The Navajo Country occupies northeastern Arizona and parts of Utah and New Mexico. The eastern boundary of the region is the 108th meridian. The boundaries on the other three sides are the valleys of the large rivers — the San Juan, the Colorado, and the Little Colorado and Puerco, natural boundaries that have long been recognized by the native tribes, the whole area lying approximately between parallels 34° 55' and 37° 17' and meridians 108° 45' and 111° 45'. The region thus outlined contains approximately 25,725 square miles, or an area a little larger than Connecticut, Delaware, Massachusetts, Vermont, and the Panama Canal Zone combined. Of this vast area, 22,400 square miles, an area nearly as large as the Netherlands and Turkey in Europe combined, are held in reserve for the Navajos and Hopi Indians, though the Navajos extend their range to the very limits of the whole region.

For the purpose of administration the Indian lands are divided into the following reservations — the Hopi, Southern Navajo, Navajo Extension, Pueblo Bonito, San Juan, and Western Navajo — each in charge of a superintendent. The administrative centers are reached from the railway as follows: Tuba City, from Flagstaff, Arizona, 90 miles; Kayenta, from Flagstaff, via Tuba City, 165 miles; Shiprock, from Farmington, New Mexico, 35 miles; Pueblo Bonito (Crown Point), from Thoreau, New Mexico, 28 miles; Fort Defiance, from Gallup, New Mexico, 35 miles; Chinle School, from Gallup, New Mexico, 95 miles; Keams Canyon, from Holbrook, Arizona, 100 miles; or from Gallup, New Mexico, 107 miles; Leupp, from Canyon Diablo, Arizona, 12 miles. The Atchison, Topeka and Santa Fe Railway skirts the southern edge of the region from Winslow, Arizona, to Thoreau, New Mexico; and the Denver and Rio Grande corners it at Farmington, New Mexico. The larger part of the region is accessible only by trails. In the far-distant past nomadic tribes, followed by Basket-Makers and Slab-House peoples inhabited the land. Then came the Small-House, Cliff-House, and Pueblo peoples who literally swarmed the land; for their towns and small-house ruins and cliff-houses are as numerous over the whole region as farm houses dot central
Iowa today. When the white man came he found the Utes, Hopis and Athapascans in possession.

The first white people to visit the region were the explorers sent out from Zuñi by Francisco Vasques de Coronado in 1540. The first expedition, under Friar Juan de Padilla and Don Pedro de Tovar, passed through the region, presumably on the Ganado-Keams Canyon route, to the then seven Hopi pueblos in what was termed the Province of Tusayan, the Hopis making them presents of turquoise, corn, native fowl, piñon nuts, tanned skins, and cotton cloth. The second expedition, under Don García López de Cárdenes, followed the Hopi trail northwestward from Hopi and after marching twenty days they came to the great river — the Colorado, whose banks extended "three to four leagues in the air," and were "broken into pinacles higher that the tower of the Cathedral of Seville," they probably visiting it in the vicinity of

**GEOLOGICAL MAP**

**OF THE**

**UPPER BLACK MESA COUNTRY, ARIZONA**

![Map of the Upper Black Mesa Country, Arizona](https://scholarworks.uni.edu/pias/vol41/iss1/66)
Grand Canyon. Later on (1583) Antonio de Espejo and his companions likely visited the site of the present Tuba City, naming one of the springs "Ojo Trieste;" and November 17, 1898, Marcos de Los Godos, a captain under Oñate, and eight companions, discovered the Indian village of Moencopi, near Tuba City, which they named "Rancheria de los Gandules." In 1661, a Spanish soldier (?), Ghos by name, visited Inscription House, west of Marsh Pass, and left his inscription thus, "Ghos 1661 Ano."

In 1776, after a lapse of 200 years of desultory missionary and trading enterprises, both Fray Garcés and Padre Hernando d'Escalante Fontafieda visited the region as scouts of the church, the latter entering the region from Utah, crossing the Colorado at the "Crossing of the Fathers," named from his being the first white man to cross it there.

Many other explorers also likely visited the region without leaving a record of their trips, or their manuscripts still remain unpublished. And more recently, following the stage of time, Spanish explorers, detachments of soldiers, Mormon emigrants, and government scientific expeditions and prospectors have visited the country; while today the white population of the several reserved areas is a mere handful of missionary workers and Indian Service employes.

**Physical History**

The Navajo Country is part of the Great Colorado Plateau. In the main, it is a region of flat-lying or slightly tilted sedimentary rocks, cut by canyons and surrounded by volcanic necks, scattered mesas, isolated ridges, towering spires, and a bewildering array of buttes of both sedimentary and igneous origin. While recesses, alcoves, and miniature erosive forms of great variety and rare beauty dot the region on every hand, and dwindling washes follow tortuous courses to join their master streams.

Black Mesa, the Chuska, and the Segi Mesas are mesas of mountain size, modified by the folding of the strata and bordered by sheer cliffs of commanding proportions. While two other mountain masses, Navajo and Carrixo, are laccolithic in origin and rise like domes above the surrounding country.

Forty-two square miles of this region, mostly in the Navajo Mountain section, is above 9,000 feet in altitude; 260 square miles, between 7,000 and 9,000 feet; 8,231 square miles, between 6,000 and 7,000 feet; and 17,192 square miles are below 6,000 feet, the lowest altitude being 3,400 feet in the bed of the Colorado and the highest being 10,416 feet at the crest of Navajo Mountain.
view the region as a whole, it is a plateau whose general surface stands at an altitude of about 5,600 feet, below which the canyons are sunk and above which the mountains rise. In drainage, 1,880 square miles of the area are directly tributary to the Colorado; while 9,900 square miles drain into the Little Colorado, and 14,845 square miles, into the San Juan.

A short summary of the geology of this region is here given, from the Permian to the Quaternary; in but few places are there any other rocks exposed.

The Permian system is represented by the DeChelly sandstone series as exposed in the El Capitan-Monuments region, in the De-Chelly section and Fort Defiance plateau, and at several other places in the region. It is a thousand feet thick in the Canyon DeChelly section and in the Monuments, and 300 or more feet of the formation is exposed on the Defiance plateau. It is a massive, cross-bedded, and often strongly cross-laminated series. Cross-bedding, cross lamination to exaggeration, sweeping, interlocking curved bands and wide spread joints are characteristic features of the formation. This formation is underlain by the Moenkopi, also of Permian age, showing a thickness of approximately 700 feet.

Below the Moenkopi the Pennsylvanian is exposed in some of the canyons, especially in the Canyon of the San Juan and that

GEOLGY OF THE CORNFIELDS DISTRICT
AND
THE HOPI VOLCANIC BUTTES FIELD, ARIZONA

https://scholarworks.uni.edu/pias/vol41/iss1/66
of the Colorado, beneath which older rocks are exposed, or drilled into in drilling for oil. Drilling has also penetrated granite at several places on the Defiance plateau, north of Fort Defiance.

The Triassic is represented by the Doloresian series of Cross, the formations being locally designated as "Chinle formation," and "Shinarump conglomerate." The latter is the lowest member and is shown in exposures in canyons and in patches and wide surface areas on the Defiance plateau and in the El Capitan-Monuments' region. A few small patches are also met with elsewhere in the Navajo country. It is a grayish to whitish rock, varying from a pebbly conglomerate to a coarse grit or sandstone. It is firmly cemented and contains many fragments of silicified wood. It is a conspicuous marker and probably exceeds 50 feet in total thickness. While the Chinle formation, which is probably 600 feet in thickness, covers the inner valley of Pueblo Colorado wash from the reclamation dam and the Ganado Mission above Ganado southward throughout the region and is also the surface rock of all the southern part of the region. It is composed of limestone conglomerates, cherty limestone conglomerates, soft sandstone (often approaching the shaly stage), shales, and marls. This formation and the Shinarump conglomerate contain the petrified forests of the region, which are of such great interest to tourists.

The Jurassic sedimentation is represented by four distinct formations, as follows: The base is the massive Wingate sandstone, which is 300 or more feet in thickness, usually being composed of bright red to light red, massive, highly cross-bedded sandrock which is occasionally interbanded near the base with irregular white bands of a foot or so in thickness. This is followed in upward series by the Todilto limestone, interbedded with which there is a hard layer of reddish-white calcareous sandstone, containing numerous limestone "pebbles" the size of walnuts. The Navajo sandstone tops this and is very similar to the Wingate sandstone in make-up, but is much lighter in color, even being white in some locations. Its thickness exceeds 400 feet. The McElmo, which reaches a maximum thickness of 765 feet north of Cornfields and Sunrise Springs, north of Colorado Wash, is very variable in make-up, its cliffs of usually finely laminated, thinly bedded sandstone having a snow-bank whitish sheen in the moonlight.

The Cretaceous system is represented in the region by the following: The Dakota overlies the McElmo. It is several hundred feet in thickness and forms a band surrounding Black Mesa, as is the case with the next three formations to be described. It ter-
minates at the top in a yellow sandstone, which in places exceeds sixty feet in thickness and often forms the cap of outlying segments. Underneath this cap are 200 feet of white, slightly greenish, friable, lensy to hummocky, very variable sandstone and sandy shale, carrying an occasional coal seam, the shale carrying numerous plant impressions. The Tununk sandstone and shale series is intermediate between the Dakota and the Mancos, of probably 140 feet in thickness, containing numerous shells of *Exogyra columbia*, *E. laeviuscula*, *Gryphaea newberryi*, *E. suborbiculata*, and *Ostrea (Gryphaea) patina*. The Mancos, which contains various phases, principal of which are those of Pierre, Benton and Colorado ages, is over 500 feet in thickness. The Mesaverde formation is the rim-cap of Black Mesa, being composed of massive, coarse, often cross-bedded sandstone, shale and seams of coal, being about 300 feet in thickness. Topping Black Mesa, as later Cretaceous formations above the Mesaverde, are thinned out sections of the Lewis shale and Pictured Cliff sandstone, the Fruitland or Zilhlejini formation, and the Kirtland shale and Ojo Alamo sandstone. Here the Zilhlejini formation is composed of freshwater and brackish water beds, consisting of irregularly bedded clayey sandstone, clayey shale, and sandy shale in various degrees of definite shales and sandstones, interbedded with seams of coal, the coal of the whole Black Mesa series being estimated at eight billion tons. This formation, which exceeds 200 feet in thickness, contains beds and lenses of *Ostrea soleniscus*, *O. glabra*, and *Modiola laticostata*.

The Tertiary-Pleistocene (marked Tertiary on the map) is the surface rock in an irregular belt, from along the southwestern edge of Defiance plateau, twenty miles west of Fort Defiance, Arizona, westward to the west side of the Hopi Volcanic Buttes' field north of Holbrook. It also extends from Beautiful valley and the “foothills” of Black Mesa on the north nearly to the Santa Fe Railway on the south. It is composed of volcanic ejectamenta, interbedded with stratified stream and lake deposits. The strip of country which it covers, where it has not been removed by erosion, is 100 miles in length from east to west, with a varying width of from 20 to 70 miles from north to south; and, in the main, it is a sandy, rolling, badland country. It exceeds 300 feet in maximum thickness. One hundred and sixty feet from its top in White Cone Butte are numerous shells of *Planorbis trivolvis* Say and *Lymnaea stagnalis appressa* Say, both of Pleistocene (and present) age; while at the base of the formation, remains of the short nosed...
The Quaternary of this region (not mapped), which includes the recent, is composed of two series of material—dune material and valley fillings, which in places exceed 100 feet in thickness. In a bank of the latter (the valley fillings), one fourth of a mile east of Ganado, there was found the head and one tusk of a mastodon (*Mammut americanum*), same now being in possession of a Mr. Moss. Vertebrate bones taken from a terrace of these fillings at Shato Springs, west of Marsh Pass, belong to the Pleistocene genera *Elephas*, *Megalonyx*, *Equus*, and *Bison (?)*, bones of similar species being also obtained from the John Day spring at Tuba City. While in these fillings in the Segi canyons, west of Marsh Pass, Albert Smith found a molar tooth of an *Elephas*, now in possession of Mr. John Wetherill, at Kayenta, Arizona.1

The region is located in a belt of westerlies, on the northern edge of the world zone characterized by high pressure and consequent aridity. There is a winter season of cyclonic storms from November to March, the precipitation then being largely in the form of snow (or rain), coming largely with moisture bearing winds from the Pacific. The rest of the year the region is out of the usual path of cyclonic storms. The months from March to July are characterized by clear, dry, windy weather with warm days and cool nights. Some years there are occasional frosts even till the middle of June. In July clouds appear and from then on till September the hot mornings are followed by violent thunder showers, some where in sight if not in the immediate vicinity of the observer. The rainfall at this time of year is derived from the moisture of the western winds being augmented by moisture brought by winds from the Gulf of Mexico. This influx of warm, moist winds from the Gulf is due largely to the low pressure conditions over the hot, interior plateaus and the relatively high pressure over the Gulf. If crops can hold out till the rainy season sets in, in any region above 6,000 feet elevation, there is usually rainfall enough to mature them.

The temperature of the region varies with the altitude and is very variable, marked by sudden changes and wide fluctuations.

1 The tooth differs from a description or drawing of any molar tooth of any *Elephas* species so far described so far as the writer can learn. It is much narrower in cross-section than the tooth of *E. columbi* and also had finer plates and finer lamellae. The lamellae resembled those of *E. primigenus*; but the tooth itself differed much from the described teeth of that species. It was only about two-thirds as wide across the top of the crown and was more than a third longer from crown to root. It seemed to be a tooth of a species midway between *E. columbi* and *E. primigenus*, representing a mountain species of that family that advanced southward down the backbone of the continent as the glacial ice-sheet advanced. The writer suggests that it be named *E. primigenus*, var. *segii*.
In the valleys in summer it gets very hot; while on the mountains and mesas it is much cooler, to often very pleasant even on the hottest day. The nights are always cool, even in summer, and an intensely hot day may be followed by a rather chilly night; shade is synonymous with cold, sunlight with heat. The high temperature of a summer forenoon may be followed by a cold rain or a hail storm. When storms come the country is flooded; at other times the country is more or less a desert.

The places where meteorological observations have been continuously taken in the region are Hite, Utah, in the canyon of the Colorado at the mouth of Trachyte creek (elevation, 3,500 feet); Aneth, Utah, in the San Juan valley (elevation about 4,700 feet); Tuba City, Arizona, on the southeastern edge of the Kaibito Plateau, in the midst of a desert overlooking the Little Colorado (elevation, about 4,700 feet); Holbrook, on the Little Colorado (elevation, 5,069 feet); Fruitland, New Mexico, in the San Juan valley (elevation, about 5,200 feet); Chinle, Arizona, on the east side of the broad Chinle valley, at the mouth of Canyon de Chelly (elevation, about 5,200 feet); Keams Canyon, Arizona, in a narrow canyon out in the southern edge of Black Mesa, 100 miles from Holbrook (elevation, 6,600 feet); and Fort Defiance—St. Michaels, Arizona, on the Defiance Plateau, near the New Mexico-Arizona line (elevation 6,900 feet). On the following page are the average meteorological records of these stations for the past twenty years, ending in 1920.

The maximum annual range of temperature for the reserved lands is 118°, and the daily range about 40°. In 1905, 17.63 inches of rain fell at Holbrook and the precipitation of 1923 was even greater. While at Fort Defiance a rainfall of about 20 inches fell in 1911. The average rainfall for the whole area is a little less than a foot per annum. The growing season in days at each of the meteorological stations above is as follows: Hite, 124; Aneth, 161; Tuba City, 133; Holbrook, 127; Fruitland, 161; Chinle, 124; Keams Canyon, 105; and Fort Defiance, 97. The bearing of these figures on irrigation and agriculture may be readily seen, from the fact that corn requires from 90 to 150 days to mature and fruit an even longer period.

The soil of much of the Navajo country is weathered country rock, limestone and lime cemented sandstone, and dust particles from volcanic calcareous and argillaceous rocks blown over the valleys by the wind. Alkali is present occasionally but usually not in damaging quantity, to take the region as a whole. Buried organic
<table>
<thead>
<tr>
<th>Place</th>
<th>Mean summer temp.</th>
<th>Mean lowest summer temp.</th>
<th>Mean temp. May to Sept.</th>
<th>Mean winter temp.</th>
<th>Av. lowest winter temp.</th>
<th>Mean An. rain fall</th>
<th>Av. date of first killing frost in the fall</th>
<th>Av. date of last killing frost in the spring</th>
<th>Earliest date of killing frost in autumn</th>
<th>Last date of killing frost in spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hite</td>
<td>78.3</td>
<td>62.</td>
<td>75.4</td>
<td>35.5</td>
<td>5.0</td>
<td>6.94</td>
<td>Oct. 20</td>
<td>March 20</td>
<td>Oct. 19</td>
<td>May 24</td>
</tr>
<tr>
<td>Aneth</td>
<td>76.</td>
<td>42.</td>
<td>71.7</td>
<td>30.6</td>
<td>-3.3</td>
<td>4.97</td>
<td>Sept. 21</td>
<td>April 13</td>
<td>Sept. 12</td>
<td>May 13</td>
</tr>
<tr>
<td>Tuba City</td>
<td>74.3</td>
<td>41.</td>
<td>70.3</td>
<td>33.9</td>
<td>-7.6</td>
<td>5.4</td>
<td>Sept. 22</td>
<td>May 13</td>
<td>Sept. 19</td>
<td>June 6</td>
</tr>
<tr>
<td>Holbrook</td>
<td>71.9</td>
<td>39.3</td>
<td>68.3</td>
<td>34.2</td>
<td>-12.7</td>
<td>9.2</td>
<td>Oct. 12</td>
<td>May 11</td>
<td>Sept. 17</td>
<td>June 13</td>
</tr>
<tr>
<td>Fruitland</td>
<td>70.4</td>
<td>36.</td>
<td>65.1</td>
<td>33.2</td>
<td>-9.7</td>
<td>6.98</td>
<td>Sept. 20</td>
<td>April 13</td>
<td>Sept. 12</td>
<td>April 27</td>
</tr>
<tr>
<td>Chinle</td>
<td>69.0</td>
<td>65.</td>
<td>64.4</td>
<td>28.5</td>
<td>-6.3</td>
<td>8.0</td>
<td>Sept. 21</td>
<td>April 1</td>
<td>Sept. 12</td>
<td>June 12</td>
</tr>
<tr>
<td>Keams Canyon</td>
<td>64.0</td>
<td>38.</td>
<td>61.8</td>
<td>32.0</td>
<td>-3.0</td>
<td>11.0</td>
<td>Sept. 23</td>
<td>June 10</td>
<td>Sept. 13</td>
<td>June 14</td>
</tr>
<tr>
<td>Fort Defiance</td>
<td>66.0</td>
<td>28.7</td>
<td>61.1</td>
<td>28.6</td>
<td>-19.</td>
<td>13.0</td>
<td>Sept. 18</td>
<td>June 11</td>
<td>Sept. 15</td>
<td>July 7</td>
</tr>
</tbody>
</table>
deposits, including roots and stalks of semi-desert plants furnish the organic constituents of the soil. On the mesas the soil is thin, with high porosity. The accumulated deposits in the valleys often exceed seventy feet in thickness and are of a sandy constituent to adobe clay, with many grades between. The whole region is fairly fertile when sufficient water can be obtained for the growth of plants.

**Vegetation**

Topography and altitude, not latitude, determine the character of the plant life and the boundaries of ecologic provinces. For the region as a whole with its hundreds of plant species, about 200 of which have been so far identified, the following plant zones are readily recognized:

1. **The treeless zone**, from 2,500 to 5,000 feet in altitude; type area, Little Colorado valley. In this zone the plant life is of the arid type, the vegetation is scanty, and over large areas, very inconspicuous. Weather-beaten cottonwoods grow here and there along the streams. The other characteristic plants are the "flat-leaved" and globular cacti, yucca, tufted grass, small-sized sage, greasewood, and sparse scrub piñon and juniper. Some of the other plants that make a quick growth during the rainy season are yellow sunflowers and related compositae, wild flax, and the Mariposa lily. In this zone agriculture is carried on only by irrigation. Where there is sufficient water crops do wonderfully well, and such favored places are real garden spots.

2. **Zone of sagebrush (Artemisia) and greasewood (Sarcobatus)**; altitude, 5,000 to 6,000 feet; type locality, upper valley of Pueblo Colorado wash. Within this zone there is a striking, generally scrub-size cedar-piñon formation usually along rocky ridges, characterized by a sparse growth of nut pine (Pinus edulis) and cedar (Juniperus occidentalis monosperma), associated with the sagebrush (Artemesia tridentata) and greasewood (Sarcobatus). Agriculture in the desert part of this zone is possible only with irrigation; but in favorable situations as to soil conditions in the cedar-piñon formation beans, corn, and squash may be grown by the method of dry farming.

3. **Zone of juniper and piñon**; altitude, 6,000 to 7,000 feet; type locality, west edge of Defiance plateau and the south edge of Black Mesa. In this zone the juniper generally occurs at lower altitudes than the piñon, both reaching their greatest development along the south edge of Black Mesa. Patches of greasewood and
sage brush in the open, park areas, surrounded by groves of piñon, are of usual occurrence throughout the zone, and aspen (*Populus tremuloides*), juniper (*Juniperus scopulorum*), and pine are found in well watered canyons—trees that would yield 1 to 25 cords of firewood per acre; it is estimated that 7,000,000 cords of fuel may be obtained from this forest type. While grass, in scattered mats and tufts, grows everywhere except in the densest shade. Crops are raised by the dry-farming process in most of this zone, though irrigation is also resorted to wherever the streams carry sufficient water. It is also from this zone that the great piñon-nut crop is gathered by the Indians.

4. Zone of forests; altitude, 7,000 to 10,416 feet—zone of yellow pine, 7,000 to 8,500 feet, and zone of Englemann spruce, 8,500 to 10,416 feet. In the open spaces beneath the pine and spruce sage, gooseberry, raspberry, blackjack, willow, poplar, ground juniper, manzanita, Gambel oak (*Quercus gambelii*) and other oak species and varieties attain luxuriant growths, while flowers in a large variety are embedded in fine grass. Cottonwood groves and scattered trees are in evidence up to 7,000 feet, and Douglas fir and quaking aspen commonly occur in the upper mountain valleys.

Crops can be raised anywhere in this zone without irrigation; but the short season has hampered agriculture, as it also does the raising of fruit. However, it is the writer's opinion that fall wheat and rye could be raised successfully as could oats and potatoes, and same is now being undertaken successfully in Buel Park at the summit of the Defiance plateau, near the east Arizona line.

The yellow pine (*Pinus ponderosa*) is best developed on the Defiance plateau where it forms a solid forest over many square miles, besides occurring in isolated patches on the higher parts of Black Mesa, the Chuska Mountains, and the Segi Mesas, but due to the lack of moisture, it is found only in secluded, protected places, often at the head of canyons and along the north slopes. This pine is mature. It averages over 20 inches in diameter six feet from the ground and reaches an average height of 80 feet. The merchantable pine covers 235,500 acres and will cut about 870,000,000 board feet of lumber; and the scattered pine will yield 702,000,000 board feet, making a total of 1,572,000,000 board feet of merchantable pine, in addition to 300,000 cords of fuel.

Douglas fir, in groves of few individuals, is found here and there clinging to canyon walls on all the higher sections of the
Englemann spruce is best developed on Navajo Mountain. Small groves of it also were noted on Dutton plateau, the Chuska Mountains, and Defiance plateau. Where best developed the trees average from 12 to 30 inches in diameter and 70 to 80 feet in height. On Navajo Mountain alone it covers 4,500 acres, and will cut approximately 13,000,000 board feet of lumber.

The above gives a total of 1,485,000,000 board feet of lumber and 7,300,000 cords of fuel for the whole area. It might also be added that roads for logging may be cheaply constructed.

FAUNA

The writer has identified 31 animals and 45 birds in the Navajo Country; and so far as he can learn that is all the work that has been done along that line in this part of the Southwest.

Previous to the coming of the white man the natives had domesticated the turkey and dog. Formerly there were antelope, black-tailed deer, and mountain sheep in abundance in the region. They were even seen in large numbers as late as 1854 by Sitgraves, 1858 by Lethermann, and 1878 by Beadle, but the last two species are now extinct in the area and antelope are only occasionally seen.

Bear is too plentiful, as are also wild cats and coyotes. The most common wild animals now seen in the low untimbered area are the prairie dog, rabbit, coyote, trade rat, and field mouse, and those seen in the wooded areas are the chipmunk, brown squirrel, wild cat, wolf, fox, porcupine, and bear. The principal birds seen are the eagle, hawk, night hawk, raven, crow, burrowing owl and common owl, swallow, catbird, rock wren, robin, junco, blue bird, humming bird, tree sparrow, wood thrush, many species of duck, sandhill crane, and an occasional wild turkey in the timbered area.

The Navajos are now a pastoral people; and on every side in their country are seen horses and burros, some cattle, and numerous flocks of sheep.

WATER SUPPLY — IRRIGATION — FARMING

The Navajo and DeChelly sandstone and the Moenkopi formation are very cross-bedded sandstone. They also contain soft spots, which are blown out by the wind, forming potholes if a horizontal surface, or cliff spaces and caves if along vertical faces. When it rains the potholes fill with water and remain so till evaporated, or it seeps through the rock to some underground outlet. And again, the shifting sand piles whole washes full, as it is now filling up
Reservoir canyon, and also pockets large areas in circling dunes. This ponding of the water also causes it to seep through the rocks to a lower outlet through the massive, cross-bedded, porous sandstone. Reaching the thinner-bedded sandstone and shale, it follows it. Approaching where this shale is nearly or wholly exposed, the water issues from the joints in the sandstone and from the shale exposures. This has been brought to the surface by abrasion and weathering and by exposing the water-bearing horizon by canyon cutting. Through this process many springs now come to the surface in Reservoir canyon and at and about the village of Moenkopi and at Moa Ave and Tuba City and at many other places in the Navajo lands. The larger springs have dams to impound the water and hold it for stock and for the purpose of irrigation. The water from the smaller springs is used for stock and for house use, and a careful husbanding of this water makes it possible to keep the stock on the range.

It might be added here that due to the underground water from the above causes, the Reclamation Service has put down many wells in the region, and besides the watering of thousands of head of horses, cattle and sheep from them, a purer water is obtained for domestic purposes, thus insuring better health for the inhabitants.

The other source of water supply is from the various streams.

The use of flood waters for irrigation has probably been practiced in this region for hundreds of years, as it is evidenced by the stone remains of check dams left by the ancient cliff- and village-dwellers. Earth dams were also probably constructed by those early peoples; but have since been removed by the ravages of time. The Hopis who are descendents from those early villagers still follow the same method of irrigating as their fore-fathers did, improving on it in some ways. The Navajo follows the same method as near as he can, though endeavors to put his crop where the least work will be needed to get the water to it. He has learned to know the areas liable to be flooded during occasional showers as well as those annually inundated by successive rains during the rainy season. In these he plants his corn and pumpkins in widely spaced holes to a depth of about 14 inches; and by the time the July rains begin the corn is a foot or so high. With the coming of the rains the fields are wholly or partially submerged. The receding water usually leaves parts of the fields stripped bare of vegetation and other parts deeply buried with silt; the portion of the seeded ground remaining constitutes the irrigated fields from which the crop is harvested.
This with some occasional modifications, such as constructing earthen diversion dams a foot or more in height—dams which require renewal each year—and the building of a few check dams, constitutes the Navajo system of irrigation; and, with some added improvements, that of the Hopi as well. By this method about 30,000 acres of land, in fields of about three acres each, are cultivated by the Hopis and Navajos combined. Could the water of the side washes and master streams be properly used many times that area could be as easily irrigated.

Recently the government has taken a hand in an endeavor to furnish more water for irrigation purposes; and government stockmen are teaching the Indians how to properly use the available water.

A ditch taken out from Piute canyon below the lower crossing now irrigates several acres of good land. Diverted water from Standing Rock creek, in Redrock valley, is sufficient in quantity to irrigate more than 100 acres of cornfield. Through a series of short ditches, Lucachukai creek supplies water to cover 400 acres and makes the place a garden spot. There are also many other smaller diversion ditches in the region that are successfully furnishing water for small areas.

Besides the diversion ditches to secure water for irrigation, several dams have been constructed by the government and more are to be made in the near future. Among those completed are the dam at Kayenta (Marsh Pass region), to irrigate 1,000 acres in the vicinity of the Marsh Pass Boarding School; the one at Donohootso, to irrigate a similar area; a small dam in Piute canyon; the Moenkopi dam near Tuba City, which furnishes about 180 acre-feet of water annually; the Red Lake storage reservoir, the water of the “lake” thus formed covering 59.83 acres in extent; Reservoir canyon, furnishing about 75-acre-feet of water per annum; Wheatfields reservoir, having water enough to irrigate 700 acres on the south side of Wheatfield creek; Ganado reservoir, having water sufficient to irrigate 1,775 acres; and Leupp reservoir, having water enough to irrigate 8,000 acres.

An acre-foot of water falls on each acre of land in the Navajo-Hopi country—a total of 16,464,000 acre-feet—each year; and if the part of it that is not needed as it falls was reservoired for future use, instead of being let run out of the region in rapidly deepening washes, much of the country that is now of little use could be made into some of the best farming land of the Southwest, a thing that will some day be done.
The Navajos have no term for gold; and the Spanish explorers, always on the lookout for silver and gold, vigorously expressed their disappointment at the absence of precious metals in the region. So far, too, but very few metal ornaments and no metal tools or utensils have ever been found in the pre-Spanish ruins of the Navajo country. Yet, in spite of these significant facts and the fact that pegmatite veins and quartz reefs are unknown and the basic igneous intrusions are unaccompanied by precious metals, prospectors have conducted explorations in the more accessible parts of the reserved lands from time to time in recent years and the belief is strong in certain quarters that pay gold remains to be discovered in various parts of this part of the Plateau province. This has brought about attempts to obtain gold in the region, as follows:

In 1869 Calvin Jackson and twenty-one companions reached the San Juan river by way of Fort Wingate and Fort Defiance on a prospecting tour, without finding gold or silver along the route. At a later date, one of the party, Adnah French, is reported to have returned and the worthless prospect holes in the slate underlying the cap of French Butte are credited to him. The finding of nothing on this exploring trip discouraged prospecting in the region for the next twenty years.

GOLD ON THE SAN JUAN

In 1892 it was reported that there were rich deposits of gold in the gravel bars and terraces of the San Juan, below the mouth of Montezuma creek. This led to the “Bluff excitement” of that year, at which time 1,200 people worked along the river in search of the precious metal. In 1906 the Oregon Gold Mining Company put a plant at the mouth of Montezuma creek on the San Juan, including buildings, runways, dredges, separators, and screens, costing a total of $12,000. They planned to treat large quantities of gravel taken from the bed of the river; but after a great deal of experimenting, in which only about $100 worth of gold was recovered, the stock was sold. The Zahn Brothers similarly tried to obtain gold by washing the gravel bar three miles below the mouth of Nakai canyon, about twenty miles above the junction of the San Juan and the Colorado, with like success, finally abandoning the work during the summer of 1909. At the great bend of the San Juan, six miles below where the Zahn Brothers had their plant what was known as “Spencer Camp” was later established.
machinery was erected for washing the gravel in the terraces, bars, and talus and for crushing the partly disintegrated rock. Pierce riffles were used and gasoline power provided, but the plant failed to pay, so was abandoned in 1909, only to be followed in 1910 by the Red Rock Mining and Exploring Company's attempt to secure gold from the same source. This company installed a crusher and screens four miles below the mouth of Nakai canyon and undertook the establishment of a line of boat transportation from Lee's Ferry, on the Colorado; but their labors, too, failed of success. And so far as known to the writer all the gold-mining operations on the lower San Juan have been discontinued.

That there is gold in the San Juan gravels and talus material is evidenced by the fact that "nearly every pan from the bar shows a color"; but the metal is in excessively thin flakes. On account of the cost of transportation being so great to the out-of-the-way places in the river where the gold is found and the smallness of the quantity, 25 cents worth per ton, it so far does not justify commercial operations.

GOLD IN THE CARRIXO MOUNTAINS

There has been considerable prospecting in the Carrixo Mountains at different times, and prospecting permits are still asked for now and then.

In 1891 two companies of prospectors, fifteen men in all, entered the field without permission, only to be escorted to the limits of the reservation by the Sixth Cavalry. Later (in May, 1892) a commission of which Gen. A. Mcd. McCook, U. S. Army, was chairman, and J. G. Allyn secretary, visited the area to test the claim of the ousted prospectors that very valuable deposits of gold and silver had been located. These men were accompanied by two geologists and a professional prospector and also two prospectors from Gallup, New Mexico, William Smith and Ollie Bishop, who had previously worked in the Carrixo and claimed to know the location of thick and rich veins. After weeks of laborious work in which some copper and iron pyrites (neither in working bodies) were found and some quartz ore that contained 2.95 ounces of silver and an average of .002 ounces of gold per ton, this commission reported "that the region was barren of metallic wealth and worthless for mining purposes." Notwithstanding this adverse report, however, there has been considerable barren prospecting and some work done in the region since it was made, particularly in 1901, 1902, and 1907, one shaft having been sunk in the region to a depth of 47 feet, without finding anything of value.
Vanadium and uranium were found by Mr. John Wetherill near Oljeto, Utah, north of Kayenta, Arizona. There is a large body of the ore, which appears to be a laterite deposit of McElmo age, at least, of McElmo rocks. The property has been leased but so far no work has been done on it.

Other exposures of McElmo rocks show this laterite deposit, but to what extent or richness is unknown.

COPPER

OCCURRENCE

Malachite, chrysocolla, and rarely azurite are found in the Navajo sandstone, in the sandstone of the Chinle formation, and in the lowest strata of the McElmo, and occasionally in the Shinarump conglomerate. It occurs as disseminated grains, patches and bands in the sandstone and as hollow logs of petrified wood in the Shinarump conglomerate, some of the copper-impregnated rock in the Segi Mesas and on the Kaibito plateau often covering a surface area of from ten to sixty feet square. (The Indians who are constantly in search of “blue stone” (turquoise) knew of these copper exposures before the coming of the white man, and specimens exhibited by them ultimately led to the finding of that mineral in Copper and Nakai canyons and elsewhere throughout the region, especially in the area north and west of Marsh Pass where numerous small pits testify to a somewhat thorough search.)

WHITE MESA COPPER DISTRICT

Thomas V. Keams and several companions located about forty copper claims in the area known as White Mesa, or Keams' Copper district, northwest of Tuba City, between that city and Lee’s Ferry, thirty-five of which were eventually recorded. On practically all of these claims development and prospect holes were sunk from four to six feet in cross section and from two to twelve feet in depth; and shallow trenches and open cuts were made on the flanks of several of the low mesas. Four tunnels were also dug and several shafts were sunk to depths ranging from twenty to forty-three feet. From all these considerable ore was obtained, much of which still remains on the ground. The rest was removed to Tuba City, from which place a small amount was sent to mills for testing. Since then there has been but little work done in the region, except assessment work to validate titles.
THE ORE DEPOSITS

The copper of White Mesa occurs in a fine-grained rock of Navajo sandstone age. This sandstone is composed of white and red quartz grains, usually held together by calcareous-ferruginous cement. It is a much cross-bedded rock, with well developed joints. Its color is nominally red, to light red, but as the copper constituent increases it changes to greenish white, light green, and dark blue green. The copper is in patches, not in veins; is along joints; in a band structure in the sandstone; along leaves of cross-bedded strata and on bedding planes, in nodule-areas; in cylindrical and lozenge-shaped masses, and in widely distributed grains of the ore.

Eighty per cent of the copper mineral is chrysocolla, azurite is rare, and the rest malachite which forms irregular masses within the chrysocolla or occurs as separate grains.

The ore in the different claims runs: light-green ore, 0.5 to 3.5 per cent; dark-green, 5 to 8 per cent; one specimen from the Paislee-chee claim, 14 per cent, and one from another claim, 32 per cent. Yet the scarcity of water for leaching and the absence of flux for smelting, the inaccessibleness of the section, and the very irregular distribution of the copper together with the low average value, make mining under present conditions unprofitable.

ORIGIN OF THE ORE

By some it is believed that the copper of this region is ore that has leached down from above rather than that it is an original deposit from uprising solutions; while others consider that the copper has been separated from solution by the clayey substance present in the rock. But as the ore, for the most part, replaces the ferruginous and calcareous cement in the sandstone and is confined to one group of strata throughout which it is widely distributed, it would appear to indicate that it likely had a sedimentary origin by some yet unknown process.

SALT

Salt in small quantities is found in the strata of Permian(? ) age, and the water in wells along the southern border of the region is so highly charged with salt as to be unfit for use. Before the coming of the white trader the natives obtained salt from the Zuni salt springs near Winslow on the Little Colorado.

PRECIOUS STONES

PERIDOT

Peridot (olivine) suitable for gem purposes occurs at a number of locations in the Navajo country, occurring principally in the
basic rocks of volcanic necks and dikes in the form of phenocrysts. These gem stones are found in greatest numbers in Buell Park, near Fort Defiance, Arizona. The gems average about four millimeters in size and are yellowish green to clear golden green in color. They are highly prized by the Indians and are also of some commercial value.

GARNET

"Arizona rubies" are offered for sale both as uncut stones and as jewelry in all the trading stores in the region, and many cities of the west also have them for sale. These stones are pyrope garnets and range in color from the light shades to the very dark shades of the characteristic color of Burgundy wine. They are collected by the natives who find a ready market for them.

These garnets are seen associated with basic intrusive rocks at more than twenty-one places in the Navajo country, occurring most abundantly in agglomerate of volcanic origin; and are sufficiently abundant to be of commercial value in four localities—Moses Rock, Mule Ear, Garnet Ridge, near the Utah-Arizona line, and Buel Park, in the Red Lake volcanic field. Their ultimate source appears to be a richly garnitiferous diorite gneiss, boulders of which are fairly abundant as inclusions in igneous rocks. Many of the garnets possess great beauty and are much in demand. The rest have little value as gem material because of their small size and imperfections.

JASPERIZED WOOD

Petrified wood is found scattered over a large part of the Navajo country, in the Shinarump conglomerate, Chinle and McElmo formations, the Dakota sandstone, and the Tertiary sediments. The largest forests of this wood are at Willow Springs, Beautiful Valley, Round Rock, Lithodendron creek, and at Adamana. Only the wood that is found in the Chinle beds where the above forests are exposed is of such color as to be of commercial value, probably the largest jasper deposits in the world being exposed there. Much of the jasper, among which there are varying amounts of quartz crystals, chalcedony, and amethyst, is highly colored in red, dark blue, yellow, lusterless brown, and brilliant scarlet tones. Besides the wood takes on a beautiful polish.

BUILDING MATERIAL

Like the ancient and present aborigines the white people have constructed their buildings from the materials at hand, wood, adobe, and stone from various formations. At Crown Point, the
Hopi villages and Keams Canyon the government and traders' buildings are constructed of Mesaverde rock; at Chine, Tolcheco, and Leupp, of Moenkopi sandstone; and at Fort Defiance, of adobe, brick, wood, and Chinle sandstone. The Red Lake store north of Tuba City is built of McElmo sandstone; and the rock of the Marsh Pass Indian school at Kayeta and a great part of the buildings at Tuba City, from the LaPlata group, Moenkopi rock being also used at the latter place.

The only clay suitable for brick is found in the Mancos shale, for the reason that the strata are prevailingly arenaceous, and the alluvial deposits are almost wholly sand and gravel, more or less charged with gypsum and lime. At the present time brick is made only about Gallup and that only from clays that have been carefully selected, for even the Mancos shales of which the clays are the broken down product carry much carbonaceous material, gypsum, and lime in many places. It might be added here that a semi-refractory clay of Cretaceous age is found in beds at Gallup and Clarks­ville and is now used for lining copper converters at Jerome and other points in southern Arizona.

The only rock in this region that could be classed as good building material is the limestone of the Todilto formation, and due to the thinness of the formation it might almost be classed as nil. Furthermore, the Navajo sandstone, a rock that is exposed over large areas of the region, deteriorates rapidly when exposed to the weather and therefore cannot be classed as a durable building ma­terial at all.

**COAL**

Practically wherever rocks of the Cretaceous age are exposed in the Navajo country coal seams are exposed. Besides detached areas, there are two extensive coal fields of this age exposed in the region — what might be called the Durango-Gallup field, extend­ing from the San Juan river to the Santa Fe Railway at Gallup, New Mexico, and the Black Mesa area, wholly within Arizona.

**DURANGO-GALLUP FIELD**

Coal is mined by the Santa Fe Railway and various companies near Gallup in the south end of this field. The mining there shows seams as follows: Thin lenses traversed by numerous partings in the Dakota sandstone at Pyramid Butte and nearby localities; two beds about forty inches thick in the Mancos formation at Zuñi School coal mine and a ten foot bed of semi-bituminous coal in the same formation at Satan pass; and several three to four foot
veins and one eight and a half foot one in the southern part of the Gallup field in the Mesaverde formation, where much coal is mined at the present time. Coal mining in this region began in 1882 and today it is the principal industry of the entire section, something like a million tons being put out annually.

North of the Gallup field the coal is as extensive as about Gallup, but here mining is on a small scale, only to supply fuel for the government and mission schools. Mining for this purpose at St. Michaels, Crown Point, Fort Defiance, and Tohachi produce about 2,000 tons each year. Yet this part of the field has billions of tons of coal waiting to be mined.

THE BLACK MESA FIELD

This field is an irregular, fringe-edged, oval-shaped mesa wholly within the Navajo lands, its southern edge being about 100 miles north of Holbrook, Arizona, the famed Hopi Indian villages being perched on its southern prolongations. It is approximately 250 miles in circumference and everywhere its rock, which is of Cretaceous age, exposes coal seams in quantity sufficient to justify mining in practically every part of it that has ever been examined.

The Ganado Mission coal mine at Steamboat, Arizona, is in the Dakota formation and shows a good quality of coal in veins from two to four feet in thickness. This seems to be an exception for the Dakota formation as its carbonaceous strata are usually impure and usually variable in extent, rarely attaining a foot in thickness. The coal, too, is usually in lenses, rather than in beds. The coal mine for the Tuba City Indian school is in the Mancos shales, showing one seam of coal of approximately four feet in thickness, besides three smaller seams. Twelve seams of coal are known to exist in the Mancos shale of this mesa, one approximately six feet in thickness. Also at all the locations examined the seams possessed a sandstone roof, making them favorable for mining. Besides several other operating mines, the government coal mine at Keams Canyon and the one at Marsh Pass Indian school at Chilchinbito are in the Mesaverde formation, in both of which a good quality of coal is obtained, about 3,000 tons being mined annually. From these mines and from an examination of the region it is easily seen that the Mesaverde formation contains much more coal than the Mancos. It is further seen that the coal is a better grade and the beds in general are thicker and more constant.

General remarks on Black Mesa and its coal.—Coal outcrops can be seen all around Black Mesa, which as we have seen, is composed wholly of Cretaceous rocks. These coal outcrops often range...
from three to five feet in thickness, a few seams exceeding even that. The region is so far untouched, and many geologists estimate that it contains eight billion tons of workable coal, which it will probably exceed in amount.

**OIL**

Oil has been found in three regions of the Navajo country — in the San Juan field, the Little Colorado field, and the Durango-Gallup field.

**SAN JUAN FIELD**

Oil seaps were noticed in San Juan canyon thirty miles below Bluff, Utah, in 1882 by E. L. Goodridge who staked a claim at the townsite which bears his name. Drilling was begun in 1907 and in 1908 high grade oil under artesian pressure was struck at a depth of 225 feet in Crossing Well No. 1, on the banks of the San Juan, at Goodridge. Twenty-seven wells were drilled up to 1911, nine of which were productive. Later there was more drilling in the region, the drilling extending to the region of the Monuments within the Navajo lands, where, north of El Capitan north of Kayenta a well is reported to have been put down to a depth of 4,000 feet, obtaining some oil. The output of the producing wells of the region, however, has proved so small in amount, four to five barrels per day per well, that but little work has been done in this field for several years.

The oil occurs in five beds of sandstone of the Goodridge formation, of Pennsylvania age, and the productive wells are in a synclinal trough between Raplee and Mitten Butte anticlines. The results so far obtained indicate that the oil is of good quality, but no great yield is to be expected.

**THE LITTLE COLORADO FIELD**

In the vicinity of Holbrook and about Adamana much oil drilling is going on, and some oil has been found in the Goodridge (Lower Aubrey) sands of Pennsylvania age there. The work was recently extended to the Zuñi dome north of the Little Colorado where ten drills were in operation for a time.

**THE DURANGO-GALLUP FIELD**

The oil in the Durango-Gallup field is found principally in the Mesaverde formation of Cretaceous age, principally in the Table-Mesa-Hogback-Rattlesnake country near Farmington, New Mexico, and in the Seven Lakes district on the Chaco plateau, northeast of Fort Defiance, Arizona.
SEVEN LAKES OIL FIELD

The presence of petroleum in surface sand near Banks trading post and the finding of gas in wells at Gallup led to exploration for oil in the vicinity. As a result several wells were sunk along the west base of Dutton plateau in 1910, the deepest well being sunk to a depth of 1,500 feet, all failing to find oil in paying quantities. Later (in 1911) oil was discovered on the Chaco plateau; and at about the same time, in section 18, T. 18, N.R. 10 W. New Mexico Principal Meredian, a considerable amount of gas and some oil was found. As a result 3,000 claims were soon located in twenty townships in the vicinity. Soon then drilling on a moderate scale was begun and by the end of 1912 oil with gas had been found in six wells, in quantity not sufficient to justify exploitation on a commercial scale. For years then the field was practically abandoned; but recently there has been renewed activity, its being reported that a well recently brought in in this region produces 500 barrels of oil per day, a report which the writer has not yet had time to verify.

THE TABLE-MESA-HOGBACK-RATTLESNAKE AREA

It had been known for years that there was oil in the Hogback-Rattlesnake area, about twenty miles west of Farmington, New Mexico, but intensive work did not begin in the region until about 1923. Since then the activity has gradually increased, with the bringing in of many wells producing a high gravity oil. This has led to the leasing of large areas of Indian lands for oil prospecting and developing. So far the main producing wells are on the Hogback, Rattlesnake, and Table Mesa structures, though there are other producing wells in the district, the oil from the wells being piped out from the field to Gallup, New Mexico. The wells of this region having produced as high as 2,830 barrels in a single month.

CONCLUSION

The scenic and recreational features of this region and its fine summer climate, together with its villages and cliff-houses of ancient peoples, are even now making it a tourist center. Furthermore, its actual and potential wealth in timber, oil, and coal, and its farming possibilities under proper impounding and handling of its water and a scientific cultivation of the land, will undoubtedly make it one of the rich spots of the Southwest. In addition its healthful climate makes it an ideal place in which to live.²