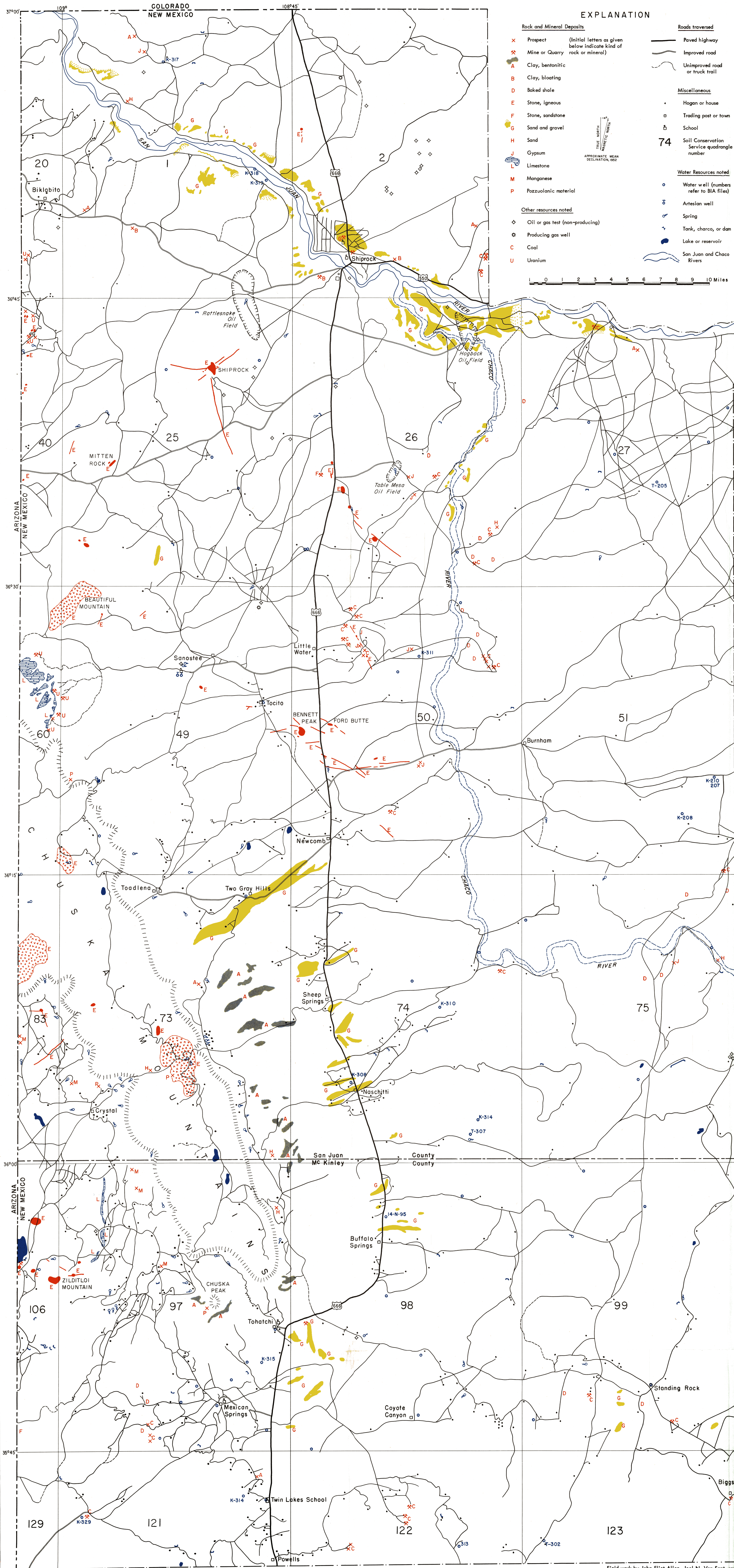

Base from U. S. Geological Survey, Topographic Division
Data plotted on Photomosaics of Soil Conservation Service,
U. S. Department of Agriculture

1955

Field work by John Eliot Allen, Joel N. Van Sant, and Stanley A. Mayer, assisted by Robert Ahkeah, 1953-54

MINERAL RESOURCES OF THE NAVAJO INDIAN RESERVATION IN NEW MEXICO

(exclusive or uranium, coal, oil, gas, and water)

by John Eliot Allen

1955

Prepared under contract for the U. S. Department of the Interior
Bureau of Indian Affairs

PREFACE

In 1952 the Federal Bureau of Indian Affairs, acting under direction from the Congress as provided in the Navajo-Hopi Rehabilitation Act, turned to the New Mexico Bureau of Mines and Mineral Resources with the challenging request to point out mineral or other natural resources in the Reservation which, if utilized, could improve the standard of living and increase the participation of the Navajo Indians in the economic pattern of the nation. In response to this request, the New Mexico Bureau, on a contract basis, undertook the detailed study of an area of 500 square miles near Fort Defiance and Tohatchi where a typical section of the geologic formations of the eastern part of the Reservation were exposed, and each could be evaluated as to its economic possibilities. The comprehensive report on this project to the Bureau of Indian Affairs was published in 1954 (Allen and Balk, 1954).

In 1953 under a second contract the New Mexico Bureau was directed to conduct a wholly different kind of study of the entire Reservation within New Mexico. By specifically excluding known resources and those currently being investigated or exploited by other organizations, such as oil, gas, helium, coal for fuel, uranium, and water, the investigation was designed to attempt to find such other mineral resources as might have present or future economic possibilities of interest to the Navajo Tribe. This report and map provide the results of the consequent studies under this project.

An investigation of this kind encounters problems of a complex nature. A high-grade coal bed, freely exposed along its outcrop, of a known thickness and a predictable area, is a fundamental resource to which a dollar value can be attributed with some degree of assurance. However, a special kind of clay, sand, or limestone, a particular kind of lava, weathered coal, or gravel, cannot be listed so simply as a resource. Economists distinguish resources now being utilized from others that have a future or potential value and importance. A special kind of clay may become the foundation of a million-dollar industry, provided it crops out less than X miles from an all-weather road, provided there is a chemical factory less than Y miles away, or provided an oil company is drilling less than Z miles away. A particular limestone becomes an important resource, provided its silica content is less than X percent, provided the bed averages not less than Y feet in thickness, and provided a coal mine is available not more than Z miles away. In short, the evaluation of a so-called minor mineral resource is nearly always conditioned by a large variety of supplementary economic factors, trends of industrial activity, fluctuations of demand, competition, uses, substitutes, and other economic conditions.

In the text that follows, the writer, a geologist, has chosen to present the known locations or probably areas of distribution of numerous mineral resources and, as far as possible, to give critical estimates or determinative data of these substances, with the encouraging or discouraging factors freely stated. Final economic evaluation of the data presented in this report as the basis for the actual establishment of an industry must await critical study of all economic factors expected to obtain during the proposed period of operation.

SUMMARY AND RECOMMENDATIONS

The investigation of the mineral resources of the Navajo Reservation in New Mexico has indicated the presence and location of a number of rock and mineral deposits of present or potential economic value, as specified in the contract between the Bureau of Indian Affairs, U. S. Department of the Interior, and the New Mexico Institute of Mining and Technology. Most of these deposits require further detailed sampling, testing, drilling, exploration, and marketing studies, before their utility and value can be determined to the point where exploitation can be justified.

These may be listed according to use as follows:

Construction materials
- Crushed stone, crushed gravel, and baked shale for road surfacing, macadam chips, and for conrete aggregate
- Sand and gravel for concrete aggregate and plaster
- Dimension stone, flagstone, rough-cut stone and rip-rap for construction of buildings, bridge abutments, and channel linings
- Bentonitic clay for lining stock tanks, dams, and ditches
- Bloating clay for light-weight aggregate for concrete blocks

Industrial materials
- Low-magnesian limestone for cement rock, flagstone, chemicals, and numerous other uses
- Bentonitic clay for drilling mud and for pelletization of powdered ores
- Weathered coal for soil conditioner, drilling mud additive, and uranium precipitation
- Sand for green glass

Minor occurrences
- Manganese, gypsum, and pozzuolanic material

In view of marketing possibilities for the considerable quantities of igneous rock, bentonitic clay, limestone, and weathered coal occurring on the Reservation, it is recommended that tonnage and commercial grade be established by means of detailed mapping, sampling, and necessary drilling for igneous rock at quarry sites at Bennetts Peak, Ford Butte, and Foster Peak; for bentonitic clay west of Sheep Springs; for limestone west of Sanostee; and for weathered coal in the area around Burnhams.

Thought should be given to the expansion of tourist trade in this area, through road construction and increase in available accommodations. This applies particularly to the scenic areas of Todilto Park (west of Tohatchi) and west of Sanostee.

INTRODUCTION

The Navajo Indian Reservation in New Mexico includes slightly more than 4000 square miles in San Juan and McKinley Counties in the northwest corner of the State, extending 90 miles in a nogth-south direction, and having an east-west width of about 45 miles.

The Reservation contains coal reserves estimated recently as totaling 38½ billion tons (Read, et al. 1950). These coals currently are being studied and remapped by the Fuels Branch of the U. S. Geological Survey. The Reservation also contains important reserves of gas, oil, and helium which since the first discovery have yielded a total income to the Navajo Tribe of nearly $10 million; the annual income from leases and royalties now averages over $1½ million. Along the western margin of the reservation in New Mexico are deposits of uranium and vanadium ores whose value is as yet undetermined; production is now being obtained from several properties, and extensive exploration by mapping, sampling, and drilling, especially west of Sanostee, is being carried on by the Atomic Energy Commission. A plant for the extraction of uranium from these ores is under construction at Shiprock. In a region of semiarid climate such as that of the Reservation, study of the occurrence, amount, and quality of both surface and underground waters is of extreme importance; this study is being carried on by the Ground Water Branch of the U. S. Geological Survey.

In a discussion of the mineral resources of any region these resources can be separated into two categories: those which are being utilized currently, and those which have future or potential value and importance. The Navajo Reservation is a relatively undeveloped region, and the above mentioned resources are far from being fully utilized; numerous other rock and mineral substances will fall into the second category. It was the function of this project to locate and report upon those substances not excluded under the terms of the contract and discuss their possible value to the Navajo Tribe.

Geographic Factors

In the Navajo Reservation of New Mexico the area east of U. S. Highway 666 is referred to as the Chaco Valley, and the more mountainous terrane west of the highway as the Chuska Mountains.

The Chaco Valley is a wide monotonous expanse of arid, alluviated basins tributary to the Chaco River, and intervening low ridges, mesas, cuestas, and hogbacks. Elevations range from 4900 feet at Shiprock to 6800 feet in Hogback Mountain and 8620 feet in Hosta Butte, but the average is around 5500 feet in the northern and 6000 feet in the southern and eastern part of the area. The relief is seldom more than 1000 feet.

The Chuska Mountains proper extend in New Mexico from Tohatchi on the south to lava-capped Beautiful Mountain on the north. Continuing northward into Arizona, they are called the Lukachukai Mountains. Essentially a high (8000-9000 feet), flat-topped forested plateau about 8 miles wide and 60 miles long, they are bounded on the south by the mesa country of the Manuelito Plateau, rising to 7500 feet, and on the east by a steep escarpment. Below this escarpment a wide area of landslides, sloping mesas, and terraces is cut by narrow canyons extending down toward Chaco Valley. North of Beautiful Mountain, gently undulating uplands and east-dipping cuestas extend northward across the shallow canyon of the San Juan River to the Colorado State line. Eroded remnants of ancient volcanic cones such as Shiprock, Mitten Rock, Bennett Peak, and Ford Butte stand out spectacularly in otherwise broad horizons. Steep-cliffed mesas rise as much as a thousand feet from the gently sloping plains, particularly north of the San Juan River.

Economic Factors

Five factors are vital for the economic develpoment of any region: transportation facilities, fuel, water, housing and labor, and markets.

Transportation facilities. The southern edge of the reservation is paralleled by the Santa Fe Railroad, passing through Gallup, and the Denver, Rio Grande and Western Railroad, extending from Durango as far as Farmington. Paved highway U. S. 66 parallels the railroad through Gallup, and the north-south U. S. 666 bisects the New Mexico part of the Reservation. U. S. Highway 550 follows the San Juan River eastward from the town of Shiprock to Farmington, Aztec, and Durango.

The only other improved roads consist of a paved highway just south of the Reservation boundary extending west to Window Rock, and graded but unpaved roads from Highway 666 to Mexican Springs, Sanostee, Red Rock, Burnhams, and Beclabito. Transportation facilities for valuable ores and materials in these days of inexpensive truck haulage are thus favorable, since 30 miles of road, east or west of Highway 666, will reach all parts of the area. Low-cost materials, however, will seldom pay for long truck haulage, and are thus handicapped at the present time.

Fuel. Adequate fuel for even a large industry is present in the area in the form of natural gas (a new pipeline is being built westward through the area from the gas fields east of Bloomfield) and coal, which is found in numerous localities along almost the entire eastern part of the area.

Water. Except along the San Juan River, water in very large quantities is lacking, and even along the river it is questionable whether unallotted amounts could be supplied continuously throughout the year without expensive storage facilities. Any industry having large water requirements (and some, particularly chemical industries, need millions of gallons per day) would need to make a careful survey of flow records of the San Juan River, requirements of present and future irrigation projects, downstream allotments or demands, and possible diversions upstream. Water, evn for present-day domestic use, is inadequate in the Gallup area, and a recent survey of the Chuska Mountains water resources (Harshbarger and Repenning, 1954) indicates that intermittent surface waters are now being largely used for irrigation, and springs are no more than adequate for present domestic and irrigation use. Ground water is obtained from several sandstone horizons, usually at depths of over 500 feet, but even in favorable localities a well would have to be over 2000 feet deep to obtain free-flow of over 40 gpm or about 60,000 gpd total pumped capacity.

Housing and labor. Gallup, a railroad town of 9,133 population (1950), lies 12 miles south of the Reservation; and Farmington, with a 3,637 population in 1950 (probably 11,000 in 1954), lies at the opposite end, 125 miles to the north and east. The Navajo population on the Reservation is widely distributed. The largest center in the area, Shiprock, has a permanent population of only 125. During 1954 all three towns were undergoing acute housing shortages, with trailer courts overflowing, despite building booms. In Farmington, this was due largely to an expanded program of gas-well drilling and to the uranium rush. In Shiprock it is due to the construction of the new uranium-concentration mill; and in Gallup to construction at Fort Wingate, to uranium activity, and to new government building.

Markets. New construction projects underway or contemplated in the area, which may use local materials, include a dam near Shiprock and one farther east near Kutz Canyon; and new gas pipelines. Road improvements to serve uranium mining developments at Monument Valley and Cove Mesa (and possible tourist roads to Todilto Park and Sanostee) should soon be forthcoming. A potential market for bentonite exists in the extensive gas-well drilling to be undertaken in the San Juan Basin during the next few years. The presence within a limited area of large tonnages of high-grade limestone, large coal resources, and abundant natural gas would immediately suggest the advisability of a survey of possible chemical industries which might use these raw materials in a locally situated plant, provided an adequate supply of water can be assured.

Investigations in the Area

The geology of the Reservation is now being mapped by the Fuels and Ground Water Branches of the U. S. Geological Survey (Beaumont, 1953; Beaumont and Zieglar, 1954; Halpenny, 1951; Harshbarger and Repenning, 1954), and detailed studies of uranium-bearing areas are being made by the Atomic Energy Commission (Droullard and Jones, 1951). Prior to the present study, the New Mexico Bureau of Mines and Mineral Resources mapped Fort Defiance and Tohatchi quadrangles for the Bureau of Indian Affairs (Allen and Balk, 1954). The only other mapping published in recent years is of the coal measures of the southeastern corner of the area (Sears, 1934) and along the eastern edge (Reeside, 1924).

Using previous geologic data as a guide to units which may be more or less "favorable" to rocks or minerals of economic importance, the present survey mapped 5000 miles of road during 1953 and 1954, and collected over 200 samples of rocks and minerals. Members of the survey have interviewed, with the assistance of Mr. Robert Ahkeah as interpreter, over 500 Navajo families, with the hope that some knowledge might be obtained as to the location of economic materials. Postcards addressed to Bureau headquarters were left with these families, in case they secured information they wished to impart to the investigators. Early in 1954 it became evident that the influx of uranium prospectors and promoters had cancelled any value this approach may have had.

The results of the survey are in part outlined on the accompanying map, which shows roads, hogans in many but not all areas, and the location of the various construction and industrial materials. Water, oil and gas wells, tanks (locally called charcos), coal mines, and uranium prospects were plotted only when they were noted in passing, since the terms of the contract excluded investigation of these considerable resources.

Acknowledgments

The cooperation of the officials of the Bureau of Indian Affairs, particularly the Director of Resources, Mr. Russell Fister, and later Mr. K. W. Dixon, is gratefully acknowledged. The Tribal Mining Engineer, Mr. K. N. Girard, has given cheerful assistance in spite of press of duties connected with the rush of uranium prospectors.

Three competent graduate mining engineers were engaged in the survey at various times: Mr. Willow Burand, now with the Santa Fe Railroad at Operation Haystack, was in the field from July 22 to August 13, 1953; Mr. Joel Van Sant, now with the U. S. Bureau of Mines at Denver, was in charge from August 24 to November 6; and Mr. Stanley A. Mayer, now with the Atomic Energy Commission at Moab, Utah, was in charge of field work from January 24 to May 19, 1954. Field work by the writer has been done at various times during the period 1953-54. The writer visited all these men in the field, transcribed their notes, checked many of the localities, and takes responsibility for their work.

Test work on bloating clays was done by Mr. James Deatherage and on glass sands by Mr. Stephen Faillance. Analysis of bentonitic clays was done by the Phillips Petroleum Company, of glass sand by the Hazel-Atlas Glass Company. The map was drafted by Mr. William Arnold.

Geologic Setting

Of the total area of the Reservation in New Mexico of 4016 square miles, 3510 square miles (87.5 percent) is underlain by monotonous and barren yellow-drab sandstone, siltstone, and gray shale of Cretaceous or slightly later age; 247 square miles (6.1 percent) by Tertiary Chuska sandstone and igneous rocks; and 259 square miles (6.4 percent) by formations of Jurassic and Triassic age, mostly exposed within a few miles of the Arizone line. The only older rocks cropping out on the Reservation in New Mexico are two small exposures of Permian De Chelly Sandstone near Toadlena.

The accompanying small map gives a generalized idea of the distribution of rocks of different age. The symbols refer to the units described in the chart below. This chart lists the rock units recognized, and sketches their changing thicknesses and relationships from north to south in the Reservation. It also gives a short description of the characteristic lithologic features of the units together with two columns listing the construction and industrial materials found in the various units. Since the rock units have been described in numerous papers (Sears, 1934; Allen and Balk, 1954; Harshbarger, et al. 1951; Harshbarger and Repenning, 1954, etc.), and more detailed studied are expected to be published by the Fuels Branch of the U. S. Geological Survey, no purpose would be served here by giving more than the brief description of lithology outlined in the chart.

Generally speaking, the stratified rocks dip eastward and northward into the San Juan Basin, and thus progressively younger rocks are encountered as one goes eastward from near the Arizona line. Nearly horizontal Tertiary Chuska sandstone, however, overlies the beveled surfaces of older formations at an elevation ranging a few hundred feet above and below 8000 feet; Tertiary volcanic rocks intrude older rocks at many places and overlie the Chuska sandstone at Washington Pass, Beautiful Mountain, and several localities between the two. Furthermore, several gentle flexures, such as the Sanostee and Tocito anticlines, interrupt the eastward dips of pre-Tertiary rocks.

ROCK AND MINERAL DEPOSITS

Rock and mineral deposits mentioned in the following text can be located on the large map by means of key numbers which follow them in parentheses. The first number refers to the 15-minute quadrangle (Soil Conservation base) in which they occur, the initial letter to the distance in miles east of the western boundary of the quadrangle, and the last figure to the distance in miles south of the northern boundary of the quadrangle.

Bentonitic clay (A)

Bentonite is believed to originate as a fine volcanic ash which has changed to the clay mineral montmorillonite. Bentonite has many uses, for instance, as an additive to well-drilling muds to increase their visosity and gelling characteristics (Stern, 1941), as an oil-refinery filter, and as a component of foundry sands (A.I.M.E., 1949, pp 124-5). A multitude of other less important uses are made of bentonite in ceramics, insulation, briquetting ores, detergents, sprays and insecticides, and for sealing leaky reservoirs, earth-fill dams, and mine workings. There are two chief types, those which swell markedly upon addition of water, and those which do not, but may be "activated" by chemical treatment for use in oil-refining processes. The former has a high ratio of soda to lime, the nonswelling type a reverse ratio.

Impure bentonite in relatively thick beds is widespread along the east side of the Chuska Mountains between Tohatchi and Newcomb, and appears elsewhere in a number of localities.

Four samples, taken four miles west of Sheep Springs (73-N-10) were analysed according to A.P.I. Code No. 29. Detailed results may be consulted at the New Mexico Bureau of Mines and Mineral Resources office in Socorro; the conclusions are quoted as follows:

> "The bentonite samples tested appear to be low-yield clays, slightly heavier than good bentonites. There was a positive gelation characteristic present in all four samples, as can be noted in the trend toward high initial and 10-minute gels. It is doubtful, however, that the materials could be useful in drilling muds except in rare cases where low-yield high-weight clays could be tolerated."

A summary of the range exhibited by the four samples is given as follows:

Moisture content	3.74%	to	5.29%
Average specific gravity	2.56%	to	2.59%
Yield in fresh water, bbls/ton	.21%	to	.57%
Yield in salt water, bbls/ton	.19%	to	.27%

A further possible use for impure bentonitic clay is as a pelletizing agent for powdered ores. Finely divided iron oxide obtained by grinding and concentration from such ores as taconites, requires reconstitution into pellets before it can be smelted. One of the cementing agents used is bentonite, which as the tonnage of taconite mined increases, will be used in increasing amounts. Tests on the bentonitic clays west of Sheep Springs showed that they were amenable to this use, although not as effective as some bentonites of higher grade.

Clay, bloating (B)

Certain clays, upon passing through heated rotary kilns, will swell and bloat into a hard, sharp, porous slinker, which upon cooling may then be crushed and sized for use as aggregate in the production of strong, light-weight structural concrete slabs or concrete blocks (Hardy, 1954).

Three samples of Mancos shale from outcrops near main roads were collected 2 and 15 miles west of Shiprock on the main Monument Valley road, and 3 miles east of Shiprock. These samples were crushed and heated in the assay furnace to temperatures approaching that to which they would be subjected in a large commercial rotary kiln. The degree of bloating of the shale from the western deposit, when heated to 2200°F was 33 percent, producing a light, tough clinker. Easily accessible reserves from this locality are almost unlimited. Further testing of larger samples will, of course, be necessary before plant operation can be contemplated. In view of the high cost of cinder block, which is now shipped to the Farmington and Shiprock area from Santa Fe, it is suggested that production of bloated clay aggregate might be the base of an economically feasible industry.

Clay, structural

Numerous clays collected from widely separated locations on the Reservation, with one exception, proved upon X-ray analysis to have high montmorillonite content, in other words, they are bentonitic. Although highly plastic when wet, these clays have excessive drying shrinkage and check so badly that they cannot be used for brick, tile, or pottery without considerable admixture of kaolinitic clays.

One sample, collected from the bed of Catron Creek 5 miles due west of Mexican Springs, was tested by Mr. Roger Sherman, of the Navajo Clay Products plant at Gamerco. It showed favorable features which made it of value for pottery purposes. This clay had been deposited to a thickness of six inches in a pool in the creek bed, and no large or reliable tonnage can be expected. Clay associated with coal beds in the Gallup area are known to be of value, and it is expected that similar clays may be found on the Reservation upon closer search.

Coal (C)

A major resource of the Navajo Reservation in New Mexico is coal. Important coal beds occurring in the Mesaverde Group crop out almost the entire length of the Reservation. They occur east of Highway 666 on both sides of the Chaco River, in the southeast part of the Reservation northeast of Powell's Trading Post as far east as Biggs, and about 5 miles south and west of Mexican Springs on several of the headwaters of Catron Creek.

These extensive coal deposits are being mapped and evaluated by the Fuels Branch of the U. S. Geological Survey, but there are potential uses of coal other than fuel which should be mentioned here.

In the region east of Highway 666 the dip of the coal beds is very low, and wide expanses of coal are exposed at the surface. Coal in this weathered outcrop area, though of little value for fuel, can be used as a soil conditioner, a product which is now being manufactured in Gallup and elsewhere under various trade names. The ground, weathered coal is reported to have specifications consisting of a pH of 4.1, 65 percent organic matter, 10 percent water, appreciable amounts of Ca, Mg, SiO_2, and trace elements. It is recommended for the treatment of alkaline and clayey soils.

A second important use for ground weathered coal is as a drilling mud additive (Rogers, 1953, pp 323-4), a low-cost "extender" to supplement Quebracho, a tannin extract, imported from Argentina, which has the property of thinning the mud and inducing a low viscosity gel strength even in heavily weighted muds. This promotes efficient removal of cuttings, suspension of solids while quiescent, lower fluid loss, release of gas, removal of sand in pits and shakers, and maximum drilling speed.

A third potentially important use for weathered coal may be as a "collector" for uranium in water solution. Recent work in Oklahoma indicates that water flooding in oil fields associated with uranium-bearing beds apparently will dissolve and bring to the surface solutions from which uranium can be precipitated by passing through beds of partially oxidized coal. It is reasonable to expect that if this technique proves successful, it will be applied to San Juan Basin areas, and the immediate presence of extensive deposits of weathered coal should facilitate its economic development.

Baked shale (D)

In a number of places on the Navajo Reservation the outcropping coal beds have in the past caught fire and for considerable distance have burned along their outcrop and to some extent underground, producing large quantities of coal ash, slag, clinker, and baked shale. In an area where little other hard material for road surfacing occurs, this can be a satisfactory low-cost substitute, available over a large area and at the surface for inexpensive quarrying.

Stone, igneous (E)

Crushed stone for use in road building, as chips for cover-stone for bitumen surfacing and as a concreteaggregate, accounts for tonnages in the United States second only to mineral fuels. Large blocks and fragments are used for rip-rap, in the construction of bridge abutments, and for flood protection along stream-channels. On the Navajo Reservation in New Mexico igneous rock from Outlet Neck just south of Red Lake (97-W-L-6) has been crushed for use in dam construction at Red Lake; and igneous gravel from the terrace north of Shiprock (2-D-15) is crushed for concrete aggregate for cement blocks. These quarries represent two types of material which are widespread in the northern part of the Reservation. The cobbles in the gravel (G) of the pediments along Highway 666 are less resistant and stable than the igneous gravel along the San Juan River east and west of Shiprock. The areas of igneous rock (E) comprise both resistant and less resistant material, and any investigation of these areas for crushed stone would require drilling and exploration to separate good and waste material. The igneous material is also hydrophobic (water resistant), another favorable factor, since hydrophobic material is less affected by freezing and has little included clay or other material which on wetting will swell and split the rock.

Stone, sandstone (F)

Sandstone is used for dimension stone (cut-stone, rough building stone, and flagstone) and for rip-rap for abutments and for flood protection along stream channels.

Sandstone is one of the most abundant rock materials on the Reservation, but only locally does it show characteristics which make it of potential commercial value. Tp date ,its use has been chiefly as a building stone, and it has been used for the construction of houses and schools at many of the communities, and for building hogans in a few localities where especial permanence was desired or where other materials were less available.

Because of its abundance, sandstone has been noted on the map only in a few places where particularly attractive colors are apparent (east of Fort Defiance) or where it is easily available in large amounts (13 miles south of the town of Shiprock).

Sand and gravel (G)

Sand and gravel deposits on the Navajo Reservation in New Mexico occur in two areas, where they differ in origin and physical characteristics.

The gravels south of Newcomb lie on gently east-sloping mesas (pediments), are relatively thin although fairly widespread, and are composed predominantly of pebbles, cobbles, and boulders of Chuska sandstone, a rock which is usually fairly hard and resistant because of siliceous cement. When crushed, this rock breaks down into angular chips, but the chips do not have the same resistance to wear and weather as igneous chips, since they are more or less porous.

The gravels in the bed of the San Juan River and on the high terraces which extend a mile or so to the south and north are composed predominantly of igneous and metamorphic rocks with notable hardness and toughness. They crush into sharp angular chips which are ideal for road surfacing and concrete aggregate, and are hydrophobic and resistant to chemical or mechanical breakdown. The gravels which occupy the present bars, flood plains, and bottom of the river have not been mapped. They are, however, outlined by the channel line, and by the area between this line and the line of terraces which marks the lowest of the upper terrace deposits. The river deposits may be expected to carry a higher sand content than the terrace gravels.

Depths of gravel deposits should be determined by churn drilling or bulldozer excavation, and samples as representative as possible of the entire deposit should be taken and subjected to tests to determine where they fall in the specifications of the American Society for Testing Materials.

Sand (H)

Sand is used for a multitude of particular purposes other than in concrete and in road building or construction (plaster) aggregate. Among these are foundry sand, glass sand, filter sand, abrasive sand, and furnace sand. These are mostly low-cost products, depending for value upon nearness to market and low production cost. The absence of a local steel or metalworking industry, for example, means that no market exists for sand in some of the categories listed above.

Besides sand which may be screened from the gravel deposits on the Reservation for various construction purposes, there are numerous areas of blow-sand or sand dunes, particularly along the lee (northeast) side of the main drainage channels such as the Chaco River, and on the lee side of the higher ridges.

It was hoped on the initiation of this project that sand might be found that would permit a small Indian glass industry to produce articles similar to the green glass objects now imported from Mexico. Such low-quality glass requires sand with certain specifications (A.I.M.E., 1949, p. 973) which are listed in the first column below. Analyses of raw sand from three widely separated localities and origins on the Reservation are given in the other three columns:

		Specified	73-N-18	75-M-6	1-D-6
Percent SiO_2	over	95			
Al_2O_3	less than	4	0.8		
Fe_2O_3	less than	0.3	0.88	0.709	0.709
CaO and MgO	less than	0.5			

The high iron content is critical, since it gives the sand a dark yellowish green cast. The crude sand obviously must be beneficiated, so the samples noted above were run through a small magnetic separator with the following results:

	73-N-18	75-M-6	1-D-6
Fe_2O_3	0.355	0.355	0.280

Glass beads made from these separations had a pleasant pale-green color, lighter than most of the Mexican glass received in this country.

It is believe that with some instruction colored "tourist" glass could be made from any of the local sands.

Gypsum (J)

Gypsum is used in the building industry for plaster and acoustic tile, and for agricultural purposes as a controlof soil conditions. It is relatively abundant, however, and commands a price of less than $3 per ton for crude gypsum. Small beds of gypsum up to 6 inches thick occur in rocks of the middle and upper Mesaverde group at several localities on the Reservation. Since there are large reserves of gypsum in the Todilto limestone on the east and south sides of the San Juan Basin, much closer to the chief New Mexico markets, it is not believed that the occurrences on the Reservation will ever be of value.

Limestone (L)

Limestone is used as crushed rock for road surfacing, and as ground rock for agricultural use as a soil sweetener. Limestone is burned or calcined to form quicklime, which is widely used chemically as a base, causticizer, and neutralizer (Bowles, 1952); and as a component of mortar and plaster. Limestone is also used extensively in paper making, in textile and paint making, and in water-treatment plants. It can also be used as rip-rap and flagstone.

The Todilto limestone is a bed from 7 to 14 feet thick, which crops out intermittently along the Arizona line from a point in Todilto Park (north of Window Rock) to Beautiful Mountain. Since it is thin, the Todilto limestone will be economically available only in places where the dip of the bed is low and where there is little overburden. West of Sanostee and south of Beautiful Mountain (60-MN-5 to 9) a series of smooth-topped east-sloping mesas are capped by Todilto limestone without appreciable cover. The total area underlain by limestone exceeds two square miles, the limestone averages very close to 7 feet in thickness. Incomplete analyses (W. H. Herdsman, Glasgow, analyst) of channel samples of the entire 7 feet, taken at three places from one-half to one mile apart, gave the following results:

	(1)	(2)	(3)	Average
SiO_2	13.04	12.15	11.63	12.27
Al_2O_3	1.08	.59	.72	.79
CaO	45.84	47.06	47.00	46.63
MgO	.72	.68	.83	.74
K_2O	.58	.56	.32	.48
Na_2O	.12	.14	.15	.14
CO_2 (calculated)	36.03	36.97	36.90	36.63
Total	97.41	98.15	97.35	
$CaCO_3$ (calculated)	81.87	84.03	83.90	83.60
$CaCO_3$ (silica free)	97.03	97.71	97.87	97.53

It should be noted that the silica impurity consists of thin sandy beds within the lower part only of the seven feet of limestone; if the upper six feet only were mined, the silica-content would be materially reduced and the lime-content improved, as suggested in the last line of calculated analyses. The low magnesia-content is also of importance in several chemical uses.

Reserves of limestone with only a few feet of soil cover amount to over 36 million tons; stripping of overlying sandstones from 10 to 30 feet thick would give an additional 15 to 20 million tons. The deposit lies 42 miles from Shiprock. It is reached from Highway 666 over a road leaving the paved highway 25 miles south of Shiprock, and running west 17 miles over gentle gradients. Half of this road (as far west as Sanostee School) is graded and graveled, the other half would require building and improvement. With coal, gas, and water also available near Shiprock, the potentialities for a chemical industry in the area should be seriously considered.

Manganese (M)

The high price of manganese during the last few years has led to considerable interest in this metal, which is essential to the metallurgical and chemical industries. It is used in all steels, especially to produce tough and work-hardenable steels. It is also necessary for batteries and a multitude of minor uses.

Small deposits on the Arizona line 6 miles northwest of Crystal (83-L-10) were investigated late in 1953 but were not found to be of economic importance. Other occurrences of similar nature appear at the lower contact of the Chuska sandstone where it overlies older rock, on the west side of Chuska Mountain (73-A-13; 97-E-1 and 2; and 97-G-7). It is not expected that commercial deposits will be found in this area.

Pozzuolanic material (P)

In recent years it has been found that mixtures of pozzuolanic material with portland cement produces a more resistant and impervious concrete than one made without this mixture. Volcanic ash and pumicite which might be used for pozzuolanic portland cement occur in several localities in the Chuska Mountains (73-C-13; 73-H-13; 49-A-12) in beds which may be thick enough to mine economically if a market should ever be developed. Transportation difficulties and low prices will probably prevent such development.

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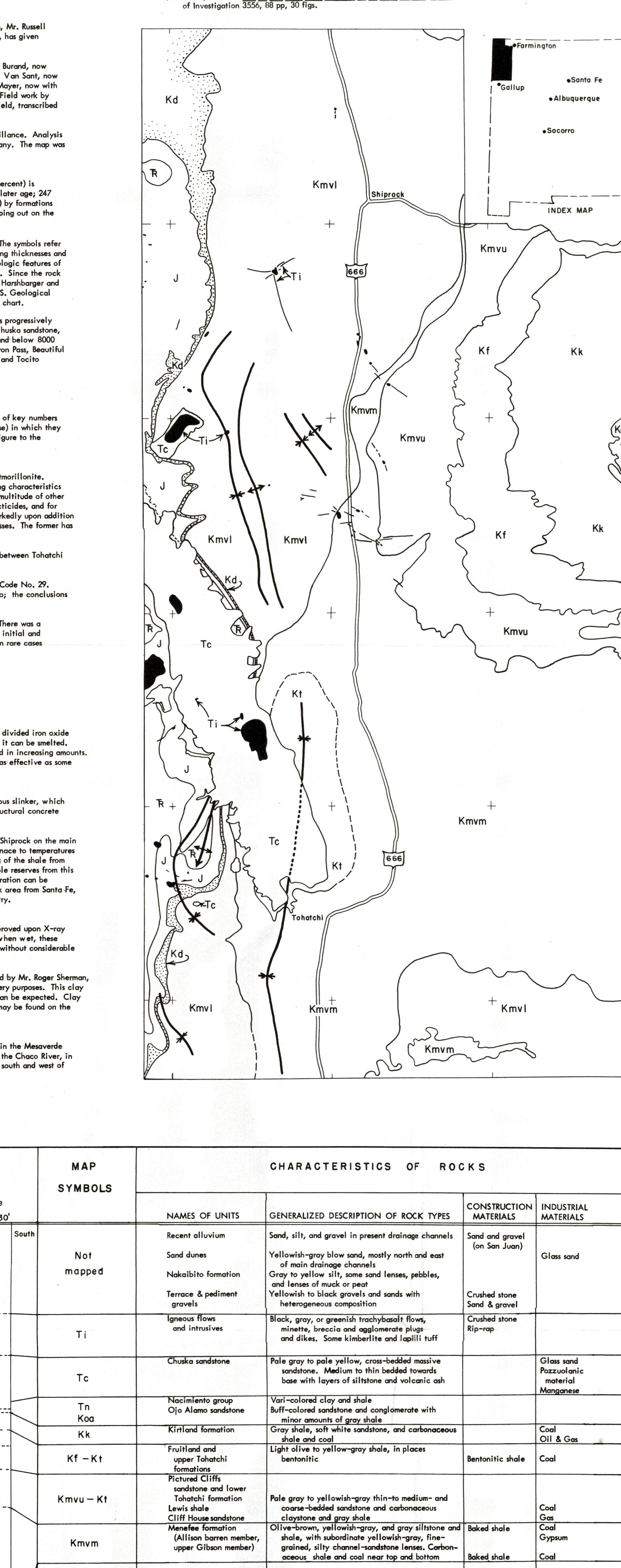
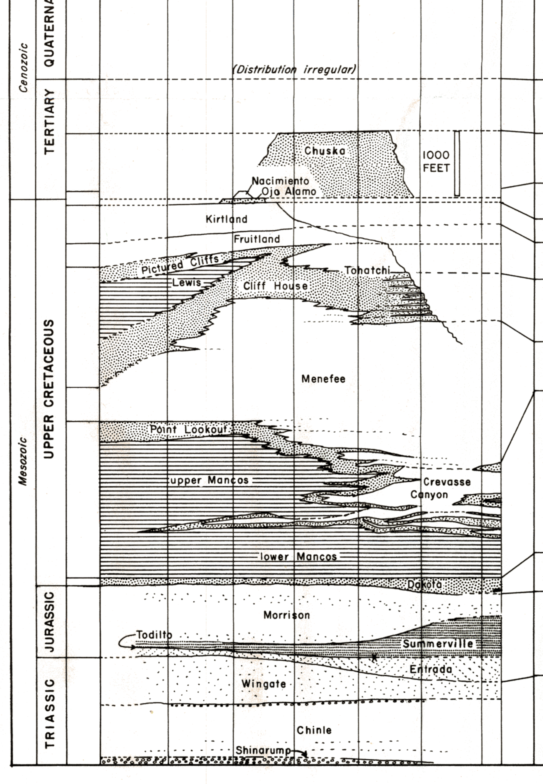


COMPOSITE STRATIGRAPHIC SECTION

North to South



CHARACTERISTICS OF ROCKS

MAP SYMBOLS	NAMES OF UNITS	GENERALIZED DESCRIPTION OF ROCK TYPES	CONSTRUCTION MATERIALS	INDUSTRIAL MATERIALS
Not mapped	Recent alluvium	Sand, silt, and gravel in present drainage channels	Sand and gravel (on San Juan)	
	Sand dunes	Yellowish-gray blow sand, mostly north and east of main drainage channels		Glass sand
	Nakaibito formation	Gray to yellow silt, some sand lenses, pebbles, and lenses of muck or peat		
	Terrace & pediment gravels	Yellowish to black gravels and sands with heterogeneous composition	Crushed stone Sand & gravel	
Ti	Igneous flows and intrusives	Black, gray, or greenish trachybasalt flows, minette, breccia and agglomerate plugs and dikes. Some kimberlite and lapilli tuff	Crushed stone Rip-rap	
Tc	Chuska sandstone	Pale gray to pale yellow, cross-bedded massive sandstone. Medium to thin bedded towards base with layers of siltstone and volcanic ash		Glass sand Pozzuolanic material Manganese
Tn Koa	Nacimiento group Ojo Alamo sandstone	Vari-colored clay and shale Buff-colored sandstone and conglomerate with minor amounts of gray shale		
Kk	Kirtland formation	Gray shale, soft white sandstone, and carbonaceous shale and coal		Coal Oil & Gas
Kf – Kt	Fruitland and upper Tohatchi formations	Light olive to yellow-gray shale, in places bentonitic	Bentonitic shale	Coal
Kmvu – Kt	Pictured Cliffs sandstone and lower Tohatchi formation Lewis shale Cliff House sandstone	Pale gray to yellowish-gray thin-to medium- and coarse-bedded sandstone and carbonaceous claystone and gray shale		Coal Gas
Kmvm	Menefee formation (Allison barren member, upper Gibson member)	Olive-brown, yellowish-gray, and gray siltstone and shale, with subordinate yellowish-gray, fine-grained, silty channel-sandstone lenses. Carbonaceous shale and coal near top and bottom	Baked shale Baked shale	Coal Gypsum Coal
Kmvl	Point Lookout sandstone (Hosta sandstone, Satan tongue) Upper Mancos shale and Crevasse Canyon formation (lower Gibson, Dalton, Dilco) Gallup sandstone (Tocito sandstone) Lower Mancos shale	Yellowish-gray to reddish-orange, massive, cross-laminated sandstone Gray, thinly-laminated, silty shale siltstone, silty sandstone, carbonaceous shale, and coal, with massive, pale yellowish-gray sandstone (Dalton) near base Grayish-yellow, massive, poorly sorted sandstone, some siltstone, shale, and conglomerate Gray, thinly-laminated, silty shale, some thin sandstone lenses	Baked shale Baked shale Flagstone	Oil and gas Coal Oil Bentonitic shale
Kd	Dakota sandstone	Gray to yellow, coarse-to fine-grained sandstone, and silty shale. Carbonaceous shale and thin coals at top and bottom		
J	Morrison formation Summerville formation	Vari-colored coarse-grained sandstones and shales Alternating gray and pink banded, medium-grained silty sandstone		Uranium
	Todilto limestone	Gray, thick-and thin-bedded limestone; absent south of Todilto Park(x)	Limestone	Uranium Limestone
	Entrada sandstone	Reddish, medium-to fine-grained, massive, cross-laminated sandstone		
Ꞧ	Wingate sandstone	Pink, medium to fine-grained, thin-to thick-bedded, silty sandstone		
	Chinle formation	Varicolored shale, with lenses of siltstone and sandstone. Limestone-pellet conglomerate lenses near top	Flagstone Dimension stone	Uranium Bentonitic shale
	Shinarump conglomerate	Yellow, brown, or gray conglomerate in lenses, locally ferruginous or silicified	Gravel	Uranium