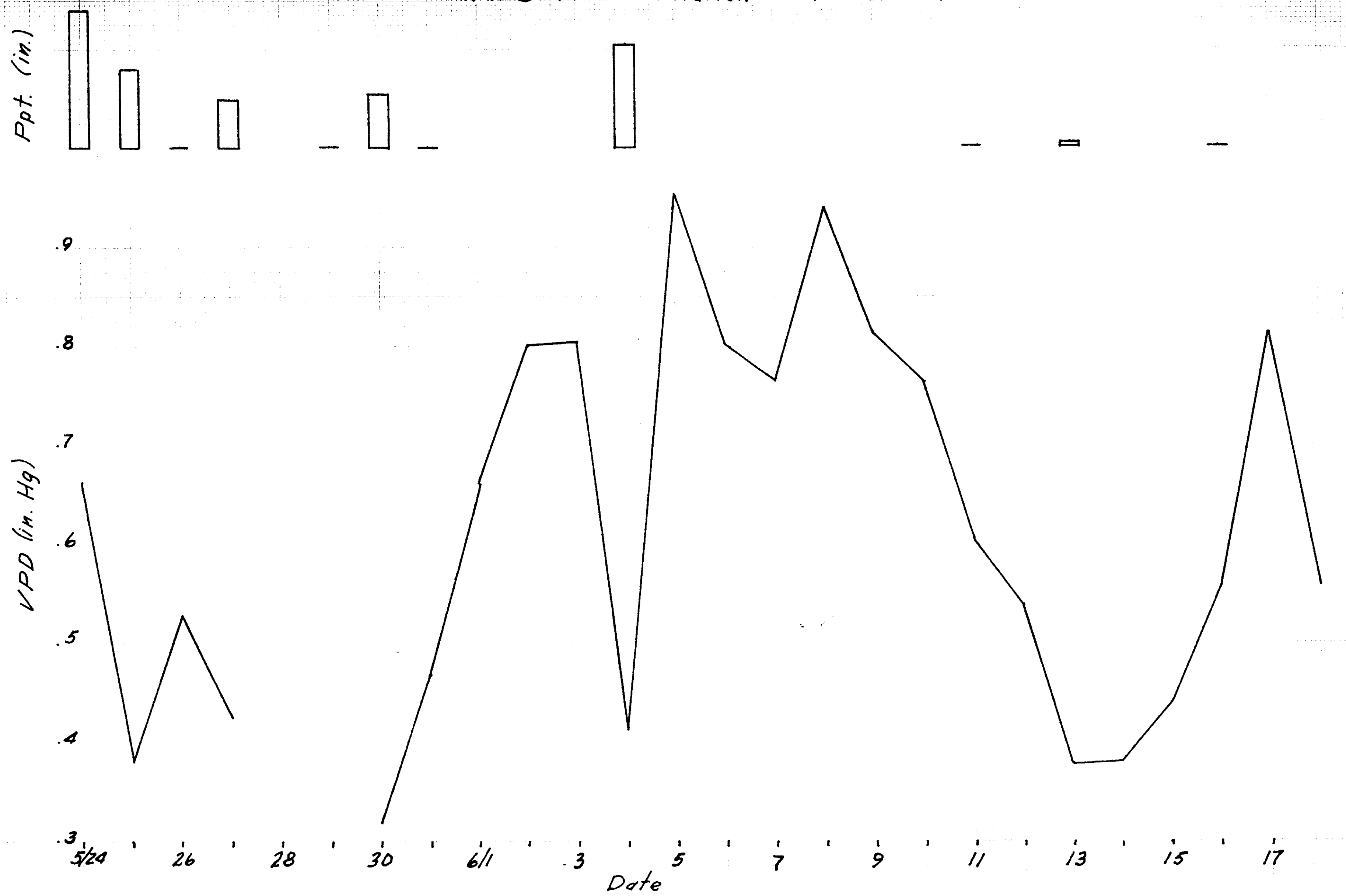


Fig. 2.

Precipitation- Modern Grand Canyon

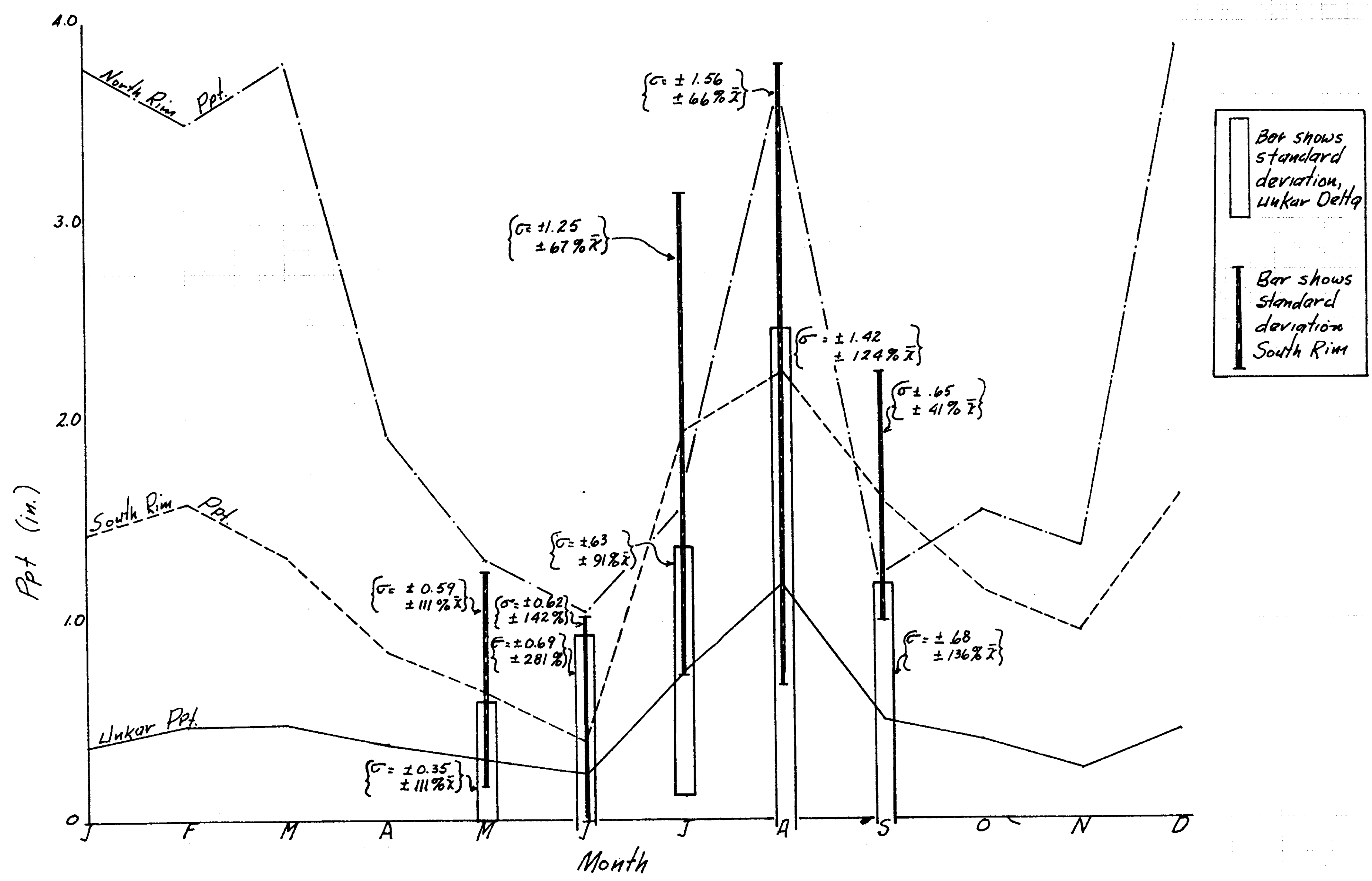
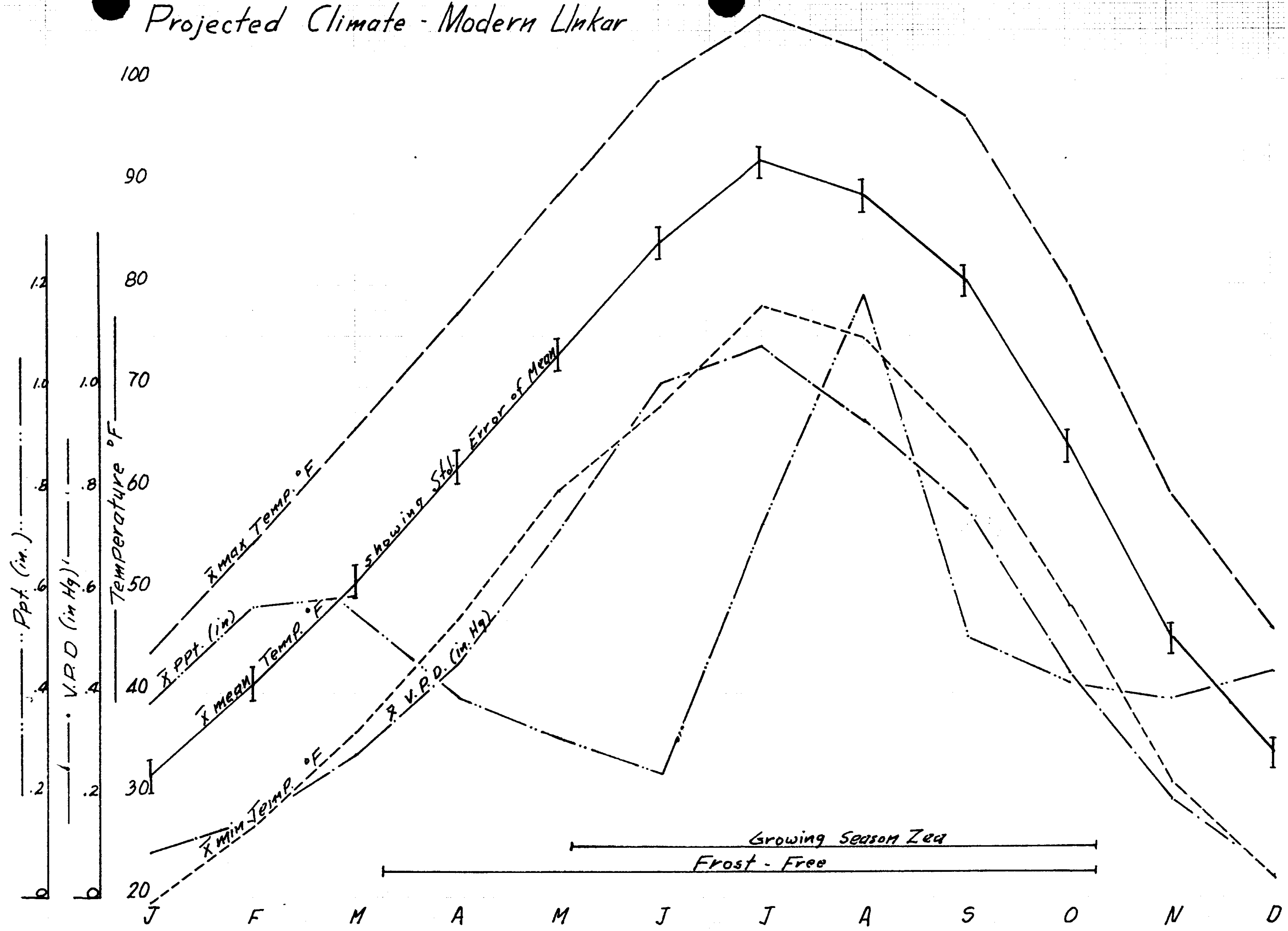


Fig. 3

Projected Climate - Modern Unkar



Unkar Climate

Fig. I

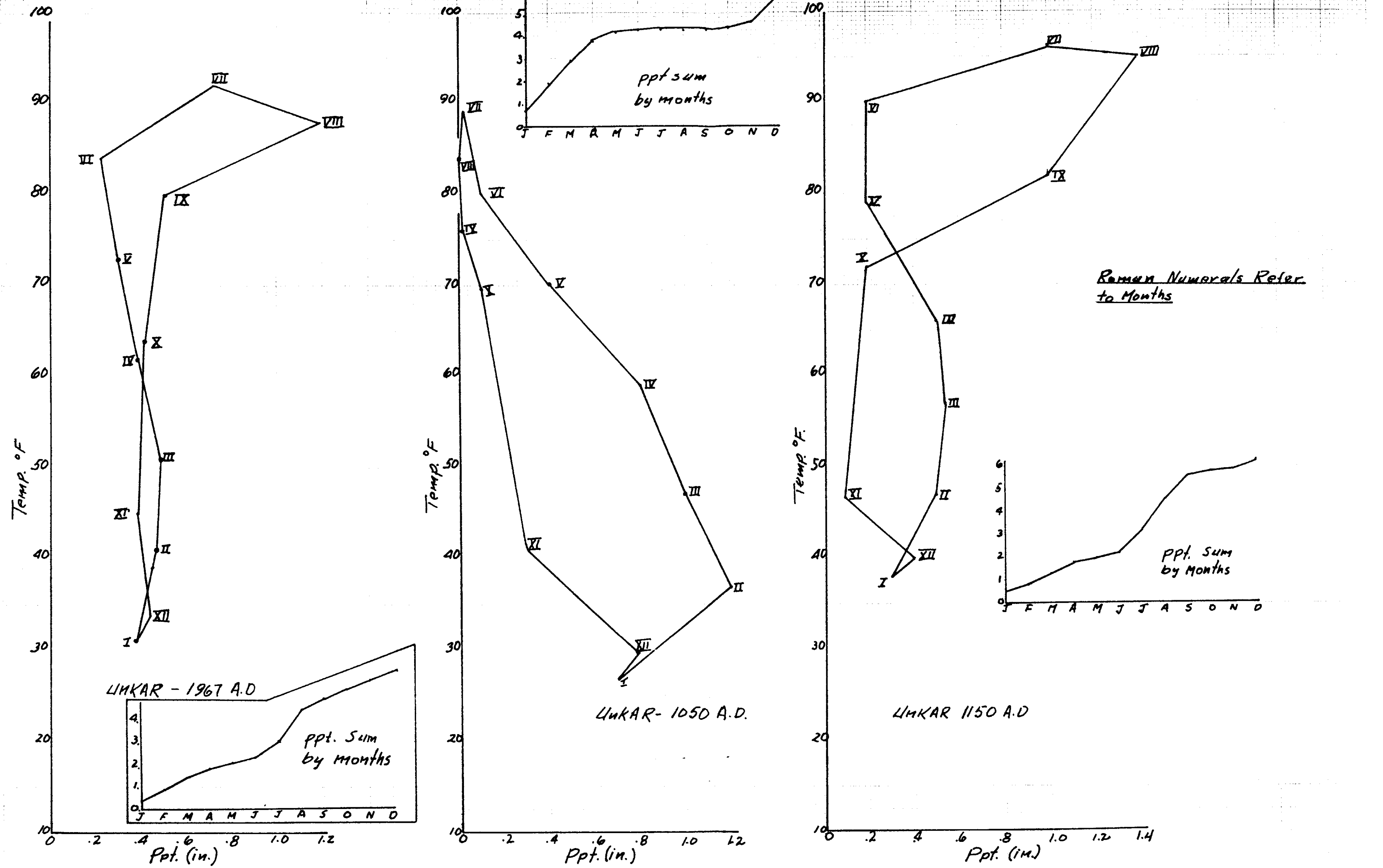
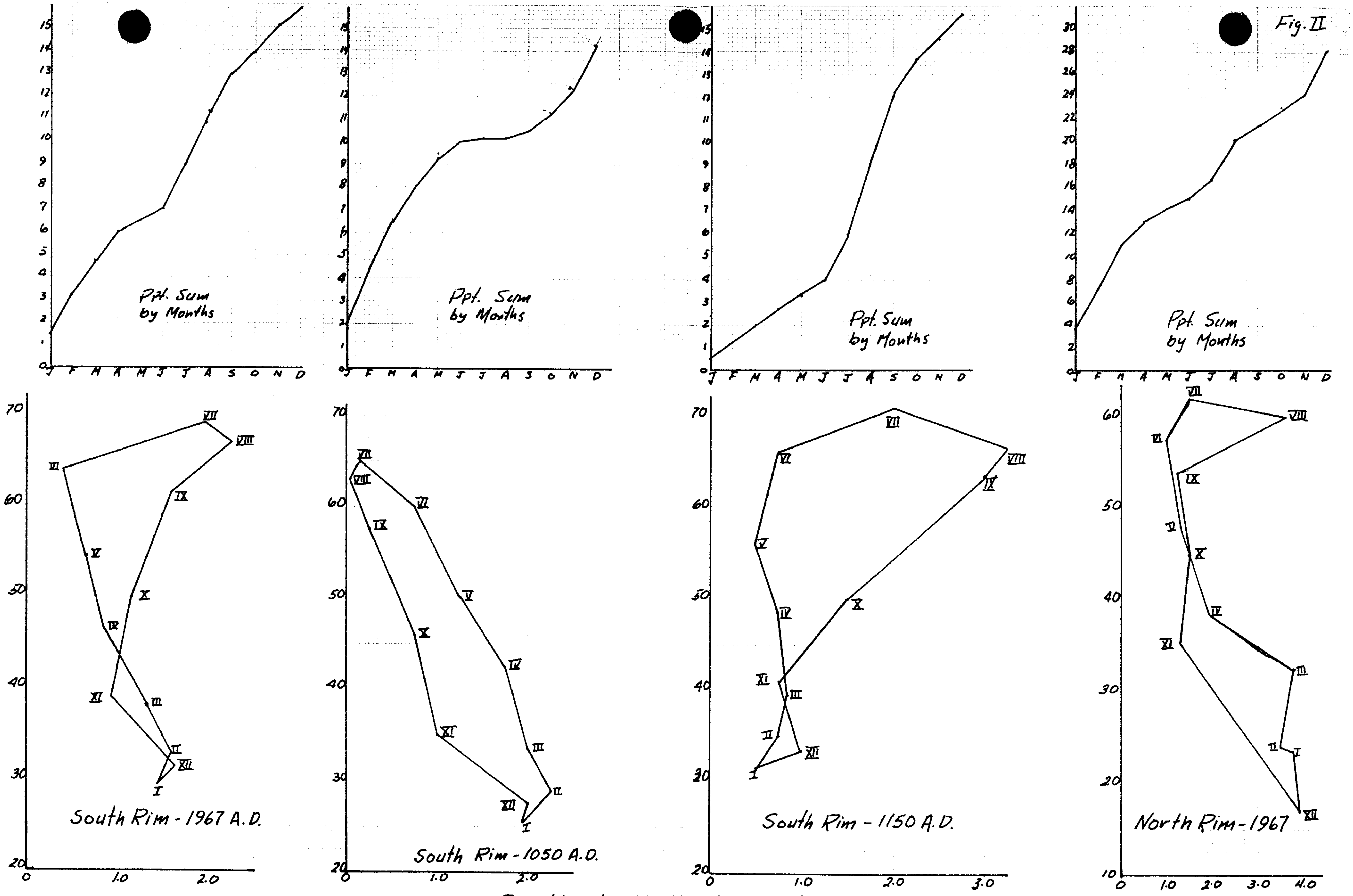


Fig. II



South & North Rim Climates

APPENDIX

Assigning Parameters to Temperature and Precipitation for the Paleoclimates of Unkar Delta and South Rim.

At the outset we must realize that most of the material that follows is speculative and should be open to question, re-examination, and re-evaluation as more data becomes available.

That a basic belief of palynologists is the reconstructability of paleoclimatic regimens is well known. All we have to do is decide how the evidence should be interpreted. The ecological significances of the various taxonomic groups used for these reconstructions are imperfectly known. Some generalizations can be made:

1) Annual and biennial taxa as well as other plants that are dependent on an ephemeral (non-permanent) water supply are favored by summer precipitation in the western United States. Perennial species are not so favored because of the intense competition that develops between their seedlings and the ephemeral plants capable of rapid growth, maturation, and abundant seeding. The timing of precipitation is evident therefore in the pollen record.

2) The amount of effective moisture available in the environment bears a direct relationship to the flora and the vegetation that develops. Forests require more effective moisture than chaparral or grassland and this moisture must be reliably delivered to the root zone of the deeply rooted arboreal species prior to the growth period.

Some generalizations about climate must also be made:

1) Summer precipitation in the southwest results mostly from convection storms. These storms require thermal convection currents to carry moist air upward to a height where condensation can take place. Increased convection storm activity presupposes

increased ground temperature and increased evaporation at the ground level. This increased absolute humidity may result either from enhanced sources of water vapor or from higher ground temperatures, or both.

2) The mean annual temperature at Grand Canyon has been in a state of statistically significant flux since the early 1900's. At first a warming trend took place until the mid 1940's. Since that time there has been a cooling trend amounting to an ecological change in elevation amounting to 400 to 500 feet higher. There is evidence for this to be found in the Grandview area at Grand Canyon in the spreading (through seedling survival) of the western yellow pine and other cold adapted species. Such shifts in the past are presumed to have taken place periodically to a greater or lesser degree.

These criteria have been used together with the modern climates for the tentative reconstruction of the paleoclimates at Unkar and South Rim.

The modern and 1150 climates at Unkar (See Fig. I) bear considerable resemblance to each other as expected. The 1150 climate was a slightly enhanced version of the modern. Note that these summer precipitation climates have their maximum areas at the top of the diagram. The difference between 1967 and 1150 is that more precipitation fell in late summer and less in early winter during the earlier period. This was more of a summer dominant precipitation pattern than we have now. This type of climate is still to be found in east and north central New Mexico. It favors growth of late summer blooming species chiefly in the Compositae and Cheno-Ams. The modern climate is more favorable to the growth of arboreal species. This is also true of the modern South Rim climate.

The 1050 pattern for Unkar is entirely different: Most of the area is at the bottom of the figure indicating winter-dominant precipitation, with the fall much drier than the spring. This climate type is found today in the cooler and drier parts of the Pacific Northwest. Note that the moisture is favorably distributed for best tree growth and that the slightly lower temperatures favor more extensive forest distribution.

The climate diagram for the South Rim in 1150 is unlike the modern diagram, but the differences are of degree and not type; both curves are similar in arrangement (See Fig. II). In 1150 summer precipitation was more strongly developed than at present, therefore the area at the top of the diagram is larger. The differences between the modern and 1150 climates are similar on the South Rim and at Unkar. Both climates seem to respond in a linear relationship to long term climatic factors. Note that the deviation from the expected mean temperature was 4.4° F. at Unkar and 4.5° F. on the South Rim during the May-June observation period in 1967, which is a close agreement. The similarities between these diagrams bear out this conclusion, particularly since they were derived independently from each other.

Likewise the 1050 diagrams for the South Rim and Unkar are quite similar, differing only in detail. The Unkar curve compared to the South Rim curve shows slightly more winter dominant precipitation. South Rim rainfall distribution would appear to be a little stronger in the late spring months. The South Rim was blanketed with a dense forest at this time because of the more favorable distribution of moisture and the slightly cooler temperatures.

The North Rim diagram bears little resemblance to that of the South Rim or Unkar Delta. It is a more continental type climate such as is found in the Rocky Mountains. More precipitation falls in the winter than in the summer (See Ppt. Sum by Months inset, Figs. I and II). This leads to a different ecology. Cold-wet adapted species (spruce and fir) are dominant plants. Comparison of this diagram with that for Unkar Delta in 1967 will serve to reinforce the statements made in the body of this report about the degree of adaptation necessary to move a culture from the North Rim into the bottom of Grand Canyon.

THE CLIMATES OF UNKAR DELTA AND SOUTH RIM, GRAND CANYON, ARIZONA, 1967

Oct. 11, 67

K.V.L. LABORATORY
P.O. Box 293
Grand Canyon, Arizona

UNPUBLISHED REPORT
SCHOOL OF AMERICAN RESEARCH

Report to: Dr. Douglas Schwartz
From: Peter S. Bennett, K.V.L. Laboratory
Subject: Supplementary report, Unkar 1967

Schoenwetter uses phytogeographical terms for vegetation. The definition of such terms in relation to the modern pollen rain is necessary in my opinion. However, it can only give the crudest insights into the ancient vegetation or the environmental forces that brought it about. The time and expense involved usually prevents a thorough analysis of the modern vegetation in terms of actual abundance. Density figures for the vegetation expressed in terms of basal areas give a better picture of a habitat than empirical terms. They are also of greater value to the palynologist.

The interactions between abiotic factors and the biota are complicated and little understood. In my opinion, the terms 'woodland, grassland, and savannah' are relatively meaningless. Such terms may be locally understood by a worker, but may mean different things in other areas. Furthermore, these terms do not necessarily say much about the environmental parameters that have brought the conditions about which they attempt to describe. For example, the woodland near the top of the San Francisco Peaks is the result of different forces than the woodland near the rim of Grand Canyon only 70 miles distant. For these reasons, both woodlands need to be carefully defined. My use of Merriam's zones (Merriam, 1890) - used in the strictest sense and in the area where he did his work - was an attempt to make such a careful definition and I don't think that it can be said to be an expression of my orientation. Since the time when Merriam did his work, the physical parameters he used have been shown to be oversimplified and in some cases invalid. The use of his zones does not imply that such parameters are known, but it does suggest that the biota of any one of his zones in a limited area are acted upon by similar forces and form a valid unit, widely published and understood. Any other specific units or communities may also be used. Remember that one man's savannah may be another's woodland, particularly if he is not familiar with the vegetation under discussion.

The use of any name for a vegetation unit is not enough to spell out the environment. It begs the issue by defining the unknown in terms of a presumed but usually unproven similarity between two vegetations, often separated geographically as well as chronologically. Such use of 'lables' neither says nor implies how the unknown environment would affect the modern day vegetation or vice versa. Until further research can show that apparent similarities do exist, there is not much that can unqualifiably be said about paleoenvironments.

The 1967 pollen work at Unkar brought out many examples of the problems mentioned above. Arboreal pollen was found in significant quantities in all samples. The Schoenwetter system of vegetation analysis tells us that the Unkar Delta should have been classified as a savannah if compared with his New Mexico work. (Schoenwetter and Eddy, 1964) Since the conditions at Unkar are unlike those at Chuska Valley (Harris, Schoenwetter, and Warren, 1967), adjustments must be made.

The arboreal pollen at Unkar has been imported, at least in the modern samples and probably in the fossil ones also. Most of this importation has taken place from cooler and wetter habitats near the

Canyon's rim by the prevailing southwesterly winds, probably along a line running from Unkar southwest over Grandview Point. The balance of this pollen has come from the North Rim, carried mostly by water but also by wind. The arboreal pollen, for reasons that I will shortly make clear, is the most accurate climatic indicator at Unkar. Therefore Inner Canyon ecology will be indirectly reconstructed using the arboreal pollen from the rim.

This importation of pollen from places that differ widely in ecology from the study area introduces problems. Some of the pollen collected has been rebedded from older deposits. The large water-bedded gravel lens in the kiva fill (Un-2) and the riparian pollen from North Rim communities is supportive evidence for such rebedding. The effect of rebedded pollen is hard to assess. Samples containing pollen types (Juglans, Betulaceae, etc.) that are unlikely to have originated from the South Rim are therefore suspect.

Much of the pollen carried by the southwesterly winds has come from vegetation quite different from that found at Unkar today. Winds approaching the canyon from this direction cross successively Artemisia flats, juniper savannah, pinyon-juniper woodland, ponderosa woodland, pinyon-juniper woodland, juniper savannah, semi-desert chaparral, burrobrush flats, barren rock, a small patch of riparian vegetation, burrobrush flats, and finally the Unkar Delta. The modern and presumably the fossil pollen records at Unkar are a result of the pollen production of all these ecological units or communities. This mixture and the rich flora of the region make an ecologically complex situation. Interpretation of the spectra at Unkar cannot, therefore, be left to intuition alone.

Margaret B. Davis (1963) published a system for a non-intuitive rendering of pollen spectra. This system allows pollen spectra to be correlated with vegetation. The Unkar results demonstrate that this correlation is not always simple, nor does it show any fixed relationship between pollen percentages and vegetational composition or density. Davis convincingly makes the point that pollen percentages say little about the vegetation. I recommend a reading of her paper.

The desirability of relating the pollen to the vegetation has long been recognized by palynologists. Unfortunately, the expense and time involved in such studies usually make them impractical. There are other drawbacks also. The first is that the modern pollen : modern vegetation ratios should be determined on the basis of large samples. The plant associations that contribute the pollen must be sampled to determine the basal areas of the important or key taxa on randomly selected plots, and a large number of pollen grains must be counted. The latter is very important if uncommon or rare species are to be included. Davis (1963) estimates that 10,000 grains must be counted to give high statistical reliability.

An important assumption is that vegetation contributing to the pollen spectrum at a given location has not radically changed its distribution with time. Such shifts are likely to alter the pollen to vegetation ratios in an unknown manner and render determinations of the ancient vegetation inaccurate. The degree of ratio alteration with movement would depend upon the distance that the pollen is transported. Theoretically, pollen distribution whould vary inversely with the square of the distance. Shifts close to the sampling point would cause greater errors than shifts at localities farther away. If the distance is fairly large, e.g. more than three miles, the effects of small vegetational shifts would be minimal. The minimum pollen flight from Grandview Point to Unkar Delta would be seven miles. I therefore presume that the vegetation figures calculated for this report are fairly accurate for arboreal pollen.

Determinations for the non-arboreal pollen are less accurate since most of this pollen has been derived from plants growing within the Canyon and hence closer to the sampling points. Even small shifts would have a greater effect. Because of this proximity, non-arboreal pollen is over represented. (See Appendix A.)

Another assumption is that the agencies transporting pollen to the spot under consideration have always acted in the same manner that they do now, both in magnitude and vector. Over short periods of geological time there is little reason to suspect that such factors change significantly.

Because of these considerations and limited by these assumptions, the Unkar pollen spectrum is converted mathematically to yield vegetational percentages on the basis of basal areas. The first step of the conversion was to analyze the vegetational composition upwind from Unkar Delta. Since the flora in this area is composed of about 2,000 species, it was necessary to confine the investigation to a few key taxa. Those considered were: Pinus ponderosa, P. edulis, Juniperus, Quercus, Rosaceae, Compositae, Gramineae, Cactaceae, the Cheno-Ams, and Ephedra. Ephedra, although not vegetationally important, was considered because of its importance in determining the periods of summer or winter precipitation.

The modern pollen rain was considered to be the average of the fou surface samples taken at Unkar Delta in 1967 (KVL #1726 - 29). Counts made earlier were extended to about 4,000 grains. The ratio between modern pollen and modern vegetation was next determined for each taxon considered. This ratio was 'reduced' in such a manner that the least was valued at unity (1.00). These values were then used throughout the Unkar vegetational study and appear in my calculations as R. (See Appendix B.)

The next step was to reconstruct the ancient vegetation from the fossil pollen by dividing the fossil pollen percentages (FP) by the appropriate R value to yield a Corrected R value (Cor. R_{fp}). The 6orrected R values were totaled and the percentage of vegetation compositions found by determining the percentage of the individual Corrected R values to the total Corrected R values. Since most of the unconsidered and unknown pollen was non-arboreal, their value was included under this section. These results were plotted (1 in. = 10%) and represented by a solid line while the old pollen percentages are shown with broken lines, making a comparison possible.

Even a brief study of these diagrams shows that there are wide discrepancies between the calculated vegetation percentages and those for the pollen. These departures are likely to be found when the vegetational units are moving to a significant degree. They are therefore corroborative evidence for ecological change.

With this new data at hand I can speculate with greater certainty about the past climate and ecology at Unkar. Chronometric dates for the discussion are based on the pollen spectra derived from Tusayan Ruin dated by Haury in 1932 from tree-ring data.

From about 1100 to 1300 A.D. there was a period when summer precipitation became dominant over winter precipitation. The drastic change in climate is clearly reflected by both the vegetation and flora, and by the pollen spectra. These changes were also seen in the fossil pollen rain at Tusayan Ruin. (See Curve, Appendix A.) Haury and Douglass (1931) have dated Tusayan on the basis of six tree-ring dates:

Specimen #	Dates A.D.
353	1115 to 1184
354	1138 to 1170 ± 10
355	1146 to 1188 ± 5 or 10
356	1143 to 1189 ± 10
357	1137 to 1205 ± 1
358	1149 to 1188 ± 5

This gives a mean cutting date of 1187 ± 6. Gladwin (1946) attacked the Haury - Douglass dates, giving instead a mean cutting date of 1068. Gladwin's date for the ruin has not been accepted by Al Schroeder (1967) Regional Archaeologist, S.W.R.O., National Park Service. The correlation among the 1187 date for the onset of summer precipitation, the Haury date for Tusayan, and the ceramic date for the Unkar site are in excellent agreement. We therefore accept the 1187 date until further evidence alters this conclusion.

Between 1000 and 1100 A.D., there was a gradual and accelerating trend toward a summer rainfall pattern. During the latter part of this time period, forest density began to decline, reaching its minimum at 1140 A.D. or so. As the forest shrank there was a tendency for a decrease in the density of the non-arboreal plants as well, indicating a trend toward less effective moisture.

With the full onset of summer precipitation around 1100 A.D., changes in the vegetational pattern were well underway. The pinyon - juniper woodland, which had been largely confined to the Inner Canyon in the Grandview district, extended its upper margins onto the rim just before 1100, and started to spread into the adjacent ponderosa forest. Much of this migration was by the pinyon pines, the junipers remaining behind at the lower end of the old pinyon - juniper woodland as a juniper savannah. This migration of the pinyons took considerable time. At the lower and drier end of the pinyon - juniper woodland, the adult pinyons would have persisted for some time but reproduction (seedling survival) of the species would have been severely curtailed. Eventually, these adult trees became weakened and subject to disease and the species died out locally. The lower limit of the pinyon - juniper forest in 1150 A.D. was at an elevation of 6,500 feet, the lower limit of the juniper savannah being at its present elevation, about 4,500 feet.

The changes below 4,500 feet were relatively minor, and mostly quantitative. Just before 1100 A.D. effective moisture values dropped. Rainfall in the Inner Canyon was about 5.3 inches at that time. Species not preadapted to such dry conditions under their winter rainfall regimen, decreased in abundance leaving ecological niches open for the future spread of types with a low effective moisture - summer rainfall adaptation. In 1100 A.D., just before occupation, the Inner Canyon was rather bare and inhospitable. Grasses were the most common and important groundcover though sparse, leading to instability and soil erosion; an effect somewhat offset by comparatively gentle winter storms.

By 1100 or 1120 A.D., preadapted plants had expanded their basal areas to a significant degree. On the Tonto Platform the Rosaceae (Coleogyne) show a marked increase starting about 1090 A.D. Rosaceae pollen was not found in samples 1750 and 1747 (KVL #s), which date at 1200 A.D. and 1175 A.D. respectively. I suspect that Rosaceae pollen is under-represented in these samples, giving false values. More likely this taxon declined in abundance (to about 15% basal area representation and did not disappear. The causes for such a drastic change are not fully clear as yet. Changes in the storm pattern and a rise in effective moisture values might be partially responsible. Both factors could adversely affect distribution. Further sampling in this time period should help resolve the problem.

The grasses and composits follow a pattern similar to that proposed for the Rosaceae (hypothesizing higher representation from 1175 to 1200 A.D.) This may have been the result again of the firm establishment of summer precipitation forms and as the consequence of slightly enhanced moisture values in this time period.

The situation with the Cheno-Ams is interesting. They show a gradual increase from the time of maximum development of the ponderosa forest just prior to 1000 A.D., then a decline during the maximum of the summer rainfall. One can speculate that the maximum soil disturbance would occur at the height of summer rainfall. Around 1100 A.D. the Cheno-Ams reach one of their all time lows. There is no evidence that they have responded positively to these disturbed conditions, if such conditions existed. A plausable hypothesis is that just after the trend to summer rainfall started, the balance between precipitation and evaporation was right for causing a buildup of excessive soil alkalinity This would provide the proper edaphic conditions for Cheno-Am increase. The decline could have resulted from a lowering of soil pH as a consequence of leaching with the full onset of the summer rain. While there is a similar pattern found in the pollen record following the onset of summer rains ca. 1300 A.D., it is not as marked and took longer to develop.

The Unkar ecology during the period of occupation was sketched in the first report. Further details can be added now. In 1100 A.D. the mean annual rainfall at Unkar Delta was about 5.2 inches, mostly falling during the summer months. Peak rainfall was probably in August if rainfall distribution was similar to the present time. By 1140 or 1150 A.D. the annual precipitation had increased slightly to about 5.7 inches.

The forest at Grandview was rather different than now, showing a marked decrease in basal area of ponderosa pine and simultaneous increase for oaks. The forest assumed an appearance of an Upper Sonoran - Transition ecotone as described by Merriam. The resultant openings were first colonized by grasses (*Bouteloua*, *Agropyron*, and possibly *Agrostis*), and forbs (*Chenopodium*, *Gutierrezia*, *Aster*, *Haplopappus*, etc.). Within 10 years *Artemisia* and *Cowania* would have become established at the expense of the earlier colonizing plants. The climax type reached its full development by 1150 A.D. approximately. This forest was rather open, dominated by scattered ponderosa pines with pinyon pines and oaks as sub-dominates. Openings had considerable growth of brush; *Artemisia*, *Cowania*, and *Chrysothamnus* being the most common. Herbaceous species such as the perennial grasses, *Gutierrezia*, *Aster*, *Hymenoxys*, and *Helianthus* were restricted in distribution and definitely not prominant in the vegetation.

Although a forest mixture of this type would seem to be more open and sparse, it actually is more productive. The biomass of the pinyon pine forest west of the Grandview area today is about 14% more productive than the best pure ponderosa forest. It is also floristically more varied. Certainly such a forest would be better for hunting and gathering than a pure ponderosa stand.

Important changes also took place elsewhere. The Inner Canyon composits show their greatest biomass between 1000 and 1300 A.D., almost five times greater than at present. The genera Aster, Gutierrezia Chrysothamnus, Hymenoxys, Erigeron, Verbesina, and Helianthus seem to be the most common. Most of these genera are used by the Pueblos of today, particularly for medicinal purposes (Whiting, 1939 and others). Whether they were so used in 1100 A.D. is a question. There certainly was a wider selection of all types of plants for possible use within the Canyon then found there today.

The Rosaceae counts were high also. Most if not all of this pollen was derived from the Tonto Plateau southwest of the site. The principal species was probably Coleogyne ramosissima. Although this plant is of no known economic use, its higher density speaks for fairly good soil stability in that area.

On the Delta proper, a similar aspect of richer vegetation and fair soil stability prevailed. The sand dunes that are prominant now were in existence at this time. Mesquite (Prosopis) is the chief dune stabilizer at Unkar; moist sand is a favorite habitat. I assume that high mesquite counts indicate past stability of these dunes. Since mesquite is entomophilous, 3% is quite high (See first report). Counts of this magnitude are common during occupation but drop shortly after abandonment.

Corn could have been grown with minimal irrigation by 1120 A.D.

But the cultivation of cucurbits without irrigation doesn't seem to me to be very feasible as they require plenty of water and have no adaptations for conserving it. Hence they have high water loss rates. Plant growth is limited by many factors. A single unfavorable condition might not prevent growth, but a combination of only moderate deficiencies could have serious effects. Low moisture values in the soil plus high salinity would make cultivation of cucurbits difficult if not impossible. The proposed agricultural site represented by #1751 has these faults. I would judge that cucurbit culture was carried on in areas close to Unkar Creek that could be irrigated easily when the creek was flowing. Such places could be expected to have less soluble salts in the soil, making crop yields better.

By 1200 A.D. effective precipitation increased and a weakening in the summer dominant rainfall pattern took place. There was a closing up of the ponderosa forest and a general return to the conditions prevailing prior to 1100 A.D.

In 1300 A.D. there was a return to summer dominant precipitation and another drop in effective moisture. These changes in rainfall pattern, effective moisture, and the return to a more open forest type were less pronounced than in 1100 A.D. but were qualitatively similar. The 1300 A.D. changes were less because the peaks for these parameters were less pronounced. The 'lows' in both times were of the same magnitude.

The vegetation in 1300 A.D. was similar to that in 1100 A.D. with the following notable exceptions: the basal area of the junipers was inexplicably much higher, there were more plants in the 'other' classification (mostly small herbs), composit plants remained at a fairly low level, and the oaks retained much of the prominance that they had around 1200 A.D. As a guess, these anomalies may have been due to changes in temperature with a warming trend, partially offset by heavier rainfall. If this hypothesis is correct such a change would not be represented in the rainfall curve which was calculated upon vegetational ratios involving only one element of the anomalous vegetation, Juniperus. Further sampling might clarify this situation.

From about 1300 A.D. to the present, the ecological picture is difficult to read because of the apparent degradation of the soil surface. Much of the pollen record for this time period has been lost, rendering analysis uncertain.

In spite of recent doubt about the age of the Unkar site, I still feel that it dates from 1100 ± 50 A.D. on the basis of pollen alone. Wilson comments on my theoretical discourse about accuracy of pollen dating by saying that '... inspite of these reasons the system works.' In this same paper on p. 7 he gives a date for NA7207 of 780 ± 180. Even an optimistic view of pollen dates would not give a result closer than ± 25 years. There are theoretical reasons why pollen chronometric dating should be neither precise nor accurate and it isn't.

The upper limit of occupation is less fixed than the lower one. The first layer of kiva fill above the roof dates at about 1200 A.D. in comparison with the pollen spectrum at Tusayan Ruin. The earliest reasonable date for this fill would be 1287 - 6 (the uncertainty of Haury's date). -25 (the minimum) uncertainty of my date) = 1156 or if my maximum uncertainty is used = 1131 A.D. I am inclined to date the fill at 1200 A.D. however, since it fits better with the Tusayan data. (See Appendix B) Tusayan was abandoned about 1210 A.D. at a [illegible]n when arboreal vegetation was at or near its peak. The successional relationships between the taxa in #1750 and #1722 show a period when the ponderosa forest was being invaded and otherwise opening up in response to a return of summer rainfall. This makes a dating at 1200 A.D. more reasonable than 1150 A.D.

If we assume that the period of time between #1723 and #1722 to be about 100 years, we can then arrive at chronometric dates for the relative dates of some of the samples. The construction of the kiva (Un-2) is associated in time with building phase I. Building phase I would date at 1096 to 1144 mean 1120 A.D. Building phase II would date at 1114 to 1166 mean 1140 A.D. These differences are not statistically significant. Therefore the time period between phase I and phase II was short, probably less than 10 years.

Sample #1750 (the first kiva fill) dates at 1147 to 1213 mean 1180 A.D., calculated on the probably invalid 'uniformitarian' basis. At any rate pollen chronometric dates and the 'uniformitarian' dates are fairly close together.

The 'why' of abandonment is hard to even speculate about. There are several curious ecological events that took place from 1140 to 1175 A.D. The first is a closing of the ponderosa forest, making it ecologically less varied and biologically less productive. This would have crowded out some of the browse plants for deer and probably reduced herd size both on the rim and in the Canyon. If hunting was important to the Unkar people, this could be a factor in abandonment. This time may also have been marked by violent summer storms as the summer rainfall regimen reached its height. Also mesquite reached its lowest level of abundance. Humans are, of course, affected by the same types of ecological factors as their less intelligent mammalian neighbors. Since the Anasazi culture is unavailable for direct study, I don't really know what its ecologically limiting factors were. A reduction in game abundance, heightened erosion, and inundation of the agricultural areas by mud and debris or their destruction by gullying, the scarcity of water for irrigation during stream entrenchment, or movement of sand from the previously more stable dune areas (following the destruction of mesquite and other dune stabilizers) could have brought about abandonment. While none of these factors may have been important in itself, they may have combined to present a discouraging picture to the Unkar inhabitants, especially if such paleoecological imponderables as soil exhaustion and human disease entered the picture.

One interesting question that pollen analysis can say nothing about at this time is where did the inhabitants go to find greener pastures? I wonder if the median date for abandonment at 1180 A.D. and the construction of Tusayan at 1187 A.D. is a coincidence. I do not know of any other good dates for nearby rim sites. It would be interesting to know if there was a general spate of construction at this time on the rim and if there was a general trend toward abandonment in the canyon.

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