Geology and Ground Water of the Red Lake Area Navajo Indian Reservation Arizona and New Mexico

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1576-B

Prepared in cooperation with the Navajo Tribe

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By J. P. AKERS, N. E. McCLYMONDS *and* J. W. HARSHBARGER

WATER SUPPLY OF INDIAN RESERVATIONS

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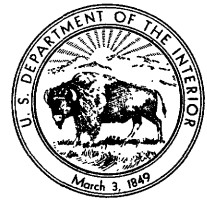

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GEOLOGY AND GROUND WATER OF THE RED LAKE AREA, NAVAJO INDIAN RESERVATION, ARIZONA AND NEW MEXICO

By J. P. Akers, N. E. McClymonds, and J. W. Harshbarger

ABSTRACT

The Red Lake area in the Navajo Indian Reservation, Arizona and New Mexico, was studied by the U.S. Geological Survey to determine if 1 mgd (million gallons per day) of water could be obtained for the requirements of a proposed sawmill. Geologic mapping and stratigraphic studies indicated three favorable areas where ground water may be developed. Test holes were drilled under contract in the areas, and pumping tests indicate that 500,000 gpd (gallons per day) is available from alluvium along Tohdildonih Wash near Frog Rock, 100,000 gpd is available from the Shinarump member of the Chinle formation and the De Chelly sandstone near Red Lake, and 800,000 gpd is available from alluvium and cinder beds in lapilli tuff in Buell Park, an eroded diatreme.

The diatreme at Buell Park is about 2½ miles in diameter. It was formed by several explosions in which lapilli tuff and cinders were erupted. These materials, together with later basaltic intrusive and extrusive rock, now fill the diatreme. The tuff and cinders are water bearing, and they receive recharge from rainwater and snowmelt moving through overlying alluvium and from storage in the De Chelly sandstone which encloses the east half of the diatreme.

The quality of water from all areas is suitable for domestic use. However, special treatment may be necessary to make the water suitable for pulp processing.

INTRODUCTION

Studies of the timber resources indicate that the forests on the Navajo Indian Reservation are capable of producing an annual timber yield several times the present production. In order to harvest the maximum potential of the forests, the Tribal Council in 1958 initiated plans for constructing a timber-processing plant in the Red Lake area about 12 miles north of Fort Defiance, Ariz. It was estimated by industrial consultants that the new plant and adjoining town would

require about 1 mgd. Officials of the Tribal Council and Bureau of Indian Affairs requested the U.S. Geological Survey to conduct a study of the area to determine if the required water supply could be developed.

The study was begun in March 1958. The Red Lake area lies on a synclinal valley between the Defiance Plateau on the west and the Chuska Mountains on the east. A geologic map (pl. 1) was prepared, special attention being given to the structural features as related to ground-water occurrence. Several sites were selected for test drilling in alluvium southeast of Red Lake and in volcanic material in Buell Park. One site was selected for a deep test in consolidated sedimentary rocks on the southwestern bank of Red Lake (pl. 1).

PREVIOUS INVESTIGATIONS

Previous work was done in the Red Lake area in 1950 through 1955 by the U.S. Geological Survey in the course of a regional study of the ground-water resources of the Navajo and Hopi Indian Reservations. The geologic map (pl. 1), with minor revisions, was compiled from maps prepared during this regional study. Two papers resulting from the study (Harshbarger and Repenning, 1954; Harshbarger, Repenning, and Irwin, 1957) are pertinent to the Red Lake area.

Other papers on the general area include reports by Whitcomb and Halpenny (1950), and Allen and Balk (1954). The occurrence of ground water in diatremes was first described in the Hopi Buttes area of Arizona by Callahan, Kam, and Akers (1959).

TOPOGRAPHY AND DRAINAGE

The major topographic features in the Red Lake area are the Defiance Plateau, including Buell Park, to the west; Black Creek valley in the central part; and Zilditloi Mountain to the east. The Defiance Plateau is a timbered high tableland which extends 90 miles along the eastern border of northern Arizona. Buell Park is 2 miles southwest of Red Lake near the crest of the eastern slope of the Defiance Plateau. It is a circular depression of volcanic origin, about 2½ miles in diameter; the rim ranges from 7,400 to 7,800 feet in altitude and the floor is about 7,200 feet above sea level. Black Creek valley, in which Red Lake is impounded, lies at an altitude of 7,070 feet, and is 1 to 2 miles wide. A hogback east of the valley is formed by resistant limestone ledges of the Owl Rock member of the Chinle formation, and farther east are sheer red cliffs of the Entrada sandstone and the Summerville formation. Zilditloi Mountain is formed of Jurassic and Cretaceous sediments capped by basaltic lava flows.

The Red Lake area is drained by Black Creek, an intermittent stream flowing southward. Its major tributaries are Buell Wash and Tohdildonih Wash. Buell Wash is mostly intermittent through Buell Park, but is perennial for a short distance downstream from a spring near the drainage outlet of the park. Tohdildonih Wash, a perennial stream, originates in the Chuska Mountains east of the area and water from this wash is diverted by a dam and canal into Red Lake.

Underflow from Tohdildonih Wash also supplements the ground water in this vicinity by supplying water to what is probably its former channel east of the limestone hogback south of the Tohdildonih Wash Dam.

GEOLOGY

SEDIMENTARY ROCKS AND THEIR WATER-BEARING PROPERTIES

The consolidated sedimentary rocks in the Red Lake area range from Permian to Cretaceous in age. They consist of a thick sequence of alternating shale and sandstone containing minor amounts of conglomerate and limestone. Deposits of Quaternary alluvium along drainage channels overlie the older bedrock. In general, the older bedrock units are exposed to the west and younger to the east.

PERMIAN ROCKS

SUPAI FORMATION

The Supai formation crops out along the western periphery of Buell Park and is present beneath younger rocks in most of the area to the east. Its thickness is not uniform because it was deposited on an erosion surface of considerable relief. However, it probably attains a maximum thickness of about 1,000 feet in this area. The formation consists of reddish-brown, thin to thick, flat-bedded, fine- to medium-grained sandstone interbedded with dark-red shale. A few thin limestone beds and pebble-conglomerate lenses are present at several horizons. The upper 250 feet is mostly sandstone but includes minor shale beds.

Although in most areas the Supai formation is not considered to be an important aquifer, in the Defiance Plateau several wells yield from 10 to 25 gpm (gallons per minute) of water of excellent quality from the upper sandstone beds. Several springs issue from the Supai formation just west of Buell Park. The largest of these yields about 50 gpm.

DE CHELLY SANDSTONE

The De Chelly sandstone crops out along the eastern periphery of Buell Park and is present at depth in the area to the east. It conformably overlies the Supai formation in this area, and consists of 350 to 400 feet of light-red to grayish-yellow, fine- to medium-grained massive sandstone exhibiting on its weathered surfaces large-scale tangential crossbedding. The ripple marks displayed on parting planes and crossbeds are characteristic of windblown deposits and the De Chelly is considered to be of eolian origin.

The De Chelly sandstone is water bearing, but it has a low permeability and unless fractured the yield to wells is low.

TRIASSIC ROCKS

CHINLE FORMATION

Unconformably overlying the De Chelly sandstone is the Chinle formation which crops out along the sides of Black Creek valley. It comprises four members. The Shinarump member at the base consists of about 100 feet of medium- to coarse-grained sandstone containing quartz, jasper, and quartzite pebbles. Thin lenticular beds of mudstone are interbedded with the sandstone. Most of the sandstone beds display low- to high-angle medium- to large-scale trough crossbedding. The Shinarump member grades upward into and intertongues laterally with the lower red member which consists of about 200 feet of interstratified mudstone, sandstone, and conglomerate. The mudstone units are dusky red with subordinate hues of blue and gray, and make up most of the member. The sandstone units are composed of very fine grained to medium-grained angular to well-rounded quartz grains bound in calcareous cement. They commonly exhibit low-angle crossbedding of the planar and trough types. The conglomerate units are composed predominantly of limestone pebbles but include subordinate amounts of petrified wood, flattened mud pellets, and bone scrap in a matrix of calcareous silt and sand. The lower red member grades upward into the Petrified Forest member.

In the Red Lake area the Petrified Forest member is divided into an upper and lower part by the Sonsela sandstone bed. Beneath the Sonsela, the lower part of the Petrified Forest member is composed of about 200 feet of reddish-purple, grayish-blue, and grayish-red mudstone and minor thin crossbedded lenses of sandstone and siltstone. The Sonsela sandstone bed consists of gray, medium- to coarse-grained sandstone containing quartz and limestone pebbles as much as an inch in diameter. It is about 100 feet thick in this area. The

upper part of the Petrified Forest member is 500 feet thick and is lithologically similar to the lower part, but contains many red, sandy siltstone beds.

The Owl Rock member grades downward into the Petrified Forest member. It consists of about 250 feet of mottled-pink and pale-blue cherty limestone interbedded with pink calcareous siltstone. Beds of the siltstone units are irregular and lenticular. The limestone units are 1 to 5 feet thick and in some areas have been traced for 20 miles.

The Shinarump member and the Sonsela sandstone bed are aquifers. In some areas the sandstone beds in the lower red member yield water, but the yield is small because of low permeability.

WINGATE SANDSTONE

Conformably overlying the Chinle formation is the Wingate sandstone. In most areas of the Navajo Country the Wingate sandstone comprises two units, the Lukachukai member and the underlying Rock Point member. In this area only the Rock Point member is present. It consists of about 250 feet of flat-lying, thin-bedded, orange-red sandstone and siltstone which weathers into flaggy outcrops. Ripple marks, clay slicks, worm borings and trials, and low-angle trough-type crossbedding on a small to medium scale suggest that the Rock Point member of the Wingate sandstone is of fluvial origin. It is not water bearing.

JURASSIC ROCKS

Jurassic rocks crop out in the cliffs at the east side of Black Creek valley and in the flanks of Zilditloi Mountain. In the Red Lake area none of the Jurassic rocks yield significant amounts of water and are not considered to have a potential for ground-water development.

ENTRADA SANDSTONE

In the Navajo Country the Entrada sandstone is divided into three members—upper and lower clean sandy members separated by a silty member. Only the silty member and the upper sandy member are present in the Red Lake area. The silty member consists of about 60 feet of reddish-brown, silty, very fine grained flat-bedded sandstone displaying small-scale crossbedding. The silt content, flat bedding, and crossbeds suggest subaqueous deposition.

The upper clean sandy member is about 180 feet thick in this area. It is composed of reddish-orange to grayish-pink fine- to medium-grained sandstone displaying planar or trough-type crossbedding

ranging from small to large scale. This member also displays persistent parallel bedding planes. These bedding planes suggest that at least part of the sandy member was deposited under subaqueous conditions. The rest of the unit is considered to be of eolian origin.

TODILTO LIMESTONE

In Todilto Park, the type locality 4 miles east of Red Lake, the Todilto limestone consists, from bottom to top, of 16 feet of yellowish-orange mudstone containing sandstone lenses, 4 feet of olive-gray thin-bedded limestone, and 5 feet of reddish-purple mudstone. In this area the upper and lower contacts of the Todilto are sharp and irregular.

SUMMERVILLE FORMATION

The Summerville formation in the northern part of the Navajo Country is divided into an upper sandy member and a lower silty member. In the Red Lake area only the upper sandy member is present. South of this area between Window Rock and Lupton, Ariz., the Summerville formation intertongues with the Cow Springs sandstone. In the Red Lake area the Summerville formation is about 250 feet thick; it consists of reddish-brown fine-grained, flat-bedded sandstone displaying crossbedding in individual beds in its upper part. The upper sandy member probably represents a deposit laid down near shore in a shallow sea.

COW SPRINGS SANDSTONE

Conformably overlying the Summerville formation is the Cow Springs sandstone, which consists of about 100 feet of greenish-gray to pink fine-grained, crossbedded sandstone. The crossbeds are large-scale, high-angle wedge, planar, and asymmetrical trough types which are interpreted as resulting from eolian deposition. Southward and westward from the Red Lake area the various members of the overlying Morrison formation intertongue and grade laterally into the Cow Springs sandstone.

MORRISON FORMATION

Two members of the Morrison formation are in the Red Lake area. These are the Recapture member and the overlying Westwater Canyon member. The Recapture is composed of lenticular, fine- to medium-grained sandstone interbedded with shaly mudstone units. The sandstone beds are reddish brown to grayish pink and contain large amounts of coarse-grained conglomeratic material. They commonly have low-angle trough and wedge-planar types of crossbedding sug-

gesting eolian deposition. The mudstone units are reddish brown and greenish gray. The Westwater Canyon member of the Morrison formation in this area consists of gray to greenish-yellow sandstone containing minor shale lenses. The sandstone beds are composed of fine- to coarse-grained quartz sand that is conglomeratic in some places. Pebbles in the conglomerate are composed of quartz, chert, and quartzite, and are as much as 3 inches in diameter. The sandstone units commonly exhibit crossbedding of the trough and planar types suggesting eolian or fluvial deposition. The total thickness of the Morrison formation in this area is about 500 feet.

CRETACEOUS ROCKS

The only Cretaceous rocks exposed in the area are those of the Dakota sandstone on the northeast flank of Zilditloi Mountain and on a mesa south of Zilditloi Mountain. The Dakota sandstone unconformably overlies the Morrison formation and consists of about 80 feet of gray, fine- to medium-grained sandstone containing a few conglomerate lenses near the bottom.

QUATERNARY ALLUVIUM

Quaternary alluvium, composed of gravel, sand, and silt, is present in moderately extensive deposits along the drainage channels in the area. In some areas the alluvium contains pine cones, juniper berries and needles, and twigs buried at depths of as much as 60 feet. This plant material is virtually unaltered, suggesting that the alluvium is very recent in age. Southeast of Red Lake, the upper part of the alluvium is mostly fine to coarse sand containing considerable granule-sized material. The gravel is as much as half an inch in diameter and is composed of quartz, quartzite, petrified wood, basalt, and limestone. Along Tohdildonih Wash and nearby drainage channels the alluvial fill ranges from 60 to 95 feet in thickness and the gravel is confined mostly to the bottom 10 feet. In Buell Park the alluvium ranges from 20 to 50 feet in thickness. In all these areas the alluvium is water bearing.

IGNEOUS ROCKS AND THEIR WATER-BEARING PROPERTIES

Most workers consider the igneous rocks in the Red Lake area to be of Tertiary age and assign them to the Pliocene epoch. The igneous rocks in this area are all of volcanic origin and are of two types—basaltic flows, dikes, and necks and lapilli tuff. Only the lapilli tuff is important as a source of water.

Well-consolidated lapilli tuff forms the Green Knobs and, together with alluvium, forms the floor of Buell Park. The tuff is gray green and contains fragments of igneous rocks and angular and rounded pebbles of material derived from country rocks at depth. Most of the pebbles are composed of chert, quartzite, and slate; a few are composed of granite. The matrix is tuffaceous and contains abundant olivine and garnet crystals. At many levels the tuff contains interbedded cinders which greatly increase the permeability. The basaltic rocks occur as flows, dikes, and plugs; they have the general composition of minette or trachybasalt, and are associated with agglomerate, breccia, and tuff.

Buell Park, an eroded diatreme, has a complex history. During its development, several explosions occurred which spread olivine, garnet, and diopside minerals, common to Buell Park, over a radius of 9 miles. Lapilli tuff and cinders were erupted and lenses of this material presently dip 15° to 30° into the park. Later, basaltic dikes, flows, and necks were intruded and the area was eroded. The less resistant tuff was removed faster than the basaltic intrusive rock and the surrounding sedimentary rock now stands above the floor of the diatreme.

STRUCTURE

Two main structural features occur in the area, the Defiance monocline and the Zilditloi Mountain syncline (pl. 1).

The anticlinal bend of the Defiance monocline is well defined and the strata dip toward the east as much as 20°. To the east the Zilditloi Mountain syncline is relatively broad and flat. The strata forming the syncline dip as much as 16° near the Defiance monocline; the west limb dips more steeply, but near the synclinal axis dips are about 1° to 2°. The syncline plunges southward under Zilditloi Mountain.

GROUND WATER

The investigation of the Red Lake area indicates three areas from which ground-water supplies for the proposed sawmill can be obtained. These are on the south and west sides of Frog Rock from alluvium; on the southwest side of Red Lake from the Shinarump member of the Chinle formation and the De Chelly sandstone; and in Buell Park from alluvium and volcanic material.

FROG ROCK AREA

A minor stream originating on Zilditloi Mountain skirts the south side of the volcanic neck known as Frog Rock and loses its identity upon reaching the alluvial flats (pl. 1). This stream and its tributaries

are in part the source for water in the wells penetrating alluvium south and west of Frog Rock. The underflow of this stream is supplemented by Zilditloi Wash which heads on the south side of Zilditloi Mountain, turns northward on the alluvial flats, and loses its identity before reaching the area west of Frog Rock. Test drilling revealed that an old channel of Tohdildonih Wash followed a southward course southeast of the diversion dam and east of the limestone hogback (Owl Rock member of the Chinle formation). Underflow from this old channel also supplements the ground water west of Frog Rock. The alluvium in the channel contains gravel near the bottom at depths ranging from 60 to 85 feet and is saturated below 15 to 20 feet. The alluvium outside the channel is fine grained and yields insufficient quantities of water for large-scale development.

AREA SOUTHWEST OF RED LAKE

One deep test well, 18T–505, was drilled near the west shore of Red Lake just east of the Arizona-New Mexico State line; it penetrated 790 feet of the Chinle formation, 390 feet of the De Chelly sandstone, and 103 feet of the Supai formation. Water was tapped in the Sonsela sandstone bed and the Shinarump member of the Chinle formation and in the De Chelly sandstone.

BUELL PARK AREA

Two production wells were completed in crudely bedded lapilli tuff interbedded with cinders that underlies the alluvium at Buell Park. Both the volcanic material and the alluvium contain water; and because they are in contact with the De Chelly sandstone, which also contains water, they and the De Chelly sandstone are part of the same hydrologic system (pl. 1). This system, in effect, is similar to a gravel-packed well 2½ miles in diameter.

If the upper 100 feet of the Supai formation contains water as in nearby areas, the thickness of the enclosing water-bearing bedrock on the eastern periphery of the park is about 250 feet. The depths to which the tuff extends are not known. In well 18T–514 the tuff was present to a depth of 460 feet. However, most of the water came from cinder zones at depths of 120 to 130 feet and 220 to 230 feet.

Conditions for recharge in Buell Park are excellent. The area is in a cold-humid zone and receives an average of more than 11 inches of precipitation annually. The bed of the main wash in Buell Park is composed of coarse sand which absorbs and transmits water readily. Large areas of the Shinarump member of the Chinle formation and the De Chelly sandstone are exposed on the northeast. Rainwater and snowmelt moving into these formations are available for recharge into the tuff within the park (pl. 1).

WELL CONSTRUCTION AND TEST DATA

Four production wells, about 800 feet apart, were completed in the old buried channels near Frog Rock. The wells, 18T–524 through 18T–526, are 32 inches in diameter and have 17½-inch concrete casing; they are perforated in the lower 20 feet. Well 18T–527 has 16-inch steel casing that is perforated from 39 to 67 feet. These four wells are gravel packed with crushed rock ¼ to ⅜ inch in diameter. The alluvium penetrated by the wells ranges from 44 to 83 feet in thickness and contains granule- to small pebble-sized gravel in the lower 3 feet. The rest of the material consists of fine to coarse sand and a thin layer of silt at the top. One test well, 18T–508, was cased and used as an observation well during pumping tests.

Each production well was pumped at a rate of about 200 gpm during development for about 36 hours. Drawdown at the end of this time was about 50 feet. Well 18T–524 was pumped continuously for 96 hours at 200 gpm. The drawdown from the static level of 11.9 was 53.7 feet to the pumping level, 65.6 feet. Observation wells 18T–508, 18T–526, and 18T–527 were 280, 820, and 1,730 feet, respectively, from the pumped well and the drawdown in these observation wells was 3.15, 0.29, and 0.18 feet, respectively.

The computed coefficient of transmissibility obtained from the test is 22,000 gpd per foot, which indicates a moderately productive aquifer for this region. The computed storage coefficient is about 0.03 and indicates water-table conditions.

The Sonsela sandstone bed, penetrated from 220 to 250 feet in well 18T–505 near Red Lake, yielded 75 gpm with a drawdown of 185 feet from a static water level of 95 feet. This unit was cemented off, however, because it contains brackish water (table 1). The Shinarump member of the Chinle formation and the De Chelly sandstone act as a single aquifer in the Red Lake area. Water flowed at 4 gpm from these units. During a 72-hour pumping test the Shinarump-De Chelly in this well yielded 55 gpm with a drawdown of 540 feet.

Well 18T–514 in Buell Park yielded 174 gpm for 72 hours with a drawdown of 50 feet from a static water level of 20.7 feet. Well 18T–521 penetrated a cinder zone at a much shallower depth—between 50 and 70 feet. This well was drilled to a total depth of 115 feet. In a 72-hour pumping test it yielded 625 gpm with a drawdown of 28.5 feet from a static level of 31.5 feet.

The test data indicate that the required water supply of 1 mgd can be developed from either the Frog Rock or Buell Park areas. Recharge conditions are good in both areas. However, the amount of water in storage and the amount recharged each year cannot be determined from presently available information, and construction of

production wells in both areas would be insurance against excessive pumping drawdowns in either area. The test data further indicate that the volume and yield of the water-bearing material in Buell Park are considerably more than in the area near Frog Rock and southwest of Red Lake, and that Buell Park offers the best possibility for larger production of water.

QUALITY OF WATER

The observed chemical quality of the water from production wells from the Shinarump-De Chelly aquifer in the Red Lake area is satisfactory for general domestic use. However, special treatment may be necessary to make the water suitable for pulp production. Water in the Sonsela sandstone bed at well 18T–505 is not satisfactory for most uses. The samples analyzed are believed to represent the areas from which they were taken. Chemical analyses of water made during the investigation are shown in table 1.

TABLE 1.—*Chemical analyses of water from wells in the Red Lake area, Navajo Indian Reservation*

[Analyses by U.S. Geological Survey. Chemical constituents in parts per million]

	Well and aquifer			
	18T–505	18T–505	18T–511	18T–514
	Sonsela sandstone bed	Shinarump-De Chelly	Alluvium	Lapilli tuff and cinders
Temperature (°F)	52	----------	52	53
Silica	6. 4	12	8. 6	25
Iron	----------	----------	0. 14	--------
Total iron	----------	----------	6. 3	--------
Calcium	14	43	54	24
Magnesium	1. 7	16	9. 7	45
Sodium and potassium	767	34	64	90
Bicarbonate	317	247	348	347
Carbonate	20	0	0	0
Sulfate	551	31	4. 5	120
Chloride	590	9. 0	16	19
Fluoride	2. 7	0. 4	. 4	0. 3
Nitrate	4. 3	0	. 2	4. 3
Dissolved solids:				
Parts per million	2, 110	266	328	499
Tons per acre-foot	2. 87	. 36	. 45	. 68
Hardness as $CaCO_3$	42	174	174	245
Percent sodium	98	30	44	44
Sodium-adsorption ratio	51	1. 1	2. 1	2. 5
Specific conductance (micromhos at 25°C).	3, 450	458	557	791
pH	8. 6	----------	7. 8	8. 2

CONCLUSIONS

The yield from 7 wells, 4 southeast of Red Lake in alluvium, 2 in Buell Park in alluvium and volcanic rock, and 1 deep well in the Shinarump member of the Chinle formation and the De Chelly sandstone, has demonstrated that the required minimum of 1 mgd of water is available in the Red Lake area. As much as 400 gpm, or more than 550,000 gpd, can be pumped from the well field southeast of Red Lake. At least 600 gpm, or about 850,000 gpd, is available from Buell Park. Another 100 gpm, or about 100,000 gpd, can be obtained from well 18T–505; however, the lift would be nearly 400 feet. The combined yield of all these areas is 1,100 gpm, or more than 1,500,000 gpd.

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