Mining and Metallurgical Section.

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The Petrified Forests and Painted Desert of Arizona.

BY PROF. OSCAR C. S. CARTER.

The physiographic division of Arizona is extremely simple and well marked. There is a high plateau in the northern half of the State and a low desert area in the south; a high wall or escarpment separates them. This escarpment enters Arizona from Utah on the north and trends from the north-west to the southeast; it is really the southern border or end of the great Colorado Plateau, which includes parts of Utah, Arizona and New Mexico, and extends from Utah southward, often as a series of gigantic steps. It is called the Colorado Plateau on account of the river of that name, which has cut in the plateau the most stupendous gorge in the world—"The Grand Cañon of the Colorado." Portions of this plateau are more than a mile higher than the desert area in the southern part of the State, and, as Merriam has pointed out, it acts as a barrier to the passage of animals and plants, but it must not be supposed that the boundary is always a cliff.

In this northern plateau in Arizona there is a vast depression or basin called the Painted Desert, which is the drainage area of the Colorado Chiquito or Little Colorado, which empties into the Colorado. The corrosion of the stream and its tributaries, which are often dry, and all the other forces of erosion have cut this basin and its channel and widened it. From near the mouth of the Little Colorado this Painted Desert extends southeasterly for a distance of 200 miles, and even enters the border of New Mexico. In its widest part, near the middle, the desert is about 75 miles wide. The slope, of course, is toward the Colorado River. It is called the Painted Desert on account of the bright colors of the sandstones, shales and clays.

Mesas of bright red sandstone are common. The shales are eroded into bizarre and fantastic shapes; all of these forms of erosion are colored, blue, yellow, red or green as the case may be, and with the bright sunlight and clear, dry air, the coloring is often brilliant. The Petrified For-

FIG. 1.

est is near the southern border of the Painted Desert, between the Rio Puerco and Zuni River, which are tributaries of the Little Colorado. The Painted Desert is not much of a basin or depression in this southern part of its area, as the

average elevation is over 5,000 feet above tide; neither has it any connection whatever with the low desert area in the southern part of the State. It is wholly in the plateau country. The Petrified Forests of Arizona may be classed among the strange corners of our country, and lie more or less off the beaten track. The general public do not as yet visit this locality as they do the Yellowstone or the Yosemite, yet it is quite accessible. More than 3,000 people visit the Yellowstone annually, and the number is increasing, yet Adam Hanna informed me, in 1889, that he had about a dozen visitors annually to his ranch on the Painted Desert, which is the nearest place to the Petrified Forest.

Thousands of visitors at the World's Fair became interested in the Petrified Forest when they admired the logs and polished slabs of petrified wood of various colors, bright red predominating. Sometimes they are cut into table-tops and pedestals. Very few, however, had any idea as to how the forest may be reached. The Mormon town of Holbrook is always associated with the Petrified Forest, probably because it is the only town of any size near the forest, except the still smaller station of Carrizo, which can be reached by a drive of 20 miles or more. If we take a folder of the Santa Fe Railroad we will see a flag station named Adamana, which is the best place to reach the forest. It is simply a signboard or mile post marked 233 Adamana, and is near the southern border of the Painted Desert, although the desert does not have the rich colors which the shales give it farther north. The forest is found scattered over from 8 to 10 square miles of territory, principally in township 17. Adamana is about 21 miles east of Holbrook. The conductor will have no compunction about dumping you down in the desert among the sage and soapweed, providing you keep on the alert and remind him not to run past the mile post. When the train rushes by you can see Adam Hanna's ranch in the distance, from which the station takes its name. The river fringed with cottonwoods (*Populus monilifera*), known as the Rio Puerco, or dirty river, runs lazily past the ranch. It is well named dirty, for it is always the consistency and color of strong chocolate. It is so muddy that no living creature is found in its waters.

FIG. 2.—View of a part of the Petrified Forest.

FIG. 3.—Agate bridge, 111 feet long, spanning ravine between mesas.

FIG. 4.—Agate log called the cannon, on top of the mesa.

FIG. 5.—Differential weathering of sandstone and shale in Petrified Forest.

On consulting a map we get the impression that it is a fair-sized river, but it is a river merely by courtesy. There are no large rivers in the arid district of the Southwest. What they call rivers, we call creeks in the East. The rainfall is slight, only 10 inches a year, often less, and evaporation so rapid that the air takes up the water like a sponge; hence, large rivers are out of the question, and some of them even disappear entirely under the summer's torrid sun. In a country like this they don't need to hang up clothes to dry, they will dry quickly enough on your back should you take a bath impromptu. Even the perspiration which comes so freely in traveling over the desert is soon dissipated by the hot dry air. It is no unusual sight, in the desert region farther north, to see a copious shower of rain falling from the clouds above, which never reaches the parched and dry shales of the desert because the hot dry air above the desert evaporates and absorbs it so quickly that it soon disappears. Even when a cloudburst occurs and the rain comes down in sheets, which is a common occurrence in the rainy season in July and August, and the arroyos are full of turbid streams of often liquid mud several feet in depth, yet in a few hours the desert is as dry as punk, and there is no evidence of a shower except the alkaline water which stands for a short time in the mud-bottomed pools. The Rio Puerco, in the summer, is not wider than a country creek and can be forded by the horses, but after cloudbursts in the higher plateau country, a stream of liquid mud 10 feet deep spreads from the mesa to the Santa Fe road, and even comes to the door of Adam Hanna's ranch. Fording the stream, however, is not child's play unless you know the ground, because the horses become mired and sink to their middle.

As Adamana is the nearest and best place to reach the forest, and Adam's ranch is the only one for miles at which the tourist can stop, our host deserves perhaps more than a passing notice. His life since boyhood has been spent in the Southwest, and has been a checkered one. He has been sheriff, herder, scout and section boss. Adam drove the stage between Denver and Salt Lake City in the early days

when it was a perilous undertaking; an Indian arrow wound in the leg testifies to his worst experience. He was also sheriff of San Juan County, Colo., and was located at Silverton, where the desperadoes made their headquarters when driven from Leadville. He was scout for General Buford for a while, and recently served two terms as sheriff of Apache County, Ariz., where he now lives. The office of sheriff in parts of Colorado and Arizona was not always a sinecure, and his reminiscences are sometimes entertaining. Adam took government claim of 160 acres and built his ranch alone in 1884. He had between 250 and 300 horses scattered over the near country, as well as many cattle. He drives cattle from Mexico to Deeming, Colo., where they are sold. When on these long journeys his wife stays alone on the ranch and plays the part of hostess.

There are no neighbors for miles. Two road-agents, who held up the Santa Fe train successfully, took supper there, but she did not know who they were until afterward. There is certainly a charm about the desert with all its disadvantages. The sunsets are beyond description. No matter how hot it is during the day, the nights are always cool. In that rare and dry atmosphere radiation is rapid, and the earth cools so rapidly that out of doors a blanket is comfortable at night. Cool nights on the desert are the rule much further south also, and in the report of the Mexican Boundary Commission, Capt. D. D. Gaillard reports temperatures of 110° F. and 115° F. in the shade, and even higher temperatures were recorded by standard thermometers; yet in the evening the temperature would drop to 65° F., a range of 50° during the day. Unfortunately it was not the shade temperatures with which the commission had to contend in traveling across the desert. The traveling was done in the open, and the low leafless flora of the desert are useless for shelter. Even the Giant Cactus (*Cereus giganteus*), which attains a height of from 40 to 50 feet, and the large and striking cactus called pitahaya by the Mexicans, which were passed by the commission near the Mexican boundary line, afford no shelter worthy of the name. At the Petrified Forest and to the north in the

FIG. 6.—Agate logs, from 15 to 20 feet in circumference.

FIG 7.—A stranded log *in situ* on an eroded ledge of sandstone, once embedded in that rock.

FIG. 8.—Enormous logs stranded on shale along the slope of the mesa.

FIG. 9.—A log *in situ* embedded in sandstone.

higher plateau country the nights are so clear that one can almost read a newspaper; Percival Lowell took advantage of this fact when he located his observatory at Flagstaff, Ariz., where some most important work has been done mapping out the canals of Mars, which has attracted attention at home and abroad. Work of this character could not be done in a smoky and hazy atmosphere like the East. At Adam's ranch the coyotes come close to the house for water from the pond; the Rio Puerco is too muddy. One can hear their peculiar bark at almost any hour of the night. The fauna and flora of the desert here are of a source of interest. Bright-colored lizards dart across the sand and an occasional horned toad seems clumsy when its movements are compared to the lightning darts of the lizards. The jackass rabbits which one starts from every clump of bushes are making sad havoc with Adam's little patch of Kaffir corn, the only crop he irrigates. Birds are scarce; the burrowing owl and desert sparrow are there, and Hanna says that one hears the mocking bird and oriole among the cottonwoods that fringe the Rio Puerco. Mrs. Hanna recently moved away from a wild cat among the branches directly overhead. Adam and a cowboy drove one from the cottonwoods and lassoed him in the open.

Small nocturnal forms of desert rats and mice and bats are met with. The sage (*Artemesia*), Mexican grease-wood (*Atriplex canescans*), soapweed, cacti and yuccas is the flora, with here and there a blade of grass struggling through the sand, scarcely enough for the cattle and horses when there is little rain. Those who have taken the trip to the Grand Cañon in the higher part of the plateau to the north during the rainy season of July and August have noticed how the open pine forests and vicinity are often carpeted with wild flowers, which soon gain a foothold after the rains. Some of these wild flowers are occasionally seen on the desert during the rainy season, but they do not last long.

An interesting fact about subterranean water for irrigation is that abundance of pure soft water is reached at a depth of less than 50 feet on Adam's ranch. The underground water of the Southwest is often hard, Adamana is

an exception. A windmill on the ranch supplies an enormous pond, more than 100 feet in diameter and 4 feet deep, with a plentiful supply sufficient for irrigation. The soil is fertile enough, and with irrigation fruits and vegetables of all kinds suitable to the climate could be raised. Under the present administration irrigation is receiving a fresh impetus, which will work wonders where irrigation is possible and reclaim much worthless land for the settlers. It has been

FIG. 10.—Pictographs made by cliff dwellers on sandstone, near Petrified Forest.

estimated by some that the arid land that can be reclaimed amounts to from 70,000,000 to 100,000,000 acres, an area larger than the New England States, New York and Pennsylvania combined; but it must not be forgotten that a greater part of the arid region can never be irrigated at all on account of elevation, absence of water above and underground, and other causes.

In some parts of the United States 25 acres of watershed

are required to collect enough water to irrigate an acre of ground. This helps to realize this fact. I stopped once at a little station called Humboldt, in Nevada, the surrounding desert was desolate and bare of trees; but I was surprised to find a grove of cottonwoods and a bright green sward in the struggling town, while a little fountain played at the station. It was a veritable oasis in the desert. A crowd of loungers, when questioned as to the source of the water

FIG. 11.—The Eagle's Beak. A freak of erosion of sandstone and shale.

supply, said it was piped a long distance from the mountains. They were asked, "Why not sink artesian wells?" Whereupon the spokesman said it reminded him of a question he once asked in a Kansas town. He asked a native where they obtained so much water and was informed that they piped it 7 miles from the hills. "Why don't you put down artesian wells?" he asked. "Distance just the same," replied the man.

The trip to the Petrified Forest is best made in the cool

hours of early morning. After fording the Rio Puerco, where the horses sink to their knees in mud, we soon strike the trail, and after an hour's journey we reach the mesas. These mesas rise to 60 or 70 feet above the desert. They are made up of a white disintegrating sandstone rock, which is held together by a feldspathic cement. Between the layers of sandstone are layers of red shale colored by red oxide of iron. It is at the base of and between these mesas that the petrified trees are found. The first indication of petrification one sees is bright red and yellow pieces of agate and chalcedony, showing the outlines of the bark; these are scattered over the ground long before one reaches the mesa, but no logs or large pieces are met with yet. After reaching the mesa we are strongly tempted to collect specimens, which would be considered fine enough to grace any mineral cabinet in the East, but Adam cautions us to wait, as there are more beautiful specimens farther on. Suddenly the horses make a turn around the edge of the mesa and then we see scattered over many acres enormous logs completely changed to agate, jasper or chalcedony. The sections or ends of the logs show brilliant reds, yellows and dull blues. The bark is not brilliant but dull and wonderfully well preserved, being almost lifelike in its naturalness. Some trees show even the knots to perfection; but even these trees, spread over many acres, are not the finest.

After a short drive between the mesas and another turn we come to some enormous logs. These are 4 feet in thickness and from 10 to 12 feet long. They have no branches, but the hundreds of small pieces, varying from a couple of inches to 1 foot in diameter, are probably in some cases the remains of branches. After a drive of several miles along the base and on top of the mesa through many hundreds of petrified trees, we failed to see a tree with branches or even one standing upright. All of the trees were lying on one side. Another important fact is that no tree, except one, was found which showed the entire length. There were many logs from 3 to 30 feet long. The one exception to this was well worth a visit. After clambering across the mesa we come to a ravine 50 feet in depth in the deepest part.

In the bottom are growing a clump of cedars, the only trees about the mesa. Spanning this ravine, which is 44 feet wide, is an enormous petrified tree which measured 4 feet in diameter in the thickest part. The tree does not end on the edge of the chasm, but continues across the sandstone mesa and enters a ledge of sandstone, making the length of the tree that is visible 111 feet. How far it extends into the sandstone we cannot tell. This is the only perfect tree we saw. It is interesting to account for the preservation of this entire tree and also to account for the fact that logs instead of trees are the rule.

It is the writer's opinion that some of these trees were broken into logs after they were petrified, and while they were imbedded in the solid rock. The entire plateau country comprising New Mexico, Arizona and beyond, were elevated in recent geological times (Tertiary) from 4,000 to 8,000 feet above tide. This elevation was gradual, but the strata, nevertheless, were subjected to pressure and enormous strain, which fissured them and cracked the trees while they were still imbedded in the sandstone and shale, before they were loosened by erosion. This seems more reasonable than the statement that they were split into sections by heat and cold, although, doubtless, many were. This large tree spanning the ravine has been called the natural bridge of agate. Unfortunately, there are several transverse cracks in this tree, and one near the mesa seems to extend entirely through the tree, making the position insecure. This is shown in the photograph. It should be braced in some way so as to prevent the entire collapse of the tree into the ravine below, as it will always be a source of wonder and interest to tourists, when the area is set aside as a Government Park, which will probably be done, as the bill has already passed the House. It may be that these trees are not *in situ*, but floated there in past geological ages, perhaps, down an ancient river into an inland sea, where they were buried in the sand and mud near the shore after they became waterlogged. These layers of mud and sand became shale and sandstone in after years, when the sea receded or evaporated owing to a change in climate

and other causes. The fact that shifting currents were active is readily proved. Photographs of sandstone showing cross bedding to a marked degree were obtained. It may be, however, that these trees grew along a shore line that was afterwards submerged, and they became buried in sand and mud. They are much crowded and the former view may be the correct one, although we cannot prove it.

How do we account for the fact that these trees are found stranded at the base and on the top of mesas? This is very simple. These mesas were once a continuous plateau of sandstone and shale, when a break, crevice or line of weakness once began, erosion soon completed the work and the gaps widened until finally the plateau was dissected into a series of mesas. As the disintegration of the sandstone and shale proceeded, the trees imbedded in the rock would be loosened and finally roll down to the foot of the mesa, where the most of them are now found. As these strata are of mesozoic age, many layers of rock must have disappeared since that time by erosion, so that the trees at the foot of the mesas and in the arroyos are not in place, but came from a higher horizon of sandstone which has disappeared by erosion. There are, however, many trees in place imbedded in the solid sandstone rock, their branches and trunks projecting from the edges of the mesas and plateaus; but most of these trees in place are in the highest part of the forest at an elevation of 5,700 feet above tide; these trees in place are several hundred feet above the valleys and arroyos in which the loose stranded trees are found. The Natural Bridge is the largest tree in place, and most of the trees in place are found in a coarse-grained sandstone, with a feldspathic cement; the cross bedding indicates shifting currents. While examining one of these trees, a lizard of brightest green darted under a rock. It seemed to be about 8 inches long and the scales fairly glistened in the sun. That layers of sandstone of immense thickness have disappeared from the top of the mesas one can readily see at a glance, because some of the trees are loose on top of the mesas where they were deposited when the rock eroded away. All of the trees have been changed to some form of

quartz, either agate, chalcedony, jasper or opal. By far the greatest number have been changed to the varieties of silica which have a waxy lustre. It is a well known fact that quartz resists erosion of all kinds better than any other mineral. It is practically insoluble in mineral acids and also in cold water. The only solvent met with in nature besides some organic acids, from decaying wood and vegetable matter, is hot water containing the alkalies, potash and soda in solution. So we may consider quartz one of the most insoluble minerals known. When granite rocks are exposed to the action of waves along the shore line, parts of all the minerals of the rock dissolve in the course of time except the quartz, and that forms the beach sands. Along the Atlantic Coastal Plain are quartz sands, and this would not be the case were it soluble and easily eroded. We can understand from this then, why petrified trees have resisted erosion and lasted so many ages, while the sandstone and shale in which they were imbedded have disintegrated and been swept away. Sandstone is simply made up of grains of sand held together by some cement. It may be clay, iron oxide, feldspar or lime carbonate. If the cement be slightly soluble the grains of sand are soon loosened and the rock disintegrates and is washed away.

We can easily see from this how the mesa in which the trees were imbedded has eroded, while the trees rolled down to the base of the mesa or were left stranded on top. Several peculiar mounds of rather striking appearance were noticed on the desert near the mesa, not far from the trees. These have been pronounced by some, after superficial examination, to be extinct geyser cones. There is no evidence whatever to support such a statement. The mounds are simply mounds of disintegrated colored shale, the peculiar form being due to weathering; no indication of geyserite was found. The mounds are certain to attract attention. They are due to erosion, because some mound-like forms were seen capped with a pinnacle of harder resisting sandstone. As soon as this topples over and disintegrates and is washed away by rains, then the underlying and softer shale will be moundlike in form. One of the most interest-

ing and bizarre forms due to erosion, which surpasses many unique forms in the Garden of the Gods, is the so-called Eagle's Peak.

This is a mound of peculiar shape at the base, surmounted by a shaft about 25 feet high, on top of which was a slab; both shaft and slab are of sandstone. When erosion proceeds far enough and the peak topples over, one of those peculiar mounds will be formed. The geological horizon to which the sandstone and shale of the forest belong is in dispute. J. W. Powell, formerly director of the U. S. Geological Survey, claims to regard them as Jurassic, while the other evidence seems to point to Cretaceous age. They occur probably in the Shinarump group of Powell. Sections of this wood under the microscope show that it is conifer. In 1853 Mollhausen discovered a petrified forest in a ravine near the Little Colorado in Arizona. The wood was submitted to Dr. Goppert, who pronounced it a conifer belonging to the Abitineæ. The Rio Puerco is a tributary of the Little Colorado. One of the logs in front of the U. S. Museum at Washington was taken from the mesa 2 miles north of Fort Wingate, N. M., which is not far from the Rio Puerco and just over the Arizona line. They were studied by F. H. Knowlton, who states that they are the same as Goppert's *Araucarites Mollhausianus*. Not *Araucarites* as that genus is understood, but *Araucarioxylon Arizonicum* from the fact that most of the wood is found in Arizona. F. Kunz, who visited a part of the forest near Carrizo, Ari., states, in the *Popular Science*, that he found trees projecting from volcanic ash and lava, which are covered with a depth of sandstone from 20 to 30 feet. He says the trees lie in gulches where the water has worn away the sandstone and the trees were overthrown and covered with a volcanic ash and tufa.

Dr. P. A. Dudley, of New York, examined this wood and says it belongs to the genus *Araucaria*, and that *Araucaria excelsa*, the present Norfolk Island pine of the South Pacific, grows to a height of 150 to 200 feet. Other pieces, he says, resemble red cedar *Juniperus Virginianus*. Be this as it may, many specimens show that the wood was going to

decay before it was petrified. The writer was not able to find any trees imbedded in lava of any kind; all the trees in place were imbedded in sandstone. The paleobotanist, Lester Ward, states that all the imbedded trees he examined were in sandstone. Scattered over the desert, way beyond the mesa, the writer found isolated pieces of lava, very small. Cinder showers and volcanic ash were common in Arizona in past ages, and lava flows are so common in the plateau country that one can pitch his tent almost every night on a lava flow, but most of the flows took place in tertiary times and many are more recent still, as their fresh surfaces little worn by erosion indicate. The trees are of mesozoic age, so that these trees were petrified long ages before the most of the lava flows took place. The writer believes that most of the petrification took place in the sandstone and shale, and was due to soluble silicates derived from decomposition of feldspar, which is the cement binding the sandstone. The silicate of potash or soda produced the petrification when it came in contact with the vegetable matter or trees that were imbedded. The silicates are soluble in rain water, and as they percolate through or over imbedded woody material the organic acids derived from the decomposition of the wood will decompose the silicate of potash and set free silica in the amorphous or gelatinous form, which will be precipitated on the wood and in the pores until the substitution is complete. In Pennsylvania pieces of petrified wood are found in new red sandstone; a feldspathic cement binds the grains of sand. We find petrified wood in many other localities far removed from lava.

Near Adam's ranch a small plant was erected by a Denver company, who intended to crush the agate trees and use the powder for an abrasive agent as a substitute for emery. The plant was never started, probably because of the introduction of a harder abrasive called carborundum, made in the electric furnace from coal and sand. At Sioux Falls, Dak., they polish petrified wood and make magnificent table tops and pedestals.

In the Yellowstone Park (U. S. Geological Survey Mono-

graph XXXII, Part 2) are found many petrified trees, but they are standing upright. They do not rise to any great height. They are mostly trunks on the slopes of mountains, and the highest of them rise to only 20 or 30 feet. They are found near Lamar River, the finest exhibit being on Amethyst Mount and Specimen Ridge, near the road between Mammoth Hot Springs and the town of Cooke, Mon. Yancey's fossil forest is one mile south of his hotel, on the slope of a hill 1,000 feet above the valley. There are only two trees of considerable size, the largest stump being 15 feet high and 13 feet in circumference. The bark is not preserved, so that the true diameter cannot be ascertained. They belong to the genus *Cupressoxydon*. Some trunks rise only a few inches above the ground. Some of the trunks near Specimen Ridge are sequoias. In early tertiary times these forests were supposed to have been buried under debris ejected from volcanoes and afterwards surrounded with water charged with silica, which petrified them. The largest trunk in the park is 10 feet in diameter. These trees which grew in tertiary times cannot, of course, be compared in age with the trees of the Petrified Forest, Arizona, which grew in mesozoic times.

CENTRAL HIGH SCHOOL,

PHILADELPHIA, January 30, 1904.

Correspondence.

SOME FURTHER NOTES ON CAST IRON.

To the Committee on Publications :

(1) Noticing the comments of Dr. Goldsmith (entitled "Does Cast Iron Grow?") in your current issue, I would say that I think it highly probable that the pressure caused by expansion of occluded gases in cast iron plays a prominent part in the phenomena noted in my paper on "Recent Investigations and Discoveries in Cast Iron," printed in the *Journal of the Franklin Institute*, February, 1904. I believe, however, that these gases ultimately escaped through the pores of the metal which has been expanded by repeated heating and cooling, and the intermolecular spaces are now filled with air.

In a paper entitled "The Mobility of Molecules of Cast Iron," read before the American Institute of Mining Engineers, at its recent meeting at Atlantic City, I stated my reasons for this belief, and in the original address