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GEOLOGY

OF

THE PETRIFIED FOREST NATIONAL MONUMENT

By

Vincent W. Vandiver,
Regional Geologist,
National Park Service.

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CONTENTS

Page

INTRODUCTION 1

LOCATION 2

HISTORY 2

PHYSIOGRAPHY 5

CLIMATE 7

VEGETATION 7

POPULATION 8

GEOLOGY 8

- General 8
- Stratigraphy 10
- Moenkopi 11
- Shinarump 14
- Chinle 15
- Post Triassic 20
- Igneous Rocks 21
- Structure 21

PETRIFIED WOOD 22

- General 22
- Replacement 23

FOSSILS 24

- Plant Localities 25
- Invertebrates 25
- Vertebrates 26

ARCHEOLOGY 27

WATER RESOURCES 29

MAPS 31

MUSEUMS 32

PAINTED DESERT SECTION 33

ECW SEVENTH PERIOD PROJECTS 33

PLATES

Page

PLATE I....General Location Sketch 3

PLATE II...Colorado Plateau 6

PLATE III..Generalized Section 9

PLATE IV...Paleographic Map 13

PLATE V....Geologic Map 16

PLATE VI...Stratigraphic Column 19

PLATE VII..Fossil Localities 28

GEOLOGY
OF
THE PETRIFIED FOREST NATIONAL MONUMENT

INTRODUCTION

Approximately two weeks was spent in the field gathering data which is embodied in this report. Naturally in so brief a time it was impossible to endeavor to make the most detailed investigation. An attempt is therefore made to bring the essential facts to your attention relative to this important monument. The writer has reviewed much of the geological literature available on the general area and has used some of the material as deemed advisable. A summary of the references available is appended herewith.

The purpose of the study as developed with Mr. Earl A. Trager, during his recent visit, may be briefly summarized as follows:

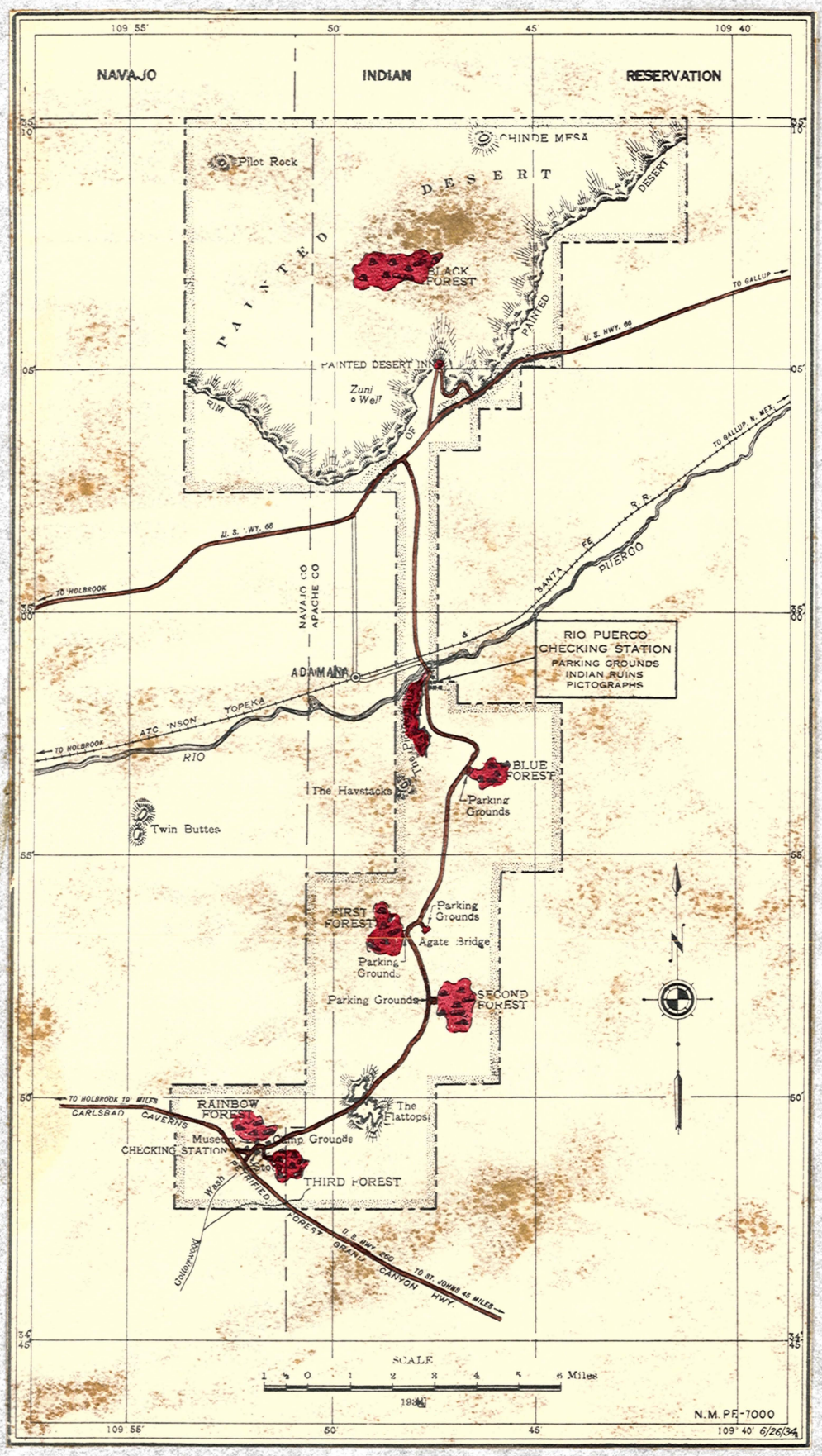
1. To consider the water resources of the monument.
2. To inspect the proposed Painted Desert addition and review plans for the utilization of same with the superintendent.
3. To make what recommendations possible relative to the development of the museum.
4. To ascertain possible future ECW projects to best demonstrate the geological features.
5. To have material available in order to write a comprehensive report for the information of visitors.
6. To make observations pertaining to the source of the trees now present in silicified form.

LOCATION

The Petrified Forest National Monument is situated in eastern Arizona, about twenty miles east of Holbrook, extending in a north-south direction along the Navajo-Apache County boundary line for a distance of approximately twenty-five miles. The monument is well provided with means of approach. U. S. Highway 66, the main route across New Mexico and Arizona, extends through the Painted Desert section. The southern portion is crossed by U. S. Highway 260 which extends northwest from Springerville, the connecting link with U. S. Highway 60. This southern approach is designated as the Grand Canyon-Petrified Forest-Carlsbad Caverns highway. A north-south road through the monument is maintained by the Park Service. This road, with numerous side extensions to points of interest, connects the two main avenues of approach mentioned and extends from the Painted Desert Inn to the Administration Building. (See Plate I following) The Atchison, Topeka, and Santa Fe Railway crosses the central section of the reserve. A station is maintained at Adamana, only a mile distant from the west boundary.

HISTORY

The first record of fossil wood in northern Arizona was recorded by Captain L. Sitgreaves, in 1851, during an expedition down the Zuni and Colorado rivers. He observed petrified wood six miles northwest of the mouth of the Zuni River near the southern boundary of the present monument. A. W. Whipple discovered the so-called North Forest in a


109 55'
50'
45'
109 40'
NAVAJO INDIAN RESERVATION
CHINDE MESA
Pilot Rock
DESERT
PAINTED
BLACK FOREST
TO GALLUP
U. S. HWY. 66
PAINTED DESERT INN
Zuni Well
RIM
OF
TO GALLUP, N. MEX.
U. S. HWY. 66
TO HOLBROOK
NAVAJO CO
APACHE CO
SANTA FE R. R.
PIERCO
RIO PUERCO CHECKING STATION
PARKING GROUNDS
INDIAN RUINS
PICTOGRAPHS
ADAMANA
ATCHINSON
TOPEKA
TO HOLBROOK
RIO
The Havstacks
BLUE FOREST
Parking Grounds
Twin Buttes
FIRST FOREST
Parking Grounds
Agate Bridge
Parking Grounds
Parking Grounds
SECOND FOREST
N
TO HOLBROOK 19 MILES
CARLSBAD CAVERNS
RAINBOW FOREST
The Flattops
Museum
Camp Grounds
CHECKING STATION
Stone
THIRD FOREST
PETRIFIED FOREST
Wash
Colorado
U. S. Hwy. 260
TO ST. JOHNS 46 MILES
GRAND CANYON HWY.
SCALE
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1934
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50'
45'
109 40' 6/26/34

Plate I.

traverse of northern Arizona in 1853. He suggested the name Lithodendron Creek for the northern tributary of the Rio Puerco because of the large quantities of silicified logs found there. J. S. Newberry in his report on the Colorado River, covering the Ives Expedition of 1857-58, describes the fossil wood observed at Ives Mesa and at Fort Defiance. The Powell and Wheeler surveys a few years later established the fact that the petrified wood accumulations were not local in character but were fairly extensively distributed throughout the plateau province. Interest in the preservation of the scenic and scientific features of the area in the vicinity of Adamana, where large accumulations of silicified wood occurred, led to the investigations by Lester F. Ward, geologist of the United States Geological Survey. In 1899 he submitted his report to the Department of the Interior with recommendations that the area be reserved as a national monument. This recommendation was carried out in 1906 when President Theodore Roosevelt issued a proclamation establishing the national monument. The present area contains 141.09 square miles (90,302.37 acres) if the proposed extension of the Painted Desert section is included.

The abundance of fossil wood in northeastern Arizona and southern Utah made a profound impression on the native tribes long before Capt. Sitgreaves' discovery in 1851. According to Doctor Gregory the Navajos considered the fossilized logs as "yeitsobitsin", the bones of "yeitso", a monster who was destroyed by the sun and whose blood was congealed in lava flows. In the Piute mythology the broken trunks are the spent weapons of Shinarav, the great Wolf God; the accumulated masses marking the sites of battle fields.

PHYSIOGRAPHY

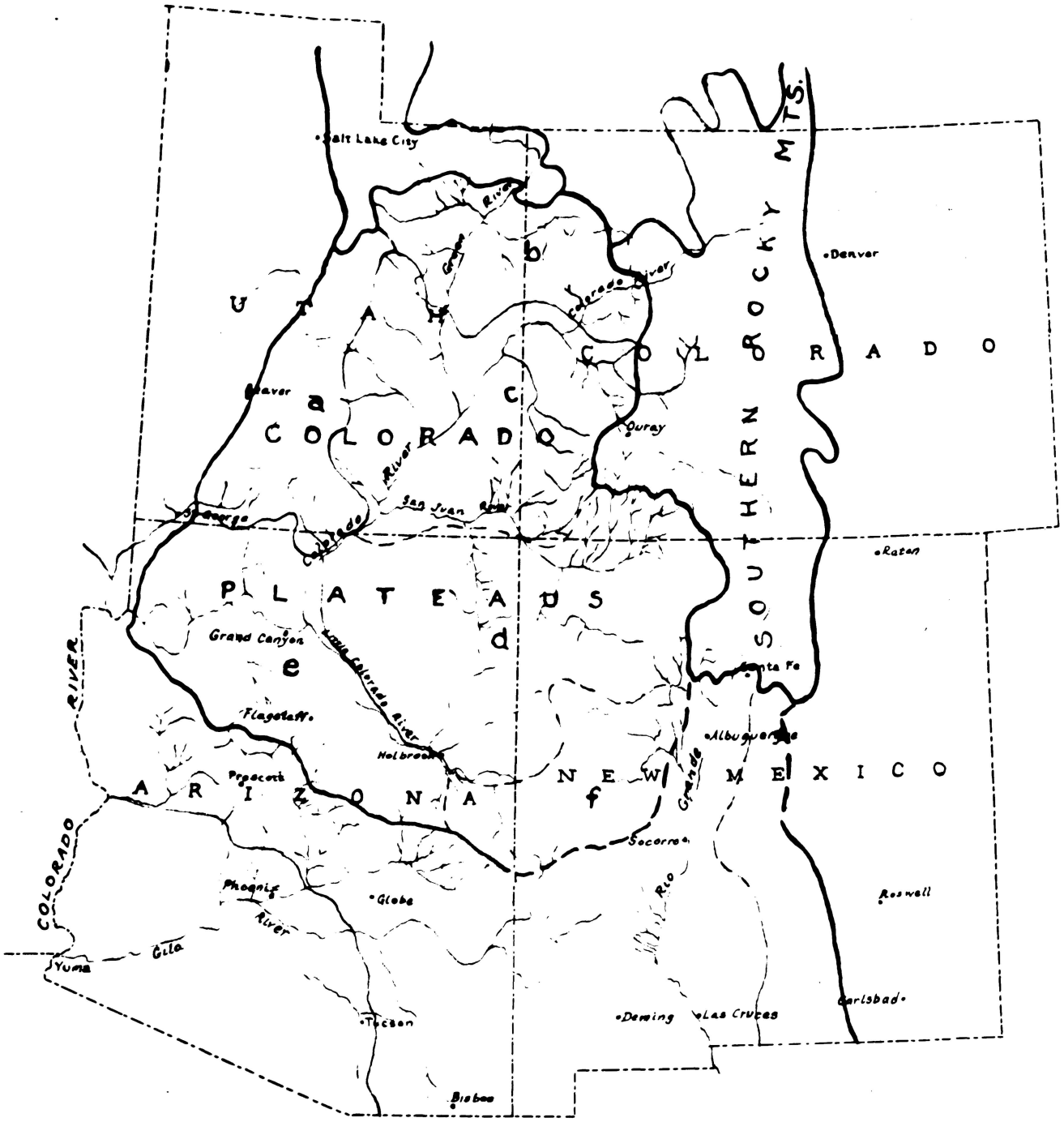
The Petrified Forest is located in the south-central portion of the Colorado Plateau. This large area, combined with the Columbia Plateau to the northwest and the Basin and Range Province to the west and south, makes up the great Intermontane Plateau which separates the Rocky Mountain System on the east and Pacific Mountain System on the west. A sketch map is included (Plate II) which indicates the major divisions of the Colorado Plateau Province. It may be noted that the monument is in the Navajo section consisting of young plateaus, of smaller relief than the Canyon section (c) to the north, into which it grades.

The Colorado Plateau generally is a region of many plateaus, broken by fault scarps trending north and south, by erosion escarpments trending east and west, and by canyons whose trends are in the main north and south with the exception of the Grand Canyon of the Colorado River. The general surface has an altitude of about 5,500 feet above sea level, above which the mountains rise and below which the canyons are carved. The varying character of the alternating sedimentary formations exert a strong topographic control. The massive sandstones and limestone members form vertical cliffs or level mesa tops while the shales produce slopes and local areas of badlands. Most of the Petrified Forest is occupied by these badlands carved in the Chinle formation.

The Colorado River is the master stream of the Plateau province. Drainage in the vicinity of the monument is controlled by the Little Colorado River and eventually reaches the Colorado proper. It is

THE COLORADO PLATEAU

From H. E. Gregory, U. S. G. S.



a. High plateaus of Utah. High block plateaus, partly lava capped, terraced S. side.
b. Uinta Basin. Dissected plateau; strong relief.
c. Canyon Lands. Young to mature canyoned plateaus; high relief.
d. Navajo Section. Young plateaus; smaller relief than (c) into which (c) grades.
e. Grand Canyon Section. High block plateaus, trenched by Grand Canyon.
f. Datil Section. Lava flows entire or in remnants; volcanic necks.

estimated that surface waters from 9,900 square miles reach the latter stream through the Little Colorado. Streams throughout the area are classed as perennial and intermittent. The Little Colorado River is intermittent through a large part of its course and receives no perennial through-flowing stream from its rather large drainage basin. In this section streams that flow in response to showers are the prevailing type.

CLIMATE

The climate of the Plateau country varies according to altitude from semitropical to temperate. The mean annual rainfall for Holbrook (elevation 5,069 feet) is approximately 9 inches. July and August are normally the wet months. Temperatures of from -25° to 127° maximum have been recorded in this area. The prevailing winds are from the southwest.

VEGETATION

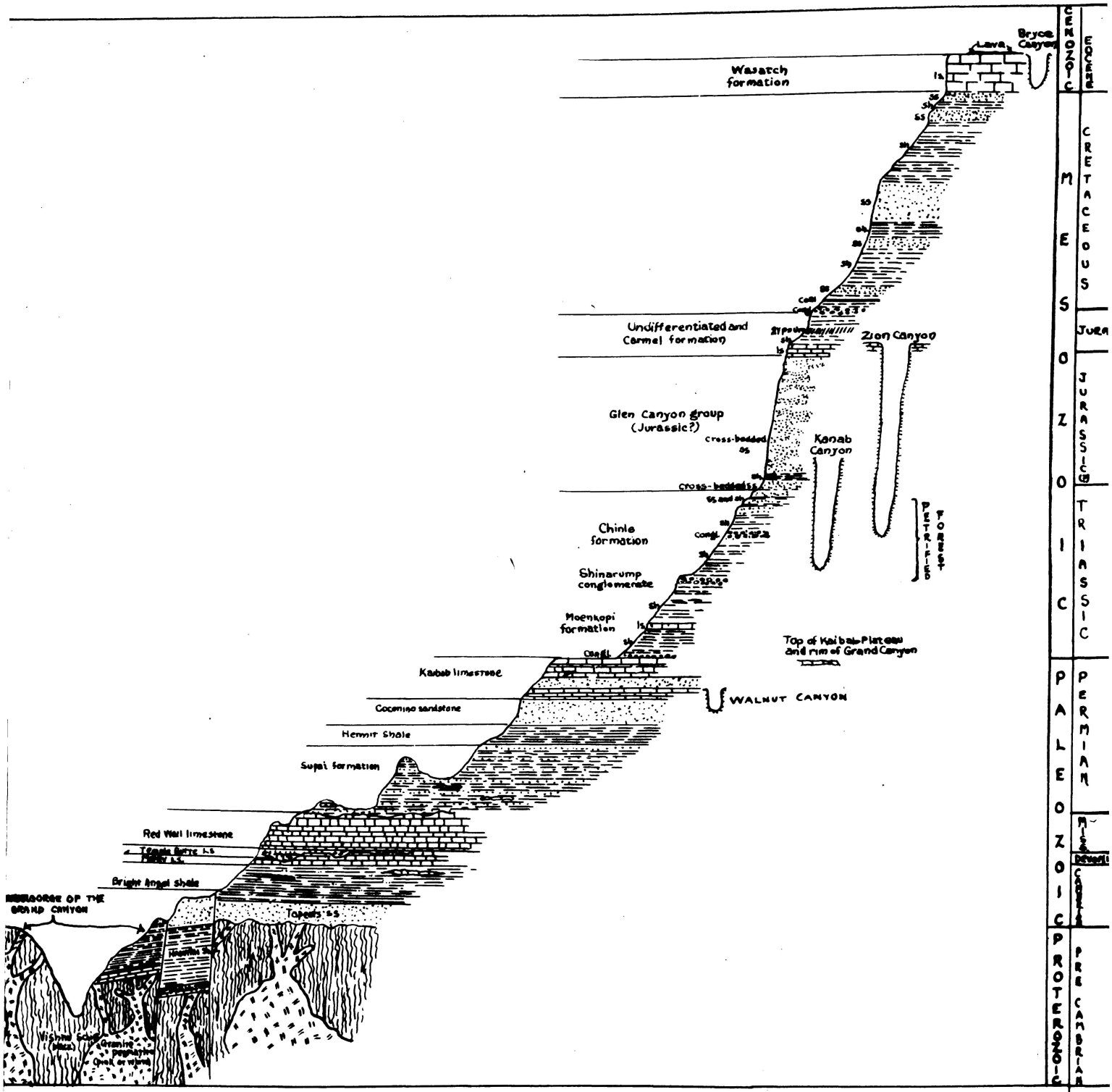
Where the badlands are not in evidence sagebrush, greasewood, and scattered clusters of juniper and pinon are present. Hardy grasses occur throughout the area. Much of the lands have been overgrazed and it is for this reason that protective measures have been taken. Most of the monument area has been closed to grazing and it is believed that this will result in a rejuvenation of the grass lands and in due course decrease the necessity for erosion control measures on a broad scale. The whole Colorado Plateau country is most suitable as a cattle and sheep range.

POPULATION

The nearest town of any size to the Petrified Forest is Holbrook, with a population of 1,115. The principal industry which sustains the settlement is stock raising. In recent years tourist travel has supplemented this industry. There is also considerable trade with the Indians of the Navajo and Hopi Indian Reservations a few miles to the northwest. The local Park Service staff secure their supplies at Holbrook. As there are no accommodations at the monument for the visiting park staff most of them secure quarters in town.

GEOLOGY

General. One of the most complete geological sections in the world may be observed in northern Arizona and southern Utah. In the Grand Canyon section rocks ranging in age from the Archean to the Permian are present with the exception of the Ordovician, Silurian, and Pennsylvanian. Northward from the Grand Canyon and above the 4,000 feet of Paleozoic section exposed here there may be observed some 8,000 feet additional of Mesozoic and Tertiary strata. Southeast toward the Petrified Forest and vicinity, the formations are none the less interesting, comprising a Mesozoic sequence of Triassic, Jurassic, and Cretaceous sediments. A geologic cross-section to illustrate the stratigraphy from the Grand Canyon to the Petrified Forest is being drawn by the writer. There follows on Plate III, page 9, a stratigraphic column showing the relative position of the Petrified Forest in the section as well as certain other parks and monuments of the plateau province.



Mesozoic and Cenozoic section from Internat. Geol. Cong. Guidebook 18, p. 13, 1932;
Proterozoic and Paleozoic section after Noble, L. F., U. S. Geol. Survey.

Approx. Vertical Scale
1000 Feet 2000 3000 4000

PLATE III

Stratigraphy. A discussion of the stratigraphy of the monument begins some 200,000,000 years ago at the close of the Permian (Kaibab) of the Paleozoic era which was followed by widespread emergence of the lands. The strata of the Petrified Forest area belong to the Triassic period of the Mesozoic era, forming a part of the huge region of continental Triassic extending through the Rocky Mountain region from Idaho to New Mexico. The Triassic, as now defined, includes three subdivisions: the Moenkopi formation, the Shinarump conglomerate, and the Chinle formation. Strata within the boundaries of the monument are all incorporated in the Chinle formation.

The Moenkopi beds contain fossils of Lower Triassic age. After the deposition of the Moenkopi there was an interval of erosion as evidenced by the removal of parts of this formation, beveling of beds, carving of channels and the changes in sedimentation that preceded and followed the erosion. Due to the stratigraphic position of the Shinarump conglomerate, unconformably overlying the Lower Triassic Moenkopi and below the Upper Triassic Chinle, its age is generally considered as Upper Triassic. Fossil coniferous wood of a species characteristic of the Chinle is abundant in the Shinarump. There are many conglomerate lenses of the Chinle which contain similar pebbles of the Shinarump as well as fossils of like character. There are breaks in the continuity of the Shinarump especially in the southeastern portion of its extent. In view of this evidence the writer agrees with Camp that it would probably be best to discard the name Shinarump and emphasize its true character - a basal conglomerate of the Chinle. It is, so far as is

known, conformable with the latter formation. The U. S. Geological Survey considers the Shinarump as a separate formation and it will be so used in this report.

Moenkopi Formation. As stated above in post Permian time there was a period of up-lift and erosion prior to the deposition of the Triassic sediments. There is widespread evidence of unconformity at the base of the Moenkopi. This formation consists of chocolate or reddish-brown sandy shale and sandstone with fairly uniform bedding planes. Many of the sandstone layers are ripple-marked and considerable evidence of current action is present in the form of cross-bedding. Gypsum occurs in crystals and in scattered irregular veins. Increasing towards the west there are prominent gypsum beds as well as marine fossil-bearing limestone. The Moenkopi is from 400 to 500 feet in thickness in the vicinity of the Petrified Forest. Its thickness decreases eastward and increases towards the west to as much as 2,000 feet in Nevada. It is evidently marine to the west and of lagoonal or deltaic origin to the east.

A complete section of the Moenkopi a few miles south of Tanner's Crossing by Gregory shows 389 feet of section consisting of alternating shales and sandstones, mostly red-brown to chocolate colored, the sandstones in members 2 to 5 feet thick and the shale members in bodies from 15 to 25 feet in thickness. There is a 40-foot shale member near the middle, below which are 52 feet of fine-grained sandstone. Some cross-bedding is in evidence and there are a few conglomerate streaks. Gregory states that there are so many variations in the stratigraphy that no two sections are closely alike.

Along the escarpment north of the Little Colorado River, just east of Holbrook, there are over 100 feet of Moenkopi exposed. Here the formation contains alternating beds of chocolate brown sandstones and shales in beds from a few feet in thickness up to 25 feet. There is much variation from place to place and it is exceedingly difficult to trace individual members over very long distances.

Fossils are quite rare in the Moenkopi with the exception of a few rather poorly preserved plant remains. Vertebrate and invertebrate tracks have been found. The latter were probably made by insects or worms. The vertebrate tracks are now referred to the Thecodonts, a group of primitive reptiles from which the crocodiles and dinosaurs were probably evolved.

Besides the traces of life the available evidence of the physical conditions during Moenkopi time lend much to a fairly complete picture of conditions. Various types of ripple-marked sandstones, casts of sun-cracked mud surfaces, rain drop impressions, etc., indicate a vast low flood-plain, oscillating back and forth over a semi-desert area through which temporary streams meandered, carrying loads of fine sand and silts. (See Plate IV following, illustrating land-sea conditions during much of Triassic time.)

Following the deposition of the Moenkopi formation there was a long interval of erosion that affected a large part of the plateau country. In northern Arizona erosion channels 50 to 100 yards wide and 20 to 100 feet in depth, carved in the Moenkopi beds, are filled with the massive grit of the Shinarump. Middle Triassic formations are known to the west

Paleogrephic map emphasizing the land-sea relations in the Rocky Mountain region during much of the Triassic. (From Branson and Mehl, Triassic Amphibians from the Rocky Mountain region). The source of the sediments comprising the Shinarump and Chinle formations of northeastern Arizona was from the old land mass southwest of the ward Arizona on the sketch. The pebbles in the Shinarump conglomerate become increasingly larger in this direction towards the Mogollon plateau where huge boulders may be observed in this formation. Kaibab (Permian) fossils found in the Shinarump and also in conglomerates of the Chinle in the vicinity of the Petrified Forest indicate a source in this direction.

Missouri, Univ. Studies, vol. 4, no. 2, 1929.

but are absent in this region. The amount of Lower Triassic deposits which have been eroded prior to the deposition of the Shinarump is not known.

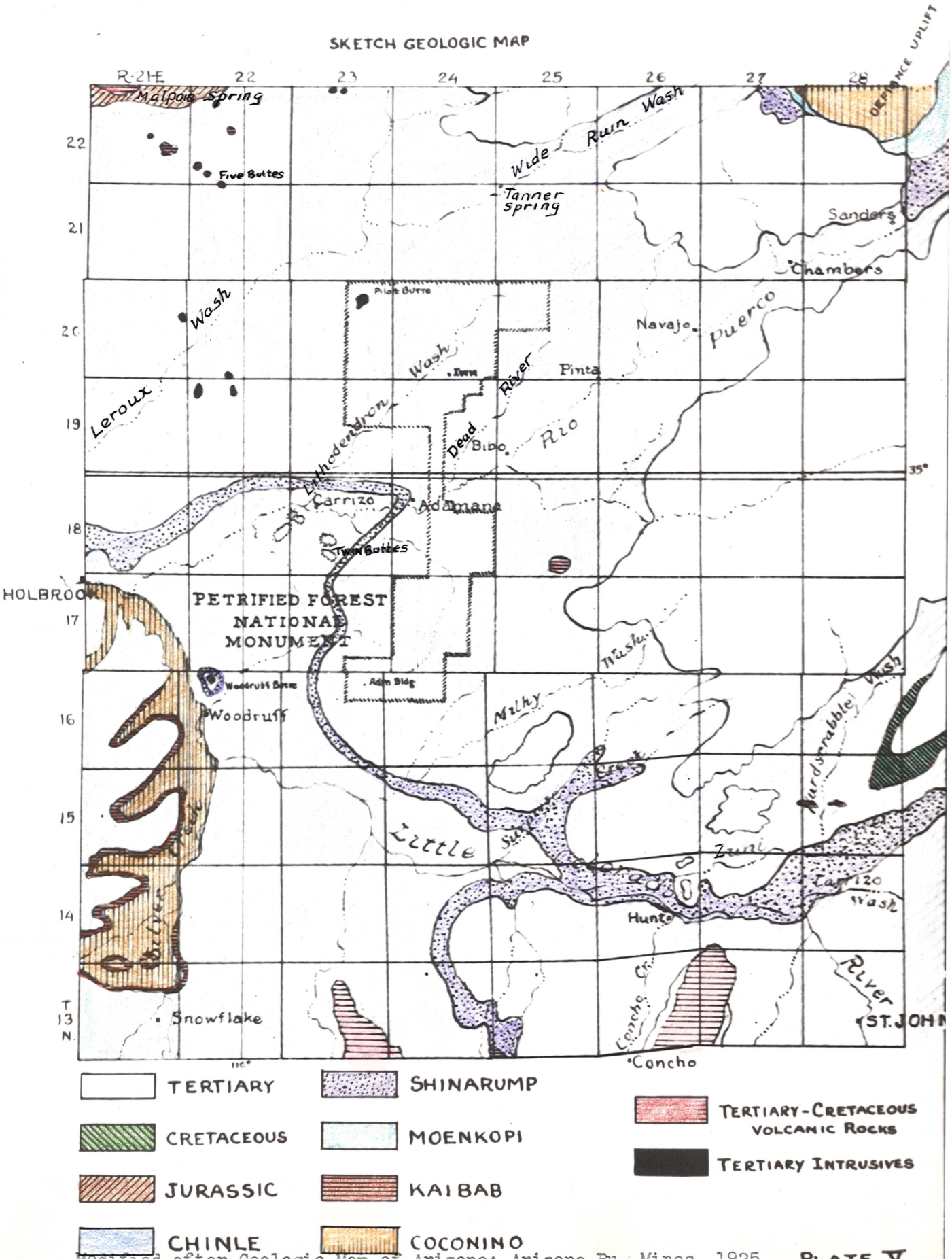
Shinarump Conglomerate. Unconformably overlying the Moenkopi and forming the lower member of the Upper Triassic is a stream-laid deposit, consisting of gravels and grit, now cemented into hard rock and known as the Shinarump conglomerate. Its thickness ranges from 30 feet to 100 feet or more. It is estimated that this deposit was spread over an area of not less than 75,000 square miles. Petrified logs occur at some places and the fragments of petrified wood are very common. This fossil wood is of a species characteristic of the Chinle above. Due to its position between two less resistant formations it forms prominent cliffs throughout the plateau province.

The Shinarump is almost wholly siliceous, usually grey to white, with shades of brown exceptional. In the area immediately west of the monument area there are some mottled yellowish beds containing lime. The pebbles ranging up to two inches or more in diameter are well rounded. The size of the pebbles increases to huge boulders southward towards the Mogollon plateau. They contain Kaibab (Permian) fossils similar to those in the conglomerate lenses of the Chinle above. The source of much of the material making up the Shinarump was probably from the south and southwest. (See Plate IV) The principal characteristics of this formation are that it is lenticular, cross-bedded, most variable in structure and texture and that it almost invariably contains fragments of fossil wood.

Branson states "There are numerous references in the literature to the Shinarump vertebrate fauna, but they are misleading, as they may designate either indeterminable scraps of fossils in associated beds. In the writer's experience much worn scraps of bone are common in typical Shinarump, but no specimens can be identified. It is probable that many finds reported from the Shinarump have come from conglomerate lenses in the Chinle." Brachiopods, crinoid stems, sponges, and bryozoa were observed in the pebbles making up the Shinarump. They have all been identified as Permian (Kaibab) in age.

A sketch geologic map follows as Plate V, page 16, showing the distribution of this formation in the immediate vicinity of the Petrified Forest. Time did not permit detailed mapping but the writer is convinced that there is no Shinarump within the boundaries of the Petrified Forest as shown on the State geological map of Arizona. Only the Chinle is present.

Chinle Formation. Conformably overlying the Shinarump is the Chinle formation which comprises the uppermost member of the Upper Triassic. Probably the most vivid feature of the terrain of northern Arizona is the display of colors in this mass of shales, sandstones, and limestone conglomerates. Much of the "paint" of the Painted Desert country comes from these rocks. Reds, browns, blues, and greys are paramount though almost any shade or color may be found over the wide expanse of outcrops to appeal to individual favor. The beds are frequently carved into badlands and the successive bands of color form a striking display



Modified after Geologic Map of Arizona: Arizona Bu. Mines, 1925. PLATE V

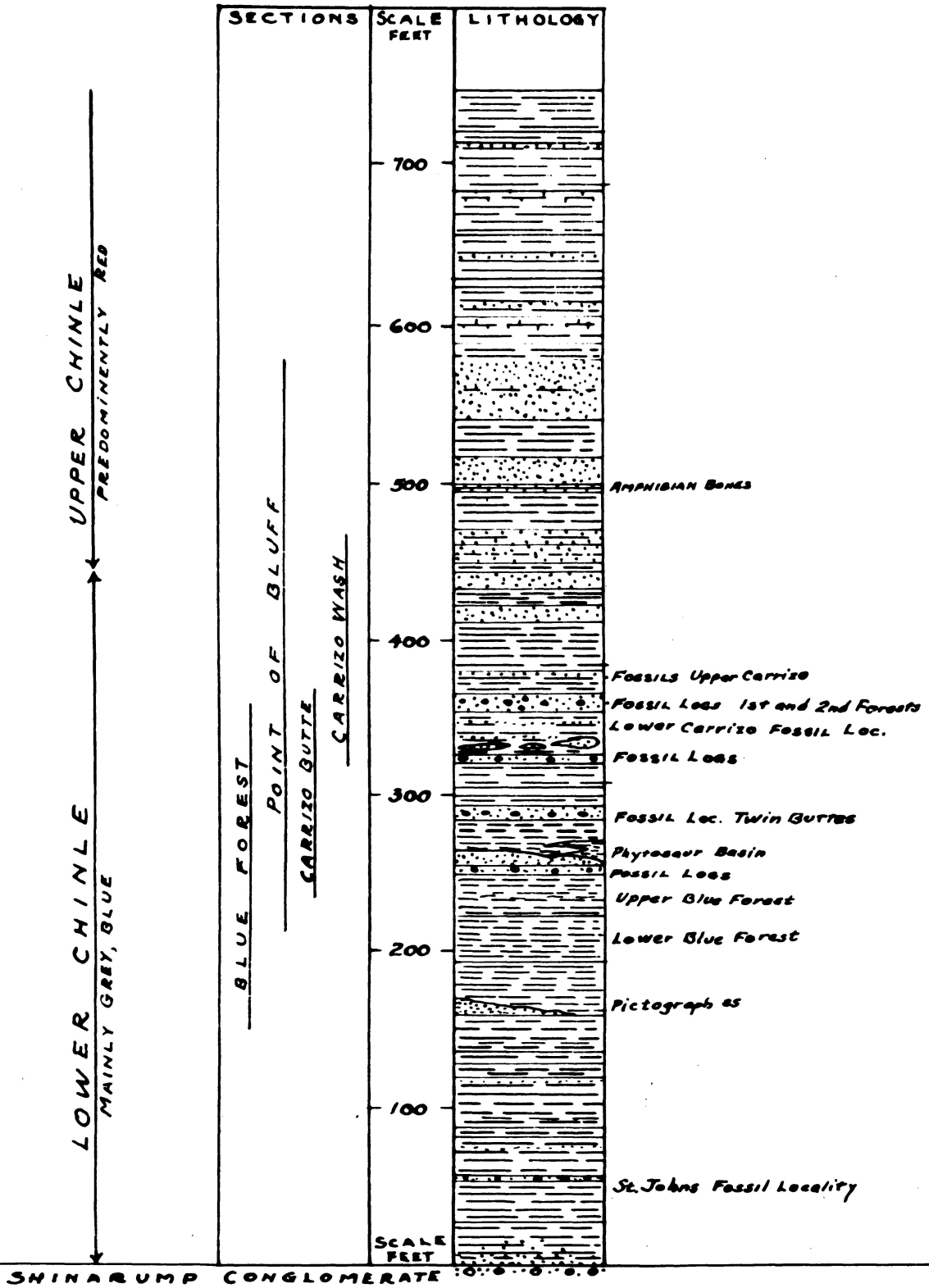
long to be remembered. The shales, especially in the lower part of the formation, include much volcanic ash or bentonite. Color, texture, and composition changes are indeed most frequent. The following is from Gregory and Moore's (15) report on the Kaiparowits Region: "In essentials the Chinle of the Kaiparowits Region is identical with that of the Navajo country, where this formation is thicker and more widespread and has been studied in greater detail. All types of rocks and of fossils are common to the two areas, and in a broad sense the arrangement of strata is the same. During Upper Triassic time the conditions of sedimentation appear to have been uniform over most, if not all, of the plateau province. Although as a whole the beds that compose the Chinle constitute a stratigraphic unit of unmistakable individuality, a comparison of the 16 sections measured in the Kaiparowits region makes apparent the wide variation in the order of deposition, composition, texture, color, and structure of the Chinle beds. Within an area of a few square miles all sections may show the same range of color and include the same kinds of rock, but the colors of individual beds are not persistent, and one kind of rock may be replaced by another kind within short distances along the strike. The relative amounts of limestone, shale, and sandstone differ with each section, as does also the position of these strata in the series. Moreover, the gradation in composition of the strata and their included lenses and accessory materials is such that no two workers are likely to describe the rock or to sub-divide the beds in exactly the same manner."

Gregory in his Navajo paper has distinguished four subdivisions for the Chinle in Arizona. For the Petrified Forest area it is difficult to recognize these subdivisions. In order for this to be done in a satisfactory manner it will be necessary to measure numerous sections from his type localities southeast to the monument area. The writer has considered two divisions of the Chinle as did Camp in his paper: "A Study of the Phytosaurs". See Plate VI on page 19 following for generalized columnar section. It will be noted that the Lower Chinle exceeds 400 feet in thickness, is characterized by more varied colors of grey and blue, and contains much ash. The Upper Chinle exceeds 300 feet in thickness, is predominantly red in color and contains limestone layers with chert which is absent in the Lower Chinle.

The thickness of the Chinle in the type locality, the Chinle valley to the north, is 1,182 feet. In general the Chinle may be said to range from 400 feet to about 1,000 feet in thickness. It is thickest in northeastern Arizona and southwestern Utah. The formation thins to the west and northwest and as to how much of this thinning is due to smaller original thickness and how much to erosion that preceded the deposition of more recent sediments remains to be determined.

When one considers the lithologic character of the Chinle, the local variations, bedding, and fossil content, it must be agreed that it is a fresh water deposit. It was independent of the sea and was spread by sluggish streams over a broad basin of desert-like character. Swamps and shallow lakes were present in the lowlands and on the higher

GENERALIZED STRATIGRAPHIC COLUMN — PETRIFIED FOREST



grounds surrounding the basins were scattered stands of conifers. To the west explosive volcanoes shed ash far and wide, as evidenced especially in the Lower Chinle. No marine fossils have been reported but instead there is found in abundance silicified wood and in places fresh water shells and bones of land vertebrates. The more or less gradational nature of the beds near the contact with the Shinarump conglomerate further indicates its continental origin. In nearly all exposures at the base of the Wingate sandstone (Jurassic), Chinle formation contact, there is an abrupt change of material, suggesting unconformity.

Post Triassic. In northern Arizona some 8,000 or 10,000 feet of sedimentary section has been measured above the Chinle formation to include rocks of the Jurassic, Cretaceous, and Tertiary. Doubtless several thousand feet of this material was once deposited over the area of the Petrified Forest covering the Chinle formation to a great depth. At the close of the Cretaceous there was a period of general uplift in this region followed by erosion on a large scale prior to the deposition of the Eocene above. After Eocene deposition and uplift, the present major lines of drainage were established, and erosion continued. Later uplifts made possible the final stripping of the Permian in the Grand Canyon section. At or near the beginning of the Quaternary the present canyon cycle was inaugurated by great general uplift. Thus through long periods of submergence, deposition, uplift, and erosion, Jurassic, Cretaceous, Tertiary, and Quaternary sediments have been deposited and removed by erosion. No doubt 5,000 feet or more of these

sediments once covered the monument area and have since been removed, exposing the present Triassic section.

Igneous Rocks. The two major volcanic fields of the plateau province include Mount Trumbull and the San Francisco Mountains. Large sections of Arizona are covered by volcanic rocks. It is generally assumed that the major portion of the materials came from eruptions during Tertiary times. There has not been sufficient study to date to make precise correlations. It is known that some are of Cretaceous age while others belong to the Quaternary. On the geological sketch map (Plate V) several areas of volcanic rocks are indicated in the immediate area of the Petrified Forest. The intrusive rocks consist of necks, dikes, and sheets. Extrusive forms consist of lavas and ash. Lava capping the Chinle may be observed in the Painted Desert section near the Inn.

Structure. Generally speaking the Petrified Forest is located in the broad structural basin between the Mogollon plateau on the southwest and the Defiance uplift on the northeast. Synclines and anticlines follow one another in this depression. There is little evidence of faulting in this district and it has certainly not played an important part as in the region to the northwest. Regional dips are northeast although along the crests of minor structures many variations may be observed. The cross-section upon which the writer is working will illustrate in graphic form the structural features better than most any description.

PETRIFIED WOOD

General. The Petrified Forest area was reserved by the National Government in order to preserve the most interesting feature of the Chinle formation - the fossilized wood. This reserve enables one to see one of the most unique exhibits of the national park chain and now added to the fossil wood and the numerous vertebrate fossil finds is the scenic Painted Desert section all of which will no doubt eventually place the monument in the sphere of a national park.

Three forms of trees have been described from the area as follows: Araucarioxylon arizonicum, Woodworthia arizonica, and Schilderia adamanica. It is peculiar that the two latter species have been found only north of the Rio Puerco, with the exception of a questionable specimen of Schilderia taken from the Blue Forest. Accumulations of fossilized wood occur mainly in the lower 400 feet of the Chinle with occasional concentrations in the Shinarump conglomerate below.

The source and manner of accumulation of large amounts of petrified wood in the Triassic sediments is not entirely clear. There are those who believe that the trees grew on the spot where fossilization took place and others who consider that they were transported hundreds of miles prior to petrification. There is very little evidence in the writer's opinion that the trees are actually in place. It is apparent that they did not grow in the immediate area in which they are found and that they have been transported some distance at least. This is especially true in the area south of the Rio Puerco. Here many of the trees have worn ends and battered sides and are mainly without bark.

Many sizes are bunched together in heaps with the blunt ends of one trunk inclined against the sides of its neighbor. Although there is an abundance of material for observation no roots were found extending downward from the stumps. It is possible that discoveries may be made to illustrate this feature but there should be many examples considering the amount of material to make it convincing.

In the Black Forest of the Painted Desert the writer is not so sure that the petrified wood is far removed from where the trees grew. Smaller parts of branches are more in evidence and there are many stumps apparently in an erect position. Excavation should be undertaken to ascertain the nature of their roots. Some of the larger stumps have lengthy roots attached and it is hard to believe that trees of this size could have been transported long distances with roots remaining intact.

For most of the forests it may be safely said however that the trees have been transported upwards to 50 or 100 miles. During Chinle time as sluggish streams meandered over broad basins, the higher lands with stands of conifers were flooded. The trees after falling were carried down stream, accumulating in eddies and sand banks, much like the driftwood now present along the Colorado and Little Colorado rivers. Several illustrations of the occurrence of petrified wood may be found in the photos attached.

Replacement. After the trees became lodged in sandbanks and were covered by sediments the process of replacement began. Most of the wood has apparently become silicified in its present location. The chemical process was favored by the rapid burial of the trees and the

free circulation of ground water in this type of sedimentary deposit. Deposition of dissolved mineral matter does not always take place in openings already present in the strata. Water frequently makes room for the substance deposited by dissolving matter already present, leaving behind an equal volume of another substance, deposited from solution. Waters permeating the stratigraphic horizons of the buried logs were probably alkaline, containing soda and potash. Silica is readily soluble in alkaline solutions. As the logs slowly decayed their organic matter was replaced, molecule by molecule, by silica mainly in the form of jasper and chalcedony. Some of the logs maintain the grey color of the sands in which they were buried, but most of them have been colored by iron and manganese, carried in solution by the underground waters and deposited at the time of the replacement of the organic matter by the silica, thereby supplying the beautiful variety of colors. Many brilliant tones of red, brown, yellow, and blue are present. Superoxidation of these minerals since the tree trunks have been exposed to the atmosphere has added much to the display of colors. The fragments are more likely to be colored throughout whereas on the larger trunks the most brilliant colors occur near the surface. The wood presents beautiful objects for study and when thin-sections are made and placed under a microscope they show the original wood structure perfectly, all cells being distinct, though now replaced by silica.

FOSSILS

The Triassic period, to which the rocksof the Petrified Forest belong, marks the beginning of the Mesozoic which was fittingly called by Louis

Agassiz the "Age of Reptiles" for the seas, lands and air were dominated by these monstrous creatures. Arid and semiarid climates were widespread although parts of the lands were well watered, much as parts of the present continents are humid.

Plant Localities. Besides the fossil trees just mentioned there is considerable evidence of plant life in the Chinle of the Petrified Forest. Within the Blue Forest fern leaves, cycad leaves, Equisetum stems and lycopod stems are present. Plant stems are found in a sandstone member near the ruins just north of the administration building. Casts of Equisetum stems also occur here. Approximately two miles south of Ortega's Ranch there are plant stems in a sandstone lense. Three miles west of the Blue Forest are leaves and cone scales. A study of the trees and plants of the forest has been made during the past two seasons by Lyman H. Daugherty, of the University of California, for his thesis. Specimens of some 110 ferns, cycads, etc., were turned over to him for study by the Park Service. It is assumed that his report will be forthcoming in the near future and that much new information will be developed. Mention should also be made of the huge casts of Equisetum stems present near Camp's quarry northeast of St. Johns. Most of these stems are in an erect position apparently in place.

Invertebrates. Unios (Pelecypods) were observed at several different localities. The best collecting grounds are in the Flattops locality, the ruins just north of headquarters, two and one-half miles southeast of Ortega's Ranch and three miles north and slightly west of

the Painted Desert Inn. Three species have been identified but, as there is little variation in this form until the Cretaceous, it is doubtful if they will be useful for correlative purposes and will prove little except the presence of fresh-water conditions.

Snails (Gastropods) have been found in only one locality to date. This is at the same location as the Unio locality mentioned above, three miles north and slightly west of the Painted Desert Inn. Mr. Walker, Park Naturalist, has loaned Dr. Junius Henderson, of the University of Colorado, Boulder, Colorado, a set of clams and snails for study and determination. His report should facilitate proper arrangement of these interesting forms in the museum.

Pebbles from the Shinarump conglomerate and from conglomerate lenses of Chinle have yielded the following Permian (Kaibab) forms: Bryozoa, (of Fenestella group); Productus (Dictyoclostus) occidentalis Newberry; Productus (Dictyoclostus) ivesi Newberry; Lophophyllum sp.; sections of crinoid stems; Aviculopecten occidentalis Newberry; Spiriferina kentuckyensis (?) fragmentary; and sponge sections.

Vertebrates. One of the most noted collecting grounds for Phytosaurus (Belodou), the large crocodile-like reptile, and the large amphibian known as the Stegocephali, with the shovel-shaped skull, is in the vicinity of the Petrified Forest. Fragments of bones of these animals are widely distributed but some of the more important localities where more or less complete specimens have been obtained are as follows: 2½ miles southeast of Ortega's Ranch, the Flattops, the Blue Forest, on the Carrizo

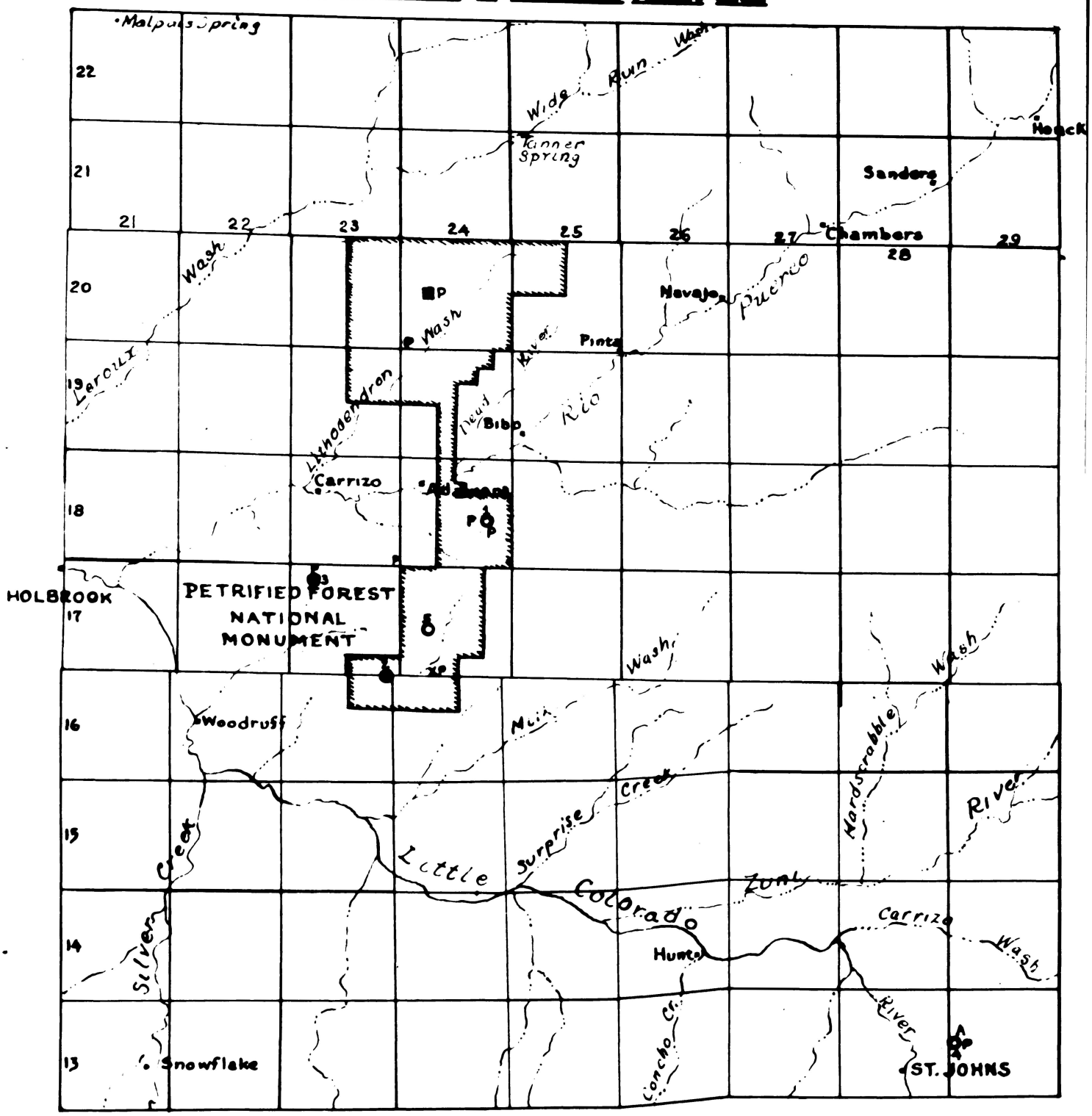
in the Painted Desert, 3 miles north of the Painted Desert Inn, near the Tepees of the Blue Forest many teeth are found with the bones, and in and around Camp's quarry northeast of St. Johns. At the latter locality there was recently discovered the remains of a large mammal-like reptile called an Anomodont. It has heretofore been known only from the Triassic of South Africa. This find is of much importance because of the evidence of the distribution of the type of animal from which the mammals were believed to have been derived. Specimens of Phytosaurus and Stegocephali are exhibited in the museum. This type of information has an intense public appeal and is of real scientific value. Too much emphasis cannot be placed on the development of this important feature -- the collecting and preservation of these rare vertebrate fossils.

The main fossil localities were visited by the writer. It was at first considered best to try and prepare some of these specimens in place for public view. It will not be possible to do this in most cases without a much larger ranger staff for their protection. The most satisfactory method will no doubt prove to be to show the material in a museum. Plate VII following on page 28 indicates the most important fossil localities of all kinds. Location of the fossil wood accumulations may be found on Plate I, page 3.

ARCHEOLOGY

Numerous ruins and pictographs of a pottery-making people are present in the Petrified Forest. The first of these are supposed to be of southern origin (Adamana). These were followed by another apparently from the same direction who met and seem to have merged to a

Fossil Localities of Petrified Forest Area



Q- Plants: In the Blue Forest are Fern Leaves; Cycad Leaves; Equisetum Stems (Horse Tail Branches) and Lycopod Stems. Plant Stems and casts of Equisetum are found at locality No.2. Stems of trees and plants at locality No. 3. Large Equisetum casts at St. Johns. Leaves and Cone Scales at locality No.5.

X- Phytosaurs were observed at these localities.

D- Dinosaurs are rather scarce and they were observed at only one locality.

P- Phytosaur and Stegocephalian bones are found at many places but the best localities for collecting are indicated on the sketch.

A- Ancestral locality. (Mammal-Reptiles). Only previous good material has been secured in South Africa.

certain degree with still another group from the north who made white or grey ware (Woodruff-Lino). Later the area was further subjected to influences derived from the north, east, and south and finally appears to have been abandoned during the Homolovi stage. This type of study is intensely interesting to a great many people and as the area was apparently on the border line of peoples of different origin it becomes all the more fascinating. These aspects may well be developed in the museum and supplemented by certain exhibits on the trails. It should be remembered however that this monument is primarily a geological exhibit and the archaeological features should not be permitted to interfere with this division. Exhibits showing the archaeology of northern Arizona and New Mexico are well displayed at the Museum of Northern Arizona at Flagstaff and also at Santa Fe, New Mexico, while the geological features of the Petrified Forest cannot be duplicated elsewhere.

WATER RESOURCES

The nature of the Chinle formation, mainly a fine-grained compact shale, precludes it as an important source of ground water. Locally some of the channel sandstones and conglomerates may prove productive. The Shinarump conglomerate is a good water bearer in some localities but due to its variable thickness and composition it should not be considered as an important source of water for the Petrified Forest. The Moenkopi sandstones and shales form a good reservoir and large quantities of water are obtained from this formation. However, due to its extreme saline content it is rarely potable. The Kaibab formation

below if present would serve only as a cap rock between the Moenkopi and the Coconino sandstone. The best water producing horizon thus far discovered in the region is the Coconino sandstone of the Permian. It is a wind-blown deposit of fine-grained sandstone, often firmly cemented, but containing several more porous beds which produce abundant quantities of potable water.

Plans were made in 1932 to drill a water well at the administration headquarters to produce from the Coconino sandstone. Estimates were made that the Coconino sandstone would be reached at a depth of 645 feet below the surface. According to the samples obtained the approximate correlation is as follows:

Headquarters Well Log - Petrified Forest

Elevation Approx. 5,475'

Chinle Formation.....	0 - 300	300	feet
Shinarump Conglomerate..	300 - 355	55	"
Moenkopi Formation.....	355 - 755	400	"
Kaibab Limestone.....	755 - 795	40	"
Coconino Sandstone	795--1023	228	"

Numerous drilling difficulties were encountered in this test. The casing was set at 745 feet. The casing is frozen and efforts to pull it have failed. There is 238 feet of open hole in this well which includes a section of the Moenkopi formation, a prolific saline water producer. The test at the Administration Headquarters is therefore not a fair criterion as to what the Coconino will do. The well was put on the pump and produced about 1,500 gallons per hour but was not of potable quality.

Several artesian wells have been drilled into the Coconino sandstone in the Petrified Forest area. The belief is current that satisfactory

supplies cannot be obtained from this formation north of the Little Colorado River. The entire area is in a large structural basin and no evidence of faulting was observed which might account for this condition. Briefly it is believed that the Coconino has not received a fair test and that regardless of local shallow water supplies developed it will be necessary eventually to drill to this formation with a satisfactory casing shutoff at the top of same. Logs of surrounding wells have been collected by Mr. Walker and the writer but it is not deemed necessary to include them in this report. They can well be summarized in a special water report when needed. In this connection Mr. Walker has written a detailed water report on the area.

At the present time the potable water is hauled from the Rio Puerco, a distance of 16 miles, to the Administration Headquarters and stored in a 1,500 gallon reservoir. This supply is obtained from shallow wells and is certainly surface seepage into a channel of the Rio Puerco. Surprisingly no analysis has been made of this water although it is used by the CCC camp and the park personnel. There are numerous washes where supplies of this type may be developed. Efforts should be made to give the Coconino sandstone a thorough test before depending on surface supplies of this sort. As to the location of such a test it will probably be best to await the completion of the master plans for the monument which would include the Painted Desert section.

MAPS

The topographic maps available for this region are of the editions 1886 to 1892 with contour interval of 200 feet on a scale of 1:250,000.

There is one sheet covering a limited area with a contour interval of 100 feet. The topographic relief in this section is so low that many of the most important features are not indicated. It is most difficult to locate accurately points on these maps. A satisfactory topographic map should becompleted of the Petrified Forest and surrounding area in order to facilitate detailed geologic mapping, the location of important fossil localities, and the construction of roads or trails or in fact most any type of construction within the monument.

MUSEUMS

Plans for museum construction have not been completed as yet due to the pending land situation at the Petrified Forest. When the additional acreage is obtained (the Lore property), which is the key to the development of this section, it is considered that the main museum should be located in the vicinity of the Painted Desert Inn. A museum at this point could be modelled somewhat after the observation station at Grand Canyon. Petrified wood should of course be featured with the scenic view of the Painted Desert emphasized as well as the fossil vertebrates found in the vicinity. Some space could be given to archeology but it is thought that a small museum on the Rio Puerco could best portray this aspect. The present museum could be used strictly as a geological exhibit and possibly a checking station combined. It will be necessary to have a checking station on highway 66, preferably at the entrance to the southern section, in order to contact the vast number of tourists along this main road.

The above museum setup is in line with Mr. Walker's ideas as to proper development. At the present time he is working over the exhibits

in the museum at the south entrance. No revision of the material has been made since the museum was installed and considerable work will be necessary to bring the situation in line with present ideas which are generally accepted.

PAINTED DESERT SECTION

Detailed plans for the utilization of this area have not been made because of the land situation. This part will form a valuable addition to the monument and the necessary acreage should be acquired. Two of northern Arizona's principal natural attractions would thus be combined under one monument -- the Petrified Forest and the Painted Desert. It appears that for this area which contains the interesting Black Forest very little in the way of trail construction or roads will be required. A trail down from the Inn may be maintained but when the flats are approached it is agreed that no construction should be undertaken and that visitors should be permitted to travel by foot or horseback for an inspection. Only a few directional signs will be required. The natural beauty will thus be preserved intact.

ECW SEVENTH PERIOD PROJECTS

The program for this period which involves geological features was discussed in detail with Superintendent Smith. He has outlined a proposed work schedule and it is assumed that you have received copies by this time. I would consider the following as noteworthy projects to be undertaken during this period.

1. Due to the varied opinion as to whether the trees have been transported or grew on the spot where they are now found, all possible

evidence pro and con should be assembled. Stumps in the Black Forest should be excavated to show the nature of the root structure, and to ascertain if possible as to whether they are in place. Similar work should be done in the area south of the Rio Puerco where trees and stumps are stated to be in place.

2. Mr. M. V. Walker, the Park Naturalist, is a trained vertebrate paleontologist. As has been previously stated, this area is a most important collecting ground for Phytosaurus and Stegocephali. The bones are weathering out of the Chinle at several localities and if they are not collected the specimens will deteriorate and be lost. Mr. Walker should be given time to collect and prepare these specimens for the museum while he is stationed at this point. The Phytosaur now on display in the museum which has been loaned by Camp is about 95% reproduction and is not at all impressive. The writer feels that this specimen should be returned to the University of California and one of the more complete specimens which Mr. Walker now has or that he may collect be substituted.

3. A natural open air theatre to seat approximately 600 people is proposed for this period. This is a desirable project and could be used as a point to conduct lectures on the monument during the summer months when the traffic is heavy.

4. It is proposed to build a 100,000 gallon reservoir near the present headquarters mainly for fire protection. This could well await the closing of the land deal in the Painted Desert section and the drawing up of the master plans for the whole monument. It is likely that

at this time a permanent water supply will be considered to drill a well to the Coconino sandstone.

5. Fencing as proposed Painted Desert section (south portion) will be necessary to protect the Black Forest from souvenir hunters and cattle..

6. Portals along highway 66 should be constructed to show the geological section.

7. The lookout tower for the rim near the Inn could be combined with the museum and observation station.

8. Informational signs should be added at strategic points. It is understood that there is some objection to having them placed along the main roads. Small parking areas might be established at these points. More interest might be had if contacts, erosional features and such were pointed out on the ground. Such things are usually missed as the limited personnel does not permit guided tours.

The heavy stone curbing now being installed along the main roads and at the parking areas is a rather drab sandstone and not very soothing to the eye in looking over the landscape. The curbing is probably necessary though it might have been better to secure a more pleasing type of stone even if more expense were involved.

The masonry steps near the administration building (see photo No. 8) forming a section of the loop trail through the Rainbow Forest are unnatural and probably not necessary. This type of construction detracts from the natural beauty of the monument.

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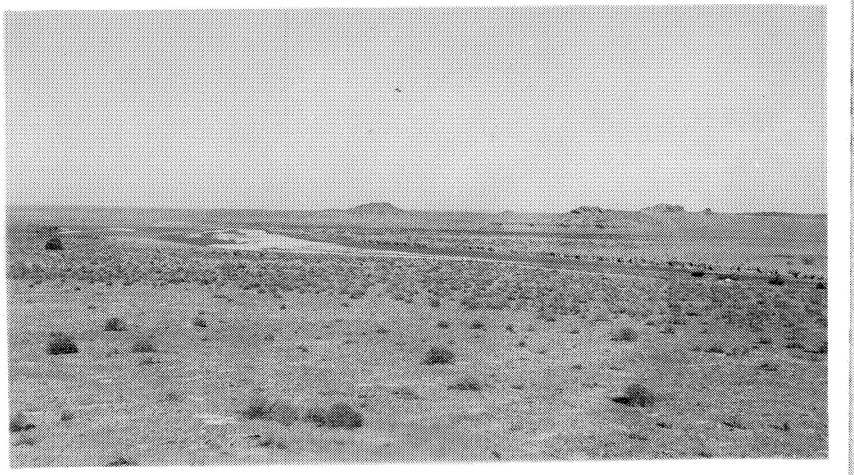
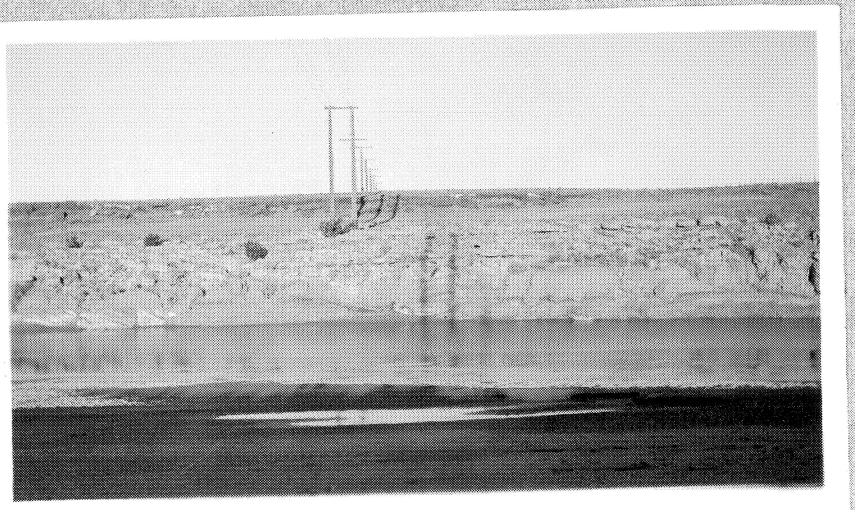


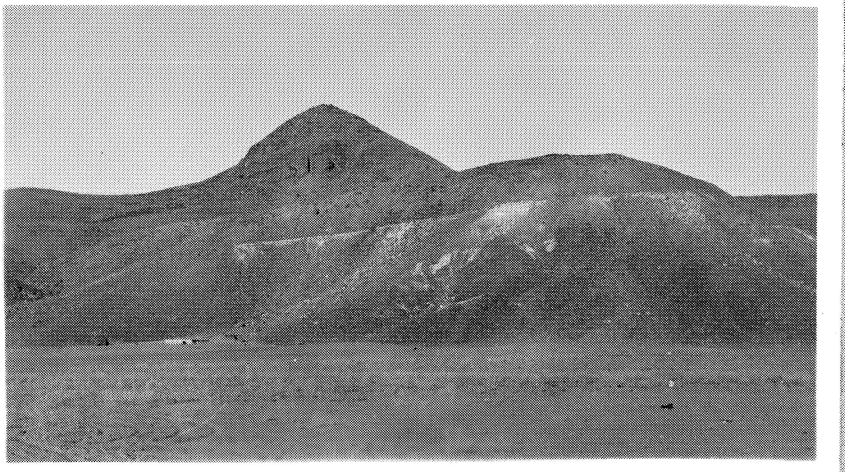
No. 1. The Little Colorado River valley immediately east of Holbrook and about 18 miles west of the Petrified Forest. This valley is carved in Moenkopi sandstones. The escarpment in the distance is of the same formation although capped by Shinarump conglomerate.



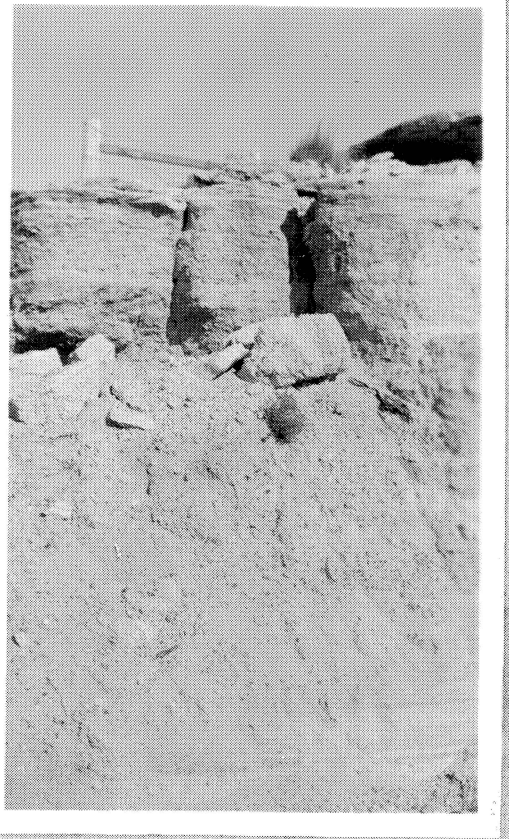
No. 2. Looking east across the Little Colorado River a few miles east of Holbrook and near highway #260 bridge. The telephone poles are set in cross-bedded Coconino (Permian) sandstones near the contact with a yellow sandy limestone, a few feet in thickness, which may represent remnants of the Kaibab limestone of Permian age.

No. 3. North of Woodruff Butte, on a tributary of the Little Colorado River, a section composed of Coconino sandstone at the base, possibly a few feet of yellow Kaibab limestone and above which is seen the chocolate brown Moenkopi sandstones.

No. 4. Woodruff Butte from the north. This landmark is situated 8 miles west of the southwestern boundary of the monument. Moenkopi, Shinarump, and Chinle sediments are visible on the flanks and they are in turn capped by basalt. It is likely that the source of the basalt is from a vent in the butte. This is the nearest volcanic material to the southern section of the monument with the exception of course to the bentonite in the Chinle formation.



No. 5. Woodruff Butte from the south. The sedimentary formations are more clearly visible in this photo than in the one preceding (No. 4). The basaltic cap may be plainly seen in the left center.



No. 6. A conglomerate bed in the Chinle formation. This outcrop is in a road cut on highway 260 near the western entrance to the Petrified Forest. From the state geological map of Arizona this bed was apparently considered Shinarump. The contact of the Shinarump and Chinle may be observed some 3 miles west on this highway. The intervening rocks are all Chinle. Kaibab (Permian) fossils were found in quartzite pebbles making up the conglomerate.

No. 7. The southwestern approach to the Petrified Forest on highway #260. NM-1 Camp may be seen in the distance to the right of center. The sediments visible are all of the Chinle formation and its variable character may be noted to some extent from this photograph. The Rainbow Forest is along the flats to the right.

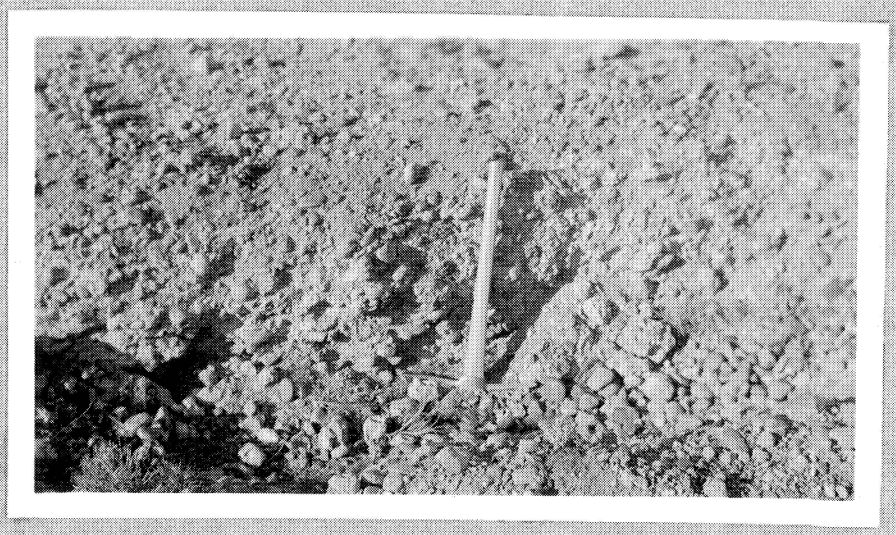
No. 8. At the top of the hillock to the right may be observed a section of the loop trail through the Rainbow Forest. A concrete stairway has been constructed at this point. It is plainly visible from the museum and administration headquarters as well as the road. A certain type of trail may have been desirable but this type leads to artificiality and should be resorted to only in extreme cases of necessity. In this instance the natural beauty of the landscape has been marred according to the writer's opinion.

No. 9. A view looking northeast from highway 66 toward the Painted Desert and the Navajo Indian Reservation. Pilot Butte is visible near the center. This landmark is at the approximate northwest corner of the Petrified Forest National Monument.

No. 10. Basalt capping a conglomerate lense in the Chinle formation, 16 miles northeast of St. Johns, and west of highway 81.

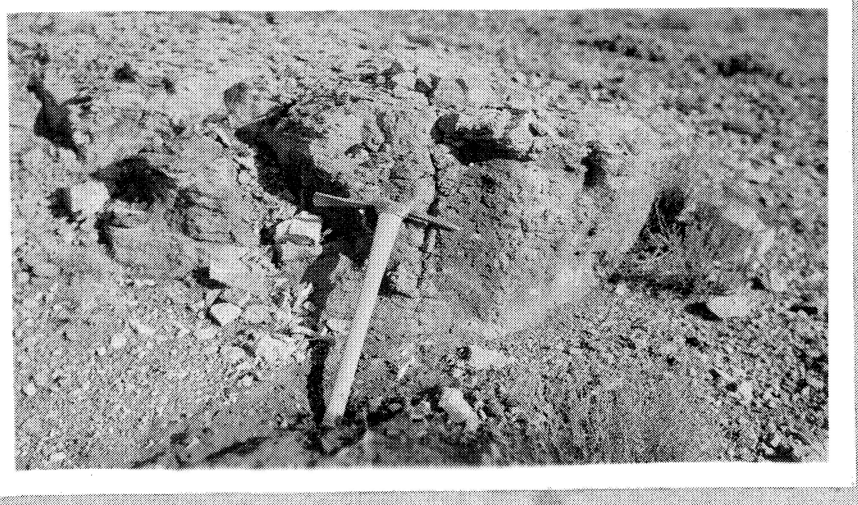
No. 11. The beautiful erosion features of the Chinle formation of the Blue Forest are in evidence in this photograph. The shales in this vicinity are of darker shades of blue, violet, and purple, presenting a real picturesque landscape. The beds are traversed by joints and cracks, running at all angles, and percolating water during storms finds its way through these crevices to a lower slope, eventually reappearing at the surface. Some of these crevices become rapidly enlarged resulting in surface funnels leading downward from the hillsides into open shafts and tunnels, a hundred feet or more in length. These funnel-cave systems are clearly visible in this photograph.

No. 12. Mottled pinkish grey sandstone beds of the Chinle formation in the Painted Desert section along Lithodendron Wash. The erosional forms in this area are indeed fascinating.



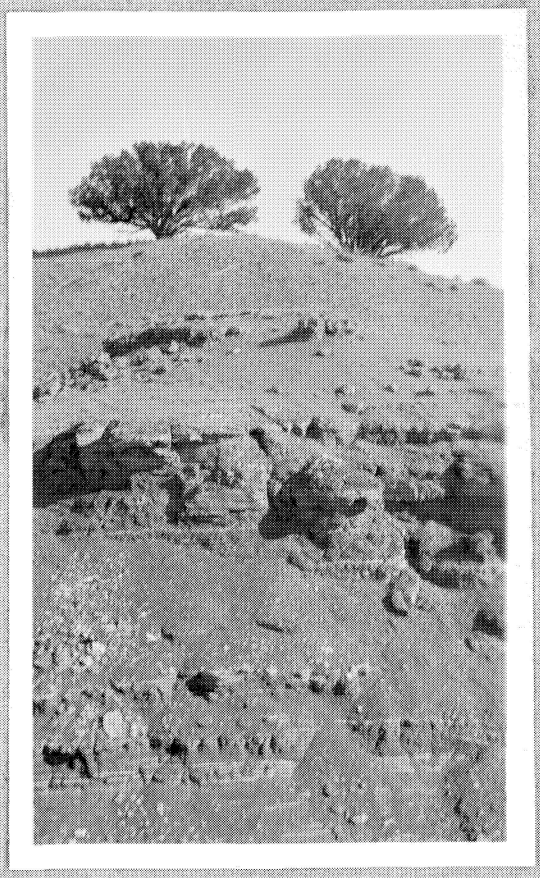
No. 13. Shinarump conglomerate in gravel pit along highway 260, 5½ miles west of the south checking station of the Petrified Forest. This outcrop is near the contact with the underlying Moenkopi sandstone and only a short distance from the overlying Chinle shales. The Shinarump occurs about 3½ miles west of the southwest boundary of the monument and does not outcrop within the reserve area as indicated on the state geological map of Arizona. The quartzite pebbles contain Kaibab (Permian) fossils.

No. 14. Shinarump conglomerate between Ortega's Ranch and Twin Buttes, taken about 5 miles northeast of photo No. 13. The formation in this vicinity presents a mottled aspect with considerable lime. The contrast with the underlying Moenkopi and the Chinle varicolored marls is readily observed.



No. 15. Shinarump conglomerate 13 miles southeast of the administration building on highway 260.

No. 16. Shinarump conglomerate just above the Moenkopi contact west of the Steel Bridge on highway 260, southeast of the Petrified Forest.



Nos. 17 and 18. These photographs show the variable character of the Shinarump conglomerate. Views taken 1 mile south of highway 260 and 19 miles southeast of the Petrified Forest. Some of the material is apparently reworked Moenkopi and these photos were taken near the contact with this formation.

No. 19. The famous Agate Bridge, probably the most noted petrified log in the world, is located just across the monument highway to the east of the First Forest. This log spans an arroyo some 40 feet in width and about 20 feet deep, forming a natural bridge. It is about 4 feet in diameter. Due to weathering processes and the work of souvenir hunters (prior to area being made a reserve) a concrete base for support has been installed.

No. 20. A natural bridge in the Black Forest (Painted Desert) section of the Petrified Forest.

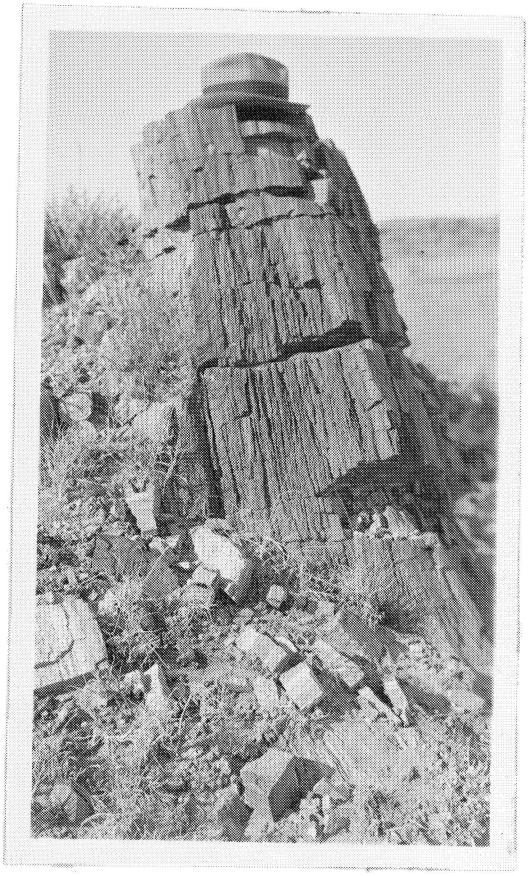
No. 21. The Black Forest Section of the Painted Desert looking northwest towards Pilot Butte. In this forest stumps are more in evidence than in other parts of the monument. Smaller parts of trees such as stems and branches are present. Roots may be seen on huge tree trunks which would seem to indicate that the fossilized trees grew in the immediate area.

No. 22. Petrified trees weathering out of the Chinle just north of the Rainbow Forest.

No. 23. Highly colored fossil wood of the Chinle near the western boundary of the monument in the vicinity of the Rainbow Forest. Upon first inspection it appears that the logs are oriented mainly in one direction, however, after looking over the various areas where the petrified wood is concentrated this does not seem to follow.

No. 24. Another view of the Black Forest. Trees attaining a diameter of 10 feet at the base with lengths exceeding 100 feet are not uncommon here. It is estimated that many of these trees stood 200 feet high.

No. 25. Woodworthia log in the Oak Forest just south of highway 66. The photo was taken to show the pitted character along the sides of the trunk but they do not show up very well. Log was placed in erect position.



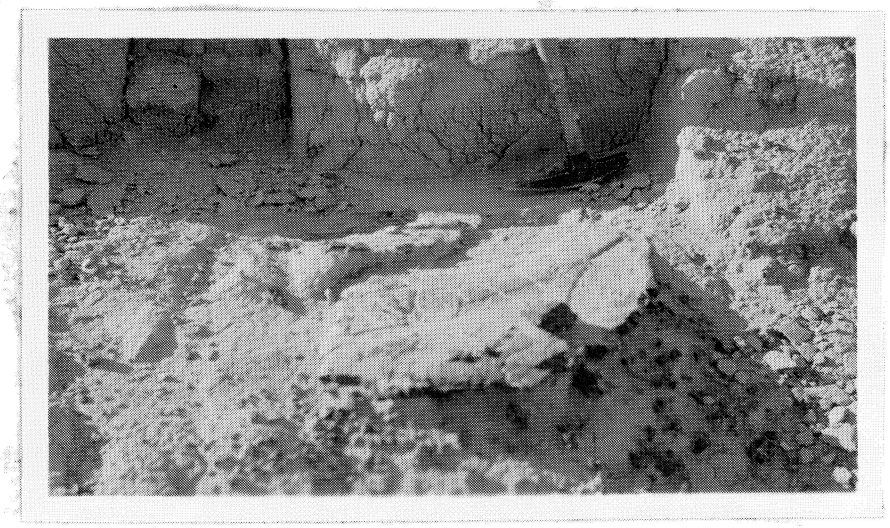
No. 26. Stump in the Black Forest which is more or less erect and seemingly very much in place. Excavations should be undertaken to ascertain the position of the roots of some of these stumps and endeavor to determine if they are actually in place.

No. 27. Stump which is partially erect in the Black Forest. Note the rather massive sandstone of the Chinle which has been washed in around the base, at a time when the tree was in a vertical position.

No. 28. Phytosaur Canyon of the Blue Forest where Charles L. Camp uncovered important fossil remains for his publication "A Study of Phytosaurs".

No. 29. Phytosaur bones weathering out of the Chinle, Carrizo Wash, Painted Desert section of the Petrified Forest. This photo shows clearly how the bones weather out of the soft shales and are lost if measures are not taken to collect them. Some of the best preserved specimens to be found in the United States, if not in the world, have been collected from this vicinity. Valuable scientific discoveries have been made and others are possible if proper research is carried on. Several of the most important Phytosaur localities are within the boundaries of the monument.

No. 30. Equisetum cast found in the Chinle formation east of St. Johns. These were large rush-like plants commonly known as horsetails. Many of the stems are eight to ten inches in diameter and some of them are apparently in place, that is, more or less erect, the sediments having been carried in and deposited around and over the plants, thereby entombing them.



No. 31. Stegocephalian bones in the Chinle formation at Blue Forest. These were primitive amphibian-like reptiles, six to nine feet in length, heavy, flat, and sluggish. Fragmentary bones and plates are widespread in the Petrified Forest and vicinity but complete specimens are rare.

No. 32. Gastropods (snails) have been found at only one locality in the Petrified Forest. This photograph was taken near Lithodendron, Wash, looking northeast towards Pilot Butte in the distance. The formation of course is Chinle and many gastropods may be collected here in a short time from a local lense in this formation. Large size molluscs also occur in this bed.