Environment of Mesa Verde, Colorado

National Park Service Archeological Research Series

---

1 Archeology of the Bynum Mounds, Mississippi (PB 177 061).*

2 Archeological Excavations in Mesa Verde National Park, Colorado, 1950 (PB 177 062).*

3 Archeology of the Funeral Mound, Ocmulgee National Monument, Georgia (PB 177 063).*

4 Archeological Excavations at Jamestown, Virginia (PB 177 064).*

5 The Hubbard Site and other Tri-wall Structures in New Mexico and Colorado.

6 Search for the Cittie of Ralegh, Archeological Excavations at Fort Raleigh National Historic Site, North Carolina.

7–A The Archeological Survey of Wetherill Mesa, Mesa Verde National Park, Colorado.

8 Excavations in a 17th-century Jumano Pueblo, Gran Quivira, New Mexico.

9 Excavations at Tse-ta'a, Canyon de Chelly National Monument, Arizona.

7–B Environment of Mesa Verde, Colorado (Wetherill Mesa Studies).

7–C Big Juniper House, Mesa Verde National Park, Colorado (Wetherill Mesa Excavations).

7–D Mug House, Mesa Verde National Park, Colorado (Wetherill Mesa Excavations).

*These publications are no longer available from the Superintendent of Documents, but may be ordered by title (and parenthetical code number) by writing to: Clearinghouse, U.S. Department of Commerce, Springfield, Virginia 22151. These reports are available in two forms: microfiche at 65¢ per document, or paper copy at $3.00 per volume, prepaid.

ARCHEOLOGICAL RESEARCH SERIES NUMBER SEVEN-B

Wetherill Mesa Studies
environment
of Mesa Verde, Colorado

James A. Erdman, Charles L. Douglas and John W. Marr

NATIONAL PARK SERVICE / U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON 1969

March 3, 1849

United States Department of the Interior
WALTER J. HICKEL, *Secretary*

This publication is one of a series of research studies devoted to specialized topics which have been explored in connection with the various areas in the National Park System. It is printed at the Government Printing Office and may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Price $3.50.

National Park Service
GEORGE B. HARTZOG, JR., *Director*

LIBRARY OF CONGRESS CATALOG CARD NUMBER: 72-600243

foreword

From 1959 to 1963, the National Park Service, with generous support from the National Geographic Society, made a comprehensive study of the archeology and ecology of Wetherill Mesa, in Mesa Verde National Park. Wetherill Mesa is being developed so that increasing numbers of visitors will be able to observe the evolution of a prehistoric Indian culture over some 700 years, both here and in the nearby and more familiar section of the park known as Chapin Mesa.

This is the second monograph of the Wetherill Mesa Project. The report not only provides substantive data on environmental variations at Mesa Verde and their bearing on the prehistoric settlement pattern and land use of the area, but also demonstrates the critical importance of such research to a fuller understanding of human ecology of the past elsewhere. James A. Erdman, now with the U.S. Geological Survey, Denver, and Charles L. Douglas, now on the staff of the Texas Memorial Museum, University of Texas, Austin, came to the Wetherill Mesa Project from the Institute of Arctic and Alpine Research, University of Colorado, in Boulder. John W. Marr is director of the Institute.

Additional reports in the Wetherill Mesa series will deal with several other aspects of the archeology and ecology of the area.

GEORGE B. HARTZOG, Jr. *Director*

acknowledgments

Without the contributions of many agencies and individuals this aspect of the scientific program of the Wetherill Mesa Project could not have been carried out.

First and foremost, our thanks go to the National Geographic Society, which provided financial support for the work.

We are grateful to the Ute Mountain Utes for granting permission to operate the station at the Lowest Mesa-top Site, M–1, on tribal lands.

The Institute of Arctic and Alpine Research, Boulder, Colo., organized and furnished some of the equipment for the research. Markley W. Paddock devised the initial program design and planned the instrumentation; John Clark supervised the installations; and David M. Gates, formerly of the National Bureau of Standards, Boulder Laboratories, and consultant to the Institute, assisted with the interpretation of the solar radiation data.

Appreciation is extended to William C. Bradley of the Geology Department, University of Colorado, for his advice on the section on geology and soils, and to William A. Weber of the University of Colorado herbarium for providing current plant nomenclature and for verifying critical material.

We are grateful to Harold C. Fritts and David G. Smith of the Laboratory of Tree-Ring Research, University of Arizona, for help with the data analysis. Fritts was responsible for enabling us to reduce and analyze the data through the University of Arizona's Computer Center, and made valuable suggestions in our interpretations. Smith was involved in the data handling both at Mesa Verde National Park and at Tucson. Our thanks go to him and to Thomas P. Harlan, also of the Tree-Ring Laboratory, for the dates for modern cores and burned samples collected at Park Point in Mesa Verde.

We are indebted to the Numerical Analysis Laboratory of the University of Arizona for donating computer time and for analyzing the environment data. Robert L. Baker of the Laboratory's Systems Engineering Department programed the monthly summaries.

For a better understanding of the Mesa Verde soils, and specifically for the profile descriptions of each station site, we are grateful to Orville A. Parsons of the Soil Conservation Service, Fort Collins, Colo. Parsons' reading of the manuscript is also appreciated.

Our thanks go to George A. King, architect, of Durango, Colo., who drafted the base map of Mesa Verde.

Our thanks go to the following members of the Wetherill Mesa Project staff: to laboratory assistants Pauline Goff, Natalia Ellis, and Ruth Chappell for data handling and preliminary analysis; to Marilyn Colyer for her help in the field on vegetation analysis and for the preparation of the graphs; and to project photographer Fred E. Mang, Jr., whose pictures were often taken under less-than-ideal conditions and from some rather hazardous spots. His sense of the fitting, yet dramatic, photograph gives our report a dimension it would not otherwise have had.

This publication is Contribution 41 of the Wetherill Mesa Project.

J. A. E., C. L. D., and J. W. M.

contents

illustrations

tables

CHAPTER 1

introduction

Mesa Verde is an imposing landmass that rises abruptly above the semiarid country of southwestern Colorado. It is a relatively flat tableland, between the high San Juan massif to the northeast and and the lower desert to the southwest. The mesa lies on the eastern edge of the Colorado Plateau physiographic province, "a land of gently folded sedimentary rocks eroded on a majestic scale into broad plateaus, precipitous mesas and buttes and dark canyons" (Hack, 1942, p. 3). This great landmass dips gently over a 15-mile stretch from an elevation of 8,500 feet at the northern escarpment to about 6,500 feet at the southern end. The mesa is not an unbroken tableland, as its Spanish name suggests. It is more a plateau than a mesa, but usage has firmly established the latter term. Moreover, scores of canyons dissect the once continuous surface into somewhat isolated segments, each of which is locally called a mesa (fig. 1).

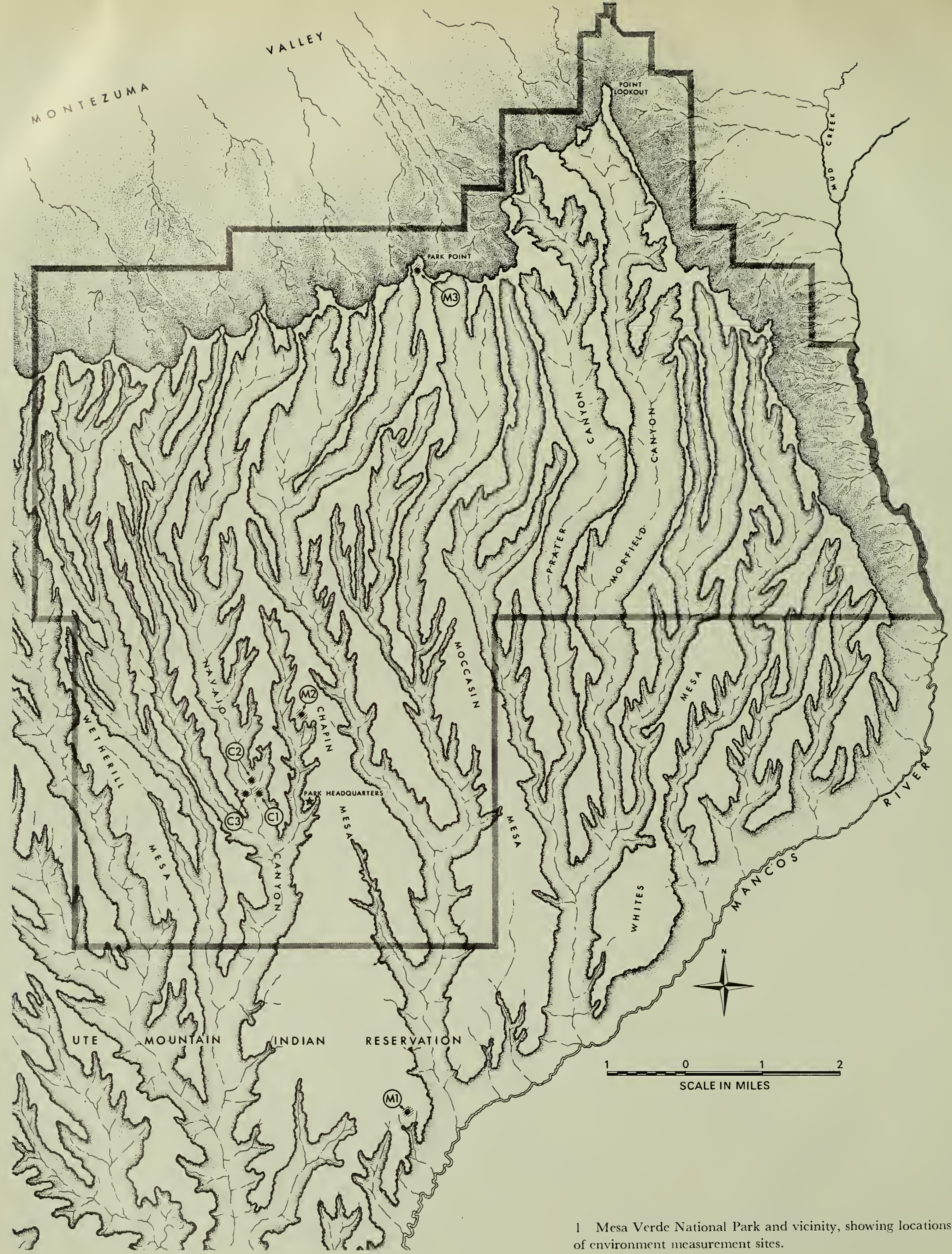
Mesa Verde is fascinating not only because of its spectacular terrain and interesting geology and biology, but because of its prehistoric occupation by aboriginal man. For about 700 years, up to the close of the 13th century, Pueblo Indians lived and farmed successfully here under difficult climatic and soil conditions. Their impact on the landscape is still visible in numerous and varied dwelling sites, midden deposits (often supporting sagebrush where forest normally occurs), and agricultural check-dam systems. What other features are ascribable to the Indians' activities constitute a tantalizing problem for ecologists. Following its abandonment around A.D. 1300, the mesa was essentially undisturbed until white settlers began moving into the area in the 1870's.

Part of the mesa became Mesa Verde National Park in 1906, but the landscape is so rugged that few studies had been made of the soils, atmospheric factors, biota, and ecological processes within it. The Wetherill Mesa Project provided an opportunity to fill many gaps in our knowledge of the total Mesa Verde environment. This report is concerned primarily with quantitative data on the atmospheric factors and vegetation of representative stand ecosystems in Mesa Verde.

GEOLOGY AND SOILS

The Mesa Verde is composed of marine sediments of Upper Cretaceous age. These rocks form a discrete geological unit, the Mesaverde group, whose members include the Cliff House sandstone, the Menefee formation, and the Point Lookout sandstone. The resistant Cliff House sandstone caps the mesa and is underlain by the Menefee formation, a coal-bearing deposit that outcrops on the steep canyon slopes. The lowest and least conspicuous member is the Point Lookout sandstone, exposed along the North Rim and in the deeper canyons of the south and west extremities of the mesa. The top two layers are primarily responsible for the rugged canyon-mesa terrain so characteristic of the area.

Headward erosion of the canyons, perhaps during more



1 Mesa Verde National Park and vicinity, showing locations of environment measurement sites.

moist climatic regimes, produced numerous large alcoves situated along the upper cliffs, many of which contain the ruins of cliff dwellings built by the prehistoric Indians. These alcoves have been sculptured by spring-sapping, a weathering process that weakens and undercuts the sandstone cliffs where they are in contact with the impervious shale strata. To a lesser degree, some of the shallower alcoves, called exfoliation caves, have resulted from release of confining pressures when erosion exposed rocks that were once deeply buried. (For further information on cave origins of this type, see Bradley, 1963.)

The regional and local geology have been described by Douglas Osborne (in Hayes, 1964). Osborne's discussion is based largely on the work of Hunt (1956) and Wanek (1959).

The soils are primarily wind-deposited loess in origin (Arrhenius and Bonatti, 1965), although along the upper reaches of Mesa Verde some residual soils are developed from weathered sandstone. Soil depth is extremely variable. Deep profiles occur at the heads of canyons, on alluvial-colluvial terraces, on the canyon floors, and on the broad mesa where the loess soil may reach depths of 15 feet. But soils are either very shallow or nonexistent in the mesa-top drainages and rim areas, on the canyon talus slopes, and on the narrow, more easily eroded ridges of the northern third of the mesa.

The carbonate content of the underlying sandstone, and consequently of the soils, also varies considerably. In the brush zone along the North Rim, the residual soils are darker colored and slightly acid, with little or no free lime (Roberts, MS.). They contrast sharply with the almost white, flaky soils encountered in the juniper-dominated woodland toward the southern end of the mesa. In this area the soil surface is highly calcareous, which may be due to different parent material, less precipitation, and higher temperatures.

Trewartha (1954, p. 286) states that "steppe [or semiarid] lands are often the recipients of large amounts of fine dust or loess blown out of the drier and less well protected deserts." Because of the relatively meager rainfall, leaching is not a serious detriment to soil productivity. Mineral plant foods are usually abundant. "Yet, because of the low and variable rainfall in which they develop, and to which they largely owe their quality, [semiarid lands] are not extensively used for crop production. It is the old story of fruitful soils and prolific climates seldom being areally coincident" (ibid). Nonetheless, as will be shown later, the prehistoric Pueblo Indian farmers made use of the Mesa Verde soils to a remarkable extent.

More detailed edaphic information is available in the soil reconnaissance reports of Wetherill Mesa by Roberts (MS.) and White (MS.). A standard soil survey of the area, made by Orville A. Parsons, will be published as a report of the Wetherill Mesa Project.

VEGETATION

The plants of Mesa Verde are part of the Sierra Madrean flora that occupies the Great Basin, Colorado Plateau, and the Sierra Madre of northern Mexico (Benson, 1957, p. 598). Vegetal material identified from the Wetherill Mesa Project's excavations and earlier collections indicate a prehistoric flora similar to that of the present day (Welsh, MS.).

Ecologically, the mesa is in the pinyon-juniper climax region that forms the lowest forest zone in the Rocky Mountains and is the only zone present on many of the low ranges of the Great Basin. The total geographic range of the climax region extends from eastern Oregon and southern Idaho southward along western Colorado, northeastern Arizona, and New Mexico. The trees at Mesa Verde grow relatively tall (up to 35 feet) and close together, producing a pinyon-juniper type unlike the scrubby trees in an open "pygmy woodland," which are characteristic of the climax region generally.

The almost continuous mantle of pinyon-juniper trees over the mesa gives an impression of monotonous homogeneity when viewed from the air. Walking through the forest, however, you find a surprising variety of plants. These plants are organized into several different stand-types because of subtle variations in slope, altitude, soil, the effects of fires, and the influences of prehistoric man.

Pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) are the dominant trees, but there are some small stands of Douglas-fir (*Pseudotsuga menziesii*), aspen (*Populus tremuloides*), and ponderosa pine (*Pinus ponderosa*). Cottonwood (*Populus fremontii*) and Rocky Mountain juniper (*Juniperus scopulorum*) are scattered throughout the area, the latter common along the northern escarpment. Douglas-fir, the most abundant of these less common trees, occurs in sheltered side canyons, seep areas, and at the higher elevations. It is the source of the names "Spruce Canyon" and "Spruce Tree House," probably through an error in identification. Aspen is restricted to the coves of the North Rim and some of the more moist and protected canyon sites. There are only a few scattered stands of ponderosa pine, and reproduction is limited. Gambel oak (*Quercus gambelii*) and Utah serviceberry (*Amelanchier utahensis*) are the dominants in a shrub zone caused by recurrent fires along the higher parts of the mesa, while big sagebrush (*Artemisia tridentata*) is common on the sandy loam terraces along the canyon floors and also on some prehistoric trash deposits on top of the mesas.

Fire has had an important effect on the vegetation. A reconnaissance of the larger burns and a study of aerial photographs show that fires have been more common in the higher, north part of the mesa than in the lower areas. Possibly the prehistoric Indians deliberately burned these upper parts of the mesa, which are of marginal farming value, in order to maintain the shrub vegetation, which supports a heavier game population than a pinyon-juniper forest approaching climax. Many fires, however, were undoubtedly started by lightning. The mountain brush vegetation in the North Rim area is relatively unstable. Pinyon reproduction has increased as a result of stringent fire-protection measures by the park, and the area is gradually becoming reforested.

The present-day vegetation probably closely resembles that which flourished before the prehistoric Indians entered the area. To be sure, today's dense oak thickets on abandoned terraces and on reservoirs behind check dams, as well as concentrations of sagebrush on many midden sites, were lacking in preoccupation time. But these vegetation units occupy only a small part of the mesa. As long as the Indians were active in the area, the vegetation was probably a patchwork of forest, agricultural fields, and brushland. Sagebrush may have been more abundant than it is today. It would have grown rapidly in abandoned fields and burned areas, and it was used in quantity for roofing material in the prehistoric structures. After the Indians left, the vegetation pattern changed through natural ecological processes and in due course most of the region returned to preoccupation conditions.

CLIMATE

According to Köppen's classification of world climates based on annual and monthly means of temperature and precipitation, Mesa Verde has a cold, middle latitude, semiarid climate (BSk of the Köppen system, see Trewartha, 1954, pp. 225–226). Trewartha (op. cit., p. 268) observes: "In general, the steppe [or semiarid type of dry climate] is a transitional belt surrounding the real desert and separating it from the humid climate beyond." Though it lies in an area of dry climate, Mesa Verde is closer to a humid than to a desert climate because of the proximity of the San Juan Mountain massif to the northeast and of the rest of the southern Rocky Mountains farther east.

The following statements by Trewartha (op. cit.) are pertinent to the intermountain region of which Mesa Verde is a part:

> Dry climates in the middle latitudes usually are found in the deep interiors of the great continents, far from the oceans, which are the principal sources of the atmosphere's water vapor. Further intensifying the aridity of the deep continental interiors is the fact that in both Eurasia and North America these locations are commonly surrounded by highlands that block the entrance of humid maritime air masses and of rainproducing storms (p. 280).
>
> The essential feature of a dry climate is that potential evaporation from the soil surface and from vegetation shall exceed the average annual precipitation. In other words, during a normal year the capacity of the atmosphere to acquire water evaporated from the soil surface and transpired from plants is greater than the water added to the soil through precipitation. In such a climate there is a prevailing water deficiency and a constant groundwater supply is not maintained, so that permanent streams cannot originate within such areas. It may be possible, however, for permanent streams to cross areas with dry climates . . . provided they have their sources in more humid regions (p. 267).

The Mancos River, which borders Mesa Verde and drains its many canyons, has its headwaters in the La Plata Mountains to the north. Within the mesa proper the only natural water supply available to man and other animal life comes from springs and seeps in the canyons.

A climatic summary of the immediate region is excerpted from Gittings (1941, p. 808):

> The distinct climatic feature of the western section [of Colorado] . . . is the comparative uniformity of the weather from day to day. Severe cold waves, common on the eastern plains, are comparatively rare. . . . There is a tendency for a high-pressure area to form in western Colorado in winter and to remain stationary for several days. When such a pressure distribution controls the weather, the sky is clear, the day temperatures are moderately high and uniform, and the nights are cold, though seldom excessively so except when the ground is covered with snow and where the air drainage is poor. Night temperatures depend largely on the topography, air drainage exerting a greater control than does the actual elevation. . . . In western sections of the State the most important part of the precipitation occurs in winter and early spring; January, February, and March are the months of heaviest snowfall. . . . In southwestern counties there is a marked tendency toward drought in late spring and early summer; June is practically rainless.

The following account of the recent climate of Mesa Verde is taken from the 41-year record (in part, shown in table 1) of the U.S. Weather Bureau station near the Mesa Verde National Park headquarters, and from a discussion by Erdman (MS.). The approximate location of the station is lat. 37° 12′ N. and long. 108° 29′ W. Its position and elevation (7,070 feet) make it as representative of the Mesa Verde physiographic unit as possible. Since 1923, the average annual precipitation has been 18 inches. The late winter months constitute one of the "wet seasons," February being one of the wettest months of the year with almost 2 inches of moisture. Most of the moisture during this period occurs as snow. Winters seem to be relatively mild, perhaps because of the predominantly sunny days. January, the coldest month, has a mean temperature of 29° F. and 19 inches of snowfall. The coldest recorded temperature (−20° F.) occurred during the severe nationwide cold wave of January 1963. According to Trewartha (1954, p. 181), in this climate "the winter season has many more large and steep-gradient cyclones and anticyclones than summer, so that

TABLE 1.—WEATHER DATA, MESA VERDE NATIONAL PARK

United States Weather Bureau station, Chapin Mesa, elevation 7,070 feet. Deviation of the 1962 and 1963 annual summaries from the 41-year record (1923–63)

Month	Air temperature, in degrees Fahrenheit															Precipitation, in inches					
	Maximum			Minimum			Mean maximum			Mean minimum			Mean of maximum and minimum			Water			Snow		
	41-year record	Deviation		41-year record	Deviation		41-year record	Deviation		41-year record	Deviation		41-year record	Deviation		41-year record	Deviation		41-year record	Deviation	
		1962	1963		1962	1963		1962	1963		1962	1963		1962	1963		1962	1963		1962	1963
Jan.	62	−9	−15	−20	+14	0	40	−1	−7	18	−2	−7	29	−1	−7	1.68	−.97	+.01	19.4	−7.7	−.2
Feb.	68	−9	−3	−15	+13	+18	45	−1	+3	22	+2	+3	33	+1	+3	1.82	+.51	−.44	17.6	+5.8	−8.6
Mar.	72	−5	−3	4	0	+9	50	−4	+2	26	−3	0	38	−4	+1	1.74	−.41	−.91	13.6	+3.8	−5.6
Apr.	84	−4	−9	9	+15	+2	61	+5	0	34	+4	−2	48	+4	−1	1.37	−.92	−.69	4.5	−4.5	−1.5
May	90	−10	−8	23	+5	+18	71	0	+6	43	−2	+4	57	−1	+5	.98	+.09	−.87	.4	−.4	−.4
June	101	−11	−7	32	+9	+7	83	−1	+1	52	−1	−1	68	−2	−1	.67	−.51	−.60	t.	0	0
July	102	−9	−6	43	+8	+10	88	−1	+1	57	+1	+2	72	0	+2	1.76	−1.39	+.30	0	0	0
Aug.	101	−5	−11	41	+8	+10	85	+3	−2	56	+2	0	70	+3	0	2.16	−1.95	+2.20	0	0	0
Sept.	94	−4	−8	28	+9	+18	78	0	+2	49	+2	+4	63	+2	+4	1.69	+.38	−.49	.2	−.2	−.2
Oct.	85	−9	0	13	+22	+20	66	+1	+5	39	+2	+7	52	+2	+6	1.63	+1.02	+.15	.9	−.9	−.9
Nov.	75	−8	−3	−3	+18	+20	51	+3	+3	28	+5	+2	40	+4	+2	1.03	+.66	−.32	5.5	+.4	−2.5
Dec.	67	−10	0	−6	+8	+8	42	+3	+1	21	+2	−1	32	+2	0	1.62	−.31	−1.00	16.0	−9.7	−8.0
Year	102	−6	−6	−20	+14	0	63	+1	+2	37	+1	+1	50	+1	+1	18.15	−3.80	−2.66	78.1	−13.4	−27.9

the cooler seasons have more variable weather than the warmer periods of the year." This proved to be the case in our own observations: temperatures were more variable during the winter than during the summer months.

Winter moisture is a critical factor as it determines the vegetational aspect of the landscape in late spring and early summer, typically the driest period of the growing season. Annuals and some perennials are highly dependent upon the surface moisture during these periods of low rainfall.

Although July is the hottest month of the year, with a mean temperature of 72° F. and a maximum of 102° F., the heat is tempered by rains which normally begin about this time of year. Rainfall reaches its peak in August (average of 2 inches) and decreases gradually into the autumn. During the late summer months the days begin with cloudless skies, but by noon, because of intense air turbulence, cumulus clouds develop and thunderstorms are common. Precipitation is usually localized and intense for a short period of time. Consequently, runoff is high and the precipitation is not nearly so effective as winter and spring precipitation in controlling the growth of indigenous plants.

During 1962 and 1963, Mesa Verde experienced subnormal rainfall and above-average temperatures, the latter occurring especially throughout the autumn months (table 1). Although the amount of precipitation between the 2 years did not differ appreciably, its pattern varied greatly. A sustained dry period prevailed throughout most of 1962, broken finally by heavy rains in the fall. The precipitation record approached the normal pattern the following year, although May and June were unusually dry and August was abnormally wet.

Lightning-induced fire is a perennial threat to parched vegetation. Prehistoric burns in the northern third of Mesa Verde National Park and on several large tracts in the southern part of the park were undoubtedly caused by lightning. More recently, in July 1934, a lightning fire burned about 5,000 acres on the northern third of Wetherill Mesa and adjacent areas (Watson, 1934, pp. 16–17). And in July 1959, lightning ignited a fire that burned 3,043 acres of forest and brush in Morfield Canyon in the southeastern part of Mesa Verde. Fire as a byproduct of summer storms has been an important ecological factor in the area.

In considering the relationship of man to his environment, a subject of no small importance in the prehistoric and present-day occupation of the region, Trewartha (1954, p. 283) makes this comment:

> Because of the greater precipitation than in deserts, the steppes are somewhat better fitted for human settlement, but this, together with the unreliable nature of the rainfall, also makes them regions of greater economic catastrophe. A succession of humid years may tempt settlers to push the agricultural frontier toward the desert, but here also drought years are sure to follow, with consequent crop failure and ensuing disaster.

In essence, then, and as we might well expect, the semiarid, broken landmass we call Mesa Verde suffers from erratic rainfall that affects not only plant and animal life but man, especially when his main sustenance derives from the soil itself.

design of the study

The scientific program of the Wetherill Mesa Project as envisioned by the project's supervisor, Douglas Osborne, included not only comprehensive archeological investigations on Wetherill Mesa but studies of the total environment of the Mesa Verde area. One approach in the latter range of studies was to obtain and compare precise quantitative data on selected environmental factors at sites that differed from one another in elevation or topography, over a period of at least 2 years. Such data on the present environment, it was reasoned, would contribute to studies of possible changes in the environment of the past, and ultimately lead to a fuller understanding of the prehistoric occupation of the area.

Since the Institute of Arctic and Alpine Research had operated an environment measurement program on the eastern slope of the Front Range in Colorado for 9 years (Marr, 1961), Osborne invited Marr and the Institute staff to plan the study, select and install the instruments, and provide technical supervision of the operation. Two of the authors, Erdman and Douglas, ecologists on the Wetherill Mesa Project staff, serviced the instruments and processed the data. As the study progressed, they made numerous improvements in the initial design and procedures. Other Wetherill Project personnel contributed in a variety of ways.

Harold C. Fritts of the Laboratory of Tree-Ring Research, University of Arizona, worked out, with Osborne, a dendroclimatological study to be integrated with the environment program. Its objective was to provide a basis for using tree rings as indicators of past climates (Fritts, Smith, and Stokes, 1965).

Six sites were chosen as samples of the environment gradient induced by changes in elevation along the tops of the mesas and by differences in topography within the canyons. The mesa-top sites were on Chapin Mesa and Park Point, and the canyon sites were in Navajo Canyon to the west (fig. 1). These sites, rather than sites on and adjacent to Wetherill Mesa, were chosen because of their accessibility to year-round visitation.

Station	Elevation, feet	Location
M–1	6, 650	Near the south end of Chapin Mesa.
M–2	7, 150	About 5 miles north of M–1 and near park headquarters.
M–3	8, 575	About 5 miles north of M–2 on Park Point, the highest point of Mesa Verde.
C–1	6, 500	West-southwest exposure slope.
C–2	6, 382	Canyon floor directly below and between C–1 and C–3.
C–3	6, 500	Directly opposite C–1 on northeast exposure slope.

We studied stand ecosystems (Marr, 1961) and collected information on the vegetation and soil as well as the weather. Since organisms, environment factors, and processes are interrelated, by knowing one an estimate can be made of the other components. For example, an area with vegetation and soil similar to our C–1 station probably has a similar total environment.

ENVIRONMENT FACTOR MEASUREMENTS

Measurements were taken from September 1961 through December 1963. The main body of data deals with solar radiation, air and soil temperature, precipitation, relative humidity, evaporation, wind, and soil moisture. In addition, at each station during the weekly servicing visit, observations were made on the type and amount of cloud cover, wind direction and velocity, and the depth and extent of snow cover. Stations were located in clearings where the effect of vegetation on the factors measured would be minimal. The hygrothermo-

2 Recording instruments at M–2. Within the shelter are a hygrothermograph, a 3-pen mercury thermograph, and maximum-minimum thermometers. On the roof is a pyrheliometer, and mounted on the side is an atmograph.

graphs and recording units of soil thermographs were in a standard Weather Bureau cotton region-type instrument shelters, with the floor about 4 feet above ground in each instance (fig. 2). The shelters were erected in the summer of 1961 and dismantled in the spring of 1964 after our study was completed.

The environment factors, except soil moisture, and the instrumentation for them are listed below:

The pyrheliometer was mounted on the top, and the atmograph was attached to one side, of each shelter. Rain gages were mounted on individual supports with their rims about 4 feet above the ground. Anemometers were mounted on a tree (fig. 3) or on utility poles (figs. 4 and 5), so that the instruments were several feet above the general level of tree crowns. Soil samples for gravimetric measurement of water content were collected at the edges of the clearings.

The Piche atmograph records evaporation from a standard 5.0 cm. filter disk provided with a continuous supply of distilled water; during dry intervals of high evaporation, we substituted 3.0 cm. filters. Wet and dry bulb temperatures were determined with a Bendix motor-aspirated psychrometer at each station visit when humidity was reasonably stable. These data verified the accuracy of the hygrograph record. Weather Bureau-type maximum and minimum thermometers mounted on the inside wall of the instrument shelter were read and reset at each servicing; these data gave a check on the accuracy of the thermograph trace. As a check of accuracy for the soil thermographs, a Kahl asphalt-type skewer thermometer was periodically inserted to the depth of each soil-temperature sensing unit.

Some difficulties were encountered over which we had no control. In spite of careful tests in the laboratory prior to installation, the M–2 and C–3 soil thermographs went out of adjustment for short periods, the M–2 instrument during the fall of 1962 and the C–3 instrument during November and December 1962. Also, recent calibration tests of the pyrheliometers suggest that although the instruments were in excellent agreement with one another the values recorded may have been higher than those which actually occurred.

The stations were serviced each week and on the last day of each month, all stations being visited on the same day except when adverse weather precluded this. Erdman or Douglas evaluated the raw data of each servicing in search of possible errors. Any adjustments indicated were recorded on the original data sheet or chart. Laboratory assistants transferred the data to initial summary tables. In the case of solar radiation,

Factor	Instrument	Station	Recording
Solar radiation	Belfort pyrheliometer	M–2 and C–2	Continuous.
Air temperature	Belfort hygrothermograph	M–2, M–3, C–1, C–2, and C–3.	Do.
	Bendix-Friez hygrothermograph	M–1	Do.
Soil temperature at 2, 6, and 12 inches.	Kahl 3-pen remote sensing mercury thermograph.	All stations	Do.
Precipitation	Standard 8-inch diameter precipitation gage.	M–1, M–2, M–3, and C–2	Weekly and monthly totals.
Relative humidity	Belfort hygrothermograph	M–2, M–3, C–1, C–2, and C–3.	Continuous.
	Bendix-Friez hygrothermograph	M–1	Do.
Evaporation	Piche atmograph	M–1, M–2, M–3, and C–2	Continuous from May through October.
Wind	Bendix-Friez or Belfort 3-cup totalizing anemometers.	M–1, M–2, M–3, and C–2	Weekly and monthly totals.

this task involved measurement of the area under the daily traces on the pyrheliograph chart with a compensating polar planimeter. This area under the curve was then converted to a gram calorie unit (gm. cal./cm.^{2}/day) by computer at the Numerical Analysis Center at the University of Arizona.

Correctness of the data transfer was insured by two laboratory assistants working together, one reading the original data and the other checking figures on the data transfer sheet. The initial data summaries were transferred to IBM punch cards at the Numerical Analysis Center. An IBM 1401 program, produced by Robert Baker, computed the daily means, monthly totals, and monthly averages, and printed the monthly summary tables. At Mesa Verde, annual summaries (see appendix) were compiled from the monthly summaries.

The summaries were checked by Marr and Institute assistants by comparing the data from the different stations and tracing apparently odd relationships back to the original data. (The original charts and printed and punched monthly summaries are filed at the Institute of Arctic and Alpine Research and are available for study by interested scientists.)

Soil Studies

The descriptions of soil profiles used in this report were supplied by Orville A. Parsons. The soil moisture constants of percent moisture at ⅓ and at 15 atmospheres (field capacity and permanent wilting percentage equivalents, respectively) were determined by pressure membrane techniques for soils collected at each station. The samples were collected and screened through a 2 mm. sieve at Mesa Verde. Measurements were made by the Department of Agronomy, Colorado State University, Fort Collins.

In order to determine how much the moisture tension values were in accord with the actual permanent wilting points of these soils, wheat seedlings were planted in four replicate samples of the soils from stand M–2, and the soils were allowed to dry until permanent wilting was reached. The percentage of moisture was then determined for each sample. The following results show the close agreement between the pressure membrane method and the seedling wilt method:

Sample depth	15 atmospheres		Permanent wilting point	
	Percent moisture	Range	Percent moisture	Range
2 inches	7. 1	2. 2	7. 5	2. 2
6 inches	10. 6	5. 2	10. 6	1. 2
12 inches	9. 3	2. 2	9. 8	2. 5

3 A 3-cup totalizing anemometer atop tree at the canyon-bottom site.

5 M–2, near park headquarters on Chapin Mesa, at 7,150 feet elevation, looking southwest. Note pioneer vegetation on the abandoned dirt tennis court.

Vegetation Studies

Native vegetation is regarded as the best expression of the totality of a climate. Köppen selected many of his climate boundaries with vegetation limits in mind (Trewartha, 1954, p. 225). The understory and, indeed, the appearance of the trees themselves serve as valuable indicators of the local environment.

Erdman studied the vegetation of each stand, using the point quarter method of Cottam and Curtis (1956) for features of mature trees, and ten 4- by 50-foot belt transects spaced at 25-foot intervals for tree reproduction data. Categories used in the reproduction study were: seedlings = less than 1 foot high; saplings = stems less than 2 inches in diameter; trees = stems more than 2 inches in diameter. A list was made of species observed in each community (see ch. 3, table 2), using the nomenclature in the checklist by Welsh and Erdman (1964), with certain up-to-date changes furnished by William A. Weber. Increment cores were collected from representative pinyons to get an estimate of the age of the stands. Dating of these samples was done according to the Douglass system (Glock, 1937).

Ages of the mature junipers could not be determined because of lobing and erratic growth.

← 4 The juniper-pinyon/bitterbrush community characteristic of M–1, near the southern end of Chapin Mesa, at 6,650 feet elevation. The 30-foot anemometer support indicates the stunted nature of the trees, their height ranging from 15 to 20 feet. Note the paucity of the understory.

CHAPTER 3

description of the stands

LOWEST MESA-TOP SITE, M-1

This site was near the south end of Chapin Mesa, about 5 miles from park headquarters (fig. 1). The lowest of the mesa-top sites, at 6,650-foot elevation, M–1 was on a broad, level ridgetop flanked by two shallow washes that empty into the 1,000-foot deep Mancos River canyon about ¼ mile away.

The vegetation is a juniper-pinyon/bitterbrush woodland with sparse herbs (fig. 4). Ephemeral spring flowers are important in the ground cover. All species observed in the stand are listed in table 2; quantitative data on trees are given in table 3. Ten of the largest trees were 300 to 400 years old, with the oldest pith date being A.D. 1529. The trees are small and widely spaced, and bitterbrush (*Purshia tridentata*) and black sagebrush (*Artemisia nova*) are common in openings between them. Herbs are conspicuous only during the spring and early summer growing season. Some of the most common ones are mutton grass (*Poa fendleriana*), vetch (*Astragalus wingatanus*), and phlox (*Phlox hoodii*).

The soils at the lower elevations of Mesa Verde are generally high in calcium carbonate, due in part to the nature of the underlying sandstone and in part to low rainfall and high temperatures. Even though soils are relatively shallow in the M–1 area, the ground surface is free of rock material. According to Parsons, the soils at this site are quite variable in depth as well as texture, but the dominant type has been classified as Penrose channery loam. Montvale fine sandy loam also occurs in small amounts. The soil profile in table 4 is typical of the M–1 soils.

The fine texture of the soil plays an important role in the relationship of soil moisture to the growth of the plant community. As shown in table 5, the storage capacity of growth-water in the heavy soils at M–1 is relatively high, especially when compared to that of the soils at most of the other sites.

Once the soil dries out, however, and this occurs quite early in the year, a large amount of water is required to moisten the ground to the depth where roots are located. Moreover, because of the sparse vegetational cover, even a light rain will induce splash erosion of the surface particles, causing the pore spaces to clog and subsequent rainfall to be largely lost as runoff. Thus, in the coarse to fine loamy soils found at M–1, only a small amount of the precipitation percolates into the ground; this is especially true during the summer, when rainfall is heavy. This phenomenon is shown graphically in figure 15 (see ch. 4). The autumn frontal storms of 1962 wet the soil down to the 12-inch level, whereas the 1963 summer thunderstorms were not so effective.

Data for the atmospheric and soil factors are presented in the appendix. Some of the features commonly used by ecologists to characterize environments are given in table 6.

There was less precipitation and a greater variation between the 2 years of observations at M–1 than at the other five sites. The highest wind velocity measured was 30 m.p.h., in October, when a storm was approaching. A mantle of snow persisted only from early January to early or mid-March. The frost-free period varied from 166 days in 1962 to 171 days in 1963. This period in each year extended from mid-May through October.

Plant growth began at M–1 earlier in the spring than at the other mesa-top stands. Several spring perennials, *Arabis selbyii*, *Phlox hoodii*, and *Poa fendleriana*, were in flower by late March.

This type of stand is extensive at the lower elevations on the southern part of Mesa Verde (Erdman, MS.). Evidence from vegetational analyses and from tree-ring

TABLE 2.—LIST OF SPECIES OBSERVED IN THE ENVIRONMENT MEASUREMENT SITES

Species	Sites					
	Mesa top			Canyon		
	M–1	M–2	M–3	C–1	C–2	C–3
TREE LAYER						
Juniperus osteosperma (Torr.) Little	[1] X	X	X	X	X	X
Juniperus scopulorum Sarg			X			
Pinus edulis Engelm	X	X	X	X	X	X
Pseudotsuga menziesii (Mirb.) Franco			X			
SHRUB LAYER						
Amelanchier utahensis Koehne			X	X		X
Artemisia nova A. Nels	X		X			
Artemisia tridentata Nutt				X	X	X
Atriplex canescens (Pursh) Nutt				X	X	
Cercocarpus montanus Raf			X	X		X
Chrysothamnus depressus Nutt	X		X			
Chrysothamnus nauseosus (Pall.) Britt				X	X	
Chrysothamnus viscidiflorus (Hook.) Nutt					X	
Ephedra viridis Coville	X			X		X
Fendlera rupicola A. Gray			X			X
Gutierrezia sarothrae (Pursh) Britt. & Rusby	X			X	X	X
Philadelphus microphyllus A. Gray						X
Purshia tridentata (Pursh) DC	X			X		
Quercus gambelii Nutt			[2] X°		X	X
Rhus trilobata Nutt. ex T. & G					X	
Ribes leptanthum A. Gray					X	
Stanleya pinnata (Pursh) Britt				X		
Symphoricarpos oreophilus A. Gray			X°	X	X	X
Tetradymia canescens DC			X			
Yucca baccata Torr	X	X	X	X		X
GRASS AND FORB LAYER						
Agropyron smitthii Rydb				X	X	X
Bouteloua gracilis (H. B. K.) Lag					X	
Bromus tectorum L				X	X	X
Hilaria jamesii (Torr.) Benth				X		
Koeleria gracilis Pers			X		X	
Oryzopsis micrantha (Trin. & Rupr.) Thurb					X	
Poa agassizensis Boivin & D. Löve					X	
Poa fendleriana (Steud.) Vasey	X	X	X	X	X	X
Sitanion longifolium J. G. Smith	X		X°	X	X	X
Stipa comata Trin. & Rupr			X			
Achillea lanulosa Nutt			X°		X	
Amaranthus hybridus L					X	
Androsace septentrionalis L					X	X
Antennaria dimorpha (Nutt.) T. & G			X			
Antennaria parvifolia Nutt						X
Arabis drummondii A. Gray			X			
Arabis pulchra M. E. Jones ex S. Wats	X					
Arabis selbyi Rybd	X	X	X	X		X
Arenaria congesta Nutt. ex T. & G						
Artemisia ludoviciana Nutt			X°	X	X	X
Aster arenosus Blake				X		
Astragalus calycosus Torr. ex S. Wats	X					
Astragalus flexuosus Dougl. ex Hook				X	X	
Astragalus lentiginosus Dougl				X		
Astragalus schmollae C. L. Porter		X				
Astragalus scopulorum T. C. Porter		X	X			
Astragalus wingatanus S. Wats	X					
Balsamorhiza sagittata (Pursh) Nutt			X			
Calochortus nuttallii Torr	X					
Castilleja chromosa A. Nels			X	X		
Castilleja linariaefolia Benth. in DC					X	
Chaenactis douglasii (Hook.) H. & A				X		X
Chenopodium fremontii S. Wats :		X		X		X
Claytonia lanceolata Pursh			X°			
Comandra umbellata (L.) Nutt			X			
Crepis cf. *occidentalis* Nutt			X			
Cryptantha bakeri (Greene) Payson	X			X		X
Cryptantha gracilis Osterhout	X					X
Cymopterus bulbosus A. Nels			X			
Cymopterus purpurascens (A. Gray) M. E. Jones						X
Cymopterus purpureus S. Wats	X			X		
Delphinium nelsonii Greene			X°			
Descurainia pinnata (Walt.) Britt	X					
Draba reptans (Lam.) Fern	X					X
Echinocereus coccineus Engelm				X		

See footnotes at end of table.

TABLE 2.—LIST OF SPECIES OBSERVED IN THE ENVIRONMENT MEASUREMENT SITES—Continued

Species	Sites					
	Mesa top			Canyon		
	M–1	M–2	M–3	C–1	C–2	C–3
GRASS AND FORB LAYER—continued						
Erigeron divergens T. & G.						X
Erigeron flagellaris A. Gray			X			X
Erigeron pumilus Nutt			X			
Erigeron speciosus (Lindl.) DC			X°			
Eriogonum alatum Torr	X					
Eriogonum jamesii Benth				X	X	
Eriogonum racemosum Nutt		X	X			
Eriogonum umbellatum Torr		X	X	X		
Euphorbia fendleri T. & G.	X					
Frasera albomarginata S. Wats	X					
Fritillaria atropurpurea Nutt			X			
Galium coloradoense W. F. Wright				X		X
Gilia ophthalmoides Brand						X
Haplopappus armerioides (Nutt.) A. Gray	X			X		
Haplopappus nuttallii T. & G.	X					
Hymenopappus filifolius Hook	X					
Hymenoxys acaulis (Pursh) Parker	X					
Impomopsis aggregata (Pursh) V. Grant					X	
Lappula redowskii (Hornem.) Greene					X	
Lathyrus pauciflorus Fern			X°			
Lepidium montanum Nutt				X	X	X
Lesquerella rectipes Woot. & Standl	X					
Lithospermum incisum Lehm						X
Lithospermum ruderale Dougl. in Lehm			X			
Lomatium dissectum (Nutt.) Math. & Const			X°			
Lomatium grayi Coult. & Rose			X			
Lomatium simplex (Nutt.) Macbr			X			
Lupinus caudatus Kellogg		X	X			
Machaeranthera bigelovii (A. Gray) Greene				X	X	
Mammillaria vivipara (Nutt.) Haw	X					
Melilotus officinalis (L.) Lam					X	
Mertensia fusiformis Greene			X°			
Microsteris humilis (Dougl.) Greene					X	X
Mirabilia multiflora (Torr.) A. Gray						X
Moldavica parviflora (Nutt.) Britt					X	
Oenothera caespitosa Nutt					X	
Opuntia phaeacantha Engelm. ex Gray				X		
Opuntia polyacantha Haw	X	X			X	X
Pedicularis centranthera A. Gray	X	X				X
Penstemon bridgesii A. Gray				X		X
Penstemon eatonii A. Gray				X		
Penstemon linarioides A. Gray		X		X		X
Penstemon strictus Benth	X		X°			
Petradoria pumila (Nutt.) Greene	X		X			
Phacelia heterophylla Pursh			X°			
Phlox hoodii Richardson	X			X	X	X
Phlox longifolia Nutt	X			X	X	
Physaria australis (Payson) Rollins	X					
Polygonum sawatchense Small		X				
Portulaca oleracea L.					X	
Sclerocactus whipplei (Engelm. & Bigel.) Britt & Rose	X					
Senecio multilobatus T. & G. ex A. Gray	X			X	X	X
Sisymbrium linifolium Nutt					X	X
Solidago sparsiflora A. Gray					X	
Sphaeralcea coccinea (Pursh) Rydb				X		
Sphaeralcea parvifolia A. Nels					X	
Streptanthus cordatus Nutt. ex T. & G.	X			X		
Taraxacum laevigatum (Willd.) DC					X	
Townsendia incana Nutt	X					
Zygadenus venenosus S. Wats			X			

---

[1] Boldface X indicates species dominant within the stand.

[2] X° indicates species occurs in both the oak thickets and the sagebrush openings at M–3; those restricted to the thickets are *Quercus gambelii, Lathyrus pauciflorus. Ligusticum porteri,* and *Phacelia heterophylla.*

studies indicates that the stand has been relatively undisturbed during the past 400 years and is probably climax; that is, a steady-state condition in which no further directional change in vegetation takes place under prevailing environmental conditions (Hanson and Churchill, 1961, p. 159). However, the present-day proportion of seedlings of the two tree species suggests that some change may be in progress. Among the mature trees, juniper is dominant over pine, but there are more pine than juniper seedlings. This combination of stand characteristics may indicate that pine seedlings are more successful than juniper in getting established but their

TABLE 3.—TREE DATA AT M-1

A. Point quarter analysis based on 10 points

Species	Number of trees	Average distance, feet	Total basal area, square inches	Average B.A./diameter	Density trees/acre	Relative—			Importance value
						Density (%)	Frequency (%)	Dominance (%)	
Pinus edulis	22	....	645	29/6	156	55	50	30. 2	135. 2
Juniperus osteosperma	18	....	1, 493	83/10. 5	127	45	50	69. 8	164. 8
Total	40	12. 4	2, 138	54/8	283	100	100	100. 0	300. 0

B. Pinyon-juniper reproduction based on number of individuals that occurred within ten 4 x 50-foot belt transects

Species	Number of—			Total
	Seedlings	Saplings	Trees	
Pinus edulis	24	22	10	56
Juniperus osteosperma	12	3	11	26

survival rate is lower, so that the overall proportions are constant. Or it is possible that the present regional climate may be favoring a subtle shift toward pine dominance (Erdman, MS.). There are differences in the germination characteristics of the two species. Pinyon germinates as soon as optimum moisture and temperature conditions occur (Meagher, 1943), whereas juniper requires exposure to low temperatures that occur only in winter (Johnsen, 1959). Consequently, one might expect to find more pine seedlings, at least in some seasons. Unfortunately, there are no data on seedling survival.

The occurrence of bitterbrush on these heavy soils seems to be an exception to recent findings relating to the ecology of this species. Nord (1959, p. 2) states that in California this shrub does not generally develop where the soil is calcareous within 3 feet of the surface and is either imperfectly or poorly drained.

Bitterbrush, so common in this stand-type, is undoubtedly an important factor in the abundance of deer, as it is one of their favorite browse plants.

TABLE 4.—SOIL PROFILE UNDERLYING THE M-1 JUNIPER-PINYON/BITTERBUSH STAND*

Horizon	Depth, inches	Description
A_1	0–3	Brown (10YR 5/3 dry) to dark brown (10YR 3/3 moist) channery loam; weak fine platy structure, breaking to moderate very fine granular; consistence soft dry and friable moist; many fine roots and pores; about 20 percent sandstone and shale channery; strongly calcareous; lower boundary clear and smooth.
C_{ca1}	3–6	Pale brown (10YR 6/3 dry) to dark brown (10YR 4/3 moist) channery loam; moderate fine granular structure; consistence slightly hard dry and friable moist; many fine roots and root casts; approximately 25 percent sandstone and shale channery; some small chalky concretions; violently calcareous; lower boundary gradual and wavy.
C_{ca2}	6–11	Light yellowish brown (2.5Y 7/3 dry) to brown (2.5Y 5/3 moist) channery loam; weak coarse subangular blocky structure; consistence hard dry and firm moist; somewhat sticky and plastic when wet; 33 percent sandstone and shale channery; a few very fine patchy clay skins show on rock surfaces; few small chalky concretions and cicada casts; violently calcareous; lower boundary clear and smooth.
C	11–17	Very pale brown (10YR 7/3 dry) to brown (10YR 5/3 moist) light clay loam; massive structure; slightly hard dry and firm moist; slightly sticky wet; fine roots somewhat matted between sandstone fragments; approximately 50 percent sandstone and shale channery; strongly calcareous; lower boundary clear and smooth.
R	17+	Interbedded sandstone and shale with numerous tongues of overlying horizon extending into cracks in rock.

*Soil classified as Penrose channery loam.

TABLE 5.—SOIL MOISTURE CONSTANTS IN PERCENT DRY WEIGHT*

Moisture constant	Depth, inches	Sites					
		M-1	M-2	M-3	C-1	C-2	C-3
Field capacity	2	15. 0	12. 5	12. 1	17. 2	7. 5	9. 1
	6	19. 6	20. 0	14. 0	18. 6	5. 6	11. 4
	12	20. 4	16. 7	....	....	5. 7	......
Permanent wilting percent	2	8. 1	7. 1	7. 2	10. 1	4. 3	5. 0
	6	11. 6	10. 6	8. 9	10. 1	3. 1	6. 3
	12	12. 4	9. 3	....	....	3. 5	......
Storage capacity of growth-water	2	7. 0	5. 5	4. 9	7. 1	3. 2	4. 1
	6	7. 9	9. 5	5. 2	8. 5	2. 5	5. 1
	12	8. 0	7. 4	....	....	2. 2	......

*Based on triplicate samples and determined by the moisture tension method.

MIDDLE MESA-TOP SITE, M–2

The M–2 site was selected as representative of a type of stand that occurs about midway between the northern and southern extremities of Chapin Mesa. It was at 7,150 feet elevation, about 1 mile north of park headquarters and within one-half mile of the Weather Bureau station. Instruments were placed in a clearing that had served as a dirt tennis court between 1937 and 1942 (fig. 5).

The vegetation is a pinyon-juniper/mutton grass community in which trees and grass are conspicuous and dominant, while the shrubs common in other parts of Mesa Verde are absent from most stands of this type (fig. 6). Mutton grass (*Poa fendleriana*) is the understory dominant, but the swordlike leaves of yucca (*Yucca baccata*) occasionally break the monotony of the predominantly tree-grass landscape. There are fewer plant species in this stand than in any of the others studied. Data on the two species of trees are given in table 7. The trees are the largest and the vegetation is the most dense of the six stands investigated. Trees are up to 30 feet tall, about twice as high as those at M–1, and the largest pine and juniper were 17 and 26 inches in diameter, respectively. The 10 largest pinyon trees were an average of 265 years old, the oldest being 362 years old (pith date, A.D. 1601). These data illustrate the problem of estimating age from size: a 16-inch-diameter tree was 320 years old, whereas a 17-inch neighbor was almost 100 years younger.

6 The pinyon-juniper/mutton grass community characteristic of M–2. Mutton grass and broad-leafed yucca are the only conspicuous understory plants. The forest here attains a height of about 35 feet, the maximum height on Mesa Verde.

The surface soils at M–2 are loams, with underlying clay loams, and are part of an extensive soil type found at Mesa Verde, probably covering the greatest area on the mesa tops at this elevation. As can be seen from table 8, the upper 3 feet of the profile are noncalcareous, or only slightly calcareous, and consist of an older soil buried by water-deposited and eolian sediments of uniform texture. This soil has been classified as Witt loam, although at M–2 it is somewhat less well developed and the underlying sandstone bedrock occurs only 4 feet below the surface. The profile at the type location on Chapin Mesa is nearly 10 feet deep, and similar soils at pithouse excavations rest on the Cliff House sandstone at depths ranging from 4 to 15 feet (Roberts, MS.).

The soil moisture constants for M–2 are given in table 5. The high silt and clay content of the soil probably favors establishment of grasses over the deeper-rooted shrubs, because fine-textured soils tend to retard root penetration. The shrubby plants on Mesa Verde are generally most abundant on the shallower soils along the mesa rims, in the coarse soils of the canyon talus slopes, or on the narrow ridges to the north.

Environment data are given in table 6 and the appendix. The maximum wind gust measured was 36 m.p.h. A comparison of the M–2 data with that from the Weather Bureau station is made in Chapter 4.

One important finding is the quantitative effect of cloudiness on the amount of solar radiation that reaches the earth's surface. The influx of solar radiation was 644 gm. cal./cm.^{2}/day in August of 1962, a month which

7 M–3, on the North Rim, at 8,575 feet elevation, looking south to Mesa Verde tableland, in late winter.

TABLE 6.—SOME CLIMATIC FACTORS OF THE MESA-TOP SITES

Factor	1962			1963		
	M–1	M–2	M–3	M–1	M–2	M–3
Air temperature (in degrees Farenheit):						
January:						
Maximum	46	52	50	44	44	44
Mean maximum	37	38	31	34	32	30
Minimum	–2	–11	–5	–23	–26	–20
Mean minimum	13	13	16	11	8	15
Mean	25	26	24	22	20	23
July:						
Maximum	97	91	84	97	93	86
Mean maximum	89	84	77	91	86	79
Minimum	46	48	47	52	50	50
Mean minimum	56	54	55	59	56	58
Mean	73	69	66	75	71	68
Annual:						
Maximum	98	94	88	97	93	86
Month	Aug.	Aug.	Aug.	July	July	July
Mean maximum	64	62	54	64	61	55
Minimum	–3	–11	–5	–23	–26	–20
Month	Feb.	Jan.	Jan.	Jan.	Jan.	Jan.
Mean minimum	36	35	36	37	34	37
Mean	50	49	45	50	48	46
Frost-free period, days	166	161	162	171	171	171
Last freeze in spring	22 May	28 May	28 May	12 May	12 May	12 May
First freeze in autumn	5 Nov.	6 Nov.	7 Nov.	31 Oct.	31 Oct.	31 Oct.
Relative humidity (in percentage):						
Lowest	1	5	9	4	8	13
Month	May	May	May	Apr.	May	Nov.
Lowest monthly mean	22	36	35	29	33	36
Month	June	June	June	May	May	May
Annual mean	43	53	51	50	52	54
Precipitation (inches):						
Monthly total:						
Highest	2. 38	2. 74	2. 94	3. 96	4. 54	7. 62
Month	Oct.	Oct.	Oct.	Aug.	Aug.	Aug.
Lowest	0. 09	0. 20	0. 39	0. 02	0. 07	0. 07
Month	June	June	Apr.	June	June	June
Annual total	9. 17	15. 80	18. 86	13. 88	15. 04	18. 81
Wind velocity (in miles per hour):						
Monthly mean:						
Highest	7. 0	6. 0	12. 3	7. 3	6. 5	10. 7
Month	May	Apr.	Jan.	Apr.	Apr.	Apr.
Lowest	4. 9	4. 1	8. 2	4. 4	4. 1	7. 5
Month	Dec.	Dec.	Dec.	Jan.	Dec.	Oct.
Annual mean	6. 0	5. 0	10. 3	5. 9	5. 3	9. 1

TABLE 7.—TREE DATA AT M–2

A. Point quarter analysis based on 10 points

Species	Number of trees	Average distance, feet	Total basal area, square inches	Average B.A./diameter	Density trees/acre	Relative—			Importance value
						Density (%)	Frequency (%)	Dominance (%)	
Pinus edulis	30	....	1, 273	42/ 7.5	270	75	58.8	59	192.8
Juniperus osteosperma	10	....	883	88/10.5	90	25	41.2	41	107.2
Total	40	11	2, 156	54/ 8.5	360	100	100.0	100	300.0

B. Pinyon-juniper reproduction based on number of individuals that occurred within ten 4 x 50-foot belt transects

Species	Number of—			Total
	Seedlings	Saplings	Trees	
Pinus edulis	44	15	31	90
Juniperus osteosperma	19	13	6	38

had relatively little cloudiness, and it dropped to 514 (a 20-percent decrease) in August of 1963, a period of considerable cloudiness.

The frost-free period at M–2, lasting from the latter part of May through October, was 161 days in 1962 and 171 days in 1963. It is interesting that in 1963 the frost-free season was the same at both M–1 and M–2, although there is an elevational difference of 500 feet between the sites. Snow covered the ground from mid-December to

8 A black sagebrush-grass community typical of the openings in the mountain brush zone near M–3. In addition to several pinyon trees (one at left), many seedlings and saplings have become established here. Oak thicket at right.

the latter part of March during the winters of 1961–62 and 1962–63.

Flowering of the early perennials began in April of 1963, several weeks later than at M–1.

The total character of this forest stand suggests that the site provides near optimum growing conditions for both pinyon and juniper. This stand type is an important climax ecosystem on the mesa, because it occurs on the broad mesa tops in an altitudinal belt across the entire Mesa Verde landscape where there is a thick mantle of soil. It is a relatively tall, dense forest compared to the M–1 type and those in most other parts of the pinyon-juniper climax region of the Southwest, and it thereby gives ecological uniqueness to Mesa Verde.

HIGHEST MESA-TOP SITE, M-3

The M–3 site (fig. 7) was located at Park Point, an 8,575-foot ridge that is the highest point in Mesa Verde. This unique setting, providing a spectacular view of the surrounding country, made it our windiest site. As shown in figure 1, this site was on the upper escarpment, or North Rim, of Mesa Verde, about 5 miles north of and 1,500 feet higher than park headquarters and the area of the M–2 site.

The mountain brush zone so prevalent along the North Rim is really a patchwork of dense thickets of oak and serviceberry, interspersed with openings dominated by black sagebrush. Within this patchwork many coni-

9 An oak thicket in the mountain brush vegetation near M–3. This thicket, about 10 feet tall, recovered after a fire swept over the ridge in the mid-19th century. The major understory species are mutton grass and snowberry.

fers are gradually becoming established. These are pinyon, primarily, and some junipers (*Juniperus osteosperma* and *J. scopulorum*) and Douglas-fir (*Pseudotsuga menziesii*).

The vegetation of the openings consists of a large number of species, and the foliage cover is extensive. Black sagebrush is the dominant species in the community, but a few trees and several saplings and seedlings of pinyon are established in the sample opening. Black sagebrush is a long-lasting successional dominant like big sagebrush, but it seems to be better adapted to shallow soils than the latter. At present, it covers the roadbeds along the North Rim that were abandoned in the early 1930's.

Because the study area is a complex of shrub stands, rather than being a continuous forest as in the other areas, the vegetation data consist only of a list of plants (table 2) present in the two types of local stands—in other words, a black sagebrush opening (fig. 8) and an oak thicket (fig. 9).

Soils at M–3 (table 9) are classified as Mughouse stony loam. The Mughouse series includes well-drained, noncalcareous Brown soils which are developing in residual materials derived from the underlying sandstone and interbedded shales. These are the typical soils of the upland hills and ridges along the North Rim. The soils at Park Point are somewhat darker colored than average and a hint of A_2 horizonation may be found under the older stands of oak brush. Soil depth is quite variable,

TABLE 8.—SOIL PROFILE UNDERLYING M–2 PINYON-JUNIPER/MUTTON GRASS STAND*

Horizon	Depth, inches	Description
A_1	0–2	Brown (7.5YR 5/3 dry) to dark brown (7.5YR 4/3 moist) loam; weak to moderate medium platy breaking to moderate very fine granular structure; consistence soft dry, and very friable moist; noncalcareous; lower boundary clear and smooth.
B_1	2–5	Reddish brown (5.0YR 5/4 dry) to (5.0YR 4/4 moist) clay loam; moderate coarse subangular blocky structure breaking to moderate medium and fine subangular blocks; consistence hard dry and very friable moist; thin patchy clay film on peds; very many fine pores; noncalcareous; lower boundary clear and smooth.
B_{21t}	5–14	Light reddish brown (5.0YR 6/4 dry) to reddish brown (5.0YR 4/4 moist) clay loam; weak medium prismatic structure breaking to moderate medium subangular blocks; consistence very hard dry and friable moist; thin almost continuous clay skins; noncalcareous; lower boundary clear and smooth.
A_{1b}	14–22	Light brown (7.5YR 6/4 dry) to dark brown (7.5YR 4/4 moist) light clay loam; weak medium prismatic structure breaking to moderate medium subangular blocky structure; consistence very hard dry and friable moist; calcareous in spots and patchy films on outer surface of soil peds; lower boundary gradual and smooth.
B_{2b1}	22–34	Light reddish brown (5.0YR 6/4 dry) to reddish brown (5.0YR 4/4 moist) clay loam; moderate to strong medium prismatic structure breaking to moderate or stronger medium angular blocky structure; continuous clay films; consistence extremely hard dry and friable moist; very many fine pores; chalky spots and lime films on outside of soil peds with some disseminated lime; lower boundary gradual and smooth.
B_{3bca}	34–43	Light reddish brown (5.0YR 6/4 dry) to reddish brown (5.0YR 4/4 moist) clay loam; weak medium prismatic structure breaking to weak medium subangular blocky structure; thin patchy clay films; chalky spots with films and disseminated lime; lower boundary gradual and wavy.
C_{cab}	43–47	Pink (7.5YR 7/4 dry) to brown (7.5YR 5/4 moist) loam; massive structure; consistence very hard dry and friable moist; almost caliche; lower boundary abrupt and smooth.
R_1	47	Sandstone.

*Soil classified as Witt loam.

ranging from 18 inches for the weather station profile (table 9) to 43 inches in the opening shown in figure 8. This, however, approximates the range in depth to bedrock for the series (20 to 40 inches). A considerable portion of the station site is covered by a pavement of sandstone slabs and channery. The profile in table 9 was described from the station site, where the ridge slopes south from 5 to 10 percent. Under the oak thickets there would be a thicker A_1 horizon with a deep litter cover.

In spite of the relatively low storage capacity of growth water in these soils, their shallow depth and heavy charge of rock fragments probably induce quite a favorable moisture regime.

The large amount of coarse rock and gravel in these soils creates more pore space and increases their permeability to rainfall. In addition, much of the underlying parent material is an unconsolidated, weakly cemented residuum which allows deeper wetting. Thus the underlying bedrock may be an important source of moisture, acting as a temporary reservoir. These coarse-textured soils also favor root penetration.

TABLE 9.—SOIL PROFILE UNDERLYING M–3 MOUNTAIN BRUSH VEGETATION*

Horizon	Depth, inches	Description
A_1	0–4	Gray brown (10YR 5/2 dry) to very dark gray brown (10YR 3/2 moist) stony loam; strong very fine granular structure; consistence soft dry and very friable moist; approximately 25 percent sandstone channery and stone; noncalcareous; lower boundary clear and smooth.
B_1	4–8	Brown (10YR 5/3 dry) to dark brown (10YR 3/3 moist) stony clay loam; moderate to strong fine angular blocky structure; hard dry and friable moist; thin patchy clay films on faces of soil peds and on some of the sandstone; approximately 50 percent of horizon is sandstone channery and stone; noncalcareous; lower boundary clear and and smooth.
B_{2t}	8–13	Light olive brown (2.5Y 5/3 dry) to olive brown (2.5Y 4/3 moist) stony heavy clay loam; strong fine angular blocky structure; extremely hard dry and very firm moist; thin nearly continuous clay skins on surfaces of soil peds and sandstone rock; approximately 50 percent sandstone rock and channery; noncalcareous; lower boundary gradual and smooth.
B_3	13–18	Variegated colors ranging from light brownish gray (2.5Y 6/2 dry) and light olive brown (2.5Y 5/4 dry) to grayish brown (2.5Y 4/2 moist) and olive brown (2.5Y 5/5 moist) clay loam extremely hard dry and firm moist; thin patchy clay films on soil peds and rock surfaces; approximately 50 percent sandstone flags and channery; noncalcareous; lower boundary clear and smooth.
R	18+	Sandstone and interbedded clay shale with numerous tongues of overlying horizon filling cracks in bedrock.

*Soil classified as Mughouse stony loam.

One rarely visits the Park Point ridge without experiencing a conspicuous feature of this site—strong wind. Wind velocities at the Park Point station were almost twice those measured at the other stations, and they seem to be less patterned than those occurring at the other stations. For reasons we cannot explain, the early part of 1962 was exceptionally windy at the North Rim site; however this was not the case at the lower elevations (fig. 19).

Although gusts of wind up to 40 m.p.h., were recorded at M–3, little is known about their duration or frequency. As Daubenmire (1959, p. 269) stresses, mean velocities for long intervals of time can be very misleading; winds of gale proportions may blow for a few minutes, yet not be indicated in the weekly or monthly record.

Wind has an indirect bearing on the precipitation data at M–3. Measurement of precipitation is difficult at any site, but where wind velocities are high, as at Park Point, the difficulties are compounded. According

10 The Navajo Canyon setting of the canyon-bottom and slope sites, looking north.

to Conrad and Pollak (1950, pp. 14–15), "the amount of water or snow collected in the ordinary gage depends, to a certain degree, upon the wind velocity and upon the resistance offered by the air to the particles of precipitation. The stronger the wind and the greater the air resistance, the smaller is the amount caught in the gage compared with that collected under otherwise similar conditions during absolute calm." Daubenmire (1959, p. 92) points out that precipitation gages with large diameters tend to deflect wind upward as it strikes the instrument, a phenomenon which may reduce the actual amount of moisture by more than half. Because snow would be deflected even more easily than rain, the winter record is probably in greater error than the summer one. Thus it is necessary to take into account the effect of wind on the overall moisture record at M–3.

One important effect of wind on plants is to increase transpiration. Our evaporation data give information on this point. Evaporation at M–3 during summer months was the highest of all sites measured, even though the air temperatures were comparatively low.

Wind also has a significant effect on the length of the frost-free period. Since M–3 is higher than the other mesa-top sites, one would expect it to have a shorter frost-free season. But this was not the case. In 1963, this period was 171 days, identical to that of the other mesa-top stations. In 1962, it was 162 days, again very similar to the other sites. According to Geiger (1957, p. 110), higher wind velocity means increased convection, and increased convection results in decreased temperature gradients. Consequently, temperatures are lower during the day and higher at night. It is the moderating effect of wind at night that is responsible for the extended frost-free period at this site.

The similarity in the frost-free periods between sites does not mean that the growing seasons of plants are the same at all the sites. Actually, plant growth begins long before the last spring frost. In the spring of 1963, flowering of the indigenous plants at M–3 did not begin until late April, 2 to 3 weeks later than at M–2. The delay in growth at M–3 may have been due to a late snow cover and to a lag in the warming of the soil. Snow cover, though variable because of drifting, persisted from late November through March. The soil temperature records for 1963 show that substantial thawing and heating of the ground did not occur before May. Mutton grass, which began flowering early in April at the lower elevations, did not flower until the first week in May at M–3. Similarly, serviceberry started to flower at the canyon stations the last week of April, but did not begin flowering along the North Rim until a month later. In general, therefore, a 3- to 4-week delay in flowering was evident between the northern and southern ends of Mesa Verde.

The M–3 vegetation is undergoing stages of changes from pioneer stands that developed after fires to the relatively stable climax cover of a pinyon and juniper forest. Burned stumps and charcoal throughout the area indicate that only small islands of the landscape have escaped burning.

Through the use of dendrochronological techniques, both on the burned specimens and modern increment cores from the present stand of scattered trees, it appears that a fire swept over the ridge about 1840. An earlier fire may have occurred in the 1600's, as the oldest pith date from the sample collection is 1710, with several more specimens giving approximately the same date. Moreover, these trees were relatively young when they burned.

Shrubs have fared better because they are able to produce new shoots from adventitious buds on the root crowns that survive fire. The local trees lack this regenerative capacity. Trees are now reproducing from seed throughout the area, so we do not doubt that forest will eventually replace the shrublands if fires are suppressed.

That the M–3 shrub vegetation is successional does not in itself indicate the area has soils or atmospheric factors different from the other stands we studied. In the absence of a true climax stand, however, we are unable to characterize the type in detail. The lushness of the shrubs and the more favorable water complex suggest that the forest would be more mesophytic, except on exposed sites where wind would produce more arid conditions.

CANYON-BOTTOM SITE, C–2

The canyon sites were in Navajo Canyon (figs. 1 and 10), about one-half mile west of park headquarters and 1½ miles southwest of the M–2 site. The canyon-bottom site was on an alluvial terrace at 6,382-foot elevation, about 800 feet lower than the mesa top. The terrace is a remnant of an alluvial deposit that has been dissected by the intermittent stream.

The vegetation of C–2 (fig. 11) is almost a pure stand of big sagebrush, averaging 5 feet high. Sagebrush covers over 75 percent of the stand, and cheatgrass (*Bromus tectorum*) is the only other plant in abundance. Additional herbs present are listed in table 2. This is a climax stand, and such stands of big sagebrush occur on all the alluvial terraces in the Mesa Verde canyons. On the mesa tops, sagebrush is successional, but in the canyon bottoms it is better adapted to the deep alluvial soils than other species and is able to maintain its dominance.

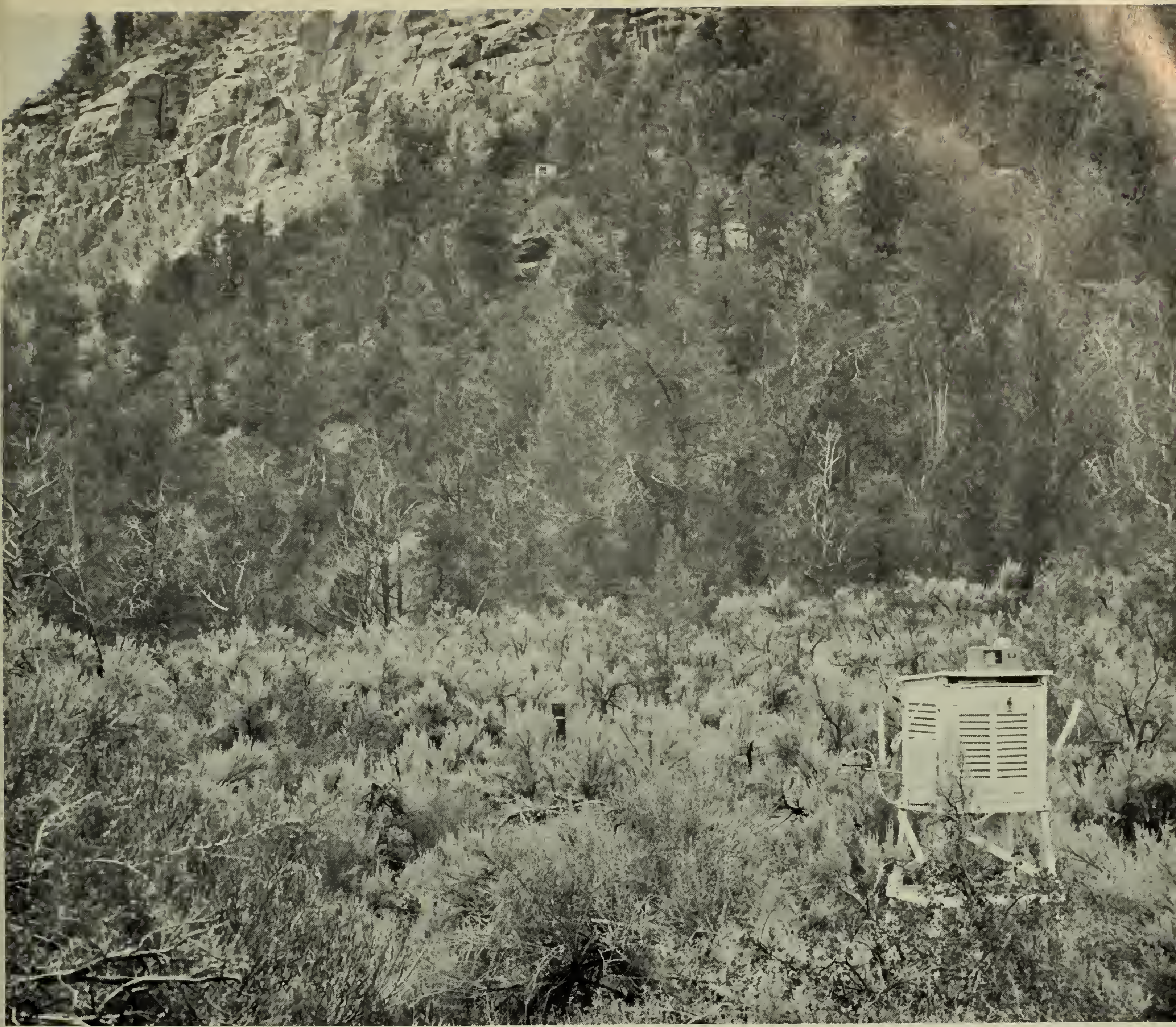
The boundary between the sagebrush community and the adjacent pinyon-juniper forest on the canyon slopes is very pronounced (figs. 10 and 11), the line occurring where the coarse colluvium of the talus abuts the alluvial sediments of the terraces. The soils on these terraces are azonal; that is, the profile has an A, C horizon sequence (table 10). These soils were developed on a flood plain or low terrace formed over the bedrock of the rather narrow canyon bottom. Subsequent erosional processes have cut the present intermittent stream channel, which dissects the old flood plain. The soil at the C–2 station is classified as Bankard fine sandy loam. It is a deep, coarse-textured, alluvial soil developing from wind and water-sorted sediments derived from the Mesaverde group.

The presence of charcoal fragments, described as "many dark flakes of carbonaceous material" in the A_1 horizon, is probably the result of a fire that occurred in

TABLE 10.—SOIL PROFILE UNDERLYING C–2 BIG SAGEBRUSH/CHEATGRASS STAND*

Horizon	Depth, inches	Description
A_1	0–4	Brown (10YR 5/3 dry) to dark brown (10YR 3/3 moist) loamy fine sand; soft dry, very friable moist; weak platy breaking to weak very fine granular structure; many dark flakes of carbonaceous material; noncalcareous; lower boundary clear and smooth.
C_1	4–32	Light brownish gray (10YR 6/2 dry) to dark gray brown (10YR 4/2 moist) very fine sand; single grained; soft dry, very friable moist; noncalcareous; lower boundary gradual and smooth.
C_2	32–54	Light brownish gray (10YR 6/2 dry) to dark gray brown (10YR 4/2 moist) very fine sand; single grained; soft dry, very friable moist; weakly calcareous; lower boundary gradual and smooth.
C_3	54–60	Light brownish gray (10YR 6/2 dry) to dark gray brown (10YR 4/2 moist) moderate to very fine sands; massive; soft dry, very friable moist; calcareous.

*Soil classified as Bankard fine sandy loam.



11 C–2, on an alluvial terrace in the bottom of Navajo Canyon, at 6,382 feet elevation. The big sagebrush community is restricted to the sandy soil of the terrace. In the background, upper center, is the environment station for the east-northeast-facing slope.

the station area. Several charred juniper trees were found near the anemometer support.

The soil moisture coefficients listed in table 5 are indicative of the relatively light soil prevalent at C–2. The storage capacity of this soil is very low, a feature detrimental to the growth of shallow-rooted plants.

Two features of the C–2 site—cold night temperatures throughout the year and deep soil—make its growth regime similar to that found in the Sagebrush Desert of the Great Basin, a region where the frost-free season is very short and where frosts occur almost every night in fall, winter, and spring (Oosting, 1956, p. 321). The pronounced differences in temperature between the canyon floor and the other stands are discussed on page 48. Other environmental data are in table 11 and the appendix.

Benson (1957, p. 617), in discussing Cold Desert vegetation, states that the typical sagebrush community has a higher water requirement and is therefore restricted to better and usually deeper soils. The general limitation of big sagebrush to this type of site may be due more to its deep root system which can tap water sources not available to many other shallower rooted plants—it is better adapted to these sandy, well-drained soils. Roberts (MS.), in his study of the soils of Wetherill Mesa, says that the occurrence of big sagebrush is closely correlated with

TABLE 11.—SOME CLIMATIC FACTORS OF THE CANYON SITES

Factor	1962			1963		
	C–1	C–2	C–3	C–1	C–2	C–3
Air temperature (in degrees Fahrenheit):						
January:						
Maximum	48	47	48	48	48	44
Mean maximum	39	38	38	34	34	35
Minimum	−2	−7	−2	−20	−28	−19
Mean minimum	16	8	16	10	4	12
Mean	28	23	27	22	19	24
July:						
Maximum	95	97	95	98	97	102
Mean maximum	89	90	90	92	91	92
Minimum	51	42	54	54	44	54
Mean minimum	55	50	57	59	52	59
Mean	72	70	74	75	72	75
Annual:						
Minimum	97	98	100	98	97	102
Month	Aug.	Aug.	Aug.	July	July	July
Mean maximum	65	65	64	65	65	64
Minimum	−2	−8	−2	−20	−28	−19
Month	Jan.	Feb.	Jan.	Jan.	Jan.	Jan.
Mean minimum	37	30	37	37	31	37
Mean	51	47	51	51	48	51
Frost-free period, days	168	102	173	171	123	184
Last freeze in spring	22 May	29 May	18 May	12 May	11 June	29 Apr.
First freeze in autumn	7 Nov.	9 Sept.	8 Nov.	31 Oct.	13 Oct.	31 Oct.
Relative humidity (in percentage):						
Lowest	4	4	10	4	8	10
Month	May	May	May	May	May	June
Lowest monthly mean	37	42	37	29	45	35
Month	May	Aug.	June	May	June	May
Annual mean	52	57	56	49	59	54
Precipitation (inches):						
Monthly total:						
Highest	....	2.52	....	....	4.15	....
Month	....	Oct.	....	....	Aug.	....
Lowest	....	0.18	....	....	0.06	....
Month	....	June	....	....	June	....
Annual total	....	13.93	....	....	14.52	....
Wind velocity (in miles per hour):						
Monthly mean:						
Highest	....	3.1	....	....	3.4	....
Month	....	May	....	....	June	....
Lowest	....	1.3	....	....	1.5	....
Month	....	Dec.	....	....	Feb.	....
Annual mean	....	2.2	....	....	2.2	....

areas where the roots can have a deep feeding zone with relatively high available moisture.

The most striking climatic phenomenon in the canyons is the nocturnal flooding of cold air down the drainageways, ultimately flowing along the bottom of the canyon. This produces a pronounced difference in nighttime air temperature and humidity between the canyon bottom and the adjacent slopes. A combination of relatively low winds at C–2 (see appendix) and its topographic setting favors high temperatures during the day and cold nocturnal temperatures. The temperatures regime is thus marked by a diurnal range exceeded nowhere else in the Mesa Verde complex.

Because of the lower minimum temperatures at C–2, the frost-free period is shortened considerably. In 1962, it was only 102 days long, lasting from late May until early September. The 1963 season was longer (123 days), extending from mid-June to mid-October.

The initiation of flowering in the canyon bottom is delayed as a result of the short frost-free period and late-lying snows. In 1963, *Phlox hoodii*, one of the first perennials to flower on the entire mesa, did not bloom at C–2 until the second week in May; and from the phenological observations made throughout the spring, there seemed to be little plant development prior to that time.

The absence of a variety of herbs is probably due to suppression under the extensive crown cover of sagebrush (Hanson and Churchill, 1961, p. 85) and to competition with cheatgrass. The latter is a winter annual that germinates in the fall and puts on a burst of growth in the spring, when its extensive root system can absorb water from the melting snow. Few herbs can compete with it in vigor during the early part of the warm season.

Cheatgrass plays another potentially critical role in the ecology of this stand type. The grass dries up as the warm season progresses and becomes tinder that ignites easily and often sets fire to the sagebrush. Such fires are common in the West today, but they are of relatively recent origin, since cheatgrass was introduced to North America from Europe only in the 19th century.

12 C–1, on west-southwest-facing talus slope in Navajo Canyon, with instrument shelter visible in lower center, between sandstone outcroppings, about 125 feet above the canyon floor.

SOUTHWEST EXPOSURE CANYON-SLOPE SITE, C-1

This site was 125 feet above the canyon floor, at an elevation of 6,500 feet. It was halfway up a southwest-facing talus slope of 35° (fig. 12). The vegetation is a juniper-pinyon community with scattered big sagebrush. The trees are small and widely spaced (fig. 13), the average distance between them being more than 20 feet, which is considerably greater than in the other stands (table 12). Most of the local shrubs, with the exception of oak and fendlerbush, are represented in the community. Sagebrush is confined to deep, well-drained soils at other sites on the mesa, but on talus slopes it is common on the heavy soils associated with shale outcroppings. Since there are lenses of shale throughout the slope, sagebrush is the characteristic shrub of the stand. The other species present are listed in table 2.

The largest juniper and pinyon were 24 and 14 inches in diameter, respectively. The oldest of 10 pines sampled was 240 years, and the average for the 10 was 160 years. This is the only stand type sampled in which juniper is more abundant than pine.

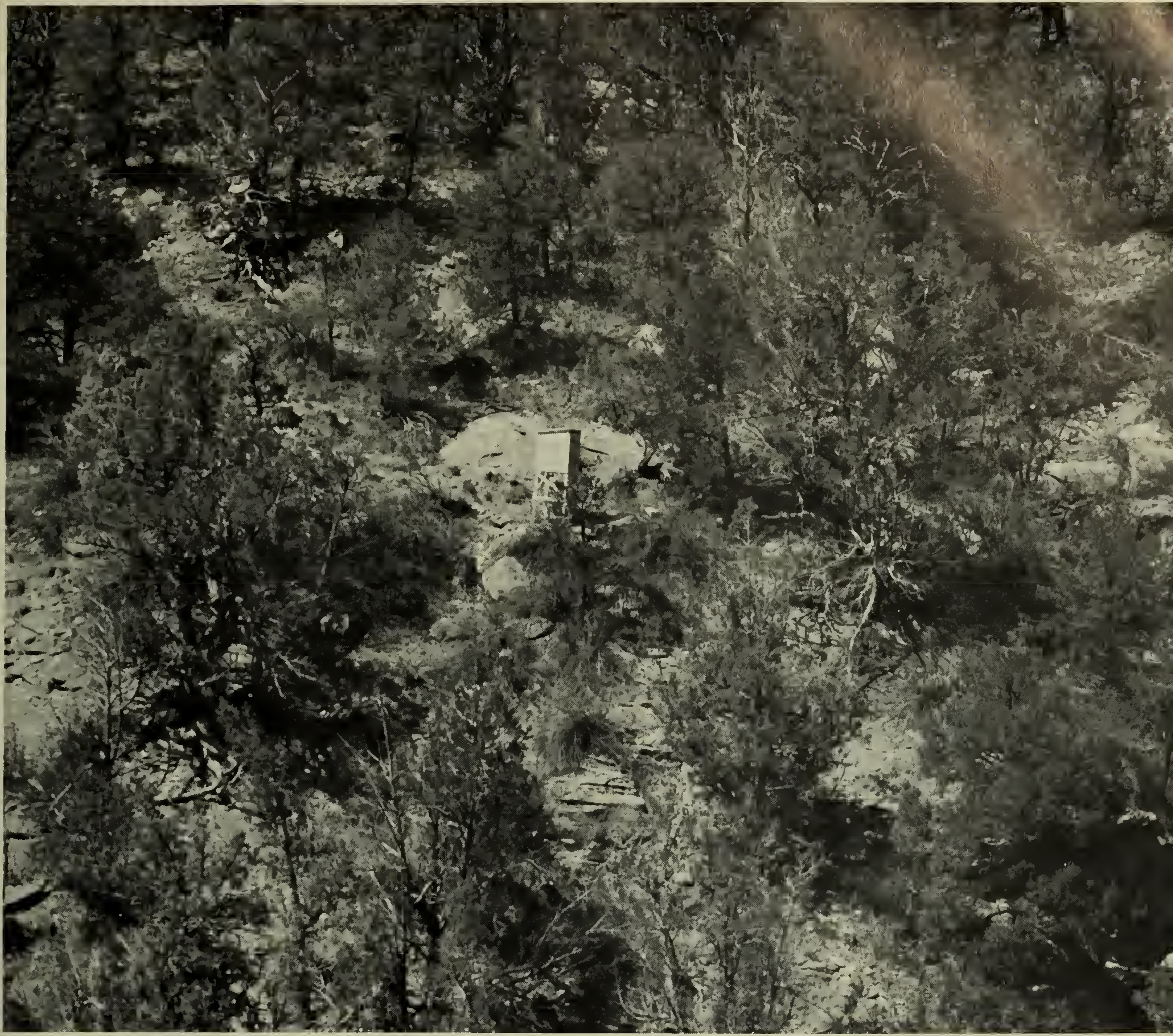
The soils on the steep canyon slopes are formed partly from coarse colluvial-alluvial materials and partly from the underlying bedrock. Because several different soils

13 C–1 instrument shelter, at about 6,500-foot elevation. The soil here is a Sandstone Outcrop–Stonyland Complex, and the vegetation is an open juniper-pinyon/big sagebrush community.

could be recognized and because of the steepness of the slope, the general soil type suggested for the southwest-facing talus on which C–1 is situated is the Mughouse-Rock Outcrop Complex. The soil at the site is classified as a shallow phase of Mughouse stony loam. It is shallower, less developed, and somewhat more brown than normal, but it fits the series fairly well.

Developing on interbedded shales and sandstones of the Menefee formation, the soil is quite stony, with most of its coarse material having come from the more resistant Cliff House sandstone above. The depth of the soil is variable; below the cliffs it is often less than 12 inches deep. Many shallow outcroppings of shales and sandstones occur on this broad talus slope. The profile description in table 13 is taken from the open area just to the right of the shelter in figure 13.

A contact zone between the Cliff House sandstone and the underlying Menefee formation (primarily shales) is replete with seeps and springs. Below this point of contact, moisture from lateral flow of ground water seems negligible, at least over much of the canyon slopes. Thus the primary source of water for the slope vegetation is precipitation, but retention of moisture varies greatly where soils are so variable. Where coarse colluvium



14 C–3 instrument shelter on the east-northeast-facing talus slope in Navajo Canyon, directly across from C–1. There is a decided increase in the density of the pinyon-juniper forest and in the abundance of the brush understory.

occurs, the interstices between the rocks and boulders trap and retain much of the runoff to the advantage of the deeper rooted plants. But where the soils are fine textured along the shale lenses, porosity and water permeability are low, even though the water-holding capacity (as shown in table 5) is quite high.

The C–1 site represents a segment of the Mesa Verde terrain whose climate is controlled by the local topography or, more precisely, by exposure. Facing west-southwest, the slope receives more insolation, on an annual basis, than any of the other sites. This is especially pronounced during the winter months. (See air temperature data in the appendix). As a result, daytime temperatures exert the greatest influence on the environment. Whereas M–1 represents the most arid mesa-top environment, C–1, indicative of the more exposed canyon slopes, is in the more arid part of the canyon landscape.

At C–1, moderate soil temperatures during the winter and the southerly exposure favor early spring development of the vegetation. Snow rarely blankets the slope for any extended period of time. During the winters observed, snow persisted from the latter part of December through late January; otherwise, cover was generally

TABLE 12.—TREE DATA AT C–1

A. Point quarter analysis based on 10 points

Species	Number of trees	Average distance, feet	Total basal area, square inches	Average B.A./ diameter	Density trees/acre	Relative—			Importance value
						Density (%)	Frequency (%)	Dominance (%)	
Pinus edulis	19	...	1, 031	54/ 8.5	51	47.5	52.6	25.9	126
Juniperus osteosperma	21	...	2, 952	141/13.5	56	52.5	47.4	74.1	174
Total	40	20.2	3, 983	100/11.5	107	100.0	100.0	100.0	300

B. Pinyon-juniper reproduction based on number of individuals that occurred within ten 4 x 50-foot belt transects

Species	Number of—			Total
	Seedlings	Saplings	Trees	
Pinus edulis	5	5	5	15
Juniperus osteosperma	2	9	6	17

spotty. All these factors support the conclusions drawn from our phenological information: that plant growth commences earliest at this site. In 1963, the flowering of *Phlox hoodii* began the third week in March and was abundant by the end of the month. This was delayed about a week the previous year. Flowering of the shrub species, beginning with *Amelanchier*, also occurred first at the C–1 site.

In brief, the environment of the southwest-facing canyon slopes is comparable to that along the southern part of Mesa Verde, and plant growth is least favorable at these locations. Data on the atmospheric factors are given in table 11 and the appendix.

TABLE 13.—SOIL PROFILE UNDERLYING C–1 JUNIPER–PINYON/BIG SAGEBRUSH STAND*

Horizon	Depth, inches	Description
A_1	0–5	Gray brown (10YR 5/2 dry) to very dark gray brown (10YR 3/2 moist) stony loam; moderate to strong fine granular structure; consistence soft dry very friable moist; many fine roots; approximately 25 percent sandstone cobbles and flags; noncalcareous; lower boundary clear and smooth.
B_{21t}	5–9	Light gray brown (10YR 6/2 dry) to dark gray brown (10YR 4/2 moist) stony clay loam; moderate medium to coarse subangular blocky breaking to moderate to strong fine angular and subangular blocky structure; consistence very hard dry; firm moist; very thin patchy clay skins; few fine roots; largely concentrated along faces of soil peds; rock fragments 25 percent; noncalcareous except for small fragments of weathered shale; lower boundary gradual and wavy.
B_{22t}	9–21	Gray brown (2.5Y 5/2 dry) to very dark gray brown (2.5Y 3/2 moist) stony clay; weak subangular blocky structure extremely hard dry, firm moist sticky and plastic wet; thin patchy clay skins on peds and rock surfaces; 25 to 50 percent rock fragments; noncalcareous except for fragments of weathered shale; lower boundary gradual and wavy with stringers of horizon extending downward into cracks in underlying rocks.
R	21+	Interbedded sandstone and shale.

*Soil classified as Mughouse stony loam.

NORTHEAST EXPOSURE CANYON-SLOPE SITE, C–3

The northeast exposure site is directly across the canyon from C–1. Located on a 35° talus slope at an elevation of 6,500 feet, C–3 is about 100 feet above the canyon floor (fig. 14).

The pinyon-juniper vegetation is more dense than that on the opposite slope, and two additional shrubs, oak and fendlerbrush, occur in the stand here (table 14). Other species of plants present are listed in table 2. The trees averaged 250 years old and the oldest individual was just over 260 years. The trees are older on this slope than on the opposite, southwest-facing (C–1) slope. This might be due to a sampling error, but the same relationship was found between the trees on the northeast- and southwest-facing slopes of Rock Canyon. These observations suggest that trees may actually live longer on northeasterly exposures.

The soil at this site is included in the Cliffhouse series, although it lacks strongly structured clay characteristic of the lower B horizon in this series. It is a moderately deep soil developing on the interbedded sandstone and shales of the Menefee formation. Cliffhouse soils are found primarily on the uplands or mesa tops and are not typical of the canyon's talus soils. Soil moisture samples and the soil profile described in table 15 were taken from a high, sloping bench slightly above the the C–3 site.

In the soil survey of Wetherill Mesa and adjacent canyons, the predominant soils of the talus situations were of the Mughouse-Rock Outcrop Complex. Since soils of the C–1 slope in Navajo Canyon are also in this category, it is reasonably safe to assume that the soils of the C–3 slope, as a whole, fall into the Mughouse series.

The data for growth-water storage listed in table 5 are somewhat conservative, since the nature of the underlying bedrock favors deep penetration and may carry some laterally moving water. Cracks in the bedrock also serve as moisture storage zones, as evidenced by the presence of roots, soil, and clay skins.

Environment data are presented in table 10 and the appendix. The local environment at C–3, like that of C–1, is strongly influenced by exposure to solar radiation. C–3 has slightly higher maximum air temperatures than

TABLE 14.—TREE DATA AT C–3

A. Point quarter analysis based on 10 points

Species	Number of trees	Average distance, feet	Total basal area, square inches	Average B.A./ diameter	Density trees/acre	Relative—			Importance value
						Density (%)	Frequency (%)	Dominance (%)	
Pinus edulis	30		989	33/ 6.5	145	75	58.8	26.5	160.3
Juniperus osteosperma	10		2, 754	275/18.5	48	25	41.2	73.5	139.7
Total	40	15	3, 743	94/11.0	193	100	100.0	100.0	300.0

B. Pinyon-juniper reproduction based on number of individuals that occurred within ten 4 x 50-foot belt transects

Species	Number of—			Total
	Seedlings	Saplings	Trees	
Pinus edulis	8	3	8	19
Juniperus osteosperma	3	1	3	7

C–1, but nocturnal temperatures on the two slopes are essentially identical because these temperatures are determined by the mass movement of cold air, which is independent of slope exposure.

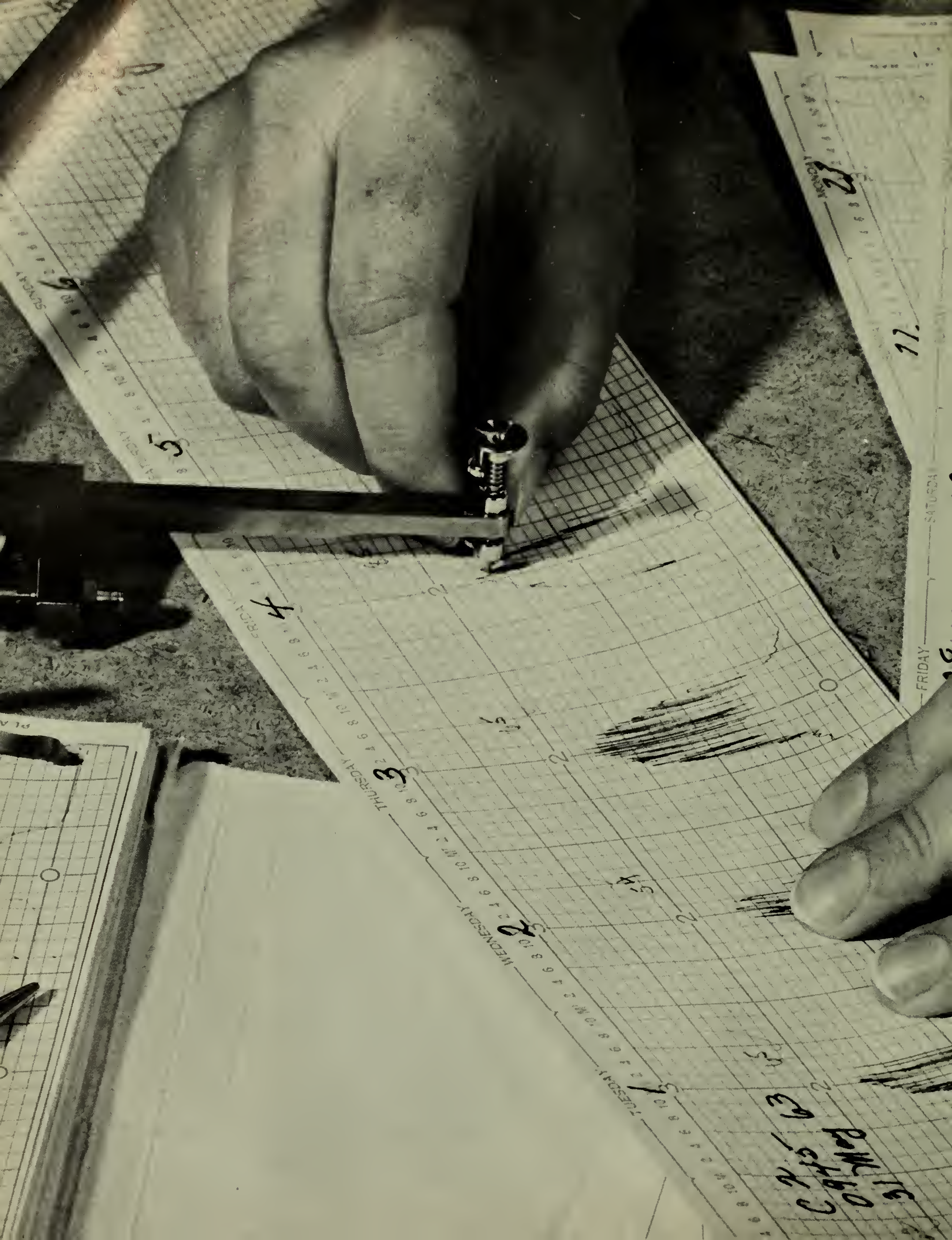
Slope direction, which affects the duration of snow cover and its relationship to soil moisture during the growing season, is probably the most important factor controlling the stand vegetation. Although the frost-free period at C–3 was similar to that at C–1 (173 days in 1962 and 184 days in 1963), the duration of snow cover at the two sites was not the same. The C–3 slope kept a mantle of snow for several months, whereas C–1 had an ephemeral snow cover. In 1963, the late-lying snows were probably responsible for the delay in flowering on the C–3 slope until early April. The more favorable soil moisture conditions may account for the denser vegetation on the less-exposed slopes.

The stand at C–3 is a climax ecological unit whose character is influenced strongly by topography and soil. The presence of oak and fendlerbush indicates that this site is more mesic—that is, relatively more moist—than adjacent sites in the canyons and on the mesa top. These two shrubs suggest that C–3 is more-like M–3 than any of the other sites studied at Mesa Verde.

TABLE 15.—SOIL PROFILE UNDERLYING C–3 PINYON-JUNIPER/MOUNTAIN BRUSH STAND*

Horizon	Depth, inches	Description
A_1	0–4	Dark brown (7.5YR 4/3 dry) to dark brown (7.5YR 3/3 moist) fine sandy loam; moderate to strong very fine granular structure; very friable moist; abundant fine roots; approximately 10 percent sandstone fragments; noncalcareous; lower boundary clear and smooth.
A_3	4–11	Gray brown (9YR 5/2 dry) to very dark gray brown (9YR 3/2 moist) very fine sandy loam; weak coarse subangular blocky structure; consistence hard dry, very friable moist; many fine roots and pores; about 10 to 20 percent sandstone fragments; noncalcareous; lower boundary clear and smooth.
B_{21t}	11–16	Brown (7.5YR 5/4 dry) to dark brown (7.5YR 3/4 moist) loam or sandy clay loam; weak coarse prismatic structure breaking to weak to moderate medium subangular structure; consistence very hard dry and friable moist; many fine roots and pores; thin patchy clay skins; 20 percent sandstone fragments; weakly calcareous; lower boundary clear and smooth to slightly wavy.
B_{22t}	16–21	Pale brown (10YR 6/3 dry) to dark brown (10YR 4/3 moist) sandy clay loam; weak coarse prismatic structure; consistence very hard dry and friable moist; very thin very patchy clay skins; about 20 percent sandstone fragments; weakly calcareous; lower boundary clear and smooth.
R	21+	Relatively soft interbedded sandstone and shale with roots and soil from above horizon extending a few inches into the numerous weathering cracks.

*Soil classified as Cliffhouse fine sandy loam.


SUNDAY
6
SATURDAY
5
FRIDAY
4
THURSDAY
3
WEDNESDAY
2
TUESDAY
1
MONDAY
11.
SATURDAY
FRIDAY

CHAPTER 4

discussion of site interrelations

Data collected at the six sites were presented in the previous section, along with observations on the interrelations of the different ecosystem components. Many comparisons of the environmental data can be made. The comparisons discussed in this chapter were chosen for their relevance to the project's objectives. The annual environment data are included in this report (see appendix) in order to make them readily available for use in other studies.

SOIL AND VEGETATION RELATIONSHIPS OF SELECTED SITES

A comparison of soil types indicates a similarity among the M–3, C–1, and C–3 sites—all are stony loams in the Mughouse series. These fine-textured soils are relatively shallow, have a large proportion of rock fragments, and support woody shrubs.

The M–1 and C–2 sites have azonal soils (lacking a natural horizonation) but are otherwise very dissimilar. The M–1 soils—lithosols—support black sagebrush (*Artemisia nova*), an indicator of shallow soils. The alluvium at C–2 supports a dense stand of big sagebrush, a shrub best adapted to deep, friable soils.

The M–2 site is unique in that its soil, a Witt loam, is highly developed, as well as deep, and supports a climax stand of forest and grass that is generally devoid of any woody shrubs.

Some characteristics of soil moisture, a critical factor in any semiarid area such as Mesa Verde, are given in figure 15. The annual pattern of soil moisture shows similarities as well as differences during the 2 years of our study. In both years, moisture from melting snow built up in the soil in early spring and then dropped rapidly as the dry season came on in late spring. In 1963, precipitation in August recharged the soil moisture in a way that is probably typical of the area. The year of 1962, on the other hand, provided an example of an extremely dry summer. There was so little precipitation that soil moisture remained deficient until fall.

Comparisons between sites show that moisture was deficient at the 6-inch depth for the longest period at the southwest exposure site (C–1) and for the shortest period in the canyon floor site (C–2). The latter case was due to the frozen condition of the ground, which persisted well into the spring.

COMPARISON OF 1962 AND 1963 WEATHER

An important aspect of climate from an ecological standpoint are year-to-year variations in weather factors. There was little difference between the 2 years of our study in annual averages and totals; however there were striking differences in the monthly records for these years.

Solar radiation. This was similar in all months of the 2 years except August, when the daily values were 644 gm. cal./cm.^{2}/day in 1962 and only 514 in 1963. The lower value for 1963 resulted from greater cloudiness, precipitation, and relative humidity—conditions that would reduce the amount of solar radiation reaching the ground.

Precipitation. As mentioned earlier, the annual precipitation at Mesa Verde averaged 18 inches over the past 41 years. The 14 inches in 1962 and 15 inches in 1963, recorded at the Weather Bureau station, were thus somewhat below normal. Total precipitation differed very little—about 1 inch during the 2 years of the environment program. This was also true of the canyon and other mesa-top sites, except for M–1 at the lower end of Chapin Mesa. There, a difference of almost 5 inches was recorded (fig. 16).

The hazards in generalizing about a year's weather from such information can be seen in figure 16. Only the late spring was dry in 1963, whereas the entire summer was relatively dry in 1962. The effects of such a distribution of moisture on plants, especially cultigens dependent upon summer rains, is obvious.

The extremely wet summer of 1963 deserves further comment. Although August is usually the wettest month of the year, the Weather Bureau station received twice the normal amount in August 1963. Moreover, at the M–3 site on Park Point, almost half of the year's precipitation came during that month! In contrast, in August of 1962 the Weather Bureau station received less than one-tenth of the average for August. Snowfall in both the winters of 1961–62 and 1962–63 was below normal, but the former had more snow than the latter.

Evaporation. At all sites, this was higher in 1962 than in 1963. The potential summer evaporation, as measured by the atmographs, greatly exceeded the actual yearly precipitation. Some summer months had evaporation potentials that were about half the yearly precipitation.

Temperature. Temperature recordings at the Weather Bureau station during 1962 and 1963 are shown in table 1. Air temperature fluctuations at all the environment measurement sites were more alike during 1963 than during 1962, perhaps because of the greater amount of cloudiness and rainfall in 1963. Clouds and moisture would tend to reduce the effect of locally modifying forces, and thus local conditions would approximate regional conditions.

COMPARISON OF INDIVIDUAL FACTORS BETWEEN SITES

Solar radiation. As one of the major controls of other environmental factors, solar radiation was consistently higher at M–2 than at C–2 throughout the year. The reason for this difference is obvious; when the sun is low during the early morning and late afternoon, the canyon floor is in the shadow of the upper cliffs of the mesas.

Although we did not measure this factor on the talus slopes, we have studied it from indirect sources because of its importance in understanding the local environments of the canyons. There are many indications that C–1, with its southwest exposure, receives more solar radiation than does C–3, on the opposite slope. Although the following measurements of incident angles of direct sunlight show that the southwest slope receives more solar radiation at noon, the actual maximum radiation occurs in late morning at the northeast exposure and in early afternoon at the southwest exposure. The smaller the angle, the more direct the sunlight perpendicular to the slope. It is evident that the radiation regimes become more alike in summer.

An effect of the solar radiation load on the two slopes can be seen in the temperature differences. The march of air temperatures on clear summer and winter days (fig. 17) indicates that solar radiation was higher on the southwest exposure slope during late autumn and winter, whereas the northeast slope received more radiation during late spring and summer. We believe that the southwest exposure receives more solar radiation on a yearly basis, but the northeast slope probably receives more during the growing season. The topography and orientation of the two sites is such that the sun reaches the northeast exposure first during all seasons of the year (calculated from Geiger, 1957, p. 221).

Perhaps the most reliable indicator of solar radiation intensities on the two slopes is the persistence of snow; snow cover is intermittent on the southwest exposure, while it persists most of the winter on the C–3 slope.

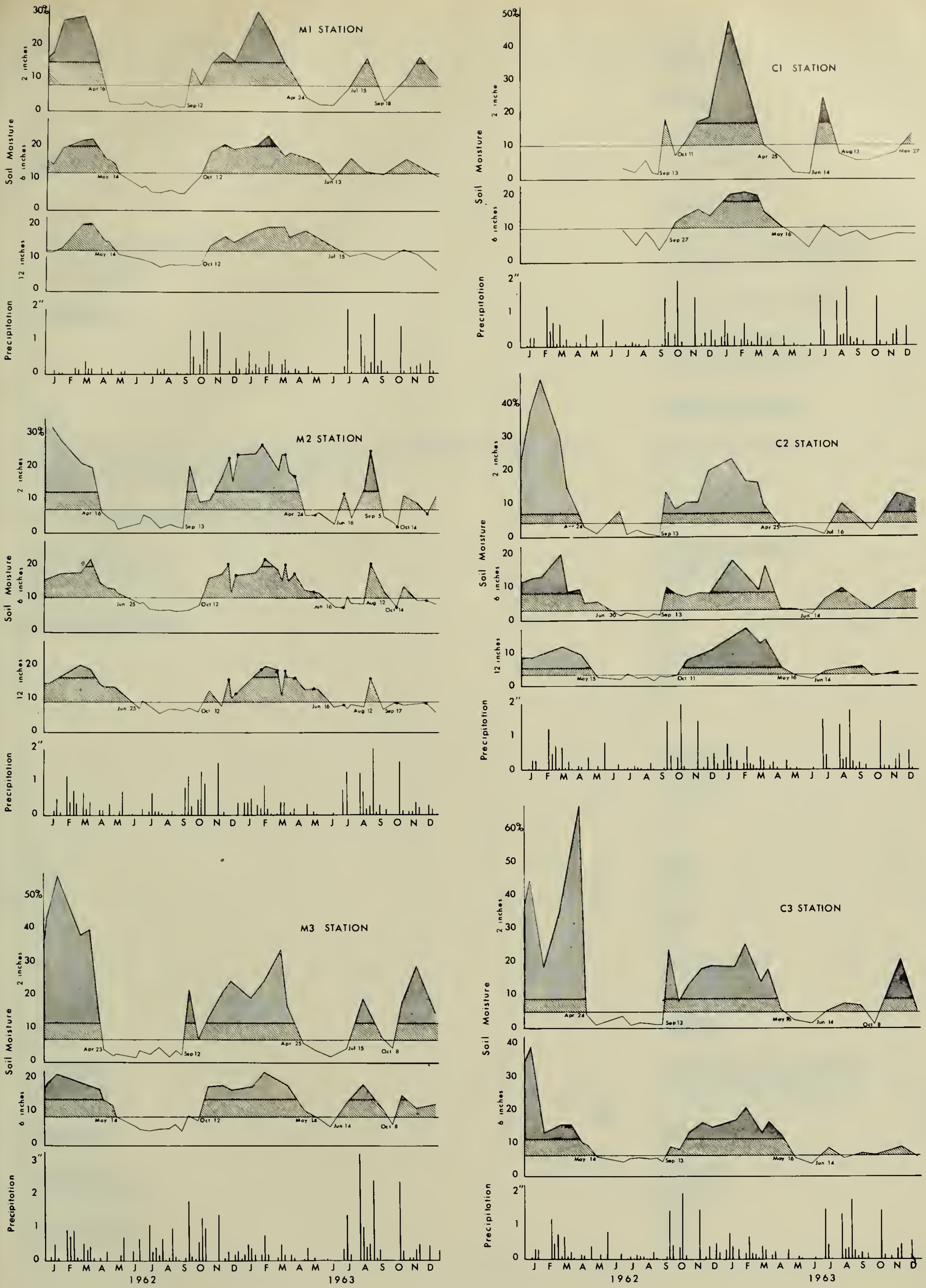
The density of the vegetation is both a result and a cause of differences in the amount of solar radiation. If both slopes were bare of plants, the southwestern exposure would receive more total radiation for the year and, consequently, it would be less mesic. Since plants are present, they tend to produce a more complete cover on the more mesic, northeastern exposure. The more open vegetation of the southwestern slope thereby permits greater heating of the soil and air.

The effect of clouds on insolation is difficult to determine. Clear mornings and cloudy afternoons are common throughout the summer. A rather complete cloud cover in the afternoon would reduce the total daily radiation on the southwestern slope more than on the northeastern slope because at that time of day solar radiation is potentially more direct on the former. Scattered cumulus clouds could, however, actually increase radiation through reflection.

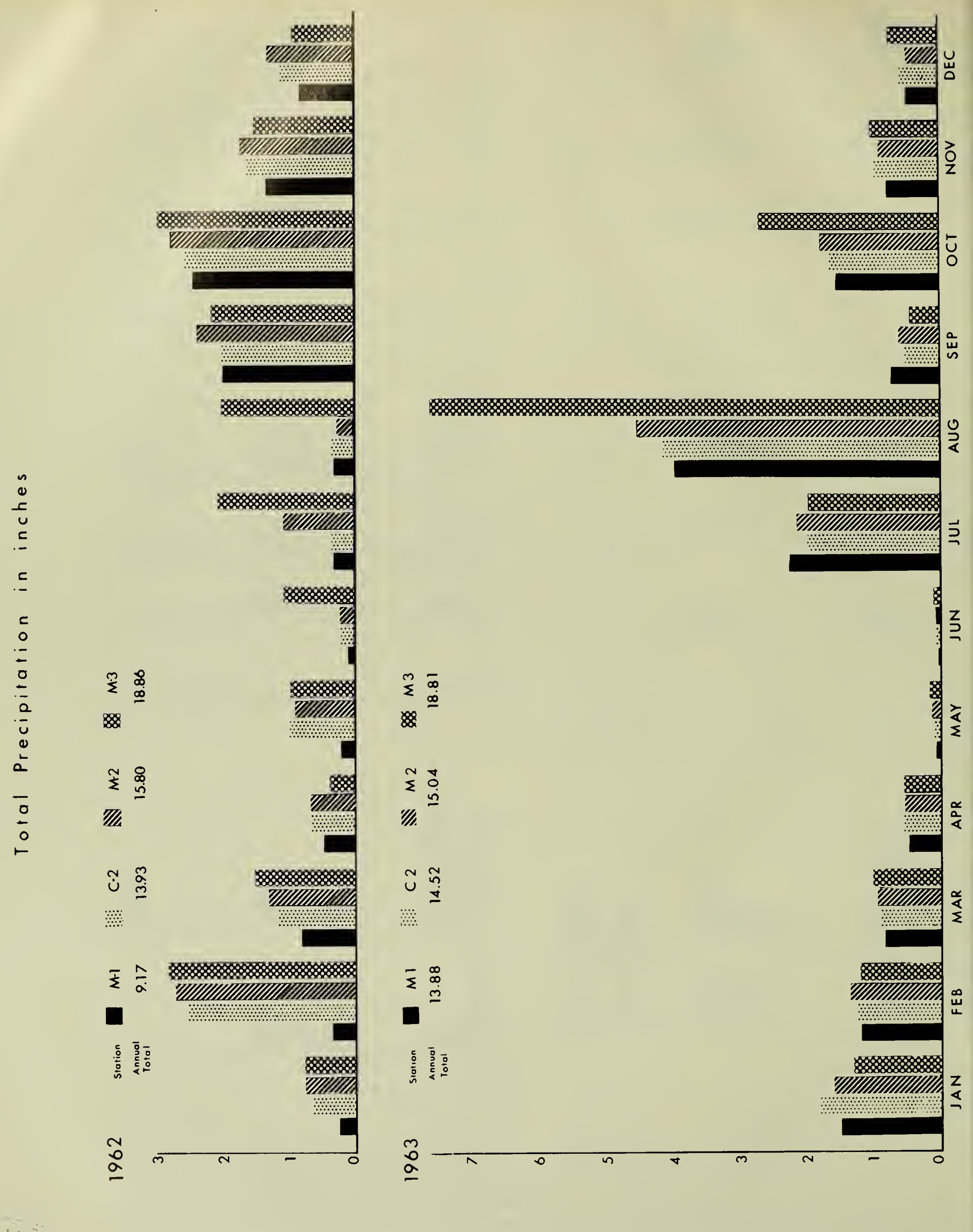
Air temperature and cold-air drainage. At all sites, minimum air temperatures varied more from day to day than did maximum temperatures. Both maximum and minimum temperatures varied more in the winter than in the summer.

Early study of our data showed the expected pattern of cold-air drainage. Air that becomes colder, and therefore more dense due to local cooling, drains downslope and accumulates in lowlands. The drainage is most striking on clear and calm nights in summer. In order to study this phenomenon more intensively, Weather Bureau-type maximum and minimum thermometers were mounted at shoulder height on the north side of trees in small, ventilated shelters. These shelters were established at intervals of 50 feet along a transect from the canyon floor to the base of the cliff (fig. 18).

During the summer, cold air builds up to a level less than 50 feet deep in the canyon bottom. Above the 50-foot level, minimum temperatures are almost isothermal to the bottom of the cliff, while the mesa top is as cool as the 50-foot level. During the day, however, the cold air is



15 Graph showing soil moisture content and precipitation at the six sites in 1962 and 1963. The light hatching indicates available moisture, while the darker shading reprcsents moisture content above field capacity. A continuous horizontal line marks the permanent wilting coefficient for each depth. Precipitation is shown in the bar graphs. At M–2, four replicated gravimetric samples were collected each month during 1963; their average moisture content is indicated by dots.



16 Graphic comparison of monthly precipitation in 1962 and 1963 at the mesa-top sites and at the canyon-bottom site.

warmed or replaced rapidly, and the low wind velocities present on the canyon floor allow temperatures there to build up more.

The cold air lake that occurs at night increases in depth during the winter and influences air temperature minima to over 50 feet above the canyon floor. Again, as is shown in figure 18, the upper slopes were warmer at night than both the mesa top and canyon floor. This is a common temperature phenomenon (Geiger, 1957, p. 205).

Soil temperature. Two generally known features of soil temperature are illustrated by our data. First, the amount of variation is greatest near the surface and decreases with increase in depth to about 12 inches, where there is little fluctuation throughout the year. Secondly, soil temperatures, except near the surface, are more moderate than air temperatures, both warmer in winter and cooler in summer. Since soil temperatures are controlled, in part, by the composition of the soil, overall comparisons have not been made.

Precipitation. On the mesa tops, precipitation varies directly with increase in altitude, the highest site, at Park Point, receiving more precipitation than any other (fig. 16). Elevation is less important as a control in the canyons. For example, C–2, in the bottom of Navajo Canyon, received about the same amount of moisture as M–2, 800 feet above.

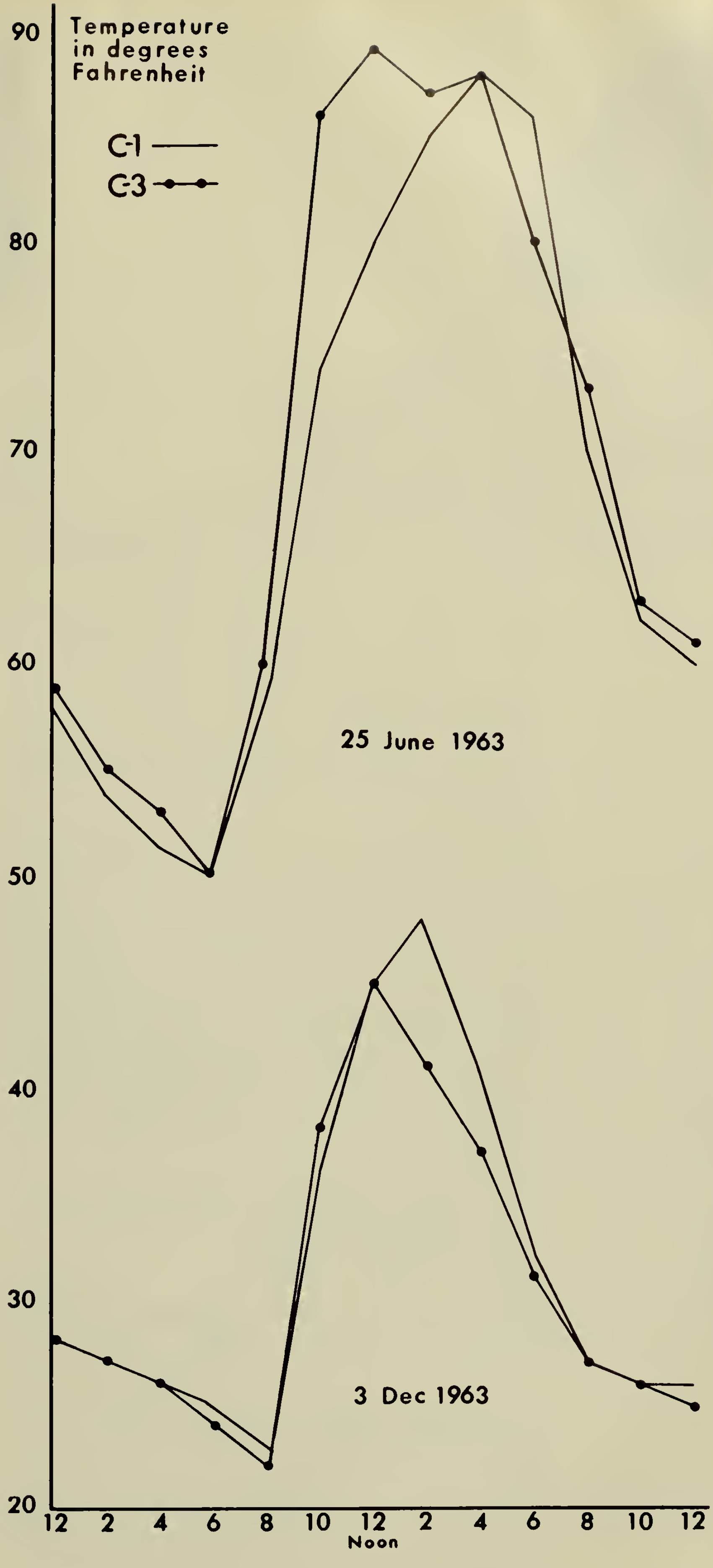
The long-term data from the Weather Bureau station show that there are generally two wet seasons each year—one in late winter and another in late summer, with August being the wettest month. Our data show that this pattern is characteristic of Mesa Verde as a whole.

Almost half of the yearly precipitation occurs as snow, with the greatest snowfall coming in the month of January. Snowstorms are not unusual as late as April, particularly at the higher elevations.

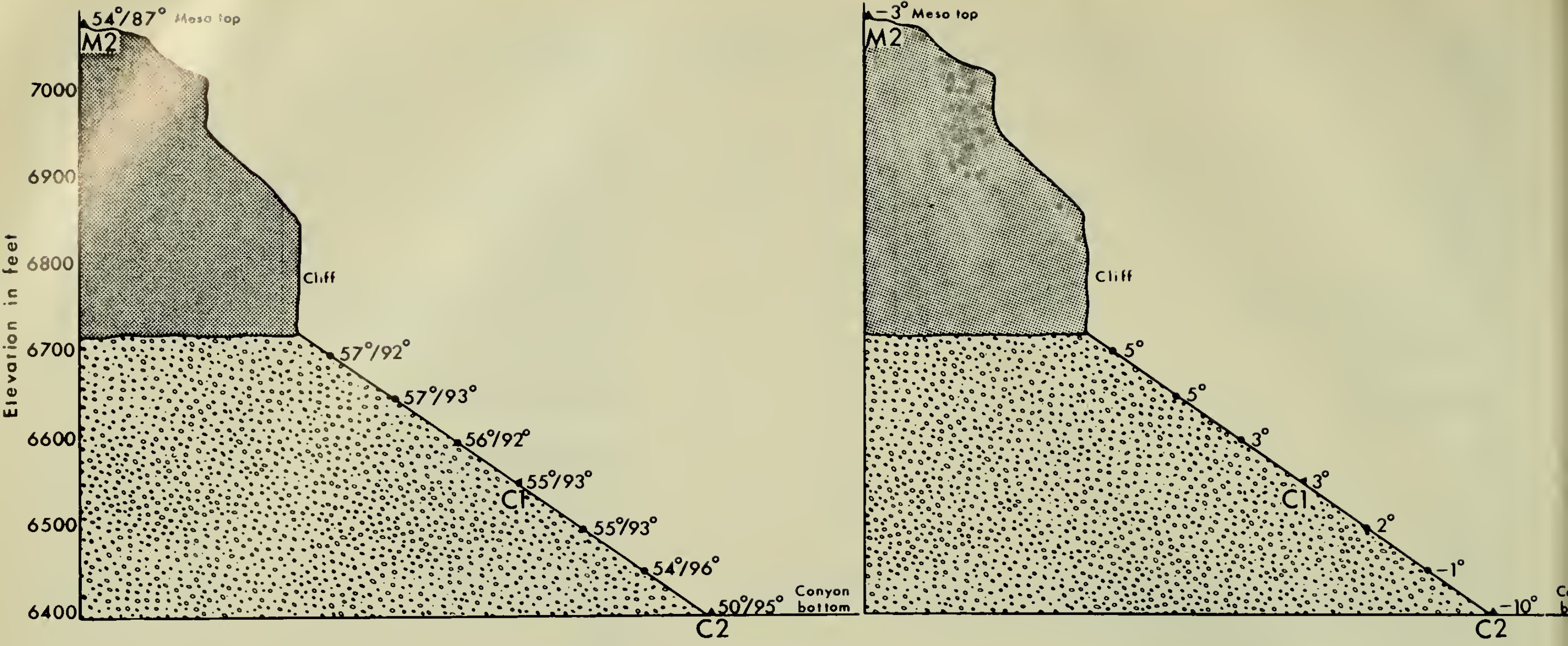
The effect of snow on soil temperature and moisture was complicated because of movements of snow by changing wind. This circumstance was most pronounced at Park Point, where areas covered by a drift 1 week were free of snow the next.

Relative humidity. The humidity record of M–2 may be considered typical of most of the mesa top. Humidity at the canyon floor and other low areas is markedly different, since these localities are subject to cold-air drainage. The C–2 data, as well as personal observations, indicate that air at the bottom of the canyon is saturated, or nearly so, almost every evening of the year.

Evaporation. Because of consistently poor evaporation records, comparison of evaporative rates between sites is not possible. However, by selecting five intervals of 6 days each during which there were continuous atmograph records (at sites having this instrument), we did find that the amount of evaporation appeared to be dependent more on wind than on temperature. Evapora-



17 Graph showing relationship of air temperatures to exposure under cloudless skies. As shown, the heat load varies from a summer maximum on the east-northeast exposure (C–3) to a winter maximum on the west-southwest exposure (C–1).



18 Air-temperature profiles of the west-southwest-facing slope in Navajo Canyon, showing the pronounced cold-air drainage at the bottom and the "thermal zone" on the talus. The profile at left shows minimum and maximum temperatures during August 13–19, 1963, while the profile at right gives only minimum temperatures during the winter of 1963–64.

tion was lowest at C–2, higher at M–2 and M–1, and highest at windswept M–3.

Wind. The prevailing winds at Mesa Verde are southwesterly. Spring and early summer are the windiest times, with the wind diminishing to its lowest point in winter (fig. 19).

M–1 and M–3, near the extremities of the mesa, experienced more wind than M–2, the middle mesa-top site. This suggests that topographic setting has more influence on wind than does altitude. M–1, at the southern end of the mesa, was influenced by the nearby Mancos River canyon, whose northeast-southwest orientation acts as a natural wind funnel. Since the prevailing winds there are generally from the southwest, the spillover from the canyon probably accounted for the small increase in wind at this site, in comparison with the situation at M–2.

C–2, on the canyon floor, had the least wind. Usually, the wind blew up-canyon during the day, and the cold air draining off the mesa tops and slopes produced down-canyon breezes at night.

COMPARISON OF WEATHER BUREAU STATION AND M-2 SITE

The 41-year record of the park's Weather Bureau station provides valuable information on the climate of the Mesa Verde. Our M–2 data supplement the Weather Bureau record by adding data on hour-to-hour temperature conditions and on factors not previously measured at that station. In addition, our study provides a means of testing how representative the long-term record is for the mesa as a whole.

Although the Weather Bureau station and M–2 were within a mile of each other and had similar topographic settings, their weather measurements do not agree closely. These unexpected results are probably due, in part, to the fact that the Weather Bureau station is in a small enclosure, which of course is influenced by adjacent buildings and trees.

Both maximum and minimum air temperatures were several degrees lower at M–2 than at the Weather Bureau station. This relationship was consistent throughout the 2 years of measurement. Actually recorded temperatures were more alike between the Weather Bureau station and M–1 lying 5 miles to the south and about 500 feet lower in elevation.

The occasional lack of accord in the precipitation records is more understandable. In 1962, M–2 had about 1.5 inches *more* precipitation than did the Weather Bureau station, but in 1963 it had 0.5 inch *less*. This erratic pattern occurred from month to month as well, and can be expected in an area where rainfall is commonly very localized.

COMPARISON OF MESA-TOP SITES

The three environment measurement sites on top of the mesas gave some indication of how factors vary along an elevational gradient.

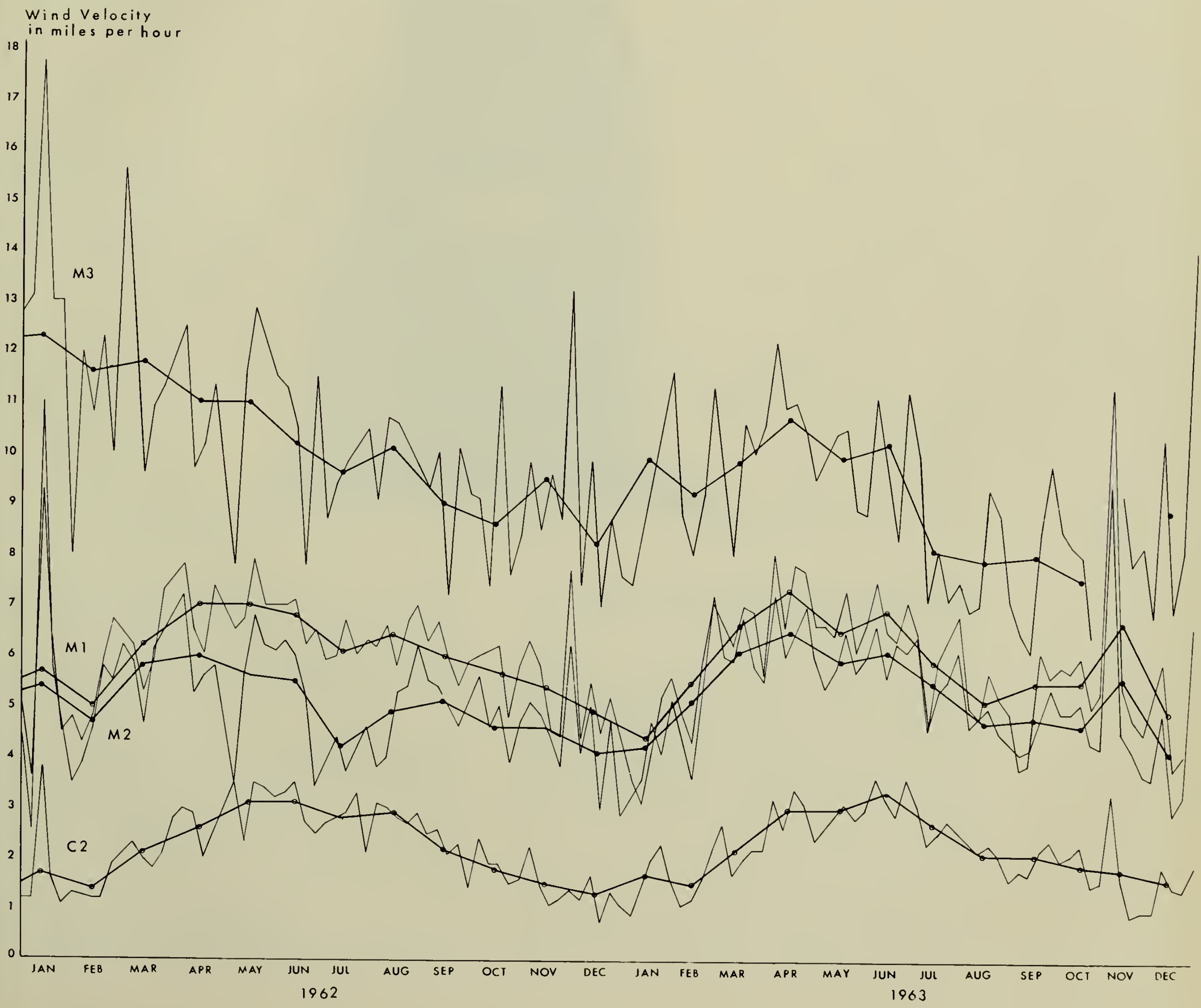
Air temperature. M–2 recorded the lowest temperature of the mesa-top sites, –26° F., and M–1 recorded the highest temperature, 98° F. As pointed out earlier, the temperature regime at M–3 was surprisingly moderate, diurnal and seasonal temperatures fluctuating much less than at the other sites. In winter servicing trips, we often found that Park Point was the warmest spot on Mesa Verde. This is to be expected however, since temperature variations decrease with increasing altitude and wind, and Park Point was the highest and windiest site.

Precipitation. The sample of a given rain or snowstorm caught in a gage varies with the amount of wind. Since our sites differed in this respect, comparison between them is not meaningful. It is clear, however, that annual precipitation increased with increasing altitude, being greatest in 1962, when the stand at the lowest mesa elevation received about two-thirds as much precipitation as the stand in the middle of the mesa and about half as much precipitation as the stand at Park Point. These differences resulted largely from variations between stations during the January–August interval. In 1963, the difference between stands was largely due to the fact that the stand at the highest elevation received almost twice as much precipitation (nearly 8 inches) as the other two during August, which was an exceptionally wet month.

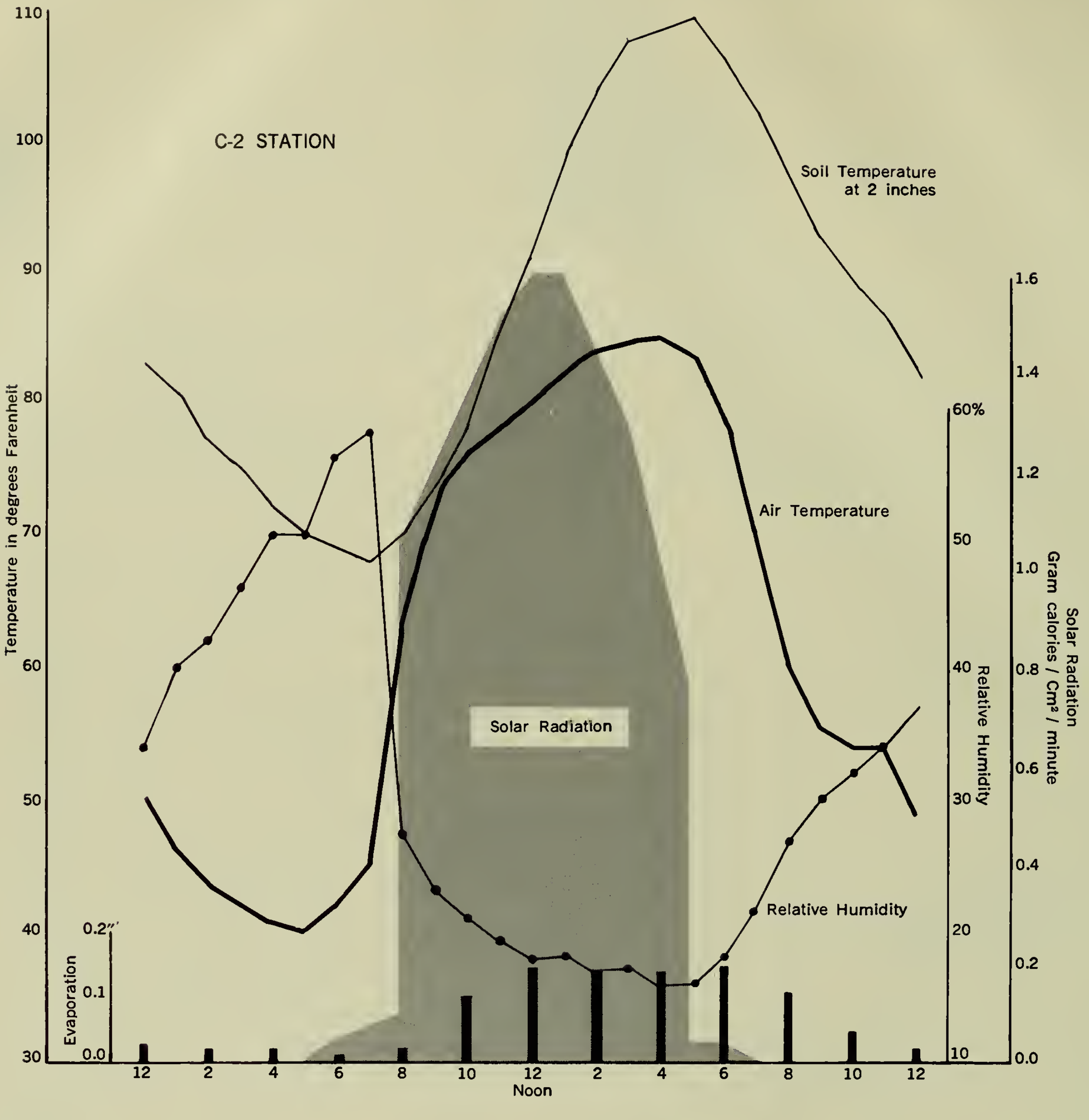
Relative humidity. This was lowest at M–1, particularly in 1962, when this site received much less rainfall than the other mesa-top sites. M–2 and M–3 averaged about the same, although the humidity was not nearly as variable at higher M–3. Because of rapid, short-term fluctuations often associated with local showers, average values based on daily maxima and minima are not to be considered too significant.

Evaporation. This was greater at the ends of the mesa than in the middle, primarily due to more wind. M–3 had the highest values in both 1962 and 1963.

19 Graph showing average wind velocities at the mesa-top and canyon-bottom sites in 1962 and 1963. Averages for servicing intervals and for months are indicated by light lines and heavy dotted lines, respectively. The gap in the M–3 record, in November 1963, was due to instrument failure during the first week of that month.



20 Graph showing progressions of five climatic variables at C–2 and M–2 on June 22, 1963, a cloudless day.



COMPARISON OF MIDDLE MESA-TOP AND CANYON-BOTTOM SITES

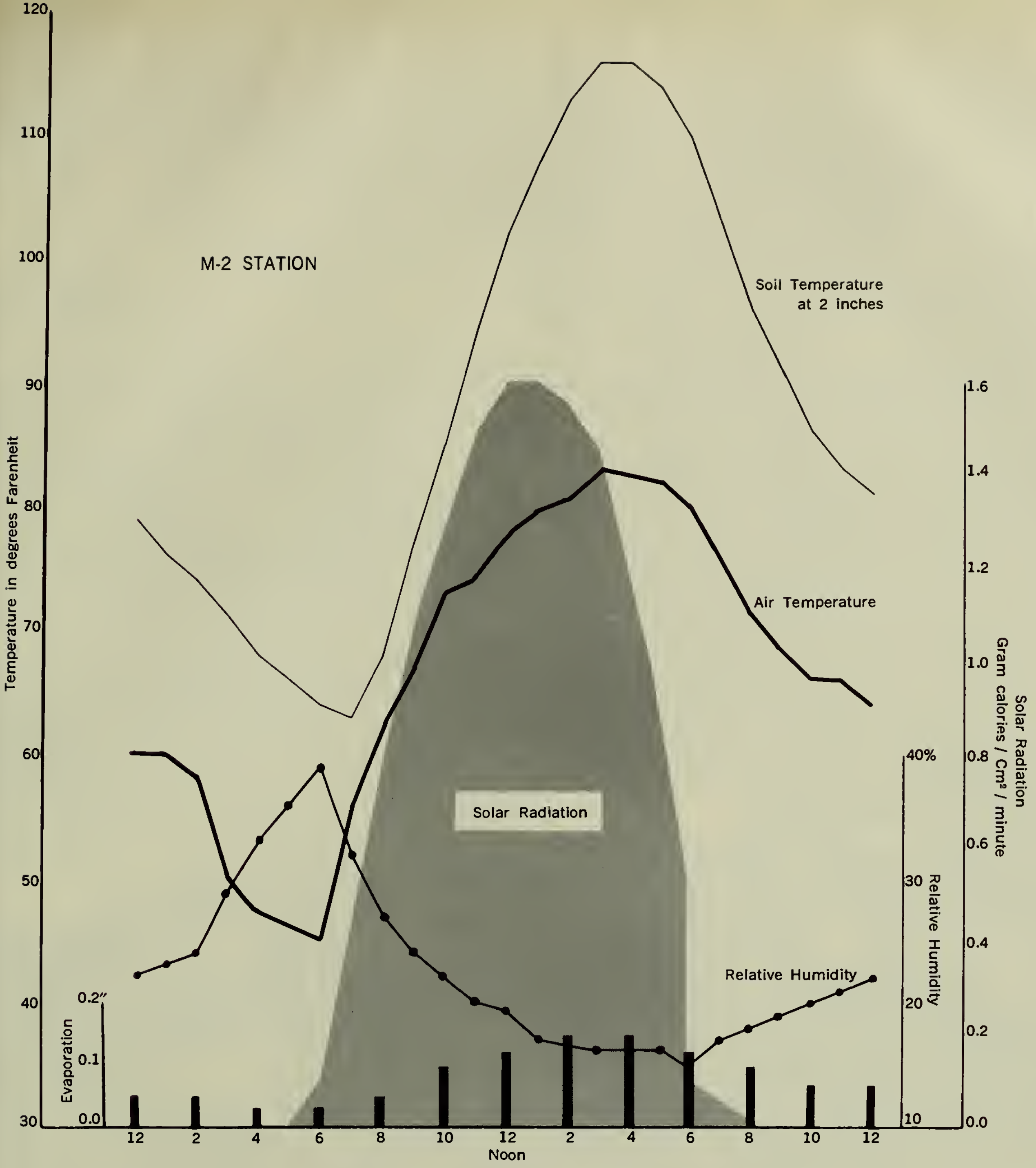
Mesas and plateaus are striking features of a landscape, but Mesa Verde is especially impressive because of the many deep canyons that dissect the upland surface. Such contrasting features as flat mesa tops, cliffs and steep slopes, and narrow, sometimes flat canyon floors produce a variety of landscape types. Our data clearly show the effects of elevation and topographic setting on local stands or ecosystems.

Solar radiation. There are two notable differences in the solar radiation regimes between the mesa tops and canyons. First, the period of direct illumination is shorter in the canyon because the sun's rays are intercepted by the cliffs early and late in the day. Secondly, daylight begins and ends more abruptly in the canyon. These conditions are shown graphically in figure 20, which plots the progression and interaction of several factors at M–2 and C–2. In 1963, incoming radiation at C–2 was almost 10 percent lower than that at M–2. This was caused by the "cliff effect."

Precipitation. Month-to-month differences in precipitation between the M–2 and C–2 were slight.

Wind. At C–2, wind velocity was about half that recorded at M–2, on the mesa top above. Nocturnal cold air movement may account for some of the wind along the floors of the canyons.

The significant differences in temperature, humidity, and evaporation rates between M–2 and C–2 (fig. 20) are definitely attributable to cold-air drainage, the controlling feature on the canyon floor.



COMPARISON OF CANYON SITES

The canyons contain a variety of ecosystems resulting from differences in altitude, soil parent material, substrate stability, exposure to solar radiation, and temperature related to cold-air drainage.

The three sites in Navajo Canyon were about one-half mile due west of park headquarters and 1½ miles southwest of the middle mesa-top site, M–2. Navajo Canyon, like many others in Mesa Verde, is oriented northwest-southeast. Consequently, the slopes receive different amounts of solar radiation, which results in the northeast-facing (west side) slope being somewhat cooler and more moist than the opposite slope.

Nocturnal conditions play a major role in controlling the vegetation at C–2 but have little effect on C–1 and C–3 nearby. Exposure to incoming solar radiation or to insolation appear to be the major cause of differences in the stands at C–1 and C–3. Therefore, daytime conditions, especially on a year-round basis, are important at the two canyon-slope sites.

Air-temperature averages at C–1 and C–3 show surprising similarities (table 11). Relative snow cover and soil moisture conditions were found to reflect the slope differences more vividly. The more direct insolation on the southwest-facing slope in winter is felt to be responsible for the greater aridity at C–1.

CHAPTER 5

the environment and the prehistoric occupation

Information on the soils, climate, and vegetation of Mesa Verde contributes to an understanding of the settlement pattern and farming practices of the Pueblo Indians who lived here prehistorically. The techniques of many disciplines, including floristics, palynology, and dendroclimatology, have all been brought to bear on these cultural problems.

EVIDENCE OF PREHISTORIC CLIMATE

Identification of plant remains recovered in the excavation of certain cliff dwellings on Wetherill Mesa indicates a flora similar to that of today (Welsh, MS.). In a preliminary statement, Schoenwetter (MS.) reported that the fossil pollen record gave no indication that a major climatic change has occurred since the Indians withdrew from the area at the end of the 13th century. According to a later report by Martin and Byers (1965, p. 122), "The main stratigraphic event in the pollen sequence of the last 1,000 years is a relative increase in juniper and pine pollen following abandonment 700 years ago." Although this increase may also reflect a minor climatic change, it is probably "the result of secondary plant succession with juniper and then pinyon invading fields when human disturbance ended" (ibid.). Paleoclimatic studies by Fritts, et al. (1965) were based upon the interpretation of present and past growth patterns in pinyon, Utah juniper, and Douglas-fir. Tree-ring chronologies for these species indicate that intense droughts occurred throughout the time of Pueblo occupation and well into the 17th century. These dry periods have not been surpassed since then.

In light of these data and studies, it would appear that the climate of today approximates that of the 13th century in most significant aspects.

INFLUENCE OF ENVIRONMENT ON THE PUEBLOAN CULTURE

The prehistoric sites of Mesa Verde are not distributed uniformly over the plateau but are concentrated in a belt along the 7,000 -foot contour, about midway between the Mancos River canyon and the escarpment of the North Rim (Hayes, 1964). This concentration was doubtless the result of many factors, including those of vital concern to an agrarian people—water from seeps and springs; large areas of deep, fertile soil; and moderate climate. The environment of the middle mesa-top site, M–2, may be considered most typical of that in which the aborigines spent much of their time. There is no direct evidence to prove that the Indians farmed the middle mesa top, but archeologists feel strongly that they did. This central belt has extensive, deep soils with more than adequate nutrients. The lower end of the mesa may have been too hot and dry for farming, and the higher parts may have lacked adequate soil.

There is ample evidence of farming in the washes and gullies of the mesa rims and on the canyon slopes. As the population grew, it is reasonable to assume that some marginal areas, places difficult to till, had to be exploited in the production of food, primarily maize, beans, and squash. Consequently, systems of check dams and farming terraces were constructed wherever possible. According to Rohn (1963, p. 442), each check dam consisted of rough-hewn sandstone blocks stacked across a small, intermittent stream channel to form a thick wall with a marked upstream batter and a level top course. Such a system trapped the runoff water, causing fine soil particles and organic debris to be deposited behind the stone walls. Parts of some hillsides were also terraced, occasionally in conjunction with the systems of check dams in the erosional channels. These terraces used available moisture

21. Map showing locations of prehistoric farming terraces on Wetherill Mesa and in adjacent canyons.

to advantage and undoubtedly increased the annual harvests considerably.

The distribution of farming terraces was studied to determine whether the use of those slopes and mesa rims that harbor more favorable moisture regimes was intentional. The distribution pattern of terraces on Wetherill Mesa, mapped during the archeological survey (Hayes, 1964), is shown in figure 21. The pattern indicates that the more mesic canyon and mesa slopes *were selected* for agricultural purposes. Of the terrace systems on talus slopes, about 75 percent of the sites surveyed have a northeastern exposure and about 25 percent of the sites have a southwestern exposure. Even more revealing are the "contour" terraces—extensive hillside steps not unlike those found today in the Orient and in the vineyards of Europe—which are found, with few exceptions, on the northeastern exposures of Wetherill Mesa. (Discussions in ch. 4 give some information that may explain this apparent preference for northeastern exposures as locations for farming plots.)

The combination of favorable temperature conditions, as a result of exposure and the stratification of thermal zones, slightly higher humidity, and adequate soil moisture on the northeastern slopes create what may be the most favorable environment for maize agriculture in the entire Mesa Verde.

There is no direct evidence that the canyon floors were cultivated. We might conclude that cold-air drainage makes this habitat unsuitable for maize and other vegetables, but some check dams at the base of talus slopes near the canyon floors suggest that farming may have been at least marginal in these places. Moreover, soil moisture conditions here may have been more favorable than they are today, for Reed's (1958, pp. 615–167) investigations in Mancos Canyon suggest that the present-day terraces in Mesa Verde were the alluvial floors of the canyons in prehistoric times. The arroyo cutting which produced the present terraces may have started as late as 1880.

Farming sites along the mesa-top rims are also predominantly on northeastern exposures (fig. 21). Sixty percent of those surveyed face approximately northeast, while 40 percent have a southwestern exposure. The northeast-facing sites receive less insolation, and late-lying snow beds improve moisture conditions in the soil.

In conclusion, it appears that the Pueblo Indian farmers deliberately selected the more mesic exposures wherever possible. We do not know if the choice was made by reasoning that crops would grow best where snow persisted longer and temperatures were more favorable, or whether it was arrived at by trial-and-error. Perhaps trial-and-error was supplemented by increased knowledge of the landscape and by observations of crop growth throughout the seasons. From what clues we have as to their farming practices, it is evident that these people were skilled in the management of their most priceless natural resources—soil and water.

references

ARRHENIUS, GUSTAF, and ENRICO BONATTI

1965. The Mesa Verde Loess. Memoirs of the Society for American Archaeology, no. 19; American Antiquity, vol. 31, no. 2, pt. 2, pp. 92–100. Salt Lake City.

BENSON, LYMAN

1957. Plant Classification. D.C. Heath and Company. Boston.

BRADLEY, WILLIAM C.

1963. Large-scale Exfoliation in Massive Sandstones of the Colorado Plateau. Geological Society of America, bulletin 74, pp. 519–527. New York.

CONRAD, V., and L. W. POLLACK

1950. Methods in Climatology, Harvard University Press. Cambridge.

COTTAM, G., and J. T. CURTIS

1956. The Use of Distance Measures in Phytosociological Sampling. Ecology, vol. 37, pp. 451–460. Durham.

DAUBENMIRE, R. F.

1959. Plants and Environment. John Wiley and Sons. New York.

ERDMAN, JAMES A.

MS. Ecology of the Pinyon-Juniper Woodland of Wetherill Mesa, Mesa Verde National Park, Colo. Unpublished M.A. thesis, 1962. University of Colorado. Boulder.

FRITTS, HAROLD C., DAVID G. SMITH, and MARVIN A. STOKES

1965. The Biological Model for Paleoclimatic Interpretation of Mesa Verde Tree-Ring Series. Memoirs of the Society for American Archaeology, no. 19; American Antiquity, vol. 31, no. 2, pt. 2, pp. 101–121. Salt Lake City.

GEIGER, RUDOLF

1957. The Climate Near the Ground. Harvard University Press. Cambridge.

GITTINGS, EDWIN B.

1941. Supplementary Climatic Notes for Colorado, in Climate and Man, Yearbook of Agriculture, pp. 807–808. U.S. Department of Agriculture. Washington.

GLOCK, WALDO S.

1937. Principles and Methods of Tree-Ring Analysis. Carnegie Institution of Washington, publication 486. Washington.

HACK, JOHN T.

1942. The Changing Physical Environment of the Hopi Indians of Arizona. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 35, no. 1. Cambridge.

HANSON, HERBERT C., and ETHAN D. CHURCHILL

1961. The Plant Community. Rheinhold Publishing Corporation. New York.

HAYES, ALDEN C.

1964. The Archeological Survey of Wetherill Mesa. Archeological Research Series 7–A. National Park Service. Washington.

HUNT, C. B.

1956. Cenozoic Geology of the Colorado Plateau. Geological Survey, professional paper 279. Washington.

Johnsen, Thomas N., Jr.
1959. Longevity of Stored Juniper Seeds. Ecology, vol. 40, pp. 487–488. Durham.

Marr, John W.
1961. Ecosystems of the East Slope of the Front Range in Colorado. University of Colorado Studies, Series in Biology, no. 8. Boulder.

Martin, Paul S., and William Byers
1965. Pollen and Archaeology at Wetherill Mesa. Memoirs of Society for American Archaeology, no. 19; American Antiquity, vol. 31, no. 2, pt. 2, pp. 122–135. Salt Lake City.

Meagher, G. S.
1943. Reaction of Pinon and Juniper Seedlings to Artificial Shade and Supplemental Watering. Journal of Forestry, vol. 41, pp. 480–482. Washington.

Nord, Eamor C.
1959. Bitterbrush Ecology—Some Recent Findings. U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station Research, note 148. Berkeley.

Oosting, Henry J.
1956. The Study of Plant Communities. W. H. Freeman. San Francisco.

Reed, Erik K.
1958. Excavations in Mancos Canyon, Colorado. University of Utah Anthropological Papers, no. 35. Salt Lake City.

Roberts, Ray C.
MS. Initial Field Review of the Soils on Wetherill Mesa, Mesa Verde National Park, Colorado. Unpublished manuscript, 1960, on file at Mesa Verde National Park, Colo.

Rohn, Arthur H.
1963. Prehistoric Soil and Water Conservation on Chapin Mesa, Southwestern Colorado. American Antiquity, vol. 28, no. 4, pp. 441–455. Salt Lake City.

Schoenwetter, James
MS. Pollen Stratigraphy of the Wetherill Mesa Region. Unpublished manuscript, 1960, on file at Mesa Verde National Park, Colo.

Trewartha, Glenn T.
1954. An Introduction to Climate. McGraw-Hill. New York.

Wanek, Alexander A.
1959. Geology and Fuel Resources of the Mesa Verde Area, Montezuma and La Plata Counties, Colorado. Geological Survey, bulletin 1072–M. Washington.

Watson, Don
1934. Unusual Weather. Mesa Verde Notes, vol. 5, no. 1, pp. 16–17. Mesa Verde National Park, Colo.

Welsh, Stanley L.
MS. Identification of Vegetal Materials, Report no. 7. Unpublished manuscript, 1961, on file at Mesa Verde National Park, Colo.

Welsh, Stanley L., and James A. Erdman
1964. Annotated Checklist of the Plants of Mesa Verde, Colorado. Brigham Young University Science Bulletin, Biological Series, vol. 4, no. 2. Provo.

White, Everett M.
MS. Wetherill Mesa Soil Investigation. Unpublished manuscript, 1960, on file at Mesa Verde National Park, Colo.

appendix

ANNUAL SUMMARIES OF ENVIRONMENT DATA

Station: M-1; elevation: 6,650 feet; site: Mesa top; year: 1962

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity, m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	46	—2	37	13	25.3	100	20	93	33	63.2	...	...	4,224	5.7
February	58	—3	43	23	33.1	100	15	94	34	63.9	...	...	3,345	5.0
March	65	5	45	22	33.7	100	8	73	23	47.9	...	...	4,594	6.2
April	80	26	67	36	51.5	100	2	56	12	34.1	...	...	5,006	7.0
May	83	24	71	40	55.7	100	1	46	9	27.3	...	...	5,254	7.0
June	95	41	84	49	66.7	100	2	36	8	22.4	...	...	4,915	6.8
July	97	46	89	56	72.9	100	2	51	11	31.1	...	...	4,544	6.1
August	98	40	89	54	71.6	100	2	44	12	27.9	...	...	4,810	6.4
September	90	36	77	49	63.5	100	8	65	23	44.1	...	...	4,319	6.0
October	76	36	67	41	53.6	100	2	70	19	44.4	...	...	4,272	5.7
November	67	16	55	32	43.4	100	4	69	26	47.7	...	...	3,831	5.4
December	57	0	44	22	32.9	100	16	91	36	63.4	...	...	3,674	4.9
Year	98	—3	64	36	50.0	100	1	66	21	43.1	...	...	52,788	6.0

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	0.25	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
February	.35	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
March	.80	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
April	.47	*88*	*37*	*78*	*47*	*62.5*	*69*	*48*	*64*	*53*	*58.4*	*62*	*52*	*59*	*55*	*56.5*
May	.20	97	36	86	51	68.4	75	47	69	58	63.3	68	50	63	59	61.1
June	.09	116	52	104	62	83.1	88	59	81	69	74.6	80	60	73	69	71.1
July	.30	117	62	110	69	89.5	90	72	86	76	81.2	82	74	80	76	78.3
August	.28	120	59	110	67	88.9	92	71	87	76	81.5	84	73	81	77	78.9
September	1.95	110	41	94	58	75.8	85	50	77	66	71.6	78	56	73	69	71.1
October	2.38	*83*	*41*	*75*	*46*	*60.3*	*71*	*49*	*64*	*53*	*58.4*	*65*	*55*	*61*	*58*	*59.4*
November	1.30	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
December	.80	*32*	*22*	*29*	*25*	*26.9*	*32*	*26*	*30*	*27*	*28.4*	*34*	*27*	*32*	*29*	*30.2*
Year	9.17	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: M-1; elevation: 6,650 feet; site: Mesa top; year: 1963

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean	Total	Mean	Total miles	Velocity, m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.					
January	*44*	*−23*	*34*	*11*	*22.3*	*100*	*11*	*90*	*47*	*68.5*	....	....	3,277	4.4
February	61	2	46	24	35.3	100	12	88	35	61.5	....	....	3,636	5.5
March	66	8	50	25	37.8	100	7	79	21	49.6	....	....	4,926	6.6
April	76	16	59	29	44.2	100	4	69	20	44.7	....	....	5,268	7.3
May	84	29	77	44	60.5	100	6	46	12	29.1	....	....	4,826	6.5
June	95	36	83	48	65.3	100	7	53	17	35.1	....	....	4,945	6.9
July	97	52	91	59	75.0	100	8	60	18	38.8	....	....	4,372	5.9
August	92	52	83	57	69.8	100	13	91	26	58.7	....	....	3,806	5.1
September	86	46	81	52	66.4	100	11	73	20	46.8	....	....	4,009	5.5
October	84	30	71	43	57.0	100	12	63	26	44.5	....	....	4,072	5.5
November	64	16	53	29	40.9	100	16	89	30	59.5	....	....	4,836	6.7
December	52	2	41	17	28.8	100	12	86	36	60.9	....	....	3,668	4.9
Year	97	−23	64	37	50.3	100	4	74	26	49.8	....	....	51,641	5.9

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	1.50	34	22	31	28	29.1	33	25	31	28	29.6	35	26	33	30	31.1
February	1.20	51	29	38	33	35.1	40	29	35	32	33.6	39	30	36	33	34.9
March	.85	70	30	51	36	43.4	57	31	43	37	40.1	52	33	42	39	40.2
April	.48	78	34	67	45	55.6	64	40	57	49	52.9	59	43	54	50	52.2
May	.06	98	51	88	60	73.9	80	55	74	64	68.9	70	56	66	62	63.9
June	.02	115	55	101	65	83.1	92	64	82	71	76.4	78	61	72	67	69.3
July	2.25	115	66	107	75	90.6	96	71	91	80	85.4	84	70	80	76	78.1
August	3.96	112	61	99	69	84.0	94	66	86	75	80.3	83	65	77	73	74.9
September	.72	101	55	93	62	77.3	85	62	79	67	73.3	74	62	70	66	68.4
October	1.55	91	37	76	49	62.4	75	44	64	55	59.1	68	46	59	56	57.4
November	.79	*57*	*28*	*48*	*33*	*40.5*	*48*	*30*	*42*	*37*	*39.6*	*45*	*30*	*41*	*38*	*39.4*
December	.50	32	19	28	24	25.9	32	23	28	25	26.5	33	23	28	25	26.6
Year	13.88	115	19	69	48	58.4	96	23	59	52	55.5	84	23	55	51	53.0

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: M–2; elevation: 7,150 feet; site: Mesa top; year: 1962

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G.-cal./sq.cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	52	−11	38	13	25. 6	100	20	94	35	64. 8	....	....	3, 994	5. 4
February	56	−10	42	21	31. 3	100	22	92	37	64. 3	....	....	3, 129	4. 7
March	63	2	45	21	32. 6	100	16	81	28	54. 8	....	....	4, 317	5. 8
April	78	24	64	34	49. 2	100	12	70	22	46. 1	....	....	4, 331	6. 0
May	78	23	68	38	52. 8	100	5	62	20	40. 7	20, 874	673	4, 155	5. 6
June	91	38	80	47	63. 9	100	10	54	18	36. 0	22, 100	737	3, 947	5. 5
July	91	48	84	54	69. 1	100	10	68	19	43. 8	20, 320	655	*1, 822*	*4. 2*
August	94	46	86	55	70. 2	100	10	59	21	40. 0	19, 950	644	3, 652	4. 9
September	86	38	75	49	61. 7	100	17	77	32	54. 9	14, 423	481	3, 692	5. 1
October	74	34	64	39	51. 5	100	15	91	34	62. 8	11, 542	372	3, 431	4. 6
November	63	13	52	30	41. 1	100	10	86	36	60. 9	7, 022	234	3, 331	4. 6
December	*53*	*−2*	*44*	*20*	*31. 7*	*100*	*18*	*89*	*34*	*61. 7*	6, 502	210	3, 049	4. 1
Year	94	−11	62	35	48. 5	100	5	77	28	52. 5	....	....	42, 850	5. 0

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	. 75	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
February	2. 70	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
March	1. 30	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
April	. 65	*84*	*32*	*75*	*42*	*58. 9*	*68*	*42*	*63*	*49*	*55. 8*	*61*	*49*	*58*	*53*	*55. 1*
May	. 87	*93*	*33*	*83*	*46*	*64. 2*	*76*	*43*	*67*	*53*	*60. 1*	*68*	*49*	*62*	*57*	*59. 8*
June	. 20	111	47	100	59	79. 6	86	53	80	65	72. 5	81	58	74	69	71. 8
July	1. 03	113	60	104	65	84. 9	87	65	82	69	75. 5	82	72	80	75	77. 3
August	. 23	114	56	106	65	85. 6	86	61	81	67	74. 4	84	72	80	76	78. 0
September	2. 33	107	42	90	55	72. 4	77	41	68	55	61. 8	77	54	71	67	68. 7
October	2. 74	82	34	70	39	54. 4	59	33	50	38	44. 1	62	45	55	50	52. 6
November	1. 70	64	25	48	30	39. 0	45	20	34	26	29. 8	50	30	41	38	39. 5
December	1. 30	42	24	34	27	30. 1	34	17	29	25	26. 8	35	23	31	28	29. 6
Year	15. 80	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: M-2; elevation: 7,150 feet; site: Mesa top; year: 1963

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity, m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	44	−26	32	8	20. 3	100	21	93	43	67. 9	5, 494	177	3, 156	4. 2
February	58	2	45	23	33. 6	100	18	90	38	64. 1	8, 165	292	3, 397	5. 1
March	63	12	47	24	35. 4	100	15	84	29	56. 7	13, 264	428	4, 516	6. 1
April	70	15	55	28	41. 5	100	8	73	25	48. 9	16, 489	550	4, 687	6. 5
May	77	31	72	41	56. 2	92	8	51	15	33. 0	20, 992	677	4, 335	5. 9
June	90	35	79	45	62. 0	96	9	55	19	36. 9	20, 311	677	4, 394	6. 1
July	93	50	86	56	71. 1	98	10	63	19	41. 2	20, 286	654	4, 073	5. 5
August	88	50	79	54	66. 6	91	12	83	27	54. 9	15, 943	514	3, 476	4. 7
September	83	44	78	49	63. 6	100	14	76	24	50. 0	15, 649	522	3, 441	4. 8
October	82	29	68	41	54. 5	100	16	72	31	51. 6	11, 080	357	3, 406	4. 6
November	62	17	52	28	39. 9	100	20	91	34	62. 4	7, 266	242	4, 092	5. 6
December	51	4	41	17	29. 1	100	18	86	34	60. 2	6, 754	218	3, 017	4. 1
Year	93	−26	61	34	47. 8	100	8	76	28	52. 3	161, 693	442	45, 990	5. 3

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	1. 60	32	22	29	26	27. 6	32	25	30	27	28. 7	35	23	33	28	30. 4
February	1. 35	51	27	36	29	32. 7	40	28	34	30	31. 8	37	29	35	31	33. 0
March	. 95	75	25	52	32	41. 7	59	29	43	34	38. 2	52	31	40	37	38. 4
April	. 54	82	30	69	39	53. 9	64	35	57	44	50. 2	59	40	53	48	50. 5
May	. 12	107	45	96	55	75. 6	81	50	74	60	67. 0	75	54	69	64	66. 5
June	. 07	120	48	107	61	84. 0	91	57	82	67	74. 2	85	65	77	72	74. 5
July	2. 13	120	58	107	69	87. 8	92	63	86	71	78. 7	87	71	83	78	80. 5
August	4. 54	118	58	96	64	80. 0	90	58	78	66	71. 9	87	67	78	74	76. 0
September	. 59	97	52	92	58	74. 9	77	54	72	59	65. 8	75	61	71	66	68. 4
October	1. 77	96	36	77	48	62. 7	72	38	60	49	54. 2	68	45	58	54	56. 4
November	. 88	61	24	48	31	39. 8	46	23	37	30	33. 6	46	29	39	36	37. 6
December	. 50	36	17	33	26	29. 5	33	16	29	25	27. 4	36	24	32	28	30. 1
Year	15. 04	120	17	70	45	57. 5	92	16	57	47	51. 8	87	23	56	51	53. 5

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: M-3; elevation: 8,575 feet; site: Mesa top; year: 1962

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity, m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	50	−5	31	16	23. 6	100	23	85	38	61. 5	....	....	9, 148	12. 3
February	50	1	34	22	28. 3	100	21	86	50	67. 9	....	....	7, 826	11. 6
March	55	4	34	19	26. 5	100	17	70	34	51. 8	....	....	8, 810	11. 8
April	68	18	54	35	44. 7	100	12	64	25	44. 5	....	....	7, 916	11. 0
May	70	27	59	40	49. 5	100	9	54	24	39. 0	....	....	8, 304	11. 1
June	81	35	70	49	59. 5	100	14	47	22	34. 7	....	....	7, 427	10. 2
July	84	47	77	55	65. 6	100	17	67	26	46. 6	....	....	7, 167	9. 6
August	88	47	78	55	66. 5	100	12	55	23	39. 2	....	....	*4, 835*	*10. 1*
September	79	37	68	49	58. 0	100	16	74	34	53. 6	....	....	6, 506	9. 0
October	66	33	57	41	48. 9	100	14	71	33	52. 3	....	....	6, 376	8. 6
November	58	12	44	31	37. 7	100	18	71	45	58. 0	....	....	6, 802	9. 5
December	48	0	36	23	29. 8	100	20	74	42	58. 6	....	....	6, 134	8. 2
Year	88	−5	54	36	44. 9	100	9	68	33	50. 6	....	....	87, 251	10. 3

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	0. 75	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
February	2. 80	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
March	1. 50	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
April	. 39	*72*	*29*	*63*	*40*	*51. 3*	*59*	*36*	*53*	*45*	*48. 9*	*54*	*39*	*49*	*45*	*47. 0*
May	. 93	79	33	68	44	55. 7	67	39	58	48	53. 0	59	40	53	49	50. 9
June	1. 03	103	42	87	56	71. 6	81	47	72	61	66. 4	72	49	64	61	62. 7
July	2. 02	104	55	95	62	78. 7	83	63	78	68	72. 9	74	64	71	68	69. 7
August	1. 97	105	52	95	61	77. 9	85	60	79	67	73. 2	76	63	72	69	70. 2
September	2. 13	96	38	80	53	66. 3	77	45	68	59	63. 4	69	48	63	60	61. 8
October	2. 94	76	34	64	39	51. 7	64	38	56	44	50. 2	56	41	51	47	48. 8
November	1. 50	*64*	*30*	*48*	*33*	*40. 3*	*54*	*31*	*43*	*37*	*39. 9*	*48*	*32*	*41*	*38*	*39. 4*
December	. 90	41	24	32	28	29. 8	35	26	31	29	30. 4	33	26	31	29	30. 2
Year	18. 86	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: M-3; elevation: 8,575 feet; site: Mesa top; year: 1963

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	*44*	*−20*	*30*	*15*	*22.5*	*100*	*23*	*82*	*50*	*65.7*			7,372	9.9
February	*46*	*20*	*39*	*28*	*33.5*	*100*	*34*	*82*	*51*	*66.4*			6,208	9.2
March	54	5	38	21	29.6	100	19	77	33	55.0			7,271	9.8
April	66	13	49	28	38.5	100	15	69	30	49.9			7,722	10.7
May	72	32	66	46	55.7	100	16	48	25	36.3			7,326	9.9
June	82	38	70	49	59.8	100	16	55	27	40.9			7,341	10.2
July	86	50	79	58	68.3	100	16	63	28	45.4			5,981	8.1
August	82	45	71	52	61.7	100	24	92	41	66.2			5,919	7.9
September	75	44	69	51	60.4	100	17	71	33	51.6			5,752	8.0
October	74	29	61	45	52.6	100	20	63	37	50.2			*3,814*	*7.5*
November	57	20	45	31	38.2	100	13	79	38	58.6			*4,468*	*8.5*
December	*46*	*11*	*37*	*23*	*29.8*	*100*	*20*	*75*	*38*	*56.6*			6,678	8.9
Year	86	−20	55	37	45.9	100	13	71	36	53.6			75,852	9.1

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	1.30	*31*	*23*	*28*	*27*	*27.5*	*32*	*25*	*30*	*28*	*29.1*	*34*	*25*	*31*	*29*	*29.9*
February	1.20	34	26	31	30	30.4	35	28	32	31	31.4	35	28	33	31	32.1
March	1.00	64	24	38	29	33.2	51	27	34	31	32.6	45	28	34	32	33.0
April	.55	73	28	59	35	47.1	59	32	50	40	45.2	53	35	46	42	44.1
May	.16	95	42	83	52	67.5	76	46	69	57	63.1	68	48	62	59	60.6
June	.07	111	45	96	58	76.8	89	55	77	65	71.2	79	59	71	67	69.1
July	1.97	110	55	99	64	81.8	90	61	83	70	76.7	81	66	77	73	75.3
August	7.62	*110*	*54*	*90*	*59*	*74.5*	*87*	*58*	*77*	*65*	*70.7*	*80*	*63*	*72*	*68*	*70.3*
September	.45	99	49	90	55	72.9	79	56	74	61	67.8	71	61	69	65	66.6
October	2.70	100	36	82	47	64.5	77	43	65	54	59.9	70	49	61	58	59.8
November	1.04	*66*	*24*	*47*	*31*	*39.2*	*54*	*32*	*42*	*36*	*38.8*	*49*	*34*	*42*	*39*	*40.5*
December	.75	*44*	*24*	*40*	*27*	*33.6*	*36*	*29*	*34*	*31*	*32.7*	*36*	*32*	*35*	*34*	*34.6*
Year	18.81	111	23	65	43	54.1	90	25	56	47	51.6	81	25	53	50	51.3

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: C–1; elevation: 6,500 feet; site: Canyon slope, southwest-facing; year: 1962

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	48	−2	39	16	27.6	94	24	84	36	59.9	....	....	....	....
February	58	−2	44	23	33.4	90	22	84	37	60.7	....	....	....	....
March	70	5	47	22	34.4	92	12	75	26	50.5	....	....	....	....
April	80	27	67	36	51.5	93	10	64	19	41.4	....	....	....	....
May	84	27	71	40	55.5	93	4	57	17	36.9	....	....	....	....
June	*92*	*53*	*88*	*55*	*71.4*	*100*	*22*	*86*	*29*	*57.3*	....	....	....	....
July	95	51	89	55	72.0	100	10	68	21	44.9	....	....	....	....
August	97	46	89	55	72.0	100	8	59	20	39.8	....	....	....	....
September	90	38	78	49	63.7	100	14	72	32	51.9	....	....	....	....
October	78	35	68	40	53.7	100	14	88	32	60.0	....	....	....	....
November	68	17	56	31	43.6	100	20	85	32	61.6	....	....	....	....
December	58	3	46	22	33.8	96	21	85	37	61.2	....	....	....	....
Year	97	−2	65	37	51.1	100	4	76	29	52.2	....	....	....	....

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	....	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
February	....	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
March	....	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
April	....	*77*	*43*	*69*	*50*	*59.4*	*63*	*49*	*59*	*53*	*56.2*	*59*	*50*	*56*	*53*	*54.5*
May	....	*82*	*43*	*71*	*53*	*62.0*	*69*	*48*	*62*	*56*	*59.2*	*64*	*49*	*59*	*56*	*57.6*
June	....	92	52	84	63	73.1	79	56	72	65	68.7	75	56	69	64	66.5
July	....	94	66	89	70	79.4	82	69	78	72	75.1	77	69	76	72	73.7
August	....	98	64	92	71	81.6	83	71	80	74	77.1	81	71	78	74	76.0
September	....	100	48	85	63	74.3	79	55	74	68	70.9	77	60	73	70	71.1
October	....	84	42	73	48	60.9	69	49	62	55	58.4	66	53	61	58	59.4
November	....	*72*	*38*	*65*	*43*	*53.9*	*59*	*46*	*55*	*49*	*52.0*	*53*	*49*	*53*	*49*	*50.9*
December	....	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Year	....	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: C-1; elevation: 6,500 feet; site: Canyon slope, southwest-facing; year: 1963

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	48	−20	34	10	21.8	100	22	89	45	66.9	....	....	....	....
February	65	3	48	24	36.4	100	18	90	38	63.9	....	....	....	....
March	68	13	52	25	38.4	100	14	84	28	55.8	....	....	....	....
April	74	17	59	30	44.5	100	10	62	21	41.2	....	....	....	....
May	84	32	77	43	60.1	81	4	45	12	28.7	....	....	....	....
June	95	37	82	48	65.3	84	6	45	15	29.8	....	....	....	....
July	98	54	92	59	75.0	84	8	56	16	36.5	....	....	....	....
August	92	52	84	56	69.8	82	10	74	23	48.5	....	....	....	....
September	89	47	83	52	67.3	100	14	74	24	49.0	....	....	....	....
October	85	32	72	44	57.6	100	17	69	31	49.8	....	....	....	....
November	67	18	55	30	42.3	100	22	86	34	60.2	....	....	....	....
December	54	5	43	18	30.3	100	20	83	37	60.0	....	....	....	....
Year	98	−20	65	37	50.7	100	4	71	27	49.2	....	....	....	....

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	....	*33*	*25*	*31*	*28*	*29.5*	*33*	*26*	*32*	*29*	*30.3*	*35*	*25*	*33*	*29*	*30.9*
February	....	59	29	46	33	39.3	43	31	38	34	36.3	42	31	38	35	36.1
March	....	65	31	51	37	43.9	52	33	43	38	40.6	49	34	41	38	39.7
April	....	68	37	59	44	51.8	56	41	51	46	48.9	53	41	49	46	47.6
May	....	80	49	75	58	66.4	70	50	65	59	61.8	67	49	62	58	60.0
June	....	92	55	82	64	72.7	78	59	71	65	68.0	75	60	69	64	66.6
July	....	*97*	*61*	*89*	*69*	*78.9*	83	66	79	72	75.5	80	67	76	72	74.1
August	....	96	61	88	67	77.1	82	65	76	70	73.1	80	67	75	71	73.1
September	....	93	57	89	64	76.2	78	62	75	67	71.1	75	65	73	69	70.7
October	....	92	46	78	55	66.5	75	52	66	60	63.3	73	55	66	62	64.1
November	....	68	32	57	39	48.0	56	38	50	45	47.2	56	41	51	47	49.0
December	....	52	25	38	30	33.8	44	30	37	34	35.2	45	32	39	36	37.3
Year	....	97	25	65	49	57.0	83	26	57	52	54.3	80	25	56	52	54.1

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: C-2; elevation: 6,382 feet; site: Canyon bottom; year: 1962

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	47	−7	38	8	23.1	100	24	94	36	65.0	....	....	1,283	1.7
February	57	−8	44	19	31.2	96	18	91	37	64.1	....	....	953	1.4
March	67	−2	46	17	31.7	100	11	93	26	59.5	....	....	1,586	2.1
April	79	20	66	29	47.4	100	8	88	20	53.9	....	....	1,907	2.6
May	82	19	71	34	52.5	100	4	78	18	48.2	19,631	654	2,313	3.1
June	95	33	83	42	62.5	96	11	74	18	45.6	21,605	720	2,253	3.1
July	97	42	90	50	69.8	98	8	76	17	46.2	18,782	606	2,079	2.8
August	98	36	90	48	68.7	100	5	68	16	42.2	18,152	586	2,159	2.9
September	90	28	79	43	61.0	100	12	78	29	53.6	13,364	445	1,615	2.2
October	78	28	68	34	50.8	100	14	100	32	66.0	10,559	341	1,370	1.8
November	67	13	55	25	40.2	100	18	98	38	68.0	7,594	253	1,049	1.5
December	58	−6	44	14	29.2	100	25	100	42	70.7	5,351	173	954	1.3
Year	98	−8	65	30	47.4	100	4	87	27	56.9	....	....	19,521	2.2

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	0.65	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
February	2.50	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
March	1.15	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
April	.65	*72*	*38*	*66*	*44*	*55.0*	*64*	*43*	*60*	*47*	*53.6*	*57*	*45*	*54*	*48*	*51.0*
May	.96	81	36	74	49	61.3	72	41	66	53	59.4	63	44	59	53	56.1
June	.18	103	50	90	61	75.3	88	53	80	67	72.3	77	55	70	64	67.3
July	.32	105	62	99	68	83.5	89	68	85	73	79.3	79	69	77	72	74.8
August	.33	108	55	99	67	83.1	92	65	86	73	79.6	82	68	78	72	75.2
September	1.97	97	44	84	58	71.1	83	48	76	63	69.2	74	54	70	65	67.1
October	2.52	76	34	64	41	52.4	69	38	58	44	51.3	60	42	53	48	50.7
November	1.60	56	28	44	31	37.8	51	30	41	34	37.5	48	32	41	36	38.5
December	1.10	*40*	*18*	*31*	*25*	*28.0*	*39*	*20*	*32*	*27*	*29.3*	*37*	*23*	*33*	*28*	*30.7*
Year	13.93	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: C-2; elevation: 6,382 feet; site: Canyon bottom; year: 1963

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	48	—28	34	4	18. 9	100	21	99	48	73. 6	5, 393	174	1, 284	1. 7
February	65	—3	49	20	34. 2	100	16	100	39	69. 3	6, 888	246	1, 006	1. 5
March	68	6	51	21	36. 1	100	14	99	29	64. 1	11, 794	380	1, 606	2. 2
April	75	13	60	25	42. 3	100	11	85	22	53. 7	14, 725	491	2, 145	3. 0
May	84	25	77	37	56. 7	98	8	75	16	45. 9	19, 824	639	2, 194	3. 0
June	94	32	82	41	61. 5	98	10	71	18	44. 8	19, 228	641	2, 447	3. 4
July	97	44	91	52	71. 7	99	10	80	19	49. 5	18, 673	602	2, 025	2. 7
August	*91*	*48*	*84*	*53*	*68. 5*	*94*	*13*	*91*	*25*	*57. 8*	14, 372	464	1, 582	2. 1
September	*86*	*40*	*81*	*46*	*63. 2*	*96*	*14*	*90*	*23*	*56. 4*	12, 676	423	1, 483	2. 1
October	83	25	70	35	52. 8	100	18	91	31	61. 0	9, 862	318	1, 381	1. 9
November	65	14	54	23	38. 4	100	18	100	34	66. 8	6, 602	220	1, 300	1. 8
December	53	—5	42	9	25. 2	100	17	99	37	67. 5	6, 527	211	1, 155	1. 6
Year	97	—28	65	31	47. 5	100	8	90	28	59. 2	146, 564	401	19, 608	2. 2

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	1. 80	*30*	*20*	*27*	*23*	*24. 9*	*30*	*21*	*27*	*24*	*25. 3*	*30*	*21*	*28*	*23*	*25. 6*
February	1. 25	35	24	32	27	29. 5	35	24	32	27	29. 4	34	22	31	27	28. 9
March	. 90	64	24	44	29	36. 1	56	25	38	30	34. 0	46	25	35	30	32. 1
April	. 55	73	29	60	37	48. 5	62	32	54	40	47. 2	52	34	47	42	44. 6
May	. 10	100	42	86	53	69. 6	81	47	73	58	65. 6	70	48	63	47	60. 1
June	. 06	116	53	102	66	83. 6	93	58	83	68	75. 3	80	61	72	67	69. 6
July	1. 98	118	62	103	73	87. 8	98	63	91	74	82. 6	87	68	81	75	78. 2
August	4. 15	105	62	93	68	80. 5	95	62	84	68	76. 0	87	65	77	71	74. 0
September	. 51	94	50	87	59	72. 7	82	49	74	58	66. 1	73	55	67	62	64. 3
October	1. 65	84	36	69	46	57. 5	68	34	57	45	50. 8	62	40	54	49	51. 4
November	. 97	56	24	43	31	37. 1	45	22	35	28	31. 6	42	24	36	31	33. 4
December	. 60	32	13	27	19	22. 6	28	12	21	15	18. 3	29	18	24	20	21. 6
Year	14. 52	118	13	64	44	54. 2	98	12	56	45	50. 2	87	18	51	45	48. 6

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: C-3; elevation: 6,500 feet; site: Canyon slope, northeast-facing; year: 1962

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	48	−2	38	16	26.9	100	34	95	46	70.8				
February	57	−1	43	24	33.7	100	28	96	48	72.2				
March	66	5	45	23	34.0	100	21	84	37	60.3				
April	80	27	66	37	51.2	100	17	73	28	50.7				
May	83	26	71	40	55.5	100	10	63	25	44.1				
June	*94*	*43*	*82*	*48*	*65.1*	*92*	*14*	*53*	*21*	*36.9*				
July	*95*	*54*	*90*	*57*	*73.7*	*100*	*11*	*65*	*20*	*42.6*				
August	100	48	90	56	73.1	100	10	55	21	38.2				
September	93	41	79	51	65.3	100	17	71	34	52.2				
October	78	36	67	41	54.0	100	12	85	37	60.7				
November	68	18	54	32	43.3	100	25	85	46	65.8				
December	54	4	43	23	33.0	100	29	95	49	72.0				
Year	100	−2	64	37	50.7	100	10	77	34	55.5				

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January																
February																
March																
April																
May																
June																
July																
August																
September																
October																
November		*47*	*22*	*37*	*26*	*31.5*	*41*	*27*	*36*	*31*	*33.7*	*40*	*27*	*35*	*32*	*33.4*
December		35	14	26	21	23.9	35	24	29	26	27.8	32	19	27	24	25.7
Year																

NOTE.—Italic figures represent a sample size of less than 28 days.

Station: C-3; elevation: 6,500 feet; site: Canyon slope, northeast-facing; year: 1963

Month	Air temperature, degrees F.					Percent relative humidity					Solar radiation, G-cal./sq. cm.		Wind	
	Extreme		Mean		Mean	Extreme		Mean		Mean			Total miles	Velocity m.p.h.
	Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Total	Mean		
January	*44*	*−19*	*35*	*12*	*23.7*	*100*	*26*	*93*	*56*	*74.6*	....	....	....	....
February	62	4	46	25	35.1	100	22	93	44	68.5	....	....	....	....
March	68	13	50	26	38.0	100	16	86	34	60.1	....	....	....	....
April	78	18	60	31	45.6	100	13	68	26	46.7	....	....	....	....
May	86	34	78	45	61.7	99	12	52	18	35.2	....	....	....	....
June	97	38	85	49	66.7	90	10	51	20	35.5	....	....	....	....
July	102	54	92	59	75.4	99	14	61	22	41.2	....	....	....	....
August	94	52	83	56	69.3	99	16	87	30	58.3	....	....	....	....
September	88	47	81	52	66.4	100	14	73	27	50.0	....	....	....	....
October	86	32	71	43	57.1	100	16	66	32	48.7	....	....	....	....
November	65	18	52	29	40.8	100	26	85	38	61.3	....	....	....	....
December	52	5	40	18	28.7	100	21	83	41	62.0	....	....	....	....
Year	102	−19	64	37	50.7	100	10	75	32	53.5	....	....	....	....

Month	Precipitation in inches water	Soil temperature, degrees Fahrenheit														
		2-inch depth					6-inch depth					12-inch depth				
		Extreme		Mean		Mean	Extreme		Mean		Mean	Extreme		Mean		Mean
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.	
January	....	32	19	29	25	26.7	32	23	29	26	27.7	32	19	29	25	26.8
February	....	39	25	34	30	31.8	35	27	33	30	31.5	36	25	33	29	31.2
March	....	69	26	47	32	39.4	57	29	41	34	37.5	52	29	39	35	36.9
April	....	78	32	67	42	54.5	65	37	58	46	52.1	60	40	54	49	51.3
May	....	100	48	90	58	74.1	83	52	76	62	69.3	76	54	70	64	66.8
June	....	120	54	106	65	85.1	94	63	86	71	78.3	83	63	76	69	72.3
July	....	120	62	109	72	90.4	98	68	93	77	85.0	87	69	83	77	79.8
August	....	117	60	97	67	82.0	97	65	86	72	78.8	87	65	78	72	74.7
September	....	98	52	90	59	74.4	83	58	77	64	70.5	74	58	69	63	66.1
October	....	90	35	73	46	59.4	73	42	61	51	56.3	65	41	55	51	52.8
November	....	56	24	42	29	35.6	48	27	39	33	36.3	41	24	35	31	33.0
December	....	29	14	25	19	21.7	30	20	25	22	23.8	30	18	22	20	20.8
Year	....	120	14	67	45	56.3	98	20	59	49	53.9	87	18	54	49	51.0

NOTE.—Italic figures represent a sample size of less than 28 days.

U.S. GOVERNMENT PRINTING OFFICE : 1969 O—271-475

604