GEOLOGY

Of the Navajo Country

By Theodore H. Eaton, Jr.
Ruth N. Martius, Agnes J. Walker

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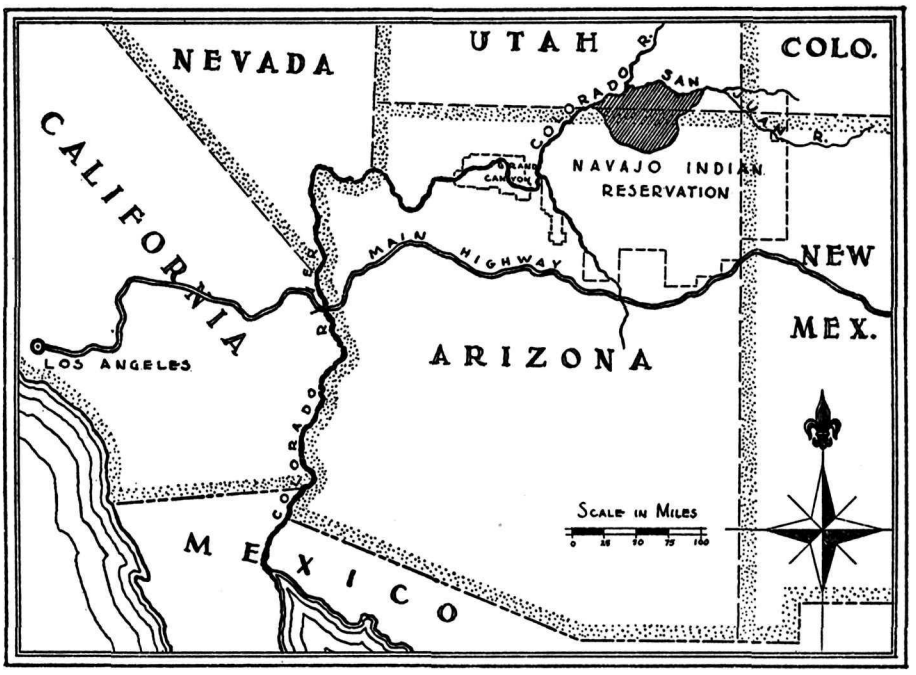
National Youth Administration
(Project 6677-Y)

Berkeley, California

1937



Map Showing Location of Navajo Indian Reservation

Shaded portion indicates area where mapping and scientific field studies are being carried on by the Rainbow Bridge-Monument Valley Expedition.

Foreword

This is one of a series of bulletins on the northern Navajo country, produced under Project 6677-Y of the National Youth Administration, Berkeley, California. In its inception the project had for its main objective the publication of scientific data made available by the Rainbow Bridge - Monument Valley Expedition, resulting from four years of field work in the northern Navajo country.

Dr. Theodore H. Eaton, Jr., who has served as a member of the Expedition's biological staff in the field, was chosen N. Y. A. project director to supervise the assembling, editing and publishing of this fund of knowledge in some form in which it might be useful to the layman or student. As the work progressed it was decided to widen the scope of the project to include information from all reliable sources with a view to producing a usable scientific manual of the Navajo country. This necessitated a research program pursued mainly among publications in the library of the University of California and that of the Expedition.

Acknowledgment is due to a number of agencies and individuals without whose cooperation the production of these bulletins would not have been possible; to the Alameda County Free Library for the earlier sponsorship of the project; to the National Park Service for space necessary for the work; to the University of California for furnishing published material, collections, and space for investigators; to the trustees of the American Exploration Society (under which the Rainbow Bridge - Monument Valley Expedition operates) for unpublished scientific data collected in the field and for contributions in cash toward publication expenses; and - most of all - to Arthur M. Yale, Frederick S. Clough and other administrative officers of the National Youth Administration, who have recognized the importance of this work and have assisted in many ways toward its completion. To all these, and to all the other individuals who have assisted without recognition here, the undersigned, sponsor of the project, expresses his sincere thanks.

Ansel F. Hall

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Berkeley, California
April 10, 1937

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The history of the earth is one of constant small but significant developments which have, throughout the eons of time, remolded the world we live in. The rain, wind, rivers, and oceans are tools which have always been used by nature to sculpture the face of the earth. Rain and snow wear away rocks and wash the fragments into the streams. Where some parts of the rock are harder than others, this erosion does not take place evenly. Here and there in the Navajo country, for example, pinnacles of hard volcanic rock are left standing above the level of the surrounding country because the softer material which enclosed them has weathered away.

Rushing down a furious course or meandering along an easy way, innocent looking rivers do a great deal in their own channels toward wearing down the earth's surface. As it flows along, the river picks up soil and rock from its banks and bottom and carries it down toward the sea. During times of high water, when the current is swift, the water has greater power to cut the rocks through which it flows, and thus carries a greater load of material. As the current subsides, the river loses its carrying power and drops part of its load. In this way layers of sediment are piled up, building sand bars, beaches, and deltas. In time these layers are consolidated and form beds of hard rock, called strata.

In arid regions, like the Navajo country, wind erosion of rocks is of tremendous importance. Scooping up sand and loose soil and beating against rock formations with violent force, the wind soon sculptures the rocks and wears them away. Just try driving through the desert during a sand storm and you will realize the destructive power of the wind--your windshield will be cut and scratched by the flying sand.

Paradoxically enough, while these various "tools" are constantly working to wear down the land, they are also helping to build up the surface. Sediments deposited by the wind and water become in time hardened into sedimentary rocks. Clay becomes shale, sand becomes sandstone, gravel becomes conglomerate, and when volcanic eruptions cover great mountain slopes, the land surface is built up by the formation of igneous rocks from the molten lava. Not only by lava flows do volcanoes build up the surface; often the work is done from within the earth. Quantities of molten rock, called magma, force their way from the interior into cracks, and, spreading out in wall-like masses or pushing up the earth's crust

in domes, this magma cools and solidifies into what is called intrusive igneous rock. There is a third class of rocks, called metamorphic, which is formed out of sedimentary and igneous rocks through alteration by tremendous heat and pressure. For example, marble, a metamorphic rock, was once limestone, which is sedimentary; metamorphic slate was once sedimentary shale; and schist may be formed by the metamorphosis of igneous quartz.

Sedimentary rocks usually originate in layers. However, the beds do not always remain in a perfectly regular arrangement. In many places they become mixed up, and the surface of the earth has been folded so much that the beds are often at all angles. Sometimes the crust has been cracked and the layers of rock have slipped out of their original positions. We must also consider the changes in the distribution of land and water. At least once in ages past a great sea, somewhat like the Gulf of Mexico, covered the central portion of the United States; including the Navajo region. Under such circumstances, sedimentary rocks were deposited. On the other hand, in certain places sediment was not even laid down because at the time the land in that particular locality was above water. By studying the formations, a geologist can see what changes have taken place.

Although the wind, rain, and water affect the earth's surface as has been shown, it is evident that some other force must be responsible for the gradual rising and sinking of the surface through the ages. Since the crust of the earth has a certain degree of flexibility, the removal of great quantities of sediment from one place and their deposition in another upsets the equilibrium enough to cause folding or wrinkling of the layers of rock and the raising or sinking of certain sections in relation to one another. This also results in such local effects as the formation of mountains and plateaus--effects which are particularly important in the Navajo region.

The Navajo Country

Bounded by the San Juan, the Colorado, and the Little Colorado rivers, and the 108th meridian, the Navajo country extends over an area of 25,725 square miles--an area full of scenic beauty and of wide interest not only to the scientist but to the casual traveller as well. As early as 1853, explorations were made in the region, but it was not until Dr. H. E. Gregory's expeditions (1909-10) penetrated far into the interior that much real knowledge of the country appeared. In recent years the Rainbow Bridge-Monument Valley expeditions have made more detailed exploration of the north-central portion, and as interest has grown, the country is being opened to tourist travel, roads improved, and many, though by no means all, of the difficulties encountered by the first pioneers have been overcome.

Chart of Formations in the Navajo Country

After H. E. Gregory

Eras	Periods	Sub-Periods	Group and Formation	Thickness in Feet
CENOZOIC (Age of warm-blooded animals and plants)	Quaternary	Recent Pleistocene	Alluvium, Ash, Mostly eolian deposits and unconsolidated sediment	
	Tertiary	Pliocene		
		Miocene		
		Oligocene		
		Eocene	Chuska sandstone	700 - 900
			— Unconformity —	
			Tohachi shale	200-1100
MESOZOIC (Age of Reptiles)			— Unconformity —	
	Cretaceous	Upper Cretaceous	Post Mesa verde rocks	300 +
			Mesa Verde Formation	275-800
			Mancos shale	500-800
			Dakota Sandstone	0-295
			— Unconformity —	
			McElmo Formation	400-700
			— Unconformity —	
	Jurassic	La Plata Group	Navajo Sandstone	400-1000
			Todilto Formation	3-200
			Wingate Sandstone	30-450
			— Unconformity —	
	Triassic		Chinle Formation	1182
			— Unconformity —	
			Shinarump conglomerate	20-100
			— Unconformity —	
PALEOZOIC (Age of higher invertebrates)	Carboniferous	Permian	De Chelly Sandstone	0-585
			Moenkopi Formation	300-500
			— Unconformity —	
		Pennsylvanian	Aubrey group in Little Colorado River region Goodridge formation San Juan River region (relations unknown)	
			~~Unconformity~~	
	Devonian			
	Silurian			
	Ordovician			
	Cambrian			
Proterozoic		Pre-Cambrian	At one locality - quartzite overlain unconformably by Moenkopi formation	100 +
Archeozoic				

Come to the Navajo country and see for yourself the picturesque features of the landscape--the solitary volcanic necks, remnants of cones long extinct, rising above the mesas and buttes. Explore the steep-walled canyons and examine the strata. Here in the rocks is written the story of countless millions of years of slow growth and even slower destruction by wind, rain, and snow. Here in a curiously textured outcrop you may find fossils or other characteristic features which will enable you to recognize this formation when you come upon it somewhere else, perhaps many miles away. In this way the geologist works, comparing and classifying rocks until he is able to recognize a formation and to place it properly on a chart. Let us suppose that you have succeeded in finding a canyon wall whose strata are complete from the beginning of geologic time and in perfect order. Here is your key to the geologic history of the country. Although it is impossible to find a complete succession of strata anywhere, we may construct a chart showing how the formations would appear if they were all present in one place.

In some respects the Navajo country presents a forbidding appearance, but yet one cannot help feeling drawn on and on into this vast, sparsely-populated wilderness. The climate is extremely variable. Clear, hazy blue skies alternate with sandstorms and short but violent thunderstorms. Says Gregory, "The summers are very hot; the winters are very cold; daylight is accompanied by heat; darkness by chilliness." Most of the year water is scarce, but during the short rainy season (July and August) parts of the region are often flooded. The rivers and creeks are then swift and cut deeply into their banks, only to deposit their load of sediment when the rain stops and the streams dry up. The Colorado River, which forms the western boundary, with its northeastern branch, the San Juan, and its southeastern branch, the Little Colorado, comprises the main drainage system. The first two are constantly flowing, but the Little Colorado is permanent only in the last few miles of its course.

Explanation of Geologic Chart

This chart shows how geologic time is divided into eras, epochs, and periods from the time of the oldest rocks to the present. The Archeozoic and Proterozoic eras extended from the beginning of geologic time to the period of the formation of the first distinct sedimentary strata. The Paleozoic era extended from almost the oldest fossil-bearing rocks through the long ages when fishes and invertebrates were the dominant forms of life and came to a close as the first reptiles appeared. The Mezozoic was the era of dinosaurs and lasted a hundred

Explanation of Geologic Chart (Continued)
and fifty million years or more. At the end of the Cretaceous period the dinosaurs and many of their relatives became extinct and were replaced in the Cenezoic era by a great variety of warm-blooded mammals and birds. The Cenezoic era is devided into Tertiary and Quaternary epochs, the latter including the great ice age and the coming of man.

During the Quaternary epoch, very little rock was formed in the Navajo region. Deposits are mainly eolian (of wind-blown origin), some volcanic ash, alluvium, gravels, and other more or less unconsolidated sediments. In the Eocene period of the Tertiary era, Chuska sandstone and tohachi shale were formed. The Chuska is a gray and white, fine to medium grained sandstone with some conglomerate. It is cross-bedded and forms cliffs. The Tohachi is made up of shales and thin sandstone with some lignite. It is poorly consolidated, banded red, blue, yellow, brown, and white, and contains animal and plant fossils. The Mesa Verde formation (found in the Upper Cretaceous period) is made up of massive sandstone at base and top and sandstones with sandy-shales and some coal in the central portion. It forms cliffs and contains fossils of Montana and Colorado (?) age. Dakota sandstone is gray and brown in color, coarse in texture, contains plant fossils, and is irregularly stratified. The McElmo formation is separated from other Jurassic rocks by an unconformity; an unconformity occurs when the formation of rock is interrupted for a period long enough to allow erosion to alter the surface before the formation of more rock. It usually appears as a line between beds of different texture. This shows that the older strata were eroded before the deposition of the later beds.

In the LaPlata group, the Navajo sandstone is a light-red, cross-bedded, uniformly fine-grained sandstone, with variable amounts of limestone near the top. It is a prominent cliff maker. The Todilto is limestone with shales, and contains dinosaur footprints. The Wingate is massive cross-bedded, fine-grained, bright-red sandstone and, like the Navajo sandstone, is a cliff maker. Chinle formations are composed of shales with thin sandstone and limestone conglomerate. The Chinle has four divisions: Division A (top), is banded red shales and sandstones; B, alternating bands of red shale and gray-purple limestone conglomerate; C, shales and marls; banded pink, red, purple, ash, etc.; D, red and chocolate-colored shales and shaly sandstones. Fossil wood and vertebrate and invertebrate remains are present in the Chinle formation. Shinarump conglomerate is cross-bedded conglomerate and sandstone; the pebbles are composed chiefly of quartz, quartzite, and petrified wood.

Explanation of Geologic Chart (Concluded)
De Chelly is a cliff making sandstone: light-red, uniform-grained and cross-bedded. The Moenkopi formation is chocolate-red and is made up of banded shales and thin sandstones. It is extremely variable in stratification and contains fossil plants. The Aubrey group is a buff-colored, thin-bedded limestone for the most part. The Goodridge formation is buff and red limestones and sandstones and contains fossils of Pennsylvanian age. The only exposed pre-Cambrian rock (at Fort Defiance) is massive bedded gray quartzite, overlain unconformably by the Moenkopi formation.

Interesting Features of the Navajo Country

Rainbow Bridge

One of the most striking natural phenomena to be found in the Navajo country is Rainbow Natural Bridge. Located in a narrow canyon about five miles from the Colorado River and northwest of Navajo Mountain, it is a huge natural arch of fine symmetry and graceful proportions. It rises 309 feet high and spreads to a width of 279 feet; the causeway at the top is 33 feet wide. The bridge is large enough to accomodate the dome of the Capitol at Washington under its arch, and still leave some room to spare. The rock in which the Rainbow Bridge is cut was at one time just one of the many buttress-like cliffs which occupy the many bends in the canyon. Through a process not yet fully explained, characteristic Navajo arches formed in both faces of the buttress, and years of constant weathering by wind and rain wore away the rock until at last a small window was formed near the base of the arch. Erosion then proceeded more effectively, enlarging the window until finally the opening extended low enough so that the stream changed its course and flowed through the gap under the bridge. (Figure I) The bridge can be reached by a trail about 16 miles in length from Rainbow Lodge, located just south of Navajo Mountain.

Navajo Mountain

At the northwestern corner of the Navajo Country, a great dome-like mountain rises 4000 feet above the surface of Rainbow Plateau, "an island in the midst of a sea of waterworn and windworn, brilliantly colored sandstone." (Gregory) This is Navajo Mountain--a huge laccolith which looms above the flat plateau. Broken and jagged cliffs rise on every side, with narrow gorges here and there between them, finally leveling out at about 8500

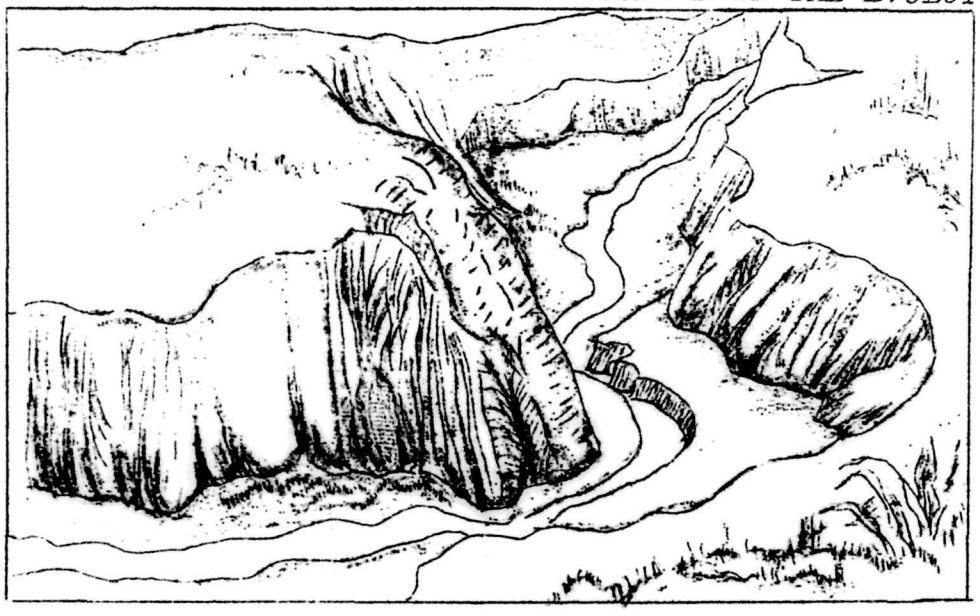
feet, where a forest-covered bench partly encircles the mountain. Above this, but much less abrupt, is the summit, with long talus slopes of fallen boulders on the sides, a gentle incline above, and nearly level at the top.

Navajo Mountain was built by an intrusion of igneous rock which forced its way through the earth's crust and pushed up the surface into a dome. Hundreds of thousands of years from now, when erosion and weathering will have eaten away the covering of sedimentary rock, this igneous mass will be exposed to view, and, if the normal cycle of erosion is not interrupted, in time even this hard rock will be worn down. Navajo Mountain presents many good examples of the results of erosion, particularly by water. The sides of the mountain have been cut by streams into vertical canyons and deep gorges. "The intricacy and grandeur of the stream-carved sculpture are unexcelled in any other part of the Plateau province." (Gregory) Part of the mountain is less eroded and forms a plateau with flaring edges, while the north and northwest sides are segmented by short, steep canyons. The almost flat top is covered by a forest of Engelmann spruce and aspen, and below the summit in the midst of groves of Douglas fir, yellow pine, willow, and aspen, War God Spring flows out of the underbrush and provides an excellent water supply.

Painted Desert

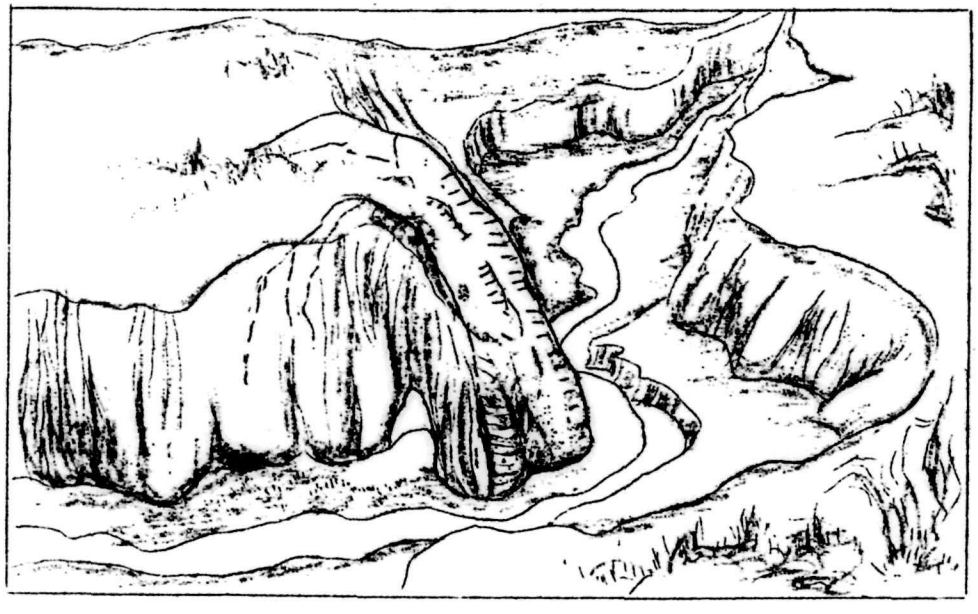
From Holbrook to the main Colorado, the Little Colorado River flows through a brightly colored valley known as the Painted Desert. If it were not for the magnificent coloring of the cliffs and valley floor, this barren expanse would be just another desert--dry and intensely hot, subject to frequent bad sandstorms, and bearing only the most meager vegetation. However, the dark red, chocolate, and creamy-colored sandstones of the Moenkopi formation and the low, broken mesas, surrounded by scattered dunes and carved by wind and water, redeem the desert by making it startling and beautiful. Overlooking Marble Canyon on the Colorado River, Shinumo Altar, a remnant of eroded sandstone, rises 600 feet high, and along the northern border of the desert, the brilliant vermillion of Echo Cliffs may be seen for a distance of as much as 50 miles. Along the southern part of the Echo Cliffs there is a small petrified forest, and some miles south of this there are remnants of lava flows. These appear west of the Little Colorado at Grand Falls, Black Falls, and Black Point, while on the east side, Black Knob is the only large igneous mass. It is interesting that dinosaur footprints have been found remarkably well preserved in the sandstone of the Painted Desert region.

STAGES IN THE EVOLUTION OF THE RAINBOW NATURAL BRIDGE

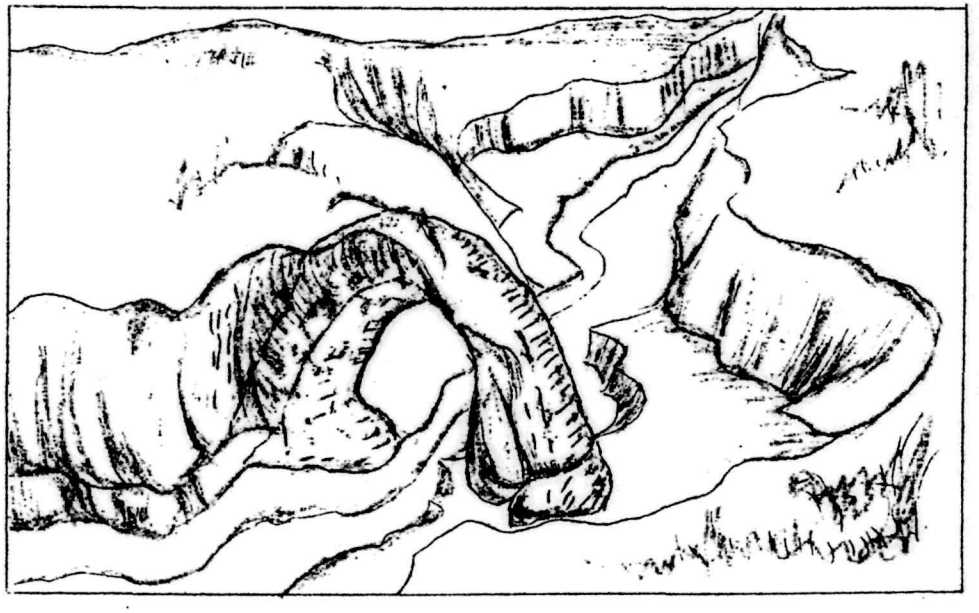


1.A BUTTRESS IN THE CANYON

2. THE NAVAJO ARCH ON BOTH WALLS OF THE BUTTRESS



3.THE ARCH BREAKS THROUGH NEAR THE BASE



4.THE STREAM TAKES A NEW COURSE THROUGH THE ARCH

San Juan River and Goosenecks

The San Juan River winds in a tortuous course through a canyon 133 miles long and varying in depth from 200 to 3000 feet. The canyon is eroded in solid rock but in some places the river runs over deposits of sediment about fifty feet deep. Tributary streams have built up bars across their mouths so that the water makes rapids before entering the main stream. The cliffs do not in all cases rise directly above the water, for talus slopes lie between the cliffs and the water's edge.

At one time far in the past this river flowed on a flat peneplain which was then very near sea level. The stream was sluggish and meandered back and forth in broad curves. As the years passed, the river slowed down even more and swept farther from side to side so that the meanders were exaggerated almost to the extent of forming circles. Then somehow or other, the whole region was elevated, which gave the river a longer distance to descend before reaching sea-level. Consequently the speed of the current increased where the slope occurred, and the river started cutting its bed deeper, without changing its course. The river, now swift and powerful, tore along in its old meandering course, eating into its bed until deep canyons were formed along the meanders to a depth of over 1000 feet. These goosenecks are one of the most striking features of the San Juan river. Located a few miles below Goodridge, they are easily reached by automobile.

Monument Valley

Monument Valley is a triangular region enclosed by the San Juan River, the Tsegi Mesas, and Comb Ridge. From the valley one sees a high plateau far to the west, a low and more irregular one closer at hand, and on all sides, a level plain out of which rise the "monuments". These are amazing formations of hard sandstone which resisted the barrage of time and are still standing--remnants of a great sandstone mesa which was broken and worn down by the wind, the rain, and the action of frost and heat. The monuments are of various shapes and sizes; square blocks, narrow walls, high pillars and needles. Some of them rise to a height of over 1000 feet. The method of erosion which attacks this area is responsible for the peculiar shape of the monuments, and the extreme variation in temperature is one of the principal agents of destruction. During the heat of the day the rocks expand ever so slightly and at night the rapid cooling of the atmosphere causes them to contract. Thus the rock formations are subjected to stresses and strains and little cracks develop, mainly along vertical lines.

Then water seeps into the cracks and, in freezing, enlarges the fractures, or else the wind hurls a sand-blast against the rocks. At any rate, the tiny vertical fractures grow until a wall-like part of the rock breaks off along the line of cleavage and falls to the ground, there to lie crumbling or to be carried away by the wind. In this way the huge rock formations, hacked at by natural forces, are slowly broken up, first on one side and then on the other, until only a "monument" remains--a silent reminder of the once great mesa. In some places all that is left is a low pile of fragments, half buried in sand.

In addition to these "monuments", the valley contains several spires of igneous rock which have been identified as the cores of volcanoes long extinct. The slopes of the volcanoes have been worn away but the more resistant igneous rock remains. Chief among these spires is Agathla, a black igneous mass, which rises so high above the valley floor (1225 feet), that it can be seen from almost every part of the surrounding country for over fifty miles. Its distinctive shape and enormous height make Agathla an unforgettable spectacle even among the many other memorable sights of the region.

Although there are a few places in Monument Valley which support a fair amount of grass, the region is, on the whole, quite arid. What water there is (at Tsegi-ot-Sosi and Laguna Creeks and Moonlight Wash) is highly charged with gypsum and unfit for human consumption.

The geologist finds much to interest him in the formations of Monument Valley. The youngest are chiefly of Permian age, but there are tilted strata of the Shinarump and Chinle formations (see chart) on the flanks of the anticline, a portion of which forms the valley. Moenkopi and Goodridge formations are, in one or two places, close to the surface.

Tsegi Mesas and Associated Canyons

The Tsegi Mesa region is the highland between Piute and Shanto canyons on the west and Monument Valley on the east. The highest point is Skeleton Mesa (7790 feet) which is flanked on the east by the Tyende and Anasazi mesas and on the north by Hoskininni mesa. Thus, to one looking west from Monument Valley, the face of the Tsegi Mesas looks much like a stairway of two wide treads separated by two rises 1000 feet in height. The entire region is made up of mesas piled one on another, surrounded and dissected by deep canyons. Some of these canyons reach a depth of as much as 1000 feet, their sides cutting down in almost vertical walls. In Laguna, Copper, and Nokai canyons, prorennial streams flow lazily or in torrents as the season dictates.

Geologically, the Tsegi Mesas present an object lesson in the work of erosion. Zilnez Mesa, on the western boundary of the region, is only one of many erosion remnants which owe their preservation to a resistant stratum of limestone. Creeks have cut the mesas deeply on both north and south ends, and only fragments of the table lands remain where eastward flowing streams have cut far back. Skeleton Mesa is formed of La Plata sandstone (Navajo, Todilto, Wingate). The composition of Kit Sil Canyon's walls, alternate beds of peat and alluvial silt in addition to the exposed Navajo sandstone, indicates that at one time in this region flood plains and swamps alternated. Formations ranging from Navajo sandstone all the way down to the Pennsylvannian (?) are to be found in Laguna Canyon. This canyon once contained a chain of lakes, but they disappeared about 1880, washing away the natural dams that held them, and leaving a deeply trenched canyon bottom. Tsegi-at-Sosi Canyon also held a similar chain of lakes at one time.

Shanto Plateau, a region somewhat similar to that of the Tsegi, is made up of a group of canyons and mesas, extending from the edge of Klethla Valley (west of Marsh Pass) northward to the head of Piute Canyon and westward to Red Lake Valley and the southern branch of Navajo Creek. The average elevation of the area is 7000 feet, and the surface is made up of flat-floored valleys and poorly dissected mesas. Near the center of the area is located Shanto (the Mirror), a well-known spring which gives the plateau its name. In the valley of the Shanto and Begashibito are found chains of lakes and pools which are separated from one another by wind-deposited drifts of sand.

Black Mesa

Black Mesa is an island-plateau to the south of Kayenta--standing apart from the rest of the Navajo country. The mesa has a circumference of about 250 miles and is sharply defined on all sides by cliffs. A shelf between Ganado and Keams on the southeast forms a lower step to Black Mesa proper, and the unity is further broken by Salahkai Mesa which is partly disconnected; but for the rest, Black Mesa rises almost abruptly and stands out in bold relief for many miles. The eastern, northeastern, and northwestern sides continue with only minor interruptions for 110 miles, and long scalloped mesas project into the Tusayan Washes on the south and southwest.

The mesa reaches its greatest elevation on that portion which faces Chinle Valley. Here, for 40 miles, it maintains a height of 8000 feet above sea level. The mesas to the south and southwest fall off to about 6500 feet. Although a few detached mesas, such as Zillesa and Ziltahjini, rise above the

surface, in general the plateau presents an even skyline, broken occasionally by wide valleys whose floors are cut by shallow rock canyons. Upper Moenkopi Valley is an exception to this rule, however, for its canyon reaches a depth of 600 feet.

Black Mesa is covered by a mantle of thin, highly porous, residual soil which supports an abundant growth of pinon and juniper trees as well as much sagebrush and grass. Beneath this covering of soil and forest lie rock formations ranging from Mesa Verde down. La Plata sandstone is folded under the Mesa by the Comb monocline, and Cretaceous strata are laid in flat synclines.

Canyon de Chelly and Canyon del Muerto

Defiance Plateau (located west of Chuska Mountain) is an elongated dome, sloping westward from an elevation of 7000 feet to where the dome gradually flattens out at an elevation of about 5000 feet. The surface of the plateau is drained by wide, flat-floored valleys which are trenched by narrow, shallow canyons. The general slope of the plateau being westward, the streams flowing westward are long and often permanent, while eastward-flowing streams are short and carry little water. The largest stream on the plateau, and the one which has cut the deepest canyon, occupies the famous Canyon de Chelly and its tributary, Canyon del Muerto. The streams carry much of the run-off from Chuska and Tunitcha Mountains. Their canyons are cut 800 feet deep in magnificent red sandstone, and above the brightly colored walls rise enormous pinnacles, buttresses, and towers which have been eroded out of the over-lying layer. Remains of important cliff dwellings, containing pictographs and other records of an ancient race, are to be found in these canyon walls.

Fossils in the Navajo Region

The shells or skeletons of marine animals may, after death, rest on the sea floor until they are covered by mud or sand, which eventually becomes solidified under the pressure of more and more sediment. Ages later, a fragment of this rock, which may have been raised above sea level and then exposed to view by erosion, may show the fossils embedded in it. Fossils may exist as impressions in the sediment, the whole of the animal having been replaced by mud or sand, later solidifying as a cast of the original. Sometimes worms leave casts of the holes that they have made. Dinosaur footprints are preserved as impressions in mud or sand by deposition of more sediment over them before they are weathered. But as a rule there is a gradual chemical replacement of the original bone or shell or wood by precipitation of minerals dissolved in water, thus leaving a natural crystallized cast of the original animal or plant. These processes also apply to land plants and animals, provided they are buried in rock-forming sediments before they decompose. In comparatively recent years, and in spite of the Noah's Ark tradition, geologists have finally progressed to the point where they can determine by a thorough examination of fossil remains, not only the plants and animals that once existed, but also the climate, elevation, and general geography of the country they lived in.

The oldest fossils known in the Navajo country are of Carboniferous age and include clams, sponges, brachiopods and other invertebrates. These remains indicate the marine origin of the Goodridge formation and Kiabab limestone. During the Permian age the land was largely under shallow water and there were extensive mud flats, showing ripple marks and cracks made by drying in the sun. Fossil remains include impressions of plants, fragments of vertebrate bones, and shells of mollusks. As far as fossils are concerned, the Triassic period is the most important in the southwest. The majority of petrified forests are of this age, as are many armored amphibians (stegocephalians) and reptiles. The Chinle formation is especially rich in fossils of these creatures. Jurassic beds contain very few actual fossil remains. Jesse Peter, of the Rainbow Bridge-Monument Valley Expedition of 1933, discovered large and small footprints of two-legged dinosaurs in Wingate sandstone at 71 Mile Post. Mr. Peter also found footprints at Dinosaur Canyon and on the rim of Rainbow Lodge Valley. Omer Stewart, of the same expedition, discovered a series of dinosaur footprints in a shallow cave along the south branch of the Tsegi-ot-Sosi Canyon. On the ceiling were casts of these footprints, the original impressions of which were found on slabs of rock that had fallen and lay beneath the cliff. Dinosaur tracks occur at Navajo Canyon and at Willow Springs in the Todilto formation. Professor R. S. Lull reported that the tracks seem to have been made by bipedal carnivorous dinosaurs.

Since the Navajo sandstone was formed of wind-blown sand, it is almost barren of fossils. Therefore when members of the Rainbow Bridge-Monument Valley Expedition of 1933 found a small dinosaur skeleton at Kit Sil Canyon, the discovery caused wide comment. The fossil was described as a new genus, Tsegisaurus, by Professor C. L. Camp. A centrum of a carnivorous dinosaur was found in Mo-Elmo formation near Red Lake Store. In formations of Lower Cretaceous period there occur a few ammonite fossils, as well as oyster-like bivalves and fossil wood. A long time elapsed between the Eocene and Pleistocene ages during which no rocks were formed in the Navajo Country. Vertebrate bones found near Shanto Springs were identified by Professor R. S. Lull as bones of primitive elephants (Elephas), ground sloths (Megalonyx), horses (Equus), and Bison of Pleistocene age. In 1934 the Rainbow Bridge-Monument Valley Expedition found a cave in a branch of Tsegi Canyon containing a Pleistocene deposit from which more than 100,000 small bird and mammal bones have been removed.

Looking back over this brief account of the fossil sequence, we can see that the Navajo country has gone through many changes in elevation and climate. The surface has shifted from ocean bottom to shallow muddy bays and estuaries and from low forested land to barren sandy deserts.

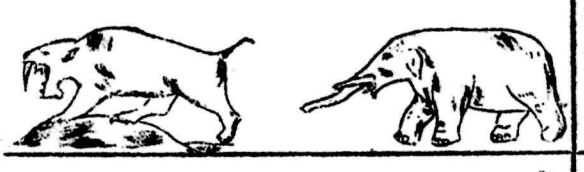
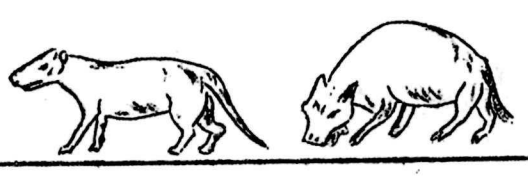
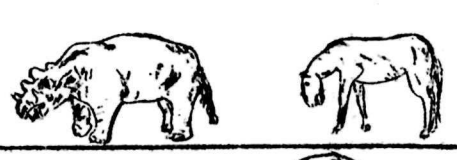
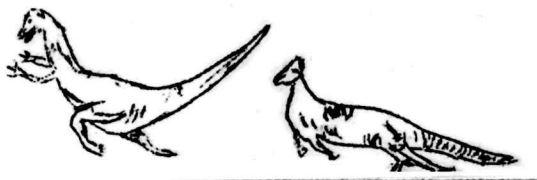
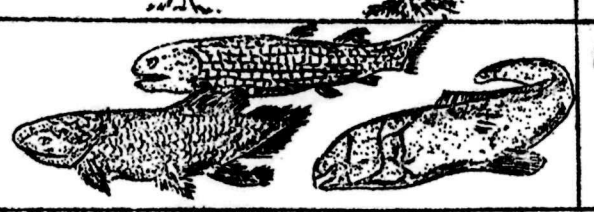
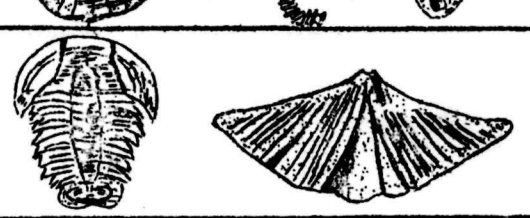
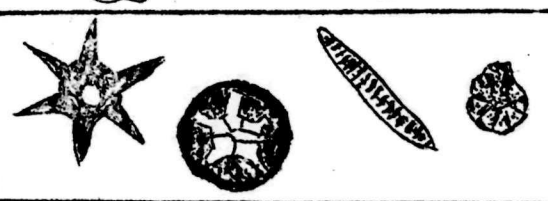
The Pre-Cambrian quartzite near Fort Defiance is the oldest known formation of the Navajo country. Where the original bedding is decipherable, the mass is seen to consist of coarse sandstone interspersed with lenses of conglomerate. Abundant ripple marks on sun-baked surfaces and a few mud cracks suggest subaerial deposition. Since deposition during Carboniferous time was continuous in adjacent areas it is probable that this mass of quartzite remained as an island through Pennsylvanian and possibly through all earlier Paleozoic time.

During Permian time the land was near sea level most of the time, although it probably underwent several minor submersions. The invertebrate fossils that have been collected in rocks of this period are of marine types. But there are abundant plant remains, and many of the formations exhibit dry land features.

The conditions prevailing in the Triassic period are uncertain. The first recorded Triassic deposit is the Shinarump formation, which is separated from Permian deposits by a widespread unconformity—indicating a long erosion interval. The coarse, siliceous conglomerate of this formation, containing a great quantity of fossil wood fragments is probably of land origin After the deposition of the Shinarump, the region was uplifted and became arid or semi-arid in climate, an area of low-lying lands, with numerous fresh and brackish bodies of water. This interpretation is based on the composition and structure of the rocks and the fossils found in the Chinle beds. Towards the end of Triassic time aridity and elevation increased, and the Navajo country became a desert of shifting sand.

GEOLOGICAL AGES

The Succession of Life

ERAS	DIVISIONS		Sketches of most characteristic plants and animals	Names of Plants and Animals
Psychozoic		Recent		Navajo Indians
	Quaternary	Pleistocene		Woolly Mammoth Great Ground Sloth Neanderthal Man
CENOZOIC (Age of warm blooded animals and modern plants)	Tertiary	Pliocene		Sabre-tooth Tiger Four Tusked Elephant
		Miocene		Oreodont (Grazing hog) Giraffe-Camel
		Oligocene		Creodont (Wolf-like beast) Giant Pig
		Eocene		Uintathere (Rhino-like beast) Eohippus (First horse)
MESOZOIC (Age of Reptiles)		Cretaceous		Triceratops (Armored Dinosaur) Toothed Birds
		Jurassic		Archaeopteryx (First bird-like creature) Plesiosaurs (Carnivorous marine reptile)
		Triassic		Anchisaurus (Carnivorous dinosaur HADROSAURUS AQUATIC DINOSAUR
PALEOZOIC (Age of higher invertebrates)	Age of first four legged animals and coal formations	Permian		Cotylosaurs Conifers Cacops
		Carboniferous		Tree Ferns Lepidodendrons
	Age of fishes	Devonian		Arthrodites (Armored fish) Ganoid Dipnoid (Lung fish)
		Silurian		Nautiloids (Like pearly nautilus)
	Age of invertebrates	Ordovician		Cephalopods (Shell fish) Crinoids Gastropods
		Cambrian		Trilobites Brachiopods
PROTEROZOIC (Age of unicellular life)				Radiolaria Foraminifera
ARCHEOZOIC (Age of primitive marine invertebrates)				No actual plant or animal remains found Indirect evidence only, Graphite, limestone & iron ore

S.H.

In Jurassic time these conditions prevailed during the deposition of the La Plata group of sandstones. The arrangement of the group indicates wind as well as water deposition. During later Jurassic time, arid conditions prevailed and land probably extended over an area including the Navajo and Hopi reservations. Bodies of water--salt, brackish, and fresh--were present and sparsely inhabited by fishes and invertebrates. The land must have supported sufficient vegetation for foraging, since skeletons and footprints are found in late Jurassic rocks. That the land surface was extensive at the close of Jurassic time is indicated by the widespread erosional unconformity which separates Jurassic strata from Cretaceous.

This period of vigorous erosion removed all traces of deposition during Lower Cretaceous time, if any strata of this age were ever present. In upper Cretaceous time, the heterogeneous Dakota sandstone, laid down chiefly by streams, indicated that streams were active and that parts of the country were swampy or estuarine. The sea was also present, but its work was chiefly that of shifting sediments previously deposited. The Mancos formation, consisting of shale and sandstone, containing marine fossils alternating with beds of soft lignitic coal, is evidence that for a long period after the deposit of the Dakota formation, the land was alternately below and above sea level. During the latest part of Cretaceous time, this alternate submersion and re-elevation continued--as shown in the composition of the Mesa Verde formation. With the beginning of the Tertiary period, the sea was permanently excluded from the Navajo country. Deposits containing freshwater shells indicate the presence of lakes, while the great extent of cross-bedded sandstone suggests the work of winds, since with every change in the direction of the wind, the material it carries is laid down at another angle. Folding and uplifting, beginning during the early Tertiary, brought the land to its present position above sea level. Vulcanism was active, and continued into the Quaternary period.

In the late Tertiary, during Pliocene time, erosion was dominant and parts of the Navajo region were reduced to a peneplain (a land surface of low or faint relief almost forming a plain). Regional uplifts, with increasing stream gradients, resulted in eroding away a great part of the Mesozoic and Cenozoic strata. Still later other uplifts of 3000-4000 feet further increased the power of streams and enabled them to cut the canyons which are conspicuous features of the Navajo country.

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