ESTABLISHMENT REPORT

GOUDY CANYON RESEARCH NATURAL AREA

Coronado National Forest

Graham County, Arizona

February 23, 1972

NARRATIVE REPORT

I. Principal Distinguishing Features

The proposed Goudy Canyon Research Natural Area is a mixed conifer stand with a high percentage of Mexican white pine (Pinus strobiformis) on the east-facing slope. In some areas, it is nearly a pure stand. The topography is all relatively steep to precipitous with few slopes less than 30%. Because of the steep topography the area is relatively inaccessible to motor travel though the Swift Trail forms the north boundary of the proposed area making it readily available for research use. There is no grazing on the area.

II. Location

The area is not surveyed, but according to the protraction diagrams would be located in sections 25 and 36, T. 8 S., R. 23 E., and section 30, T. 8 S., R. 24 E., Gila & Salt River Meridian. The area is entirely within the Goudy Canyon drainage, within the Mt. Graham Division of the Coronado National Forest, and some 14 miles air line southwest of Safford, Arizona. All of the land is in Nation Forest ownership (see attached map), comprising 560 acres.

III. The Area by Cover Types

The principal cover types are not well described by any of the types used in the SAF Register. The entire area is a mixed conifer stand with approximately 130 acres most nearly described as SAF-210 (Interior Douglas-fir) in which the principal species are Douglas-fir, white fir, and Mexican white pine; 220 acres in SAF-237 (Interior Ponderosa Pine), in which the principal species is ponderosa pine; and 190 acres with the principal species Mexican white pine and ponderosa pine with some Douglas-fir. The remainder of the area is

comprised of 15 acres aspen (SAF-217) and 5 acres of grassland
which should probably be Festuca-Wheat Grass (K-50) but the
most important species are fescue and bluegrass. The more
common species on the entire area are ponderosa pine (Pinus
ponderosa), Mexican white pine (Pinus strobiformis), Douglas-
fir (Pseudotsuga menziesii), white fir (Abies concolor),
Gambel oak (Quercus gambelii), quaking aspen (Populus tremu-
loides), New Mexico locust (Robinia neomexicana), bracken fern
(Pteridiumaquillinum), Arizona peavine (Lathyrus arizonicus),
sedge (Carex spp.), nodding brome (Bromus anomalus), mountain
muhly (Muhlenbergia montana) and Junegrass (Koeleria cristata).

IV. Physical and Climatic Conditions

A. __Topography.__ The topography is all quite steep lying on
either side of Grady Canyon which runs to the south. Much
of the slope ranges above 70%. Elevations range from 7,500
feet to 10,000 feet above sea level. The drainage is all
to the south into the flats north of Willcox.

B. __Climate.__ The average annual precipitation is approxi-
mately 30 inches with some 16 inches coming in the form of
snow. The climate is relatively severe with frost possible
any time of the year. The summer high seldom exceeds 90°
F., and winter lows of -20° F., can be expected frequently.
The growing season is generally from about May 15 to
September 15. Soils are generally rather shallow and of
the Gray Wooded Group being derived from granite and gneiss
base rock.

V. Description of Values

A. __Flora.__ The proposed research natural area offers an
opportunity to study mixed conifer stands with Douglas-
fir and Mexican white pine in near their optimum condi-
tions in the Southwest.

B. __Geology.__ Geology is representative of the Mt. Graham
mountain and of interest in that respect.

C. __Fauna.__ The area is habitat for mule and white-tailed deer,
coyote, fox, and rodents.

D. __Minerals.__ There are no known minerals or mineral activity
in the area.

E. __Recreation.__ The only recreation is hunting and some
hiking.

F. Water Use. The water yield from the area is high.

G. Other Uses. None.

H. Recommendations. The Region 3 Research Natural Area Committee recommends that the proposed Goudy Canyon Research Natural Area be established.

Feb. 23, 1972
_____
Date

_____
Region 3 Research Natural Area Committee Member

5/4/72
_____
Date

_____
Forest Supervisor, Coronado National Forest

11/3/72
_____
Date

_____
Regional Forester

12/6/72
_____
Date

_____
Director, Rocky Mountain Station

1/16/73
_____
Date

_____
Director, Div of Recreation, WO

1/17/73
_____
Date

_____
Deputy Chief, Research

ORDER

By virtue of the authority vested in me by the Regulations posted in 36 CFR 251.23, I hereby designate as the Goudy Canyon Research Natural Area the lands described in the preceding report by the Region 3 Research Natural Area Committee dated February 23, 1972; said lands shall hereafter be administered as a Research Natural Area, subject to the said Regulations and instructions thereunder.
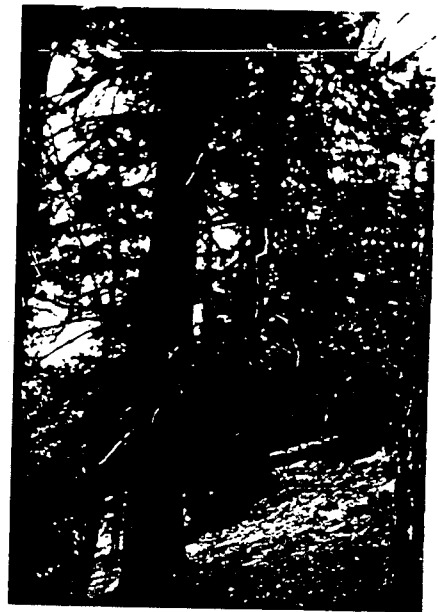
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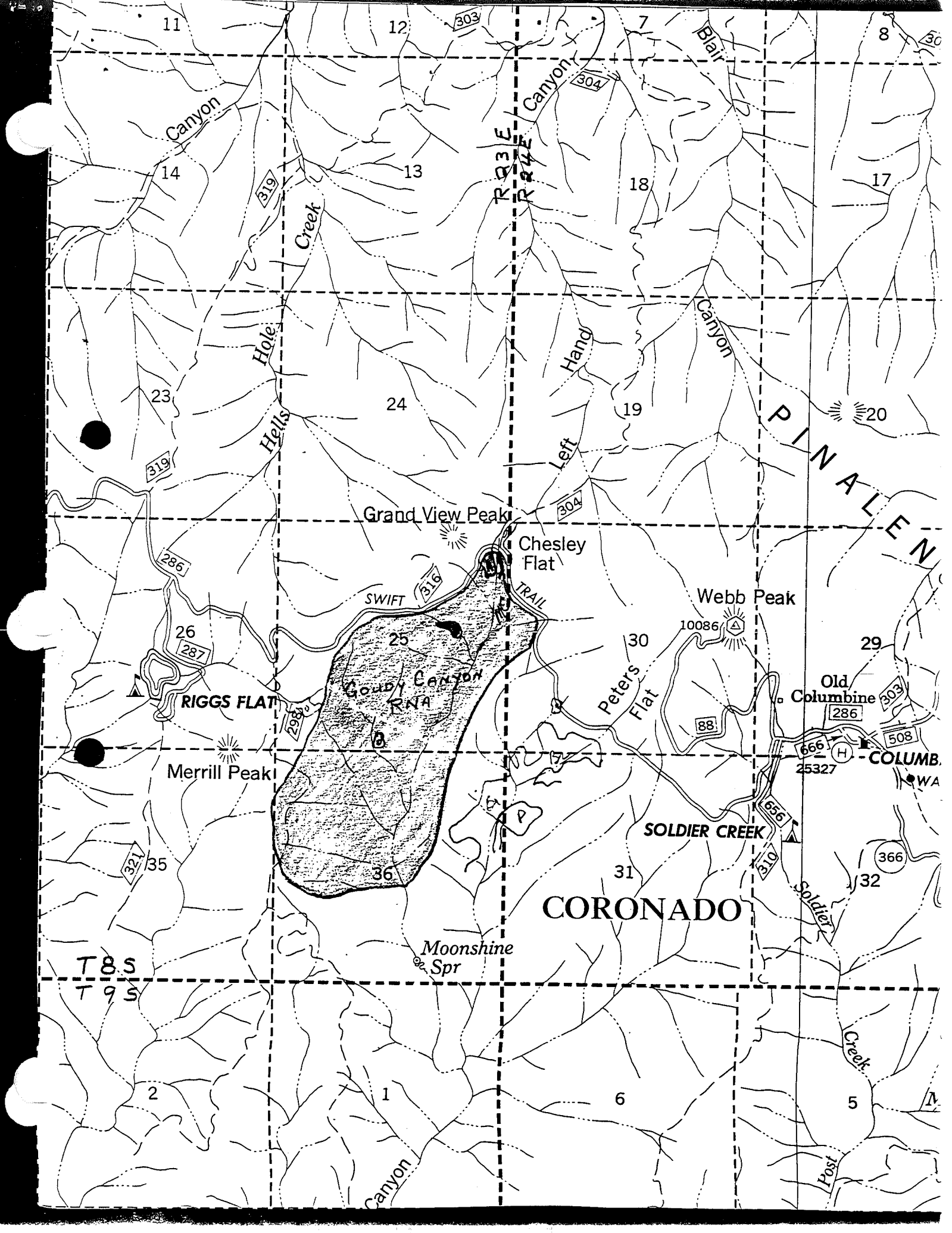Date

John R. McGuire
Chief, Forest Service
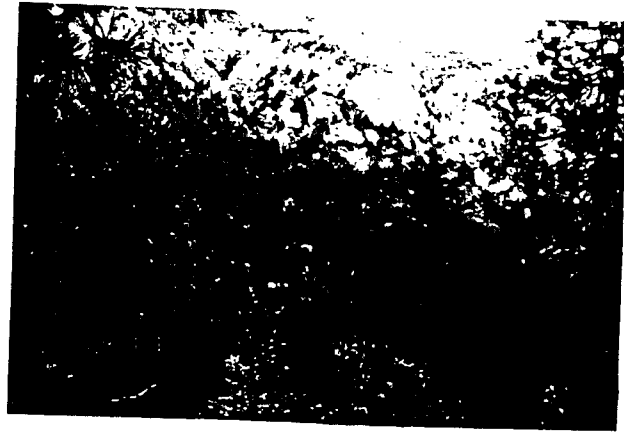
Goudy Canyon
Looking east across Goudy Canyon
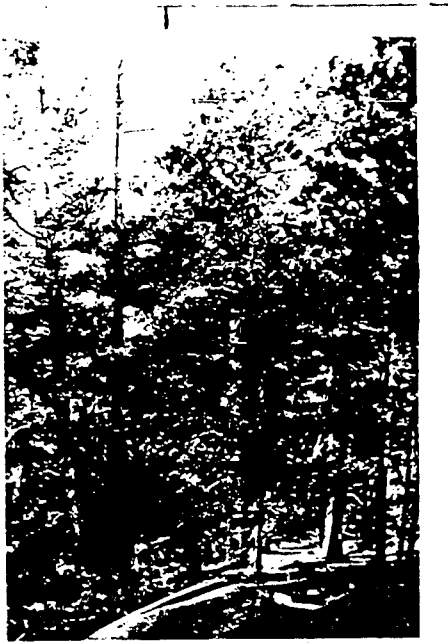
Goudy Canyon
Douglas Fir Type

Goudy Canyon
White Pine Area

Research Natural Areas

USDA Forest Service, Rocky Mountain, Intermountain, Southwestern and Great Plains States

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USDA Forest Service
Northern Region,
Rocky Mountain Region,
Southwestern Region,
Intermountain Region,
Rocky Mountain Research
Station,
and the
Montana Natural Heritage
Program

GOUDY CANYON

General Information   S.USNAHP*88

- Created: 1973
- Size: 560 (acres)
- Elevation Range: 7500 - 10000ft
- Location: *Goudy Canyon RNA is in the southern portion of the Pinaleno Mountains southwest of Safford, Arizona.*

Site Description

Goudy Canyon RNA supports a mixed conifer stand with Mexican white pine (Pinus strobiformis) on east-facing slopes. About half of the RNA is steep and rugged, but the upper portions are readily accessible and contain an excellent example of upper elevation old growth forest. As noted in the establishment report, "many of the larger Douglas-fir and white pine trees exceed 40 inches diameter." More than half of the RNA burned in varying intensities, from a light understory burn to stand replacement, in the 1996 Clark Peak fire.

Climate and Enviromental Information

Data not Available

Vegetation - Goudy Canyon

Interior Ponderosa Pine (SAF 237) Aspen (SAF 217) Interior Douglas-fir (SAF 210)

GOUDY CANYON RESEARCH NATURAL AREA

ABSTRACT

Goudy Canyon Research Natural Area in the Graham (= Pinaleno Mts.) Mountains of southeast Arizona delineates an area of mixed conifer stands in near optimum conditions. The area consists of 560 acres (226 ha) and ranges in elevation from 7,000 to 9,400 feet. Goudy Canyon drains southward and contains predominantly east- and west-facing slopes. It is administered by the U.S. Forest Service, Coronado National Forest.

Location

Goudy Canyon Research Natural Area (GCRNA) is on the south slope of the Graham (Pinaleno) Mountains, 14 airline miles (20.4 km) southwest of Safford in Graham County, Arizona. At 32° 43' N. Lat., 109° 57' W. Long., the site is located in Sections 25 and 36 of T. 8S., R. 23E. and Section 30, T. 8S., R. 24E. (See Figure 1).

Access and Accommodations

The Swift Trail (Arizona Highway 366) forms the northern boundary of GCRNA in Sections 25 and 30 (See above) and provides easy access to the site. The Swift Trail leaves Arizona State Highway 666, 7.5 miles (12 km) south of Safford, and heads southwest toward Mt. Graham and Riggs Lake. GCRNA is 31.5 miles (50.4 km) from the Swift Trail - Highway 666 intersection. The Swift Trail is paved to the Arcadia Picnic Area, a distance of 12 miles (19.2 km) and is a fairly good unsurfaced road from that point on to Clark Peak where the road ends.

It is also possible to hike into the Goudy Canyon Natural Area from the vicinity of Fort Grant. Access by this route requires permission to pass through the Fort Grant State Industrial School which may be obtained at the institution's administration building. From Fort Grant, primitive roads go part way (about 2 miles or 3.2 km) up Goudy Canyon and Grant Canyon to the east of Goudy. Both roads terminate at the start of foot trails that traverse ridges on the east and west sides of Goudy Canyon. The Jesus Trail goes up the west ridge and the Grant-Goudy Trail goes up the east ridge. Both trails are fairly well maintained and terminate at Swift Trail (See Figure 1).

There are several campgrounds along the Swift Trail (e.g. Riggs Flat) that are maintained by the Forest Service. These do not include trailer utility hook-ups but do provide water, toilets, tables and so on. The nearest indoor accommodations are in Safford which has a number of motels for visitors not preferring to use camping facilities on Mt. Graham.

Climate

The nearest weather station is at Fort Grant, 4.5 miles (7.4 km) south of GCRNA. The Fort Grant Station is also 2,600 feet lower in elevation (Green and Sellers, 1964) and consequently has a climate very different from that of GCRNA. Considering the elevation and geographic location of GCRNA (See Green and Sellers, pg. 9, 26 and 27) it is likely that annual precipitation is between 25 and 30 inches per year with about one half of this total coming during the summer (July through September) rainy season and the majority of the remainder occurring in the winter months. The two periods of precipitation are separated by spring and fall drought periods as is the case in all of southern Arizona. Winter precipitation occurs in the form of snow which often results in closure of the Swift Trail from late November through early to mid April.

Temperatures are pleasant in summer, rarely exceeding 90° F. and dropping into the fifties at night, and cold during the winter with highs frequently remaining at or near freezing and lows dropping to -20° F. or colder.

Topography and Landform

The entire south and west side of the Graham Mountains is topographically characterized by very steep slopes and deep canyons. Goudy Canyon, within the boundaries of GCRNA, drops from 9,000 to 7,000 feet in about 1.5 miles (2.4 km). On the west side of Goudy Canyon the same elevational change occurs in less than one mile. Elevational changes are less spectacular at the northern boundary of GCRNA but result in steep topography nonetheless. Goudy Canyon runs due north and south with downslope drainage to the south where Goudy and Grant Creeks come together in the vicinity of Bonita, Arizona.

GCRNA is geologically dominated by granite and gneiss bed rock which underlies shallow soils of the Grey Wooded Group.

Biota

Goudy Canyon Natural Area is an excellent example of high elevation boreal associations that occur in the southwest including mixed pine-fir forest, pine forest, mountain meadow and aspen associations. At higher elevations and in shaded, mesic canyons, white fir (*Abies concolor*) and southwestern white pine (*Pinus strobiformis*) are dominant tree species mixed with Douglas fir (*Pseudotsuga menziesi*) which becomes dominant and mixed with southwestern white pine in high elevation areas with southern exposure and/or on hillsides above moist canyon bottoms. At lower elevations (7,000-8,000 feet), on hillsides and ridgetops, ponderosa pine (*Pinus ponderosa*) becomes the dominant tree species. The latter is also found at elevations above 8,000 feet on exposed hillsides and ridgetops. Stands of aspen (*Populus tremuloides*) occur at higher elevations (e.g. Chesley Flat) and account for about 15 acres of GCRNA. Chesley flat at the northern edge of the site contributes about 5 acres of mountain meadow habitat to GCRNA. Other plant species that occur on this site include Gambel oak (*Quercus gambeli*), New Mexico locust (*Robinia neomexicana*), silverleaf oak (*Quercus hypoleucoides*), buckbrush (*Ceanothus fendleri*), snowberry (*Symphoricarpos oreophilus*), box elder (*Acer negundo*), bluegrass (*Poa* sp.) and fescue (*Festuca* sp.).

Birds of the boreal life-zones in southern Arizona include Goshawk (*Accipiter gentilis*), Red-shafted Flicker (*Colaptes auratus*), Hairy Woodpecker (*Dendrocopos villosus*), Western Flycatcher (*Empidonax dificilis*), Violet-green Swallow (*Tachycineta thalassina*), Steller's Jay (*Cyanocitta stelleri*), Mountain Chickadee (*Parus gambeli*), Red-breasted Nuthatch (*Sitta canadensis*), Hermit Thrush (*Catharus guttatus*), Solitary Vireo (*Vireo solitarius*), Audubon's Warbler (*Dendroica coronata*), Western Tanager (*Piranga ludoviciana*) and Mexican Junco (*Junco phaeonotus*). A few of the mammals likely to occur at GCRNA are (after Cockrum, 1960): Rock Squirrel (*Citellus variegatus*), Cliff Chipmunk (*Eutamias dorsalis*), a unique subspecies of the Red Squirrel (*Tamiasciurus hudsonicus grahamensis*), Deer Mouse (*Peromyscus maniculatus*), Mexican Wood Rat (*Neotoma mexicana*), a unique subspecies of the Long-tailed Vole (*Microtus longicaudus leucophaeus*), Striped Skunk (*Mephitis mephitis*), Bobcat (*Lynx rufus*) and Mule Deer (*Odocoileus hemionus*). Reptiles that may be encountered are Short-horned Lizard (*Phynosoma douglasi*), Gopher Snake (*Pituophis melanoleucus*), Sonora Mountain Kingsnake (*Lampropeltis pyromelana*) and Western Rattlesnake (*Crotalus viridis*).

Research History

No studies have been undertaken at GCRNA but the site offers outstanding possibilities for the study of southwestern coniferous forest flora and fauna. The site is of definite value as a refuge for species populations with limited geographic distribution (e.g. Red Squirrel and Long-tailed Vole). Further study of the Graham Mountains and GCRNA may uncover the presence of additional unusual species populations.

Maps and Aerial Photographs

Goudy Canyon is on the Mt. Graham Topographic Quadrangle published by the U.S. Geological Survey (1942). It is also identified on a map of the Coronado National Forest (North Portion) published by the United States Forest Service in 1969. Aerial photographs may be obtainable by researchers from the U.S. Forest Service Regional Office in Albuquerque, New Mexico or the Coronado National Forest offices in Tucson, Arizona.
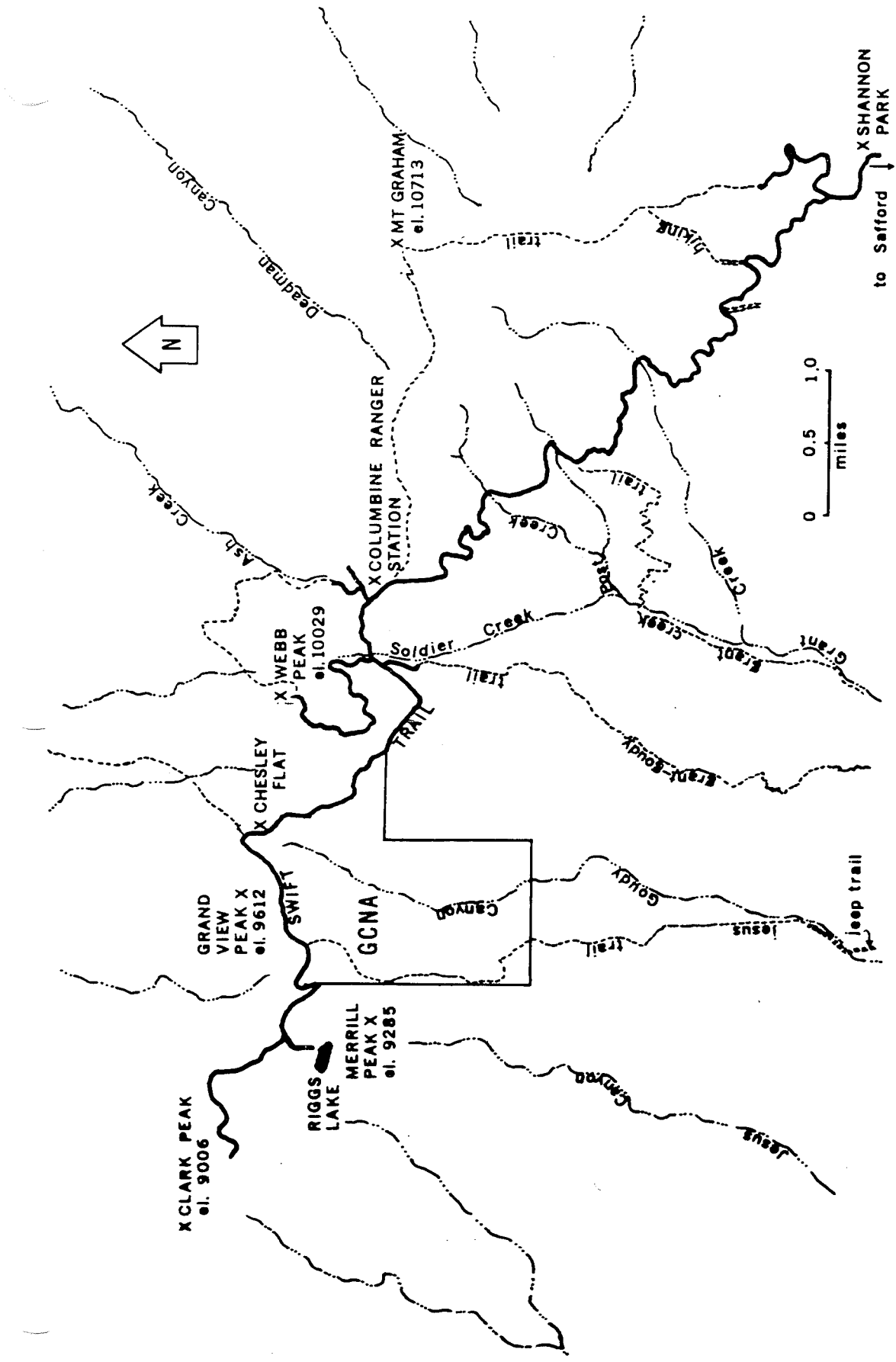
FIGURE 1. Goudy Canyon Natural Area (GCNA) in the Coronado National Forest.
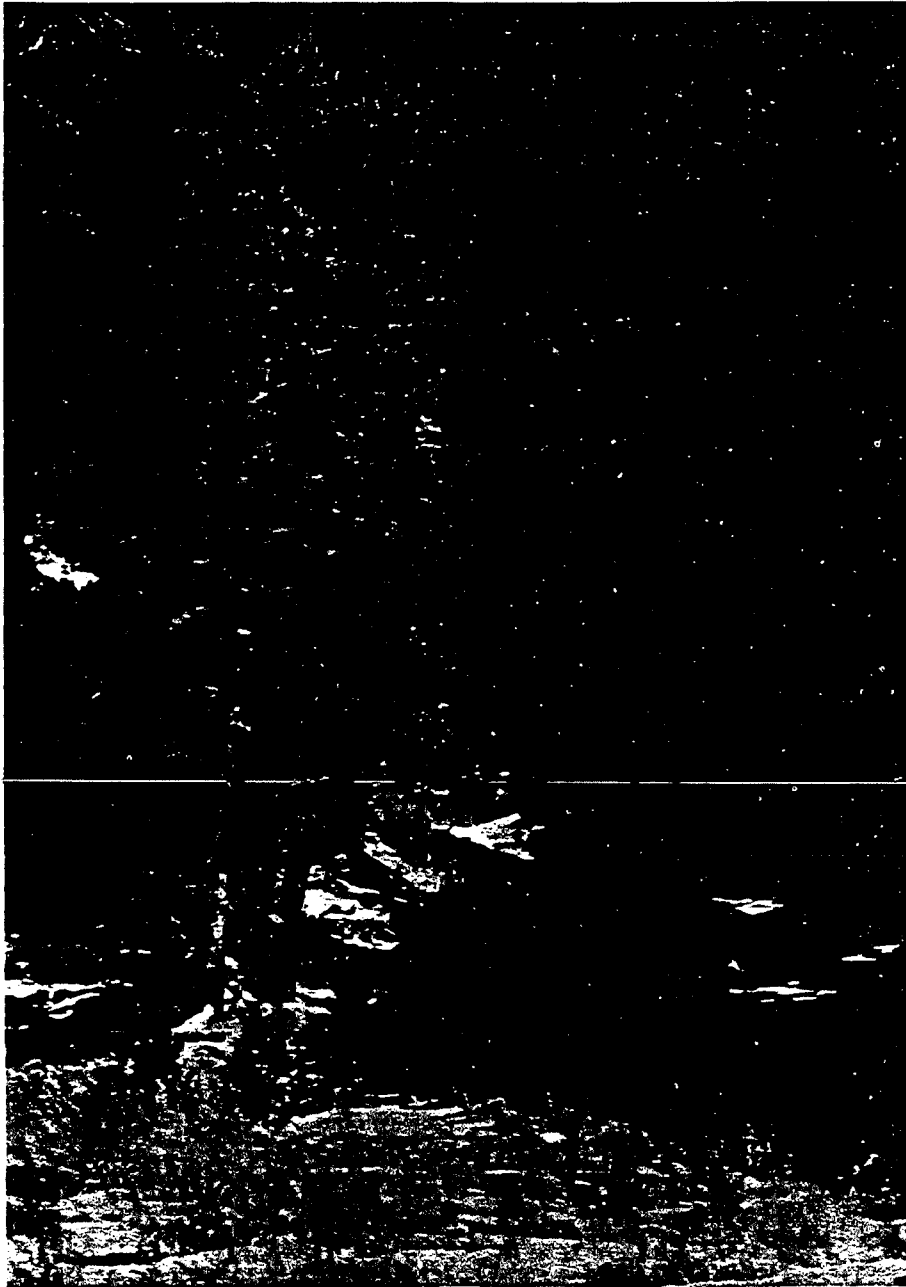
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Photo 1. Mixed white pine and Douglas fir that typify the upper elevations of Goudy Canyon Natural Area.

LITERATURE CITED

Green, C. R. and W. D. sellers
    1964.   Arizona Climate. Univ. of Ariz. Press, Tucson, 503 pp.

Cockrum, E. L.
    1960.   The recent mammals of Arizona: their taxonomy and distribution. Univ. of Ariz. Press,
            Tucson. 276 pp.

RELEASE: IMMEDIATE

NATURAL AREA NAMED IN ARIZONA

A 560-acre, Mexican white pine dominated segment of the Coronado

National Forest is Arizona's newest research natural area--land left in

its natural state to serve as an outdoor laboratory.

Southwestern Regional Forester Wm. D. Hurst said in Albuquerque his

recommendation for creating the Goudy Canyon Research Natural Area

was approved by the Forest Service's Washington headquarters.   The

area is some 14 miles southwest of Safford and entirely within the Goudy

Canyon drainage of the Mt. Graham Division of the Coronado National

Forest.

Difficult to traverse except on foot, the steep-sided canyon is a mixed

conifer stand with a high percentage of Mexican white pine. In some areas

the stand is nearly pure offering an opportunity to study mixed conifer

stands with Douglas-fir and the Mexican pine in near optimum conditions.

The geology and wildlife of the land also is of interest to natural scientists,

Hurst said.

MULTIPLE USE MANAGEMENT OF *Your* NATIONAL FORESTS   WATER   RECREATION   WOOD   WILDLIFE   FORAGE

The natural area designation closes the area to motorized equipment

unless needed as part of a research project. It also will be closed to

mining and prospecting. The area remains open to recreational use,

Hurst said.

The new natural area is the ninth within National Forests in Arizona.

University of Arizona

COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

VERTICAL ZONATION OF GREAT SOIL GROUPS ON MT. GRAHAM, ARIZONA, AS CORRELATED WITH CLIMATE, VEGETATION, AND PROFILE CHARACTERISTICS

BY

W. P. MARTIN AND JOEL E. FLETCHER

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ILLUSTRATIONS

FOREWORD

A knowledge of the physical, chemical, and microbiological characteristics of the soil profile as related to soil-forming processes is fundamental to any ecological, land use, or fertilizer study relating to the growth of plants. Such an investigation on a representative cross-sectional area of Arizona is presented in this bulletin. It is the first of its kind in the state and is preliminary to further work of a like nature.

This type of study becomes increasingly important in wartime when land use for increased production of food and fiber is intensified and dangers of permanent injury through poor use must be guarded against. Through a comprehensive knowledge of the characteristics of soils, ecologists, soil investigators, and others concerned with land management problems will be in a better position to make recommendations for the economic use, improvement, and conservation of the grazing and watershed lands of Arizona.

P. S. BURGESS

VERTICAL ZONATION OF GREAT SOIL GROUPS ON MT. GRAHAM, ARIZONA, AS CORRELATED WITH CLIMATE, VEGETATION, AND PROFILE CHARACTERISTICS[1]

By W. P. Martin and Joel E. Fletcher[2]

INTRODUCTION

Numerous short mountain ranges, running roughly from north to south and rising precipitously from the desert floor, characterize portions of the southwestern United States. As one leaves the desert with its sparse plant cover, an average annual rainfall of less than 10 inches, and a mean temperature of approximately 65 degrees F. and ascends the mountains, he encounters progressively cooler and moister regions with a more abundant plant cover.

Associated with changes in climate are changes in the vegetative cover and soil type. Botanists have recognized differences in mountain flora, and a number of critical studies have been published (58, 62, 71). Soil scientists have observed that mountain soils are zonal in nature, and some studies (26, 36, 40, 44, 59, 65, 80) have shown them to resemble the great soil groups of the world.

Thorp (80) found the profiles of soils on the west slope of the Big Horn Mountains in Wyoming to be similar to those of the (a) gray-brown desert, (b) light brown, (c) chestnut brown, (d) black earths or chernosem, (e) acid prairie, and (f) podzolic soil groups. These soils represented a range of elevation from 4,000 to 8,500 feet and an annual rainfall of less than 10 to over 30 inches.

Most investigators have limited their studies to profile descriptions, however, with attempted correlations with the great soil groups. The opportunity to obtain quickly comparative samples

[2]Assistant Soil Microbiologist, Arizona Agricultural Experiment Station (also Assistant Research Soil Chemist, Soil Conservation Service), and Assistant Soil Technologist, Soil Conservation Service, United States Department of Agriculture, respectively.

of the great soil groups in mountainous areas for physical, chemical, and microbial determinations has been largely overlooked. Klingebiel *et al* (40) determined the moisture equivalent, mechanical composition, *p*H value, organic carbon, and total nitrogen in mountain soils in Utah, and Powers (65), in a study of soil from the Umatilla Area, Oregon, included analyses for phosphorus, sulfur, potassium, calcium, and magnesium. No microbial characteristics were determined and the physical and chemical tests were limited in number.

It seemed desirable, therefore, to determine which of the great soil groups are characteristic of the mountains of southern Arizona and to correlate their physical, chemical, and microbial properties with their respective plant covers and climatic characteristics.

It is felt that such an investigation of the climate-plant-soil associations characteristic of Arizona range lands should aid materially in artifical revegetation programs. At present the nature and rate of soil formation in low-rainfall areas is little understood, and soil mapping and interpretation of surface erosion losses are difficult to interpret from the usual profile studies. Plant cover deterioration and accelerated erosion often alter large areas of the surface, and infiltration capacities and fertility may undergo change. A comparison of virgin areas with the adjacent deteriorated ones can be made in relatively few cases. Restoration of a plant cover is usually a slow process. Revegetation of overgrazed and badly eroded land for flood and erosion control is very important in Arizona where water is scarce and nearly 75 per cent of the land is used for grazing. Artificial reseeding and soil improvement are often necessary to provide for re-establishment of the vegetative cover. Such interrelationships as the influence of soil type on climax vegetation and plant types that can be grown emphasize the need for extended study of soil properties in revegetational work. A study correlating physical, chemical, and microbial soil properties with climate-plant-soil association groups will aid materially in the artificial revegetation of Arizona lands. Such a study is presented here, based upon the determination, study, and description of the great soil groups of the United States present in vertical zones on a typical southern Arizona mountain range.

REVIEW OF LITERATURE

Parallelism of soil and climatic zones in mountainous regions has long been recognized by European pedologists. Glinka (26) relates soil to elevation in the Caucasus Mountains as follows:

The immediate vicinity of Erivan is a desert steppe with gray desert soil.... As we rise higher we enter a zone of typical Tschernosem . . . and a little higher . . . typical gray forest soil . . . still higher well-developed Podsol soils are found and above this lie dark colored wet meadow soils and above them the peaty soils of the mountain peaks.

Zakharov (95) recognizes the following soil types in mountain regions: (a) mountain steppe, including brown, chestnut brown, and chernozem soils; (b) mountain forest, including dark gray, gray, light gray, and podzolized soils; (c) mountain meadow (alpine humus soils) which have no equivalent among the great soil groups; and (d) mountain tundra above the timber line.

Neustruev (57) indicates that the same zonal types do not occur in various mountain regions. In Turkestan and in parts of the Caucasus Mountains there are chernozemlike mountain meadow soils; in the Urals, marshy mountain meadow soils; in Siberia, mountain marsh tundra soils; and in the tropics, chernozemlike mountain meadow soils are missing, but above the timber line genuine mountain meadow or mountain desert soils occur.

Joffe (36) recognizes the principle of vertical zonality. He shows that altitude, slope, exposure, and general landscape configuration influence soil type, since these factors relate to climate and vegetation. He writes, however:

. . . while the analogous soils in the horizontal and vertical planes are in their fundamental natural features one and the same, those in the vertical plane have certain characteristics of their own due to topography, exposure, and microclimate.

Vertical soil zonation, although generally recognized, has been little studied in the United States. Thorp's (80) Wyoming study, cited above, was the first of this type in America.

Powers (65) in his Oregon study found (a) semigray-desert, (b) light brown semiarid, (c) chestnut brown, (d) chernozem, (e) prairielike, and (f) podzolic soils as the elevation increased from 285 to 5,070 feet and the annual rainfall from 7½ to over 38 inches. Moisture equivalents of profile samples were found to increase with altitude and depth. Below 1,200 to 1,400 feet the pH values were 7 or above; at higher elevations they were lower. Calcium contents were positively correlated with pH values. Organic matter and nitrogen content increased from the semidesert through the chernozem soils and decreased thereafter.

Klingebiel et al (40) in their Utah study correlated the following: sagebrush with gray desert soils at 5,000 to 6,500 feet; oak brush with chestnut brown soils at 6,500 to 8,000; aspen and fir with chernozem soils at 8,000 to 9,000; and spruce and fir with podzolic soils above 9,000 feet. The annual precipitation varied from 10 to over 29 inches. All these soils were derived from limestone, and in no instance was the pH less than 7.0. In general, organic matter content, moisture equivalent, and clay content increased with elevation.

Nikiforoff (59) holds that since climatic factors do not vary alike on all mountain ranges, the replacement of horizontal by vertical soil zones with elevation may not always be valid. He cites as an example the situation existing in western Washington.

The Cascades, standing as a barrier across the path of the prevailing westerly winds from the Pacific Ocean, create on their western slopes and

foothills an independent, exceedingly humid west-coast natural province and casts a dry climatic shadow over the part of Washington and Oregon east of the mountains. The exceedingly high humidity of the humid province . . . coupled with luxuriant forest vegetation composed mainly of evergreens, creates an environment that has caused the development of a group of soils fundamentally . . . different from any of the definitely established great soil groups.

Nikiforoff recognized yellow-brown, pink-brown, and black-brown soil groups in the humid province. Dark brown, brown, and gray desert soil groups occur in the semidesert area east of the Cascades. Vlasoff and Wheeting (86) have studied certain characteristics of these soils.

In order to facilitate comparison, the findings of various investigators relative to similar soil groups vertically distributed throughout America are presented in Table 1.

It is evident that with increasing elevation in any area climatic variations cause characteristic soil formations frequently similar to the great soil groups of the United States.

METHOD OF PROCEDURE

Mt. Graham and the adjacent San Simon Valley in southern Arizona were selected for the present investigation because this area would supply information on a representative cross section of Arizona's range lands. The parent materials on Mt. Graham are uniform, the soils being derived from acidic-igneous rocks. The mountain is of sufficient elevation and isolated from surrounding ranges so that its climate is not influenced appreciably by them. The rainfall increases and the temperature decreases progressively with elevation. As one rises from the desert floor to the summit of the mountain, each of the major vegetational zones in Arizona (58) is encountered.

Preliminary tests were made on profile samples collected in November, 1937, and April, 1938, from each vegetative zone and/or soil group on Mt. Graham. On the basis of results thus obtained, a final procedure was adopted as follows: Thirteen profiles were selected for detailed study (Fig. 1). Soil samples were taken by horizons (42 in all) on the following dates: (a) September 13, 1938, following the summer rainy season; (b) December 9, 1938, just prior to the start of the winter wet season and following the fall dry period; (c) April 13, 1939, at the beginning of the dry season of the spring and early summer (snow was still on the ground at elevations above 8,500 feet); and (d) July 7, 1939, just prior to the beginning of the summer rains. This procedure gave enough samples to characterize each profile on an annual basis even though too few were taken to follow seasonal variations.

At the time each profile was sampled, the following data were recorded: slope, aspect, vegetation, elevation, soil group, and erosion. These data are given in Table 3 and Figure 1 and will be discussed in a later section.

TABLE 1.—DESCRIPTION OF ZONAL TYPES OF SOIL DISTRIBUTED VERTICALLY IN MOUNTAINOUS AREAS AS REPORTED BY VARIOUS INVESTIGATORS.

Investigator and study location	Descriptive character	Gray-desert†	Light brown	Chestnut or dark brown	Chernozem	Prairie	Podzolic soils
			Great soil groups or closely related soils				
Glassey (25) Southwestern Wyoming	Elevation:	6,279 to 6,695 feet	6,860 to (?) feet		7,500 to (?) feet	8,500 feet and above	8,500 feet and above
	Rainfall:	10 inches	14 to 15 inches		20 inches or less	20 inches or more	20 inches or more
	Temperature:	42.6° F.	39.6° F.		(?)	(?)	(?)
	Vegetation:*	Chiefly sagebrush (Artemisia tridentata); some greasewood (Sarcobatus dermiculatus) and prickly pear (Opuntia sp.).	Sagebrush, rabbit brush (Chrysothamnus graveoleus), and needle grass (Stipa lettermanii).		Chiefly bluegrass (Poa pratensis); some sagebrush.	Slender wheat (Agropyron tenerum), blue and common meadow (Calamogrostis neglecta) grasses, and woody potentilla (Dasiphora fruiticosa).	Engelmann spruce (Picea Englemnii), blue spruce (Picea pungens), aspen (Populus tremuloides), and lodgepole pine (Pinus munayana).
Klingebiel, et al (40) Ephraim Cyn. Utah	Elevation:	5,000 to 6,000 feet		6,000 to 7,500 feet	7,200 to 8,000 feet	9,000 to 10,000 feet	8,000 to 10,000 feet
	Rainfall:	10 to 12 inches		14 to 16 inches	18 to 22 inches	29 inches	22 to 29 inches
	Temperature:	46.9° F.		44.5° F.	41.6° F.	32.5° F.	32.5 to 38° F.
	Vegetation:*	Sagebrush, pinyon pine (Pinus edulis), Juniper (Juniperus scopulorum), and spiked wheat grass (Agropyron spicatum).		Oak (Quercus gambelii), bigtooth maple (Acer grandidentatum), serviceberry (Amelanchier Alinfolia) and nodding brome grass (Bromus anomalus).	Oak, mt. mahogany (Cercocarpus montanus), nodding brome and slender wheat grass (Agropyron pauciflorum).	Open grassland: mt. brome (Bromus carinatus), nodding brome, and slender wheat grass; yarrow (Achellea lanulosa).	Aspen, white fir (Abies concolor), Douglas fir (Pseudotsuga taxifolia), and Englemann spruce.
	pH (Sur. soil):	8.50		8.17	7.90	7.23	7.71
	Organic matter:	2.1%		3.5%	4.2%	4.9%	6.3%
Powers (65) Umatilla Area, Oregon	Elevation:	300 to 600 feet	600 to 1,600 feet	1,000 to 2,000 feet	1,800 to 2,400 feet		2,400 to 5,000 feet
	Rainfall:	7.57 inches	(?)	(?)	(?)		34 to 42 inches
	Temperature:*						32 to 36° F.
	Vegetation:*	Sagebrush and bitter brush (Purshia tridentata).	Rabbit brush and bunch grass (Agropyron spicatum).	Bunch grass and black sage (Artemesia sp.)	Bunch grass and black sage.		White, yellow, and lodgepole pines (Pinus monticola, ponderosa and contorta), respectively, and Douglas fir.
	pH (Sur. soil):	7.32	6.92	6.12	6.62		5.98
	Organic matter:	0.84%	0.95%	1.85%	4.00%		1.74%
Thorp (80) Northwestern Wyoming	Elevation:	4,000 to 5,500 feet	5,000 to 6,000 feet	5,500 to 6,500 feet	6,500 to 7,800 feet	8,000 feet and above	8,000 feet and above
	Rainfall:	5 to 10 inches	10 to 15 inches	15 to 18 inches	18 to 20 inches	20 to 40 inches	20 to 40 inches
	Temperature:	44 to 46° F.	42 to 44° F.	38 to 42° F.	36 to 38° F.	34 to 36° F.	32 to 36° F.
	Vegetation:*	Chiefly sagebrush and salt sage (Eurotia lanata).	Chiefly sagebrush, needle and grama (Bouteloua oligostachya) grasses, and pentstemon (Pentstemon nitidus).	Same as for light brown soils but with more sagebrush and a heavier sod.	Same as for chestnut brown soils but with very heavy sod.	Very little sagebrush, heavy sod of grasses, lupin (Lupinus sp.), pentstemon, harebell (Campanula rotundifolia), etc.	Lodgepole pine, Douglas fir, and Englemann spruce.
	pH (Sur. soil):	8.55	8.50	6.5 to 7.0	6.0 to 7.0	6.2	4.9
Vlasoff & Wheeting (86) Southwestern Washington	Rainfall:	6 inches	12 inches	15 to 20 inches	20 inches		
	Temperature:	49° F.	49° F.	49° F.	49° F.		
	pH (Sur. soil):	8.13	7.70	7.12 to 7.18	7.18		
	Organic matter:	1.58%	2.47%	2.96 to 4.21%	4.21%		

*Scientific name given once only in either the vertical or horizontal column.
†Great soil group names are those referred to in the above literature.

The soil from each horizon was placed on a sheet of wrapping paper, thoroughly mixed, and divided into two portions. One portion was placed in a quart glass jar and sealed and the other in a paper bag.

Upon arrival at the laboratory, the soil in each jar was passed through a 10-mesh sieve at which time all the sticks and larger rocks were removed. Portions of this freshly sieved soil material were used for moisture and microbiological analyses and for a determination of aggregation. Care was exercised throughout to prevent undue loss of moisture from the samples.

The soil in the paper bags was dried, crushed to pass a 20-mesh screen, and used for the remaining analyses, descriptions of which are given in the appropriate sections following.

On September 13, 1938, soil samples were taken of profiles 1, 2, 13, 17, and 19 in the undisturbed state. They were obtained by forcing a brass cylinder into the soil and then carefully removing it in such manner that the soil inside was not broken. The cylinder used was 6 inches long and 4 in diameter; the outside was beveled on the bottom to prevent compaction as the cylinder was forced into the soil. The samples so taken were tightly sealed for transport to the laboratory.

DESCRIPTION OF THE AREA

LOCATION

Mt. Graham, Graham County, Arizona, is the highest mountain in the southern part of the state. It is bounded on the south and west by the Sulphur Springs-Arivaipa Valley, on the north by the Gila Valley, and on the east by the San Simon Valley. These valleys have average elevations of 4,900, 2,900, and 3,200 feet, respectively, where they border the foot of the mountain. Mt. Graham rises rather precipitously to an elevation of approximately 9,000 feet, above which it becomes a semiplateau dotted by several peaks which reach elevations of between 10,000 and 10,500 feet.

GEOLOGY AND PHYSIOGRAPHY

Physiographically Mt. Graham lies between the Basin and Range Province and the Colorado plateau. The country to the south and west consists of small mountain ranges and broad intermountain valleys which extend more or less northwest and southeast. To the north the topography rises to the plateau with the Gila, White, and other mountains rising above the general level.

According to Gilbert (24), Mt. Graham is composed largely of a mass of gneiss and syenite. Large areas also of granite and schist are reported by Darton (19). The bedrock encountered in the present study was of gneissic character. It forms the parent material of the residual soils which were studied above elevations of

4,100 feet and also occurs extensively in the transported material on which soils of the lower elevations bordering the mountain were formed. The locations of these areas are shown in Figure 1.

Forming the major portion of fill in the trough of the San Simon Valley are old lake-bed deposits of very coarse conglomerates along the margins and interbedded finer-grained sands, with clays and limey materials in the central portions. The lake-bed deposits are overlaid by a layer of alluvial fan material which was carried down from the foot of the mountains by sheetfloods during recent times. This forms the parent material of most of the soils occurring on the study sites located in the San Simon Valley. Site 14, situated near the mouth of Noon Creek Canyon, is characterized by huge boulders. Farther from the margin of the mountain the alluvial fan material is finer grained, like that found on site 15. Shallow washes carrying heavy, sandy bed loads dissect the broad alluvial fans and continue the process of transporting material from the foot of the mountain toward the center of the valley.

Site 19 is located on an alluvial swale at the center of the San Simon Valley. The soils here are developed on fine-grained alluvial deposits characteristic of river flood plains and are extremely deep in character.

RECENT EROSION

Soils developed at the higher elevations on Mt. Graham support an adequate cover of vegetation which, since it is being conservatively used, furnishes excellent protection against accelerated erosion. In the lower foothills and valley, however, where rainfall is light and conditions for plant growth less favorable, the vegetative cover has deteriorated to such an extent that it offers only limited protection against soil erosion. Sections of this area have probably always been somewhat unstable since certain characteristics of the soils, such as poor moisture retention, appear to preclude formation of a good grass cover. It is known, however, that areas such as the alluvial swales bordering the present San Simon Wash were once covered with a heavy growth of tobosa and sacaton grasses. These are still present where good land management has been practiced, and they form areas of natural water spreading. Where the cover has deteriorated, however, steep-walled arroyos are now cutting the alluvial swales at accelerating rates and present an erosion problem of serious proportions.

CLIMATIC CHARACTERISTICS

Pearson (62) published an excellent summary of the climatic characteristics most likely to be found within the various vegetational zones of Arizona and New Mexico. In addition, there are
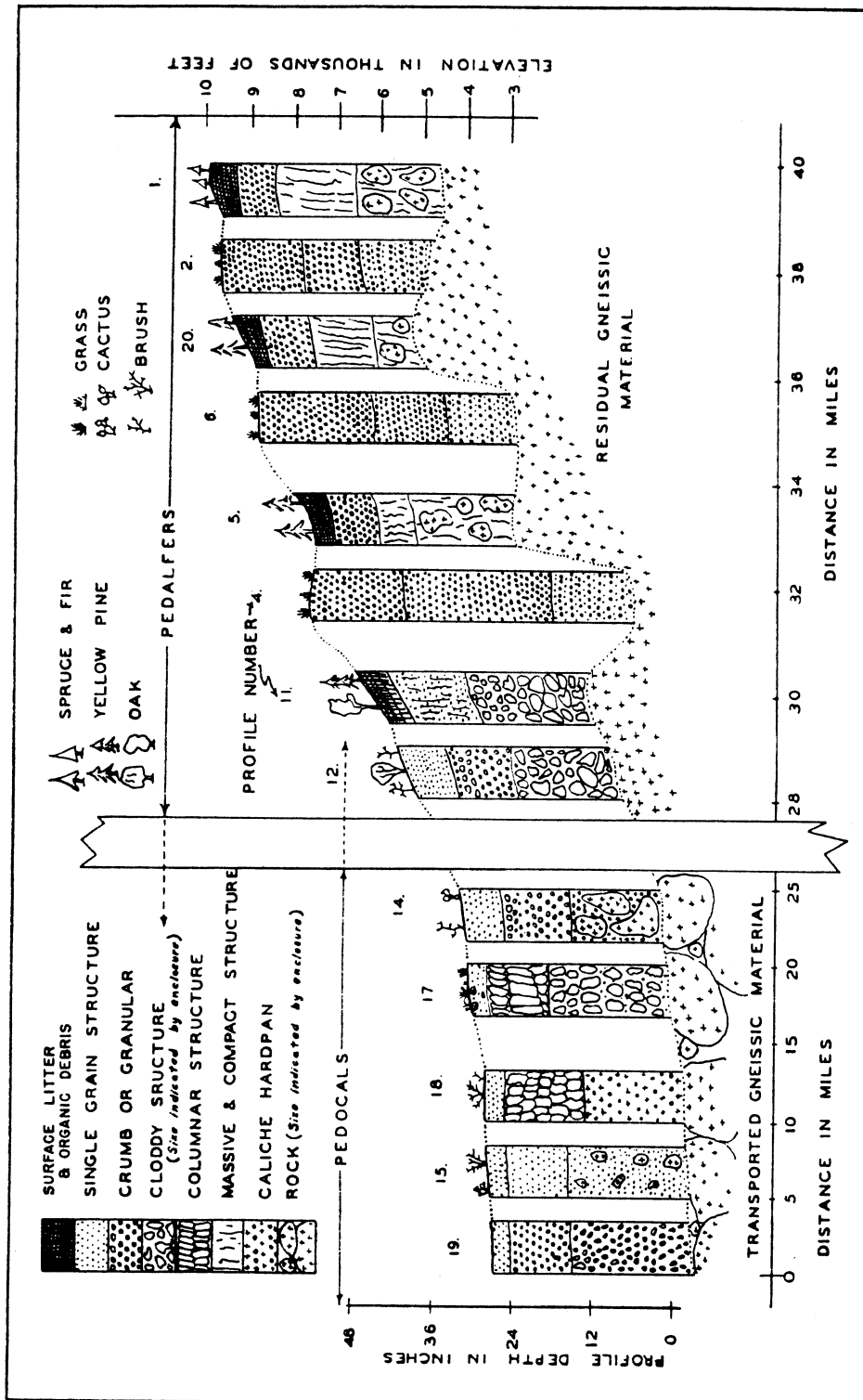
Figure 1.—Soil profile characteristics on Mt. Graham, Arizona, and vicinity.

other publications relating to parts of this area (70, 79, 82, 93). Since the present investigation was limited to southern Arizona, it seemed desirable to prepare a climatic summary relating directly to this area. Seasonal variations in precipitation are similar at different altitudes within a given locality, but they differ between localities. Averages for the state as a whole would not represent accurately the conditions on and in the vicinity of Mt. Graham, because in southern Arizona the climatic variation with the seasons at different elevations is quite different from that of the plateau region in the northern part of the state.

It was impossible to choose for this study a mountain on which climatological data had been collected for a number of years. It was possible, however, to select from the U.S. Weather Bureau Climatic Summary of the United States, data from a number of stations representative of the conditions likely to exist on Mt. Graham. Data collected by the Soil Conservation Service at Turkey Flat (elev. 7,540 ft.), on Swift Trail (elev. 3,975 ft.), and on Freeman Flat (elev. 3,000 ft.) from 1936 to 1938 were used as bases for the selection of Weather Bureau stations included in the rainfall and temperature summary given in Table 2. Only those stations whose records showed an identical monthly rainfall cycle at comparable elevations were chosen. In no instance were data used which represented a period of less than 10 years' continuous collection, and in some instances 50-year records were available. The three Mt. Graham stations were included in the rainfall summary after adjustment to a 20-year average from surrounding stations.

Rainfall.—The mean yearly temperature and rainfall characteristics most likely to be found within the different plant-association areas of southern Arizona are given in Table 2. The rainfall varies from an annual mean of 10 inches in the desert to over 24 at an elevation of just under 9,000 feet. Conditions on Mt. Graham may vary somewhat from these average figures; in fact, some investigators with whom the data have been discussed believe them to be low. It has been pointed out that the average annual rainfall on the Santa Catalina Mountains at an elevation of 7,710 feet was 38 inches for the period from 1916 to 1928 (70) and, in addition, records of the Southwestern Forest and Range Experiment Station at Workman Creek (elev. 6,910 ft.) show an average yearly rainfall of 36 inches.

Examination of the United States Weather Bureau station records for southern Arizona showed that stations on the Santa Catalina Mountains and just under the Mogollon Rim, in which location Workman Creek is found, have a much higher rainfall at comparable elevations than corresponding stations on or in the vicinity of Mt. Graham. For example, Oracle (elev. 4,522 ft.) near the base of the Santa Catalina Mountains shows a mean yearly rainfall of 19.22 inches, whereas Fort Grant (elev. 4,833 ft.) and Swift Trail (elev. 3,975 ft.) on Mt. Graham show but 14.38 and 13.04 inches, respectively. At Pinal Ranch (elev. 4,520 ft.), near

TABLE 2.—SUMMARY OF RAINFALL AND TEMPERATURE CHARACTERISTICS OF ARIZONA BY VEGETATIONAL AREAS.*

	No. of stations†	Elevation (feet)		Mean minimum temp. (°F.)		Mean maximum temp. (°F.)		Mean temp. (°F.)		Date of last killing frost in spring‡	Date of first killing frost in autumn‡	Average length of growing season (days)	Mean annual rainfall (in.)	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean				Range	Mean
Desert area§ (3,000 to 3,600 feet)..	7	2,423-3,609	3,162	44.8-51.1	46.4	79.3-82.5	80.4	62.0-67.3	64.5	Apr. 11	Oct. 31	232.4	7.4-12.3	10.1
Desert grassland area‖ (3,000 to 5,000 feet)..	17	3,538-4,833	4,900	40.0-49.4	45.2	73.8-79.3	76.7	57.9-63.5	61.6	Apr. 27	Oct. 17	214.0	11.2-19.2	13.8
Oak woodland area‖ (4,800 to 6,600 feet)..	9	5,100-6,000	5,564	39.0-48.9	43.1	65.8-74.9	71.4	52.9-61.4	58.0	May 12	Oct. 15	197.0	15.0-21.6	18.5
Western yellow pine area‖ (6,400 to 8,300 feet)..	7	6,500-7,500	6,869	30.7-33.6	32.3	60.0-70.0	64.5	45.5-52.0	48.6	June 5	Sep. 27	134.0	19.8-23.7	22.1
Douglas fir area‖ (8,000 feet & higher)	2	8,500-8,650	8,575	25.9-33.9	29.9	55.2-61.7	58.4	43.8-44.6	44.2	June 24	Sep. 14	114.5	23.8-25.1	24.4

*Summarized from U.S. Weather Bureau Climatic Summary of the United States to 1930 inclusive.
†In each area the records from a number of stations at different altitudes were averaged.
‡Latest or earliest date respectively from among stations examined.
§Summarized from Section 26 (southern Arizona) only.
‖Summarized from Sections 26 and 29 (southern New Mexico).
¶Summarized from Sections 25 (northern Arizona), 26, and 29.

the Mogollon Rim country, the rainfall was 24.85 inches. Rainfall at Turkey Flat (elev. 7,500 ft.) on Mt. Graham was 23.73 inches, whereas on the Catalinas (elev. 7,710 ft.) and Workman Creek (elev. 6,910 ft.) the rainfall was 38 and 36 inches, respectively.

In view of the above facts, the rainfall record as summarized in Table 2 is probably a fair indication of the actual conditions existing on Mt. Graham and in the immediate vicinity.

The change in precipitation from month to month within the various vegetational zones is plotted in Figure 2. It is apparent that the same type of variation in monthly rainfall occurs at the different altitudes. In each instance, the wettest months of the year are July and August (rainfall 2.0 to 4.6 in.). The driest month is May (rainfall 0.15 to 0.92 in.), followed closely by June (rainfall 0.24 to 1.12 in.). The winter rains begin in the latter part of December and extend into April. Following the summer rains of July and August, a fall dry season occurs which extends from the latter part of September well into December. As a rule, November (rainfall 0.6 to 1.3 in.) is the driest month of this period.

In all vegetational zones a greater amount of precipitation occurs during the summer season (herein considered to be May through October) than during the winter season. In most instances twice as much rain fell during the summer season as during the winter period.

The nature of the rains occurring during these two periods is of interest. According to Turnage and Mallery (82), the winter rains fall from high-lying stratus clouds and over large areas. They are considered to be temperate zone cyclones and are associated with the passage of low-pressure areas across the United States. The intensity of these storms is low so that little if any runoff occurs and most of the water sinks into the soil. The summer rains, on the other hand, even under the wettest conditions, are scattered in nature, the wetted areas being separated by dry ones. Most of the showers fall in the late afternoon and are of short duration and high intensity. Runoff and erosion are greatest during the high-intensity rains of summer. It is not uncommon to see dry washes fill to overflowing in a few minutes during one of these showers and just as spectacularly become dry again a short time after the rain has passed.

Temperature.—The mean yearly temperature characteristics of the different vegetational zones of southern Arizona are given in Table 2. With ascending elevations the mean minimum, mean maximum, and mean temperatures progressively decrease, a difference of about 20 degrees F. occurring between the desert area and the Douglas fir area near the tops of the mountains.

The mean monthly temperatures within the different plant-association groups are plotted in Figure 3. The warmest month of the year, July, is also the one in which the highest rainfall

TABLE 3.—GENERAL DESCRIPTION OF SOME TYPICAL RANGE SOILS FROM MT. GRAHAM, ARIZONA, AND VICINITY.

Profile number	General description	Profile characteristics		
		Horizon	Depth in inches	Description
Soils from forested areas				
1	Elevation: 9,860 feet. Slope: 7 per cent. Exposure: Northwest. Vegetation: Dense stand of *Pseudotsuga taxifolia** (Douglas fir) and *Abies concolor* (white fir); *Populus tremuloides* (quaking aspen); *Picea Engelmannii* (Engelmann spruce) in vicinity. Soil group: Gray-brown podzolic. [Similar to soils of the Helmer-Santa-Benewah area (75).]	A_0	0 to 4	Partly decomposed organic debris. Matted with roots and mold mycelium. Spongy.
		A_1-A_2	4 to 9	Dark yellowish brown.† Finely granular. Fibrous.
		B	9 to 21	Moderate yellowish brown. Compact. Massive.
		C	21 to 34	Strong yellowish brown substratum merging into rotten gneiss.
20	Elevation: 9,160 feet. Slope: 10 per cent. Exposure: South. Vegetation: Dense stand of *Pseudotsuga taxifolia* with some *Pinus ponderosa* var. *scopulorum* (ponderosa or western yellow pine) in vicinity. Soil group: Gray-brown podzolic. [Similar to soils of the Helmer-Santa-Benewah area (75).]	A_0	0 to 3	Partly decomposed organic debris. Felted with roots and dense mycelial threads.
		A_1-A_3	3 to 8	Dark yellowish brown. Granular. Fibrous. A_2 bleached horizon present as trace only.
		B_2	8 to 19	Dark to moderate yellowish brown. Firm.
		C_1	19 to 25	Light yellowish brown substratum; large gneissic and partially decomposed boulders present.
5	Elevation: 7,540 feet. Slope: 8 per cent. Exposure: North. Vegetation: Pure stand of *Pinus ponderosa* var. *scopulorum*; *Pteridium aquilinum* var. *pubescens* (Bracken fern) in open spots. Soil group: Gray-brown podzolic. [Similar to soils of the Helmer-Santa-Benewah area (75).]	A_0	0 to 2	Partially decomposed organic debris. Slightly matted needle accumulation. Little mold mycelium present.
		A_1	2 to 7	Dark yellowish brown. Finely granular. Fibrous.
		B_2	7 to 13	Light yellowish brown. Compact. Massive.
		C	13 to 30	Light to strong yellowish brown substratum merging into rotten gneissic bedrock.
Soils from mountain meadows				
2	Elevation: 9,710 feet. Slope: 18 per cent. Exposure: West-southwest. Vegetation: *Bromus carinatus* (Calif. brome grass); *Blepharoneuron tricholepis* (hairy dropseed); *Helenium Hoopesii* (sneezeweed). Soil group: Prairielike.	A	0 to 12	Dark yellowish brown; granular.
		B	12 to 20	Dark to moderate yellowish brown; granular.
		C_1	20 to 32	Moderate yellowish brown substratum; also granular.
6	Elevation: 8,850 feet. Slope: 16 per cent. Exposure: South. Vegetation: Chiefly *Blepharoneuron tricholepis*; *Festuca arizonica* (Arizona fescue grass); *Poa pratensis* (Kentucky bluegrass); some *Helenium Hoopesii* and seedling *Pinus ponderosa* var. *scopulorum*. Soil group: Prairielike.	A	0 to 17	Dark yellowish brown to weak brown; granular.
		B	17 to 28	Light yellowish brown to weak brown; granular.
		C_1	28 to 38	Light yellowish brown substratum; also granular.
4	Elevation: 7,540 feet. Slope: 10 per cent. Exposure: Northeast. Vegetation: Chiefly *Poa Fendleriana* (mutton grass), *Swertia speciosa* (deer's-ear), *Helenium Hoopesii*, *Carex* (sedges) and *Pteridium aquilinum* var. *pubescens*; *Symphoricarpos oreophilus* (snowberry); *Sambucus neomexicana* var. *vestita* (elderberry) and *Muhlenbergia montana* (mountain muhly grass) also present. Soil group: Prairielike.	A	0 to 14	Dark yellowish brown; granular.
		B	14 to 36	Dark to moderate yellowish brown; granular.
		C_1	36 to 48	Reddish brown substratum; also granular.
Soils from oak-woodland areas				
11	Elevation: 6,000 feet. Slope: 24 per cent. Exposure: East. Vegetation: *Quercus arizonica*, *Q. Emoryi*, and *Q. hypoleucoides* (Arizona, white, Emory, and silverleaf oak, respectively); *Pinus leiophylla* (Chihuahua pine); *Juniperus pachyphloea* (juniper); *Muhlenbergia Emersleyi* (bull grass); *Nolina microcarpa* (bear grass); and *Arctostaphylos pungens* (manzanita). Small *Pinus ponderosa* var. *scopulorum* also present.	A_1-A_2	0 to 5	Weak brown to dark yellowish brown; very finely granular. (Includes shallow A_0 horizon and ashlike gray layer.)
		B	5 to 15	Light yellowish brown; single grain structure.
		C_1	15 to 32	Light to strong yellowish brown substratum; iron mottled;

(elderberry) and *Muhlenbergia montana* (mountain muhly grass) also present. Soil group: Prairielike.

No.	Horizon	Depth	Soil profile description	Location and vegetation
	C₁	36 to 48	Reddish brown substratum; also granular.	

Soils from oak-woodland areas

No.	Horizon	Depth	Soil profile description	Location and vegetation
11	A₁-A₂	0 to 5	Weak brown to dark yellowish brown; very finely granular. (Includes shallow A₀ horizon and ashlike gray layer.)	Elevation: 6,000 feet. Slope: 24 per cent. Exposure: East. Vegetation: *Quercus arizonica, Q. Emoryi,* and *Q. hypoleucoides* (Arizona, white, Emory, and silverleaf oak, respectively); *Pinus leiophylla* (Chihuahua pine); *Juniperus pachyphloea* (juniper); *Muhlenbergia Emersleyi* (bull grass); *Nolina microcarpa* (bear grass); and *Arctostaphylos pungens* (manzanita). Small *Pinus ponderosa* var. *scopulorum* also present. Soil group: Gray-brown podzolic—oak-woodland type.
	B	5 to 15	Light yellowish brown; single grain structure.	
	C₁	15 to 32	Light to strong yellowish brown substratum; iron mottled; nutlike structure.	
12	A	0 to 7	Moderate to dark yellowish brown; subgranular.	Elevation: 5,340 feet. Slope: 10 per cent. Exposure: East. Vegetation: *Quercus arizonica; Quercus Emoryi; Garrya Wrightii* (silk-tassel tree); *Cercocarpus montanus* (mt. mahogany); *Sitanion hystrix* (squirreltail grass); *Eragrostis intermedia* (plains love grass); *Arctostaphylos pungens; Juniperus pachyphloea; Nolina microcarpa;* some *Agave Palmeri; Opuntia spinosior* (spiny cholla); *Bouteloua hirsuta, B. gracilis,* and *B. curtipendula* (hairy, blue, and side oats grama grasses) also present. Soil group: Shantung brown. [Similar to soils of the Vista-Holland-Sierra areas (75).]
	B	7 to 18	Moderate yellowish brown; finely granular.	
	C₁	18 to 36	Moderate to strong yellowish brown substratum; nutlike structure.	

Soils from desert grassland areas

No.	Horizon	Depth	Soil profile description	Location and vegetation
14	a	0 to 6	Light to moderate yellowish brown, sandy overwash material; single grain structure.	Elevation: 4,100 feet. Slope: 10 per cent. Exposure: East. Vegetation: Chiefly *Opuntia Engelmannii* (prickly pear); *Yucca elata* (soapweed); *Trichachne californica* (Arizona cotton grass); *Gutierrezia lucida* (snakeweed); *Muhlenbergia Porteri* (bush muhly); some *Haplopappus tenuisectus* (burroweed); *Acacia Greggii* (catclaw); *Prosopis juliflora* var. *velutina* (mesquite); and *Lycium Fremontii* (Fremont squawberry) also present. Soil group: Alluvial soil [associated with shantung brown soils of the Vista-Holland-Sierra areas (75).]
	b	6 to 16	Moderate yellowish brown; subgranular.	
	c	16 to 30	Moderate yellowish brown; granular. (Difficult to collect because of large boulders.)	
17	a	0 to 4	Weak orange to moderate yellowish brown; gritty; non-calcareous.	Elevation: 3,800 feet. Slope: Essentially level area. Vegetation: *Haplopappus tenuisectus; Gutierrezia lucida; Hilaria mutica* (tobosa grass); *Yucca elata;* and *Opuntia spinosior.* Soil group: Reddish brown. [Similar to soils of the White House-Tumacacori areas (75).] Soil type: Similar to Continental or Tubac sandy loam (74).
	b	4 to 16	Light to moderate brown; very heavy and compact; slightly calcareous.	
	c	16 to 30	Light to moderate yellowish brown to brown; moderately compact; calcareous.	

Soils from desert areas

No.	Horizon	Depth	Soil profile description	Location and vegetation
18	a	0 to 3	Weak orange to light brown; gritty; slightly calcareous.	Elevation: 3,365 feet. Slope: Essentially level area. Vegetation: Chiefly *Larrea divaricata* (creosote bush); some *Ephedra trifurca* (Morman tea) *Haplopappus tenuisectus,* and *Gutierrezia lucida* also present. Soil group: Red desert. Soil type: Artesia gravelly sandy loam.
	b	3 to 15	Weak orange to light brown; moderately compact; highly calcareous.	
	c	15 to	Concretelike caliche hardpan, high in lime.	
15	a	0 to 3	Moderate yellowish brown; single grain structure.	Elevation: 3,360 feet. Slope: Essentially level area. Vegetation: *Prosopis juliflora* var. *velutina; Larrea divaricata; Gutierrezia lucida; Haplopappus tenuisectus;* and *Acacia Greggii.* Soil group: Red desert. Soil type: Adelanto sandy loam.
	b	3 to 12	Strong yellowish brown; single grain structure.	
	c	12 to 30	Strong yellowish brown; gravelly; single grain structure; mildly calcareous throughout the entire profile.	
19	a	0 to 3	Light brown to light yellowish brown; single grain structure; mildly calcareous.	Elevation: 3,260 feet. Slope: Essentially level area. Vegetation: Chiefly *Atriplex canescens* (chamisa); some *Gutierrezia lucida* and *Prosopis juliflora* var. *velutina* also present in vicinity. Soil group: Alluvial soil (associated with red desert soils but has tendency towards solonchak). Soil type: Glenbar loam.
	b	3 to 12	Light brown to light yellowish brown; granular; mildly calcareous.	
	c	12 to 30	Light brown to light yellowish brown; lime accumulations; granular.	

occurs. The next warmest months, June and August, are the second driest and the second wettest month respectively. The winter rains occur during the coolest months of the year, December to March. The temperatures during the early summer dry season of May and June are appreciably higher than those of October and November in the fall dry period. Mean temperatures only are given in Figure 3; corresponding changes occur for the mean minimum and mean maximum temperatures, which are approximately 16 degrees F. below or above those shown in the graph.

Profile samples from Mt. Graham were thus taken at times which would be most representative of the four principal climatic seasons of the year. The September samplings followed a period of high temperatures and high rainfall; the April sampling followed one of low temperature and medium high rainfall; the December sampling followed a period of medium low temperature and low rainfall; and the July sampling, one of high temperature and very low rainfall.

Frost-free period.—The average length of the growing season in the various vegetational areas on Mt. Graham together with the most probable dates of the first and last killing frosts of the year are given in Table 2. The length of the growing season varies from approximately 115 days in the Douglas fir area to twice that figure on the desert.

VEGETATIONAL CHARACTERISTICS

The principal kinds of plants in the immediate vicinity of each profile sampled are given in Table 3 and have been depicted diagrammatically in Figure 1. The vegetational types fall naturally into several categories which are representative of a number of those found throughout Arizona (58).

Coniferous forests (Pl. I) cover the slopes on Mt. Graham above an elevation of approximately 6,400 feet, depending somewhat upon exposure and other local conditions. At elevations above 8,000 feet Douglas fir in association with white fir and aspen, and still higher, Engelmann spruce, dominate the landscape; whereas, below 8,000 feet ponderosa pine (western yellow pine) is in predominance. Exposure obviously has a pronounced influence on the vegetation. On north exposures, Douglas fir occurs at elevations as low as 7,400 feet, whereas on south exposures the ponderosa pine occurs at elevations as high as 9,300 feet.

In various localities throughout the forest are found typical mountain meadows (Pl. I). These occupy cold-air drainage valleys between the conifer covered slopes, and drainage is generally by way of a small meandering stream. Except when located immediately adjacent to the stream, the soils are well drained and have predominantly a grass cover. California brome grass, hairy dropseed, Arizona fescue, and bluegrass are present in abundance
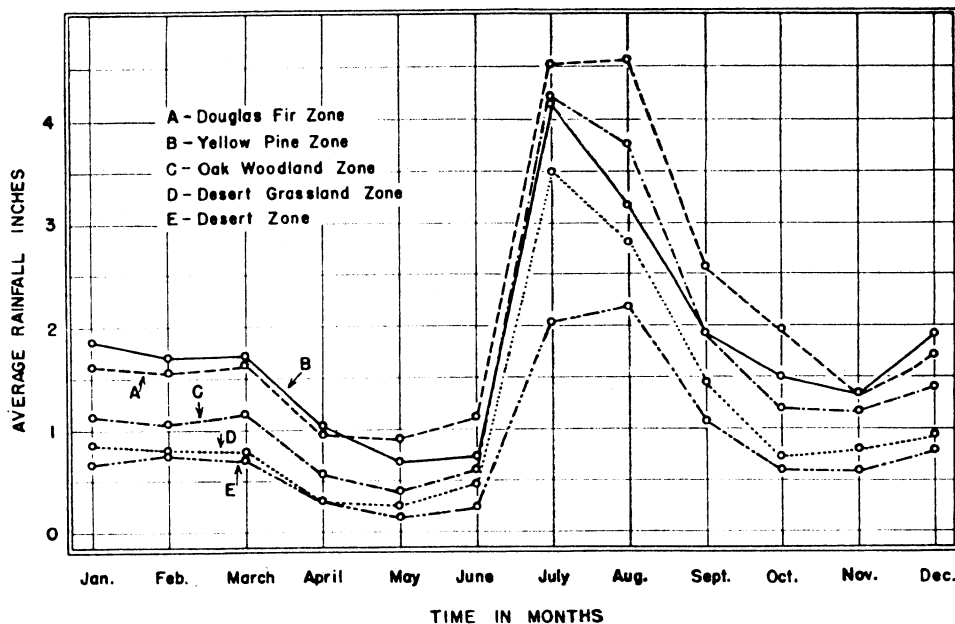
Figure 2.—Average monthly precipitation by vegetational zones in south-eastern Arizona.

on the higher meadows (profiles 2 and 6); whereas, at Turkey Flat (profile 4) bracken fern predominates, although mutton and mountain muhly grasses and snowberry and elderberry bushes are also present.

Below the coniferous forest zone is found an oak-woodland zone (Pl. II) which ranges in elevation from approximately 4,800 feet to over 6,500 feet on easterly exposures. Above 5,500 feet silverleaf oak trees predominate; in addition, Arizona evergreen oaks, junipers, Chihuahua and ponderosa pines, manzanitas, bear grass, and bull grass are found in appreciable quantities.

Below 5,500 feet the silverleaf is replaced by the Arizona and Emory evergreen oaks as predominant species, and pines are seldom found even on northern exposures. Junipers and bear grass are still prominent, but manzanita appears in increased abundance. Mountain mahogany and the silk-tassel tree make an appreciable shrub growth. Side oats, hairy and blue grama grasses, squirreltail, bull and plains love grasses, and, in addition, the spiny cholla and Palmer's agave are present in this area.

At elevations ranging from approximately 3,500 to 4,800 feet in the lower foothills region on Mt. Graham and on the higher mesas in the adjacent valley is found the desert-grassland region (Pl. II). Profile samples of site 17 were taken from this region and more specifically from what Whitfield and Beutner (93) called the "Hilaria-Bouteloua Faciation" (curly mesquite-blue grama community). According to these investigators grass species formerly dominated the area and were, in the order of their probable
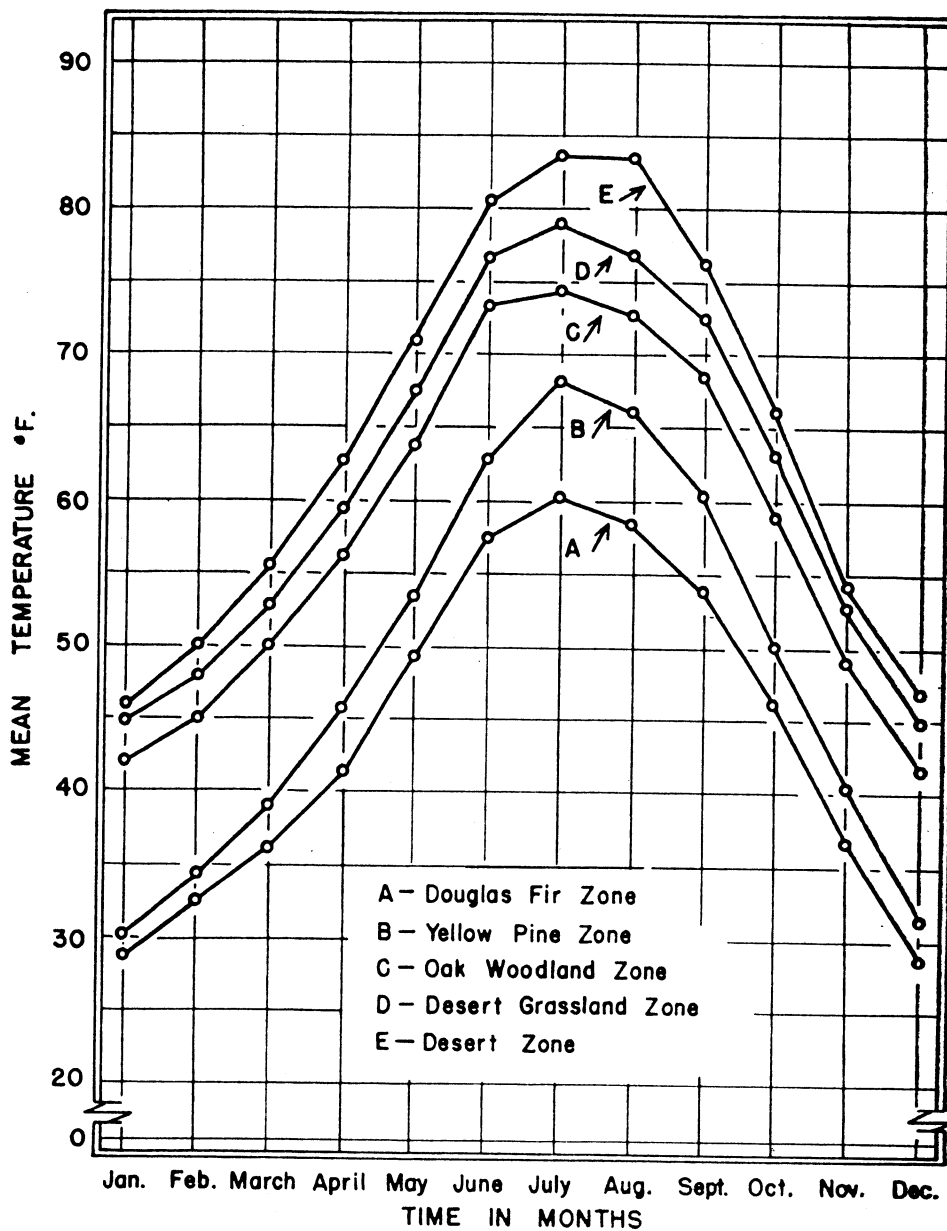
Figure 3.—Mean monthly temperature by vegetational zones in southeastern Arizona.

abundance, *Hilaria belangeri,* curly mesquite grass; *Bouteloua gracilis,* blue grama; *Bouteloua hirsuta,* hairy grama; *Muhlenbergia Porteri,* hoe grass; *Hilaria mutica,* tobosa grass, and several species of *Aristida.* Heavy overgrazing, however, has depleted the original grass cover to such an extent that only remnants of it remain today. Tobosa grass is still found in scattered small patches; but snakeweed and burroweed have become the dom-
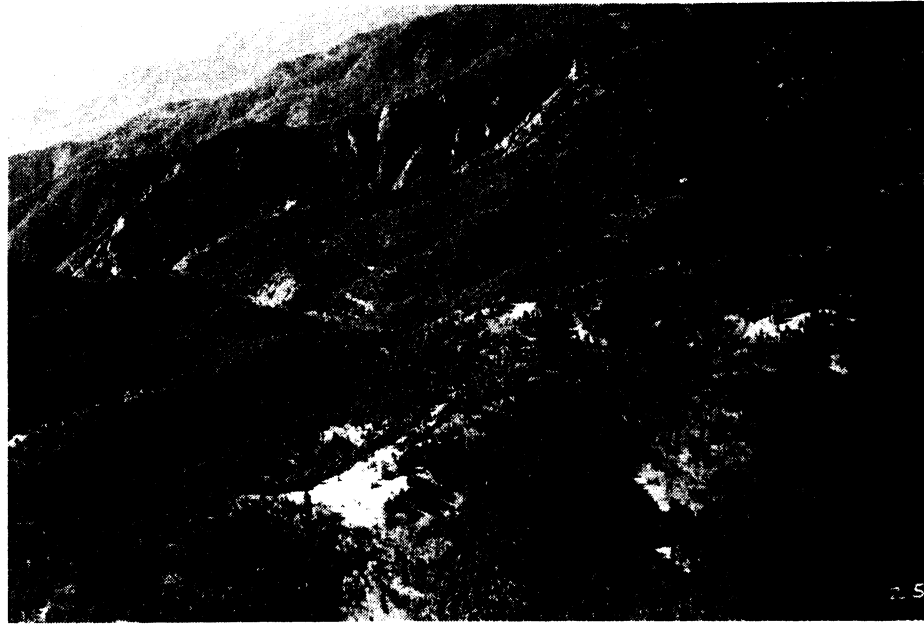
Plate I.—Aerial photograph of Mt. Graham, Arizona, showing **forested area** (chiefly Douglas fir and ponderosa pine) and mountain parks or **meadows.** California brome grass, hairy dropseed, Arizona fescue, and **bluegrass are** present on the meadows. Gray-brown podzolic soils are present in **the** forested areas; prairielike soils in the meadows.

inant species making up the greater part of the vegetative **cover,** together with yuccas, spiny cholla, and other shrubs.

Profile samples of site 14 were also taken from the **desert-**grassland area, but the profile was located on an alluvial **fan near** the mouth of Noon Creek Canyon. The slope was steep and **huge** boulders dominated the landscape so that it is doubtful **whether** or not this area was ever covered with an extensive grass flora. This location probably falls within Whitfield and Beutner's **(93)** *Bouteloua-Andropogon-Trichachne post-climax* type (side oats grama-feather grass-Arizona cotton grass) since the soil is char-acterized by a greater available water content because of its loca-tion near Noon Creek Canyon. All three of these species, **together** with bush muhly, are present in the vicinity although never in abundance. The predominant species are Englemann's prickly pear, catclaw, and mesquite with burroweed, snakeweed, yucca, and Lycium present as subdominant species.

The desert-shrub area occurs in the San Simon Valley adjacent to Mt. Graham at elevations below 3,500 feet. The vegetative cover throughout the area is not consistant but varies with the soil type, general configuration of the landscape, and degree of erosion. Near the base of the mountain on the well-drained sandy soils, developed on alluvial fans, the plant cover consists principally of creosote bush (Pl. III) and mesquite trees. These plants are

rather widely spaced because of water competition, and the surface of the sand between the bushes is often completely devoid of vegetation. In some locations, however, snakeweed and burroweed have successfully invaded the area and catclaw occasionally takes the place of mesquite.

Over an appreciable area in the San Simon Valley, the creosote bush is the dominant vegetative type. Here the soil is very shallow and is underlaid by a highly calcareous (caliche) hardpan. In addition to the creosote bush, *Ephedra* are occasionally found, together with the ever present burroweed and snakeweed. Interspersed throughout the creosote-bush types, mesquite trees, whitethorn, and catclaw bushes are found along the sand washes.

On what were formerly sacaton-tobosa swales (Pl. III) adjacent to the San Simon Wash there is now a scattered stand of chamisa, the desert saltbush. Recent erosion has resulted in considerable dissection of the area. Perpendicular walled gullies 6 to 15 feet deep have so drained the area that surface spreading of flood water no longer occurs. Lack of water has probably caused the disappearance of the sacaton and tobosa grasses, and the same may eventually be true of *Atriplex* as well. Mesquite trees and snakeweed are found occasionally in this vicinity.

DESCRIPTION OF SOIL PROFILES AND CORRELATION WITH GREAT SOIL GROUPS OF THE UNITED STATES

A description of the soil profiles taken in this study is given in Table 3. Their principal characteristics are depicted graphically in Figure 1. To show correlations that exist between soil properties and plant covers, the profiles are separated into categories by vegetational zones.

SOILS FROM FORESTED AREAS

Profile samples were taken under each of the three types of forest stands (Pl. I). Although showing characteristic differences, all profiles would be classed as gray-brown podzolic soils, specifically of the Helmer-Benewah areas (75, p. 1038).

In sampling the profiles, the undecomposed litter was removed so that only the F and H layers were included in the A_0 horizon. Usually these layers were tightly interwoven with roots and mold mycelium and had a spongy feel and appearance. The surface soils were granular, filled with roots so that they presented a fibrous appearance, and were dark brown in color from the organic matter. Occasionally a feebly developed, bleached horizon was present, often much better developed in sheltered locations adjacent to the sampling site. In one of the three profile samples, an irregular, highly organic portion of the surface soil was observed to project through or below the bleached layer into the
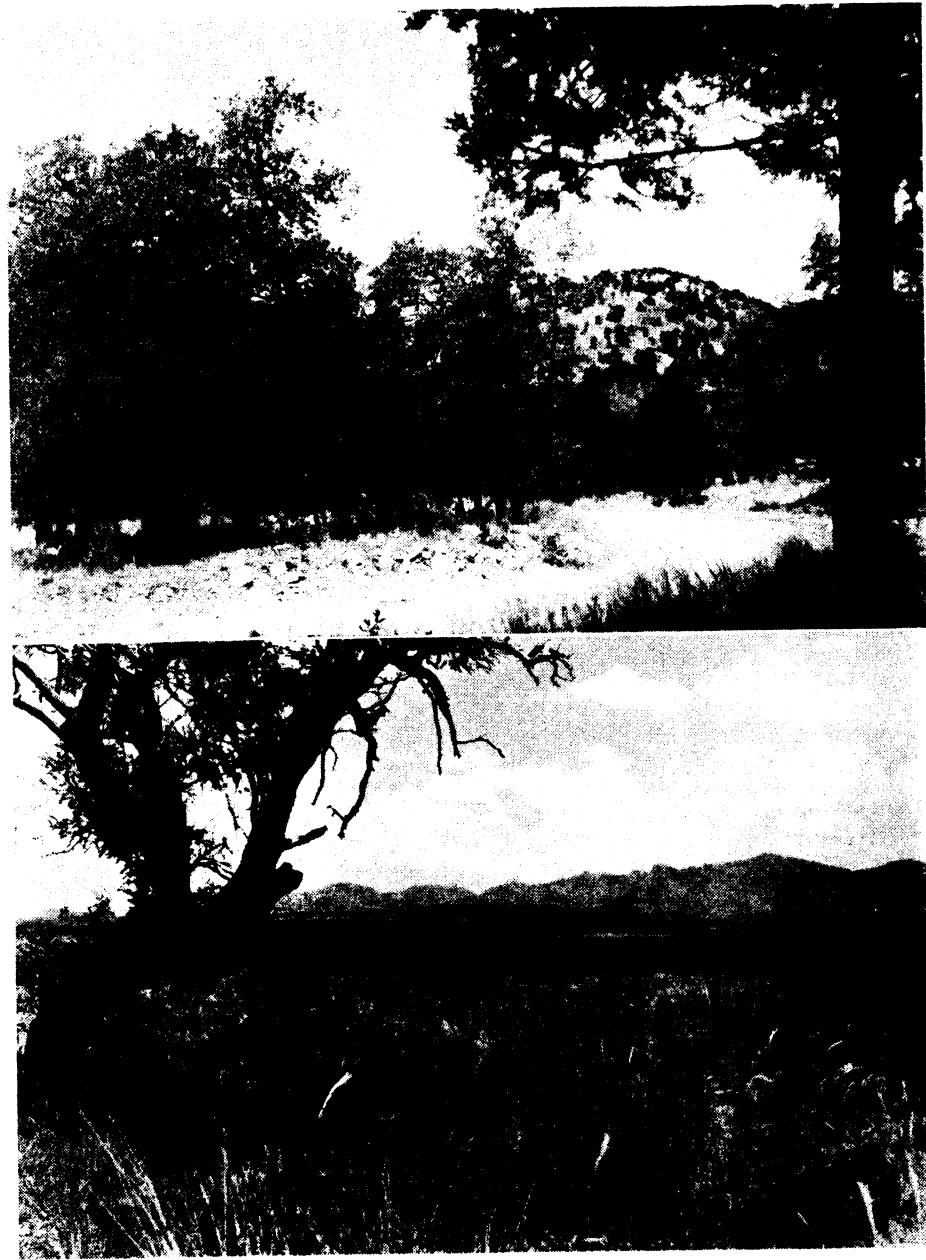
Plate II.—*Top*, oak-woodland vegetational area. Silverleaf and Arizona evergreen oak trees predominate, but in addition are found junipers, manzanitas, bear grass, mountain mahogany, and numerous grasses. Shantung brown soils are found typically in this area. Elevation, approximately 5,500 feet. *Bottom*, desert-grassland area. When grazing has not been severe, curly mesquite grass, blue and hairy grama, hoe grass, and several species of *Aristida* make an excellent growth, as in this picture. Reddish brown clay pan soils occur in these locations. Elevation, approximately 4,000 feet.

subsoil. This was included in the surface sample and labelled horizon A$_3$ though it may have included some of the B$_1$ horizon. The B horizons were 5 to 10 inches thick, the structure was compact and massive, and the color was some shade of brown. The substratum in each profile consisted of brightly colored reddish or yellowish brown gneissic material which merged at a depth of approximately 3 feet into disintegrated bedrock; however, the final depth in inches listed in Table 3 to which samples were taken does not always represent bed rock. Some soils, particularly at lower elevations, extended to unknown depths well below this limit.

SOILS FROM MOUNTAIN MEADOWS

Three soil profiles from mountain meadows at elevations comparable with the profiles from forested areas were sampled. These profiles were typical of prairie soils (44, p. 62 and 75, p. 1052).

The surface soils when moist were very dark brown, almost black, mellow and granular, and varied in thickness from 12 to 17 inches, depending upon the slope. The A horizon graded very gradually into the subsoil, distinguished chiefly by its lighter color. The structure was similar to that of the surface horizon. At a depth of from 20 to 36 inches the typical yellowish brown substratum of partially disintegrated gneissic materials was found.

These soils were mildly acid with pH values ranging from 5.79 to 6.28 in the surface. The alkalizing influence of the grasses and perennial herbs in contrast with a coniferous forest cover is evident when the pH values are compared with those of the forested samples. The pH values of the meadow soils were approximately 0.5 unit higher than those of the forested samples.

The mountain meadow soils here described have little in common with Wiesenböden or Meadow Soils (75, p. 1110). The Wiesenböden, though covered with a flora of grasses and sedges, are poorly drained, waterlogged much of the time, and are underlaid with a greenish gray glei layer.

SOILS FROM OAK-WOODLAND AREAS

Profile 11 was taken in a transition zone. It is typical of soils occurring in association with the oak trees near the upper edges of oak woodlands with which ponderosa pine is interspersed. Such profiles were more characteristic on Mt. Graham at higher elevations (up to 7,000 feet); at lower elevations, profiles similar to number 12 were found.

Profile 11 is a podzolic soil which, though associated with adjacent gray-brown podzols, developed under the influence of a deciduous oak rather than a coniferous vegetation. A disintegrated surface litter of ½ to 1 inch covered the profile, while immediately underneath was found a shallow dark yellowish brown

layer consisting chiefly of well-decomposed organic matter. In protected locations a well-defined ashy gray podzolic layer (1 inch maximum thickness) was found.

The B horizon was light yellowish brown in color, of single grain structure, and extended to a depth of 14 inches. Below this the typical yellowish brown substratum occurred; it was iron mottled and had a nutlike structure. The extracted colloid from these horizons could easily be crushed with the fingers when dry, whereas that from other profiles was tough, requiring grinding for fine subdivision.

This soil is probably a gray-brown podzol, but of the deciduous vegetation type peculiar to mountainous regions. It occurs in areas adjacent to gray-brown podzolic soils of the conifer forest type only in the transition zone between oak woodland and ponderosa pine. At lower elevations, shantung brownlike soils prevail. The two types of podzolized soil are not comparable either in vegetation or profile characteristics, since those from the pine and fir forests were developed under conditions of higher rainfall and lower temperatures. In order to distinguish the two, one is labelled *gray-brown podzolic—pine forest type,* and the other, *gray-brown podzolic—oak-woodland type.*

The organic debris layer of profile 11 is of the *mull* type (69) in contrast with *mor* type for the soils from the coniferous forests. Except for the fact that podzolization was evident from the ashy gray bleached horizon, this profile would be classed with the brown forest soils. Such soils undoubtedly exist on the mountains in this area but in the less sheltered locations. The properties of the two types of soil are probably very much alike. Further discussion will be deferred until a later section.

In marked contrast to profile 11 from an area sufficiently humid that podzolization of the profile had occurred, profile 12 is similar to the shantung or noncalcic brown soils of the subhumid, subtropical area. Among the shantung brown soils, it is similar to the Vista-Holland-Sierra series (75, p. 1097).

The surface soil occurred to a depth of about 7 inches and was lighter in color than preceding samples. The subsoil was more compact than the surface soil and was finely granular in structure. It was approximately 9 inches thick and had a yellowish brown color. The light yellowish brown substratum occurred below a depth of 16 inches.

The average pH value of the surface horizon of this profile was 6.88 and increased in the substratum to 7.34. On the other hand, the surface soil of profile 11 was mildly acid (pH 6.55), and the acidity increased progressively with depth in the profile to pH 5.42.

Profile 12 is probably on the dividing line between the pedalfers and the pedocals (75, p. 993, category VI). Since no free lime was found in the profile it was included with the pedalfers, although the high pH of the substratum and the tendency for the pH to increase with depth is characteristic of the pedocals.
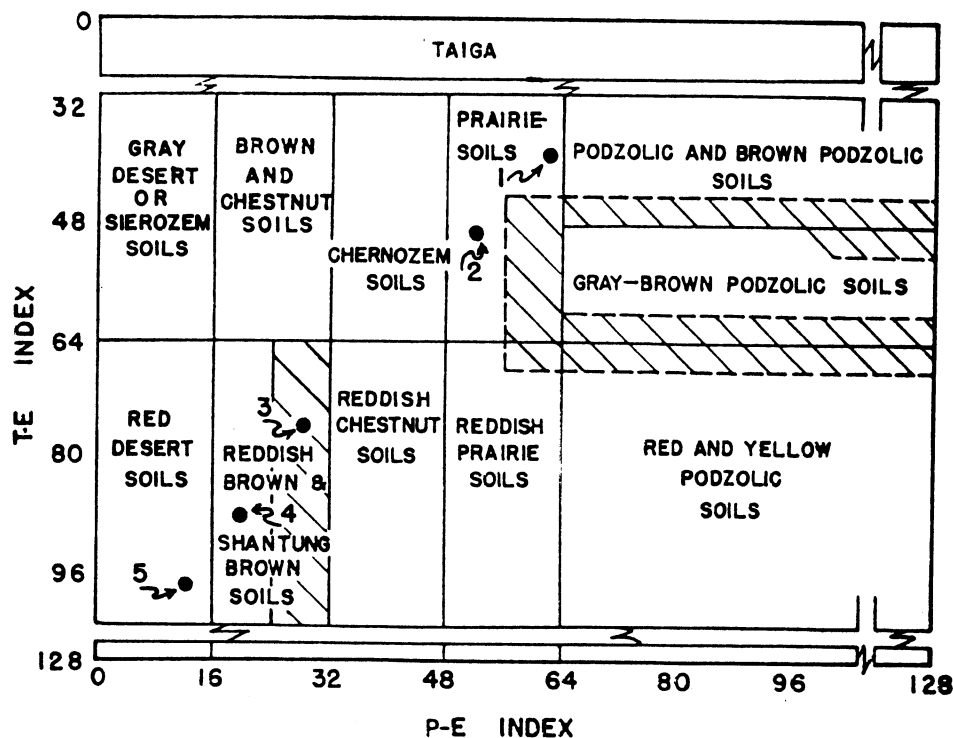
Figure 4.—P-E and T-E index boundaries for great soil groups of the United States together with locations of indices calculated for vegetational zones in southeastern Arizona. [Modified from Thornthwaite (38, 39).]

SOILS FROM DESERT-GRASSLAND AREAS

Two profiles were chosen from the desert-grassland area (Pl. II). The first of these, profile 14, is an azonal soil developed on recently deposited alluvium at the mouth of Noon Creek Canyon. Although the profile is immature, it has many of the characteristics of a shantung brown soil of the Vista-Holland-Sierra series and is associated with such in adjacent areas (75, p. 1097). This is the first soil herein described which had developed on transported materials. The light yellowish brown substratum typical of the profiles previously described and formed in place from gneissic materials was not found in this profile and constitutes one of the chief differences between it and number 12. The surface soil was weakly acid and lower horizons were neutral. The bases had

evidently been leached from all horizons. The second profile, number 17, was located some distance from the mountain on a small flat-topped mesa; it was a reddish brown soil similar to the soils of the White House-Tumacacori areas (75, p. 1094). The surface was approximately 3 inches deep, was weak orange to light yellowish brown in color, and was gritty and noncalcareous. The surface soil was mildly acid, pH 6.50. The subsoil, very heavy and compact, extended to a depth of about 12 inches. It had a well-developed prismatic structure and a pH value of 7.43. A moderately compact layer occurred below the subsoil. It was highly calcareous and at about 6 feet merged into a caliche hardpan.

SOILS FROM DESERT AREAS

Three soils from the desert area were sampled which represent extremes in desert soil development (Pl. III). Profile 18 contained 12 to 15 inches of soil underlaid by concretelike caliche. Number 15 was a very deep, well-drained, sandy soil showing little profile development. The third (no. 19), located on the banks of the San Simon Wash, was developed from recently transported alluvium. Here, too, the profile showed little horizon development; it was of considerable depth and showed evidences of solonchak development.

Except for the surface soil sample of profile 15 (pH 6.72) all the desert soils were alkaline and calcareous; all samples from number 19 had pH values over 8.0.

This area has been surveyed by the Soil Conservation Service and soil types designated. The appropriate type and profile description can be obtained from Table 3, a characterization of red desert soils from the literature (75, p. 1100).

CORRELATION BETWEEN THORNTHWAITE'S P-E (PRECIPITATION EFFECTIVENESS) AND T-E (TEMPERATURE EFFICIENCY) INDICES FOR THE VEGETATION ZONES ON MT. GRAHAM AND THE GREAT SOIL GROUPS

The temperature and rainfall data for the different vegetation zones already presented are an expression of climatic factors which have influenced soil formation on the mountain. The data are inadequate, however, for they do not indicate how much of the rain is used by plants and how much in soil formation. It is impossible to deduce from them the so-called "precipitation effectiveness," which will vary with the temperature, the rate of evaporation, the seasonal distribution of rainfall, the topography of the landscape, and other factors.

Thornthwaite (77) has recently devised a method which gives quantitative expression to precipitation effectiveness. It is based on a correlation between temperature and the rate of evaporation.

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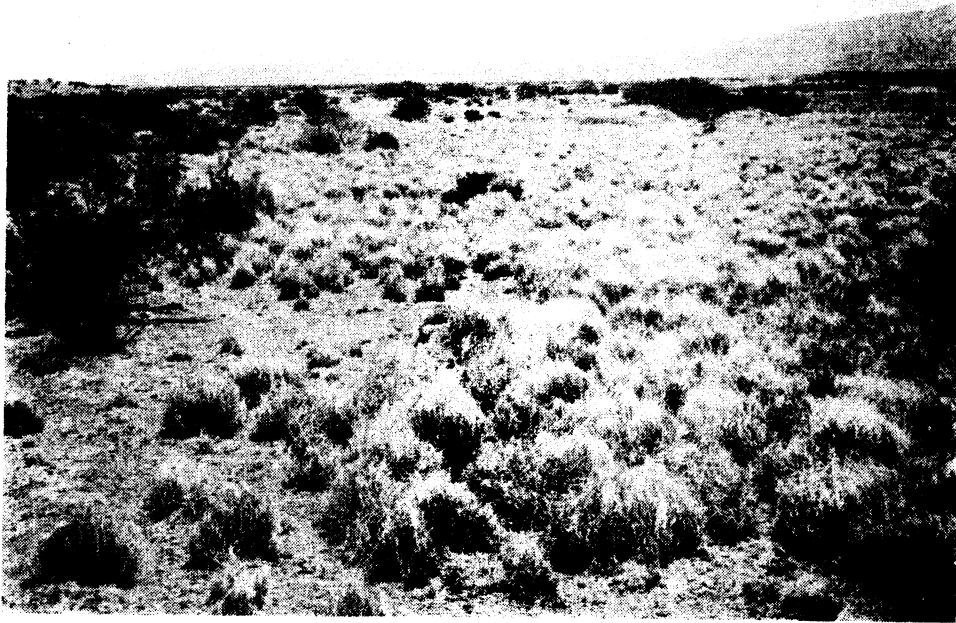
Plate III.—*Top*, creosote-bush desert area. Snake- and burroweeds **are** present in the foreground. **Red desert soils** occur in these areas. **Elevation,** approximately 3,300 feet. *Bottom*, tobosa grass swale adjacent **to San** Simon Wash; creosote bushes at **left of picture and in background. Fre-** quently these areas have been **destroyed by** erosion with **perpendicular** walled gullies 6 to 15 feet deep in the friable alluvial material **not uncom-** mon. Under the latter circumstances, **the tobosa grass disappears to be** replaced by the desert saltbrush **and burroweed.** Elevation, **approximately** 3,200 **feet.**

Vapor tension, wind velocity, and atmospheric pressure were found to have no significant influence on the result and could be ignored. The P-E Index, as Thornthwaite's factor is called, may be calculated from the following formula:

$$I = \sum_{n=1}^{n=12} 115 \left(\frac{P}{T\text{-}10}\right)_n^{10/9}$$

where P is monthly precipitation in inches, T, monthly temperature in degrees Fahrenheit, n, number of months.

A rational classification of climate should give consideration to the effectiveness of temperatures as well as of precipitation. Thornthwaite's T-E Index may be calculated from the following formula:

$$I' = \sum_{n=1}^{n=12} \left(\frac{T\text{-}32}{4}\right)_n$$

The temperatures are expressed with the same coefficients as the precipitation, and the T-E Index expresses the limiting effect of low temperatures on plant growth or soil development and the stimulating effect of high ones.

Thornthwaite and co-workers (77, 78) calculated the T-E and P-E indices for all climatic stations in the United States. The results obtained were superimposed on a soil map so that the climatic limits of the great soil groups might be apparent. This classification has received recognition by Thorp (81), who has modified it slightly. Since publication of these data, however, newer knowledge of the distribution of the great soil groups within the continental boundaries of the United States has been obtained and published by the Soil Survey Division of the U.S.D.A. (75). The information from the two sources (77, 78, 75) was combined in Figure 4, which shows the climatic limits of the soils of the United States.

In terms of precipitation effectiveness, a value of 48 divides the pedalfers from the pedocals. When the values are greater than 48, calcium and/or magnesium carbonates are absent from the profile, and iron and aluminum usually accumulate in the B horizon. When the values are less than 48, lime accumulates either throughout the profile or within any one horizon.

Brown podzolic soils occur between P-E isopleths of 96 and 127 and some of them at T-E indices greater than 48; consequently these soils overlap the gray-brown podzolic soils which occur in areas with T-E indices less than 48.

Inclusion of the Clinton-Boone-Lindley soils with the gray-brown podzolics causes an overlap of this group with the true prairie soils. The two types are intimately associated in Iowa, Wisconsin, and Illinois.

The transition between gray-brown and red-yellow podzolic soils is a gradual one so that no sharp line of demarcation between the two can be made.

No southern chernozems are recognized; soils with identical P-E indices (P-E 32-48) but with T-E indices greater than 64 are mapped as reddish chestnut soils.

Reddish brown and shantung brown soils occur in areas with P-E indices from 16 to 32 and T-E indices greater than 64. The reddish browns occur largely in areas with P-E indices less than 24, whereas the shantung browns occupy areas with P-E indices greater than 24.

The shantung brown soils have P-E indices which are identical with some reddish chestnut soils. However, these are confined to semiarid areas of Arizona, California, and New Mexico, whereas the reddish chestnut soils are found largely in the Panhandle region of Texas, western Oklahoma, and southwestern Kansas.

The P-E and T-E indices for the different vegetation zones on Mt. Graham were calculated and are plotted in Figure 4. On the basis of climatic type, the soils on Mt. Graham were appropriately classified. This is additional evidence for the climatic basis of soil classification. For a given climatic type, whether that type be in a comparatively narrow zone located vertically above or below another type on a mountain or covering a large area within a horizontal section of the United States, the kind of soil produced is essentially the same.

Three soil profiles were collected from the desert-vegetation zone, all of which proved to be red desert soils. The P-E and T-E indices for this area showed a red desert soil type (point no. 5 in Fig. 4). Two profiles were chosen from the desert-grassland zone (point no. 4): one of these was a reddish brown soil and the other, though from recent alluvium, was associated with soils of the shantung brown group. Only one profile (no. 12) was selected which was typical of the oak-woodland area (point no. 3), and this was a shantung brown soil. Profile number 11 was selected from a transitional area between the oak-woodland and western yellow pine zones. It was a podzolized soil probably because natural rainfall was supplemented by runoff from surrounding areas. Profile number 11 was on a 24 per cent slope where there was but little surface, but considerable subsurface runoff occurred. The characteristics of this profile, therefore, are not out of place climatically when it is recognized that increased moisture has been received from surrounding areas.

The soils from the Douglas fir and ponderosa pine vegetation zones (point nos. 1 and 2, respectively) were of two types: prairie soils on the well-drained mountain meadows and gray-brown podzolic soils in the forested area. In these instances, some discrepancies occur on the graph, for the gray-brown podzols are not shown to occur under the climatic conditions of these two vegetational areas. There may be two reasons for this discrepancy. First, as indicated previously, rainfall figures may be low—too few stations were available at higher elevations for accurate estimates of rainfall conditions. If the rainfall should prove to be higher

TABLE 4.—SUMMARY OF PHYSICAL CHARACTERISTICS OF SOME TYPICAL RANGE SOILS FROM MT. GRAHAM, ARIZONA, AND VICINITY.

Profile and horizon	Particles <0.05 mm. in diameter (%)	Particles <0.005 mm. in diameter (%)	Suspension percentage*	Dispersion ratio (%)	Total pore space (%)	Volume weight (gms./ml.)	Suction moisture equivalent (%)	Water holding capacity (%)	Expansion on wetting (%)	Field moisture (%)
Gray-brown podzolic soils—pine forest type										
1A₀	39.3	10.7	9.3	27.6	68.2	0.625	79.4	141.2	17.0	21.6
A	32.0	9.3	9.0	30.4	52.2	1.244	24.9	44.2	3.8	8.6
B	32.7	10.3	10.8	31.4	49.0	1.329	20.2	39.8	1.4	8.6
C	39.3	13.0	7.0	23.6	48.0	1.240	22.2	40.8	2.6	12.9
20A₀	43.7	8.7	9.5	30.6	72.2	0.481	115.1	203.0	24.5	26.7
A	48.0	13.0	10.7	27.9	54.0	1.045	35.6	50.5	3.7	9.0
B	51.3	15.8	14.8	29.2	51.2	1.250	26.7	42.7	1.5	8.8
C	53.0	15.3	18.0	37.0	49.5	1.271	27.2	41.2	3.4	7.9
5A₀	44.0	10.6	10.1	40.7	56.9	0.921	46.8	69.9	8.9	9.4
A	43.3	14.0	12.2	29.8	49.8	1.214	23.3	43.0	2.2	9.0
B	45.3	20.2	13.7	38.1	47.8	1.305	26.0	39.6	5.0	11.4
C	50.3	21.8	8.4	30.2	51.4	1.214	30.9	49.2	9.3	13.3
Prairielike soils										
2A	38.0	11.7	6.7	27.6	51.6	1.132	28.6	49.1	4.3	9.8
B	35.7	11.7	6.1	16.7	47.4	1.254	22.0	39.6	3.0	8.5
C	29.2	10.0	6.6	20.2	45.0	1.356	18.0	35.0	3.6	8.1
4A	52.0	20.0	11.8	25.2	54.8	1.130	31.1	52.1	4.8	10.5
B	50.3	18.0	14.5	32.0	46.7	1.260	24.0	38.9	3.0	6.3
C	48.3	19.7	23.6	47.6	47.8	1.315	22.8	39.2	6.5	8.3
6A	26.0	7.3	3.6	19.8	42.6	1.370	18.9	32.9	4.2	7.6
B	20.7	6.7	2.6	22.7	41.2	1.442	15.8	40.2	4.8	6.0
C	20.0	6.0	4.2	24.1	41.8	1.476	13.7	29.5	3.9	5.9
Gray-brown podzolic soils—oak-woodland type										
11A	41.3	9.7	7.0	21.7	64.2	0.890	48.3	85.6	15.5	7.0
B	38.0	12.7	18.7	50.5	38.6	1.506	17.9	25.2	0.6	3.1
C	42.3	20.3	18.5	50.6	41.5	1.460	21.4	30.1	3.6	4.9
Shantung brown soils										
12A	36.3	13.7	14.0	50.0	38.6	1.520	17.2	26.4	2.8	2.8
B	43.3	17.3	14.7	45.6	40.8	1.426	20.4	29.6	2.1	3.7
C	42.7	18.0	16.0	57.4	43.3	1.479	19.5	31.6	5.6	4.9
14a	26.7	3.6	9.2	46.4	34.9	1.731	11.0	20.8	2.9	1.0
b	28.3	6.0	10.2	53.0	35.7	1.688	11.8	22.6	6.4	1.3
c	26.3	7.3	5.5	31.8	38.6	1.573	12.3	25.1	2.8	1.6

Reddish brown soils

17a	29.1	11.3	10.8	54.0	32.9	1.685	13.6	20.4	3.7	1.1
b	47.0	38.3	5.1	32.0	53.2	1.271	42.2	52.0	20.7	9.9
c	44.0	30.0	10.4	40.4	50.1	1.352	37.4	44.6	16.9	7.7
Red desert soils										
18a	32.7	12.3	13.6	57.1	38.1	1.598	16.3	26.1	6.9	2.6
b	46.0	12.7	15.0	41.8	42.5	1.482	23.1	31.9	7.9	4.8
15a	16.0	4.5	6.8	53.3	31.1	1.767	9.7	18.6	5.4	0.4
b	17.7	6.8	6.8	47.8	34.1	1.721	12.7	21.4	6.1	1.1
c	26.0	11.3	8.5	46.9	34.5	1.722	11.4	21.8	7.7	2.0
19a	46.3	11.1	28.9	75.3	41.8	1.511	20.8	32.0	9.1	1.5
b	61.7	25.0	24.9	68.7	50.2	1.322	28.1	38.8	8.3	7.9
c	41.0	16.7	17.0	63.3	42.8	1.470	18.9	31.3	9.1	4.8

*Determined on soil at field moisture content.

Note.—Figures recorded in columns 2 to 11 are the average of duplicate determinations for each of four samplings of the soil profiles.

than that recorded, points 1 and 2 in Figure 4 would move into proper location. Second, the overlapping areas in Figure 4 may not be extensive enough. Only limited data were available for this section of the graph. It is possible that with the known close association of gray-brown podzolic with prairie soils in the Middle West, the P-E isopleth for this soil group should be less than the given value of 56. Probably more accurate information on either point would eliminate the discrepancy.

Generally speaking, however, the agreement is good and constitutes supporting evidence that mountain soils are not peculiar to their environment but are resultants of climatic factors which may be found in nonmountainous regions.

PHYSICAL CHARACTERISTICS OF THE PROFILE SAMPLES

METHODS

A determination was made on each profile sample for mechanical composition, suspension percentage, dispersion ratio, volume weight, total pore space, expansion on wetting, water holding capacity, and moisture equivalent. Undisturbed samples were examined for volume weight, pore space, expansion on wetting, and water holding capacity.

Mechanical analyses were made by the method of Bouyoucos (8), except that sodium hydroxide was substituted for sodium silicate and sodium oxalate as the peptizing agent. The results are reported on the basis of silt plus clay (particles less than 0.05 mm. diam.) and fine silt plus clay (particles less than 0.005 mm. diam.). These fractions were chosen since they are definitive in the physical behavior of soils (52, 87).

Fifty grams of soil, either air dry or at field moisture content, were allowed to slake in a liter of water for 24 hours after which the particles were suspended by shaking end over end 20 times at the rate of 30 shakes per minute. The total amount of silt and clay in the resulting suspension was measured with a hydrometer. This quantity divided by the weight of the soil multiplied by 100 is the suspension percentage. The dispersion ratio, expressed as a percentage, is the ratio of the suspension percentage determined on the air-dry soil to percentage of the total silt and clay determined by mechanical analysis. Both terms were defined by Middleton (52), and the above procedure is McGeorge's (49) modification of Middleton's method.

Determinations of volume weight, pore space, volume expansion on wetting, and water holding capacity were made by the methods of Keen and Raczkowski (38). These same procedures were used on the undisturbed samples. The original cylinder in which each sample was taken was fitted with a perforated lid and used for the different determinations. The suction method of Bouyoucos (6) was used for determining the moisture equivalent.

RESULTS AND DISCUSSION

The physical characteristics of the profile samples are shown in Tables 4 and 6 and Figure 5.

Mechanical composition.—Soil textures were surprisingly uniform. All but two soils were sandy loams; number 4 was a loam and number 15 a sand. The textural class of a soil profile, according to soil survey procedure, is determined by the texture of the surface horizon. Large variations in mechanical composition of subsurface horizons occurred among the different profiles.

All the soils except the prairie type showed a higher concentration of fine materials in subsurface than in surface horizons. In the gray-brown podzols this increase is probably due to eluviation of fine soil particles from the surface and their deposition in subsurface horizons. The heavy subsoils of the reddish brown and some of the red desert soils, however, cannot be explained on the basis of eluviation since little or no water percolation occurs. Profile 17 is typical of a large number of semidesert soils in southern Arizona (74) with heavy clay subsoils which have received some consideration by the authors. These soils retain appreciable amounts of moisture during the year (Table 4), even through the months of high summer temperature. It is conceivable, therefore. as postulated by Nikiforoff (60, 61), that the clay in these profiles was formed largely in place under conditions of intense hydrolytic weathering.

In the prairielike soils the high base content of the colloidal material tends to prevent or retard its eluviation.

Suspension percentage and dispersion ratio.—The suspension percentage, according to Middleton *et al* (53), is an empirically determined value which serves as a measure of the behavior of soils in the presence of excess amounts of water. It is a measure of the number of small-sized particles which come readily into suspension in water where they may be eroded away, washed to lower horizons, or remain in place to decrease the soil porosity (23, 73).

The suspension percentages of the soils from Mt. Graham varied from 3.6 per cent in the A horizon of profile 6 to 28.9 per cent in the surface layer of profile 19. The corresponding values for the other soils varied between these two extremes. No characteristic change in this property with great soil groups was noted, nor was such change anticipated. Two reasons may be cited. First, the values reported in Table 4 obtained at the different sampling dates refer to the soils at their field moisture contents. McGeorge (49) has shown that the suspension percentage for any soil varies through wide limits with the moisture present, sometimes increasing and sometimes decreasing with variation in moisture content. Soil relationships may vary widely if samples at different moisture contents are compared. Second, the suspension percentage is correlated significantly with the percentage of silt and clay

particles in the soil sample. Naturally a higher content of small-sized particles, other conditions being equal, will result in a higher suspension percentage. In the soils from Mt. Graham the highly significant correlation between these two variables was 0.488 (with 0.159 being significant). Free *et al* (23) obtained a similar correlation on 68 soil profiles taken from different sections of the United States. Since soils of identical textures (particularly in subsurface horizons) in the different great soil groups on Mt. Graham were not compared, group trends would not be anticipated.

High silt and clay content does not necessarily result in a high suspension percentage, however, since the small-sized particles may be aggregated into larger ones. Conditions from soil to soil become comparable only when the particles in suspension as measured by the suspension percentage under standard moisture conditions (air dry in these soils) are compared with those capable of suspension as deduced from mechanical analysis. The dispersion ratio is a measure of such comparison and is obviously related to soil aggregation—the lower the ratio, the greater the aggregation of the silt and clay particles.

The values of the dispersion ratio varied from 17 per cent in the B horizon of profile 6 to 75 per cent in the surface layer of profile 19. The lowest average dispersion ratios—that is, the greatest aggregation of silt and clay particles—occurred in the prairielike soils; the highest ratios, and therefore the lowest aggregation, occurred in the red desert soils. The gray-brown podzolic, shantung brown, and reddish brown soils ranged in ascending order between these two extremes. These results are consistent with those obtained by Baver (5, pp. 146-49) for the relationship of aggregation to climatic factors in the great soil groups of the United States. The lesser degree of aggregation in arid and semi-arid soils was attributed by Baver to low organic matter content and the dispersing effect of the sodium ion generally associated with these soils. High organic matter content and high base status characteristic of prairielike and related soils may be expected to increase aggregation.

Correlation coefficients were calculated for those properties which may affect soil aggregation. The correlation between the silica:sesquioxide ratio of the colloids and the dispersion ratios was 0.485 (least significant value 0.413) and is in accord with the work of Middleton *et al* (53, 54). Since the silica:sesquioxide ratios characterize great soil groups, this relationship was anticipated. The type clay present in a given soil is undoubtedly an influencing factor on soil aggregation. Other properties which gave significant zero order correlation coefficients may be classified as: (a) *those which may influence* and (b) *those which are influenced by* the dispersion of the soil. Organic carbon, pH, and moisture content were grouped in (a). Correlation statistics for these are given in Table 5.

TABLE 5.—REGRESSION STATISTICS FOR DISPERSION UPON
MOISTURE AND ORGANIC MATTER CONTENTS AND PH
VALUES ON MT. GRAHAM SURFACE SOILS.

	Moisture	Organic carbon	pH
Zero order correlation coefficients..	—0.797*	—0.667*	0.799*
Standard regression coefficients......	—0.206	—0.361	0.514
Multiple correlation coefficient........	R=0.903*		

*Highly significant (odds of 1 to 100).

All three variables showed a highly significant correlation with soil aggregation. Each to an extent exerted its influence on, or was a reflection of, factors which influenced aggregation independently of the other variables. Approximately 47 per cent of the variation can be attributed to the pH values of the samples, 34 per cent to organic matter contents, and only 19 per cent to the moisture contents. The multiple correlation coefficient of 0.903 is appreciably higher than any of the simple correlation coefficients.

High prevailing moisture and organic matter contents were associated with soils from the higher elevations on Mt. Graham where microbial activity was most marked and aggregation greatest. The influence of microorganisms on soil aggregation has been shown by Martin and Waksman (46) and Peele (63) to be appreciable, and it is a well-known fact that a high content of organic matter is a criterion of a well-aggregated soil (5, pp. 142-45). The pH values relate to the base content of the exchange complex, to microbiological activity, to the products of organic matter decomposition, to colloid flocculation at the isoelectric point, and to other factors which are operative in soil aggregation. It is not surprising, therefore, that the pH values should prove to be most closely correlated with this variable.

Among those properties which are influenced by the dispersion of the soil, the water holding capacity and moisture equivalent gave significant negative correlations with dispersion ratios; pore space, a highly significant negative correlation; and volume weight, a highly significant positive one. Obviously, clogging of pores by fine material increases the volume weight, decreases the pore space, and thereby reduces the moisture equivalent and water holding capacity. It was pointed out by Veihmeyer et al (85) that compacting a soil decreases its moisture equivalent. Our correlations agree with those of Free et al (23) for the same properties.

Total pore space and volume weight.—Total porosity is usually calculated from the relationship: $(1 - A/S) \times 100$, where A equals volume weight and S equals real specific gravity of the soil particles. Since S is reasonably constant for most soils, it is obvious that volume weight is inversely proportional to porosity. Pore space values reported in Table 4 are slightly higher than those obtained by use of this formula. The Keen-Raczkowski measurements define the pore space as that volume of the soil mass occupied by water when the soil is saturated; the pore space, as given by the above formula, is the total volume of the soil mass not occupied by solid soil particles. Since the soil expands on wetting, the latter expression yields a somewhat smaller value than that reported in this investigation.

The values for the total pore space, as shown in Table 4, ranged from 31 per cent in the surface horizon of profile 15 to 72 per cent in the organic debris layer of profile 20; volume weights were 1.767 and 0.481 gm./ml., respectively. Generally speaking, the total porosity increased and the volume weight decreased with increase in elevation. In the gray-brown podzols and prairie soils, pore space decreased with depth in the profile; in the shantung brown, reddish brown, and red desert soils, pore space increased with depth in the profile. These groups of soils correspond to the pedalfer and pedocal categories, respectively.

The above results may be explained on the basis of the content of silt, clay, and organic matter of the soils and the degree of aggregation of the fine soil particles. Silts and clays and high organic matter soils generally have higher total porosities than do sands (4, p. 162). In this investigation, the soils with high organic matter and/or clay contents (Tables 4 and 7) from the pedalfer region had the highest total porosities and lowest volume weights. Since in these soils the organic matter content decreased with depth in the profile, the pore space correspondingly decreased and volume weight increased. In arid and semiarid regions the organic matter content is negligibly small. In such instances a definite correlation exists between the clay content of the soil and its porosity and volume weight. Since it is evident from Table 4 that the clay content tends to increase with depth in the profile, the volume weights would be expected to decrease and porosity increase. In certain instances, such as in profiles 17 and 19, the b layers show higher accumulations of clay than do the c layers; these layers likewise show the higher porosities and lower volume weights.

Free *et al* (23) found a positive correlation between infiltration rate and total soil porosity. Since the porosity varies directly with content of silt and clay, which possess large numbers of small pores and show slow permeability, this correlation must have resulted from aggregation of small-sized particles into larger ones, thereby increasing pore size and rate of infiltration. It is significant that in the pedalfer soils from Mt. Graham, in which
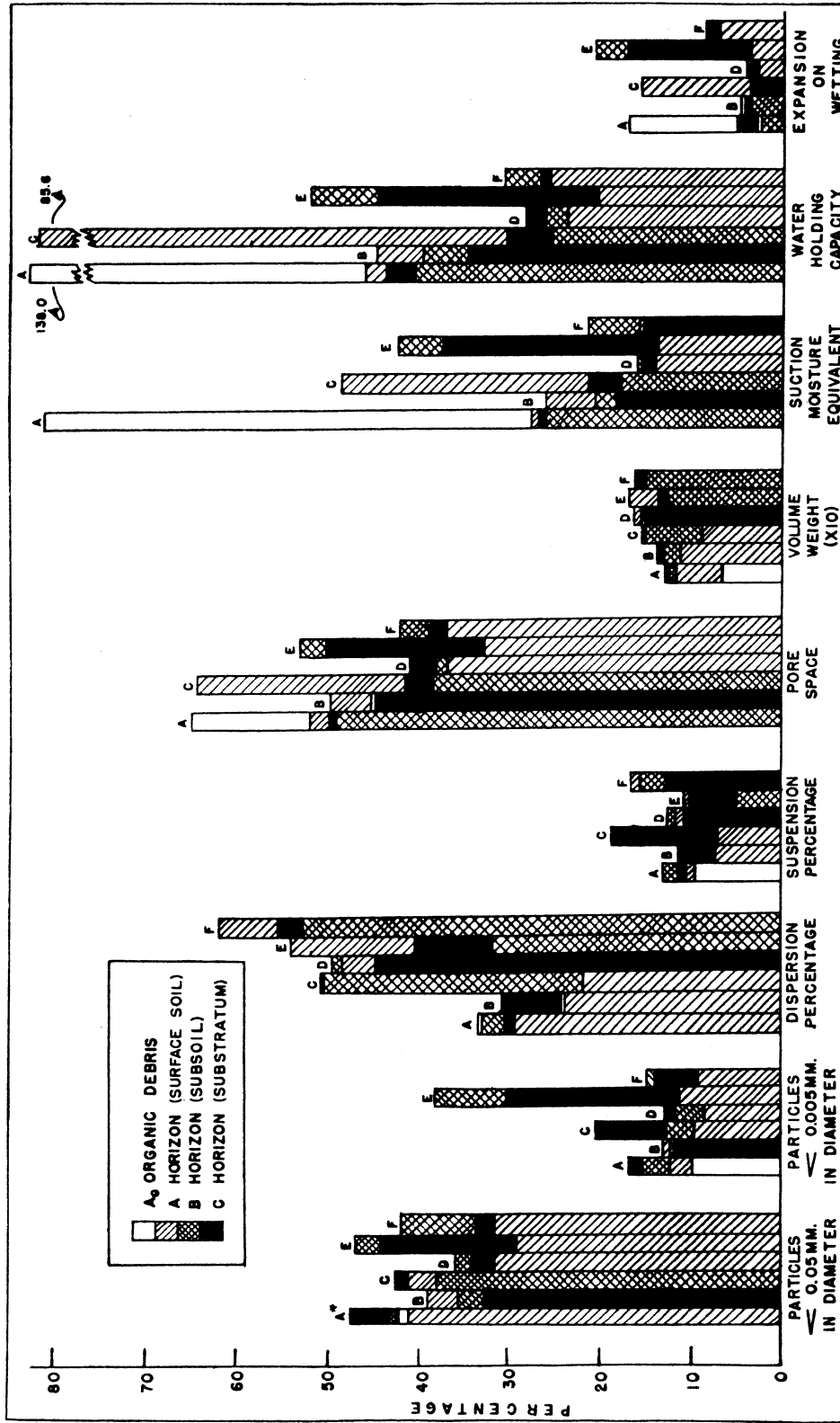
Figure 5.—Physical properties of soils representative of the great soil groups from Mt. Graham, Arizona, and vicinity. A, gray-brown podzolic soils—pine forest type; B, prairielike soils; C, gray-brown podzolic soils—oak-woodland type; D, shantung or noncalcic brown soils; E, reddish brown soils; F, red desert soils.

generally a greater percentage of silt and clay particles existed, the organic matter contents were higher and percentage aggregation greater. The correlation in the different soils between total pore space and aggregation, measured by the dispersion ratio (Table 4), was statistically significant (r is —0.394 with 0.159 being significant). In highly dispersed arid soils more rapid infiltration occurs in the coarse textured soils of low porosity and high volume weight. Had the investigation of Free *et al* (23) included more alkaline soils from arid regions, it is doubtful whether a significant correlation between total porosity and rate of infiltration would have been found to exist.

Moisture equivalent and water holding capacity.—Moisture equivalent determinations by the suction method of Bouyoucos (6) yield values which are somewhat higher than those obtained by the standard centrifugal method (64, 84). The values are generally comparable, however, and can be used to deduce moisture characteristics of the soil samples. Factors affecting the moisture equivalent likewise affect the water holding capacity. The correlation between moisture equivalent and water holding capacity for the soils from Mt. Graham was 0.981 (with 0.304 being significant).

The values for the moisture equivalent ranged from 10 per cent in the surface soil of profile 15 to 115 per cent in the surface debris layer of profile 20; water holding capacity values were 19 per cent and 203 per cent, respectively. When reduced to the volume-weight basis by multiplication of above values by the corresponding volume weights, the values become 26 per cent and 33 per cent for the moisture equivalents and 55 per cent and 98 per cent for the water holding capacities.

The moisture equivalent and water holding capacity are directly proportional to the silt and clay and/or organic matter contents of the different soil samples (10). When organic materials are present in large amounts, values for these two moisture constants are disproportionately high. The simple correlation coefficient between moisture equivalent and organic carbon content of the gray-brown podzolic and prairielike soils was 0.942 (0.200 being significant) and is very highly significant. The organic matter in these instances masks the effect of the other variables. In the pedocal soils, little organic matter is present and the small differences which do occur are not significantly correlated with the moisture values. In these soils the moisture constants vary directly with clay contents. These observations are consistent with those of Veihmeyer (83).

Since the moisture equivalent and water holding capacity correlate with organic matter, volume weight, and texture, significant correlations also exist with dispersion ratio, porosity, and pH value. In each instance, the correlation probably has little significance in a cause and effect relationship.

Expansion on wetting.—The volume expansion on wetting ranged from 0.6 per cent in the B horizon of profile 11 to 24.5 per cent in the surface debris layer of profile 20. The b layer of profile 17 showed 21 per cent expansion on wetting; all but three of the other profile samples showed less than 10 per cent expansion.

Correlations between expansion on wetting and other soil properties were not found to be significant except in the case of the organic debris layers of the podzolic soils in which a high expandability was associated with a high content of organic matter.

It was anticipated that the amount of clay present would correlate with expandability. However, except for the subsurface layers of profile 17 with highest clay contents (38 per cent and 30 per cent in b and c layers, respectively) and greatest expansion on wetting (21 per cent in b and 17 per cent in c layer), little or no correlation between these two variables was noted. There is a rough correlation, though not a statistically significant one, between aggregation and expansion on wetting in the case of the subsurface samples. It is probable, as deduced by Marchand (45) and others (2, p. 907), that the kind of clay and its state of aggregation are significant factors which determine the expandability of the soil. This would explain the results noted above.

Undisturbed samples.—Data for the undisturbed samples are given in Table 6. In each instance the conclusions derived from the data in Table 4 are consistent with those for the undisturbed samples. Generally speaking, the magnitude of each factor was the same for comparable sampling depths; in the case of expansion on wetting, however, much smaller values were obtained on the undisturbed samples. Cameron and Gallagher (18) showed that the expansion on wetting decreased with each successive alternate wetting and drying until a point was reached where it was equal to the contraction on drying. The undisturbed samples undoubtedly represent an equilibrium condition of this nature in which the expansion would be of a much smaller magnitude than that obtained on the disturbed and newly packed soils.

CHEMICAL CHARACTERISTICS OF THE PROFILE SAMPLES

METHODS

Each sample from the different profiles was analyzed for pH, carbon dioxide-soluble phosphorus, nitrate-nitrogen, total nitrogen, organic carbon, and the ratio of carbon to nitrogen was calculated. In addition, the colloidal material was extracted from representative samples and subjected to a fusion analysis for silica and sesquioxides.

A Beckman glass-electrode pH meter was used for the determination of the pH values. Determinations were made at a moisture content corresponding to field conditions, after the recommendation by McGeorge and Martin (51).

TABLE 6.—SUMMARY OF PHYSICAL CHARACTERISTICS OF SOME UNDIS-
TURBED SURFACE SOILS FROM MT. GRAHAM, ARIZONA,
AND VICINITY.

Profile	Volume weight (gms./ml.)	Water holding capacity (%)	Total pore space (%)	Expansion on wetting (%)
1	0.946	59.2	56.0	1.29
2	1.096	50.4	55.3	2.21
12	1.546	24.3	40.2	0.05
17	1.710	29.0	46.4	0.14
19	1.417	45.0	55.0	0.37

One-to-five soil-water suspensions were prepared, shaken vigorously for 30 minutes, and carbon dioxide bubbled through for 15 minutes, according to the procedure of McGeorge and Breazeale (50) for determining the "available phosphate." The suspensions were filtered and the clear filtrates analyzed for nitrate-nitrogen by the phenoldisulfonic acid method (1). Phosphates were determined on the filtrates by Zinzadze's (96) modification of the Deniges-blue method. Color comparisons were made with a Cenco photelometer. When excessive amounts of organic matter were present in the samples, the extracts were clarified with copper sulfate and calcium hydroxide according to the method of Harper (28).

Organic carbon was determined by the Walkley-Black (92) modified dichromate titration method and the total nitrogen by the Gunning-Hibbard modification of the Kjeldahl method (1).

Colloidal matter was extracted from the samples by a method essentially that of Kardos and Bowlsby (37). Two kilograms of soil screened to 10 mesh were dispersed in 17 liters of water and shaken mechanically for several hours. The soil suspension was allowed to stand for 10 hours after which the supernatant liquid was siphoned off through a 300-mesh strainer. The suspension was drawn off to a depth of only 15 cm. Except for some organic particles, the supernatant liquid contained colloidal particles of less than 5 microns. The colloid was then collected on parchment paper in a Sharples supercentrifuge. It was air dried and ground to pass a 40-mesh sieve. A majority of the particles collected for analysis had an apparent diameter of less than 2 microns, since those which settled near the inlet opening to the centrifuge bowl were discarded.

The colloidal material thus extracted was analyzed for silica and sesquioxides by the methods of the Division of Soil Chemistry and Physics of the U.S.D.A. (67).

RESULTS AND DISCUSSION

The chemical analyses are given in Table 7 and in Figure 6.

pH values.—The pH values varied over a wide range in the different soils tested. The lowest value recorded was pH 5.19 in the substratum of profile 1, a gray-brown podzol from the Douglas fir zone near the top of Mt. Graham; the highest value

was pH 8.08 from the b layer of profile 19, an alluvial desert soil from the San Simon Wash area adjacent to the mountain. A striking decrease in pH value occurs with increase in elevation. It is evident that the correlation between the pH value of the soil profile and associated climatic type, as deduced from Thornthwaite's P-E Index, is very good.

The soils naturally group themselves into two categories on the basis of the pH values of the horizons. In the prairie and gray-brown podzolic soils, the values progressively decrease with depth. In the shantung brown, reddish brown, and red desert soils the pH values are higher in subsurface than in surface soils. These two groupings correspond, respectively, to the pedalfers and pedocals of Marbut's (75, p. 983, and 43) classification.

The pedocals occur in arid or semiarid areas where water percolation is insufficient to remove completely the carbonates of calcium or magnesium. The carbonates accumulate at a depth corresponding to the average penetration of water from the surface. They induce alkaline pH values in the subsurface layers in contrast with lower values at the leached surface where some removal of the bases usually occurs.

Under rainfall higher than is characteristic for the pedocals, the pedalfers are produced. Percolation of acidic waters through the entire profile is marked. Bases are removed rapidly from the profile and it becomes acid. Bases from decomposing plant materials with which the surface is continually recharged neutralize some of the acidity so that surface layers are slightly less acid than the lower ones.

The pH value of these soils is directly proportional to the total base content of the vegetation; thus the high base content of deciduous vegetation is reflected in the mildly acid A horizon of profile 11 in contrast to more acid soils from under coniferous forest. The most marked contrast is between the prairielike soils from the mountain meadows and adjacent gray-brown podzols from forested areas. The T-E and P-E indices were identical. Percolation of water through the profile occurred at corresponding times during the year. It was similar in amount and occurred at approximately the same temperature; yet the prairielike soils had pH values about 0.5 pH unit higher on an average than the podzols. The plants of the mountain meadows require large amounts of bases, particularly of calcium, and bring these to the surface during growth. Subsequent decomposition of the abundant organic matter from this type vegetation replenishes the bases lost by leaching and decreases the acidity of the percolating waters. Coniferous needles, cones, and twigs, on the other hand, are low in the replaceable bases. Their decomposition produces organic acids which in the percolating waters effectively remove the bases from the soil profile. Thus, for this reason, the gray-brown podzols on Mt. Graham have lower pH values.

TABLE 7.—SUMMARY OF CHEMICAL CHARACTERISTICS OF SOME TYPICAL RANGE SOILS FROM MT. GRAHAM, ARIZONA, AND VICINITY.

Profile and horizon	pH	CO₂-soluble phosphorus (p.p.m.)	Nitrate-nitrogen (p.p.m.)	Total carbon (%)	Total nitrogen (%)	Carbon-nitrogen ratio	Colloid fraction analysis		
							SiO₂ (%)	R₂O₃ (%)	SiO₂/R₂O₃
Gray-brown podzolic soils—pine forest type									
1A₀	5.82	29.9	0.0	11.91	0.408	28.8	....	....	....
A	5.69	5.2	0.0	1.87	0.094	20.8	....	....	....
B	5.49	2.7	0.0	0.77	0.059	13.1	....	....	....
C	5.19	2.6	0.0	0.62	0.045	14.0	....	....	....
20A₀	5.36	60.3	0.0	22.19	0.596	64.8	....	....	....
A	5.60	3.2	0.0	3.08	0.161	19.3	....	....	....
B	5.52	2.3	0.0	1.25	0.072	17.5	....	....	....
C	5.42	2.1	0.0	1.37	0.069	20.0	....	....	....
5A₀	5.44	8.3	0.0	6.45	0.226	28.7	....	....	....
A	5.56	2.7	0.0	2.00	0.103	20.2	41.51	33.67	2.43
B	5.40	3.3	0.0	0.55	0.045	12.4	42.00	39.33	2.11
C	5.45	3.4	0.0	0.32	0.035	9.6	39.68	44.60	1.76
Prairielike soils									
2A	6.02	3.3	25.1	2.93	0.206	14.3	....	....	....
B	5.70	2.3	0.0	1.45	0.092	15.6	....	....	....
C	5.85	1.3	0.0	0.75	0.047	17.0	....	....	....
4A	6.28	2.0	32.2	3.03	0.190	16.0	42.18	36.88	2.26
B	6.16	1.6	2.2	1.13	0.079	14.2	42.70	37.98	2.22
C	5.92	1.3	0.0	0.70	0.054	13.0	42.39	38.61	2.16
6A	5.79	2.3	8.0	2.24	0.118	19.4	....	....	....
B	5.89	1.8	0.0	0.90	0.051	17.8	....	....	....
C	6.04	1.1	0.0	0.40	0.031	13.2	....	....	....
Gray-brown podzolic soils—oak-woodland type									
11A	6.50	28.0	63.2	8.42	0.338	24.5	43.04	29.90	2.84
B	5.81	2.2	0.8	0.53	0.034	15.0	45.11	34.84	2.55
C	5.42	2.1	0.0	0.38	0.028	12.4	43.56	39.32	2.18
Shantung brown soils									
12A	6.88	5.3	13.2	1.00	0.072	14.0	43.87	36.14	2.39
B	6.69	3.2	0.5	0.50	0.047	10.4	43.57	38.18	2.25
C	7.34	3.0	0.0	0.22	0.031	7.4	42.96	39.26	2.16
14a	6.74	25.1	13.2	0.34	0.039	8.7	....	....	....
b	6.98	15.6	3.2	0.37	0.042	9.0	....	....	....
c	6.98	14.5	3.2	0.42	0.046	9.1	....	....	....

Reddish brown soils

17a	6.55	7.4	6.2	0.26	0.034	8.0	49.18	30.92	3.13
b	7.43	2.7	8.5	0.45	0.062	7.5	50.19	30.12	3.29
c	8.02	4.5	3.5	0.22	0.029	7.5	48.22	27.41	3.47

Red desert soils

18a	7.63	9.0	3.5	0.32	0.033	10.0	......	......	......
b	8.06	6.2	3.5	0.29	0.034	9.5			
15a	6.72	16.0	4.5	0.14	0.022	7.1	47.12	35.42	2.63
b	7.18	23.6	1.2	0.13	0.020	6.5	47.55	31.96	2.94
c	7.88	16.0	0.5	0.14	0.024	6.3	46.96	32.19	2.88
19a	8.02	30.6	15.8	0.42	0.045	9.5	49.30	26.57	3.66
b	8.08	9.2	9.8	0.36	0.042	8.8	50.90	28.16	3.57
c	8.01	8.7	15.2	0.21	0.027	7.8	50.62	28.48	3.51

Note.—Figures recorded in columns 2 to 7 are the average of duplicate determinations for each of four samplings of the soil profiles.

Carbon dioxide-soluble phosphate.—The highest phosphate values were obtained from the organic mulch layers, the A_0 horizons, of the gray-brown podzols regardless of forest cover. These values were as high as 104 p.p.m. and averaged over 30 p.p.m. on the air-dry soil basis—hence, appreciably higher than the values obtained on the other soils.

Once the raw organic materials were converted into humus and incorporated into the mineral soil, fixation of phosphate in a difficultly soluble form occurred. Hardly more than 3 p.p.m. of CO_2-soluble phosphate were found in the mineral portions of the profiles.

High soluble phosphate values for partially decomposed forest litter has been reported by Lunt (42) who determined the content of 0.004 N. sulfuric acid-soluble phosphorus in the F and H layers of New England forest soils and found maximum and minimum values of 440 and over 100 p.p.m., respectively. Muir (55), also working with forest soils, reported 44 p.p.m. of acetic acid-soluble phosphate in the raw humus layer of a podzol but only traces in lower horizons.

Excepting the high phosphate contents of the organic mulch layers of the gray-brown podzols, the great soil groups naturally divide themselves into two categories with respect to this constituent. The shantung brown, reddish brown, and red desert soils—that is, the pedocals—contained more CO_2-soluble phosphate on the average than soils from higher elevations; namely, the pedalfers. Of the former, profiles 14, 15, and 19 contained the largest amounts of readily available phosphorus.

The zero order correlation coefficients for the relationship between the pH values of the samples and the content of CO_2-soluble phosphate were calculated and found to be 0.56 for 52 surface soils and 0.50 for 101 subsurface samples. Both values are very highly significant and indicate that the higher the pH value of the virgin Arizona soils, the greater the content of soluble phosphate. Presumably, either greater amounts of phosphorus are available in alkaline than in acid soils, or, as McGeorge and Breazeale (50) point out, the carbon dioxide method may extract more of the potentially available phosphorus from alkaline than from acid soils.

Nitrate-nitrogen.—Since the nitrate-nitrogen content of a soil is a variable quantity, the amount present at the time of sampling is largely accidental and makes comparisons between soils unreliable. Therefore, the values reported here are the amounts which accumulated over a 4-week period when the soils were incubated under optimum conditions of moisture and temperature. Since these values indicate the nitrate-supplying power of the soil they are comparable, being the resultant of the total nitrifiable nitrogen present and the overall activity of the ammonifying and nitrifying bacteria.

Apparently the gray-brown podzols under oak woodland most favored nitrate-nitrogen production, for large amounts of nitri-
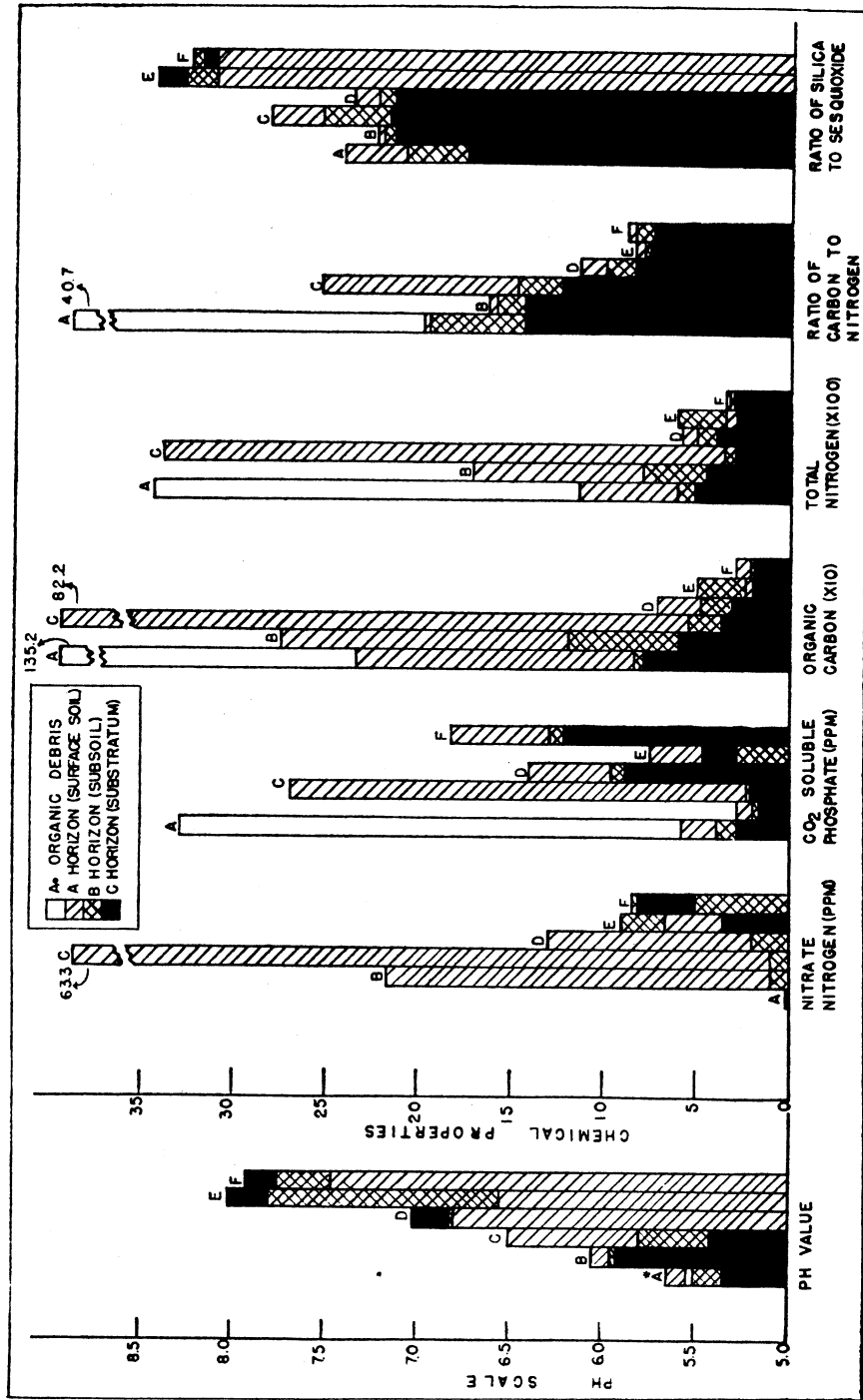
Figure 6.—Chemical properties of soils representative of the great soil groups from Mt. Graham, Arizona, and vicinity. A, gray-brown podzolic soils—pine forest type; B, prairielike soils; C, gray-brown podzolic soils—oak-woodland type; D, shantung or noncalcic brown soils; E, reddish brown soils; F, red desert soils.

fiable nitrogen were present and the nitrifying bacteria converted a greater proportion of it to nitrates than in any of the other soils. The gray-brown podzols under pine forest contained larger amounts of total nitrogen, but the nitrifying bacteria were inactive. Three explanations for this may be cited: (a) the pH values of soils under the pine forest were either 5.5 or less, corresponding to that given by Barritt (3) as the minimum value for ammonia oxidation in the soil, and nitrification may have been so slow that a 4-week period was insufficient for the accumulation of nitrates; (b) mold activity produced free acidity, over and above that existing in the exchange complex (69), and other substances toxic to bacteria in general, thus inhibiting the nitrifying bacteria by the absence of calcium or magnesium carbonate and by the presence of toxic compounds; (c) ammonia, or possibly nitrite, was utilized by the microbial population as rapidly as formed since the humus layer of the soils showed an excessively large C:N ratio of 40.7.

The soils under oak woodland received large quantities of base-forming materials from the oak litter. These materials are essential to the nitrifying bacteria and prevent excessive acidity. With large amounts of nitrifiable nitrogen present and all other factors being favorable, it is not surprising that large quantities of nitrate were found in these soils.

The nitrate-nitrogen contents of the remaining soils were proportional to the amount of nitrifiable nitrogen present. Data to be presented later showed that in general, bacteria are more active in alkaline desert soils than in mountain soils. Since the prairie and shantung brown soils contained more nitrogen than the desert and desert-grassland soils, greater amounts of nitrate accumulated in them during incubation, even though the bacteria may have been less active.

It is evident from the above that the oak and pine forest profiles resemble the biological types distinguished by Müller (56) and described more fully by other investigators (26, 68, 69, 90) — namely, *mull* and *mor*, respectively. *Mull* is a well-aerated soil containing nitrates, nitrifying bacteria, and a preponderance of bacteria over filamentous fungi. The layer of organic debris is of the open leafmold type and earthworms are normally present. *Mor*, on the other hand, contains no nitrates, nitrifying bacteria, or earthworms, and the fungi predominate over bacteria.

In addition to the observation that the soils under coniferous forests contained no nitrates, whereas those under oak woodlands contained large amounts, the data to be presented in the following section are also consistent with this correlation. Fungi were present in the pine forest soils in numbers nearly equal to the bacteria and the *Actinomyces* (ratio, 0.705), whereas the oak-woodland podzols contained over six times as many bacteria and *Actinomyces* as fungi. The organic debris layer of the pine-fir podzols was often interwoven tightly with fungus mycelium, and, in

addition, nitrifying bacteria and cellulose-destroying micro-organisms were essentially absent.

In contrast to eastern humid conditions where *mull* or *mor* may be formed from plant materials of the same type (69, 90), the *mor* soils of southern Arizona are generally associated with the pine-fir forests of the higher elevations and the *mull* soils with oak trees either transitional with or just below the conifers, and under somewhat drier and warmer conditions.

Total nitrogen and organic carbon contents.—Organic matter, as deduced from total carbon and nitrogen contents, varied through wide limits in the different soils: C ranged from 0.13 per cent to 22.2 per cent and N from 0.02 per cent to 0.60 per cent. Two trends were strikingly evident: (a) generally, the organic matter content decreased with depth; (b) organic matter contents increased with elevation. The latter trend obviously is correlated with climatic types occurring at different elevations; therefore, the correlation might better be made with Thornthwaite's climatic indices (p. 112).

Carbon content is a better measure of soil organic matter than is nitrogen content. The conventional factor 1.724, used for conversion of per cent carbon to per cent organic matter, holds surprisingly well for soils not high in organic matter. For forest samples Lunt (42) recommends the following factors: (a) litter (freshly fallen leaves), 1.89; (b) F-layer (decomposing material whose original structure is still discernible), 1.85; and (c) H-layer (well decomposed, structureless humus), 1.80. Obviously these factors are only approximations which will vary with organic matter type.

The nitrogen content of organic material, in general, is more variable than the carbon, but it is an important plant constituent. It occurs in the soil as a direct result of organic matter accumulation and is roughly proportional to the total organic matter content of the soil. In the soils studied, the nitrogen content was 0.015 to 0.167 of the carbon content; the higher nitrogen:carbon ratios occurred in the soils from more arid regions.

The largest quantities of organic matter in all stages of decomposition were obviously present in the humus layers of the forest profiles. The prairielike soils contained over 2.5 per cent carbon—a value somewhat higher than was found in the surface horizon of the gray-brown podzols below the organic debris. The amounts present decreased progressively with elevation so that less than 0.5 per cent organic carbon was found in the red desert and reddish brown soils. Organic materials were almost entirely absent. Corresponding values for nitrogen were roughly 0.18 per cent in the prairielike and 0.03 per cent in the desert soils.

These results are consistent with those of Jenny (34) and others (41), who showed that the nitrogen and carbon content of the soil decreases exponentially with increasing temperature; also with those of Hardon (27), who found that organic matter and nitrogen content rise exponentially with altitude.

Two factors are responsible for the effects here observed. First, higher rainfall on the mountain resulted in a denser plant cover which subsequently contributed to the organic matter content of the soil. Second, the rate of microbial decomposition of organic materials in relation to the total amount present decreased with elevation. This evident temperature effect is roughly in accord with van't Hoff's law that for each 10 degrees C. rise in temperature the activity of microorganisms increases two to three times. Within the physical limits of this study, the higher the temperature the greater the speed of organic matter decomposition; consequently, the less likely the accumulation of organic material. At higher elevations the production of organic materials was high and the rate of decomposition low. In the desert the production of organic materials was slow and the rate of decomposition high; hence organic matter did not accumulate.

Carbon:nitrogen ratio.—Although both nitrogen and carbon increase exponentially with the temperature, the increase is more marked for carbon than for nitrogen, as indicated previously; hence, the ratio of carbon to nitrogen varies inversely as the temperature (27, 34). The C:N ratios from the Mt. Graham samples substantiate this premise; they varied from 6.3 for one of the desert soils to over 64.8 for the mountain soils. In the surface horizons the ratio varied from 7.1 on the desert to 24.5 in the gray-brown podzols. In all instances the C:N ratio decreased with depth in the profile. These results agree with those of other investigators (27, 41, 42, 90, 91).

In cultivated mineral soils of temperate regions, the C:N ratio tends toward a value of 8 to 12 (72, 89)—the ratio in cells of the microorganisms which eventually ingest all the organic matter. In the original plant material, the ratio varies from 16 to 200 (34). In virgin soils the ratio seldom reaches the minimum range of 8 to 12 because of the perpetual return of plant substances of higher ratios under conditions not favorable to continuous decomposition. At low temperatures, the C:N ratio tends to become as wide as that of the undecomposed material because the nitrogen content of the soil approaches that of the vegetation. At most temperatures (34), the ratio is intermediate between the theoretical minimum for complete microbial decomposition and maximum for original plant material. Older organic matter in the soil has the lower ratios so that the extremely low values of desert soils, or at lower depths in the profile (41), indicate complete decomposition under these conditions. The higher C:N ratios of the podzols indicate a potentially high activity on the part of the microorganisms attacking these substances and hence an incomplete decomposition.

Silica:sesquioxide ratios.—The silica and sesquioxide contents and the molecular silica:sesquioxide ratios in the soils studied are given in Table 7. Generally speaking, the desert and desert-grassland soils contained 47 per cent to 50 per cent SiO_2 whereas

those from more humid areas contained less than 44 per cent. While it is recognized that the higher silica contents were associated with the soils developed from transported materials, these results are in line with those of Brown and Byers (13) and Kelley *et al* (39) which indicate that high SiO_2 contents are characteristics of the colloids of arid and semiarid soils. The silica: sesquioxide ratios are also consistent with the results of other investigators (16, 17, 39).

The reddish brown and red desert soils showed little change in these constituents with depth in the profile. The ratios were high—generally 3 or more. This high value is characteristic of dry-land soils (13, 39), and its constancy with depth suggests that the same type colloid occurs in the different horizons.

* Results similar to the above were obtained with the shantung brown and prairielike soils. A constant silica:sesquioxide ratio throughout the profile indicates a general movement of the colloid without fractionation from the surface downward. The ratio has a value of 2.4 in these soils, indicating increased leaching; on the other hand, slightly higher sesquioxide values in the subsurface horizons give evidence of podzolization.

In the gray-brown podzols, more thorough leaching of constituents and increased podzolization is indicated by (a) a marked decrease in the silica:sesquioxide ratio with depth in the profile, associated with a corresponding accumulation of sesquioxides in the subsurface horizons, and (b) the slight increase of SiO_2 in the B horizon. This is a fractionation of colloidal constituents typical of podzolization and similar to that found in gray-brown podzols in the northeastern United States (16, 17).

MICROBIOLOGICAL CHARACTERISTICS OF THE PROFILE SAMPLES

METHODS

Tests were made on all samples from each profile for total numbers of bacteria and *Actinomyces*, filamentous fungi or molds, nonsymbiotic nitrogen-fixing bacteria of the genus *Azotobacter*, aerobic cellulose-destroying bacteria and nitrifying bacteria. In addition, a test was made of the nitrifying capacity of the soils.

Brown's egg albumin agar (11, 12) was used for the bacteria and *Actinomyces* counts and Waksman's (22) peptone-glucose acid agar for the molds. Duplicate 20-gram aliquots of each sample were added to 185 ml. of sterile tap water for the initial dilution. The samples were shaken for 5 minutes at a rate of 120 vibrations per minute after which further dilutions were made. Quadruplicate plates were poured from at least two appropriate dilutions. For the final count dilutions were chosen to give less than 100 colonies of bacteria and *Actinomyces* per petri dish and

TABLE 8.—SUMMARY OF MICROBIOLOGICAL CHARACTERISTICS OF SOME TYPICAL RANGE SOILS FROM MT. GRAHAM, ARIZONA, AND VICINITY.

Profile and horizon	Bacteria & Actinomyces per gm. (in thousands)	Molds per gm. (in hundreds)	Cellulose destroying bacteria per gm.	Nitrifying bacteria per gm.	Nitrification of $(NH_4)_2SO_4$		Azotobacter colonies per gm.
					Nitrate-N in p.p.m.	N in $(NH_4)_2SO_4$ nitrified (%)	
Gray-brown podzolic soils—pine forest type							
1A₀	1,568	1,802	10	3	0	0	0
A	1,054	1,335	7	8	0	0	0
B	290	474	0	1	0	0	0
C	63	63	0	0	0	0	0
20A₀	1,434	30,568	92	4	0	0	0
A	728	15,159	10	2	0	0	0
B	580	1,772	1	3	0	0	0
C	359	773	1	0	0	0	0
5A₀	2,454	6,134	54	4	0	0	0
A	3,258	4,521	15	3	0	0	0
B	1,039	1,101	2	3	0	0	0
C	151	191	0	0	0	0	0
Prairielike soils							
2A	2,446	1,886	15	750	6	2.0	0
B	313	88	2	8	0	0	0
C	79	65	2	6	0	0	0
4A	3,866	1,366	166	1,425	30	10.0	0
B	726	222	4	28	1	0.3	0
C	332	186	3	2	0	0	0
6A	1,944	488	12	12	2	0.7	0
B	364	34	0	0	0	0	0
C	50	15	1	0	0	0	0
Gray-brown podzolic soils—oak-woodland type							
11A	6,918	11,058	299	1,525	48	16.0	0
B	5,292	1,092	19	192	1	0.3	0
C	886	342	1	4	0	0	0
Shantung brown soils							
12A	5,377	790	145	160	29	9.7	0
B	1,108	178	13	20	4	1.3	0
C	309	44	7	2	0	0	0
14a	2,684	420	950	4,000	18	6.0	4
b	2,329	107	196	2,962	4	1.3	14
c	1,004	33	29	2,112	3	1.0	1

Reddish brown soils

17a	1,016	82	522	4,725	26	8.7	0
b	556	59	42	648	27	9.0	0
c	228	37	6	9	3	1.0	0

Red desert soils

18a	1,336	169	575	94	39	13.0	6
b	325	30	31	11	11	3.7	0
15a	402	72	192	20	10	3.3	0
b	306	84	101	79	2	0.7	0
c	109	40	14	650	14	4.7	0
19a	2,394	146	1,238	10,500	86	29.0	10
b	1,280	130	612	64	68	22.7	1
c	599	61	16	13	17	5.7	0

Note.—Figures recorded in columns 2 to 7 are the average of duplicate determinations for each of four samplings of the soil profiles.

less than 40 colonies of molds. Incubation was at 30 degrees C. for 7 days for the bacteria and *Actinomyces,* and 2 to 4 days for the molds. The number of colonies per plate was determined with a "Quebec" colony counter.

Tests for *Azotobacter* were made by the selective-culture-agar-plate method (47). A nitrogen-free nutrient-agar medium was prepared in large petri dishes and sprinkled with each soil sample. When *Azotobacter* were present, large, partially opaque, raised colonies which turned brown with age appeared on the surface of the agar. Such colonies are typical for *Azotobacter* since no other organism can make an appreciable growth in the absence of nitrogen.

A dilution method proposed by Dubos (20) was used for estimating the number of aerobic cellulose-destroying bacteria. Tubes were incubated at 30 degrees C. for a period of 2 weeks after which they were examined for cellulose decomposition. From the greatest dilution showing the disappearance of cellulose, the minimum number of cellulose-destroying bacteria per gram of soil was calculated.

The method used for determining the numbers of nitrifying bacteria was also a dilution method, proposed by Wilson (94). Samples were incubated for 4 weeks, then tests were made for nitrites by the alpha-naphthylamine-sulfanilic acid method. A positive test indicated nitrifying bacteria at the dilution under consideration.

Dilutions were made in multiples of ten in testing for the cellulose destroyers and the nitrifiers; hence, only comparatively large differences in the number of these bacteria could be detected, and the values reported represent minimum estimates. The actual number would be greater than the highest dilution and less than the least dilution at which nitrite was formed or cellulose decomposed. McCrady's (15) tables of probability were used for three samples from each dilution to increase the accuracy of the estimates. These data are reported in Table 8. Since the interval between dilutions was wide, the differences observed are undoubtedly of real significance.

The numbers of nitrifying bacteria in soil are not always quantitatively related to the speed with which ammonia is oxidized, since the activity of the organisms varies from soil to soil—a function of their physical and chemical environments. Tests were made, therefore, for the rate of nitrification of ammonium sulfate in the various soil samples.

Although highly desirable it obviously was impossible to make nitrification studies in the field, so the soils were brought into the laboratory and nitrification rates determined under standardized optimum conditions. Even though the results thus obtained do not relate directly to field conditions, the data are comparable since all the samples are on a uniform basis.

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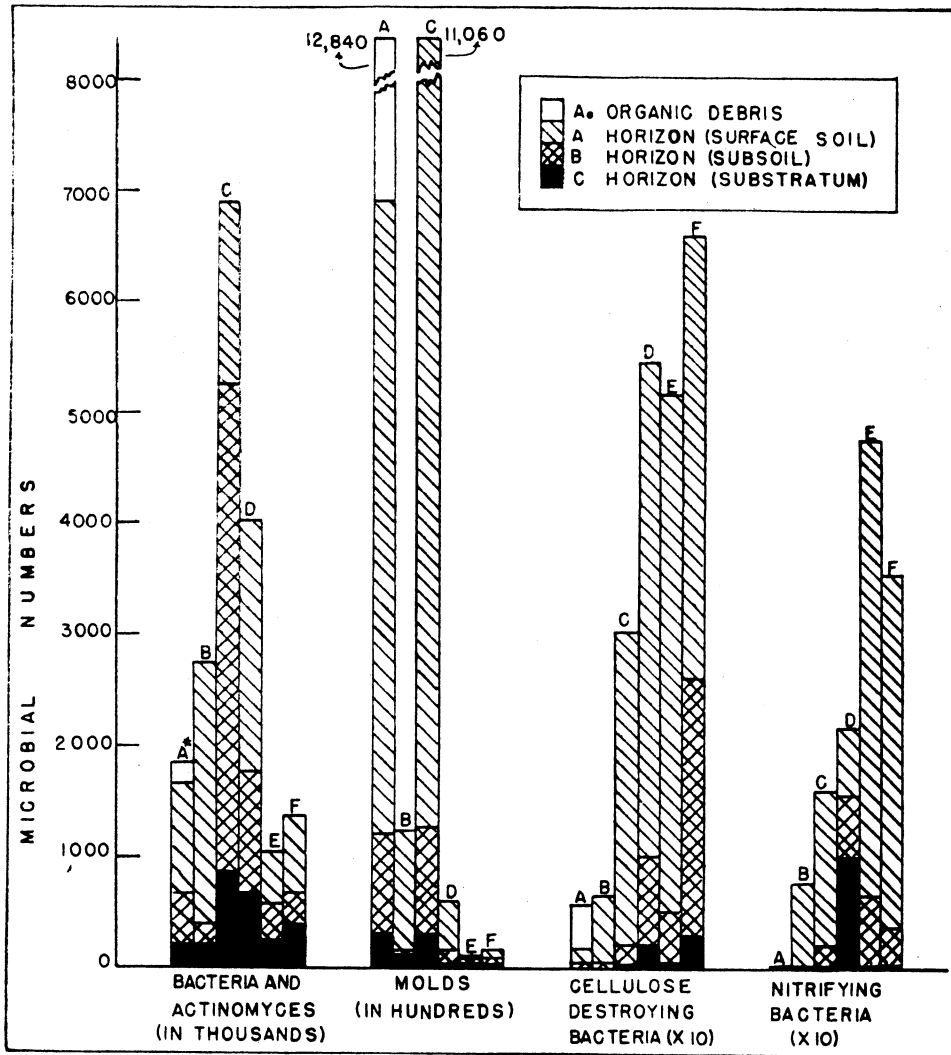:i-
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Figure 7.—Microbiological characteristics of soils representative of the great soil groups from Mt. Graham, Arizona, and vicinity. A, gray-brown podzolic soils—pine forest type; B, prairielike soils; C, gray-brown podzolic soils—oak-woodland type; D, shantung or noncalcic brown soils; E, reddish brown soils; F, red desert soils.

The nitrifying capacity was determined by the following modification of Waksman's (88) method: One-hundred-gram samples of soil were weighed into each of four glass tumblers; two of these were given no treatment and two were treated with 141.5 mgm. $(NH_4)_2SO_4$, equivalent to 30 mg. N. Water was added to optimum moisture content and each tumbler loosely covered and placed in the incubator at 30 degrees C. for 4 weeks, after which the soil from each was analyzed for nitrate-nitrogen by means of the phenoldisulfonic-acid method (1).

It is recognized that for best results the analyses should have been made periodically over an extended period and nitrification-rate curves plotted from the data thus obtained. Because of limited time and equipment the simple method was used.

RESULTS AND DISCUSSION

The microbial determinations presented problems both in comparing the profile samples and in methods. It is well known that bacterial numbers decrease with profile depth. For this study the profile samples were collected by horizons rather than depth; hence, the counts are averages of entire horizons. The A horizon on some of the mountain-meadow soils was as deep as 17 inches, whereas that of most of the desert soils was only 3 inches. This condition makes comparison difficult and must be recognized in drawing conclusions.

Another problem was that of obtaining replicate horizon samples without exceeding the capacity of available analytical facilities. Replicates were obtained by sampling each profile several times during the year. This procedure had several advantages. It is known that microbial numbers fluctuate not only seasonally but diurnally, depending upon the microenvironment. One is therefore not justified in attributing wholly to soil characteristics differences which exist in bacterial counts between mountain-meadow soils in April when snow is on the ground and concurrently taken samples from the desert. External conditions of temperature and moisture, more or less accidental on the day of sampling, would also markedly influence the results. Repeated samplings throughout the year are essential if differences are to represent both inherent soil conditions and the effect of the external environment, which were largely responsible for the development of the profile.

Speed of sample collection presented a problem in methodology. Counts are valid only when made shortly after collection. Distance between field and laboratory made a lapse of 24 hours unavoidable between collection and the making of bacterial counts, and changes of an unknown nature occurred during this period.

Other difficulties relate specifically to the methods. Since the completion of the foregoing analyses, an excellent critique of methods for making bacterial and mold counts in soils has been reported in the literature by James et al (30, 31, 32, 33, 76). It is regrettable that their method, which attaches significance to relatively small differences in microbial counts, was not available for this study. Since the limits of accuracy of the methods used herein are undeterminable, only relatively large differences between samples can be considered significant.

With these facts in mind, the microbial characteristics of the profile samples are given in Table 8 and Figure 7.

Bacteria and Actinomyces.—The number of bacteria and *Actinomyces* per gram of soil varied from 402,000 to nearly 7 million in the A horizons, from 290,000 to over 5 million in the B horizons, and from 50,000 to 1 million in the substrata.

Samples from profile 11 contained the largest number of organisms, the shantung brown soils the next largest, and the prairie-like soils next in order. The forest and desert soils contained the smallest number of organisms.

As was to be anticipated, fewer organisms occurred in the lower horizons than in the surface soils and the differences in counts between profiles were not marked, particularly in the substrata. However, the rate of decrease in number of bacteria and *Actinomyces* with depth was less in the reddish brown and red desert soils than in more humid ones.

The organisms, which grew on the egg-albumin plates and from which the number of bacteria and *Actinomyces* was calculated, are aerobic heterotrophs. They prefer a neutral to slightly alkaline medium, grow best in soils high in organic materials to which moisture is frequently supplied, and grow more abundantly at higher temperatures. None of the soils studied offer such an optimum environment. The gray-brown podzols from oak woodlands, however, offer the most favorable combination. The surface horizons of these soils had average organic carbon contents in excess of 8 per cent and total nitrogen contents of over 0.3 per cent. These soils have *p*H values above 6.5 and receive approximately 18 inches of rain annually. Their average yearly temperature is approximately 60 degrees F.

The surface horizons of the podzols from the pine-fir forests contained larger amounts of organic materials and received 20 to 28 inches of rain annually. These soils, however, are appreciably acid, with a *p*H value of 5.6 and a mean yearly temperature of 42 to 46 degrees F. These factors retard the growth of bacteria and *Actinomyces* even amidst abundant supplies of food and moisture.

The reddish brown and red desert soils have *p*H values near the neutral point or in the alkaline range, and their mean annual temperatures are 62 to 65 degrees F. The rainfall in this area, however, is only 11 to 12 inches yearly, resulting in a sparse vegetative cover and an organic carbon content in the surface soils of less than 0.5 per cent. These conditions so discouraged the growth of bacteria and *Actinomyces* that these soils contained smallest numbers.

The shantung brown and prairie soils with the second and third highest counts of bacteria and *Actinomyces*, respectively, have properties intermediate between the red desert and the gray-brown podzolic soils.

Molds.—The number of molds per gram of soil varied from 7,000 to over 3 million in the A horizons, from 3,000 to 177,000 in the B horizons, and from 1,400 to nearly 8,000 in the substrata.

These variations are extremely large and indicate significant differences in the ability of the soils to support a mold flora.

Gray-brown podzols contained the largest number of molds, followed in turn by the prairielike, shantung brown, and finally the reddish brown and red desert soils. Subsoils in contrast to the surface soils contained few molds.

A striking correlation between mold numbers and moisture and organic carbon contents is shown in Figures 6 and 7 and Table 4. Regression statistics, computed from the individual sample analyses of surface soils only, are given in Table 9.

TABLE 9.—REGRESSION STATISTICS FOR NUMBERS OF MOLDS
UPON MOISTURE AND ORGANIC CARBON CONTENTS
OF THE SOIL SAMPLES.

	Moisture	Total carbon
Zero order correlation coefficients............	0.5773†	0.5155†
Standard regression coefficients................	0.4225†	0.2864*
Multiple correlation coefficient...............	R = 0.6257†	

*Significant (odds of 1 to 20)
†Highly significant (odds of 1 to 100)

The zero order correlation coefficients show both the moisture and organic carbon contents to be highly significantly correlated with the number of molds. Hence, there was less than one chance in a hundred of obtaining such a correlation if 64 samples were chosen at random from a population in which no correlation actually existed. The standard regression coefficients show that 59.6 per cent of the variation in mold numbers can be assigned to the moisture content of the samples and 40.4 per cent to the organic carbon content. The multiple correlation coefficient of 0.6257 is highly significant and is of higher magnitude than either of the zero order correlation coefficients.

The dependence of mold count upon moisture content is unique among the microbial characteristics studied. Not only were mold numbers greater in soils of higher average moisture content, but they also reflected seasonal differences in moisture content. Samples collected in September and April contained relatively more moisture and had a higher mold count than those collected in December and July.

It is obvious that, moisture contents being equal, the strictly heterotrophic molds should occur in greater numbers in soils with higher organic carbon contents. A correlation also exists between the mold count and other factors, i.e., total nitrogen content, expansion on wetting, moisture equivalent, pore space, etc., all associated with or affected by the organic matter content of the soil. None of these characters, however, was as closely correlated with the mold count as was the organic carbon content and,

while each may affect the mold population, it is probable that the primary function of organic materials is to furnish food for the microorganisms.

A reciprocal relationship exists between the pH values of soil and the mold numbers. Since molds are tolerant of a wide pH range, they may be expected to occur in greatest numbers where food is plentiful and competition with the acid-intolerant bacteria and *Actinomyces* is small. Within reasonable limits, however, it does not appear that the pH range controls the mold population, for the prairielike soils with pH values intermediate between those of the pine forest and oak-woodland podzols contained few molds in contrast with either of these. Similarly, the surface horizon of the shantung browns was more alkaline than that of the reddish browns, yet it contained an appreciably higher mold count.

Only preliminary attempts have been made to identify the mold genera in the soils tested. Members of the genus *Aspergillus* were most numerous in every soil examined; from 10 to 12 different species were observed. The genus *Penicillium* also was distributed widely and five or six different species were identified. Three or four species of *Mucor* were observed in humid soils from Mt. Graham. Members of the genera *Acrothecium* and *Helminthosporium* were found in two soils only and the genera *Rhizopus*, *Fusarium*, and *Trichoderma* in but one soil. Several other genera await identification. This work is being continued and more comprehensive information will be presented in a subsequent publication.

Aerobic cellulose-destroying bacteria.—The number of cellulose destroyers per gram of soil varied from 10 to over 1,200 in the A, from 0 to 612 in the B, and from 0 to 31 in the C horizons. These forms were practically absent at profile depths greater than 30 to 36 inches. Apparently, only a small percentage of the total micropopulation was capable of existing on cellulose as the sole source of energy.

Most striking is the fact that few cellulose destroyers were present in the soils highest in cellulose reserves but abundant in soils very low in these materials. The gray-brown podzols with the highest organic carbon contents contained the lowest number of cellulose destroyers per gram; and the red desert soils, with the lowest content of organic carbon, contained the largest population.

The data in Figures 6 and 7 show a striking correlation between the pH values of the soil and the number of cellulose-destroying bacteria present. The zero order correlation coefficient for this relationship was found to be 0.816 (with 0.250 being significant). It is evident that cellulose-destroying microorganisms, like other heterotrophic bacteria, prefer pH values near neutrality.

Except for the probably fortuitous reciprocal relationship between organic carbon content and the count of cellulose destroy-

ers, no statistically significant correlation could be shown between the cellulose-destroying bacteria and other soil properties.

Nitrifying bacteria.—The distribution of bacteria capable of oxidizing ammonia to nitrite and nitrite to nitrate was similar to that of the aerobic cellulose destroyers; they were few in the gray-brown podzolic-pine forest soils and numerous in desert soils. The nitrifying bacteria were more abundant, however, than the cellulose destroyers. The number per gram of soil varied from 3 to 10,500 in the A horizons, from 0 to nearly 3,000 in the B horizons, and from 0 to 2,000 in the substrata.

A highly significant correlation exists likewise between the pH values of the samples and the numbers of nitrifiers. The zero order correlation coefficient is 0.657 (with 0.250 being significant) which, though not so good as that with the cellulose destroyers, is highly significant.

In the surface horizons of the prairie soils the number of nitrifying bacteria varied from 12 to nearly 1,500; in the shantung browns, from 160 to 4,000; in the desert soils, from 20 to over 10,000. Rapid decreases in numbers with depth occurred in almost all profiles except 14 and 15; in the former, over 2,000 nitrifiers per gram of soil remained at a depth of 16 to 30 inches, and in the latter they actually were more abundant in the lower horizons. No explanation for these phenomena is immediately apparent from the foregoing observations. Little difference in pH value occurs between the samples of a given soil, and increases or decreases with depth are consistent within the great soil groups. The available phosphate (Table 7) was greater at lower depths, excepting surface soils, in profiles 14 and 15, but little correlation exists between phosphate content of surface soils and the number of nitrifying bacteria. The nitrifiers appear to be so sensitive to local conditions within the profile that it would be difficult to isolate one character and assign a cause and effect relationship to it. Moreover, it would be impractical to take a sufficient number of samples to isolate the character combinations which influence the number of nitrifying bacteria.

The results do show, however, that more nitrifying bacteria generally will be found in alkaline desert soils and closely adjacent areas, even though these soils contain less total nitrogen to supply ammonia and are subject to unfavorable moisture conditions much of the year. A highly significant correlation between pH value and number of nitrifiers as found in this study, together with field observations, indicates that the high acidity of humid soils prohibits an abundant growth of the alkali-loving nitrifying bacteria though other conditions may be favorable.

Rate of nitrification.—The activity of the nitrifying bacteria, as indicated by the rate of nitrification of ammonium sulfate, is significantly correlated with the number of nitrifying bacteria present—a relationship anticipated only in part. The zero order correlation coefficient for this relationship was 0.640 (with 0.250 being significant).

The correlation might have been higher had the entire curve and not a single point been used to measure the rate of nitrification. In addition, the figures in column 5 of Table 8 are estimates of the number of ammonia-oxidizing organisms present in the samples at the time of collection and necessarily reflect environments which change frequently with climatic conditions, hence are seldom comparable for any two soils at the same time. On the other hand, the rate figures represent the adaptation of the organisms to optimum growth conditions in the laboratory. One would not, therefore, expect a perfect correlation under these circumstances, since the two are not directly comparable.

Realizing the deficiencies of the method used for determining the rate of nitrification, the conclusions must be drawn with due caution. In general, the more acid the sample, the less rapid its rate of nitrification; and, conversely, the more alkaline the sample, the more rapid its nitrification rate. No ammonia was oxidized to nitrate in a 4-week period in the gray-brown podzolic forest soils, whereas nearly 30 per cent of that added to samples from profile 19, a red desert soil, was oxidized during the same period.

Nitrification rates were quite variable within the different soil groups. For example, only about 3 to 4 per cent of the ammonia was oxidized in profile 15, a red desert soil, and even less in the reddish brown, shantung brown, and gray-brown podzolic oak-woodland soils; whereas a larger percentage was oxidized in profile 19, also a red desert soil, than in any of the others.

The gray-brown podzolic oak-woodland soils showed high microbial activity throughout the study. These samples had the highest counts of bacteria and *Actinomyces* and the second highest of molds. They showed the largest accumulation of nitrate-nitrogen from naturally occurring nitrogenous compounds and were exceeded in nitrification rate only by samples from profile 19. Reddish brown, shantung brown, and prairie soils rated third, fourth, and fifth, respectively, in nitrification rate.

An interesting correlation exists between the rate of nitrification and the nitrate-nitrogen content following the 4-week incubation period in the untreated samples (Table 7, column 4). The small but significant correlation of 0.561 (with 0.304 being significant) exists between the two because of the close association of the two variables in the gray-brown podzolic and subsurface samples only. So far as the prairie, shantung brown, reddish brown, and desert soils are concerned, an inverse relationship exists; that is, decreasing amounts of nitrate-nitrogen tend to be associated with increasing nitrification rates. Such a relationship is logical, however, since those samples with the higher nitrate-nitrogen contents also had the higher total nitrogen contents. Though the speed of nitrification may vary in the different soils, it is only natural that after sufficient time those soils with the higher contents of oxidizable nitrogen should contain the larger amounts of the oxidation product—namely, nitrate-nitrogen. The

correlation coefficient for this relationship was calculated, however, and found to be nonsignificant.

Azotobacter.—The *Azotobacter* colonies per gram of soil varied from 0 to 10 in the A horizons, from 0 to 14 in the B horizons, and were essentially absent from the substrata. No colonies appeared on the nitrogen-free, selective agar plates sprinkled with gray-brown podzolic, prairie, or reddish brown soils, nor were the bacteria present in profile samples of either number 12, a shantung brown, or number 15, a red desert soil. Moreover, those colonies which did occur were not vigorous; they were dense, very opaque, and produced little gum. Nitrogen determinations were not made because past experience has shown similar colonies to be capable of but little nitrogen fixation.

It can only be concluded that none of the soils provides a suitable environment for the *Azotobacter*. Certain of the alkaline desert soils apparently allow survival, but under these conditions the bacteria probably fix little atmospheric nitrogen. This condition is in marked contrast with the vigorous activity of the nonsymbiotic nitrogen fixers in the cultivated soils of the state (47), often in fields adjacent to soil types sampled in this investigation.

SUMMARY AND CONCLUSIONS

1. The present study consisted of a description of representatives of the great soil groups of the United States which were found in vertical zones on Mt. Graham and vicinity in southern Arizona. Vegetation and climatic changes were correlated with the different soil types examined. Finally, profile samples were submitted to a physical, chemical, and microbiological analysis.

2. Gray-brown podzols of the *mor* type were associated with the coniferous forests of Douglas fir or ponderosa pine at elevations above 6,400 feet. In adjacent mountain meadows, prairielike soils prevailed. Associated with oaks and junipers in the transition zone from ponderosa pine to oak woodland (5,800 to 7,000 feet) were gray-brown podzols of the *mull* type. At lower elevations (4,800 to 6,000 feet) in the oak-woodland vegetation zone were shantung brown soils; in the desert-grassland area (3,000 to 5,000 feet) were reddish brown. Red desert soils were found on the desert (below 3,600 feet) in association with creosote bush, mesquite, burroweed, and other desert flora.

3. Thornthwaite's (77) P-E (precipitation effectiveness) and T-E (temperature efficiency) indices were calculated from rainfall and temperature averages for the different vegetation zones on Mt. Graham. On the basis of climatic types thus deduced, the soils on Mt. Graham and vicinity conform satisfactorily to the great soil groups of the United States.

4. Each soil sampled was tested for mechanical composition, suspension percentage, dispersion ratio, volume weight, total pore space, expansion on wetting, suction moisture equivalent, and water holding capacity. A wide range of values was obtained for

each of these properties, excepting mechanical composition which proved the textural class to be sandy loam for all but two of the soils sampled.

5. Aggregation of particles, as deduced from dispersion ratios, was highest in the acid prairielike and lowest in the alkaline desert soils; gray-brown podzolic, shantung brown, and reddish brown soils ranged in descending order between the extremes. Moisture and organic matter contents and pH values showed a highly significant correlation with soil aggregation, and to an extent, each exerted its influence independently of the others. High moisture and organic matter contents and low pH values were associated with greatest aggregation of small soil particles.

6. With increase in elevation, volume weights decreased while total porosities, moisture equivalents, and water holding capacities increased. These variables were significantly correlated with one another and with the organic matter and clay contents of the samples. The increase in organic matter content with elevation probably accounts for the elevation changes noted above; in the pedocal soils, clay content was a significant factor, its effect being particularly marked in the subsurface layers of the reddish brown and some desert soils.

7. Only in the case of the organic debris layers of the gray-brown podzolic soils and the high clay-containing subsurface layers of the reddish brown soils did marked expansion on wetting occur; in all other instances the correlation between either organic matter or clay contents and expansion on wetting was insignificant.

8. In marked contrast to that of the disturbed soils the expansion on wetting of the undisturbed ones was practically nil; results with other variables were comparable.

9. Chemical tests were made on each profile sample for pH value, carbon dioxide-soluble phosphate, nitrate, total nitrogen, and organic carbon, and the C:N ratio was calculated. In addition, the colloidal material was extracted from representative profile samples and subjected to a fusion analysis for silica and sesquioxides.

10. With increase in elevation, pH values decreased progressively. The desert soils were alkaline, wheras those from the coniferous forests were distinctly acid with average pH values of less than 5.5. In the prairie and the gray-brown podzolic soils, pH values progressively decreased with depth in the profile. In the shantung brown, reddish brown, and red desert soils, the subsurface horizons showed higher pH values than the surface soils. These groups correspond to the pedalfer and pedocal categories, respectively. Prairielike soils in mountain meadows showed pH values approximately 0.5 pH unit higher than adjacent gray-brown podzolic soils in forested areas.

11. All the profile samples contained little CO_2-soluble phosphate except the humus layers of the gray-brown podzols. In the remaining samples, correlation statistics showed higher phosphate contents to be associated with more alkaline pH values; red

desert, reddish brown, and shantung brown soils contained appreciably more phosphate than soils from higher elevations.

12. A striking difference between gray-brown podzolic soils of the *mull* and *mor* types was noted in these determinations. *Mull* soils contained larger amounts of nitrate-nitrogen than any other type soil tested. *Mor* soils contained no nitrate-nitrogen even though the total nitrogen contents were high. In the other soils tested, the amounts of nitrate-nitrogen were proportional to the amounts of oxidizable nitrogen.

13. Organic matter, as deduced from total carbon and nitrogen contents, increased progressively with elevation. Nitrogen was present in these soils in an amount equivalent to from 1/6 to 1/65 of the amount of carbon present. The C:N ratio was lowest in the soils from the arid desert and highest in the soils from forested areas. In each instance, the ratio decreased with depth in the profile.

14. The ratios of silica to sesquioxides were consistent with the results of other investigators for similar great soil groups and substantiate the designations adopted.

15. Microbiological tests were made on each sample for total numbers of bacteria and *Actinomyces*, filamentous fungi or molds, nonsymbiotic nitrogen-fixing bacteria of the genus *Azotobacter*, aerobic cellulose-destroying bacteria, and nitrifying bacteria, and in addition, a test was made of the nitrifying ability of the soil.

16. Gray-brown podzols of the oak-woodland type contained the largest number of bacteria and *Actinomyces* followed in turn by the shantung brown and the prairielike soils. Soils from the coniferous forest area and from the desert contained the smallest numbers of organisms.

17. Gray-brown podzols of the pine forest type contained the largest number of filamentous fungi followed in turn by the podzols from oak woodlands, prairielike, shantung brown, and finally the reddish brown and red desert soils which contained relatively small numbers of these organisms. Correlation statistics showed that the more abundant mold population of the soils from higher elevations on Mt. Graham could be attributed largely to the prevailing high moisture and organic matter contents of these soils. The fact that these same soils did not show larger numbers of bacteria and *Actinomyces* was attributed to their high acidity which would favor the filamentous fungi in competition for available food supplies.

18. The following mold genera were identified during the investigation: *Aspergillus, Penicillium, Mucor, Acrothecium, Helm-in-thosporium, Rhizopus, Fusarium,* and *Trichoderma.* Of these genera, species of the first two were most numerous.

19. Aerobic cellulose-destroying bacteria and nitrifying bacteria were found to be most abundant in the reddish brown and red desert soils which presented the least favorable environment with respect to moisture and food supply. They were essentially

absent from the gray-brown podzols of the pine forest type, which contained the highest consistent moisture contents during the year, the largest amounts of organic matter or cellulose, and the highest potential ammonia-producing capacities of any of the soils tested. It was deduced that the high acidity of the humid soils from the mountainous areas prohibited an abundant growth of the alkali-loving bacteria even though other conditions were most favorable. The activity of the nitrifying bacteria, as indicated by the rate of nitrification of ammonium sulfate, was significantly correlated with the number of nitrifying bacteria in the different soils at the time of collection.

20. It was concluded that none of the soils provided a suitable environment for the growth of *Azotobacter*. Certain of the alkaline soils from desert regions apparently allowed survival, but it appeared likely that the bacteria were capable of fixing little atmospheric nitrogen under these conditions.

21. This investigation of representative soil profiles from Mt. Graham and vicinity has shown that the successive soil types representing climatic variation between that of the cold, highly humid forest and that of the hot, dry desert are in conformity with the system of great soil groups. The general principle that the soil profile represents a summation of climatic, topographic, and vegetational factors which affect soil formation is substantiated and evidenced by the physical, chemical, and biological factors which characterize the profile.

22. The relationship of soil characteristics to vegetative cover herein enumerated should prove of value in the management of Arizona range lands.

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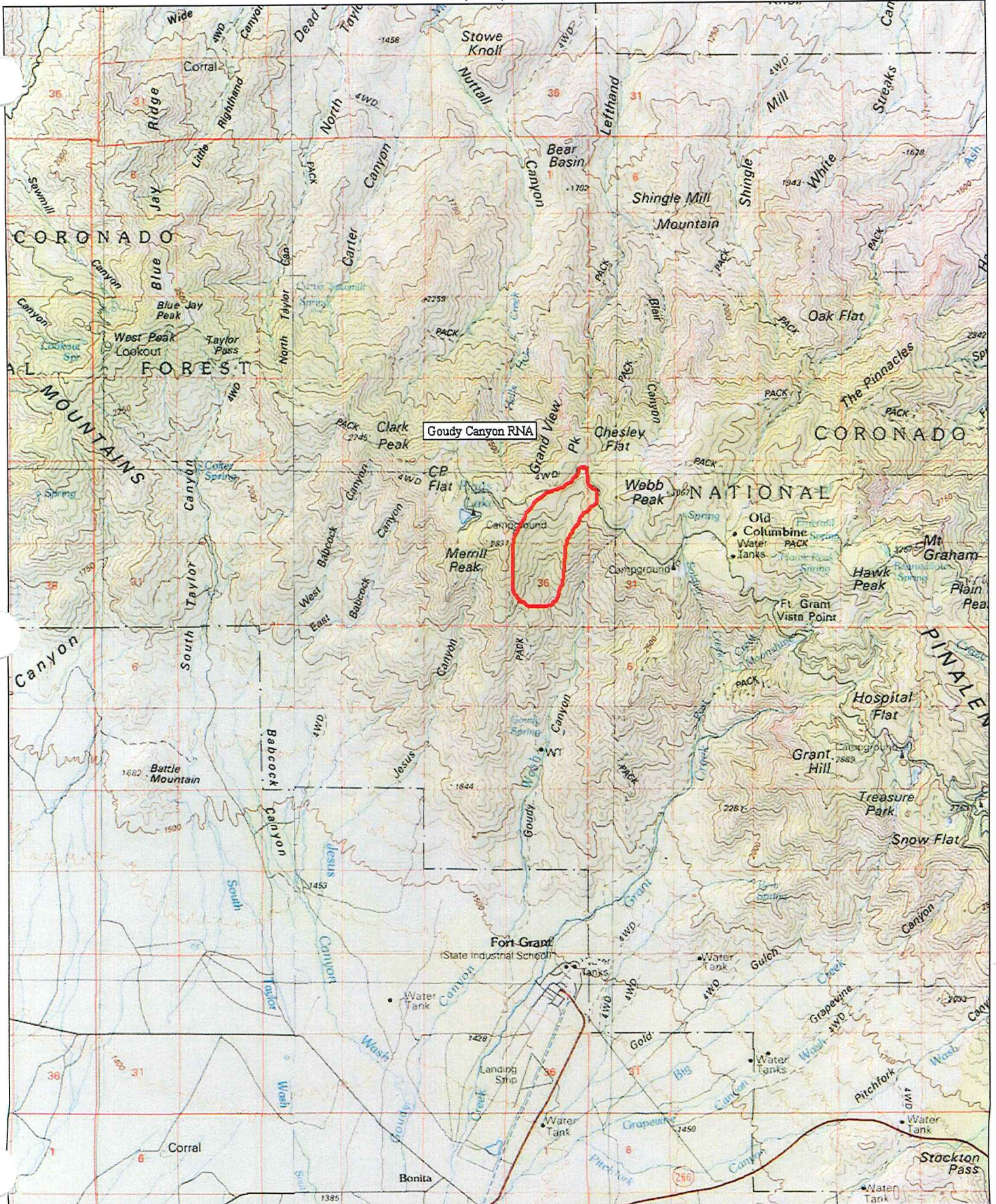
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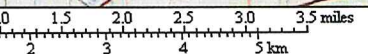   Eng. Chem., Anal. Ed., 7:227-30.

P I N A L E N O

SWIFT

CP Flat

4WD

Hells Hole

TRAIL

PACK

Canyon

Blair

8287

9518

Grand View
Peak

Chesley
Flat

M O U N

PACK

TRAIL

8983

8910

9173

4WD

TRAIL

9800

Lookout Tower
10000

Webb
Peak

9860

Goudy Canyon RNA

Riggs
Lake

Riggs Flat
Recreation Area

Peters
Flat

9804

Spring

9701

C O R O N A D O

9433

BM
9409

Merrill
Peak

9288

SWIFT

TRAIL

Soldier Creek
Campground

Soldier

941

9204

Canyon

7402

N A T I O N A L

F O R

TRAIL

PACK

Canyon

6845

Canyon

PACK

6704

8852

6812

8336

6563
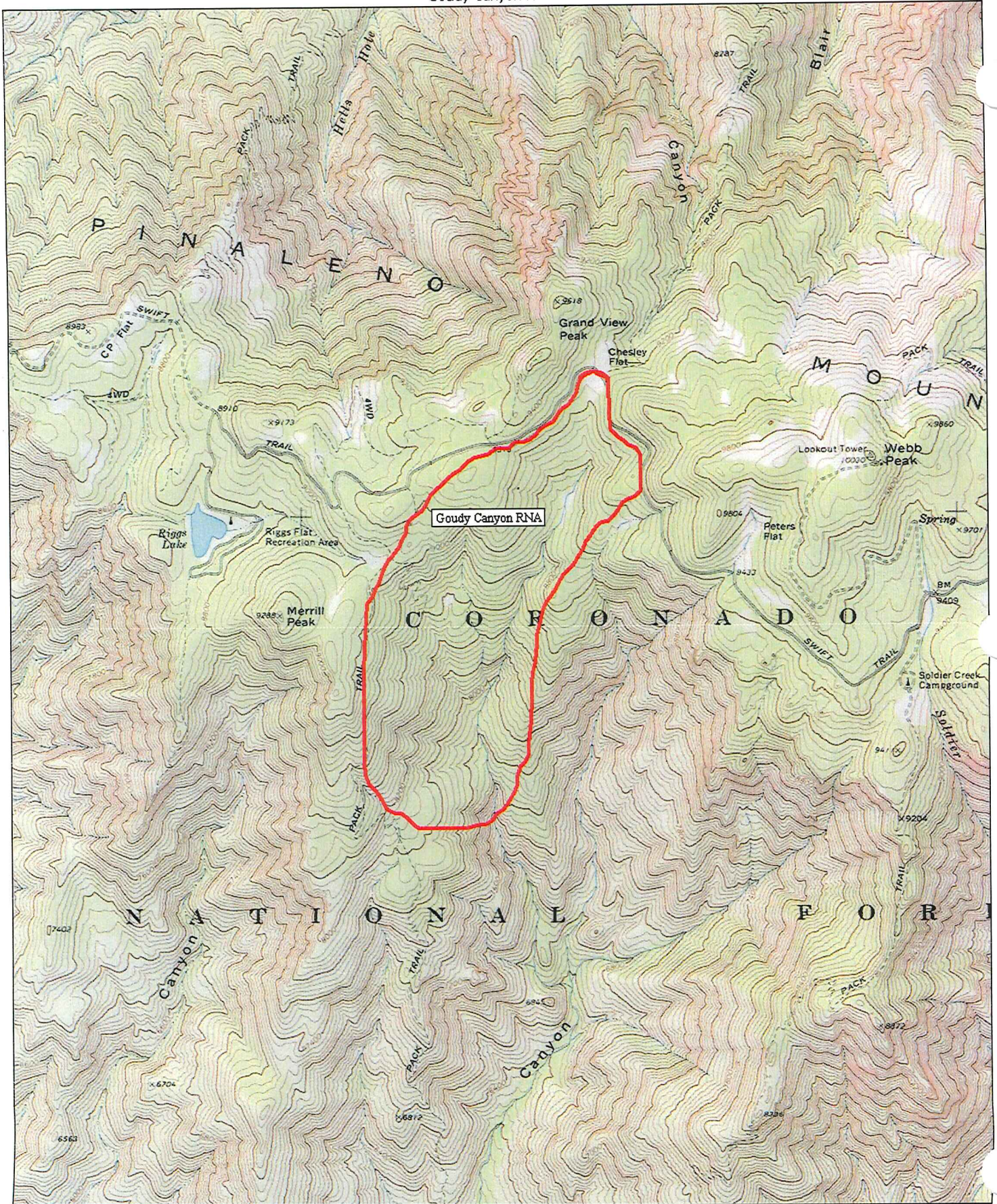
TN/MN
11°

0   5   1 MILE
0   1000 FEET   0   500   1000 METERS

Goudy Canyon RNA
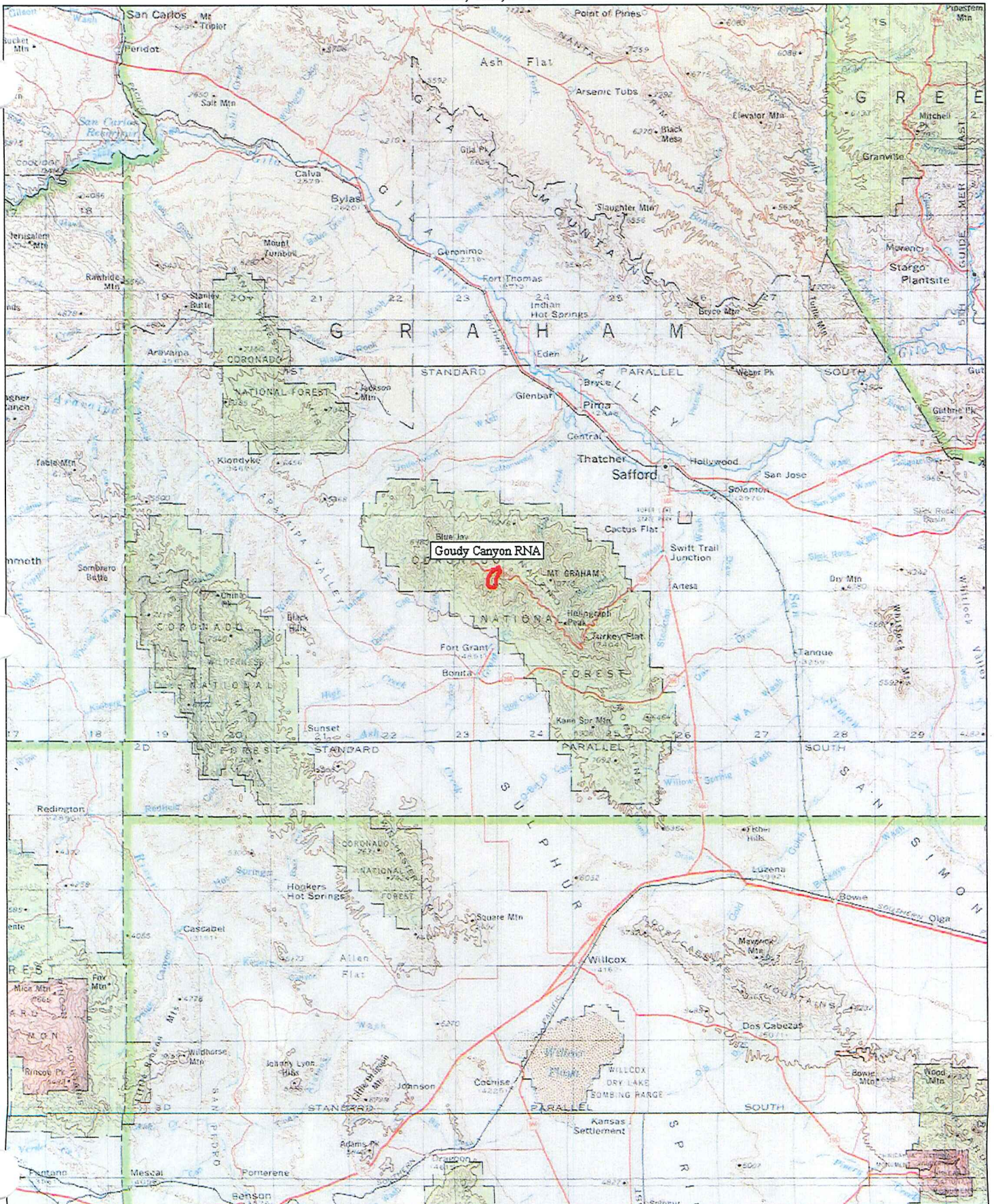
Commi   on Natural Areas

Proposed Natural Area

Name of Proposed Natural Area GOUDY CANYON

Location: State ARIZONA   County Graham

Nearest Town Safford, Arizona

Nearest Federal, State or county highway U.S. 666 and Ariz. 366

Permanence Afforded Through What Means   Regulation
(law, regulation, will, endowment, Board of
Directors, etc.)

Name of Administration Unit Mt. Graham Division, Coronado National Forest
(National forest, national park, national wildlife refuge,
State, university, etc.)

Listing of Timber Types on Area:

S.A.F. Type No.		Acres	Average Age
210	Interior Douglas fir	130	300 yr
237	Interior ponderosa pine	220	250
Mexican white pine		190	200
217	aspen	15	50
Barren, water, buffer zone, etc. grass		5	
	Total	560	

Range in Elevation: Low   7,500   Feet   High 10,000   Feet

Topography Steep sided canyon
(Level, rolling steep, broken, etc.)
Uplifting of intrusive rocks, Granitic and gneiss rock formation
Geology
(Volcanic, alluvial, moraine, etc.)

Average Height and Diameter of each major species:

Species	Average Height	Average Diameter
Mexican white pine (Pinus strobiformis)	70'	20"
Douglas fir	180'	36"

Submitted by Earl F. Aldon   Title Research Forester

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