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THE SAN JUAN CANYON
SOUTHEASTERN UTAH

A GEOGRAPHIC AND HYDROGRAPHIC RECONNAISSANCE

BY

HUGH D. MISER

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THE SAN JUAN CANYON, SOUTHEASTERN UTAH

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LOCATION

The canyon bearing the name of San Juan River, which runs through it, lies in southern San Juan County, in southeastern Utah. It extends westward from the mouth of Chinle Creek to Colorado River, a distance of 63 miles in a straight line, yet it is so crooked that the distance by stream is 133 miles. (See Pl. XV.) The canyon has close precipitous walls as much as half a mile high and is continuous except for short distances where the river flows through open country.

San Juan River rises in the high San Juan Mountains of Colorado, whence it flows southwest into New Mexico, back into Colorado, enters Utah, flows west through its canyon, and joins Colorado River near the Utah-Arizona line.

The region trenched by the canyon is a rough, arid country, difficult of access, which forms a part of the broad Colorado Plateau. It is penetrated by few trails and still fewer roads, and parts of it are impassable for man and beast. All of the region lies more than 150 miles from a railroad, and some of it is about 200 miles from a railroad. Although the region includes a part of the Navajo Indian Reservation, it has not more than a few score inhabitants. The canyon was not the habitation of a single person in 1921. Bluff is the nearest post office, and the "villages" of Goodridge and Mexican Hat, with their combined population of half a dozen persons, are the only white settlements near the canyon.

PRESENT AND PREVIOUS EXPLORATIONS

This report, which describes the San Juan Canyon, San Juan River and the tributary streams, and the geography and to some extent the geology of the region, presents information obtained by me during the descent of the river with the Trimble party in 1921. The exploration of the canyon, which was financed jointly by the

United States Geological Survey and the Southern California Edison Co., had as its primary object the mapping and study of the San Juan in connection with proposed power and storage projects along this and Colorado rivers.[1] The exploration party was headed by K. W. Trimble, topographic engineer, of the United States Geological Survey. Other members of the party were Robert N. Allen, Los Angeles, Calif., recorder; H. E. Blake, jr., Monticello, Utah, and Hugh Hyde, Salt Lake City, Utah, rodmen; Bert Loper, Green River, Utah, boatman; Heber Christensen, Moab, Utah, cook; and H. D. Miser, geologist. Wesley Oliver, of Mexican Hat, Utah, served as packer for the party and brought mail and provisions by pack train twice a month to specified accessible places west of Goodridge.

The party descended the canyon by using two 16-foot flat-bottomed rowboats, which were built in Los Angeles, Calif., shipped to Green River, Utah, and hauled 170 miles with a quad truck to a point on the river 4 miles below Bluff, Utah. The boats were launched and the canyon voyage began July 18, 1921, and the mouth of the river was reached October 3. The length of the river thus traversed was about 140 miles, though before making the voyage we did not know whether we would have to travel 100 miles or 150 miles to reach the Colorado. The voyage was attended by strenuous labor and hardships, such as may always be expected in exploring an unknown canyon with its rapids in an uninhabited region. Its successful completion was due to the painstaking preparations and wise leadership of Mr. Trimble and to the loyalty and cooperation displayed by all his assistants.

During the descent of the canyon I made detailed and reconnaissance studies of the geology not only along the river but to distant points as far as 25 miles from the river. On October 5 I joined, at the mouth of the San Juan, Sidney Paige, E. C. LaRue, and Ellsworth Kolb, who had descended by boat Green and Colorado rivers from the town of Green River, Utah. The downstream party reached Lees Ferry, Ariz., October 8, after a hurried trip with only a few short stops, including a visit to the Rainbow Natural Bridge.

Numerous oil and gold prospectors have descended in rowboats and on rafts parts of San Juan Canyon between Bluff and Zahns Camp (see Pl. XV), and it is stated that a man with pack train ascended the canyon floor a considerable distance many years ago while the river was at an exceptionally low stage. Some of the prospectors ascended the canyon with their boats, but they had to tow the boats upstream, because the current is too swift for up-

[1] The maps and profiles along Colorado and San Juan rivers that were made in 1921 have been published in 22 sheets (16 plans and 6 profiles) and may be purchased from the Director of the U. S. Geological Survey, Washington, D. C., for 10 cents each sheet.

stream rowing. Bert Loper, our boatman, who spent two and one-half years prospecting for gold in the upper part of the canyon, beginning in 1893, made a trip at that time on a raft from Chinle Creek to Slickhorn Gulch in company with Bill Clark and John Clark. This trip he repeated numerous times with a boat, and on several trips he was accompanied by George Edmonson and James Hamilton. In 1894 Loper, together with Edmonson and John Clark, descended the canyon to Zahns Camp and then returned to the head of the canyon by towing the boat upstream.

The Trimble expedition was the first engineering expedition to descend and map the San Juan Canyon, and so far as I have been able to learn from printed records and from inhabitants of Utah it was the fourth expedition of any kind that has ever descended the full length of the canyon.

The first known trip down the canyon was made by E. L. Goodridge, an oil prospector, who descended in the spring of 1882 the San Juan and Colorado canyons from Bluff to Lees Ferry with the loss of one boat.[1]

In 1894 Walter E. Mendenhall, a gold prospector, of Lake City, Colo., made the trip alone in a crude hand-made boat from Mendenhall Cabin to Lees Ferry.[2] In the summer of 1895 he repeated the trip together with F. R. Mendenhall, A. A. Savage, George Munally, Charles Murphy, Charles Rhodes, and Eli Woolman. They had several boat loads of supplies and mining equipment.[2] Their most serious mishap occurred one night while they were asleep on the bank. The largest boat with the grub and mining equipment broke its moorings and floated off unaccompanied on its wild journey down the river, but fortunately it was found three days later at the head of a rapid, where it had lodged unharmed among willows.

The mapping of the canyon by P. Holman in 1884 as it is represented on the Abajo and Henry Mountain topographic maps of the United States Geological Survey is erroneous and is therefore of little practical use.

The San Juan oil field, near Mexican Hat and Goodridge, which lies north of and adjacent to San Juan Canyon, has been visited and fully described by Gregory[3] and Woodruff.[4] Gregory[5] during his field work in the Navajo country, visited the canyon at places and gives much information on its geography and geology. Some fea-

[1] Gregory, H. E., The San Juan oil field, San Juan County, Utah: U. S. Geol. Survey Bull. 431, p. 21, 1911.

[2] Letter dated March 5, 1922, from Heber Christensen.

[3] Gregory, H. E., The San Juan oil field, Utah: U. S. Geol. Survey Bull. 431, pp. 11–25, 1911.

[4] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 76–104, 1912.

[5] Gregory, H. E., The Navajo country: U. S. Geol. Survey Water Supply Paper 380, 1916; Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, 1917.

tures of the river, including the transported silt, the movement of débris, "sand waves," and measurements of velocity and discharge, have been described by Pierce.[6] These as well as numerous other reports and articles on adjoining regions have been consulted during the preparation of this report, and much information, for which credit is given in footnotes, has been abstracted from them.

A report describing briefly the rocks of this and other parts of the Colorado Plateau of southeastern Utah and northern Arizona was published in 1923.[7]

A report describing the structure of the rocks and the oil possibilities along San Juan Canyon has recently been published.[8]

ACKNOWLEDGMENTS

I desire to acknowledge my indebtedness to the following members of the United States Geological Survey: Sidney Paige, by whose direction I made the canyon voyage, for cooperation in both field and office work; Kirk Bryan, R. C. Moore, C. R. Longwell, H. E. Gregory, N. H. Darton, and W. T. Lee, for cooperation in office work; and K. W. Trimble, for cooperation and interest in geologic problems in the canyon.

Acknowledgment is also due to Messrs. Loper, Blake, Hyde, Allen, and Christensen, other members of the party, for assistance and information during and after the canyon trip. Mr. Allen has kindly furnished prints of his excellent set of canyon pictures, numbering nearly 150, for publication and for other uses.

SUGGESTIONS TO OVERLAND TRAVELERS

To penetrate the canyon country below Goodridge and Mexican Hat requires the use of a pack outfit, because there are no roads good enough to be depended upon at all times for travel in wagons or automobiles. Few wagons and still fewer automobiles have been taken into this area—in fact, much of it is impassable for man or beast. Zeke Johnson, of Blanding, Utah, and John Wetherill, of Kayenta, Ariz., not only serve as guides but provide pack outfits. In 1921 Wesley Oliver, of Mexican Hat (post office at Bluff, 25 miles away), with his pack outfit, was employed to carry supplies and mail for the Trimble expedition. If arrangements have not previously been made for equipment at Kayenta, Blanding, or

[6] Pierce, R. C., The measurement of silt-laden streams: U. S. Geol. Survey Water Supply Paper 400, pp. 39–51, 1917.

[7] Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1–23, 1923.

[8] Miser, H. D., Geologic structure of San Juan Canyon and adjacent country, Utah: U. S. Geol. Survey Bull. 751, pp. 115–155, 1924 (Bull. 751–D).

Mexican Hat, equipment should be procured at Gallup, Flagstaff, Dolores, Mancos, Green River, or other points on the railroads.

The information given below, which was acquired by H. E. Gregory from personal experience, may be helpful to those who desire to visit the canyon country.[9]

The Navajo is vigorous, intelligent, and capable of hard work if it is not too continuous. He will render assistance for pay, frequently for friendship, and is loyal and cheerful when fairly treated. He is, however, independent and will desert with scant ceremony when unjustly treated. He will help himself to interesting trinkets and to food, but may be trusted with valuable things and with important missions. He is a past master at driving a bargain. He is an expert horseman, but knows little of harness, wagons, and pack outfits. His knowledge of distances and of directions is of such nature as to be of little use to a white man. It is essential to success that the Navajo should understand and approve of you and of your mission, and therefore frankness should characterize all dealings with him. A Navajo, preferably a school boy recommended by a superintendent, should be a member of each party, not only to serve as guide and interpreter but to obtain advance information regarding water and forage and to establish friendly relations with those Indians who have slight acquaintance with the whites.

The Piute, in my opinion, is less trustworthy and less skillful than his Navajo neighbors.

The prevalent Indian diseases are tuberculosis and trachoma, a fact which should be kept in mind when hospitality is extended or accepted.

"Roads," in the local sense—that is, routes over which a staunchly built, lightly loaded wagon drawn by two, four, or more horses may be taken by skillful drivers—may be found here and there. * * * The land of the Navajos [and also of the Piutes] is, however, preeminently a "horseback country," and a pack train is the only type of outfit which offers freedom of movement. Quicksand is to be expected in all stream channels and in the beds of "dry lakes," and crossings should be tested before wagons or pack trains are intrusted to them. Owing to sudden rises of water, streams and dry washes should be crossed at the earliest favorable opportunity, and camp should never be pitched on the floor of even the most innocent looking dry stream bed or adobe flat.

The location of camps is necessarily controlled by the distribution of water, and the traveler should have reliable information regarding water holes and springs for the particular month during which he proposes to make his expedition. Grain for horses should be provided, as very few places afford the essentials of camp—water, wood, and forage—and barren zones surround most of the water supplies. Not all stores carry grain, and inquiries as to the amount available should be made beforehand. Fuel is lacking at many camp sites or is limited to yucca, grass, and annuals. Under such circumstances the abandoned "hogans" appear tempting; but some of these deserted huts have housed dying persons and are therefore taboo, and their use may lead to trouble. The traveler should never leave camp without a supply of water and should keep in mind the deceptive character of mirages. The danger from lightning may be minimized by avoiding shelter of trees during the thunderstorms that almost invariably accompany summer rains.

[9] Gregory, H. E., The Navajo country: U. S. Geol. Survey Water-Supply Paper 380, pp. 11–12, 1916.

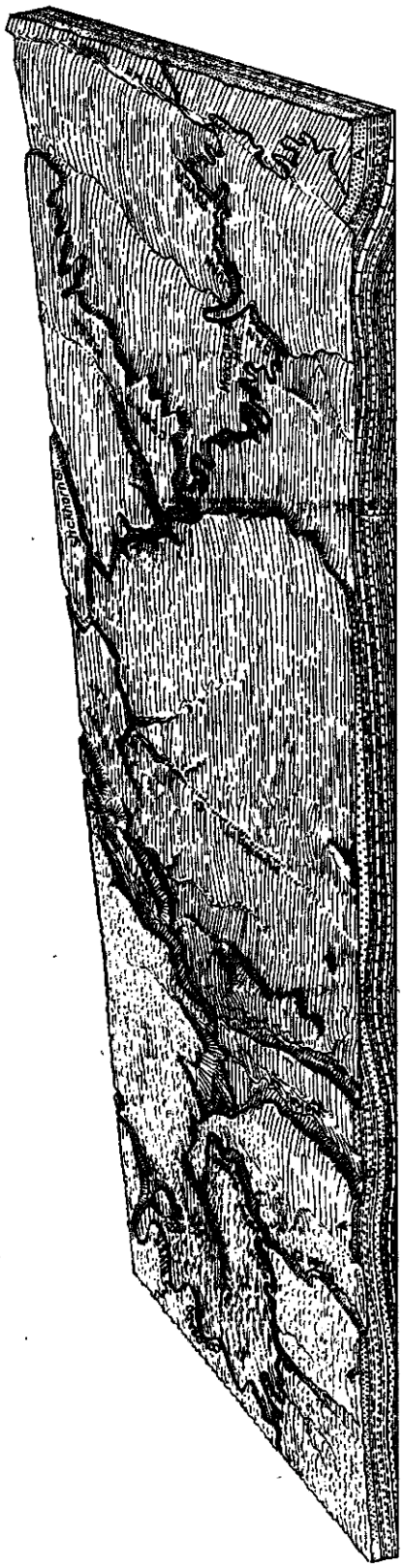


FIGURE 1.—Sketch of the country along San Juan Canyon, Utah, showing a vertical section in front, with a landscape beyond. A, Navajo sandstone, Todilto (?) formation, and Wingate sandstone; B, Chinle formation, Shinarump conglomerate, and Moenkopi formation; C, Coconino sandstone; D, Supai (?) formation; E, Chinle, Shinarump, Moenkopi, Coconino, and Supai (?) formations; F, Goodridge formation

Reliable information may be obtained from the officials at the various Government schools and from those traders and missionaries who have been long in contact with the Navajos.

GEOGRAPHY

SURFACE FEATURES

San Juan Canyon trenches a large arid region which is a part of the Colorado Plateau and which is a land of canyons, cliffs, mesas, and buttes. The general upland surface, averaging 5,000 to 6,000 feet above sea level, is not a single plateau but consists of several plateaus. (See fig. 1.) Each plateau appears quite regular and continuous in a panoramic view, yet they are all trenched by the crooked canyons of San Juan River and its many tributaries. The intercanyon areas are gently rolling to rugged and contain no extensive tracts of level land. The solitary peak of Navajo Mountain, the only mountain that stands near the San Juan in Utah, towers to a height of 10,416 feet.

The roughness of the region, combined with the meager rainfall, the almost total absence of soil, and the scantiness of grass, sage, pine, piñon, and cedar, make it a desert waste practically all of which reveals bare rock ledges. Because the rocks have many colors—gray, buff, brown, red, pink, lavender, green, yellow—

and also have many shades of a single color, any landscape view presents a kaleidoscopic variety, though buffs, browns, and reds predominate, and the exposed edges of the gray rocks are generally stained with these three colors.

The rocks, which generally lie in nearly horizontal beds, do not all offer the same resistance to weathering, and for this reason the character of the surface features depends in large measure on the character of the rocks. Thick beds of hard sandstone and limestone form vertical cliffs, above which there are benches or plateaus, whereas shale produces slopes or badland areas. Stream channels cut entirely in sandstone and limestone are confined in narrow, steep-walled canyons; but the channels that are cut into thick beds of shale are bordered by wide valleys, whose slopes are surmounted by precipitous cliffs of the overlying hard sandstone.

San Juan Canyon extends westward from a point near Bluff to the junction of the San Juan with the Colorado; the air-line distance is about 63 miles, yet the canyon is so crooked that it is 133 miles long. (See Pl. XV.) It is continuous, and the walls, which are as much as half a mile high, are close together, except for a few stretches where the river is bordered by fairly wide valleys. The features of the canyon, the tributary canyons, and the adjoining plateaus are described below, beginning with the country in the vicinity of Bluff and thence continuing downstream.

BLUFF TO CHINLE CREEK

At and near Bluff the San Juan flows in a flat-bottomed valley half a mile to 1 mile wide, in which lie the village and its adjacent irrigated tracts. (See Pl. I, *A*.) The valley is bordered by gray to red precipitous cliffs more than 200 feet high which mark the edge of broad, flat-topped mesas described by Gregory[10] as the Gothic Mesas. The mesas extend for many miles south, east, and north of Bluff; but on the west they swing away from the river toward the north and the south, so that the valley becomes wider. This wide valley is floored by red rocks and contains high gravel-capped terraces. It is limited on the west by the narrow Comb Ridge, which has a general northeasterly trend. The ridge has a gentle east slope, which is trenched longitudinally by the narrow canyon of Butler Wash, a tributary of the San Juan, and its straight, sharp crest of buff and brown sandstones, rising many hundred feet above the adjacent country, is a conspicuous feature along its entire length of 70 miles. The river runs through the ridge in a narrow silt and gravel

[10] Gregory, H. E., The Navajo country: U. S. Geol. Survey Water-Supply Paper 380, p. 31, 1916.

filled gorge several hundred feet deep, and after emerging from the gorge it is joined by Comb Wash from the north and then runs southwest for 2 miles in a wide valley of red rocks parallel with the precipitous west face of Comb Ridge. In this valley the river is bordered by large bars of yellow sand and is joined on the east by the small though long Chinle Creek, whose mud-filled channel passes through Comb Ridge not only near its mouth but at several other places farther southwest.

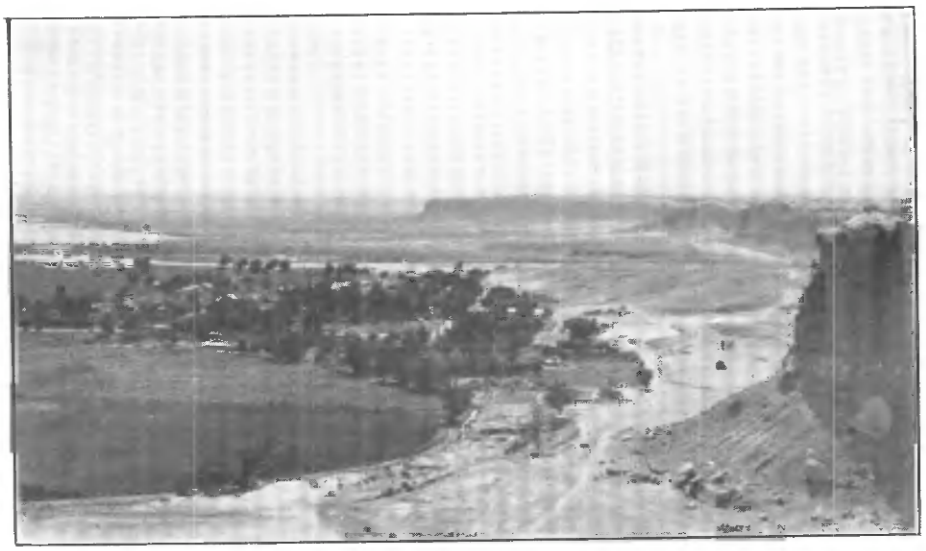
CHINLE CREEK TO CEDAR POINT

Just below the mouth of Chinle Creek the San Juan turns northwestward and enters the treacherous canyon, 133 miles long, that bears its name. (See Pl. I, *B*.) The canyon and the adjoining country from the mouth of Chinle Creek to the vicinity of Cedar Point have similar features. The canyon is less than 100 feet in depth at places near Spencer trading post (formerly Goodridge post office) and near the village of Mexican Hat, but through most of this stretch it is many hundred feet deep, attaining about 1,000 feet in the Soda Basin, east of Mexican Hat, and 1,340 feet at and near the Honaker trail. (See Pls. II–IV.) The first place that the floor of the canyon can be reached by trail below the Mendenhall Loop is at the Honaker trail. The floor can be reached by trail at only a few places between Chinle and Lime creeks.

Notwithstanding the great depths of the canyon and its inaccessibility, it is as crooked as the course of any stream that meanders on a wide flood plain. The San Juan once, in fact, flowed with a crooked course across a level or nearly level plain, and the present bends are simply the old bends that have been lowered or intrenched in the plain. The most closely spaced bends are the famous "goosenecks," 4 miles west of Mexican Hat, a panoramic view of which has been given by Gregory[11] and also by Grabau.[12] The river channel ranges in width from about 50 feet to several hundred feet. It is skirted here and there by gravel and sand bars, but at most places the water's edge is met by the base of high talus slopes and by precipitous walls that rise in a series of uniform steps consisting of alternating sheer cliffs and steep slopes. The prevailing colors of the walls are pink, brown, and red, though some rock ledges are not discolored and thus reveal their true gray color. The gray color of the rocks is also revealed in irregular patches from which slabs and boulders of rock have fallen by gravity or have been blasted by lightning, and in the bottoms of ravines of steep gradient which are

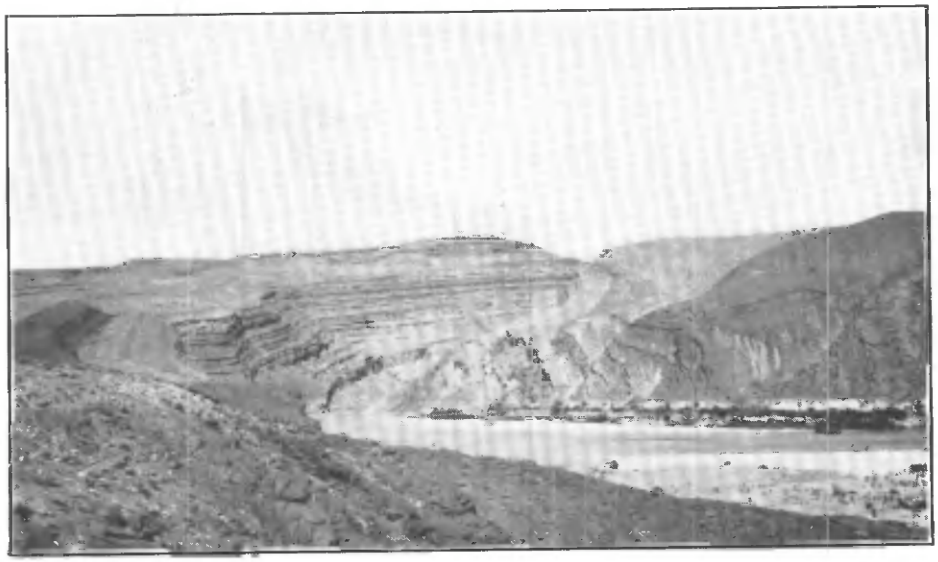
[11] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pl. 26, *A*, 1917; Military geology and topography, fig. 25, Yale Univ. Press, 1918.

[12] Grabau, A. W., A text-book of geology, pt. 1, p. 706, 1920.



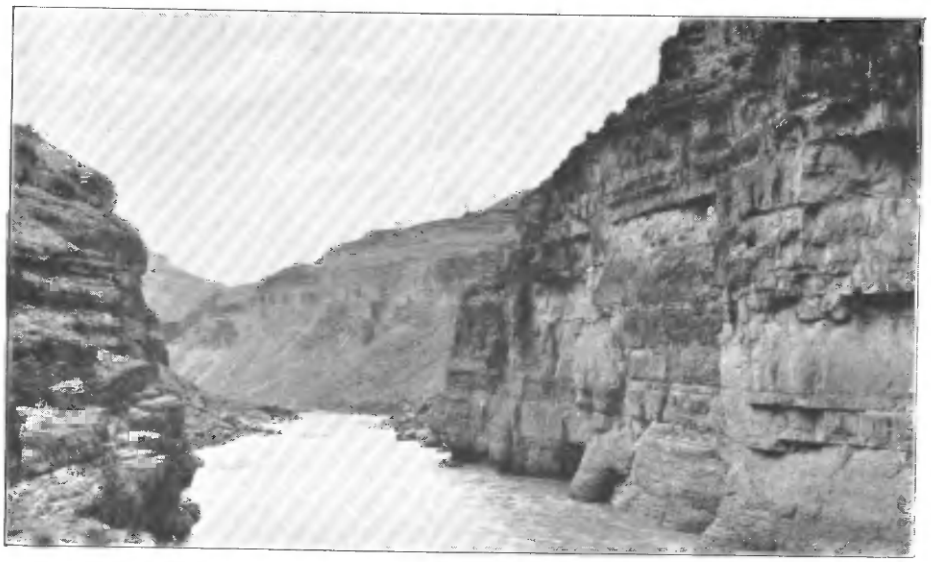
A. BLUFF, UTAH, IN VALLEY OF SAN JUAN RIVER, LOOKING SOUTHWEST

Photograph by Robert N. Allen

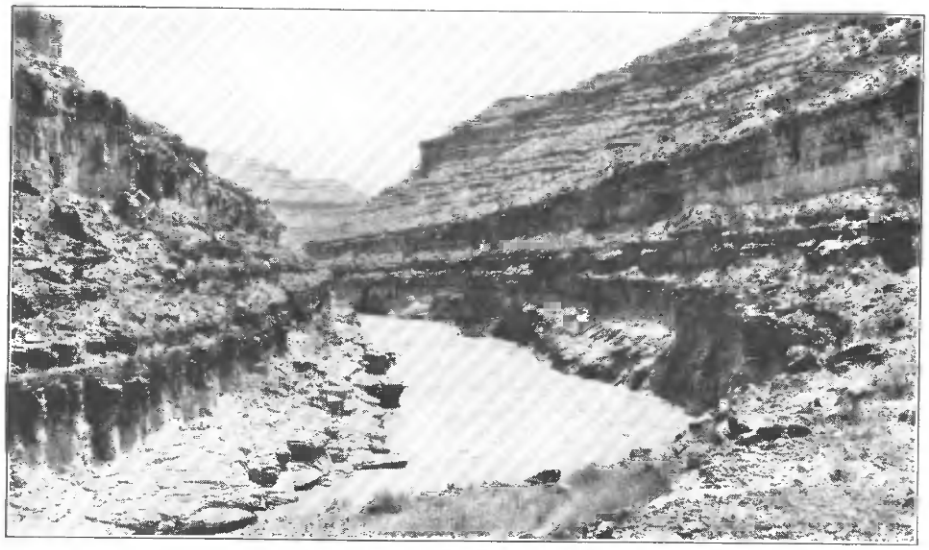


B. ENTRANCE TO SAN JUAN CANYON JUST BELOW MOUTH OF CHINLE CREEK, LOOKING SOUTHWEST

Goodridge formation produces canyon walls. Photograph by H. D. Miser



A. THE NARROWS, LOOKING DOWNSTREAM



B. SECOND NARROWS, LOOKING DOWNSTREAM

SAN JUAN CANYON

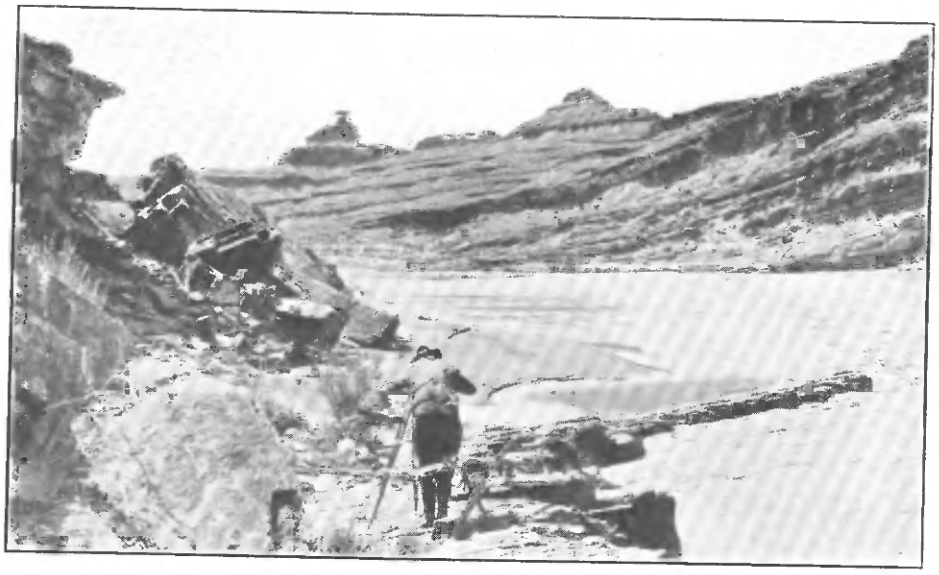
Walls are formed by Goodridge formation. Photographs by Robert N. Allen

A. THE TABERNACLE, IN A LOOP OF THE RIVER, LOOKING WEST

Canyon is trenched in Goodridge formation. Photograph by Robert N. Allen

B. VIEW LOOKING WEST FROM HEAD OF HONAKER TRAIL

Cedar Mesa to right capped by Coconino sandstone. Supai (?) formation is in lower half of escarpment of mesa. Canyon is in Goodridge formation. Photograph by H. D. Miser



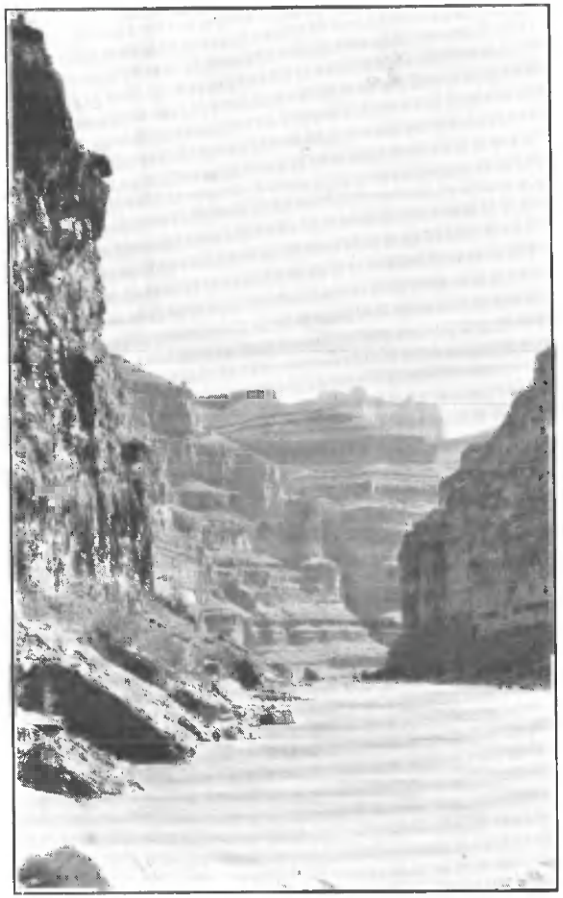
A. VIEW LOOKING SOUTH (DOWNSTREAM) TOWARD MEXICAN HAT
Sandstone ledges here produce a rapid

B. A THUNDERSHOWER—THE CHARACTERISTIC RAINSTORM OF THE SAN JUAN COUNTRY

View looking north from a point near Mexican Hat

SAN JUAN CANYON

Photographs by Robert N. Allen



A. VIEW LOOKING UPSTREAM FROM A POINT ABOUT 1 MILE ABOVE THE MOUTH OF JOHNS CANYON

Coconino sandstone forms distant high buttressed cliffs. Goodridge formation occurs in lower parts of walls. Photograph by Robert N. Allen

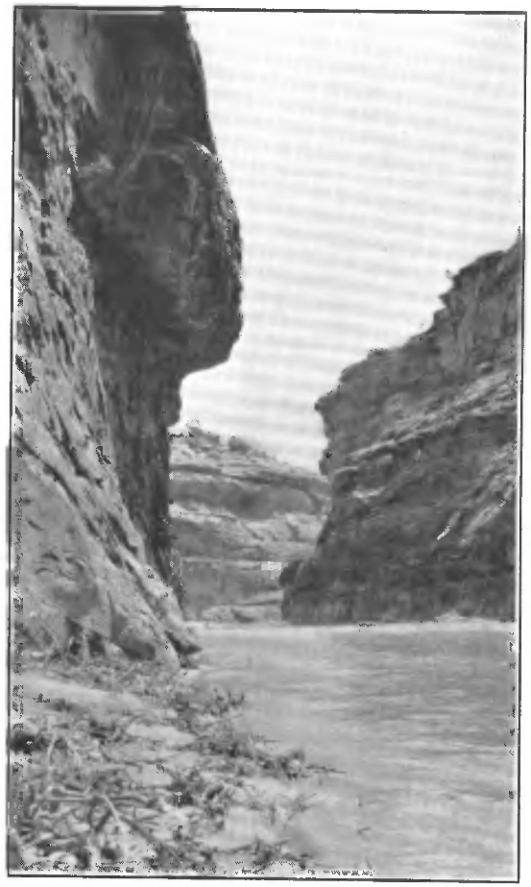
B. VIEW LOOKING UPSTREAM FROM POINT ABOUT 2 MILES BELOW MOUTH OF JOHNS CANYON

Lower part of wall formed by Goodridge formation; upper, sunlit part by Coconino sandstone and Supai (?) formation. Photograph by H. D. Miser

SAN JUAN CANYON

A. VIEW LOOKING NORTHWEST (DOWNSTREAM) TOWARD MOUTH OF SLICKHORN GULCH

Note boulder bar and rapid at mouth of gulch

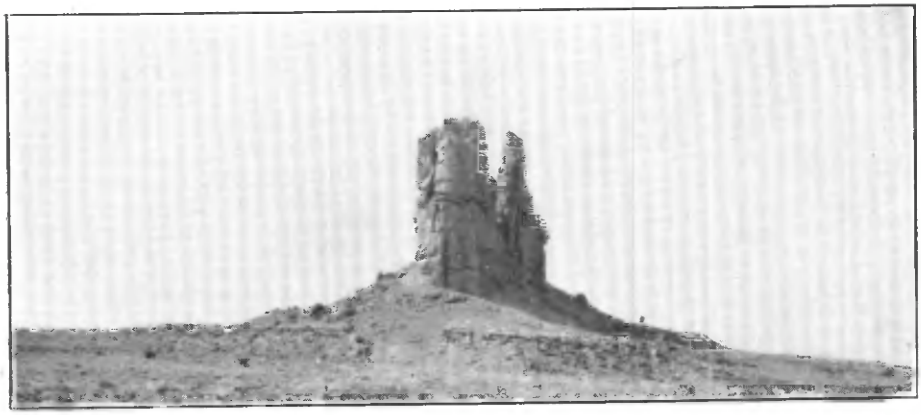


B. VIEW LOOKING UPSTREAM FROM POINT BELOW MOUTH OF MOONLIGHT CREEK

Cliffs of Coconino sandstone rise sheer from water's edge

SAN JUAN CANYON

Photographs by Robert N. Allen

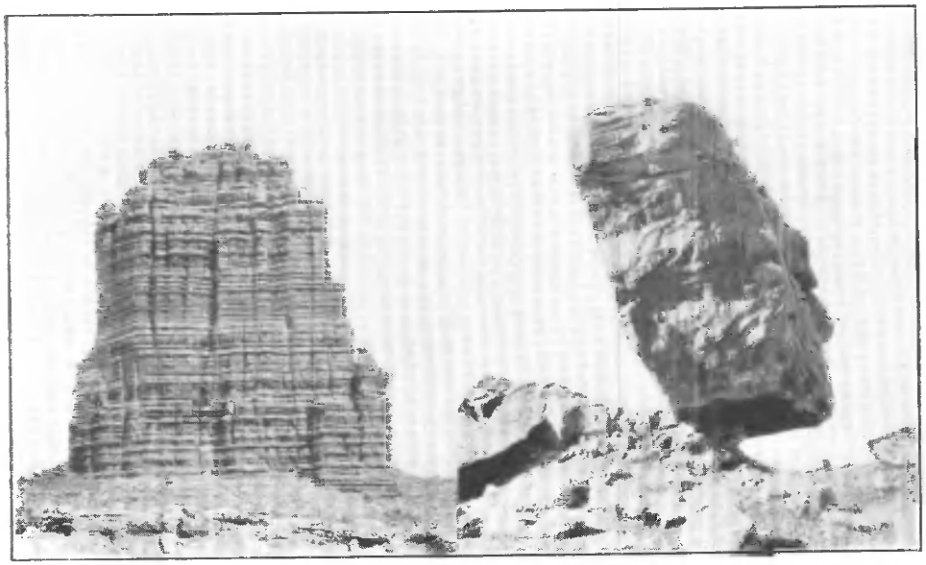


A. ALHAMBRA ROCK, A BLACK VOLCANIC NECK, RISING ABOVE A VAST EXPANSE OF RED ROCKS

Photograph by H. D. Miser

B. TRAIN ROCK

An outlier of Moenkopi formation, 800 feet high and 2 miles long, rising above floor of Coconino sandstone. View looking southeast. Photograph by H. D. Miser



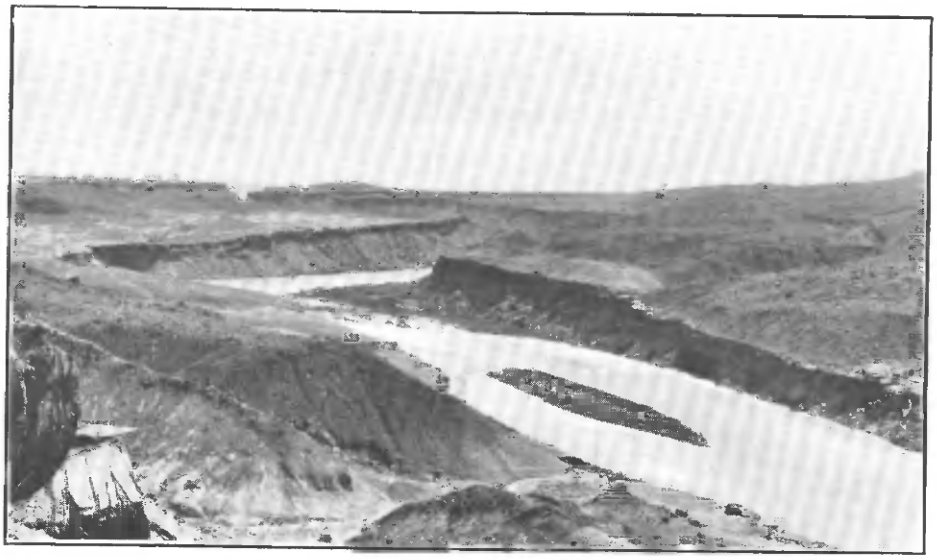
C. THE BEAUTIFUL RED ORGAN ROCK

An outlier of red Moenkopi beds, 375 feet high

D. END VIEW OF BALANCE ROCK

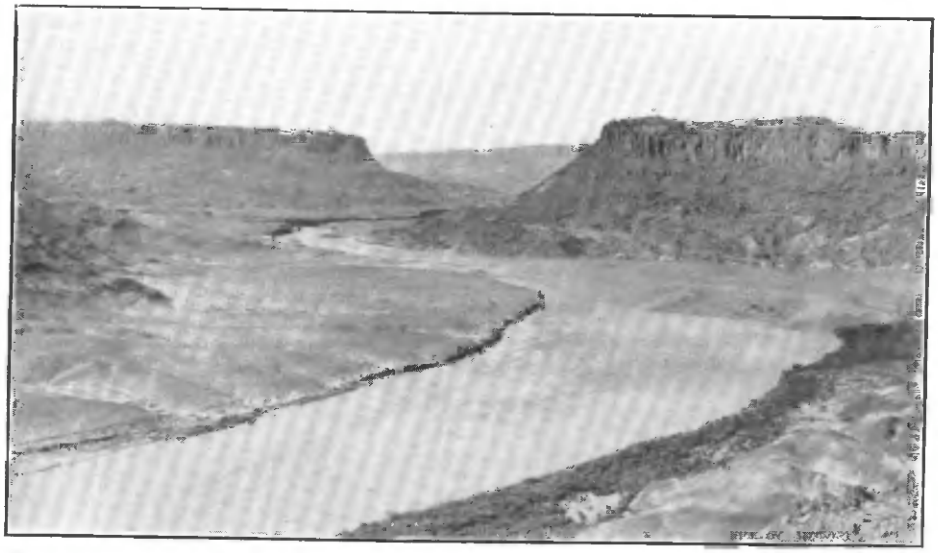
Rock is larger than a box car. Note profile of human face on right

Photographs by H. D. Miser



A. VIEW LOOKING EAST (UPSTREAM) FROM POINT HALF A MILE BELOW THE MOUTH OF CLAY GULCH

The platform trenched by the inner canyon is floored by the Shinarump conglomerate



B. VIEW LOOKING SOUTHWEST (DOWNSTREAM) FROM CLAY GULCH TOWARD COPPER CANYON

The wide shallow channel is here touched by long badland slopes of the Chinle formation, which are surmounted by impassable palisade-like cliffs of the Wingate sandstone and Todilto (?) formation. Low-walled inner canyon in distance is in Shinarump conglomerate

SAN JUAN CANYON

Photographs by Robert N. Allen

scoured by rock-laden torrents during rainstorms. A notable feature of the south canyon walls is the occurrence of yellow sand dunes that have been built in protected spots by the prevailing southwest winds.

The plateau trenched by this part of the canyon is floored by red and gray rocks which are concealed in considerable areas by scanty soil, sagebrush, and grass. It ranges in altitude from about 4,500 to 5,500 feet and is gently rolling except for numerous small tributary canyons and for a number of peaks and buttes that rise above its floor. The dark-gray, almost black Alhambra Rock (Pl. VII, *A*) stands 3 miles southwest of the Goodridge bridge, and a great number of picturesque buttes (Pl. IV, *A*) are to be seen near Mexican Hat and farther north. The best published but by no means accurate map showing the surface features of the plateau was made by Woodruff.[13] The plateau on its east side is limited by the westward-facing escarpment of Comb Ridge, already mentioned; on the south it merges with the floor of Monument Valley, where many buttes, called monuments, rise nearly 1,000 feet above the valley floor; and on the west and north it is limited by a sheer escarpment several hundred feet high, which is the east edge of a higher plateau. The east edge of the part of the higher plateau that lies north of the San Juan is known as Cedar Mesa or Cedar Ridge, and the southernmost point of the mesa is known as Cedar Point. (See Pls. III, *B*, and XVI, *A*.)

CEDAR POINT TO CLAY HILL CROSSING

San Juan Canyon is about 2,000 feet deep in the vicinity of Cedar Point, but gradually becomes shallower toward the west until it terminates at Clay Hill Crossing. Between Cedar Point and the mouth of Grand Gulch the canyon walls, which rise from the water's edge except where there are talus slopes and some bars of sand, gravel, and boulders, comprise three distinct divisions. (See Pls. III, *B*, V, and VI, *A*.) The lowest division is made up of a series of alternating sheer cliffs and steep slopes, such as are found along the canyon between Cedar Point and the mouth of Chinle Creek. It is about 1,300 feet high near Cedar Point, but gradually becomes lower toward the west until it disappears at the water's edge at a locality about 1 mile below the mouth of Grand Gulch. The middle division is a fairly uniform though steep slope of red rock about 400 feet high, and at its base there lies a narrow flat bench which is followed by a poor road running east from the mouth of Slickhorn Gulch. The top division is a continuous sheer and inaccessible cliff 400 to

[13] Woodruff, E. G. Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pl. 9, 1912.

perhaps 600 feet in height, which is composed of buff to brown sandstone. Like the middle division and the top of the lower division, it becomes lower and lower toward the west; its base is about 1,700 feet above the river at Cedar Point, about 900 feet above at Slickhorn Gulch, and about 450 feet above at the mouth of Grand Gulch. The top canyon walls are less than half a mile apart at the mouth of Grand Gulch, but as they become higher upstream the distance between them increases; near Cedar Point they are perhaps 4 miles apart.

Below Grand Gulch the sheer cliff just described continues to become lower, and at the mouth of Buckhorn Canyon its base reaches the edge of the river. The steep subjacent slope also becomes lower below Grand Gulch. Between the mouth of Buckhorn Canyon and Clay Hill Crossing the San Juan runs between vertical walls a few hundred feet apart that rise from the water's edge except at places where short sand bars are present. At and near the mouths of Buckhorn and Moonlight canyons the walls are about 600 feet high, but they descend downstream and terminate at Clay Hill Crossing. (See Pls. VI, *B* and XVI, *B*.)

Between Cedar Point and Clay Hill Crossing San Juan Canyon trenches a westward-sloping plateau. The part of the plateau lying north of the canyon is bounded on the north by Elk Ridge and on the west by the Clay Hills, and to portions of it the names Grand Flat, Polly Mesa, and Cedar Mesa have been applied. The southern part of the plateau, which is bordered on its south and west sides by higher country, was called Monument Valley by Gregory.[14] Beautiful Organ Rock, 375 feet high, and Train Rock, about 800 feet high, as well as other buttes near by, are within this valley. (See Pls. VII, *B*, *C*.) The plateau near the San Juan slopes gradually toward the west from an altitude of about 6,000 feet to about 3,700 feet but rises toward the northeast to almost 7,000 feet. It is so rugged as to be nearly inaccessible except around its borders, for its floor of gray to buff sandstone is deeply trenched by steep-walled canyons, including Johns Canyon, Slickhorn Gulch, Grand Gulch, the head of White Canyon, and the canyon of San Juan River. Grand Gulch, which I ascended to a point three-fourths of a mile from the river, presents some of the wildest scenery along the San Juan. It is a dark, narrow canyon with vertical red walls several hundred feet in height at whose base lie heaps of huge boulders and great piles of driftwood. At the mouth of the gulch there stands a castle-like column of brown sandstone 400 feet high, whose position and form suggest that it is an ancient fortress guarding the approach to the gulch.

[14] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380 and Prof. Paper 98.

CLAY HILL CROSSING TO PIUTE FARMS

Between Clay Hill Crossing and Piute Farms the river runs in a wide valley showing numerous terraces and ravines and a general badland topography; and the channel, which is skirted by very little alluvium, ranges in width from several hundred feet to more than 3,300 feet. In this stretch many islands of ripple-marked sand are revealed during low stages. The valley is sharply bounded on the west by a mesa 2,000 feet high surrounded by cliffs, but on the east it is bordered by the low country along the west edge of the plateau, which rises eastward, culminating in Cedar Mesa. (See Pls. XIX, *A* and XX, *A*.) The terraces, which are floored with gravel, are especially extensive east of the river and rise in steps toward the east, attaining an altitude of about 600 feet above the river near the mouth of Moonlight Creek.

PIUTE FARMS TO MOUTH OF RIVER

Between Piute Farms and the mouth of the San Juan the country along the river and also for many miles on each side reveals diverse surface features, though it is in general a much dissected plateau, highest to the east and lowest to the west, which attains altitudes ranging from 4,500 to 6,000 feet and which stands 2,000 feet above the westward-sloping plateau that adjoins it on the east. The plateau extends southward beyond the dome of Navajo Mountain (Pl. XII, *A*), which rises to an altitude of 10,416 feet, and it extends northward and westward across the Colorado to the lofty peaks of the Henry Mountains, about 11,000 feet above sea level; to the broad, straight northwestward-trending ridge known as the Waterpocket Fold, 6,000 to 7,000 feet; and to the broad Kaiparowits Plateau, 7,500 feet. The country west of the Piute Farms is so greatly dissected that most of its surface is extremely rugged and is accessible at only a few places. The canyons, 1,000 to 2,500 feet deep, are deepest and widest to the east, where the intercanyon areas are in reality mesas. The walls of many canyons are vertical cliffs, but others, especially the deepest ones, have walls composed of a series of alternating sheer cliffs and gentle to steep slopes. The only canyons here described are those of the San Juan and its tributaries. Parts of the intercanyon areas are level or gently rolling, but other parts, especially west of Spencer Camp and Piute Canyon, reveal numberless gigantic well-rounded mounds, domes, and "mosques" of solid bare buff sandstone. The largest and most conspicuous area of level plateau country is a grass-carpeted tract known as Wilson Mesa, about 4,500 feet in altitude, 6 to 8 miles long, and 3 to 4 miles

wide, which lies between the San Juan and the Colorado near their junction. (See Pl. XI, *B*.) The rugged country near Wilson Mesa is briefly described by Judd [15] in two recent articles.

Between Piute Farms and Spencer Camp the San Juan and its tributaries run between mesas that rise 2,000 to 2,500 feet above the river. The top edges of the mesas are bordered by inaccessible palisade-like cliffs, 200 to 900 feet high, which are composed of buff, dark-brown, and vermilion sandstones. (See Pls. VIII, *B;* IX, *C;* X.) Below the cliffs there are long badland slopes about 850 feet high which reveal in considerable areas marly shale with beautiful variegated colors but in other areas a tangle of huge angular boulders of sandstone and finer materials that have fallen from the cliffs above or have reached their present position through landslides. These slopes touch the river at Spencer Camp and for a distance of 2 miles between the mouths of Clay Gulch and Copper Canyon. (See Pl. VIII, *B*.)

From Piute Farms to a point half a mile below the mouth of Clay Gulch a comparatively level platform lies at the base of the badland slope. In this platform the San Juan has cut a narrow inner canyon and a few small tributaries have cut side canyons. (See Pl. VIII, *A*.) The walls of the inner canyon, each composed of a steep slope of soft red rocks capped by a sheer cliff of gray to brown conglomeratic sandstone, are 500 feet high to the east and become lower downstream until they terminate half a mile below the mouth of Clay Gulch. For considerable distances they extend down to the water's edge, but elsewhere their base is separated from the river by narrow bars of sand and gravel.

The San Juan enters a similar inner canyon at a point half a mile above the mouth of Copper Canyon and leaves it at a point just below the mouth of Nokai Canyon. (See Pls. VIII, *B;* IX, *C;* X, *A*, *C*.) The vertical walls, which are composed of conglomeratic sandstone, attain a height of 200 feet, and above them there are fairly level benches. The walls rise from the water's edge except where narrow short bars of sand and gravel intervene. Nokai and Copper canyons, which enter the south side of the main canyon in this stretch, also have narrow inner canyons that increase in depth and width upstream. They were followed to points several miles away from the San Juan; at such points they are 500 feet or more in depth and have serrated walls.

A conspicuous and interesting feature half a mile north of the mouth of Nokai Creek is a balanced rock standing on the crest of a spur about 400 feet above the river. (See Pl. VII, *D*.) It is so

[15] Judd, N. M., Beyond the Clay Hills: Nat. Geog. Mag., vol. 55, pp. 275–302, 1924; Explorations in San Juan County, Utah: Smithsonian Misc. Coll., vol. 76, No. 10, pp. 77–82, 1924.

A. MESA OF VARIEGATED MARLY SHALE IN CHINLE FORMATION NEAR MOUTH OF PIUTE CREEK

Photograph by H. D. Miser

B. VIEW LOOKING WEST TOWARD ONE OF THE CLAY HILLS FROM A POINT JUST NORTH OF CLAY HILL CROSSING

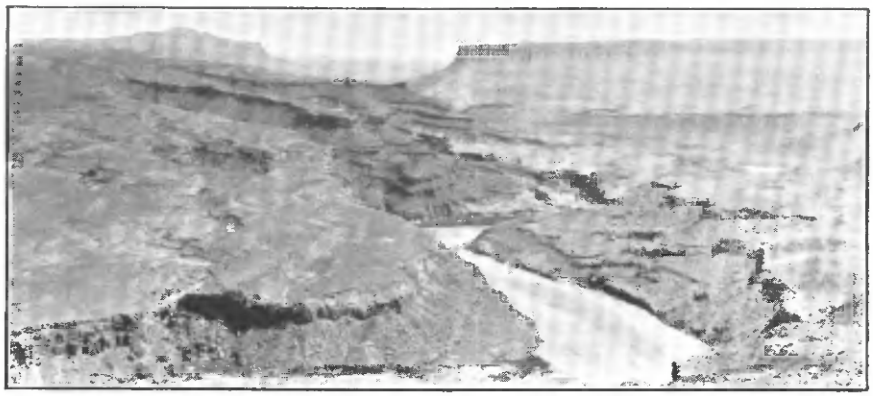
The palisade-like cliff next to the summit is formed by the edges of the Todilto (?) and Wingate sandstones. The subjacent mottled badland slope is underlain by the Chinle formation. The lower dark buttressed and fluted cliffs are produced by the Moenkopi formation. Photograph by H. D. Miser

C. VIEW LOOKING NORTH (UP THE SAN JUAN) FROM TOP OF CLIFF NEAR MOUTH OF NOKAI CREEK

Rocks are here bowed upward into broad arch. Photograph by H. D. Miser

A. VIEW LOOKING WEST TOWARD BALANCE ROCK ANTICLINE FROM POINT 1 MILE ABOVE MOUTH OF NOKAI CREEK

Cliffs of inner canyon in foreground are formed by the Shinarump conglomerate. The position of Balance Rock indicated by the cross. Photograph by H. D. Miser



B. VIEW LOOKING EAST (UP THE SAN JUAN) FROM CANYON RIM SOUTH OF SPENCER CAMP

The beds dipping toward the foreground lie on the west side of the Balance Rock anticline. Photograph by Robert N. Allen

C. VIEW LOOKING SOUTH (DOWN THE SAN JUAN) TOWARD THE MOUTH OF NOKAI CREEK

The walls of the inner canyon rise toward the right (west). Photograph by Robert N. Allen

A. VIEW LOOKING SOUTHWEST (DOWNSTREAM) AT POINT 3 MILES BELOW SPENCER CAMP

The sheer sandstone walls of the Wingate and Todilto (?) formations are surmounted by colossal domes of the Navajo sandstone

B. VIEW LOOKING WEST (UPSTREAM) IN LOWER PART OF GREAT BEND

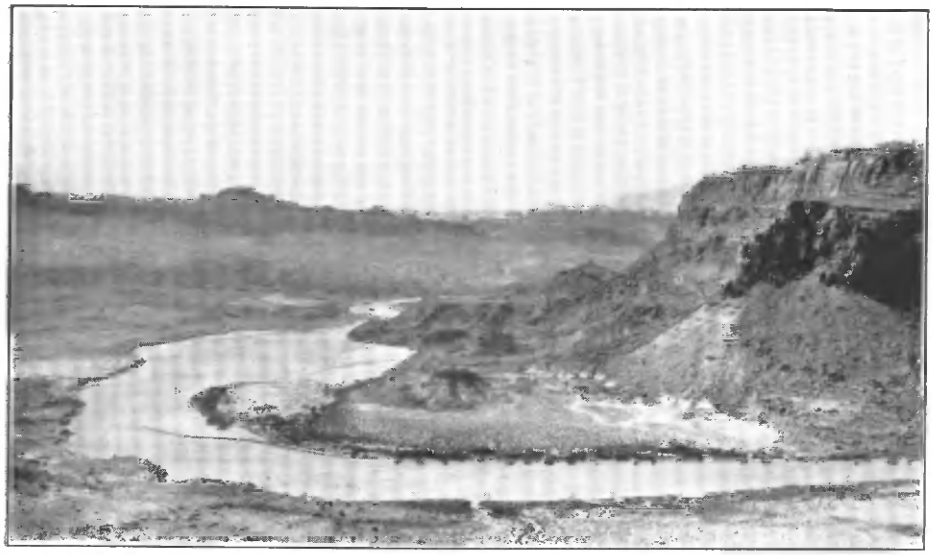
The east edge of the level Wilson Mesa lies in the center distance

SAN JUAN CANYON IN THE GREAT BEND

Photographs by H. D. Miser

A. VIEW LOOKING SOUTH (DOWNSTREAM) FROM LOWER END OF GREAT BEND

Navajo Mountain 20 miles away. Cliffs are formed by Wingate, Todilto (?), and Navajo sandstones. Boulder-strewn slope is underlain by Chinle formation



B. VIEW LOOKING SOUTH FROM LOWER END OF GREAT BEND ACROSS THE OPEN COUNTRY THAT LIES BETWEEN THE BEND AND PIUTE CREEK

Note wide sand-filled channel of river

SAN JUAN CANYON

Photographs by Robert N. Allen

large—larger than a box car—and stands in so prominent a position as to be visible for a distance of 2 miles or more in different directions. The rock, which is a mass of sandstone 30 feet long, 25 feet high, and 15 feet wide, is balanced on a crumbling base of red shale 5 feet high, 8 feet long, and 4 feet wide. That the rock can thus be supported by so weak a base is remarkable.

Just below the mouth of Nokai Canyon the inner gray to brown walls of conglomeratic sandstone and their superjacent platforms rise in graceful curves toward the west, become farther apart, and then descend to the river and terminate at Spencer Camp. (See Pls. IX, *C*, and X.) The tops of the walls between these two localities attain an altitude of about 1,000 feet above the river and inclose a picturesque basin less than 2 miles square, in which the abandoned gold-mining camp known as Zahns Camp is located. The floor of the basin, which is crossed by the San Juan in a sand-filled channel, contains flat-topped, gravel-covered hills; and its steep serrated walls of gray, buff, red, and brown rocks are not crossed by trails except at the western margin, where wooden ladders have been placed to scale some of the steepest places. The basin can be reached on its east side by a poor road running through a gravel-filled gap half a mile south of the mouth of Nokai Canyon.

In the vicinity of Zahns Camp the palisade-like cliffs and the subjacent badland slopes, which border the top edges of the high mesas, are also arched. (See Pls. IX, *C*, and X.) On the crest of the arch the highest summits of the mesas attain an altitude of 2,500 feet above the river, but they gradually descend toward the west until they stand 1,000 to 1,500 feet above the river near Spencer Camp.

The palisade-like cliffs descend to the water's edge at a point 3½ miles below Spencer Camp, and the badland slope with its enormous talus boulders therefore disappears. Thence for a distance of 6 miles by stream the precipitous canyon walls meet the water's edge except for short stretches where there are willow-covered sand bars. (See Pl. XI.) The walls are gashed by impassable hanging valleys at the mouths of side canyons, they are dented by alcoves, some of which have arched roofs, and they terminate upward in colossal sandstone domes that rise about 1,000 feet above the river. Only one of the side canyons could be entered from the river. Its precipitous walls bar entrance to it from all other directions. It was ascended in a north-northeastward direction for a distance of 1½ miles. No trails or other signs were found to indicate that it had been previously visited by man. Its picturesqueness is most impressive and equals or surpasses the beauty of the canyon in which the famous Rainbow Natural Bridge is located. Its sandstone walls, with their buff, brown, and red colors, are as smooth as the gray

granite walls of the Yosemite, and they terminate upward in gigantic rock domes which tower higher than the Washington Monument. Yet they are dented with several alcoves—some with rounded walls like the upper interior walls of a huge hollow sphere and some with straight back walls and arched roofs. To their walls there cling sparse ferns and lichens, which are fed by seeps. Rivulets leap from the rim of the canyon and join the water from springs to form a small, clear stream which runs on the rough, rocky canyon floor. The water supply maintains abundant cedars, cottonwoods, scrub oaks, grasses, and flowers. This canyon is here named Alcove Canyon.

Below Spencer Camp the San Juan runs in a northwesterly direction, then swings around and runs southeast, thus forming the Great Bend, the longest loop in the canyon. The length of the loop is 8½ miles, yet the distance across the neck is only half a mile. Colorado River is only 5 miles away from the west end of the bend, but to reach the Colorado by descending the San Juan it is necessary to travel a distance of 34 miles.

From the lower end of this loop to the mouth of Piute Canyon the San Juan runs in a channel dotted by islands of ripple-marked sand and skirted by a number of willow thickets. (See Pl. XII.) As the river runs toward the southeast the true canyon walls with their palisade-like features rise high above the river and retreat from it, inclosing a wide valley of badlands, but as the river swings toward the west near the mouth of Piute Creek the valley narrows and the palisade-like cliffs descend in this direction. Piute Canyon presents the same features—precipitous walls and subjacent badland slopes—as are found in this stretch of the San Juan.

From the mouth of Piute Canyon to the mouth of the San Juan the canyon is 1,000 to 1,500 feet deep, is partly floored with widely scattered bars of sand, gravel, and boulders, and is bent into oxbow loops, notably near the mouth of the river. Through much of this stretch the canyon walls are composed of sheer cliffs several hundred feet high and of low talus slopes at the base of the cliffs. (See Pl. XVII, *A*, *B*.) But in the oxbow loops near the mouth of the river the cliffs touch the river or touch short, narrow sand bars; the base of the cliffs rise to a height of 670 feet above the river near the Thirteen-foot rapid, where they inclose a comparatively wide valley.

Below Piute Canyon the walls are dented by alcoves, of which some are well-rounded chambers but others have arched roofs, and they are surmounted by closely packed domes of buff sandstone. There are a great number of tributary canyons. Most of them have hanging valleys with waterfalls, and those that could be ascended

were found to have crooked courses marked by bars of huge boulders, waterfalls, and water-filled potholes of small and large size.

A natural bridge of sandstone is perched on the rim of the right canyon wall at a point 2 miles by stream below the mouth of Piute Creek. The canyon wall at this locality is an unscalable nearly vertical cliff rising to a height of 1,300 to 1,500 feet. The bridge when viewed from the bottom of the canyon, a quarter of a mile below, appears as a tiny arch, yet its span and height are each estimated to be 50 feet. The bridge has apparently been formed by the partial collapse of the roof of an alcove or small cave in the massive Navajo sandstone. A distant view of the alcove indicates that two other parts of the roof have fallen in. To reach the bridge, if that is possible, would require a trip across the unmapped maze of canyons and domes lying north of the San Juan. The nearest points at which the north wall of the San Juan Canyon can be scaled are at the mouths of Piute and Wilson creeks.

An abandoned canyon-like valley trenches the rugged country north of the San Juan, beginning at a point about half a mile above the mouth of the river and extending northward about a mile to the Colorado. It ranges in width from about 0.1 mile at the south to 0.4 mile at the north, and its partly gravel-covered floor stands approximately 400 feet above the two rivers. As the altitude at its north end is the same as that at its south end, no decision could be made as to which of the two rivers formerly ran through the abandoned canyon. The old vertical wall, more than 200 feet high, which is still standing on the east side of the canyon near its north end, is curved, running southeast, south, and southwest. This trend, together with the fact that the lowest part of the gravel-covered floor is adjacent to the wall, indicates that the wall skirted a broad outer bend of a river.

A natural bridge is perched on the rim of the old wall on the east side of the abandoned canyon described above. It is not visible at any great distance, for it stands only a few feet in front of an alcove. The bridge was in fact once part of the roof of the alcove and was formed by the widening of a crack in the roof, through which an intermittent stream now plunges to the floor of the alcove and runs under the bridge. The stream formerly ran over the unopened crack and then fell from the rim of the alcove-dented canyon wall. The crack back of the bridge is 50 feet long by 4 to 10 feet wide and is parallel with the face of the cliff. The width and height of the opening under the bridge are 80 and 40 feet, respectively. The span trends S. 15° E.; its width is 15 to 20 feet, and its thickness 15 feet. A very small spring with a flow sufficient to fill a shallow pool issues on the floor of the alcove.

CLIMATE

PRECIPITATION AND TEMPERATURE [16]

The part of the Colorado Plateau trenched by San Juan Canyon is an arid region whose scanty rains fall mostly in two seasons—one in winter, in which the moisture is derived from westerly winds, and one in July, August, and September, in which the moisture is derived from southwesterly winds. The summer storms take the form of thundershowers, during which the rainfall is torrential and the lightning almost incessant, causing considerable damage to life in some exposed localities. (See Pl. IV, *B*.)

No weather stations have been maintained in San Juan Canyon for the collection of data on rainfall and temperature. Even the data furnished by the nearest stations are fragmentary. Conclusions regarding the climate of the canyon are therefore not precise.

The amount of rainfall is influenced by the topography of the country. In general the higher the country the more rain it receives. The canyon and the immediately adjacent country probably receive about 5 inches or less of rainfall a year. During the descent of the canyon from July 18 to October 3, 1921, more thunderstorms formed over and near Navajo Mountain (altitude 10,416 feet) than at any place along the canyon. The mountain therefore receives a greater rainfall than the canyon. Its vegetation suggests a rainfall exceeding 20 inches a year.

Rain from 38 or more thunderstorms fell on me during the canyon voyage. Perhaps as many more passed by less than 2 or 3 miles away. These storms occurred on 10 days in July, 13 in August, 1 in September, and 1 in October. The longest rainless interval was from August 26 to September 29.

Hite, Utah, in the canyon of the Colorado (altitude 3,500 feet), has an annual rainfall of 6.92 inches. Blanding, Utah (6,000 feet), has 14.26 inches; Bluff, Utah (4,300 feet), had 3.63 inches in 1913 and 6.26 inches in 1921; Aneth, Utah (4,700 feet), on San Juan River, 20 miles above Bluff, has 5.45 inches; Chinle, Ariz. (5,200 feet), has 9.9 inches; Kayenta, Ariz. (5,800 feet), had 10.91 inches in 1921.

The highest temperature recorded at Hite is 115° and the lowest 2°; at Aneth the extreme range is 106° to −10°; at Bluff the range is from 104° to 1°; and at Kayenta it is from 99° to 1°. Daily ranges are also very great in this region, where the skies are prevailingly clear and the atmosphere dry. All nights following even the hottest days were comfortably cool in the canyon, and all required the use of cover.

[16] Many statements here given are taken from reports by M. R. Thorpe (Jour. Geography, vol. 18, pp. 285–300, 1919) and H. E. Gregory (U. S. Geol. Survey Water-Supply Paper 380, 1916).

The keynote to the climate as a whole is variability between day and night, between sunshine and shadow, between opposite sides of mesa and canyon, and between canyon floor and rim.

WIND

The wind, whose prevailing direction is from the southwest, picks up and carries much sand and dust. Yet along the San Juan there are no extensive areas of sand dunes. Most of the dunes, which are all small, occur along the bottom of the canyon and in protected places on the south canyon walls. The scanty soil in the more level parts of the country, where grasses and sage brush are common, is probably composed in large part of wind-blown material that has lodged among the vegetation and has been held by it.

Our party experienced a violent windstorm when we were several miles above the mouth of Piute Creek. It began to blow from the south between 9 and 10 a. m. on September 18 and continued without cessation from this direction until 5 p. m. It blew in gusts and picked up sand and fine yellow dust, which were carried up into the air for hundreds if not thousands of feet. The wind shook Mr. Trimble's plane table so violently and blew so much sand into our eyes that at 11 a. m. we discontinued the descent of the canyon. The beating of the wind against the canyon walls roared like an enormous waterfall or the din of a forest storm. The wind also blew hard on September 17 and 19 but was less violent during the nights than during the daytime. On all three days considerable sand and fine dust were carried in the air. On the mornings after the sand storms much of the cloudless sky was streaked by thin light-gray to cream-colored bands that were probably composed of impalpable dust.

The river fell several inches during the daytime on September 17, 18, and 19 and rose a corresponding amount at night. This coincidence of the fall and rise of the river with the activity and pause of the windstorms indicates that they were due to the extreme evaporation of the water during the storms in comparison with the little evaporation during the pauses. The quantity of water thus evaporated was great.

Few opportunities were afforded for observing the effects of daily evaporation on the flow of tributary streams—in fact, the only recorded observation was at the mouth of a southern tributary that enters the river at a point 3 miles in a straight line west of the mouth of Piute Creek.

When we reached the mouth of the stream late in the afternoon of September 28 it was flowing half a second-foot or less over the sand bar at its mouth. The stream continued to flow across the sand bar until well toward noon next day, when the flow decreased so much

that the stream ceased to flow across the sand bar; all the water that was then flowing in the canyon farther south found its way to the river by seeping through the sand.

September 29 and all the preceding days for about four weeks were cloudless or nearly so, and in consequence the above-described daily variations in the flow of the river and the tributary here mentioned were apparently caused by the greater evaporation of the water during the daytime, in comparison with the evaporation during the night.

SOIL

The soil of San Juan Canyon and the adjacent country is exceedingly scanty. It clings here and there to canyon and mesa walls, lies in small patches on the canyon floors, and caps stream terraces and the more level parts of the plateaus. Two types of soil are found—residual soil that is derived from the rocks immediately underlying it and transported soil that has been carried by winds and streams and deposited in its present position. The soils on the canyon floors have all been transported, but the higher soils include both residual and transported soils. Transported soils predominate, because the scanty vegetation, the heavy thunderstorms, the rapid run-off after rains, and the strong winds are not favorable for the formation and retention of soil in place.

The soils are derived almost entirely from shale and sandstone that are deficient in plant food. Much limestone is exposed in the San Juan oil fields, but on account of the small rainfall and the great depth and the inactivity of ground water the limestone undergoes practically no decomposition except disintegration. The limestone has therefore furnished very little, if any, residual clay. The colors of the soils are like those of the rocks from which they are derived. They are usually buff, brown, and red.

The soils, in spite of their dryness and seeming infertility, contain sufficient plant food to support sage brush and other perennial growths and to grow grass, Russian thistle and flowers during the summer rainy season. Water is in fact the chief ingredient that is lacking in the soil. The rainfall is not sufficient in and near the canyon for dry farming, but the remains of dilapidated irrigation systems here and there indicate that the soil produces crops in response to the application of water. No cultivated patches were observed at any place in or near the canyon in 1921.

FLORA

The flora of San Juan Canyon and the adjacent country is so sparse that the widely scattered patches of green constitute only a small part of any landscape view, whether the view is taken

from the canyon floor or across the adjacent plateaus. The predominant colors in such a view are the browns and reds of bare rocks.

Very few trees grow in the canyon. Between the mouth of Chinle Creek and Piute Farms a few junipers were found that had been strong enough to withstand the floods, with their heavy loads of driftwood. No cottonwood trees remain in this section of the canyon, because they have all been swept away by floods. Probably less than two dozen cottonwood trees are to be found along the San Juan at and below Piute Farms. Yet cottonwoods are numerous at places in some of the side canyons, especially those that have not been visited by high floods within the last 20 years or more. The only yellow pine tree observed in the canyon is clinging to the southwest canyon wall near the west end of the Great Bend. The shrubs include hackberry, rabbit brush, mountain rush (Brigham tea), greasewood, ironwood, sagebrush, willow, red haw, oak, and box elder. Of these the willows are most abundant, but few of them are more than an inch in diameter. Their age, like that of most other shrubs, is dependent on the periods between the destructive floods which carry away most of the vegetation. No oaks were observed in the canyon above the mouth of Grand Gulch. The most common vines are Virginia creeper and poison oak. "Flat-leaved" and "globular" cacti are abundant; yucca is common; grass is scanty and commonly in detached tufts. During the rainy season there are many kinds of flowers and much Russian thistle.

The above-described flora falls within the limit of the lowest of the several zones of vegetation that have been distinguished in the Navajo country by Gregory.[17] The lowest zone, which he calls the zone of cottonwood, cactus, and yucca, extends from the floor of San Juan Canyon to an altitude of 5,000 feet. Some of the plateau areas adjoining the canyon that fall within this zone include much of the San Juan oil field, broad belts of low country on either side of the canyon near Clay Hill Crossing, and the level-topped Wilson Mesa.

The next higher zone, called by Gregory the zone of sagebrush (*Artemisia*) and greasewood (*Sarcobatus*), ranges from 5,000 to 6,000 feet in altitude. It was noted in the country north of the head of the Honaker trail and also a few miles south of Red House. (See Pl. XVI, *A*.) Gregory says:

> Sage within this zone attains heights of 4 or 5 feet and in places is so closely spaced as to render travel difficult and may occupy the surface to the exclusion of trees. Besides the ever-present sage and greasewood, grass is fairly abundant in this zone. Patches of piñon and juniper are irregularly distributed, usually along rocky ridges, but are in general of "scrub" size.

[17] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380, p. 72, 1916.

A third zone, called by Gregory the zone of piñon (*Pinus edulis*) and juniper (*Juniperus monosperma*), ranges from 6,000 to 7,000 feet in altitude. It occurs on Cedar Mesa, in the country north and east of Red House, on the mesas of the Clay Hills, on a mesa north of Zahns Camp, and on the mesa between Piute and Nokai creeks. The piñon and juniper I observed are of scrub size. Sagebrush and greasewood occupy open spaces. Grass in tufts and scattered mats grows everywhere except in the densest shade.

Two still higher zones occur on Navajo Mountain. They are the zone of yellow pine, from 7,000 to 8,500 feet in altitude, and the zone of Engelmann spruce, from 8,500 feet to the summit of the mountain, 10,416 feet above sea level.

ANIMALS

Among the indigenous animals observed by members of the party were cottontails, jack rabbits, one civet cat, field mice, harmless snakes, beavers, seven Arizona mountain sheep, and lizards. The mountain sheep are confined to the part of the canyon between the Honaker trail and the mouth of Moonlight Creek. They have survived here for the reasons that much of this part of the canyon is inaccessible to persons on foot and that few people have ever descended the canyon in boats. The tracks of coyotes were numerous in all parts of the canyon, and the track of a single mountain lion was observed. The birds noted include black eagles, owls, ducks, blue cranes, swallows, and rock wrens.

Several kinds of insects, especially flies, mosquitoes, ants, and scorpions proved to be far too numerous for comfort. The thousands of ants that inhabit the sand bars on which we slept were bedfellows on many occasions, and they always displayed two disagreeable traits—crawling and biting. On a few occasions scorpions who were bedfellows were crowded too much and expressed their anger by stinging. Lizards sometimes got into the beds and always caused considerable anxiety for fear they were scorpions, until a match was lighted and thus revealed their harmless nature.

Mosquitoes were not numerous except during the period from August 13 to 25, which was in the rainy season. The party had no mosquito netting, and it combated mosquitoes unsuccessfully by using smoke barrages from fires of sagebrush and cow chips. After many sleepless and restless nights caused by these pests and by the rains, which wet the bedding, our canvas bed covers were converted into pup tents. Such tents protected us from both the mosquitoes and the rain.

A few wild cattle were seen at places in the upland country north of the canyon. Burros, some of which may be wild, were noted south of the canyon below Clay Hill Crossing. Indian horses and

mules were seen grazing in Piute Canyon, also on the high mesa east of Piute Canyon and on the plateau extending north from the base of Navajo Mountain. Flocks of sheep have been grazed at places in the canyon below Clay Hill Crossing, but they, like all the Indians, had moved away from the river before our descent of the canyon. The abandoned hogans and sheep corrals along the river suggest that a few Indians with their sheep spend their winters there.

MINERAL RESOURCES

Among the prospectors to visit San Juan Canyon and the adjacent country were those in search of gold and petroleum, which are the only exploited mineral resources of the region. The gold prospects, the dilapidated oil-well and gold-mining machinery, and the piles of stones marking the corners of the numerous oil leases and mining claims are some of the most conspicuous reminders that this deserted canyon has formerly been visited by human beings.

Several oil seeps occur in the bottom of the canyon between Mexican Hat and the mouth of Slickhorn Gulch. The largest of these is a rather continuous series of seeps extending 1¼ miles upstream from the mouth of the gulch. (See Pl. VI, *A*.) Oil-prospecting permits in the country north of the San Juan have been acquired by the hundreds from the Department of the Interior, and a continuous belt of land covered by such permits extends from Bluff westward past Mexican Hat and Goodridge to Colorado River. Many wells in search of commercial quantities of oil have been drilled near Goodridge and Mexican Hat, in what is known as the San Juan oil field.[18] Oil has been found, but the production has thus far been so small as not to repay the large expenditures of capital. Further and complete exploration with the drill may, however, reveal oil in commercial quantities, but the oil prospector should always keep in mind the hardships and enormous cost of drilling wells and of marketing oil in this arid region, which is more than 150 miles from a railroad. The possibility of obtaining oil and the structure of the rocks in the canyon and the adjacent country are fully discussed in another report.[19]

Prospecting for gold in San Juan Canyon began in 1892, when tales of fabulously rich deposits caused 1,200 men to stampede to the canyon. After spending a few months there they went away empty handed, but prospecting continued at a few places as late as 1915. The gold is extremely fine in grain, being known as flour gold, and

[18] Gregory, H. E., The San Juan oil field, Utah: U. S. Geol. Survey Bull. 431, pp. 11–25, 1911. Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 76–104, 1912.

[19] Miser, H. D., Geologic structure of San Juan Canyon and adjacent country, Utah: U. S. Geol. Survey Bull. 751, pp. 115–155, 1924 (Bull. 751–D).

occurs mostly in placer deposits along the river channel and in terrace gravels. Placer deposits have been prospected at numerous places between the mouth of Chinle Creek and Zahns Camp. The results of work at Zahns Camp are not known, but the richest returns from the rest of the canyon were obtained at the Nephi claim, 4 miles below the Honaker trail, where $3,000 worth of gold was recovered in 30 days. At Spencer Camp and near the mouth of Copper Creek attempts have been made to extract gold from sandstone débris, which has been derived from the Wingate and Navajo sandstones. Small quantities of gold—20 to 40 cents a ton—are said to occur disseminated through these sandstones. For further information on the gold deposits in San Juan Canyon the reader is referred to reports by Gregory [20] and Butler.[21]

INHABITANTS

A part of Utah south of San Juan River has been set aside for the use of the Navajo Indians. The former Piute Indian Reservation, which was a belt of country lying between the San Juan and the Utah-Arizona line and extending from Colorado River eastward to the 110th meridian, has recently been returned to the public domain. The Navajo Indian Reservation extends eastward from this meridian and southward from the San Juan into Arizona and New Mexico, in which most of the reservation lies.

The country lying south of the river in the Navajo Indian Reservation is not subject to entry except by permission of the Commissioner of Indian Affairs, but the region adjoining the north side of the river and in the former Piute Indian Reservation is public domain and is subject to entry by the usual method.

San Juan Canyon was found by the Trimble party to be uninhabited by either white people or Indians, though much evidence indicates that the more accessible parts have been the temporary abode of a few Indians with flocks of sheep and that prospectors have visited the canyon in search of placer gold and of oil, of which there are seeps near the San Juan oil field. Furthermore, the country adjacent to the canyon is inhabited by very few people.

An uninhabited country fully 50 miles square lies north of the San Juan and east of Colorado River; yet it is visited during the winter by herdsmen with their cattle. The only settlements in its southern edge are at Goodridge and Mexican Hat; the only ones on the western edge are the Loper ranch, on the Colorado at the mouth of Red Canyon, and the Hite ranch, at the Dandy Crossing of the Colorado;

[20] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 139–140, 1917.

[21] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 636–640, 1920.

and the first settlements to the east are found at Bluff and Blanding and at places near the Abajo (Blue) Mountains. There is a single ranch, however, near the head of Comb Wash.

Bluff is a thriving village of white people in an irrigated valley and is visited by many Piute and Navajo Indians. (See Pl. I, *A*.) The only white people living near the river west of Bluff are at Goodridge, Mexican Hat, and a trading post near Oljeto in Moonlight Valley. Goodridge, formerly a post office, was in 1921 a trading post operated by A. H. Spencer. It consists of three frame buildings and a cellar, and is the permanent residence of not more than three or four people.

The village of Mexican Hat, which receives its name from a near-by butte (Pl. IV, *A*) that is capped by a wide circular rock standing in such a position as to resemble a huge Mexican sombrero, is 25 miles from Bluff and half a mile west of the river. In 1921 it consisted of two frame buildings, with as many white families, though a third building, the home of A. L. Raplee, was on the right bank of the river half a mile away. J. L. Oliver, who lives in the village, operates a store with a very small stock of merchandise.

Both Goodridge and Mexican Hat are field headquarters for oil men who visit the San Juan oil field, in which the villages are situated. The people living there go 25 miles to Bluff, the nearest post office, for mail; their nearest available physician lives at Blanding, about 50 miles away. No white inhabitants and only three Indians were seen during the canyon voyage from Goodridge to Lees Ferry, on Colorado River, notwithstanding the facts that the party spent two months in the canyon west of Goodridge and that members of the party walked to several points as much as 6 or 7 miles away from the river, to one point 15 miles away, and to one point 25 miles away. The three Indians referred to were Navajos who were living in Piute Canyon, 9 miles south of the river. But several abandoned hogans, farms, and corrals, whose location is discussed below, were seen on or near the river. Their character is such as to indicate that nomadic Indians have lived for short periods along the river. In fact, it appears that a few Indians take their flocks to the San Juan to spend the winter.

Above the entrance to the canyon two or three hogans were seen near the mouth of Chinle Creek, and in July, 1921, a Navajo family was found living by a cultivated patch on the north side of the river just below the mouth of Butler Wash. No hogans occur along the river near Mexican Hat and Goodridge, though one or more "sweat boxes" were noted on the west bank near Goodridge. An Indian who wishes to take a "Turkish bath" tightly closes himself and some heated stones in such a box and then while perspiring copiously rushes and plunges into the river.

Other signs of Indian habitation were not observed until the party reached Rockhouse Gulch, where there is a hogan partly constructed of stone 1¼ miles in a straight line southeast of the mouth of the gulch. Abandoned Indian farms and a corral are on the left bank of the river at a locality known as Piute Farms. A hogan is on a bench on the left bank of the river just north of the mouth of Copper Canyon; two or three were noted on Nokai Creek at points several miles south of the river. A hogan and an abandoned farm are on the east side of the river at a point 3 miles above the mouth of Piute Creek. Another with a farm is just south of the Thirteen-foot Rapid, and a third, also with a farm, is 1½ miles to the south in a tributary canyon.

IRRIGATION AND AGRICULTURE

Water from the San Juan is used for irrigation at Bluff and other places farther upstream, but in the canyon there is practically no tillable land and none was under cultivation in 1921. The thin soil on the terraces and on some of the other level upland areas below Clay Hill Crossing would probably grow crops if irrigated, but the areas of tillable land are small, and the enormous cost of utilizing water from the river, either by pumping or by building dams, precludes such practice under present conditions.

No farming has ever been done in the canyon between the mouth of Chinle Creek and Clay Hill Crossing. Farming has been carried on in recent years at and near Piute Farms, where water from both the river and small tributary streams has been utilized, but the aggregate area under cultivation there probably did not exceed several acres. The land that has been cultivated at Piute Farms is now subject to being flooded by the river during high stages, and much if not most of it has been carried away in recent years by the river. During the stay of the Trimble party at Piute Farms from August 18 to 26 the waves of the surging flood-swollen stream beat against the south bank and carried away a strip of land 75 feet wide, notwithstanding the fact that the channel was already 3,300 feet wide.

There appears to be an abandoned Indian farm on the east side of the San Juan at a point 3 miles east-northeast of the mouth of Piute Creek. Another abandoned Indian farm is just south of the Thirteen-foot Rapid on the San Juan and another is in a side canyon 1½ miles south of the rapid; both these farms were irrigated by water from the stream that drains the side canyon.

In 1921 no tract under cultivation was seen along the San Juan or along its tributaries at an altitude of less than 3,900 feet. In

fact, the only cultivated patches that the Trimble party saw during the canyon voyage below Comb Ridge were in Piute Canyon at a point 9 miles south of the river.

ARCHEOLOGY

A fairly large number of accessible cliff dwellings occur along the river at and east of Bluff, but in and near San Juan Canyon, which is west of Bluff, cliff dwellings and other prehistoric ruins are surprisingly few. This apparently means that the canyon country, with its meager quantity of tillable land and its sparse grasses, has not at any time been able to sustain more than a few nomadic inhabitants.

A small accessible dwelling stands in a recess in a cliff on the west side of Butler Wash near its mouth. Its walls have been partly demolished.

There are a few small dwellings, difficult of access on account of the steep approach and the small entrance, on the north side of the San Juan about half a mile west of the mouth of Butler Wash. They appear to be well preserved. A few ruins are said to occur at the mouth of Comb Wash. The ruins near Bluff and those in Butler and Comb washes, also some in and near the Great Caves in Grand Gulch and some north of the north base of Navajo Mountain, have been described by Prudden.[22]

A round jar having the form of an olla was found beneath a narrow projecting ledge on the right bank of the river about one mile above the mouth of Slickhorn Gulch. In this vicinity oil seeps occur in the river and at the water's edge for a distance of a mile and a quarter. Perhaps the cliff dwellers who made pottery of this type came to the locality to obtain the oil for fuel or medicine. No masonry that could have been part of a cliff dwelling was seen, but buried heaps of charcoal, corn cobs, grains of corn, and partly completed arrowheads that were found indicate that the cliff was once a place of habitation.

Fragments of pottery of several designs were noted on the surface near the mouth of Clay Gulch. The cliff at this locality is on the west side of the gulch and has a large recess, which has obviously been used as a shelter by Indians and white people.

A dwelling with an entrance 2 feet square was found beneath a huge sandstone boulder in the bottom of Copper Canyon at a point some 4 or 5 miles from the San Juan. The length and breadth of the single room are only a few feet, and its ceiling of solid rock is so low that a person can not stand erect in it.

[22] Prudden, T. M., The prehistoric ruins of the San Juan watershed in Utah, Arizona, Colorado, and New Mexico: Am. Anthropologist, new ser., vol. 5, No. 2, pp. 224–228, 1903.

A cliff dwelling beneath a projecting ledge on the northeast side of the inner canyon of Nokai Creek at a point about 6 miles from the river consists of two rooms, the larger 8 by 12 feet. The smooth walls, which were constructed of slabs of rock and red clay, stand several feet high. The walls have been partly torn down by recent Indians to obtain stone for building crude huts in which no mortar or clay was used. Many fragments of pottery of several designs were noted on the surface. The abundance of the fragments suggests that the locality was a place of habitation for a long time.

A small cliff dwelling whose walls have been mostly demolished was seen about 2 miles north of Spencer Camp. It is in an alcove in the Navajo sandstone on the northwest side of a gulch and is more than 1,000 feet higher than the San Juan. Only small pieces of broken pottery were observed on the surface.

A cliff dwelling with walls several feet high was built in an alcove in the Wingate sandstone in the northwest canyon wall of the river at a point 3 miles by stream below Spencer Camp. It is 50 feet or more above the river and can be reached by cautiously climbing the steep face of the cliff, in which shallow notches have been chiseled for steps. It is small and crude, but is in a good state of preservation. Bits of broken pottery were found in and near the dwelling.

Pictographs representing many things, such as mountain sheep, snakes, and ducks, have been chiseled by the Indians on numerous huge boulders of sandstone below the Clay Hill Crossing. They were chiseled on smooth surfaces that had a dark-brown coating of iron oxide, known as "desert varnish." None of them appear to have been made in recent times—in fact, some have been so nearly obliterated by weathering as to suggest that they are many centuries old. Some of the pictograph-bearing boulders have recesses whose upper surfaces are covered with soot. This soot and the occurrence at places of buried masonry indicate that Indians long ago used the boulders for shelter.

Two or more low circular rock walls, mostly fallen down, stand on the terraces just south of the Thirteen-foot Rapid and occupy prominent positions overlooking the adjacent flats along the river. They were very crude, being built of angular stones apparently without mortar. They are said by Loper and Christensen to antedate the architecture of the present Indians of the region.

ROADS AND TRAILS

Because San Juan Canyon and the region traversed by it are difficult of access and are inhabited by few people, the region contains only a few roads and trails. The canyon and the adjacent country are generally reached by two overland routes—one by way of Bluff, Utah, and the other by way of Kayenta, Ariz.

Bluff may be reached by automobile stage from Thompson, Utah, on the Denver & Rio Grande Western Railroad, 143 miles by road to the north, by going through Moab, Monticello, and Blanding (formerly called Grayson), Utah. It may also be reached by automobile stage from Dolores, Colo., on the narrow-gage line of the same railroad. The route from Dolores runs in a west-northwesterly direction to Monticello, a distance of about 75 miles, and then south through Blanding to Bluff. From Bluff a road runs to Mexican Hat, a distance of 25 miles, and then on to Goodridge 2½ miles by road farther south. The road between Bluff and Goodridge is used by a few automobiles, but on account of washouts it is occasionally impassible except for pack animals.

Several roads radiate from Goodridge and Mexican Hat and run to different parts of the San Juan oil field, most of which is north of the river. These roads, which are used very little except by oil drillers, are shown on Woodruff's map of the region.[23] A road, as shown on this map, crosses the river at the mouth of Comb Wash and runs southwest for several miles along the west face of Comb Ridge. In 1921 the members of the Trimble expedition found a trail running southwest from the mouth of Chinle Creek. If there ever was a road here it has been obliterated on account of disuse.

From Goodridge a wagon road runs in a southwesterly direction, crosses the San Juan over a suspension bridge half a mile west of the village, and then runs through Monument Valley and Pass to Kayenta, Ariz., the distance being about 50 miles by road. On account of deep sand and washouts, only one automobile had made the trip from Kayenta to Goodridge before 1921.

Kayenta may be reached by automobile from Flagstaff, Ariz., on the Atchison, Topeka & Santa Fe Railway, 155 miles by road to the southwest. The road between Flagstaff and Tuba is in good condition, but most of that between Tuba and Kayenta is poor. Kayenta may also be reached by automobile by way of Chinle, Ariz., from Gallup, N. Mex., on the Atchison, Topeka & Santa Fe Railway, a distance of 190 miles.

The bridge near Goodridge is the only one spanning the river below Shiprock, N. Mex. It is therefore used by many people, because the crossing of the river, by wading on foot or by fording or swimming on horseback, is precarious on account of the quicksands and the unreliable, changing channel.

The first place that the canyon floor can be reached below the bridge is at the Mendenhall Loop, where a trail descends the north wall to Mendenhall Cabin. The next place is at the Honaker trail,

[23] U. S. Geol. Survey Bull. 471, pl. 9, 1912.

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whose head is 7½ miles by road west of Mexican Hat. The trail was built in 1904 by gold prospectors, who were attempting to work the placer deposits in and near the river channel. The canyon wall descended by the trail is only 1,235 feet high, yet the trail is so crooked that it is about 2½ miles long. The trail was built with the intention of using pack animals on it, but the only horse ever to attempt the descent fell off from a particularly steep, narrow stretch known as "The Horn," and its bleached bones may still be seen lying at the base of the cliff. Before 1904 prospectors reached this part of the canyon by descending the river from Goodridge and Bluff or by ascending the canyon from Clay Hill Crossing or the mouth of Slickhorn Gulch. Also for some time they used ropes for lowering themselves and supplies into the canyon at the Honaker trail. The ropes were used over the high impassable pink cliff that is about halfway down from the rim.

A road used mostly by oil prospectors runs from the vicinity of the Honaker trail past the south base of Cedar Point and across Johns Canyon to the mouth of Slickhorn Gulch, where it descends the lower part of the canyon wall to the river. It follows the prominent bench that gradually becomes lower and lower downstream and disappears at the water's edge near the mouth of Grand Gulch. The road down the canyon wall at the mouth of the gulch was constructed many years ago by E. L. Goodridge for the purpose of lowering drilling machinery to the bottom of the canyon, where there are large oil seeps. An engine, after being brought across the desert for a distance of more than 175 miles, was safely taken down the canyon wall to a point within a stone's throw of the drilling site, but at that point, owing to an unfortunate accident, the engine tumbled from the road and over the cliffs to the bottom of the canyon and was thus broken beyond repair.

To reach the canyon below the mouth of Slickhorn Gulch there are two customary routes. One passes through a locality known as Oljeto, which is about 30 miles from Goodridge and 25 miles from Kayenta. A poor road from Oljeto runs in a northwesterly direction past Organ Rock, 375 feet high (Pl. VII, *C*), thence in a westerly and northwesterly direction down Copper Canyon to the river, and next to and across Nokai Creek to Zahns Camp. The road down Copper Creek follows the stream to a point about 3 miles from the river, ascends a low escarpment on the west side of the creek, and follows a bench to the river and downstream as far as Nokai Creek.

One or more trails run in a northwesterly direction from the vicinity of Orange Rock to Piute Farms and Clay Hill Crossing, on the San Juan. One of them was found to be marked for short distances by wagon tracks. Another trail leaves the road west of Organ

Rock and, after climbing an escarpment a few miles farther west, follows a platform or bench along the east side of Copper Creek to the river.

A trail apparently constructed by gold prospectors runs along the south canyon wall from Piute Farms to the mouth of Copper Canyon. In 1921 it was in places so narrow as to be impassable for pack animals and to require a steady nerve and sure footstep for a person to pass over it. West of Nokai Creek a fork of the trail ascends the east slope of a saw-toothed hogback ridge and thence follows a level or gently sloping bench to Spencer Camp. This trail was used by wagons in hauling gold-mining machinery to Spencer Camp. In September, 1915, a Franklin automobile was driven by the five Zahn brothers, of Los Angeles, Calif., over the route leading from Kayenta through Oljeto, down Copper Canyon, and across Nokai Creek to their gold-mining camp, commonly known as Zahns Camp.

Stock trails ascend Nokai Creek for only a few miles. A trail running from a point on the road near the mouth of Nokai Creek climbs the high mesa to the west and then crosses Piute Canyon about 9 miles south of the San Juan. This route was followed in 1909 by the combined parties of Cummings and Douglass when they were being guided by Piute herdsmen to the Rainbow Natural Bridge. This was the first time that white men had visited the bridge. In September, 1921, Wesley Oliver, packer for our party, who was to meet us at the mouth of Piute Creek, attempted to follow this trail with his pack train. When he reached a particularly steep part of the trail leading west out of Nokai Canyon he encountered a landslide of huge jagged boulders that had recently blocked the trail. Nevertheless he attempted to take his pack animals across the landslide, but before he had gone far one of the mules, in floundering on the boulders, was so seriously injured that the attempt was given up. The pack train with its provisions, which were greatly needed by the San Juan party, was returned to the bottom of Nokai Canyon, where the stock could get water and grass. Then Oliver returned to the landslide with his saddle pony, managed to cross it, and reached our camp two days late. He reported seeing the skeletons and carcasses of eight horses that had fallen from the cliffs at the landslide within the last two months. To obtain the much-needed provisions Bert Loper and I laboriously towed a boat upstream to Spencer Camp, a distance of 16 miles, where we met Oliver with his pack train, as he had in the meantime returned with his pony over the treacherous trail to Nokai Canyon. The trail across the landslide has, according to John Oliver,[24] been repaired by Indians since 1921.

Another southern route into the canyon country leads from Kayenta southwestward to the head of Marsh Pass, northwestward

[24] Letter dated April, 1923.

up Laguna Canyon past its cliff dwellings, across the head of Piute Canyon, and around the east side of Navajo Mountain to its north base, a distance of fully 75 miles, whence there are two or more trails leading north to the river and one leading west to the Rainbow Natural Bridge. One of the trails descends the west wall of Piute Canyon at a point 9 miles away from the river and then descends Piute Creek to the river. From the mouth of this creek a good trail, used by horses and burros, runs up the left bank of the river for a distance of 5 miles.

A trail constructed for the use of horses and burros ascends the south canyon wall at a point 1 mile southwest of the mouth of Wilson Creek and passes on to a nearly level grass-covered plateau that extends to the base of Navajo Mountain, several miles away. It doubtless connects with the trail that follows the north side of the mountain to the Rainbow Bridge.

The canyon that is drained by a stream entering the river at the Thirteen-foot Rapid was formerly followed by a trail. The trail led from the abandoned Indian farms near the mouth of the creek past the abandoned farm just north of the forks of the canyon and thence up the west fork for an unknown distance. Whether it connects with the Rainbow Bridge trail is not known. It was found to be so obliterated at many places by landslides and washouts as to be impassable for man or beast.

The difficulties in reaching the part of the canyon below Slickhorn Gulch from the north are fully as great as those in reaching it from the south, because only a few people, including herdsmen, prospectors, and guides, are familiar with the trails. One of the principal routes of travel runs from the town of Green River, on the Denver & Rio Grande Western Railroad, by way of Hanksville to Hite. A wagon road from Green River has been built as far as Hite. At Dandy Crossing, just above Hite, animals can easily swim the river, and supplies can be taken across in boats. From Hite the trail, which was once used as a wagon road and which is still an excellent pack trail, passes in a southeasterly direction up White Canyon to the natural bridges, 40 to 45 miles distant. From the bridges one trail runs in an easterly direction to Blanding, a distance of 40 miles, and another that has been used at times by wagons runs in a southeasterly direction to Bluff. Another route of travel is from Thompson, on the Denver & Rio Grande Western Railroad, to Blanding and thence west over the route just described.

In 1923 a party of the National Geographic Society traversed by pack train the region lying north of San Juan Canyon. The region

and the route followed are briefly described by Judd,[25] leader of the party, in two recent articles.

A road from Hole in the Rock to Bluff by way of the Clay Hill Pass and the head of Grand Gulch, was constructed in the winter of 1879–80 by a Mormon mission party, which followed this direct yet unknown route from Cedar City, Iron County, to colonize the part of the San Juan Valley where Bluff now stands. The party consisted of 200 men and women and 50 children, who took with them more than 100 teams, 82 covered wagons, and nearly 1,000 cattle. An account of the journey of the party, which underwent endless privations and hardships during the severe winter in this most rugged, barren country, and which still displayed an exemplary morale and discipline and an unbounded confidence in their leaders, is one of the most interesting chapters in Utah history. Since 1880 the road traversed by them between the Colorado and Bluff has been used very little by wagons, and to-day its location is marked simply by a trail. In fact there is not a single human habitation on it west of Bluff.

The following brief description of the route is abstracted from an article by J. Cecil Alter:[26]

About December 14, 1879, the leading wagons reached the Hole in the Rock, the only break in the continuous canyon wall through which a road could be constructed to the river. [See Pl. XIII.] Work was immediately begun in the 4-foot crevice to build a roadway 1 mile long to reach the river 800 feet below. So precipitous was the crevice that the first workmen had to be lowered by ropes from the rim and then held in suspension while they drilled the powder holes. By December 17 enough room was found in the crevice for 47 men to work. The number of workmen gradually increased, but it was not until January 26, 1880, that the first wagons could be taken down the new road to the ferryboat, which was built of lumber that had been hauled from Escalante, a distance of 60 miles. On February 10, after the last wagon had descended to and crossed the icy river, the caravan began to climb the east canyon wall, in which a road had been blasted.

On February 13, cold, stormy weather, with snow and bad roads, forced a halt about 10 miles from the Colorado, yet the summit of the "San Juan Hill" was still 2 miles distant. On February 17 the party passed near the most northerly bend in San Juan River, about 14 miles east of the Hole in the Rock, where it is said the vertical canyon walls of the San Juan obscured the stream below. [The bend referred to is obviously the Great Bend that is below Spencer Camp.]

About February 20 the leaders of the party reached the Slick Rocks, "consisting of great knobs and hummocks of sandstone, jumbled together and riven with crevices, the whole field a half mile across being tilted at a sharp

[25] Judd, N. M., Beyond the Clay Hills: Nat. Geog. Mag., vol. 45, pp. 275–302, 1924; Explorations in San Juan County, Utah: Smithsonian Misc. Coll., vol. 76, No. 10, pp. 77–82, 1924.

[26] Salt Lake Tribune, Oct. 23, 1921.

angle. A roadway had to be literally chiseled and blasted through this region, as box canyons prevented getting around it." On February 28 the first wagons slid down the chutelike roadway into Lake Canyon and reached Hermit Lake, called Pagahrit (standing water) by the Indians. This lake, which was half a mile long, was produced by a spring and stream having been dammed by beavers. "The dam went out with a flood six or seven years ago, and the beautiful lake with its willows, bushes, canes, grass, and ducks, is no more." On March 2 the advance column, after passing over rocky ridges and sand dunes, reached Green Water Spring, in Castle Wash, so named from a castle-like cliff dwelling near the spring. After another two day's travel in heavy sand in the wash the leading wagons reached the head of the Clay Hill divide or pass—the only pass in the southeast escarpment of the mesa country that extends from San Juan River in a northeastward direction to the head of Red Canyon, a distance of 20 miles. The clay hill lies east of the pass and is a long badland slope leading down to the lower plateau country to the east, which is sometimes referred to as the "Grand Flat." [See Pl. XIV, *A*.] It is only a part of a belt of badlands that runs the whole length of the southeast escarpment of the above-mentioned mesa country. To this mesa country the name Clay Hills has been appropriately applied, yet the hills, which are in reality mesas, are capped with massive cliff-making sandstones that are generally bare of soil and vegetation.

The descent of the Clay Hill was difficult, for the clay was wet and slippery, the mud was deep, and the slope was long and steep. The first wagons made the descent about March 12, and headed in a northeastward direction through a cedar-clad country, reaching the Cow Tanks after going a distance of 20 miles, and next reaching Dripping Springs, some 6 or 8 miles farther northeast. The party, after traveling 10 miles in going around the head of Grand Gulch near Elk Ridge, and in crossing Harmony Flat, reached the point where the present-day trail leads off to the north about 2 miles to the Edwin Natural Bridge. The caravan next entered the canyon of Comb Wash and followed it for 25 miles in a southerly direction to San Juan River, where a roadway had to be blasted in the face of a cliff. [See Pl. XIV, *B*.] The wagons after passing down the "dugway" went eastward 9 miles to the place since known as Bluff, where two or three families were then living. The first wagons reached that place on April 5 and the last on the next day.

During my exploration of the country adjacent to San Juan River I saw the abandoned road on both sides of the Colorado at Hole in the Rock and at a locality 9 miles west of Bluff, where a dugway was made in the face of a cliff of solid rock, and also walked over the route from Clay Hill Pass to Red House, which is about 10 miles northeast of the pass.

A trail used many years ago by wagons leaves this old road at the foot of the clay hill and runs in a southwesterly direction to Clay Hill Crossing on the San Juan, a distance of 10 to 12 miles. During the "gold" excitement of 1892 the trial was used by prospectors who rushed southward to the river, and it was also used by them when they went away empty-handed. At that time the river could be forded at Clay Hill Crossing, for the channel was narrow. Since then the tree-covered bottomland extending from the crossing to Piute Farms

has been swept away and has been replaced by the widened river channel with its shifting bed of quicksand.

Spring Gulch was found to be followed by a cattle trail that leads northward to the grassy valleys of the high country. The trail, which was followed for a distance of 4½ miles from the river, has been obliterated at some places by washouts and is in poor condition at most other places.

A trail constructed for the use of horses and cattle ascends the north wall of San Juan Canyon at the mouth of Wilson Creek and runs in a northwesterly direction on a grass-floored bench on the east side of the creek. It was followed for a distance of only 2 miles from the river. A similar trail described on page 30 ascends the south canyon wall at a point 1 mile southwest of the mouth of the creek.

GEOLOGY

GENERAL FEATURES

The rocks in and near San Juan Canyon are bare of soil and vegetation at most places and thus offer an unexcelled opportunity for their study. They include both igneous and sedimentary rocks.

The igneous rocks are found at Alhambra Rock, where there is a high, dark volcanic neck and associated dikes; 3 miles north of Mexican Hat and 4 miles south-southeast of Goodridge, where there are dikes; and 2 miles south of the mouth of Chinle Creek, where there is a volcanic neck. All these localities are in the east end of the region here described.

The sedimentary rocks, which are generally horizontal or inclined at low angles, are of Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous (?), and Quaternary age and have been grouped into a number of formations. The succession and character of the sedimentary rocks are graphically represented in the accompanying columnar section (fig. 2) and the distribution of the different formations is shown on the geologic map (Pl. XV). The oldest formations are exposed at and near Goodridge and Mexican Hat, in the San Juan oil field. Because these and the younger formations dip in all directions from the oil field, successively younger beds are found in going both upstream and downstream from the field. The different formations are described below in the order of their age, the oldest first. Their structure is briefly described on pages 40–41.

SEDIMENTARY FORMATIONS

GOODRIDGE FORMATION

The Goodridge formation, of Pennsylvanian age, is widely exposed on the crests of two broad anticlines in the San Juan oil field. In

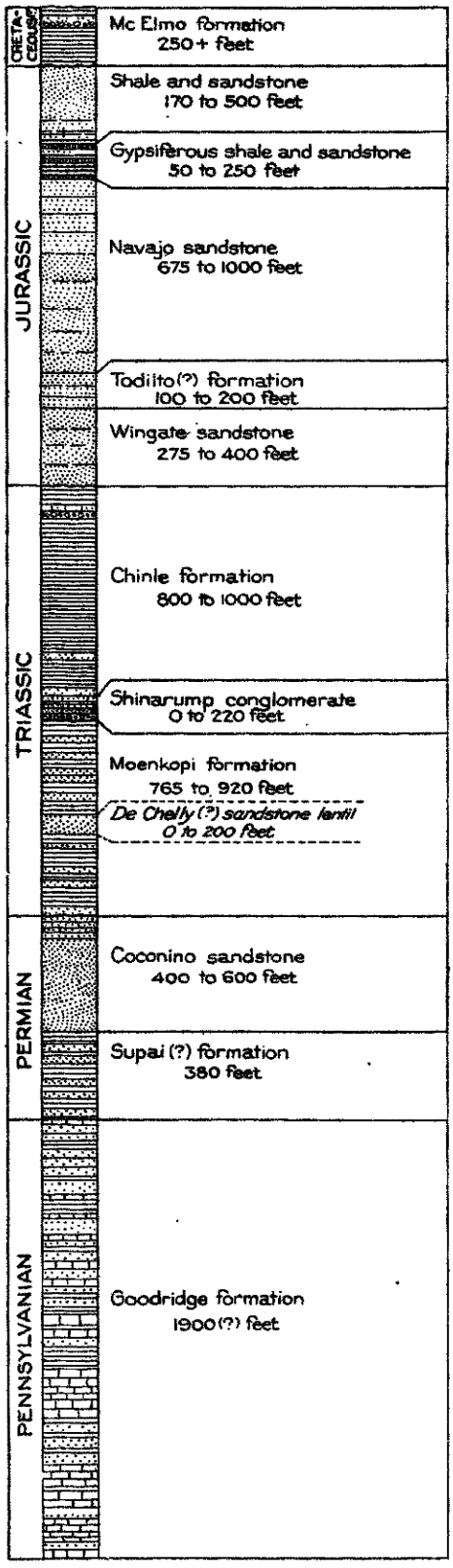


FIGURE 2.—Generalized columnar section of the rocks exposed along and near San Juan Canyon, Utah

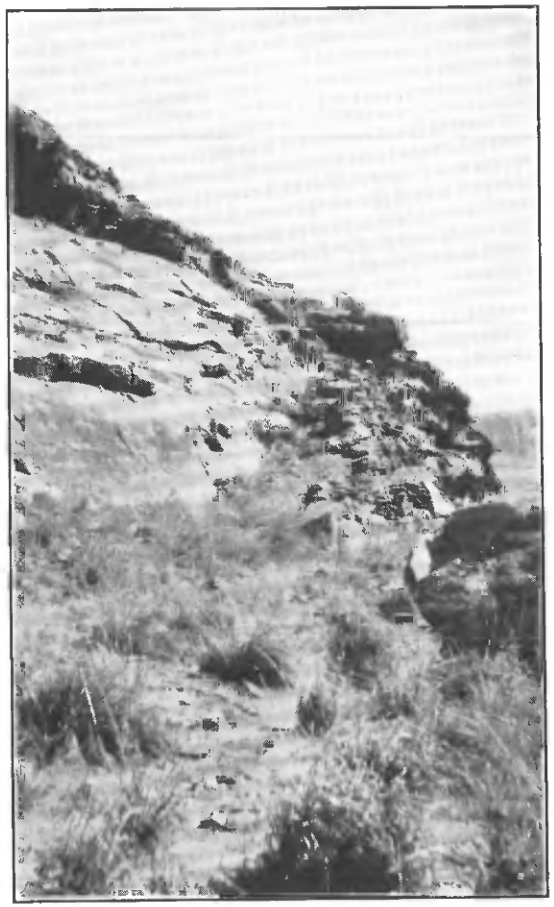
the western anticline the canyon of San Juan River has been carved into it to a depth of 1,338 feet without revealing its base, and in the eastern anticline the canyon has been carved into it to a depth of 1,000 feet. The formation is also exposed continuously down the canyon from the oil field as far as the mouth of Grand Gulch, a distance of about 25 miles by stream. Within this distance the formation makes up the lower parts of the canyon walls, and its top becomes lower and lower toward the west on account of the low westward dip. As a result of this dip the top of the formation passes beneath the river and disappears near the mouth of Grand Gulch. The formation consists of sandy shale, sandstone, and cherty limestone, all interbedded and revealed in every exposure. Most of the sandy shale is in reality nonfissile mudstone. Gray limestone predominates in the lower 500 feet, and sandstone and shale in the upper portion. Red is the most common color of the beds in the upper 700 feet.

The even bedding and interbedding of the limestone, shale, and sandstone give rise to numerous cliffs and benches in the walls of the canyons that trench the Goodridge formation. The cliffs are formed by limestone and hard sandstone, and the benches are formed by shale and soft sandstone. (See Pls. I–VI.)

Sandstone and limestone beds of the formation supply the oil in the San Juan oil field. Some of the oil-bearing beds are near the

A. HOLE IN THE ROCK, A CREVICE IN THE WALL OF THE GLEN CANYON OF THE COLORADO

A roadway was blasted in this crevice in the winter



B. RUINS OF ROAD CONSTRUCTED BY MORMON MISSION PARTY OPPOSITE HOLE IN THE ROCK

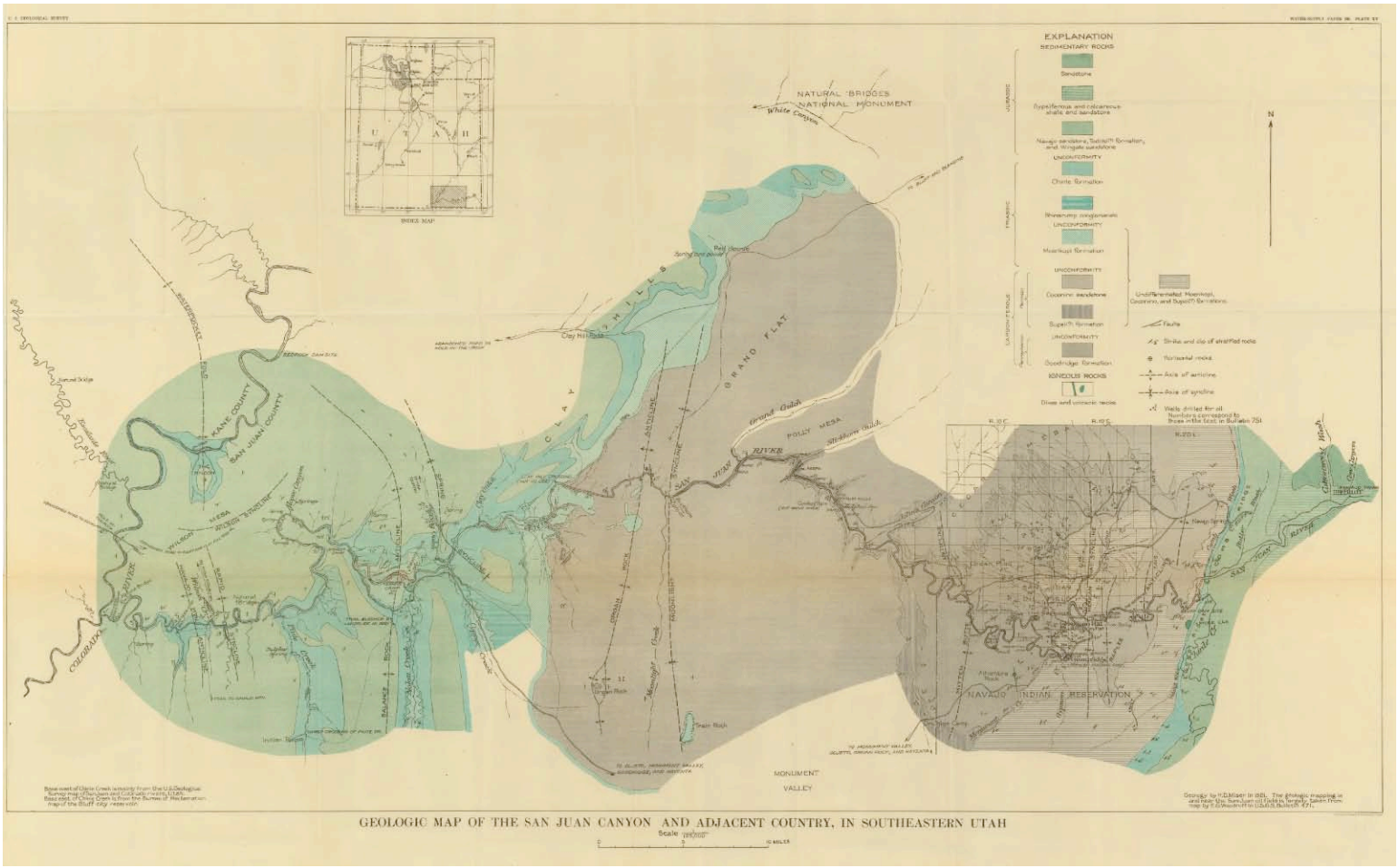
Photograph by H. D. Miser

A. VIEW LOOKING EAST FROM CLAY HILL PASS

The San Juan mission party descended the east slope of the Clay Hills through the badlands of the Chinle formation in the foreground and then passed on to the Grand Flat in the distance. Photograph by H. D. Miser

B. ROADWAY CONSTRUCTED IN FACE OF CLIFF BY SAN JUAN MISSION PARTY NEAR MOUTH OF BUTLER CREEK

Photograph by Robert N. Allen



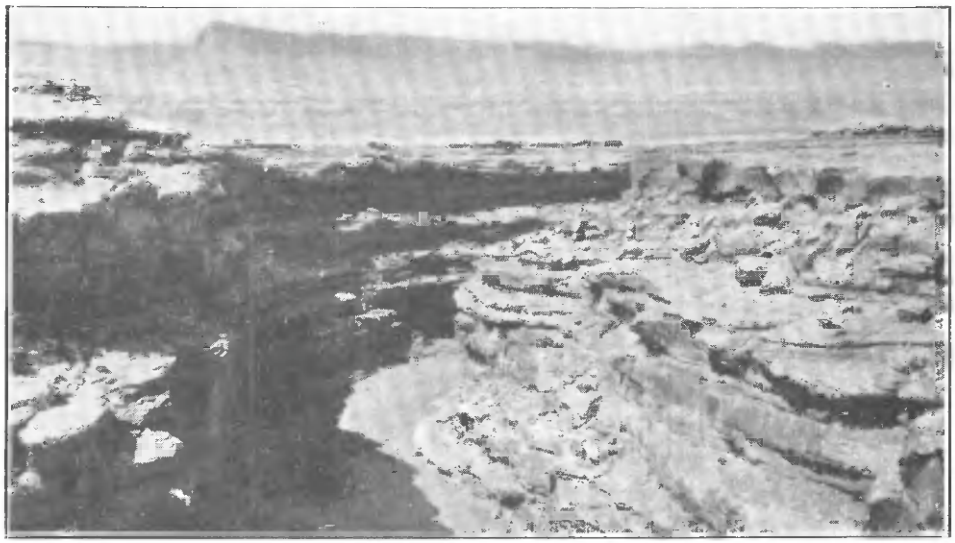
GEOLOGIC MAP OF THE SAN JUAN CANYON AND ADJACENT COUNTRY, IN SOUTHEASTERN UTAH

Scale 1:62500

0 1 2 3 10 MILES

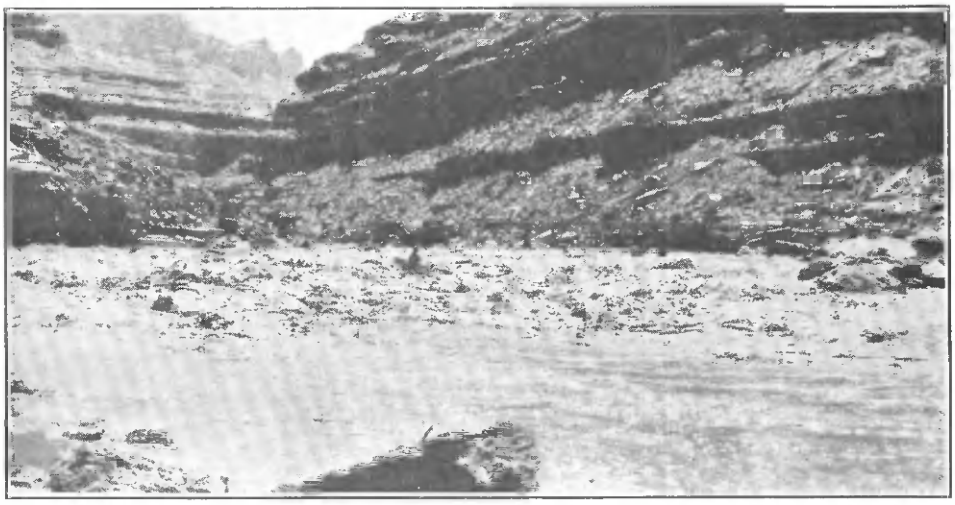
A. VIEW LOOKING NORTHWEST FROM HEAD OF HONAKER TRAIL

Cedar Mesa in distance capped by Coconino sandstone. Supai (?) formation is in lower part of escarpment of Cedar Mesa. Goodridge formation floors plateau in foreground and right distance. Photograph by H. D. Miser



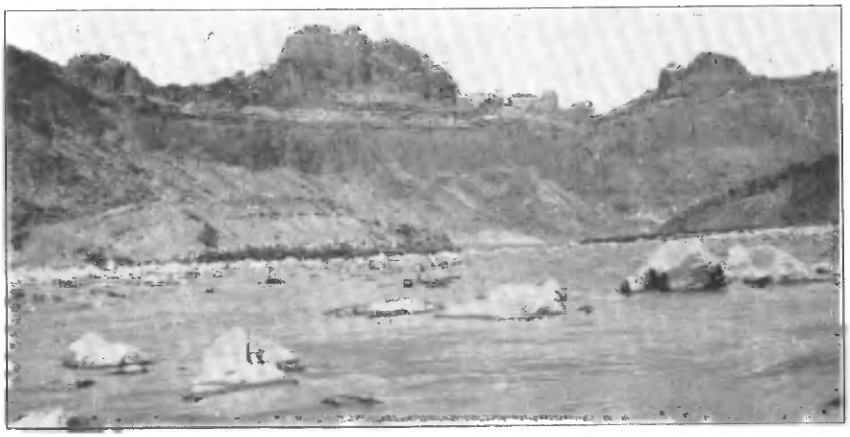
B. VIEW LOOKING SOUTH INTO SAN JUAN CANYON FROM POINT 3 MILES EAST OF CLAY HILL CROSSING

Coconino sandstone forms canyon walls and also floors adjacent plateau. Younger beds occur in distant mesa. Photograph by H. D. Miser



C. VIEW LOOKING UPSTREAM TOWARD RAPID BETWEEN JOHNS CANYON AND SLICKHORN GULCH

Equipment of Trimble expedition was portaged, and rapid was shot with empty boats. Photograph by Robert N. Allen

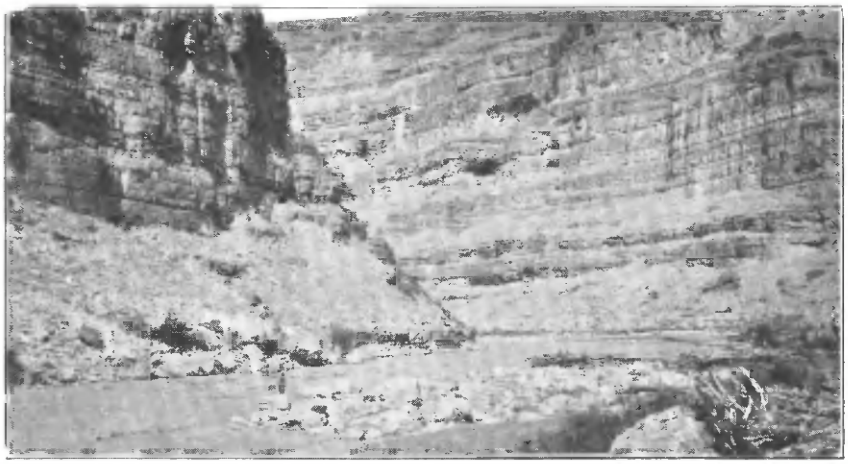


A. VIEW LOOKING UPSTREAM TOWARD FIRST RAPID AT MOUTH OF PIUTE CREEK

Equipment of Trimble expedition was portaged here, and boats were taken empty through rapid

B. VIEW LOOKING UPSTREAM TOWARD THIRTEEN-FOOT RAPID

Boats and equipment were all portaged here



C. VIEW LOOKING DOWNSTREAM AT A LOCALITY BETWEEN HONAKER TRAIL AND JOHNS CANYON

Boulder bar in foreground forms rapid

RAPIDS IN SAN JUAN CANYON

Photographs by H. D. Miser

top of the formation, but others are much deeper, the lowest being 1,300 feet below the top. The oil at the oil seeps in the canyon is also derived from the Goodridge.

SUPAI (?) FORMATION

The Supai (?) formation, of Permian age, which overlies the Goodridge formation, is exposed in and around the San Juan oil field and down San Juan Canyon almost to the mouth of Moonlight Creek. Lime and Gypsum creeks drain large areas underlain by this formation. Farther west the exposures occur in steep slopes that are surmounted by vertical cliffs of the next younger formation, the Coconino sandstone, which caps Cedar and Polly mesas and other high areas to the west and south. (See Pls. V, VI, *A*, and XVI, *A*.) At the base of such slopes there is everywhere a narrow to wide bench that is floored by the topmost beds of the Goodridge formation. The trail leading westward past Cedar Point to the mouth of Slickhorn Gulch runs on such a bench. The formation consists of red sandy shale and earthy sandstone. The thickness as measured at the mouth of Slickhorn Gulch is 380 feet. It was not measured farther east, but is probably much the same as at the mouth of Slickhorn Gulch.

COCONINO SANDSTONE

The Coconino sandstone, of Permian age, floors the broad westward sloping plateau areas that lie on both sides of San Juan River between the Clay Hills and the San Juan oil field. These areas are trenched by numerous canyons, including Grand Gulch, Slickhorn Gulch, and the canyon of Moonlight Creek. (See Pls. III, *B*, V, VI, VII, *B*, and XVI, *A*, *B*.) On the east they are limited by a precipitous, impassable escarpment several hundred feet high that separates them from the lower plateau in which the oil field is situated. To parts of the plateau north of the river the names Grand Flat, Polly Mesa, and Cedar Mesa have been applied; and the plateau south of the river, which is surrounded on its west and south sides by higher country, was called Monument Valley by Gregory.[27] A small isolated exposure of the Coconino sandstone occurs on the crest of an anticline in the lower part of San Juan Canyon at Zahns Camp.

Near the mouth of Moonlight Creek the thickness of the sandstone is about 600 feet; at the mouth of Slickhorn Gulch it is about 400 feet; and the exposed thickness near Zahns Camp is 144 feet or less, depending on whether the upper 89 feet of gray to red sandstone and shale belong with the Coconino sandstone or with the next succeeding formation, the Moenkopi.

[27] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380 and Prof. Paper 93.

Eastward from Cedar Mesa the sandstone is said by Woodruff to grade completely into red sandy shale, which is present on the southeast side of the oil field. This shale and the equivalent sandstone were included by Woodruff[28] and Gregory[29] in their Moenkopi formation.

The Coconino sandstone is massive, and its color is creamy white, though on Cedar Mesa much of it is tan. The grains are fine to medium in size, and as a rule the cement of calcium carbonate is sufficient to make the rock firm, although in places it is friable.

MOENKOPI FORMATION

The Moenkopi formation, the next younger formation, is of Triassic age and is overlain by the Shinarump conglomerate. Within the limits of the area shown on the map it is widely exposed along the river between Moonlight Creek and Spencer Camp, along Nokai and Copper creeks, along the eastward-facing escarpment of the Clay Hills, and along the west base of Comb Ridge. The beautiful Train and Organ rocks of Monument Valley are isolated outliers of the formation. (See Pl. VII, *B*, *C*.)

The formation, being easily eroded, forms badland slopes and steep, fluted cliffs underneath a capping of the resistant Shinarump conglomerate. (See Pls. VIII, *A*, and IX, *B*.)

Near Clay Hill Crossing, Piute Farms, and Zahns Camp it ranges in thickness from 765 to 920 feet and consists principally of even-bedded red sandy shale and earthy sandstone, with veinlets and lenses of gypsum. South and southwest of Piute Farms there is a thin bed of cream-colored sandstone near the middle of the formation. The bed gradually thickens toward the south, developing into a massive cross-bedded member which in Train Rock is estimated to have a thickness of about 200 feet. In the cliffs of the Moenkopi formation this sandstone forms a most conspicuous cream-colored band between the brick-red bands of the overlying and underlying parts of the formation. The sandstone disappears entirely near Piute Farms and was not recognized between Clay Hill Crossing and Red House.

The sandstone under discussion is apparently the same as the sandstone in southern Utah that has been called the De Chelly sandstone by Gregory, though Dorsey Hager[30] and N. H. Darton[31] consider the De Chelly sandstone in and near its type locality, Canyon De Chelly, in northeastern Arizona, to be equivalent to the Coconino

[28] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 86–87, 1912.

[29] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 29–30, 1917.

[30] Hager, Dorsey, Oil possibilities of the Holbrook area in northeastern Arizona, private publication, 1921.

[31] Manuscript report.

sandstone of the Grand Canyon section. Gregory treated the De Chelly sandstone as a separate formation, because in most of the region he studied in Utah and Arizona he found it above shale called by him the Moenkopi and immediately underneath the Shinarump conglomerate. The De Chelly sandstone, according to Gregory, is present on the east side of the San Juan oil field, where it is red in color and thins out toward the north.

SHINARUMP CONGLOMERATE

The Shinarump conglomerate, of Triassic age, is widely exposed along San Juan Canyon between Piute Farms and Piute Creek and also along Nokai and Copper creeks. It is apparently absent at all places between the canyon and Red House, to the north, and near the entrance to the canyon.

The formation, owing to its hardness and its occurrence between two soft shaly formations, produces precipitous cliffs and also floors benches above and back of the cliffs. (See Pls. VIII and X, *A*, *B*.) It ranges in thickness from a feather-edge to 220 feet; the greatest thickness was measured on the river near the mouth of Nokai Creek. It consists of massive gray cross-bedded coarse-grained sandstone and lenses of conglomerate with well-rounded pebbles of quartz and quartzite as much as 2 inches in diameter. Fossil logs that have been partly silicified are abundant in the lenses of conglomerate; and greenish-gray shale is a plentiful constituent, especially near the top of the formation.

CHINLE FORMATION

The Chinle formation, of Triassic age, succeeds the Shinarump conglomerate. It is exposed in a narrow belt along the west base of Comb Ridge and in wide areas in San Juan Canyon and the side canyons west of Piute Farms. It is also exposed along the east face of the Clay Hills. The exposures produce long badland slopes, which are cut by ravines and gullies and are strewn with landslides and huge jagged boulders derived from the sandstone cliffs above. (See Pls. VIII–XI, XIV, *A*, and XVII.)

The thickness ranges from 800 to 1,000 feet. Thick beds of marly shale of gray, pink, lavender, yellow, and numerous other colors makes up the bulk of the formation, and where they are not concealed by landslides, soil, and boulders they produce with their many vivid colors landscape views of amazing beauty. Cherty and conglomeratic limestone and sandstone are common, especially near the top of the formation. Silicified logs, some 40 feet or more in length and 4 feet in diameter, are numerous at places.

WINGATE SANDSTONE

The Wingate sandstone, of Jurassic age, is one of the most conspicuous cliff-makers of the region. It is from 275 to 400 feet thick, and commonly the greater part of the total thickness appears as a single massive unit which is cut by vertical joints and presents an impassible palisade-like wall at the top of the long badland slopes of the Chinle formation. (See Pls. IX, *B*, *C*, X–XII, and XVII.) The sandstone forms the western part of Comb Ridge and is widely exposed in the country of high plateaus and mesas west of Piute Farms.

At some places the lowermost beds are lenticular and are in part conglomeratic. The massive cliff-making portion, which averages about 300 feet in thickness, has indistinct and continuous bedding and is cross-bedded on a large scale. The sandstone is composed of fine rounded sand grains. The color of the sandstone on exposed surfaces gives the cliffs a striking appearance even in a "painted desert"; it is dark brown and at times assumes a vermilion color. On unweathered surfaces the rock is buff. The darker color ordinarily seen on cliffs is due to a coat of iron oxide along the joint faces.

TODILTO (?) FORMATION

The Todilto (?) formation, also of Jurassic age, ranges from 100 to 200 feet in thickness and consists of light to dark brown sandstone in comparatively thin beds, brown sandy shale, thin lenses of gray limestone, and lenses of conglomerate with sandstone pebbles. The formation as a whole is very resistant; it almost everywhere caps the cliffs of the underlying Wingate sandstone and floors wide and narrow benches wherever the overlying Navajo sandstone has been eroded from it. (See Pls. VIII, *B*, IX, *B*, XI, XII, XIII, *A*, and XVII, *A*.) The sandstone is exposed in a narrow belt near the middle of Comb Ridge and in irregular areas and crooked belts in the country of high plateaus and mesas west of Piute Farms. These areas and belts have dark-brown and vermilion colors and at a distance frequently display a tint of lavender.

NAVAJO SANDSTONE

The Navajo sandstone, of Jurassic age, forms the eastern part of Comb Ridge and caps most of the high plateaus and mesas west of Piute Farms. It forms great tracts of almost impassable badlands, in which domes, "mosques," "minarets," and canyons are common features. (See Pls. XI–XIII, XVII, *A*, *B*, and XVIII.) Caves, alcoves, and arches are conspicuous in the canyon walls of this sand-

stone, and it forms a number of natural bridges, notably the Rainbow and Owl bridges, near Navajo Mountain. The two small bridges near San Juan River have been formed in this sandstone. One of these is on the rim of the right canyon wall 2 miles below the mouth of Piute Creek, and the other is on the rim of the canyon wall of the high abandoned river channel that runs from a point near the mouth of the San Juan northward about 1 mile to the Colorado. These two bridges are described on page 15.

The sandstone is thickest on Wilson Mesa, where it is 800 to 1,000 feet thick. The usual color is tan or buff, but on Wilson Mesa the upper part of the formation is gray to buff and at places has a pinkish tint. The sand grains are small and rounded and are loosely held together by a cement of calcium carbonate. Cross-bedding on a large scale is characteristic of the greater part of the formation. True bedding planes are present but not distinct, so that the entire formation stands in some cliffs with the appearance of a single massive layer. Lenses of gray compact limestone from 2 to 5 feet thick are common in all parts of the sandstone, especially near the mouth of the San Juan. These lenses at some places contain chert. They extend laterally from a few hundred feet to half a mile.

OTHER ROCKS OF JURASSIC AGE

The Navajo sandstone is overlain by 100 to 250 feet of red gypsiferous and calcareous shales and thin sandstones at Bluff (Pl. I) and along Glen Canyon below the mouth of the San Juan. These gypsiferous beds are succeeded by a massive cliff-making, cross-bedded sandstone, which in some parts is red, in others gray or white, and in other mottled red and white. (See Pl. I.) At Bluff the sandstone is from 170 to 270 feet thick and in places along Glen Canyon it is apparently as much as 500 feet thick.

M'ELMO FORMATION

The McElmo formation, of Cretaceous (?) age, is exposed near Bluff, where it consists of gray, red, and green shales and thin beds of sandstone, with two heavy conglomerates, making an incomplete section several hundred feet thick. This and later formations of Cretaceous age are exposed along the Colorado beyond the limits of the area under discussion.

TERRACE GRAVEL

Gravel of Quaternary age floors terraces of small extent at numerous places in the canyon, especially in the several wide, open stretches, and they partly floor an abandoned canyon near the mouth

of the river through which the San Juan or the Colorado formerly flowed. The largest areas of gravel are in the wide stretch extending from Clay Hill Crossing to Piute Farms.

The gravel floors terraces at several different altitudes up to about 600 feet above the river. It was deposited mostly by the San Juan but partly by side streams when their channels stood at the altitude of the terraces. The usual thickness of the gravel deposits is 10 feet or less, but at some places they are 20 feet and at a few places as much as 100 feet thick. The deposits are all similar in character and consist mostly of limestone pebbles from the Goodridge formation of the San Juan oil field, and of quartzite, conglomerate, and crystalline rocks from the San Juan Mountains of southwestern Colorado. Much or all of the terrace gravel at and near the mouths of side streams consists of sandstone and limestone pebbles that have been contributed by the side streams. Such gravel is thus of local origin and differs in character from gravel of the common type.

The constituents of the gravel deposits range in size from pebbles a small fraction of inch in diameter to cobbles a foot in diameter; the largest ones occur near the base of the deposits. The usual diameter is probably between 1 and 3 inches. All the pebbles are well rounded, and most of them are flattened. Some of the deposits near the mouths of side streams contain boulders 6 or 8 feet in diameter, and one boulder 10 feet in diameter was observed. The gravel is poorly to firmly cemented by earthy calcium carbonate, which is concentrically banded around the pebbles. At many places the shells of calcium carbonate that have become detached from the pebbles are conspicuous on the surface, for they resemble shallow cups.

RECENT STREAM DEPOSITS

Stream deposits of recent age, consisting of sand, gravel, cobbles, and boulders, occur along the banks of San Juan River or on the river bed at most places in the canyon. These deposits are fully described under the heading "Canyon fill" on pages 58–71.

STRUCTURE

San Juan Canyon, as stated by Gregory,[82] bisects a flat corrugated dome—one of the major upwarps of the Colorado Plateau—to which he has applied the name Monument upwarp. The upwarp is broad and high and trends north. On the east it is sharply bounded by the conspicuous monocline of Comb Ridge, but on the west it merges with the Waterpocket, Kaiparowits, and other flexures.

[82] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 113, 1917.

The youngest formation involved, the Navajo sandstone, of Jurassic age, lies on the summits of the Clay Hills 3,000 feet higher than it does at the mouth of the San Juan and 2,000 feet higher than it does at the east base of Comb Ridge. The oldest beds involved are in the Goodridge formation, of Pennsylvanian age, which is widely exposed not only in San Juan Canyon near Goodridge but also farther north in the upwarp in Cataract Canyon of the Colorado. The Cretaceous strata that formerly covered the dome have been stripped back to Black Mesa on the south, to Bluff on the east, and to points beyond the Colorado on the west; Tertiary sediments may also have been present.

The strata along and inside the margins usually have dips of 1° to 5°; higher dips are exceptional, though they are common along the Comb monocline. Large areas of practically horizontal rocks underlie Wilson Mesa and also a belt of country between Piute and Wilson creeks.

Within the Monument upwarp there are several minor flexures, which include anticlines and synclines more than 20 miles in length. The folds are parallel or nearly so and have a general northward trend. The location of their axes is shown on the accompanying geologic map (Pl. XV). The folds together with the few thrust and normal faults, also shown on the map, are fully described in another report.[38]

SAN JUAN RIVER AND TRIBUTARY STREAMS

GENERAL FEATURES

San Juan River rises in the San Juan Mountains of southwestern Colorado, runs southwest into New Mexico and west through northwestern New Mexico, crosses the southwest corner of Colorado into southeastern Utah, where it runs in a general westerly direction across San Juan County, and enters Colorado River several miles north of the Arizona-Utah line. Its headwaters and some of its tributaries in Colorado drain a high mountainous region that is forest-clad and well watered. The largest volume of water from that region is carried by these streams late in the spring, when the snow melts. Comparatively little silt is carried by the streams from this region. Away from the mountainous region of southwestern Colorado the San Juan and its tributaries drain a barren arid country of mesas, plateaus, and canyons. There the streams, which receive most of their water from short, violent

[38] U. S. Geol. Survey Bull. 751, pp. 115–155, 1924 (Bull. 751–D).

thundershowers, are torrential and carry much silt, sand, gravel, and boulders.

The San Juan in its lower course in Utah runs through San Juan Canyon, 133 miles long, which has already been described. In the canyon the current is generally swift, the average fall being about 7 feet to the mile, and there are numerous rapids. These features, together with the muddiness of the water, the quicksands, and the frequent and sudden rises, are well known to the Navajo Indians, whose name for the San Juan is Pawhuska (mad water).

Jim, a Piute Indian, when told at Mexican Hat that the Trimble party was to descend the river in boats, was surprised and briefly remarked that he did not believe it. Indians at the mouth of Piute Canyon told us we were crazy for descending the river in boats; they said we would never return. A return trip has in fact not been made by us to Piute Canyon, and I suppose they think that our boats were wrecked in rapids and that our bones now lie buried in some sand bar. The next canyon voyagers may therefore expect to receive from the Indians the same admonition as was given to us.

A number of the headwater tributaries of the river are large enough to be called rivers, but all the streams that join it in the canyon are small, flowing not more than several second-feet during low stages. All of them are at times converted by thunderstorms into rushing silt and boulder-laden torrents that attain a depth of 20 feet. Chinle Creek and Comb and Butler washes join the San Juan just above the canyon. The principal tributaries in the canyon include the streams that drain Grand and Slickhorn gulches, from the north, the Moonlight, Copper, Nokai, and Piute creeks, from the south.

DISCHARGE MEASUREMENTS OF SAN JUAN RIVER

The drainage area of the San Juan comprises 25,800 square miles and includes parts of Colorado, New Mexico, Arizona, and Utah. The discharge varies greatly. In January, 1905, the river had a minimum flow of 40 second-feet; in June of the same year a maximum flow of 24,800 feet was recorded. In July, 1904, the river reached a minimum discharge of 20 second-feet, as contrasted with 20,000 second-feet in October. The discharge measurements given below show that the annual run-off ranges from 1,500,000 to 4,500,000 acre-feet. The drainage area tributary to the river above the gaging station at the Goodridge Bridge, the station nearest the mouth of the river, is about 24,000 square miles.

Monthly discharge of San Juan River at Goodridge Bridge, near Goodridge, Utah, during the years 1914–1917

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1914–15 [a]				
November	2,360	1,140	1,580	94,000
December	1,210	505	1,020	62,700
January	2,060	630	1,010	62,100
February	4,820	1,080	2,330	129,000
March	4,980	960	2,230	137,000
April	13,900	3,740	8,040	478,000
May	13,100	4,980	9,270	570,000
June	12,900	4,320	10,100	601,000
July	21,900	2,610	6,490	399,000
August	3,380	705	1,660	102,000
September	5,830	380	1,050	62,500
The period	21,900	380	4,060	2,700,000
1915–16 [b]				
October	1,960	552	941	57,900
November	824	552	667	39,700
December	793	388	637	39,200
January	5,790	505	1,310	80,600
February	2,390	854	1,400	80,500
March	16,200	1,340	6,210	382,000
April	11,000	4,850	7,570	450,000
May	15,500	5,470	9,340	574,000
June	14,400	7,130	10,500	625,000
July	7,670	2,800	5,160	317,000
August	14,500	2,200	7,120	438,000
September	5,790	1,740	2,590	154,000
The year	16,200	388	4,460	3,240,000
1916–17 [c]				
October	28,300	1,740	7,850	483,000
November	2,010	990	1,040	61,900
December	1,130	199	669	41,100
January	990	350	694	42,700
February	2,800	410	1,250	69,400
March	3,610	758	1,370	84,200
April	12,400	2,100	5,910	352,000
May	14,700	5,630	9,110	560,000
June	18,700	6,620	14,000	833,000
July	14,700	5,000	8,470	521,000
August	5,310	1,660	2,880	177,000
September	2,490	1,340	1,870	111,000
The year	28,300	199	4,630	3,340,000

[a] U. S. Geol. Survey Water-Supply Paper 409, p. 118, 1918.
[b] U. S. Geol. Survey Water-Supply Paper 439, p. 130, 1919.
[c] U. S. Geol. Survey Water-Supply Paper 459, p. 129, 1921.

Monthly discharge of San Juan River at Shiprock, N. Mex., for 1911, 1915–1920

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1911 [a]				
January 14–31	2,800	850	1,400	50,000
February	1,450	600	979	54,400
March	9,920	1,050	4,390	270,000
April	9,920	4,250	7,090	422,000
May	15,000	7,100	10,700	658,000
June	14,300	6,000	10,600	631,000
July	20,400	3,200	10,000	615,000
August	4,950	325	1,140	70,100
September	4,250	300	872	51,900
October 1–6	47,600	9,600	19,300	380,000
The period				3,050,000

[a] La Rue, E. C., Colorado River and its utilization: U. S. Geol. Survey Water-Supply Paper 395, p. 104, 1916.

Monthly discharge of San Juan River at Shiprock, N. Mex., etc.—Continued

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1915 [b]				
November 17–30	553	543	548	15,200
December	542	519	530	32,600
The period	553	519	536	47,800
1916 [b]				
January	1,020	400	641	39,400
February	18,700	480	2,370	136,000
March	33,100	595	8,430	518,000
April	13,200	3,650	7,240	431,000
May	21,600	5,700	11,700	718,000
June	21,800	8,300	14,000	834,000
July	12,400	2,010	7,230	444,000
August	21,600	2,100	7,770	478,000
September	13,500	880	2,690	160,000
October	31,800	1,330	8,850	544,000
November	2,470	740	1,410	84,200
December	1,680	390	754	46,300
The year	33,100	390	6,110	4,430,000
1917 [b]				
January	1,160	520	768	47,200
February	2,850	680	1,100	61,300
March	7,450	630	1,920	118,000
April	11,500	900	6,710	399,000
May	20,300	5,400	9,260	569,000
June	27,800	3,400	17,300	1,030,000
July	24,100	3,500	8,010	492,000
August	4,040	470	1,510	92,800
September	1,340	445	815	48,500
October	850	550	646	39,700
November	575	405	482	28,700
December	460	380	413	25,400
The year	27,800	380	4,070	2,950,000
1918 [c]				
January	670	225	459	28,200
February	1,100	500	785	43,600
March	4,600	670	1,860	115,000
April	4,600	1,420	3,060	182,000
May	10,000	3,370	5,920	364,000
June	16,100	2,280	7,900	470,000
July	5,700	990	2,820	173,000
August	6,680	645	1,540	94,600
September	14,100	485	1,960	117,000
October	610	315	481	29,600
November	990	610	808	48,100
December	610	479	550	33,800
The year	16,100	225	2,350	1,700,000
1919 [d]				
January	704	440	536	33,600
February	1,020	715	870	48,300
March	9,600	1,040	2,800	172,000
April	11,900	1,950	5,410	342,000
May	16,600	4,500	9,370	576,000
June	11,500	4,300	7,520	448,000
July	17,100	2,800	7,830	481,000
August	14,050	330	2,340	144,000
September	6,600	260	1,670	99,200
October	2,500	600	1,080	66,600
November	1,150	800	939	55,900
December	2,550	450	1,020	63,000
The year	17,100	260	3,500	2,530,000

[b] French, J. A. Surface water supply of New Mexico, 1888–1917, p. 204, 1918.
[c] French, J. A., Surface water supply of New Mexico, 1918, p. 132, 1919.
[d] Gillett, L. A., Surface water supply of New Mexico, 1919–1920, p. 161, 1921 (?).

Monthly discharge of San Juan River at Shiprock, N. Mex., etc.—Continued

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1920 [d]				
January	6,400	630	2,150	132,000
February	11,400	1,030	3,690	212,000
March	10,560	2,310	4,260	262,000
April	12,100	2,560	7,220	429,000
May	43,200	9,360	16,300	1,000,000
June	21,900	5,170	14,800	879,000
July	10,800	2,800	5,480	337,000
August	8,250	1,100	2,450	151,000
September	3,590	400	1,050	62,400
The period	43,200	400	6,380	3,464,000

[d] Gillett, L. A., Surface water supply of New Mexico, 1919–1920, p. 161, 1921 (?)

Monthly discharge of San Juan River at Farmington, N. Mex., for 1904–5, 1912–18

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1904 [e]				
June 19–30	1,300	780	1,080	24,500
July	1,580	20	375	23,100
August	4,980	1,450	2,630	162,000
September	8,620	400	1,380	81,800
The period				291,000
1904–5 [e]				
October	20,000	2,620	5,940	365,000
November	1,700	630	1,090	64,700
December	780	90	348	21,400
January	338	40	242	14,900
February	2,580	230	682	37,900
March	3,410	780	1,620	99,900
April	7,460	1,080	4,290	255,000
May	19,100	4,640	10,100	622,000
June	24,800	11,000	18,300	1,090,000
July	8,240	2,180	3,600	222,000
August	3,740	840	1,750	107,000
September	4,870	1,180	1,670	99,600
The year	24,800	40	4,140	3,000,000
1912–13 [e]				
October	1,970	502	945	58,100
November	1,450	621	1,090	64,900
December	796	240	498	30,600
January			464	28,500
February	602	366	471	26,200
March	2,510	394	683	42,000
April	6,570	2,760	4,650	277,000
May	11,100	4,520	8,020	493,000
June	9,360	3,560	5,880	350,000
July	4,340	673	1,770	109,000
August	1,310	353	621	38,200
September	4,150	628	1,450	86,300
The year	11,100		2,210	1,600,000
1913–14 [e]				
October	7,350	673	1,480	91,000
November	1,080	688	932	55,500
December	992	550	684	42,100
January	620	501	597	36,700
February	6,520	590	1,870	104,000
March	4,900	2,470	3,460	213,000

[e] La Rue, E. C., Colorado River and its utilization: U. S. Geol. Survey Water-Supply Paper 395, p. 103, 1916.

Monthly discharge of San Juan River at Farmington, N. Mex., etc.—Continued

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
1913–14—Continued				
April	5,360	3,430	4,480	267,000
May	15,100	3,540	7,940	488,000
June	20,400	4,540	9,900	589,000
July	8,620	2,680	4,260	262,000
August	3,310	866	2,020	124,000
September	4,380	887	1,610	95,800
The year	20,400	501	3,270	2,370,000
1914–15 [b]				
October	12,600	887	3,080	189,000
November	2,120	939	1,340	79,700
December	992	650	801	49,300
January	660	440	559	34,400
February	800	510	638	35,400
March	3,600	750	1,629	100,000
April	10,500	2,500	6,780	404,000
May	12,190	4,350	7,200	443,000
June	13,600	5,000	9,540	568,000
July	17,600	2,640	5,630	346,000
August	3,400	870	1,560	96,100
September	3,520	715	1,110	66,300
October	1,540	640	914	56,200
November	675	500	585	34,800
December	570	400	482	29,700
The period	17,600	400	2,790	2,528,000
1916 [b]				
January	870	355	651	40,000
February	1,750	320	969	56,900
March	9,750	1,090	4,870	299,000
April	10,500	2,340	5,040	300,000
May	14,200	7,340	9,630	592,000
June	12,300	6,560	9,620	572,000
July	6,340	2,490	4,640	285,000
August	14,200	2,000	4,700	289,000
September	7,810	1,630	3,200	191,000
October	19,800	2,760	7,530	463,000
November	3,170	1,210	1,940	115,000
December	1,360	220	840	51,700
The year	19,800	220	4,480	3,250,000
1917 [b]				
January	1,310	943	1,040	63,700
February	2,360	943	1,120	62,400
March	5,900	905	1,890	116,000
April	8,900	1,800	4,890	291,000
May	14,600	3,770	7,370	453,000
June	22,500	6,200	17,500	1,040,000
July 1–29	----------	----------	11,000	634,000
August 6–25	----------	----------	2,120	83,900
September 15–30	----------	----------	1,360	43,100
October 1–7	----------	----------	809	11,200
November 8–30	----------	----------	396	18,160
December	470	340	366	22,500
The year	----------	----------	4,660	2,840,000
1918 [c]				
January	470	390	427	26,200
February	1,790	425	620	34,400
March	5,510	895	1,780	109,000
April	3,060	1,340	2,060	123,000
May	10,100	2,900	4,830	297,000
June	16,300	2,830	6,800	405,000
July 1–28	7,490	839	2,800	155,000
The period	16,300	390	2,780	1,150,000

[b] French, J. A., Surface water supply of New Mexico, 1888–1917, pp. 201–202, 1918.
[c] French, J. A., Surface water supply of New Mexico, 1918, p. 130, 1919.

FALL OF SAN JUAN RIVER

The San Juan in running through its canyon has not only numerous rapids but a fairly swift current between the rapids. The fall of the entire river and that of parts of the river are given in the table on page 48 and are also discussed in the following paragraphs. (See Pl. XXII.)

From the mouth of Chinle Creek to the Colorado, a distance of about 132.5 miles, the San Juan descends from an altitude of 4,209 feet to 3,259 feet, a total fall of 950 feet, or an average of 7.17 feet to the mile. Only a few miles of the river has an average fall of less than 5 feet, and none has less than 3 feet. The mile in which the fall is greatest extends downstream from the head of the first rapid at the mouth of Piute Creek; here the fall is a little more than 25 feet. (See Pl. XVII, *A*.) The mile with the next greatest fall extends downstream from the head of the Thirteen-foot Rapid, 11½ miles by stream above the mouth of the river; its fall is about 24 feet, (See Pl. XVII, *B*.)

The river from the mouth of Chinle Creek to the south end of Soda Basin, a distance of 10.75 miles, has a fall of 101.5 feet, or an average of 9.4 feet to the mile. In this distance there are several small rapids, of which the largest, with a fall of 8 feet, runs over a boulder bar at the mouth of a southern tributary half a mile above The Narrows.

The part of the river from the south end of Soda Basin to a point 1.5 miles above the foot of the Honaker trail has a fairly uniform fall, yet it is marked here and there by very small rapids, the largest of which is at the mouth of Gypsum Creek. The fall of this rapid is about 3.5 feet. The length of this part of the river is 23.85 miles, the total fall 160 feet, and the average fall 6.7 feet to the mile.

The part of the river extending from a point 1.5 miles above the foot of the Honaker trail to the mouth of Slickhorn Gulch has an average fall of 8.6 feet to the mile, the distance being 23.2 miles and the total fall 199.5 feet. This part of the river has numerous small rapids, none of which has a fall greater than about 4 feet.

The part of the river extending from the mouth of Slickhorn Gulch to a point 3 miles below the mouth of Grand Gulch is especially swift, yet it is marked by only one or two rapids, one of which is at the mouth of Slickhorn Gulch. The fall of this part of the river, which is 6.8 miles long, is 79 feet, or an average of 11.6 feet to the mile.

The river between a point 3 miles below the mouth of Grand Gulch and the head of the first rapid at the mouth of Piute Creek, a distance of 46.4 miles, has a rather uniform fall, averaging 5 feet

to the mile. This part of the river has no rapids of any consequence, yet the current is swift at most places.

The part of the river extending 1.6 miles downstream from the head of the first rapid at the mouth of Piute Creek is marked by about five rapids and has a total fall of 35 feet, of which a little more than 25 feet is in the first mile.

The next 8.5 miles of the river to the head of the Thirteen-foot Rapid is marked by few rapids and the largest has a fall of 3 feet. The total fall in this distance is 56 feet, or 6.6 feet to the mile. The first mile of the river below the head of this rapid has two other rapids, and the aggregate fall in this distance is about 24 feet.

The last 10.5 miles of the San Juan has a fall of 57 feet, or an average of 5.4 feet to the mile. There are no rapids in this stretch, though the current is swift, especially where it impinges against the canyon walls and rebounds to form whirlpools across the main channel from the points of impingement.

Fall of San Juan River

From—		To—		Distance (miles)	Fall (feet)	
Point	Altitude (feet)	Point	Altitude (feet)		Total	Average per mile
Mouth of Chinle Creek	4,209	Mouth of river	3,259	132.5	950	7.17
Do	4,209	3 miles below mouth of Grand Gulch.	3,669	64.6	540	8.3
3 miles below mouth of Grand Gulch.	3,669	Mouth of river	3,259	68	410	6
Mouth of Chinle Creek	4,209	South end of Soda Basin	4,107.5	10.75	101.5	9.4
South end of Soda Basin	4,107.5	1.5 miles above Honaker Trail.	3,947.5	23.85	160	6.7
1.5 miles above Honaker Trail.	3,947.5	Mouth of Slickhorn Gulch.	3,748	23.2	199.5	8.6
Mouth of Slickhorn Gulch.	3,748	3 miles below mouth of Grand Gulch.	3,669	6.8	79	11.6
3 miles below mouth of Grand Gulch.	3,669	Head of first rapid at mouth of Piute Creek.	3,431	46.4	238	5.1
Head of first rapid at mouth of Piute Creek.	3,431	1.6 miles below head of rapid.	3,396	----------	35	----------
1.6 miles below head of first rapid at mouth of Piute Creek.	3,396	Head of Thirteen-foot rapid.	3,340	8.5	56	6.6
Head of Thirteen-foot Rapid.	3,340	1 mile below Thirteen-foot Rapid.	3,316	1	24	----------
1 mile below head of Thirteen-foot Rapid.	3,316	Mouth of river	3,259	10.5	57	5.4

CHARACTER OF CHANNEL OF SAN JUAN RIVER

The channel of the river in the box canyons is generally 150 to 300 feet wide, but at a few places near Goodridge and Mexican Hat it narrows to a width of 50 to 75 feet. One of these places is at the Goodridge Bridge, where the channel occupies a rock-walled gorge 75 feet wide, and another is at a point 1 mile due east of The Narrows, where it occupies a similar gorge only about 50 feet wide. In the box canyons the river is skirted here and there by gravel and sand bars, but at most places the water's edge is met by the base of

talus slopes and by precipitous walls. (See Pls. II–VI, IX, *C*, X–XII.) A few rock ledges extend far out into the channel; none are exposed in the middle of the channel. Boulders of all sizes up to 60 feet in their longest dimension, submerged and unsubmerged, dot the channel here and there; and great heaps of them that have been brought to the river by tributary streams and piled at their mouths form boulder bars that not only narrow the channel but produce rapids.

In the open stretches—those that are not closely bordered by canyon walls—the channel is wider, attaining a maximum width of 3,300 feet at Piute Farms. An open stretch occurs near the mouth of Chinle Creek, a second between Clay Hill Crossing and Piute Farms, a third between the mouths of Clay Gulch and Copper Canyon, a fourth at and near Zahns Camp, a fifth at Spencer Camp, a sixth between the Great Bend and the mouth of Piute Creek, and a seventh extending 3 miles downstream from the mouth of Wilson Creek. In such open stretches the river is bordered by large bars of yellow sand and a few gravel bars, is dotted by islands of ripple-marked sand, and is marked here and there by boulder bars and their accompanying rapids.

The part of the river extending from the head of the canyon to the mouth of Moonlight Creek is comparatively deep, if we may judge from the fact that our boats grounded at no place in this distance. The water was so muddy that the bottom could not be seen—in fact, it was so muddy at all times that objects held an inch below the surface were not visible. No soundings with poles were made to a depth greater than 10 to 12 feet, but a few soundings with lines and baited hooks were made in apparently favorable fish haunts in quiet water below huge boulders. Such soundings found no water more than 1 to 2 feet deep, and either the water was inhabited by no fish, or if any were there they were not hungry or could not find the bait in the muddy water.

The part of the river extending from the mouth of Moonlight Creek to the Colorado is very shallow in numerous stretches, of great and small extent. At the rapids the river runs over boulders, but between the rapids it runs over fine buff to yellow sand and a few thin deposits of yellow to red clay.

The descent of the canyon below the mouth of Moonlight Creek was difficult, because the river through much of this distance was so shallow—less than 6 or 8 inches deep—that the party had to wade and pull the boats. Occasionally the boats would ground in swift water when they were in a sidewise position. On such occasions the force of the impact and of the current would tilt the boats so high that water would run into them on the downstream side. While rowing in such shallow water we always sat ready to jump into the

water at the instant of impact. Only once did I jump into the water on the downstream side of the boat; that time the boat threw me down and skinned my legs before I could extricate myself. Ever afterward I jumped into the water on the upstream side.

In some short stretches where the water was less than 5 inches deep the boats had to be carried. We found the river shallowest between Nokai and Piute creeks, and if it had been a few inches lower we would have been required to wait for higher water or abandon the descent of the canyon.

Where the river has a wide channel whose beds and sides are loose sand the main current frequently changes its position. For example, the main channel at Piute Farms, where the entire channel is 3,300 feet wide, was observed to shift in one afternoon from the middle of the stream to the south bank; and at Spencer Camp the main current shifted a few times from the center of the stream to the edge and flowed against the sand bar on which we camped. At such times the river undercut the banks, not only causing the banks to cave but compelling us to move our meager camp equipment to prevent it from falling into the river.

During observed flood stages at Piute Farms the current beat against the left bank, which was composed of earth and shrubbery, and widened the channel fully 75 feet in the vicinity of our camp. (See Pl. XIX.)

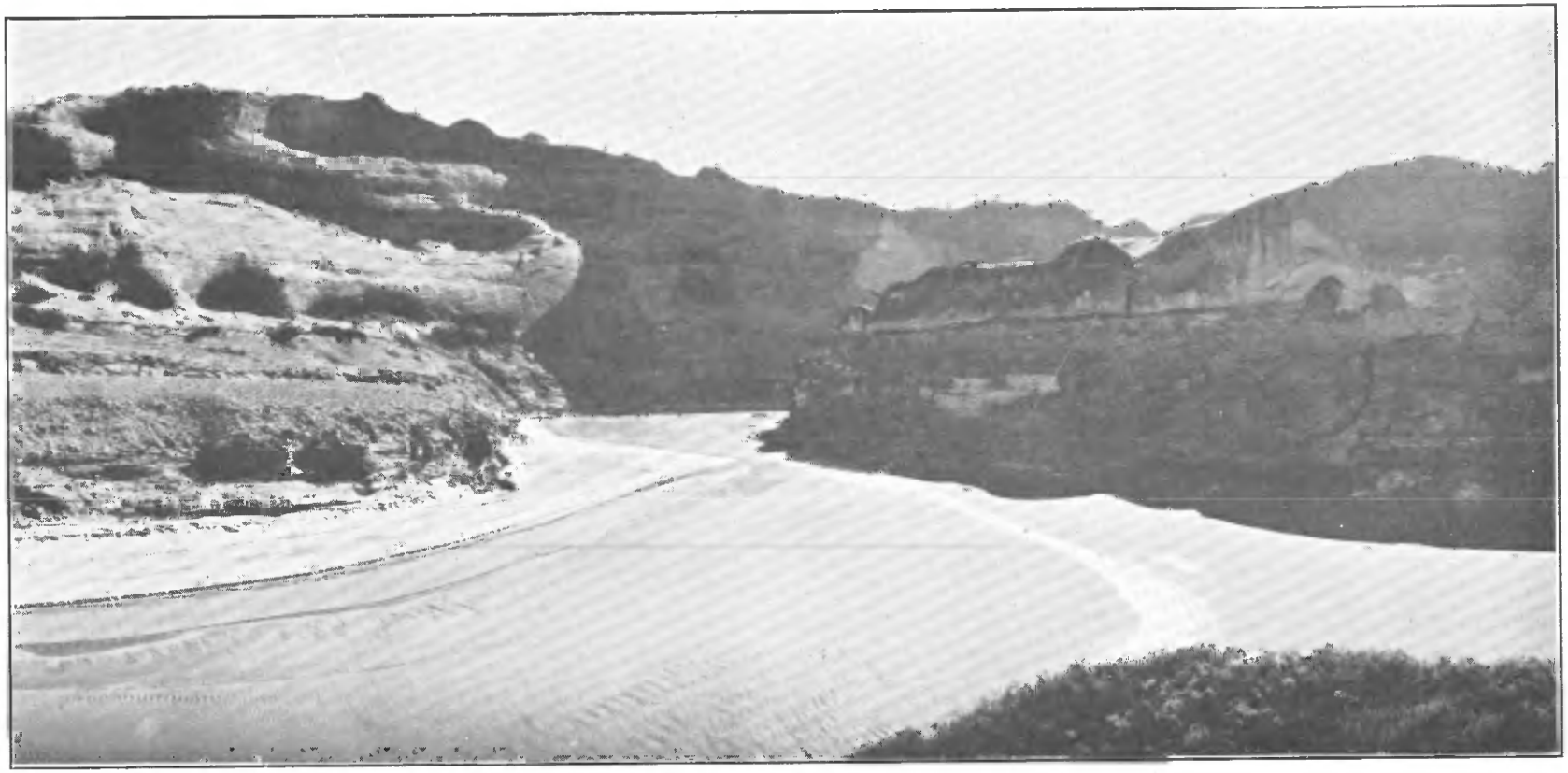
A caving bank is an unsafe place for tying up a boat. The boat would better be taken out of the river. This lesson we learned from experience, for on a number of occasions one of our boats was sunk by falling chunks of earth, resulting in the loss of oars, rowlocks, and other essential equipment.

Some years ago a caving bank and a high flood swept away much of the modern house of A. L. Raplee, which had been built on the river bank half a mile east of the village of Mexican Hat.

RAPIDS OF SAN JUAN RIVER

The San Juan in passing through the canyon has numerous rapids, though they are small, the greatest fall of a single rapid being only 13½ feet. The rapid having this fall is 11½ miles by stream above the mouth of the river and is herein called the Thirteen-foot rapid. (See Pl. XVII, *B*.) The rapid at the mouth of a southern tributary half a mile above The Narrows has a fall about 8 feet, and the first rapid at the mouth of Piute Creek also has a fall of 8 feet. (See Pl. XVII, *A*.)

Most of the rapids are produced by boulder bars at the mouths of side canyons. (See Pls. VI, *A*, XVI, *C*, and XVII.) The bars are composed of boulders as much as 18 feet in their longest dimension that have been brought to the river by the torrential streams that drain



THE JUNCTION OF THE SAN JUAN WITH THE COLORADO

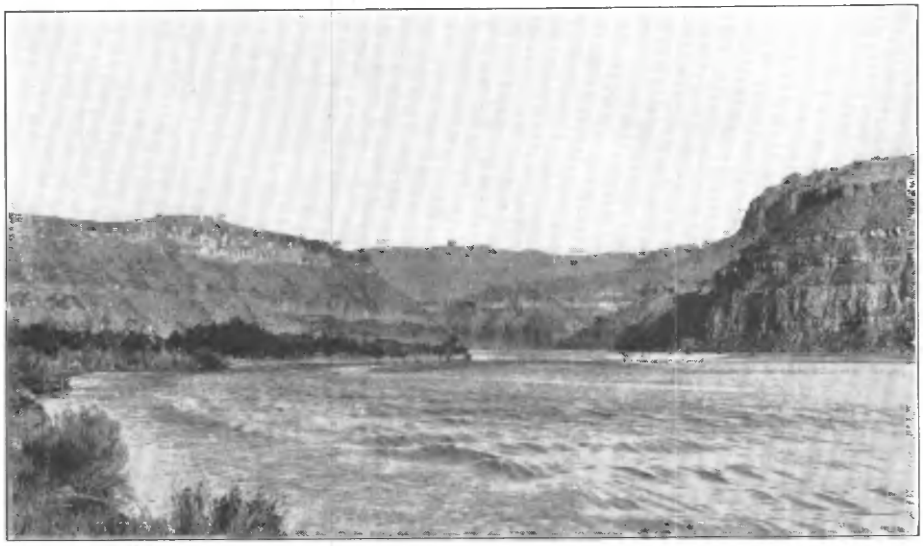
Here the turbulent muddy wave-covered San Juan has built a wide delta far across the comparatively placid waters of the Colorado. Photograph by E. C. LaRue

A. UPSTREAM VIEW OF FLOOD-SWOLLEN RIVER AT THE PIUTE FARMS

The high splashing wave at the front edge of a surge is striking the bank and rebounding toward opposite bank. Photograph by Robert N. Allen

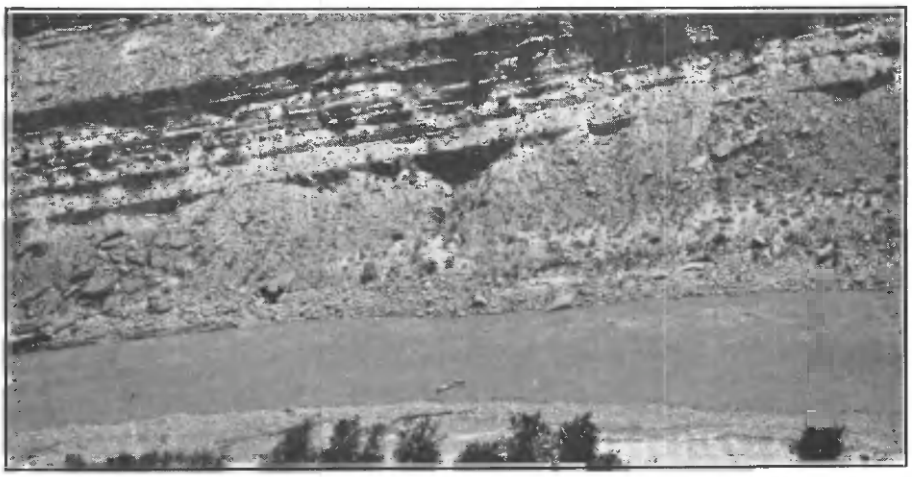
B. MEMBERS OF TRIMBLE EXPEDITION CLUBBING AND CATCHING EXHAUSTED FISH THAT WERE FLOUNDERING ON SURFACE OF RIVER DURING A FLOOD AT HONAKER TRAIL

Photograph by Robert N. Allen



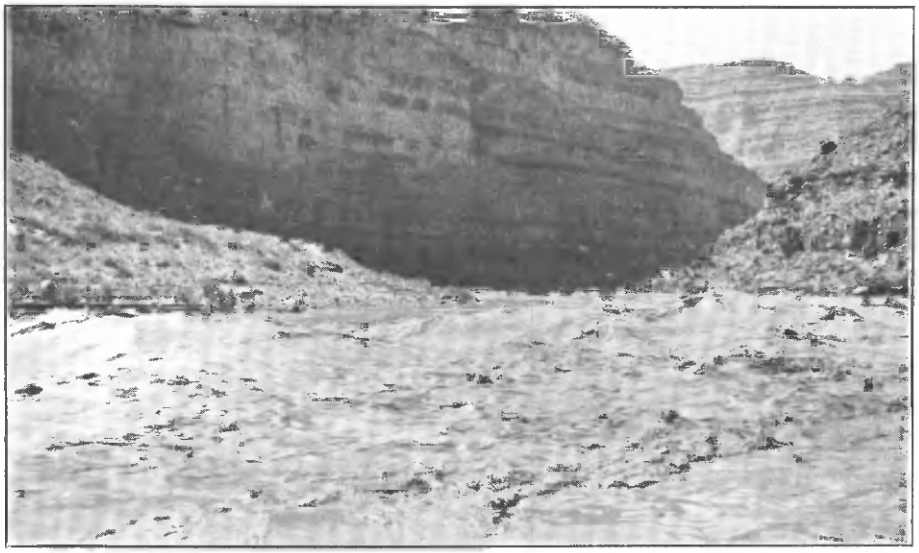
A. SMALL "SAND WAVES" NEAR THE PIUTE FARMS

Photograph by Robert N. Allen

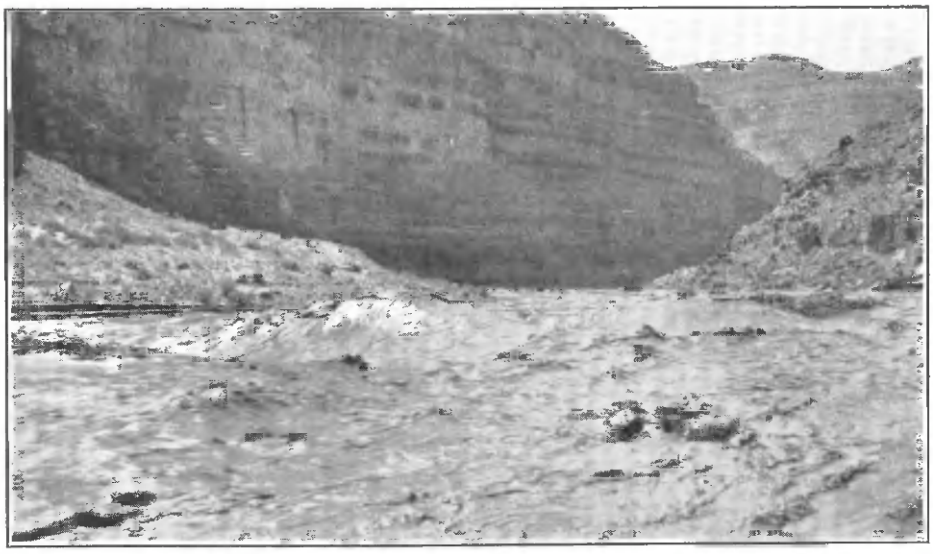


B. WAVES OF SWIFT WATER IN INTER-RAPID STRETCH NEAR HEAD OF SAN JUAN CANYON

Photograph by H. D. Miser



A



B

SAND WAVES 6 TO 8 FEET HIGH DURING FLOOD AT HONAKER TRAIL

Looking downstream. Photographs by Robert N. Allen

the side canyons. The bars attain a width and length of several hundred feet and are highest next to the mouths of the side canyons. They not only cause the river to flow against the opposite canyon wall, but some of them extend entirely across the main canyon. The rapids over such bars are known as boulder rapids. During low stages of the river hundreds of boulders protrude above the water's surface and others are but slightly submerged.

A few rapids are found where huge boulders as much as 60 feet in length have fallen from the cliffs, and others occur where the channel runs between close canyon walls, as it does at the Goodridge Bridge and at The Narrows (Pl. II, *A*) and also where rock ledges reach partly across the channel. (See Pl. IV.) Numerous small rapids are caused by the impingement of the main current against the canyon wall and by the consequent narrowing of the current next to the place of greatest impingement. If the current strikes the wall at a high angle it not only rebounds toward the opposite wall but develops a whirlpool across the channel a little below the point of impingement. A shallow submerged spitlike sand bar always lies above such a whirlpool and points toward the narrowest part of the channel.

The boats of the Trimble expedition were run through most of the rapids. In shooting the worst ones Loper, the boatman, was the only member of the party to stay in the boats; the other men walked along the banks around such rapids. The loaded boats were nosed one at a time through a few rapids by the boatman, who in wading held on to the bow and guided it downstream ahead of him. Both the boats and the camp equipment were portaged around the Thirteen-foot Rapid. (See Pl. XVII, *B*.) The equipment was portaged around a rapid 3 miles above the mouth of Slickhorn Gulch, and then the boats were run empty through the rapid. (See Pl. XVI, *C*.) The equipment was portaged around the first and second rapids at the mouth of Piute Canyon; the empty boats were nosed through the first rapid but were run through the next. (See Pl. XVII, *A*.) The loaded boats were run through a small rapid half a mile above the mouth of Johns Canyon, but one of the boats containing two members of the party not only narrowly missed striking the canyon wall but struck a boulder and was burst on one side from bow to stern. The boat was nearly filled with water by the time a landing place was reached. Then the wet equipment was unloaded, and the boat was dragged ashore and repaired.

The Trimble party before reaching the mouth of Grand Gulch expected that a portage would be necessary there, for Loper and two other men who descended the river past this locality in 1894 were required to portage their boat around a boulder-obstructed part of

the channel. In 1921, however, although the swift current at this locality was thickly dotted with enormous boulders, some standing above the water and some submerged only a few inches, a portage was not necessary, but Loper was required to use all of his skill as an oarsman to dodge the boulders. We also anticipated a portage around the rapid at the mouth of Gypsum Creek, for Loper in his previous trips past that locality had found the river extremely rough with boulders; but a change in the rapid had taken place, and our boats were run through the rapid without difficulty.

WAVES ON SAN JUAN RIVER

Waves on the San Juan were found by the Trimble party to be so numerous that no long stretches of the river were free from them. (See Pls. XVIII–XXI.) Most of the surface of the river is therefore rough, presenting a choppy or ragged appearance not only in the rapids, but in the intervening stretches. The roar of the breaking and splashing waves was heard continuously during most of the voyage of 2½ months from Bluff to the Colorado, for the party camped every night on the banks and spent most of the days on and near the river. When the Colorado was reached, on October 3, it was found to be a peaceful stream free from breaking waves and other noises—in fact, its peaceful nature, in comparison with the swift, noisy, and turbulent San Juan, was most impressive.

The character and causes of the waves form a subject to which much study could be devoted. I studied them very little, yet a few observations are here presented.

The waves are of many kinds, which depend on their form and causes. Among the kinds of waves characteristic of other swift-flowing rivers are those at the rapids that are produced by rock ledges and boulders; those around both exposed and slightly submerged boulders in the inter-rapid stretches; and those at every place where the current impinges against the canyon walls. Low, choppy waves are also produced by strong winds.

In addition to such waves the San Juan has waves that are characteristic of streams that carry heavy loads of débris. They are especially well developed during flood stages, when the current is swift and the débris load is unusually heavy.

During observed flood stages at Piute Farms the current would flow in surges almost a foot high. Each surge would be followed by another a few minutes later. The advancing front of each surge was marked by a ragged splashing wave as much as 6 feet high, which broke downstream. The waves, which extended diagonally across the shallow island-dotted channel, 3,300 feet wide, would strike and follow the banks with a violent force, tearing away earth

and shrubbery. (See Pl. XIX, *A*.) The surges completely submerged all the low sandy islands and also picked up and carried logs and stumps. In the troughs between the surges the islands reappeared, and many of the logs and stumps stood mired in shallow water and on the islands. Surges of such magnitude were not noted elsewhere along the river. Their presence here may have been due to the great width and shallowness of the channel in comparison with the greater depth and smaller width along other portions of the river. When the end of such a wave would strike and follow the bank the water in and behind it would rebound and thus give rise to a similar wave that advanced toward the opposite bank. As the rebounding waves traveled in a direction at right angles to the impinging waves the river frequently displayed what might be termed cross waves.

Waves of a type that was especially conspicuous during flood stages are commonly known as "sand waves." (See Pl. XX, *A*, and XXI.) They resemble those thrown up by a stern-wheel river steamboat. They attain a maximum observed height of 6 or 7 feet and occur as a series of parallel waves at right angles to the channel, though on one occasion they were observed to extend diagonally across the channel. Such a series of waves starts at the downstream end of a swift stretch of water and travels slowly upstream to the head of the stretch. Each wave gradually increases in height and is accompanied at its climax by a breaking toward the upstream side. This process of breaking is known as combing and is accompanied by a roaring noise. Such a noise is continuous during the entire upstream advance of the waves, for a few to several waves are always breaking at the same time. The current is somewhat checked by the waves, but below them it picks up speed and is comparatively free from waves. No sooner has one series of waves died out upstream than a new series appears downstream and begins its upstream advance.

The sand waves were so high and rough when the river was 2 feet or more above a normal stage that the Trimble party then stayed off the river, because the boats were open-topped and had no watertight compartments. That rowing under such circumstances is precarious was proved by experience on one occasion. At that time the party started rowing down the river, not realizing at first the high stage of the water. One of the boats in which Blake, Hyde, and I were riding encountered a series of sand waves fully 6 feet high, which half filled the boat before Blake, the oarsman, could get the boat into quieter water. So strenuously did Blake pull on the oars that he broke a rowlock immediately after getting out of the rough water. There was thus imminent danger of our being swept back into the rough water. Blake, by sticking an oar

down, determined the water to be only waist deep. Hyde therefore jumped into the water, followed by Blake and me. Then the boat was held and was pulled to the bank, where the water was bailed out. Everything in the boat got wet, including my camera and aneroid barometer.

The sand waves take their name from the fact that sand forms a large part of the load of débris transported by the river along its bed at such times. They are produced by a peculiar method by which the débris is transported. This and other methods of transportation are described by Gilbert [34] in the following concise statements:

> Some particles of the bed load slide, many roll, the multitude make short skips or leaps, the process being called saltation. Saltation grades into suspension. * * *
>
> When the conditions are such that the bed load is small, the bed is molded into hills, called dunes, which travel downstream. Their mode of advance is like that of eolian dunes, the current eroding their upstream faces and depositing the eroded material on the downstream faces. With any progressive change of conditions tending to increase the load, the dunes eventually disappear and the débris surface becomes smooth. The smooth phase is in turn succeeded by a second rhythmic phase, in which a system of hills travels upstream. These are called antidunes, and their movement is accomplished by erosion on the downstream face and deposition on the upstream face. Both rhythms of débris movement are initiated by rhythms of water movement.

The dune phase is accompanied by comparatively small downstream-moving waves. The smooth phase has no waves, or only small ones. During this phase, by wading the river, I found the smooth bed to be composed of compact sand. The sand waves appear when the river passes from the smooth to the antidune phase.

R. C. Pierce,[35] who has studied the sand waves of San Juan River at and near the Goodridge Bridge, describes them as follows:

> On the wide, shallow sections of San Juan River sand waves may usually be seen below the riffles at medium stages. In the deeper sections they appear at their best development on rapidly rising stages. In the immediate vicinity of the gaging station, so far as observed, the sand waves appear on rapidly rising stages between gage heights of approximately 4 and 7 feet. With the rise of stage beyond this range the movement is drowned out. Three miles above the gaging station, where the river is wider, sand waves usually may be seen at any stage from about 4 to 10 feet. That section of the river was not visited at stages higher than 10 feet, and it is not known whether the sand waves continue or are drowned out, as in the vicinity of the station.
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> The usual length of sand waves, crest to crest, on the deeper sections of the river is 15 to 20 feet, and the height, trough to crest, is about 3 feet. However, waves of a height of at least 6 feet were observed. The sand waves are not continuous, but follow a rhythmic movement. Their appearance, as seen on

[34] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, p. 11, 1914.

[35] Pierce, R. C., The measurement of silt-laden streams: U. S. Geol. Survey Water-Supply Paper 400, pp. 42–48, 1916.

the lower San Juan, is as follows: At one moment the stream is running smoothly for a distance of perhaps several hundred yards. Then suddenly a number of waves, usually from 6 to 10, appear. They reach their full size in a few seconds, flow for perhaps two or three minutes, then suddenly disappear. Often, for perhaps half a minute before disappearing, the crests of the waves go through a combing movement, accompanied by a roaring sound. On first appearance it seems that the wave forms occupy fixed positions, but by watching them closely it is seen that they move slowly upstream. In the narrow parts of the stream the waves may reach nearly the width of the river, but in the wider parts they occupy smaller proportional widths. Usually they are at right angles to the axis of the stream, but at some places, particularly in the wider parts of the river, they may suddenly assume a diagonal position, moving rather rapidly across the stream in the direction toward which the upstream side of the wave has turned.

In the experiments made by Gilbert at Berkeley he found that the water surface closely paralleled the surface of the antidunes. In natural streams this is not always the case. The writer was informed by Prof. H. E. Gregory, of Yale University, that in swimming down through a short section of the San Juan he found that in going over the crest of the antidunes he could touch bottom with his feet and at the same time keep his head above water, but that in the trough of a wave he had to go down more than arm's length below the surface to touch bottom. From this it would seem that where the antidune movement is well developed and where there is a considerable depth of water the undulations of the sand surface are not closely followed by the water surface, but that the effect is partly smoothed out in being transmitted to the top. It might be proper to infer from this that at high stages the antidune movement may still go on, although no indication of it reaches the surface. This inference must be qualified by the fact that at high stages more of the bed load is picked up and carried in suspension, thus necessitating a lowering of the bed and the movement of new débris.

FLOODS IN SAN JUAN CANYON

Floods in San Juan Canyon are numerous and disastrous. They are known to have reached stages as high as 50 feet in the narrower parts of the canyon. Not only has the flood-swollen river swept away practically all trees and shrubs from the bottom of the canyon, but it has killed fish at times when it was so laden with silt as to become a river of mud. The flood-swollen river frequently changes the position of the main channel and also eats into the short stretches of sand and silt along the banks. The floods rush down the canyon with such speed and rise so rapidly that all canyon voyagers should heed the oft-repeated admonition to seek high ground for every camp site. Among other admonitions given to the Trimble party was one from a Government official in Washington for us to keep a man well in the rear of the bulk of the party; the duty of this man on seeing an approaching flood would be to blow a shrill whistle as a warning for the other persons to flee to higher ground. The floods during rising stages carry so much driftwood including logs as to make boating precarious. Furthermore, with their high waves and great speed,

they make boating in open rowboats impossible. Equally dangerous for river expeditions are the low stages, especially in the part of the canyon below the mouth of Moonlight Creek. During such stages the river is likely to become so low and shallow over the wide, sandy channels as to prevent progress with boats of any kind.

During flood stages the river frequently has a peculiar disagreeable odor, which is noticeable as far as 50 feet away from the river. The odor is apparently due not only to the large quantity of clay in the water but also to dead vegetal matter from cedar and piñon forests and dung from sheep, goat, and horse corrals. Piñon needles and other fine vegetal matter pile up on the bank during every flood. They are found in every bucket of water taken from the river during flood stages and cover much or all of the water surface in the bucket.

During the descent of the canyon from July 18 to October 3, 1921, many floods were discharged by the San Juan; the highest attained 7 feet above low stages. High floods were discharged in 1921 by Piute Creek and the other southern tributaries farther west. Although they were not seen by members of the Trimble party, mute yet convincing evidence of them was afforded by freshly broken and twisted tree stumps, newly laid driftwood as high as 20 feet above the stream beds, and macerated and bent shrubbery and plants. None of the other tributaries had discharged such high floods in 1921 before the dates that they were observed. All the observed floods of 1921, both of the San Juan and the tributaries, took place in response to near-by or distant thunderstorms.

A flood taking place in October, 1911, as a result of a general rain stood 18 to 20 feet above low-water mark at Shiprock, N. Mex., and is said to have reached a height of 50 feet in the narrower parts of the canyon. During the flood the Indian agency grounds at Shiprock were flooded and the bridge at that place and also the one at Goodridge, Utah, were destroyed. Some of the driftwood found by the Trimble party at a height of 35 feet above the river was probably brought downstream at that time. This has been the greatest flood within the memory of the first white people who settled at or near Bluff a few years prior to 1880, though the Indians who had seen such floods warned the people not to build their homes in low bottom lands.

SILT IN SAN JUAN RIVER

The amount of silt carried in suspension by San Juan River is unusually high for streams in the United States. It is therefore known as a muddy stream. In fact, its load of silt that is emptied into the Colorado comprises a very large part of the silt carried by that stream through and beyond the Grand Canyon. (See Pl.

XVIII.) The quantity of silt is lowest during low stages of the river, and also during the early summer floods that are caused by melting snows in the San Juan Mountains of Colorado. Then the water assumes a milky color. It never gets clear. Between July 18 and October 3, 1921, it was comparatively free from silt during only two periods—on July 18 and 19 and from September 10 to 30—but even then every cup of water taken from the river would contain sand grains and fine silt. At all other times, especially during flood stages, the river was very muddy.

The usual color of the silt-laden stream is gray to buff, but it changes to a brick-red during the falling stages of floods. On August 1 a flood in the river passed the foot of the Honaker trail, where the Trimble party was camped. The highest stage of the flood—6 feet—was reached at 7 a. m. Between that time and the middle of the afternoon the river fell 3 to 4 feet, and in so doing assumed a brick-red color and ran like a stream of molten metal, whose entire surface was covered by waves of large and small size. While the river was flowing like metal the fish came to the surface in an exhausted condition and swam feebly in the eddies, with their dorsal fins sticking out of the water. The enormous load of fine red silt in the water had apparently in some way prevented the fish from obtaining the usual supply of oxygen. Many of the exhausted fish were caught by members of the party with bare hands, and many were washed ashore by waves to perish. (See Pl. XIX, *B*.) After two or three hours the fish revived and disappeared from the surface. Bert Loper, boatman of the party, who lived on Colorado River for many years, says such floods have been known to last long enough to kill thousands of fish.

The spring flood from the melting snows in the mountains of Colorado comes in June. Through the upper course of the river this flood is, according to Pierce,[36] like the spring floods of other streams that flow from high mountainous regions, but when the flood reaches the barren region of mesas, canyons, and plateaus of New Mexico and Utah it picks up a load of sand and silt that has been brought by small streams to the San Juan and that has been deposited along its course. Pierce says:

> Hence the spring flood from the high mountains carries through the lower course of the river and into Colorado River considerable silt and sand picked up in transit. Observations made by the Reclamation Service 20 miles above the gaging station [at Goodridge Bridge] show an average content of silt, by weight, of 0.37 per cent for the period from May 16 to June 30, 1915, and for the period October 18, 1914, to August 2, 1915, 0.44 per cent.
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> The heaviest loads of silt are carried during the torrential floods of summer and fall. A sample taken by the writer just after the peak of a sudden heavy

[36] Pierce, R. C., The measurement of silt-laden streams: U. S. Geol. Survey Water-Supply Paper 400, pp. 40–41, 1917.

flood that occurred in the afternoon of August 26, 1915, and examined after settling for 24 hours, showed that 75 per cent of the original volume of sample was silt and red sand, chiefly the latter. The discharge at the time was approximately 13,000 second-feet, all of which except about 1,000 second-feet was coming into the river from Chinle Creek, 10 miles above the gaging station. The flood lasted only a few hours. A sample consisting of silt and very fine sand taken two hours after the first one, at a discharge of about 5,000 second-feet, showed a silt load of 45 per cent. At the peak of the flood and for almost an hour afterward the river ran with a smooth, oily movement and presented the peculiar appearance of a stream of molten red metal instead of its usual rough, choppy surface. A sample collected at the height of the July flood, which lasted several days and reached a maximum discharge of about 30,000 second-feet, showed 12 per cent of silt by volume and 9 per cent by weight.

The silt records obtained by the United States Reclamation Service show a maximum silt content of only 1.67 per cent by weight. These samples, however, were taken 20 miles upstream, where the river is fairly wide, and from a point close to the shore, where velocities are low. Furthermore, it is probable that samples were not obtained at times of maximum silt load, as only 62 samples were taken in 289 days.

It should be borne in mind, however, that though very heavy loads of silt are occasionally carried by the San Juan, yet for the spring period, in which the greater part of the yearly run-off occurs, the loads of silt are considerably lighter.

Other silt observations were made by the United States Reclamation Service near Bluff over a period from March 17 to July 18, 1917. These indicate a silt content of 1.41 per cent by weight, or a little over 1 per cent by volume for the period. These observations indicate that 24,000 acre-feet of silt is carried each year by the river.[37]

CANYON FILL ALONG SAN JUAN RIVER

GENERAL FEATURES

San Juan River has eroded its canyon in solid rock and thus runs long distances between close precipitous walls of solid rock; yet, except during great floods, the river runs on solid rock at few places. Between such floods it runs on unconsolidated material that fills the canyon to depths of perhaps 50 feet or more. This loose material may properly be called canyon fill. It consists of material in course of transportation and of material that is permanently and temporarily deposited. Perhaps no great quantity of material is permanently deposited, for the highest floods, such as that of October, 1911, when the river is said to have reached a stage of 50 feet in the narrower parts of the canyon, may pick up and move all the material down to bedrock at many if not most places. The impinging and grinding of the transported material against the bedrock floor wears away the solid rock. In consequence of this wearing-away process the canyon is deepened at times of high floods. During

[37] U. S. Recl. Service Eighteenth Ann. Rept., p. 404, 1919.

the recession of such floods much of the débris load is deposited and thus partly fills the canyon. Between such floods much débris is added from time to time by the river and other contributing sources. It follows from the above statements that long stretches of the San Juan present most of the time the peculiar example of an alluvial or aggrading stream flowing between close towering walls of solid rock. Yet on the assumption that much or all of the canyon fill is moved at times of high flood the river is in reality not an alluvial or aggrading stream but a degrading stream. To determine whether any of the present canyon fill is or is not a permanent deposit can be settled only by observations over a period of at least a few decades.

SOURCES OF CANYON FILL

The canyon fill, including both the deposited material and the material in course of transportation, is derived from several sources. One of the contributing sources is the river's own power of erosion by which its transported material impinges, wears away, and undermines the canyon walls. A chief source is the falling or sliding of rock débris from the canyon walls due to landslides, loosening of blocks by rains, freezing and thawing of water, changes in temperature, and the blasting of rocks by lightning; such débris, which collects as talus at the foot of every cliff, skirts the river for long distances. Sand and dust are brought to the river by wind. A part of such material immediately falls into the river and a part is deposited in dunes, especially in protected positions on the south canyon wall. Fine material is contributed by the sheets of water that flow on the surface during and after rains. Both fine and coarse materials are contributed by every tributary rill and stream—in fact, the material from these two sources equals or surpasses in quantity that from all other sources combined.

The tributary streams, as is shown in the accompanying table, have steep gradients, ranging from 65 feet to more than 170 feet to the mile. They are thus able to carry much débris, especially during flood stages. All of them are actively lowering their channels in bedrock and thus transport their loads of débris to the San Juan; only a part of the load of some streams has been deposited in their channels near the river. The load of débris thus brought to the river includes clay, sand, pebbles, cobbles, mud balls, and boulders. The mud balls, which are spherical, attain a diameter of 18 inches. In rolling along the stream beds, they pick up and carry numerous varicolored pebbles and thus present a spotted or mosaic appearance. Numerous rock boulders 6 to 8 feet in their longest dimension, several 10 to 12 feet long and one 18 feet long, were observed.

Fall of some tributary streams of San Juan River, Utah

Name of stream	Distance from San Juan for which altitude was determined (miles)	Total fall in distance stream was ascended (feet)	Average fall per mile (feet)	Remarks
Chinle Creek [a]	100+	----------	13	Entire length of stream.
Stream in Johns Canyon	(b)	----------	----------	Waterfall 60 to 75 feet high at mouth.
Stream in Slickhorn Gulch	.5	150	----------	
Stream in Grand Gulch	.5	200	----------	Waterfall 50 feet high at mouth.
Moonlight Creek	(b)	----------	----------	Waterfall at least 50 feet high at mouth.
Stream in Rockhouse Gulch	4	295	75	
Stream in Clay Gulch	3.25	320	100	
Stream in Spring Gulch	2.75	325	120	
Copper Creek	4	340	85	
Nokai Creek	5.25	350	65	
Piute Creek	9	750±	80–85	
Wilson Creek and other tributaries west of Piute Creek.	----------	----------	170+	

[a] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380, p. 36, 1916.
[b] Inaccessible from the river.

The load of rock débris carried to the San Juan by its tributaries has greatly increased within the last 25 to 35 years. The tributaries formerly deposited along their courses much of their débris load and ran on smooth floors of alluvium; [38] but now they are eroding and deepening their valleys and run in inner canyons intrenched in the alluvium or in valleys from which all alluvium has been eroded.[39] This change in the character of the stream valleys is thought by Gregory to have been caused in part by overgrazing and probably in part by climatic change. Another reason for the change is suggested by Reagan, who believes that the former dense population conserved practically all the water by irrigating their fields and by impounding it in village reservoirs. This dense agricultural population, according to him, was replaced by the nomadic Navajo with his stock and by the white man with his roads and trails. The Navajo and white man use little water for irrigation, but let the torrential floods of the streams sweep down the valleys to the San Juan with their heavy loads of rock débris.

CHARACTER, TRANSPORTATION, AND DEPOSITION OF CANYON FILL

San Juan River, being confined between closely spaced cliffs in most parts of its canyon, does not have alluvial plains in such parts. Whatever alluvial material is present occurs beneath the bed of the

[38] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, pp. 228–229, 1882. Gregory, H. E., The Navajo country: U. S. Geol. Survey Water-Supply Paper 380, p. 100, 1916; Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 130–132, 1917. Reagan, A. B., Archeological notes on Pine River valley, Colo., and the Kayenta-Tuba region, Ariz.: Kansas Acad. Sci. Trans., vol. 30, pp. 262–267, 1922.

[39] Gregory, H. E., op. cit.; Reagan, A. B., op. cit.

river and as short unsubmerged bars. Alluvial plains of small extent occur only in the open stretches like those near Clay Hill Crossing, Piute Farms, and Zahns Camp. There the river has wide braided channels and narrow alluvial stretches over which the main channel frequently shifts position, especially during floods.

So swift is the current of the river that its alluvial material consists almost entirely of sand, pebbles, cobbles, and boulders; the clay, being very fine and thus carried in suspension, is mostly emptied into the Colorado; very little of it is deposited along the San Juan. The banks of the San Juan are therefore comparatively free from mud, in marked contrast to the slippery mud-covered banks of the more slowly flowing Colorado in Glen Canyon.

Much of the sand that is present along the river is being continually moved downstream. It is piled up in shifting ripple and rill-marked bars. Some of the bars are exposed as small and large areas adjacent to the river, and some rise above the water as islands, but others are submerged for depths ranging from a small fraction of an inch to perhaps many feet. Sand underlies the bed of the river for long distances. For example, Loper and I, in towing a boat upstream from the mouth of Piute Creek to Spencer Camp, a distance of 16 miles, waded the river with bare feet the entire distance and encountered gravel and boulders at only two or three places; only a few shoals were so deep they could not be waded.

The sand on account of its fine grain is generally firm and compact enough for a person to walk on its surface, though in doing so he causes wavelike movements in the sand around him and is likely to sink into it if he retraces his steps. Quicksand is usually confined to the lower ends of the sand bars, where it is being piled continually by the river and where it has not yet had time to become compact. The deepest quicksand encountered by members of the party was not more than waist deep.

Every flood in the river doubtless handles coarse as well as fine débris; but as the closing work of each flood is performed by a discharge less than its maximum, it doubtless happens that the coarsest part of a flood's load is so buried by fine material as not to be visible when the river bed is exposed at low stage. The long stretches of sand along some parts of the river are therefore without much question underlain by gravel and boulders. (See Pl. XXII.)

In the part of the canyon above the mouth of Moonlight Creek the fall or gradient of the river is high, averaging 8.3 feet to the mile (Pl. XXII); the velocity is great; the canyon fill is mostly coarse débris from adjacent cliffs or from tributary streams; the clay and sand that are brought to the river are not deposited to any great extent but are carried to the lower part of the canyon or emptied into the Colorado; and the débris is composed in large part of boulders

of hard limestone and is thus difficult to transport. With such débris the river in this part of the canyon is overloaded during normal stages and small floods; but high floods such as that of 1911, which attained a stage reported to be 50 feet in the narrower parts of the canyon, may not only move much of the débris but attack and erode the bedrock.

The river, having a steep grade between Chinle and Moonlight creeks, deposits comparatively little sand. Such as is found occurs as short low sand bars that skirt the river during low stages, among vegetation and boulders, and also on the river bed. The meager clay found in this part of the canyon fills interstices of the coarse rock débris. In this stretch the river is confined almost continuously between vertical walls and talus slopes. The boulders of the talus slopes project into the river, and many, including some 60 feet long, are found in the middle of the river. Sand is piled among these boulders. When the river is at a low stage walking along the sandy banks is comparatively easy, but if the river is in flood the sand is submerged and the traveler is thus required to follow the steep slope of jumbled boulders, some the size of an ordinary house. To go across an area of such boulders is a difficult job, requiring agility and precaution, for it is necessary to crawl, slide, and jump at numerous places.

When the river reaches a point near the mouth of Moonlight Creek the gradient decreases to about 5 feet to the mile; the current becomes less swift; a part of the load is deposited; the deposited load raises the river bed; and the main channel is not only widened at places but frequently shifts position on its bed of unconsolidated débris.

As the débris load is emptied by tributaries into the river there is a sorting of the débris, the coarser part being swept along the bed and the finer part being borne in the body of the current. Some of the finer material, however, is deposited and held in the interstices of the coarser material. Except during high floods, when the discharge of the river is great, the boulders, cobbles, and pebbles are moved little if any.

The mouths of many tributaries are marked by accumulations or bars of boulders that have been brought to the river by occasional floods that sweep down the side canyons. The boulders accumulate at such places because the flood-swollen tributaries have a greater fall, greater velocity, and probably at times a greater discharge than the river, and because the discharge of the river is not sufficient to overcome the effects of the reduction of fall and velocity of the tributaries' flood waters. Such bars not only push the river channel away from the mouths of the tributaries but produce rapids. (See Pls. VI, *A*, XVI, *C*, and XVII.)

The visible part of the débris deposited at the mouths of tributaries exhibits a gradation from large boulders at the rapids to pebbles and cobbles downstream. This is especially well displayed at and below the mouth of Piute Creek. (See Pl. XVII, *A*.) At the mouth of this creek the largest boulders are found; from this place downstream for a distance of 6 miles—as far as the débris derived from Piute Creek could be identified—the coarse débris consists of smaller boulders, cobbles, and pebbles.

Piute Creek and also the creek at the Thirteen-foot Rapid (Pl. XVII, *B*) join the San Juan at places where the channel is comparatively wide. Because the river channel is thus comparatively shallow the load of boulders that is emptied into it by these steep-gradient flood-swollen creeks is piled up and forms boulder bars and rapids. On the other hand, Nokai and Copper creeks, which drain near-by basins similar to those of the two streams just mentioned, join the San Juan where it occupies a narrow box canyon. The deep river at the mouths of these creeks has thus been able to carry away the load of boulders they have brought down and therefore has no marked boulder bars and rapids at these places.

Other tributaries, such as Lime Creek and all the northern tributaries west of Grand Gulch, have small or no accumulations of boulders at their mouths, apparently because floods in the river have swept away large parts of any such accumulations that may have formed in the past.

Most of the southern tributaries west of and including Piute Creek are marked at their mouths by boulder bars or accumulations. A large part of the boulders appear to have been brought to the river by high floods in 1921 and other recent years. The northern tributaries west of Grand Gulch have had no floods in recent years comparable in size to those of the southern tributaries, and this apparently explains the absence of large boulder bars at their mouths.

The boulder bars at the mouths of Piute Creek and some other creeks extend entirely across the river channel, suggesting that the rushing, flood-swollen, and boulder-laden waters of such tributaries dashed completely across the channel and filled it with boulders. For the river to be so powerless under such circumstances, its velocity and also probably its volume must have been far exceeded by the velocity and volume of the tributary. That some of the tributary streams have large discharges in comparison with the discharge of the river is shown by the observations of R. C. Pierce[40] at the gaging station at Goodridge Bridge. On August 26, 1915, there was at this station a flood with an approximate discharge of 13,000 second-

[40] U. S. Geol. Survey Water-Supply Paper 400, pp. 40–41, 1917.

feet, all of which, except about 1,000 second-feet, was coming from Chinle Creek.

The boulder bars built at the mouths of side canyons have the effect of dams, causing slack water above them and a consequent filling of the slack stretches with sand. (See Pl. XXII.) Although these stretches resemble reservoirs and are thus filled with sand, the river's current through them is swift, and the fall is generally about 5 feet to the mile. The longest sand-filled reservoir extends upstream from the first Piute Creek rapid to a point near the mouth of Moonlight Creek, a distance of about 45 miles.

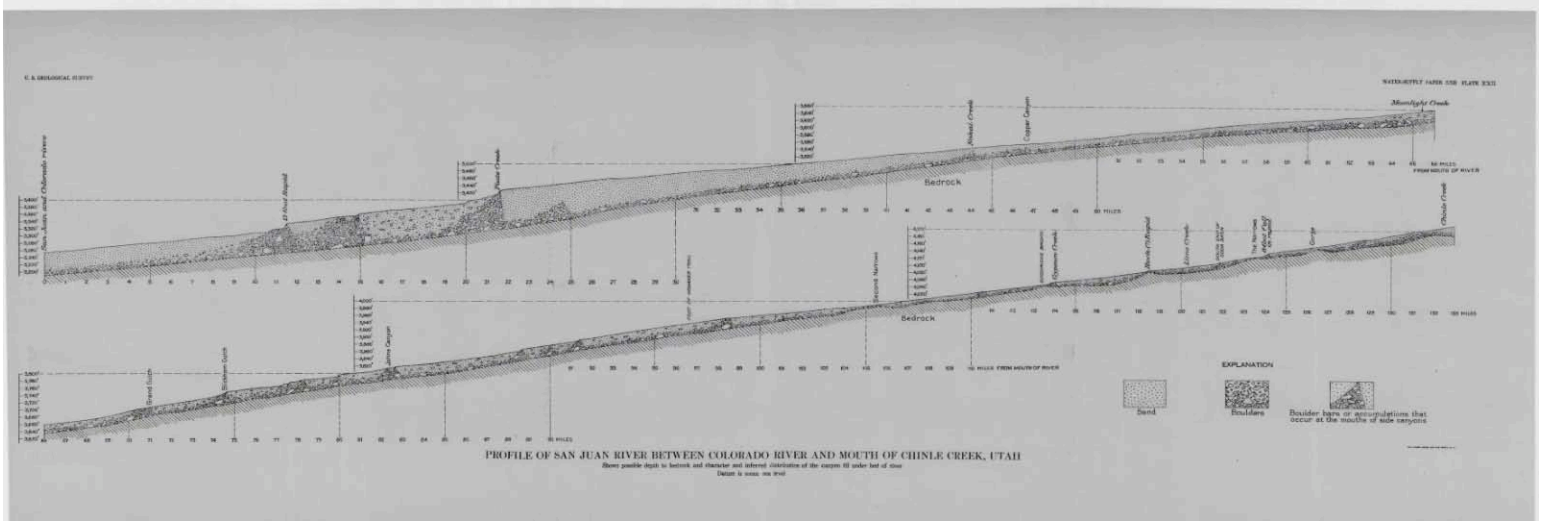
If a flood in the river should be of sufficient volume to sweep out a boulder bar it would also begin to pick up and move the sand above the bar and thus increase the gradient of that part of the river. Floods are known to have partly swept away within the last 30 years the accumulations of boulders at the mouths of Gypsum Creek and Grand Gulch.

PLACES WHERE CANYON FILL IS ABSENT OR THIN

The canyon fill apparently overlies bedrock at all or almost all places, though during high floods the river doubtless transports much of the canyon fill and thus scours its bedrock floor for shorter or longer distances. In other words, bedrock does not form the river bed during normal and low stages except at perhaps a comparatively few localities, all of which are confined to the part of the canyon between the mouths of Chinle and Moonlight creeks. Between these creeks the river is skirted at very few places by bars of sand, gravel, and boulders; at most places the water's edge is met by the base of talus slopes and by precipitous walls. Some rock ledges with low and high dips extend partly across the channel. At a few places these ledges and the canyon walls on opposite sides approach one another so closely as to produce narrows or gorges. No ledges were observed to extend completely across the floor of the canyon. If any form a part of the river bed they were concealed by the muddy water.

According to Dr. Neil M. Judd,[41] of the United States National Museum, a ledge of rock reaches across the bed of the river just above the mouth of Chinle Creek. It was formerly used by pack trains in fording the river at this place, but it has been used very little or none since the completion of the suspension wagon bridge near Goodridge in 1910. Doctor Judd says that the Byron Cummings party, of which he was a member, used the ford in 1909 on the way to the Rainbow Natural Bridge. The ledge was not seen by members of the Trimble party in 1921; it was then probably

[41] Oral communication.



PROFILE OF SAN JUAN RIVER BETWEEN COLORADO RIVER AND MOUTH OF CHINLE CREEK, UTAH

covered with the extensive deposit of alluvial sand which occurs along the river near the mouth of Chinle Creek.

The occurrence of small rapids or especially swift water in the several gorges or narrows between Chinle and Moonlight creeks suggests that bedrock immediately underlies the river at such places or that it lies at no great distance beneath the river bed. Some of the most conspicuous narrows and gorges are described below.

A notable narrows occurs in San Juan Canyon just inside its entrance, about 1½ miles below the mouth of Chinle Creek and 12 miles below Bluff. (See Pl. I, *B*.) A dam site at this locality, known as the Bluff dam site, has been mapped by the United States Bureau of Reclamation. Here solid ledges of limestone and sandstone dipping 15° E. extend to the water's edge on both sides of the river. If any fill exists at this locality it must therefore underlie the river bed. That some fill exists here is suggested by the wide braided, sand-filled channel of the river just above the narrows. James McKittrick, assistant engineer of the Bureau of Reclamation, in a report dated May 7, 1917, says, "it is believed that bedrock lies within 20 or 30 feet below the river surface." The usual depth of the water and the width of the channel as determined by the Bureau of Reclamation are 10 to 12 feet and 215 feet, respectively.

A gorge occurs at a locality 126 miles above the mouth of the river and about 2¾ miles above The Narrows. It is in reality an inner canyon whose walls stand about 50 feet apart and rise 30 feet above the normal water surface. The walls are massive hard limestone lying in a nearly horizontal position. The river occupies the full width of the gorge and runs very swiftly through it. No canyon fill may be present beneath the river bed, but if any exists it doubtless consists entirely of large boulders and is perhaps not over 20 feet deep.

The Narrows, so named by the Trimble party, is one of the most forbidding gorges in the canyon. (See Pl. II, *A*.) Its walls of limestone, which dip a few degrees upstream, rise vertically from the edges of the river and tower so high that a difficult ascent of 500 feet and an equal descent are required to pass around it on foot. The water rushes through the gorge with great speed, forming a rapid with a small fall. The Trimble party, before passing through The Narrows, camped one night just east of it. Next morning the river had risen some 2 or 3 feet and was too rough for rowing. In order that a safe passage could be made the party waited half a day for the river to run down; but during the wait Christensen and I scaled the south canyon wall, passed around the gorge, and descended the wall in a steep talus-strewn crevice. The narrowness of the channel, the occurrence of a rapid, and the massive-

ness and great hardness of the limestone suggested that little if any fill occurs under the river at this locality.

Another place where rock ledges extend far across the canyon floor and project partly across the river channel is between Soda Basin and Lime Creek. Here the rocks are massive limestone and sandstone and dip 12°–20° W. (downstream). If there is any fill below the stream bed, it would surely not be thick—perhaps not over 20 feet.

A small rapid half a mile northwest of the A. L. Raplee residence, near Mexican Hat, is obviously produced by massive hard beds of red and gray sandstone. (See Pl. IV.) The gray sandstone, 20 to 30 feet thick, is known as the "Goodridge" oil sand and contains an oil seep near the water's edge on the west side of the river. Some recent blasting has been done in the sandstone with the hope that oil might accumulate in the blasted pit. The exposed beds dip 10° SE. (downstream), and project far across the river. A small rapid occurs between the exposed ledges that project from either bank, and it is inferred that the submerged parts of the ledges occur on the bed of the river and produce the rapid.

A rock-walled gorge, which is spanned by the Goodridge Bridge, lies half a mile west of Goodridge. It is in a massive hard gray sandstone (the "Goodridge" oil sand), 27 feet thick, which dips about 2° SE. (upstream). The gorge is funnel-shaped, being narrowest at its upper end, where it is about 75 feet wide. The river on entering the gorge contracts abruptly from a width of about 150 feet and races with great velocity through the gorge—in fact, the water at the head of it is swift enough to form a rapid. It is inferred that the rapid is produced not only by a narrowing of the channel at the head of the gorge but also by the occurrence of bedrock ("Goodridge" oil sand) immediately under the bed of the river. A gaging station was maintained from 1914 to 1917 by the United States Geological Survey at a point 500 feet below the head of the gorge. At this point, where the width is about 200 feet, the river bottom is very loose sand underlain by loose gravel.[42]

The Second Narrows, with precipitous cliffs rising from both sides of the river, occurs at a locality 9 miles by stream above the Honaker trail and 8 miles by stream below the Goodridge Bridge. (See Pl. II, *B*.) An attempt was made by the party to ascend the canyon walls and pass around the narrows, because the water in the gorge was rough with boulder rapids and sand waves. The attempt failed, and therefore the boats had to be used. One of them ran into very high sand waves, and was half filled with water, and narrowly missed sinking. The narrows are produced by a bed

[42] Pierce, R. C., The measurement of silt-laden streams: U. S. Geol. Survey Water-Supply Paper 400, pp. 39–40, 1917.

of massive hard gray limestone, about 100 feet thick, which dips upstream at an angle of less than 1°. This bed is the same as the one forming The Narrows, above Goodridge. The bed produces the most persistent and impassable cliff found in the part of the canyon near Goodridge. The cliff is stained pink by wash from overlying red beds and is therefore known as the pink cliff or ledge. There may be some canyon fill underneath the river at this locality; if so, it is perhaps not more than 20 feet deep.

DEPTH OF CANYON FILL

The canyon fill is absent or thin at the localities described in the preceding section. It is probably present in all other parts of the canyon. Nothing is definitely known regarding the total depth of the fill, and little is known regarding its partial depth. The available information bearing on this subject is here presented and discussed.

The depth of the fill along some parts of the river has apparently increased within the last 30 years. This increase seems to be indicated by the change in the character of the river channel at Bluff, Clay Hill Crossing, and doubtless other places. Within the last 30 years the channel has widened at these places and has assumed a braided appearance. The increased depth of the fill is almost certainly due to the heavy débris loads of the tributary streams, in comparison with the light loads carried by them more than 30 years ago.

The depth of the fill in the main canyon at the mouths of side canyons is equal to or greater than the depth of the boulder accumulations. The partial depth of a boulder accumulation may be determined by ascertaining the average slope of the slack river current for a distance of several miles below the accumulation and then projecting the average slope upstream to the mouth of the side stream. The partial depth is the difference between the altitude of the projected slope and the actual altitude of the head of the boulder accumulation. (See Pl. XXII.)

The exposed boulder accumulation at the mouth of the stream entering the river at the Thirteen-foot Rapid consists of a series of individual bars which extend down the river for a mile below the mouth of the tributary. All the boulders and the coarse material in it have been derived from this tributary. By projecting upstream the slope of the river between the boulder accumulation and the mouth it is found that the boulder accumulation is at least 20 feet deep. (See Pl. XXII.)

Boulders and other coarse material derived from Piute Creek can be identified downstream to a point as far as 6 miles below the mouth

of the creek. The series of rapids extending from the mouth of Piute Creek downstream for 1.6 miles has a fall of 35 feet. The average slope of the next 8.5 miles of the river is 6.6 feet. If this slope is projected upstream from the base of the series of Piute Rapids, the partial height of the boulder accumulation in the canyon at the mouth of Piute Creek is found to be about 25 feet. (See Pl. XXII.)

The other boulder accumulations at the mouths of side canyons are apparently smaller than those just described. At any rate the fall of the series of rapids produced by any individual accumulation does not exceed 8 feet, so that if the above method is applied to them their partial depth would be found not to exceed a few feet.

The canyon fill at the mouth of Piute Creek and at the Thirteen-foot Rapid and in adjacent parts of the river is doubtless deeper than the partial depths given above. That the canyon fill is probably not great at any place is suggested by the short distances that alluvium was observed to extend up a few tributaries that have no

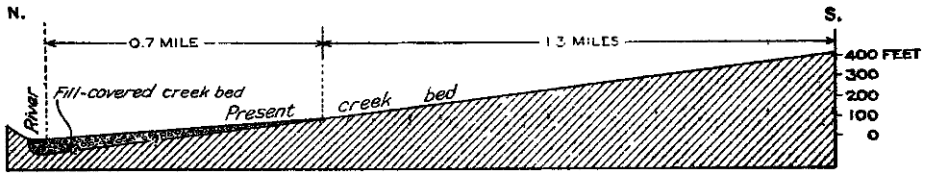


FIGURE 3.—Section and profile running from the Thirteen-foot Rapid up the southern tributary creek at this place. Shows the possible depth of the canyon fill at the head of the rapid.

waterfalls in their lower courses. The alluvium does not extend more than half a mile up Nokai Creek, it apparently does not extend much more than a mile up Piute Creek, and it extends 0.7 mile up the creek at the Thirteen-foot Rapid.

The fill-covered bed of the last-named creek is composed of the same rock formation (Chinle formation) that occurs along the creek for 1.3 miles or more south of the fill. (See fig. 3.) It seems reasonable to assume that the fall of the buried creek bed is much the same as the fall of the creek south of the filled bed, because the Chinle formation, which is composed largely of marly shale, would not here contain resistant beds that would produce waterfalls. If this assumption is correct, the fall of the buried bed, 0.7 mile long, would be 180 feet, or at the rate of 260 feet to the mile, which is the same rate as that in the 1.3 miles south of the filled channel. The present fall of the creek in the last 0.7 mile is 100 feet. By this reasoning the creek channel at its mouth has been filled to a depth of about 80 feet. Yet on account of the tendency of streams to flatten somewhat their gradient toward their mouths, this 80 feet may be a maximum estimate. This would also be a maximum

estimate for the depth of the fill in the main canyon at this locality, because there is apparently no possibility of a buried waterfall at the mouth of the tributary. The marly shale of the Chinle formation extends fully 200 feet below the river surface.

The bowlder accumulation at the Thirteen-foot Rapid stands 20 feet higher than the projected slope of the last 10.5 miles of the river. The fill at the base of the accumulation is therefore estimated to be about 60 feet deep.

The mouth of the San Juan is 73 miles above the proposed dam site at Lees Ferry, where recent borings show that the canyon fill is 78 feet deep. From the San Juan to Lees Ferry the Colorado runs continuously between canyon walls of massive uniform-textured sandstones (Wingate and Navajo) of even hardness, has a bed rock floor of these standstones under the canyon fill, and has a rather uniform fall averaging 1.8 feet to the mile. These uniform conditions suggest that the depth of the canyon fill may not differ far from 80 feet at all places between Lees Ferry and the mouth of the San Juan.

The bedrock floor may roughly parallel the water surface between the foot of the Piute rapids and the head of the Thirteen-foot Rapid for the floor is everywhere in the soft marly beds of the Chinle formation. The canyon fill through this stretch of 8.5 miles may therefore have a somewhat uniform depth, whose maximum is 80 feet. Then if the fall of the water surface in this stretch is projected upstream to the head of the Piute Rapids it is found that the boulder bar at the mouth of Piute Creek stands 25 feet above the projected water surface. The logical conclusion from these statements is that the canyon fill at the mouth of Piute Creek may be as much as 105 feet deep. Complete data, such as those used for estimating the depth of the canyon fill at the Thirteen-foot Rapid, are not available for such an estimate at the mouth of Piute Creek. The total distance that relatively thick deposits of fill extend up Piute Creek is not known. It is at least 1 mile.

That Piute Creek would carry a greater load of rock débris to the river than the creek joining the river at the Thirteen-foot Rapid and that the canyon fill is greater at the mouth of Piute Creek than at the mouth of the other creek appear to be supported by the following comparisons of the two creeks.

Both creeks join the river where its valley is comparatively open. Both have similar rocks in their drainage basins. Both are so near one another and so near Navajo Mountain, about which thunderstorms form in large numbers, that they would probably receive the same amount of rainfall. The drainage basin of Piute Creek is several times greater than that of the other creek; consequently its discharge would be greater than that of the other creek.

On the other hand, Piute Creek, with its greater discharge, might not carry a greater load of débris than the other creek; its fall per mile is only 85 feet for the first 9 miles above its mouth, whereas the fall per mile of the other creek doubtless exceeds 250 feet for its entire length, which is perhaps not more than 9 miles.

That the boulder accumulation at the mouth of Piute Creek has a considerable depth is indicated by the fact that it has acted as a dam, creating a stretch of slack water that extends about 45 miles upstream, to a point near the mouth of Moonlight Creek. (See Plate XXII.) Within this distance the river crosses several belts of hard rocks separated by soft rocks, but nevertheless the fall of the river is nearly uniform for the whole distance, indicating that the fall is not influenced at any place by bedrock. Although the river has an average fall of 5 feet to the mile in this distance, it is graded during normal stages and runs continuously over sand and minor amounts of other loose material.

The canyon fill between the mouths of Chinle and Moonlight creeks is apparently absent or very thin at the places described in the preceding section. The thick fill that occurs between the mouths of Piute and Moonlight creeks therefore thins upstream. Whether the thinning is gradual or is abrupt at places can not be foretold in advance of drilling to bedrock. Yet the belts of hard rock may form ridges or high places under the fill, in consequence of which the fill would be thinner at these places than elsewhere.

For a distance of 6.8 miles below the mouth of Slickhorn Gulch the fall of the river averages 11.6 feet to the mile, or almost twice the average fall (6 feet) of the river between Moonlight Creek and the Colorado. A part of the fall for a few miles below Slickhorn Gulch is due to the boulder bar at the mouth of the gulch and to the occurrence of huge boulders at other places, particularly near the mouth of Grand Gulch; but a part of it is probably due to a change in the character of the rocks of the canyon floor.

Between the mouths of Chinle Creek and Grand Gulch the bedrock of the canyon floor consists of the relatively hard limestone and sandstone of the Goodridge formation, except for short stretches near Mexican Hat and Goodridge. These rocks are harder and more difficult to erode than any other rocks found in San Juan Canyon. Their westward dip near the mouths of Slickhorn and Grand gulches causes the hard rocks to disappear beneath the surface of the river at a point 2 miles below the mouth of Grand Gulch. Below this point the bedrock of the canyon floor consists of soft and easily eroded rocks (shale and sandstone), which overlie the Goodridge formation. Hard rocks similar in age and character to the Goodridge do not again appear at the surface farther down the San Juan

and Colorado canyons until Marble Canyon in northern Arizona is reached.

Canyon fill is present at most places between the mouths of Chinle and Moonlight creeks. Its depth where present ranges from a feather edge to an unknown amount perhaps 50 feet. The depth at most places may not exceed 30 to 40 feet.

None of the above estimates of the depth of the canyon fill are perhaps more than wild guesses, yet the probable error is almost certainly within 100 per cent and is very likely within 50 per cent.

DRIFTWOOD ALONG SAN JUAN RIVER

Although there are few trees in San Juan Canyon, every sand and boulder bar has an abundant supply of driftwood that has been contributed by the headwaters of the river and by tributary streams during flood stages. In fact, the drift is so abundant that the river picks up enough fine trash, logs, and stumps to cover much of the surface of the stream during rising stages. The drift contains some green trees, but consists mostly of seasoned wood, including pine, piñon, cedar, and cottonwood. Some drift accumulations are 15 to 20 feet in height, some were noted as far as 35 feet above the water surface, and some occupy areas of several acres. They have furnished not only fuel for prospectors and the Indians but poles and lumber for the construction of Indian hogans.

SPRINGS AND TRIBUTARY STREAMS

Springs in and near San Juan Canyon are few and small. The tributary streams west of Bluff, although rather numerous, are in large part intermittent and the flow of all is small except during floods, when a single tributary may assume the proportions of a river. Little or nothing has been published about most of these springs and streams. They are therefore described in the following paragraphs, in geographic order from east to west.

Butler Wash near its mouth runs in a canyon about 200 feet deep in the yellow sandstone of Comb Ridge. On July 18, 1921, when the mouth of the wash was seen, no water was flowing in the bottom of the canyon. There are at places narrow stretches of sandy loam as much as 20 feet deep, in which the wash and its side gullies have cut vertical-walled channels.

Comb Wash, as is indicated by its former name, Epsom Creek, contains considerable mineral matter. It was not observed by me.

Chinle Creek on July 19 was flowing perhaps 50 second-feet. It is stated by Gregory to be a permanent stream during normal years.[48] It was crossed at a locality three-fourths of a mile above

[48] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380, p. 36, 1916.

its mouth, where boulders that project above the water could be used for a footing. An earlier attempt was made to cross the stream near its mouth. The attempt was not abandoned until after I had reached a point in the mud-filled channel where I sank more than knee deep into the stiff red mud. Wading deeper into the mud would have been hazardous, because I was alone.

A spring of good cold water was found by the Trimble party on the north side of the San Juan just east of The Narrows (Pl. II, A). Needless to say, it was used to replace the none too clear river water that was being carried in our canteens and water bags.

A spring known as Soda Spring occurs at the water's edge on the left bank of the San Juan at the south end of Soda Basin. The water is clear but is so heavily charged with mineral salts that it is not drinkable. Soda Basin, which is a comparatively wide part of the canyon, takes its name from the spring.

Lime Creek was crossed on the morning of July 22, 1921, when it was flowing several second-feet of clear water.

Gypsum Creek, which I did not cross, is said by Gregory to run practically all the time, but the water is so strongly alkaline that it is avoided by both man and beast.

The stream draining Johns Canyon has a fall of 60 to 75 feet at its mouth, though no water was flowing from the canyon on August 5, 1921, when it was passed. Beneath the fall there is an elliptical pool 70 by 100 feet filled with clear water, which was utilized by the party for drinking and bathing. The water in the pool had clarified by the settling of the mud to the bottom.

A spring named Sulphur Spring by the Trimble party, from the presence of much hydrogen sulphide in the water, issues on the right bank of the river at a point 3½ miles below the mouth of Johns Canyon. The spring, whose flow would fill a 3-inch pipe, issues among a jumbled mass of limestone boulders that lie at the base of a cliff of shaly, flinty limestone 15 feet high and at the edge of a sand bar.

The stream draining Slickhorn Gulch was observed on August 6 and 7, 1921, when it was flowing a fraction of a second-foot of pure, clear water. The last half mile of the stream was mapped by K. W. Trimble, and was found to have a fall of 150 feet.

Grand Gulch, which is a narrow and tortuous canyon, with red walls several hundred feet high, heads in the slopes south of Elk Ridge and runs in a southwesterly direction, joining San Juan Canyon at a point 3½ miles below the mouth of Slickhorn Gulch. According to earlier maps it joins the San Juan at a point some 10 miles farther west, near Clay Hill Crossing. At its mouth there is a waterfall 50 feet high. On August 8, 1921, a clear stream of pure water with a flow of a few second-feet was pouring over the

fall. In the upper part of the gulch water is stated to be found at most places throughout the year.

Moonlight Creek, according to Gregory, is perennial for the last 4 miles of its course, and is intermittent for the next 18 miles. The cascade waterfall at the mouth of its canyon was passed by the Trimble party on August 9, 1921. The creek was then pouring into the river a flood of red muddy water, much of which was breaking into red spray. The near-by cliffs and boulders had received a coat of red mud by the settling of the spray on them. The canyon could not be ascended from the river.

A waterfall, over which a clear stream flowing less than a second-foot was observed on August 9, 1921, at a point on the north side of San Juan Canyon 3¼ miles by river below the mouth of Moonlight Creek. A similar waterfall on the same side of the San Juan is about 1½ miles east of Clay Hill Crossing.

The fairly large intermittent stream that enters the San Juan from the north about half a mile east of Clay Hill Crossing is marked by seeps and water-filled potholes, but we found the water so charged with mineral salts that we could not use it.

A herdsman's headquarters during the grazing season in the winter is 25 miles northeast of Clay Hill Crossing, at a place known as Red House. Here there is a small building made of red sandstone, a spring that was filled with mud at the time of visit (August 11 and 12), and two ponds that had been filled with red water from recent rains. Although the water was still red from fine silt that had not settled to the bottom and was the abode of thousands of tadpoles, it was a most welcome sight to Bert Loper and me after we had spent a day in walking from the San Juan to this place beneath a scorching sun. The water in our canteens was exhausted two or three hours before we reached Red House, and my dry tongue had been sticking to the roof of my mouth for more than an hour.

Rockhouse Gulch, so named from a stone hogan 1¼ miles southeast of its mouth, is drained by an intermittent stream. At times we found the stream channel marked by potholes of clear pure water, and at other times there was a stream flowing several second-feet. The next stream to the southwest, entering the river from the east, is also intermittent. Its water is charged with considerable mineral matter.

The small stream draining Clay Gulch is intermittent. It was flowing late in August, 1921, but the water was heavily charged with mineral salts.

A spring flowing a fraction of a second-foot is on the south point of a ridge about 2 miles west-northwest of the mouth of Clay Gulch. It issues at the base of the Navajo sandstone at an altitude of about

1,000 feet above the river. This spring and adjoining seeps provide water for a small patch of vegetation comprising grass, flowers, oaks, cedars, and cottonwoods. The locality has apparently been visited at times by herdsmen, for it is truly an oasis in this high barren country.

Spring Creek enters the right side of San Juan a quarter of a mile north of the mouth of Copper Canyon. It was followed on August 31, 1921, to a point about 4½ miles by stream from the river. It was then flowing a few second-feet of clear pure water except along the last mile of its course, where the channel was marked by small pools of water. Two excellent springs—one flowing enough water to fill a 2-inch pipe and the other a larger spring 600 feet farther east—occur on the north side of the stream at a locality about 3 miles above its mouth. The canyon drained by this stream is followed by a poor trail. It contains many cottonwoods especially in the part of the canyon above the springs.

Copper Creek was followed on September 2, 1921, to a point about 5 miles in a straight line above its mouth. Through much of this distance its bed contained a stream flowing a few second-feet of usable water, though it tasted strongly of mineral matter.

Nokai Creek was followed on September 9, 1921, to a point about 7½ miles in a straight line above its mouth. At that time the creek was flowing a fraction of a second-foot at some places, but at other places its bed was marked simply by pools. The water, although it contains considerable mineral matter in solution, is usable.

A stream that was followed for 4 miles in a northeasterly direction enters the river from the north at a point opposite Spencer Camp. About 2 miles from the river there is a large spring of excellent water, which issues near the base of the Wingate sandstone. The water from it runs about a mile down the gulch before it disappears among boulders and other loose material. Near the spring the bottom of the gulch is covered with a tangled mass of jagged boulders, vines, shrubs, and cottonwoods. The gulch is impassable for horses, and even walking is difficult.

The part of the canyon in the Great Bend is joined by several side canyons, all of which probably contain small perennial streams. None of them could be ascended except Alcove Canyon, near the west end of the bend. No trails lead up the canyon, and no sign was found that it had been visited previously by man. The canyon was ascended to a point 1½ miles away from the river, beyond which a high waterfall prevents further progress. In the distance traversed it contains a small perennial stream fed by several springs of excellent water and by rivulets that leap from the tops of the high cliffs.

Several springs and seeps flowing a fraction of a second-foot each occur along San Juan Canyon at and near the west end of the Great Bend. The springs issue at different altitudes on the sandstone cliffs.

Piute Creek was ascended on September 22, 1921, to a point 9 miles from the San Juan. It was then flowing a clear stream of perhaps a few second-feet at some places, but at other places the creek bed was marked by pools separated by stretches of loose stream material through which the water seeped. The water was usable, though at places it tasted rather strongly of mineral matter. Gregory [44] says, "In July, 1910, the estimated flow of Piute Creek 6 miles above its mouth was 0.20 second-foot, and the average of two estimates made in June, 1913, at points near the head of the canyon was 0.15 second-foot. A sulphur spring of small size occurs in the bottom of a tributary canyon near a cluster of cottonwoods at a distance of 2½ miles from the river. Much evidence was observed to indicate that the creek had been in flood one or more times in 1921 prior to our visit. Such floods had reached a height of 15 to 20 feet in the narrower parts of the canyon and had swept away all vegetation in their path, including grass, trees, and shrubs. Very few cottonwoods are found along the bed of the canyon, and these stand in elevated places that are not reached by floods.

Five perennial streams enter the south side of the San Juan west of Piute Creek. They all run in deep canyons and apparently head in the north base of Navajo Mountain. Their names were not learned by our party, because we saw no Indians west of Piute Creek and could not identify them with certainty from Gregory's map. To three tributary creeks of the San Juan he applied the names Desha, Cha, and Junction, but his usage differs from that given on maps in recent articles by Morris [45] and Bernheimer.[46] It is therefore not advisable to apply names to the five streams mentioned above until their identification can be established.

The first southern tributary west of Piute Creek is a stream of clear, good water with a flow of less than a second-foot. It descends over a waterfall 20 to 30 feet high half a mile south of the river. The canyon drained by it was not ascended beyond the waterfall, for a ladder 20 to 30 feet long would have been required to climb a cliff at the east end of the fall. The creek had discharged one or more floods in 1921 prior to our visit in that vicinity, which was late in September of that year.

[44] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380, p. 87, 1916.

[45] Morris, E. H., An unexplored area of the Southwest: Natural History, vol. 22, No. 6, pp. 499–515, 1922.

[46] Bernheimer, C. L., Encircling Navajo Mountain with a pack train: Nat. Geog. Mag., vol. 43, No. 2, p. 198, February, 1923.

The southern tributary entering the river 3 miles in a straight line west of the mouth of Piute Creek was flowing a little less than a second-foot of clear excellent water when it was visited September 28 and 29, 1921. It was ascended by the Trimble party for a distance of 2¼ miles in a straight line above its mouth. The canyon in which it flows has numerous water-filled potholes of small and large size, around some of which it is difficult to pass. One or more floods were discharged by this stream in 1921 prior to September 28. These floods reached a height of 15 to 20 feet in the narrower parts of the canyon and swept away practically all the cottonwood trees. The few battered trees still standing are 10 years or more old, suggesting that the floods of 1921 were more violent than any others for a period of fully 10 years preceding 1921.

Wilson Creek, a perennial stream, runs in a crooked, deep, and very narrow canyon whose floor is forested with many trees, especially cottonwoods. It is so wild and inaccessible that the trail leading north from the river at this locality does not follow up the bottom of the canyon but ascends the canyon wall near the mouth of the creek. Christensen, who ascended the canyon for a short distance, found the tracks of a mountain lion. The creek when it was visited on September 29 and 30 was flowing about half a second-foot of clear, exceptionally good water. A spring whose water enters the creek is in the head of a small canyon half a mile northeast of the mouth of the creek; its location is marked by a dense growth of trees and grass.

The first canyon on the south side of the river below Wilson Creek is comparatively short, probably not much over a mile in length, and is drained by an intermittent stream. No water was flowing from it when its mouth was passed on September 30, 1921.

A perennial stream flowing a fraction of a second-foot enters the river at the Thirteen-foot Rapid, 2¼ miles in a straight line below the mouth of Wilson Creek and 11½ miles by stream above the mouth of the river. The canyon in which it runs was followed by me to the forks 2 miles away from the river and then the west fork was followed for almost 2 miles more. This fork, which heads in the north base of Navajo Mountain, presents some of the wildest scenery found on the tributaries of the San Juan. The canyon, like most others in the vicinity, is narrow; its walls are vertical, inaccessible cliffs and boulder-strewn slopes; the canyon floor is dotted here and there by dense thickets of shrubbery and trees; and the creek draining it has two low falls from which it plunges into large, deep pools. A person who traverses such canyons must use extreme caution with every step to guard against falling and serious injury. The water in the stream is clear and is drinkable. Several springs

or seeps of sulphur water, whose odor is strong at some places, join the creek below the forks of the canyon. One or more floods were discharged by the creek in 1921 prior to the time of our visit, October 1, 1921. Although the torrents did not exceed a depth of 6 or 7 feet, they toppled over some of the fairly numerous cottonwoods. The uniform age of most of the cottonwoods—apparently 10 to 15 years—suggests that one or more violent floods swept practically all the trees from the canyon some 10 to 15 years ago.

A short box canyon on the south side of the river, which is 8¼ miles by stream above the mouth of the San Juan, could not be ascended more than several hundred feet on account of a waterfall a few hundred feet high. The stream draining the canyon was discharging into the river less than a second-foot of clear, pure water when it was observed on October 2, 1921.

The last perennial tributary enters the river at a point 5¾ miles by stream above the mouth. On October 3, 1921, it was discharging into the river a few second-feet of pure, clear water. It was followed for a distance of almost 2 miles by stream above its mouth. Water was then running not only in its main canyon but also in its two forks, though no water was found in them farther than 1½ miles away from the river. A spring of excellent water with a flow sufficient to fill a 1-inch pipe occurs in the east fork a few hundred feet east of the junction. It issues from a joint in the steep north canyon wall at 60 feet above the bottom of the canyon. The water in running down the wall keeps alive a small patch of luxuriant grass and shrubs that literally cling to the steep, smooth wall, although it is solid sandstone.

WATER SUPPLIES

Water for the inhabitants of the village of Bluff is obtained from several flowing wells, four of them 800 feet deep, one 1,085 feet deep, and another 1,165 feet deep. The water-bearing beds, which occur at depths of 800 feet and less, are probably in the Wingate sandstone.[47]

Water for the few families at the village of Mexican Hat and the Spencer trading post is hauled in wagons from the San Juan and then placed in large tanks, where it clarifies by the settling of the silt. Water for Mexican Hat was for a number of years pumped from the San Juan to a standpipe near the village.

Drinking water for the Trimble party was obtained mostly from the San Juan, though some was obtained from springs, some from tributary streams, and some from rock "tanks." The water thus obtained was generally free from noticeable quantities of mineral matter in solution, but it all was charged with so much silt that the

[47] Gregory, H. E., U. S. Geol. Survey Water-Supply Paper 380, p. 182, 1916.

bottoms of our two water pails, after being filled with water, could seldom be seen. In fact, the river was muddy at all times during the descent of the canyon, from July 18 to October 3, 1921, yet the river water left standing in the pails over night would clarify by the complete settling of the silt. Water clarified in this way was used as much as possible in filling our canteens and water bags when it could not be had from other sources. Constant use was made of our canteens and water bags, even during the descent of the river, but notwithstanding this precaution the supply of clear water frequently became exhausted, requiring the use of muddy water.

On July 18 and 19 and from about September 10 to 30 the river water, though muddy and with a gray and grayish-buff color, was free enough from silt to permit its use for drinking after the sand had been permitted to settle to the bottom of the pails or drinking cups. During these periods it could also be used for washing clothes. From July 20 to about September 10 and from October 1 to 3 the river was so laden with silt that water obtained directly from it was used very little for these purposes. It was used for bathing, but the body of the bather on emerging from the river would be covered with red and dark stripes and splotches, depending on the color of the muddy water. During these periods a hole was dug deep enough in sand or gravel near the water's edge to permit water to seep into it from the river and thereby be filtered naturally by the sand and gravel. Such holes required a crude lining of stones to keep the wet creeping sand from completely filling them. The rapid and frequent fluctuations of the river made it necessary to dig several such holes at a camp within a single day. During rises they would be flooded, but during recessions they would be drained and thus left high and dry.

Water was frequently obtained from basins in sand where it was left during recessions of the river. The mud in such water would gradually settle on the bottoms and sides of the basins, thus making a relatively impervious lining. Such ponded water, after standing a few days, becomes rather strongly charged with mineral salts; this is apparently due to the evaporation of the water and the consequent concentration of the salts.

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