STATE OF SOUTH DAKOTA
Nils Boe, Governor

SOUTH DAKOTA STATE GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

Special Report 41

# GROUND-WATER SUPPLY FOR THE CITY OF MISSION, SOUTH DAKOTA

by
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# INTRODUCTION

## Present Investigation

This report contains the results of an investigation by the South Dakota Geological Survey from June 13 to July 13, 1966, in and around the city of Mission, Todd County, South Dakota (fig. 1). The purpose of the investigation was to assist the city in locating a future municipal water supply. At the present time, the city does not have a central water supply as all the water currently is obtained from private wells.

A survey of the ground-water possibilities was conducted in the Mission area. Included in this survey was: (1) reviewing the geology of the Mission quadrangle as mapped by the South Dakota Geological Survey (Agnew, 1963), (2) mapping of approximately 15 square miles south of the Mission quadrangle, (3) drilling 48 auger test holes and 6 rotary test holes, (4) collecting 12 water samples for analysis, (5) making a topographic map of T. 38 N., R. 28 W., sections 21 and 28 (east of Highway 83), and (6) running 5 electric logs. The topographic map and electric logs are not included in this report but copies are available from the Geological Survey. As a result of the ground-water survey, an area for future ground-water development is recommended about 4 miles south of the city.

The cooperation of the residents of Mission, especially City Auditor A. E. Moser and Mayor Lowell Hoffine, is greatly appreciated. Special thanks are due Clyde Coats and Ed Charboneau, local well drillers, for making their well records available. The writer wishes to thank the State Chemical Laboratory for analyzing water samples.

## Location and Extent of Area

The Mission area as used in this report includes a region that measures 9 miles north-south and 9 miles east-west. The area is located in south-central South Dakota in Todd County and is in the Tertiary tablelands section of the Great Plains physiographic province (fig. 1). The city of Mission is located in the center of the Mission area. The altitude at Mission is approximately 2,585 feet and the population is 611 (1960 census).

## Climate

The climate is characterized by an average daily temperature of 49.1 degrees F., and an average annual precipitation of 19.09 inches based on records at the U. S. Weather Bureau Station in Winner, 43 miles east of Mission.

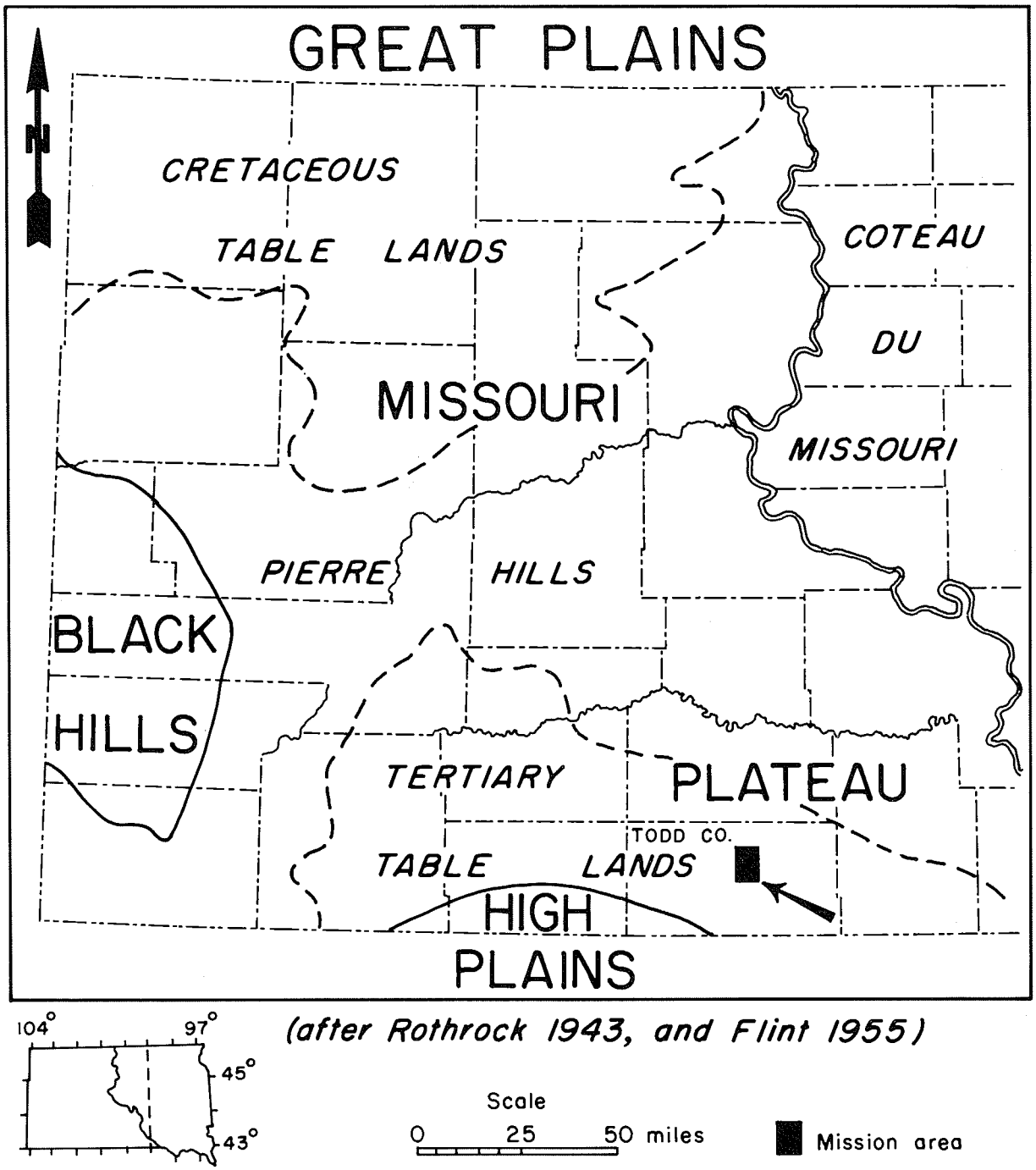



Figure 1. Map showing the major Physiographic Divisions of western South Dakota and location of the Mission area.

## Topography and Drainage

The topography of the northern part of the Mission area is characterized by a general northward slope from the east-west Mission divide that lies about 2 miles north of the town of Mission. Toward the southern part of the area the surface rises into butte and mesa topography. Antelope Creek bisects this part of the area and it joins the Keyapaha River to the east outside of the study area (fig. 2).

## Data Point Numbering System

Data-collection points (test holes and wells, fig. 3) are located in accordance with the United States Bureau of Land Management's system of land subdivision. The first numeral of a point designation indicates the township, the second the range, and the third the section in which the point is situated. Lowercase letters after the section number indicate location within the section; the first letter denotes the 160-acre tract, the second the 40-acre tract, the third the 10-acre tract, and the fourth the $2\frac{1}{2}$-acre tract. The letters a, b, c, and d are assigned in a counterclockwise direction, beginning in the northeast corner of each tract. The number of lowercase letters indicates the accuracy of the point location; if the point can be located within a $2\frac{1}{2}$-acre tract, four lowercase letters are shown in the point number. For example, data-collection point 38-29-15dbcd (test hole 12) is in the $SE\frac{1}{4}SW\frac{1}{4}NW\frac{1}{4}SE\frac{1}{4}$, section 15, T. 38 N., R. 29 W. The method of designation is shown in figure 4.

# GENERAL GEOLOGY

## Surficial Deposits

The surficial deposits of the Mission area include Pleistocene dune sand, and Recent alluvium along present drainages (fig. 2).

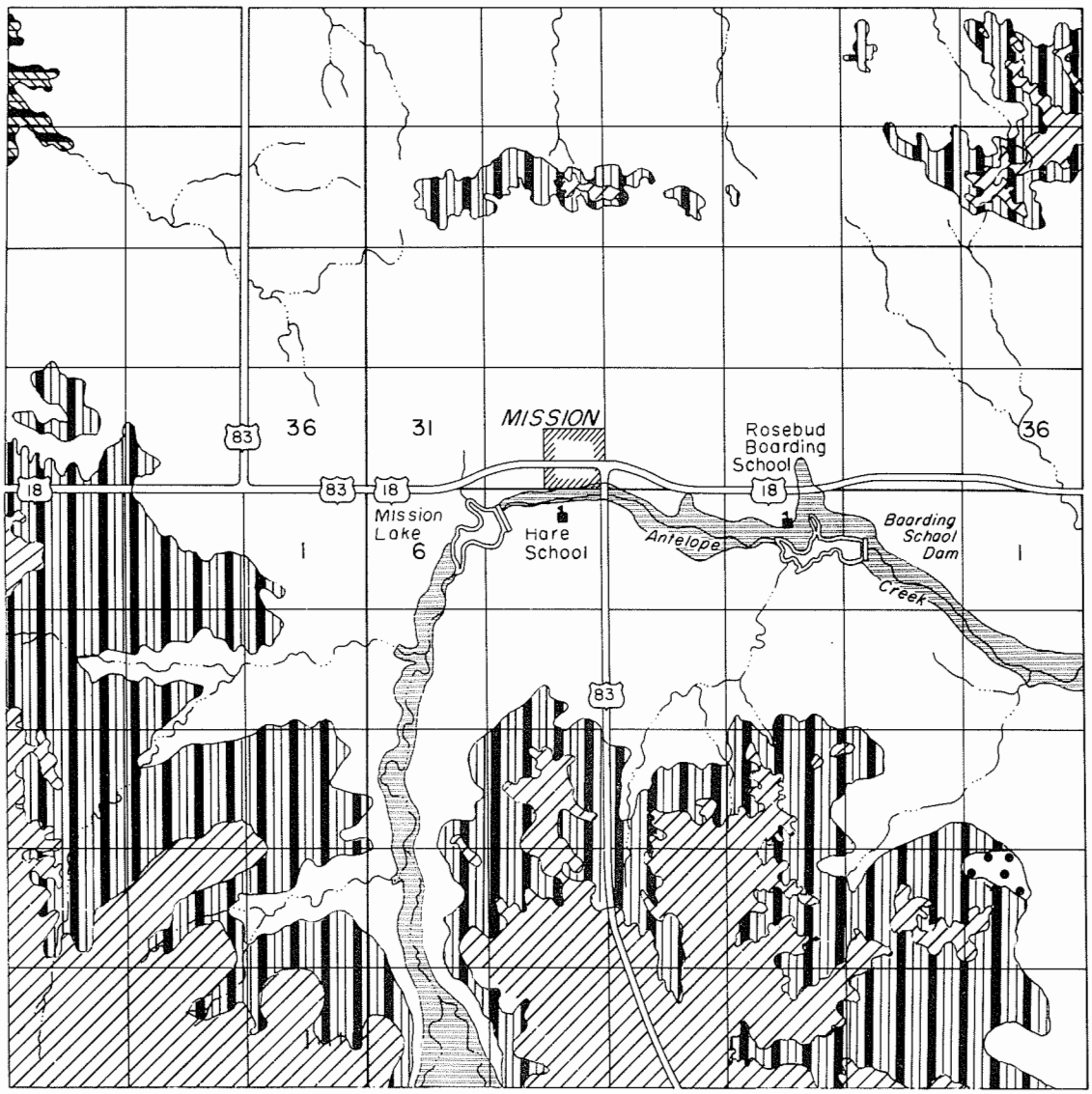
Dune sand is loose, very fine to medium grains of subrounded to rounded frosted quartz sand. The dune areas are developed on the basal part of the Valentine Formation (Agnew, 1963).

Alluvium consists of silt, sand, and gravel which has resulted from reworking of older bedrock and surficial deposits by streams. The maximum thickness of these deposits penetrated in test drilling was 26 feet (test hole 40).

## Exposed Bedrock

Stratified rocks of Tertiary age are found at the surface throughout the study area except where covered by dune sand or alluvium.

The correlation chart for the Tertiary deposits in the Mission area (table 1) shows the terminology as used in this report as compared with Agnew (1963). The Pliocene Ogallala Group is exposed in the uplands in




EXPLANATION

QUATERNARY
- PLEIST. RECENT: Alluvium
- PLEIST. RECENT: Dune Sand

TERTIARY
- PLIOCENE (OGALLALA GROUP): Ash Hollow Formation
- PLIOCENE (OGALLALA GROUP): Valentine Formation
- MIOCENE: Rosebud Formation
- OLIG.: White River Group

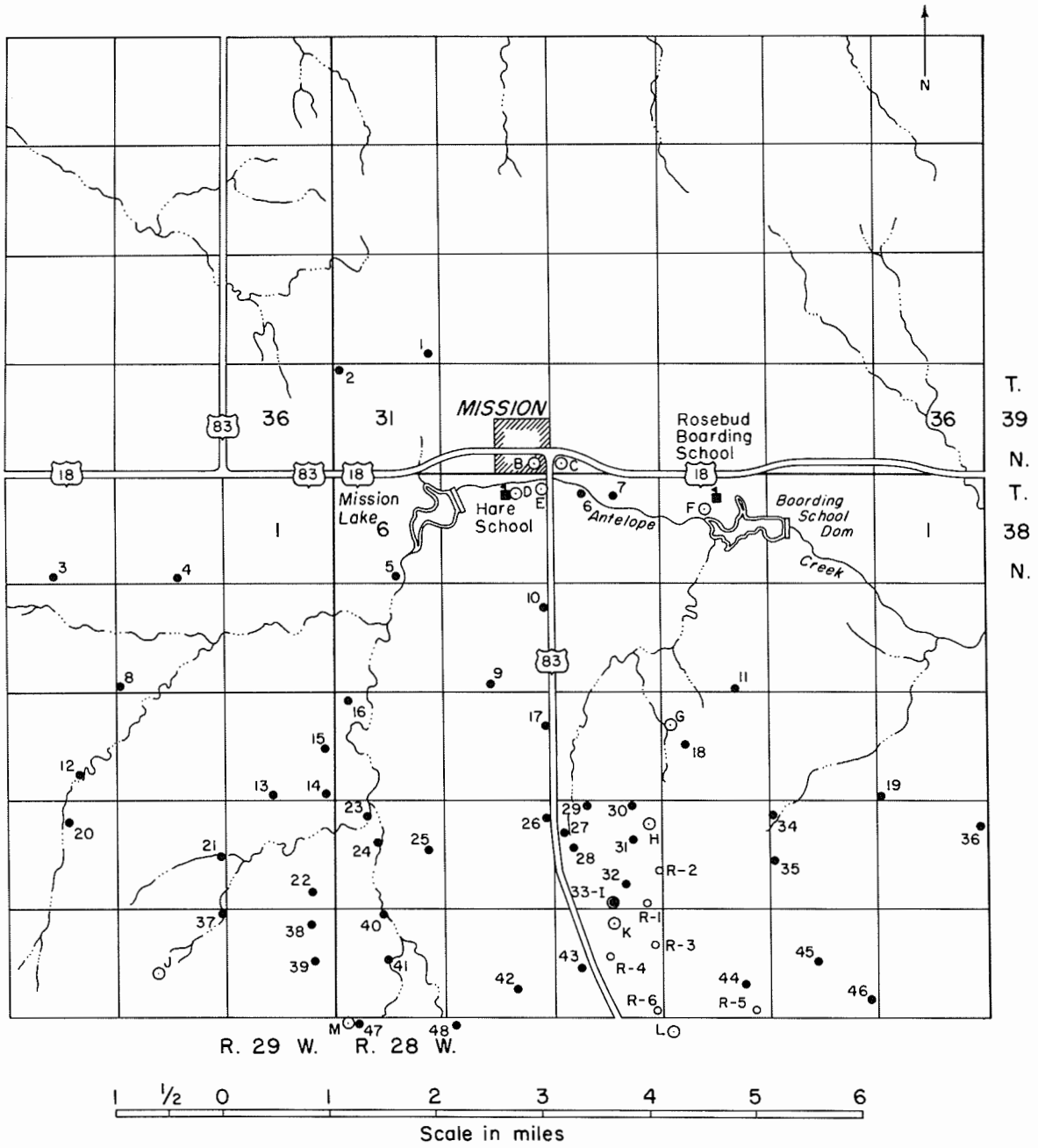
1 0 1 2 3
Scale in miles

drafted by D. W. Johnson

by
A. Barari,
1966

## Figure 2.
## Geologic Map of the Mission area.

(modified from A. F. Agnew 1956, 1963)




EXPLANATION

Water sample; letter is same as on Table 2; sample N is north of study area.

R-3 Rotary test hole

19 Auger test hole

Intermittent stream

by A. Barari, 1966

drafted by D. W. Johnson

**Figure 3. Data map of the Mission area.**

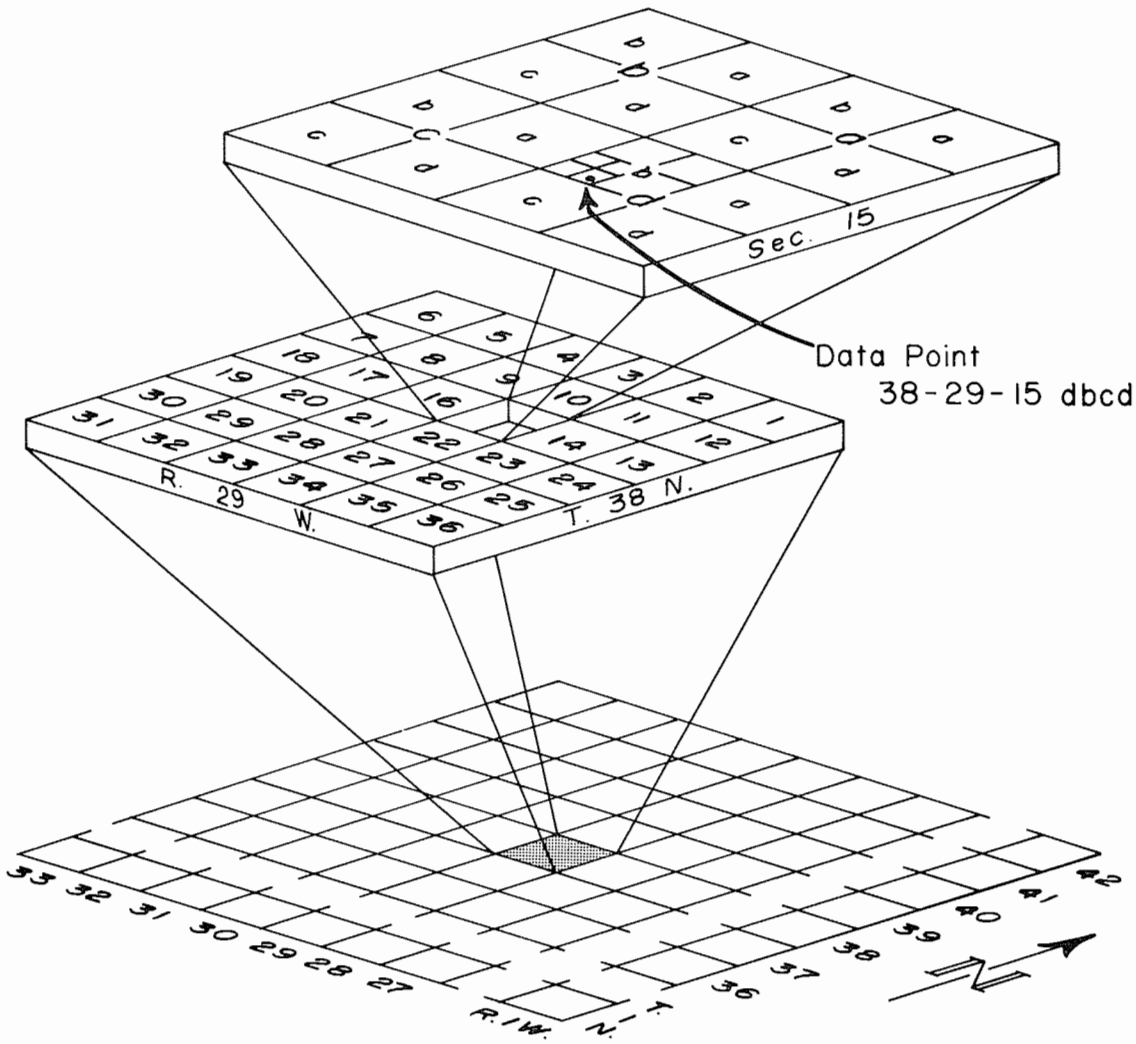



Figure 4. Data point numbering system.

Table 1.--Correlation chart of Tertiary deposits in the Mission area.

| Agnew, 1963 | | | | This Report |
|---|---|---|---|---|
| System | Series | Group | Formation | |
| Tertiary | Pliocene | Ogallala | Ash Hollow | Ash Hollow Formation |
| | | | Valentine | Valentine Formation |
| | Miocene | Arikaree | Undifferentiated / Mellette Facies | Rosebud Formation |
| | Oligocene | White River | Brule | White River Group |
| | | | Chadron | Undifferentiated |

the southern part of the area. Included in the Ogallala Group are the Ash Hollow (upper) and Valentine (lower) Formations.

The Ash Hollow Formation is light-gray to light-tan calcareous-cemented feldspar and quartz sandstone 10 to 22 feet thick. Ash Hollow rocks are found at the highest elevations and form low yet prominent bluffs.

The Valentine Formation is greenish-gray to tan feldspar and quartz sand, and contains ashy zones near the top. Outcrops show 30 to 65 feet of the formation. It also contains thin layers of greenish bentonitic clay in the lower part (Agnew, 1963). The Valentine is thin along the Mission divide, two miles north of town, but thicker in the southern part of the area. The maximum thickness of Ogallala rocks penetrated by the test drilling was 177 feet.

The Arikaree Group as mapped by Agnew on the Mission quadrangle (Agnew, 1963) has since been identified as the Rosebud Formation (J. C. Harksen, personal communication). On the present geologic map (fig. 2) the term Rosebud is used. The Miocene Rosebud Formation, which is the surface rock in the northern two-thirds of the Mission area, is mainly pink, very fine grained, poorly cemented sandstone that contains porous pink silicified claystone. It is 190 to 245 feet thick (Agnew, 1963).

The White River Group exposed in the northwest part of the Mission area has been divided into two formations, the Brule above and the Chadron below. Because of the thinness of the Chadron and its restricted outcrop area, the two formations have been combined on the map (fig. 2) as the White River Group.

The upper unit of the Brule Formation is pinkish to olive bentonitic clay and white to gray siltstone 70 to 80 feet thick that contains worm borings. The lower unit consists of 110 feet of banded pinkish to grayish laminated clayey siltstone and thin layers of hard calcareous light-gray to white siltstone.

The Chadron Formation at the base is greenish-yellow bentonitic clay and claystone poorly cemented with silica. The Chadron is 20 to 40 feet thick. The total thickness of the White River Group is 200 to 230 feet (Agnew, 1963).

## Subsurface Bedrock

The subsurface information is extrapolated to the Mission area from several wells including the Rosebud artesian well (39-27-10cd), which bottomed at a depth of 2,500 feet; the Bachman water well, 23 miles northeast of the city of Mission; and two oil tests drilled by the General Crude Oil Company in Tripp County, 23 to 28 miles east of the eastern border of the Mission area which went to the Precambrian basement rock at depths of 2,886 and 3,024 feet.

Stratified rocks of Cretaceous age lie beneath the Tertiary deposits and in descending order are: the Pierre Shale, Niobrara Chalk, Carlile Shale, Greenhorn Limestone, Graneros Shale, Dakota Formation, Skull Creek Shale, and the Inyan Kara Group.

The Pierre Shale consists of gray to dark-gray calcareous to noncalcareous shale that crops out 7 miles northwest of the city. It is 1,050 to 1,100 feet thick.

The Niobrara Chalk consists mostly of light- to medium-gray calcareous shale with white specks and is 200 to 300 feet thick.

The Greenhorn Limestone varies between a nearly white fragmental limestone and a medium-gray, very calcareous shale and is 50 to 60 feet thick.

The Graneros Shale consists of 130 to 150 feet of gray to black shale.

The Dakota Formation is approximately 400 feet thick in the Mission area and is composed of alternating sandstone and thin shale beds.

The Skull Creek Shale consists of approximately 125 feet of gray to dark-gray shale.

The Inyan Kara Group is composed of sandstones of the Fall River and Lakota Formations; however, in the Mission area these formations are not differentiated. The thickness of the Inyan Kara Group is estimated to be approximately 325 feet.

Below the Inyan Kara Group lie the Permian to Precambrian sediments. The Precambrian basement rocks in two nearby oil tests were a pink granite.

## GROUND WATER

### Concepts

Contrary to popular belief, ground water does not occur in "veins" that crisscross the land at random. Instead, it can be shown that water is found nearly everywhere beneath the surface but at varying depths. The top of the zone of saturation is known as the water table.

Nearly all ground water is derived from precipitation. Rain or melting snow either percolates directly downward to the water table and becomes ground water or drains off as surface water. Surface water either evaporates, escapes to the ocean by streams, or percolates downward to the ground-water table. The permeable rocks (including the soil) that lie above the zone of saturation are in the zone of aeration. Some of the pore spaces in this zone are also filled with water, but the water is either held in them by molecular attraction or is moving downward toward the zone of saturation by gravity. In the saturated zone it moves in a direction determined by the surrounding hydraulic head.

Recharge is the addition of water to an aquifer (formation having structures that permit appreciable water to move through it under ordinary conditions), and is accomplished in four main ways: (1) by downward percolation of precipitation from the ground surface, (2) by downward percolation from surface bodies of water, (3) by lateral underflow of water in transient storage, and (4) by artificial recharge, which occurs from excess irrigation, seepage from canals, and water purposely applied to augment ground-water supplies.

Discharge of ground water from an aquifer is accomplished in four main ways: (1) by evaporation and transpiration of plants, (2) by seepage upward or laterally to form springs or surface bodies of water, (3) by lateral movement of water in transient storage, and (4) by pumping from wells, which constitutes the major artificial discharge of ground water.

The porosity of a rock or soil is a measure of the contained pore spaces and it is expressed as the percentage of void space to the total volume of the rock. The porosity of a sedimentary deposit depends chiefly on: (1) the shape and arrangement of its constituent particles, (2) the degree of assortment of its particles, (3) the cementation and compaction to which it has been subjected since its deposition, (4) removal of mineral matter through solution by percolating waters, and (5) the fracturing of the rocks, resulting in joints and other openings. Thus, size of the material has little or no effect on porosity if all other factors are equal.

The permeability of a rock is its capacity for transmitting a fluid (water). Water will pass through a material with interconnected pores, but will not pass through material with unconnected pores, even if the latter material has a higher porosity. Thus, silt and clay may have high porosity but low permeability due to shape and arrangement and assortment of the particles. Unconsolidated sand and gravel usually have both high porosity and high permeability.

## Ground Water in the Surficial Deposits

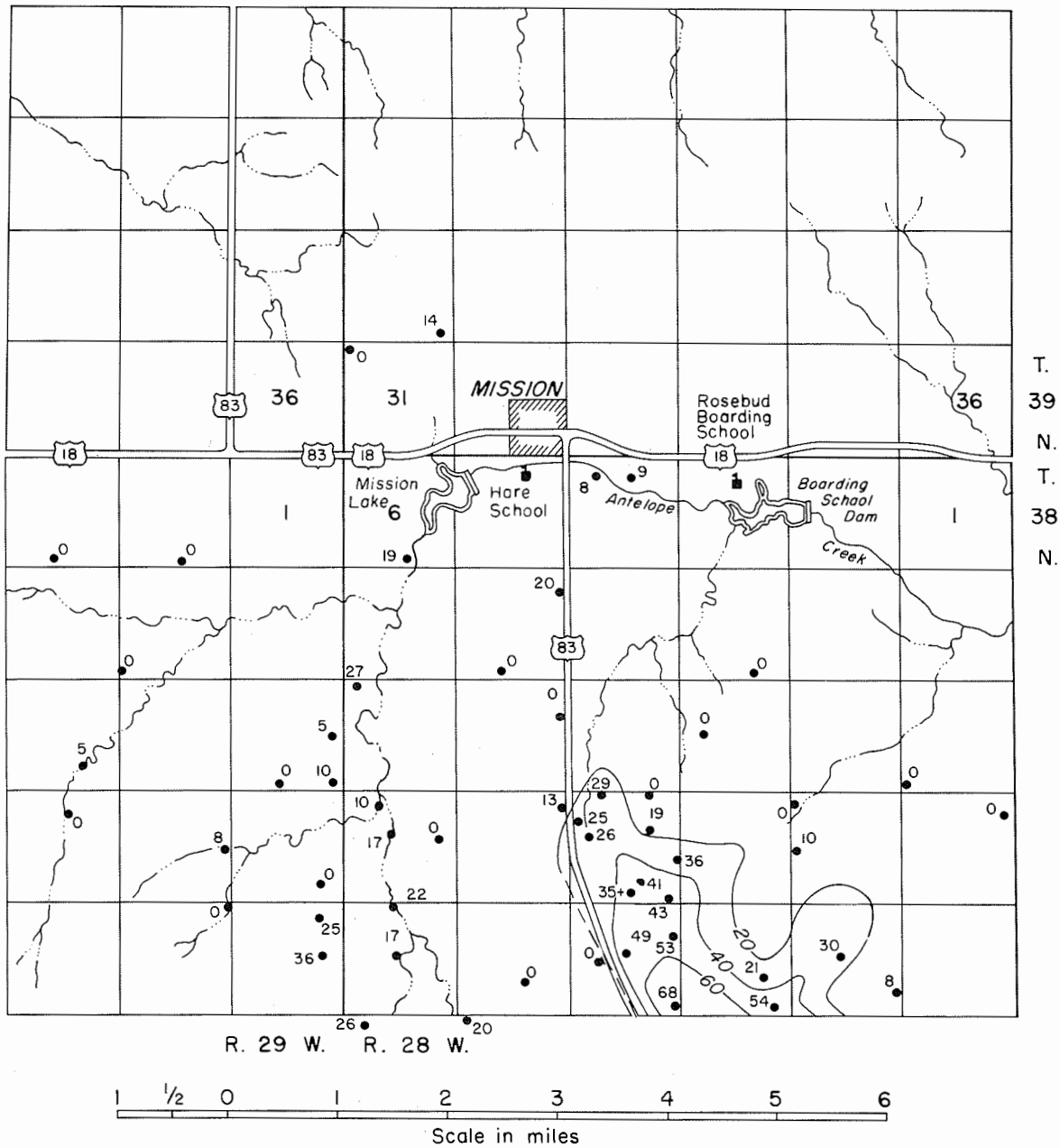
The surficial deposits in the area consist of Recent alluvium and the Pleistocene dune sand. Both of these deposits are thin and have a restricted areal extent. Thus, although locally small quantities of water are available from these deposits, they would not readily yield the required amount of water needed for a city supply.

## Ground Water in Exposed Bedrock

In the study area, the Ash Hollow Formation is usually above the water table and thus only locally will supply limited amounts of water.

The Valentine Formation comprises the main shallow aquifer in the study area south of Mission. The extent of the formation can be seen on figure 2. Although the formation is extensive, the sand unit which comprises the best aquifer varies locally in thickness (fig. 5). The greatest thickness of saturated sand encountered in the study area was 68 feet in test hole R-6 (appendix B); however, the sand thins to 20 feet within a mile of this location. The somewhat-linear pattern and rapid thinning and thickening of the sand unit (fig. 5) in the study area is strongly suggestive of a channel deposit.

The Rosebud Formation and the White River Group provide water for the private wells in the central and northern part of the area. Because these formations consist mostly of clay, poorly cemented siltstone and silty claystone, they probably would not readily yield large quantities of water needed for a city water supply.




1 ½ 0 1 2 3 4 5 6

Scale in miles

20 Lines showing equal thickness of saturated sand; contour interval = 20 feet.

68 Test hole showing thickness of saturated sand; a (+) after the number indicates that the sand was not completely penetrated; only the southeast part of the study area east of Highway 83 has been contoured.

by A. Barari, 1966

drafted by D. W. Johnson

N

Figure 5. Map showing the thickness of saturated sand in the Mission area.

## Ground Water in Subsurface Bedrock

The sandstones of the Dakota Formation are the uppermost subsurface bedrock units which could probably furnish a municipal water supply.

The top of the Dakota Formation is at a depth of about 2,000 feet in the Mission area and is under artesian pressure. Wells drilled have produced 30 to 50 gallons per minute (gpm) of highly mineralized water from this formation 12 miles northwest of Mission (Agnew, 1963).

Sandstones of the Inyan Kara Group might also yield similar quantities of highly mineralized sodium sulfate water. Water from this aquifer should rise in wells to about 1,800 feet above sea level.

Permian to Cambrian rocks may also provide enough water for a city supply. However, these formations are all likely to have highly mineralized water and may be quite warm. None of the artesian bedrock formations would flow in the Mission area.

## Quality of Ground Water

Ground water always contains minerals in various quantities. These minerals are derived: (1) from the atmosphere as water vapor condenses and falls, (2) from soil and underlying deposits as water moves downward to the water table, and (3) from deposits below the water table where the water is circulating. In general, the more minerals that a water contains, the poorer its quality.

Table 2 is a comparison of the quality of water from the Valentine Formation, Rosebud Formation, and Dakota Formation in the Mission area, with the Public Health standards for drinking water. It can be seen from this table that all the water samples taken from the shallow exposed bedrock aquifers are of very good quality with only sample K showing an excess of iron. The water from the Dakota Formation by comparison is highly mineralized and exceeds the Public Health standards in chloride, sulfate, and total hardness.

# CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, it is recommended that the city of Mission test for a municipal water supply from the Valentine Formation in sections 21, 27, and 28, T. 38 N., R. 28 W. The testing should be done in that area where the saturated sand is in excess of 40 feet (fig. 5). It would be preferable, if possible, to test near test hole R-6 where a maximum of 68 feet of saturated sand is present (figs. 3 and 5).

If a well in the area recommended is proposed, the city should hire a consulting engineer licensed in South Dakota. The engineer would plan and coordinate any additional testing done in this area. On the basis of the engineer's recommendations a commercial well drilling company should

Table 2.--Chemical analyses of water samples from the Mission area.

(for location see figure 3)

| Sample | Geologic Source | Parts Per Million | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Calcium | Magnesium | Chloride | Sulfate | Iron | pH | Hardness $CaCO_3$ | Total Solids |
| A | Valentine Formation and Rosebud Formation | -- | 50 | 250 | 500* | 0.3 | -- | --- | 1000* |
| B | | 22 | 7 | 32 | 14 | None | 7.8 | 84 | 382 |
| C | | 22 | 1 | Trace | None | None | 8.0 | 64 | 351 |
| D | | 33 | 2 | 2 | 28 | None | 7.8 | 88 | 360 |
| E | | 14 | None | Trace | 24 | None | 8.0 | 36 | 400 |
| F | | 61 | 5 | Trace | None | None | 7.9 | 172 | 454 |
| G | | 40 | 4 | None | None | None | 7.8 | 116 | 262 |
| H | | 63 | 2 | None | 74 | 0.28 | 7.6 | 163 | 254 |
| I | | 50 | 7 | 25 | None | Trace | 7.6 | 152 | 359 |
| J | | 53 | 10 | Trace | None | 0.06 | 7.6 | 170 | 286 |
| K | | 39 | 8 | None | 32 | 0.44 | 7.7 | 115 | 206 |
| L | | 53 | 6 | Trace | None | None | 8.1 | 158 | 268 |
| M | Spring in Valentine | 56 | 4 | Trace | None | Trace | 7.7 | 156 | 242 |
| N | Dakota | 25 | 17 | 590 | 255 | | | 850 | 1850 |

* Modified for South Dakota by the Department of Health (written communication, February 5, 1962)

Samples B, D, H, and K were analyzed by the State Chemical Laboratory. All other samples (except N) analyzed by the State Geological Survey. Sample N taken from Agnew, 1963.

Locations of Water Samples as Given on Table 2.

A. Drinking water standards, U. S. Public Health Service (1962)
B. Location: 39-28-32ddb, Checkerboard Cafe
C. Location: 39-28-33ccb, Antelope Motel
D. Location: 38-28-5abc, Rosebud Mission School Well #1
E. Location: 38-28-5aaa, Rosebud Mission School Well #2
F. Location: 38-28-3bac, Rosebud Boarding School
G. Location: 38-28-15bcbb, Tribal land
H. Location: 38-28-21aac
I. Location: 38-28-21dcc, Tribal land
J. Location: 38-29-26cac
K. Location: 38-28-28abcb, Archie Barns
L. Location: 38-28-34bbb, John Lolley
M. Location: 38-28-31bba
N. Location: 40-29-8 (Agnew, 1963)

be engaged to drill additional test holes. This would allow location of the best site within the area mentioned above for installation of a test well. The test well would be used to determine quality of the water, yield, drawdown, and recovery data. Pump tests should be conducted by qualified engineers and run for a minimum of 72 hours. The results of these tests are necessary for the design and installation of the most efficient pumping system.

Should the city decide to develop a ground-water supply from the subsurface bedrock formations, a test well should be drilled through the upper Cretaceous sediments to the Dakota Formation and the Inyan Kara Group. Tests should be made to determine the quality and quantity of water from the various water horizons within the interval of the Dakota Formation and base of the Inyan Kara Group. The results of the preliminary tests will afford a basis for developing the best water horizon and for proper well design.

Before a permanent well is drilled, the city officials should consult with the State Water Resources Commission to obtain water rights and a permit to drill a city well, and with the State Department of Health to determine biological and chemical suitability of the water.

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Agnew, A. F., 1963, Geology of the Mission quadrangle, South Dakota: S. Dak. Geol. Survey, map and text.

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Rothrock, E. P., 1943, A geology of South Dakota, Part I, The surface: S. Dak. Geol. Survey Bull. 13, 88 p.

U. S. Public Health Service, 1962, Drinking water standards, 1962: U. S. Public Health Service Pub. 956, 61 p.

# APPENDIX A

## Logs of Auger Test Holes in the Mission Area

(for location see figure 3)

Test Hole No. 1
Location: 39-28-30dddc
Depth to water: 39 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-14 | Clay, brownish-tan |
| 14-39 | Clay, grayish-brown |
| 39-53 | Sand, grayish-tan, fine to medium |
| 53-63 | Clay, brownish-tan |
| 63-74 | Clay, tannish-brown |

* * * *

Test Hole No. 2
Location: 39-28-31bbbb
Depth to water: 19 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Silt, light tannish-yellow, some fine sand |
| 4- 9 | Clay, light tannish-brown |
| 9-54 | Clay, reddish-tan |
| 54-69 | Clay, light tannish-gray |

* * * *

Test Hole No. 3
Location: 38-29-3cddd
Depth to water: 47 feet

| | |
|---|---|
| 0- 4 | Sand, white, fine |
| 4- 7 | Sand, greenish-brown, fine, some clay |
| 7-47 | Clay, greenish-brown, some sand |
| 47-64 | Clay, buff, sandy |
| 64-69 | Clay, brown, sandy |

* * * *

Test Hole No. 4
Location: 38-29-2dccc
Depth to water: dry hole

| | |
|---|---|
| 0- 2 | Topsoil, black |
| 2- 4 | Clay, brown, some sand |
| 4-14 | Sand, brownish-tan, fine, some clay |
| 14-24 | Sand, tan |
| 24-29 | Clay, light-brown |

* * * *

Test Hole No. 5
Location: 38-28-6dccc
Depth to water: 1 foot

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-14 | Sand, blackish-gray |
| 14-20 | Sand, brownish-tan, coarse to fine |
| 20-54 | Clay, brownish-tan |

* * * *

Test Hole No. 6
Location: 38-28-4bbdd
Depth to water: 5 feet

| | |
|---|---|
| 0- 3 | Silt, light-brown, some sand |
| 3- 5 | Sand, light-brown, fine to coarse |
| 5-13 | Sand, dark-gray, fine to coarse |
| 13-44 | Clay, light tannish-yellow, sandy |

* * * *

Test Hole No. 7
Location: 38-28-4abcc
Depth to water: 4 feet

| | |
|---|---|
| 0- 9 | Sand, brownish-tan |
| 9-13 | Sand, blackish-brown, coarse to medium |
| 13-31 | Clay, tannish-brown |
| 31-39 | Clay, greenish-brown |

* * * *

Test Hole No. 8
Location: 38-29-11cccc
Depth to water: 29 feet

| | |
|---|---|
| 0- 9 | Sand, light-tan, fine, silty |
| 9-41 | Clay, light tannish-brown, some sand |
| 41-62 | Clay, tannish-brown, some sand |
| 62-84 | Clay, light tannish-brown, some sand |

* * * *

Test Hole No. 9
Location: 38-28-8cddd
Depth to water: dry hole

| | |
|---|---|
| 0- 2 | Topsoil |
| 2- 9 | Sand, light-tan, fine |
| 9-19 | Sand, tannish-green, fine, some clay |
| 19-42 | Sand, light-tan, fine, some clay |
| 42-54 | Sand, light tannish-green, fine, some clay |
| 54-74 | Clay, light olive-green, some sand |

* * * *

Test Hole No. 10
Location: 38-28-8aadd
Depth to water: 59 feet

| | |
|---|---|
| 0- 2 | Topsoil |
| 2-14 | Clay, whitish-gray, silty, some sand |
| 14-39 | Clay, light tannish-yellow, some sand |
| 39-59 | Clay, tan, some coarse sand |
| 59-79 | Sand, tannish-yellow, fine to medium |
| 79-84 | Clay, tan, sandy |

* * * *

Test Hole No. 11
Location: 38-28-10dcdd
Depth to water: dry hole

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-14 | Sand, brownish-tan, fine to medium, silty |
| 14-27 | Silt, tannish-brown, some fine to medium sand |
| 27-29 | Clay, tannish-brown, some sand |
| 29-34 | Clay, dark tannish-brown, little fine sand |

* * * *

Test Hole No. 12
Location: 38-29-15dbcd
Depth to water: 4 feet

| | |
|---|---|
| 1- 4 | Silt, blackish-gray |
| 4- 9 | Sand, light-brown |
| 9-16 | Silt, black |
| 16-24 | Clay, blackish-brown, some fine sand |
| 24-44 | Clay, whitish-tan |
| 44-69 | Clay, brownish-yellow |
| 69-74 | Clay, green |

* * * *

Test Hole No. 13
Location: 38-29-13cddd
Depth to water: dry hole

| | |
|---|---|
| 0- 2 | Topsoil |
| 2- 5 | Sand, dark blackish-brown, fine, silty |
| 5-14 | Sand, whitish-tan, fine |
| 14-19 | Clay, pinkish-brown, some sand |
| 19-34 | Clay, light-gray |
| 34-54 | Clay, pinkish-tan, some very fine sand |

* * * *

Test Hole No. 14
Location: 38-29-13dddd
Depth to water: 4 feet

| | |
|---|---|
| 0- 4 | Sand, dark-brown, some clay |
| 4- 9 | Sand, tannish-brown, fine, silty |
| 9-14 | Sand, grayish-brown, fine, some clay |
| 14-44 | Clay, tannish-brown, with some sand |
| 44-49 | Clay, brown, some fine sand |

* * * *

Test Hole No. 15
Location: 38-29-13daaa
Depth to water: 9 feet

| | |
|---|---|
| 0-14 | Sand, light-brown, fine, some clay |
| 14-64 | Clay, light-brown, some sand |
| 64-69 | Clay, brownish-tan, some fine to medium sand |

* * * *

Test Hole No. 16
Location: 38-28-18bbba
Depth to water: 15 feet

| | |
|---|---|
| 0- 9 | Sand, tannish-brown, fine to medium |
| 9- 15 | Sand, fine, silty |
| 15- 24 | Silt, brown, some fine sand |
| 24- 51 | Sand, tannish-brown, fine to coarse, some silt |
| 51- 84 | Clay, tannish-brown, some sand |
| 84- 89 | Clay, greenish-brown |
| 89- 93 | Clay, tannish-brown |
| 93-104 | Clay, brownish-tan, some fine to medium sand |

* * * *

Test Hole No. 17
Location: 38-28-17aadd
Depth to water: 52 feet

| | |
|---|---|
| 0- 2 | Topsoil |
| 2-14 | Sand, light tannish-brown, fine to medium |
| 14-19 | Sand, greenish-brown, fine, silty |
| 19-34 | Clay, light-brown, sandy |
| 34-52 | Clay, brown, some fine sand |
| 52-67 | Clay, tan |
| 67-74 | Silt, brown, compact, sandy |

* * * *

Test Hole No. 18
Location: 38-28-15bcdd
Depth to water: 34 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 9 | Silt, brown, some fine sand |
| 9-16 | Clay, white |
| 16-19 | Sand, brownish-tan, fine |
| 19-27 | Sand, greenish-brown, fine to medium |
| 27-54 | Silt, tannish-brown, some fine to medium sand |
| 54-69 | Clay, tannish-brown |

* * * *

Test Hole No. 19
Location: 38-28-13cccc
Depth to water: 39 feet

| | |
|---|---|
| 0- 4 | Sand, dark-brown, fine to medium, some clay |
| 4- 9 | Sand, light-brown, fine |
| 9-22 | Clay, tan, some fine sand |
| 22-34 | Clay, light-pink, some coarse sand |
| 34-39 | Clay, light tannish-gray, some fine sand |
| 39-47 | Clay, tan, some fine sand |
| 47-64 | Clay, tannish-brown, some fine to coarse sand |

* * * *

Test Hole No. 20
Location: 38-29-22abcc
Depth to water: dry hole

| | |
|---|---|
| 1- 9 | Silt, blackish-brown |
| 9-24 | Silt, white |

* * * *

Test Hole No. 21
Location: 38-29-23daaa
Depth to water: 19 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Silt, light brownish-tan |
| 4- 19 | Clay, light-green |
| 19- 24 | Sand, light tannish-green |
| 24- 69 | Clay, greenish-tan |
| 69- 72 | Gravel, all colors |
| 72- 89 | Clay, light whitish-gray |
| 89-104 | Clay, whitish-tan |

* * * *

Test Hole No. 22
Location: 38-29-24ddbc
Depth to water: 15 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Clay, blackish-brown |
| 4- 9 | Clay, tan |
| 9-15 | Clay, grayish-brown |
| 15-72 | Clay, brownish-tan |
| 72-84 | Clay, with gravel stringers |
| 84-94 | Clay, brownish-tan |

* * * *

Test Hole No. 23
Location: 38-28-19bacb
Depth to water: 9 feet

| | |
|---|---|
| 0-13 | Sand, dark-brown, fine to medium |
| 13-19 | Sand, dark-gray, fine to medium, silty |
| 19-41 | Clay, tannish-brown, some sand |
| 41-44 | Clay, light tannish-brown, some fine sand, drilled hard |

* * * *

Test Hole No. 24
Location: 38-28-19bddb
Depth to water: 4 feet

| | |
|---|---|
| 0-21 | Sand, fine to medium, some silt |
| 21-31 | Clay, grayish-black, some fine to medium sand |
| 31-42 | Clay, light tannish-brown, sandy |
| 42-44 | Clay, tannish-brown, some sand |

* * * *

Test Hole No. 25
Location: 38-28-19adcd
Depth to water: 34 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Clay, brown |
| 4-14 | Clay, whitish-tan |
| 14-29 | Clay, light-gray |
| 29-34 | Clay, tannish-brown |
| 34-54 | Clay, light-gray |
| 54-69 | Clay, reddish-tan |

* * * *

Test Hole No. 26
Location: 38-28-20aaad
Depth to water: 54 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Sand, blackish-brown, fine, some clay |
| 4- 9 | Sand, tannish-brown, fine to coarse, some clay |
| 9-19 | Sand, tannish-yellow, fine, some silt |
| 19-24 | Clay, greenish-tan, sandy |
| 24-34 | Sand, light-yellow, fine, silty |
| 34-67 | Sand, yellowish-tan, fine to coarse |
| 67-84 | Clay, greenish-tan, some fine sand |

* * * *

Test Hole No. 27
Location: 38-28-21bbcc
Depth to water: 9 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Sand, blackish-brown, some clay |
| 4- 9 | Sand, brownish-black, silty |
| 9-14 | Clay, tannish-brown, some fine sand |
| 14-34 | Sand, tannish-brown, fine to medium, some clay |
| 34-39 | Sand, fine to medium |
| 39-54 | Clay, greenish-brown, some fine sand |
| 54-84 | Clay, tannish-brown, sandy |

* * * *

Test Hole No. 28
Location: 38-28-21bcdb
Depth to water: 36 feet
(continued on next page)

Test Hole No. 28--continued

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Silt, dark-brown |
| 4- 9 | Silt, tannish-brown |
| 9-19 | Sand, tannish-brown, fine to coarse, silty |
| 19-24 | Clay, greenish-tan, some fine sand |
| 24-36 | Sand, light tannish-brown, fine to medium, some silt |
| 36-62 | Sand, tannish-brown, fine to medium |
| 62-84 | Clay, tannish-brown |

* * * *

Test Hole No. 29
Location: 38-28-21babb
Depth to water: dry hole

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Sand, brownish-tan, silty |
| 4-34 | Silt, tannish-brown, sandy |

* * * *

Test Hole No. 30
Location: 38-28-21abaa
Depth to water: dry hole

| | |
|---|---|
| 1- 9 | Silt |
| 9-14 | Volcanic ash |

* * * *

Test Hole No. 31
Location: 38-28-21acad
Depth to water: 49 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Clay, dark-brown |
| 4- 9 | Clay, tannish-yellow, some sand |
| 9- 14 | Clay, greenish-tan, some fine to coarse sand |
| 14- 19 | Sand, whitish-tan, fine to medium |
| 19- 24 | Sand, tannish-brown, fine to medium, silty |
| 24- 68 | Sand, whitish-tan, medium |
| 68- 79 | Clay, yellowish-tan, sandy |
| 79-114 | Clay, brownish-pink |

* * * *

Test Hole No. 32
Location: 38-28-21dcba
Depth to water: 40 feet

| | |
|---|---|
| 0- 9 | Sand, yellowish-tan, fine |
| 9-19 | Sand, yellowish, fine to coarse |
| 19-24 | Sand, tannish-brown, medium |
| 24-81 | Sand, tannish-gray, fine to medium |
| 81-94 | Clay, greenish-gray, some fine sand |
| 94-99 | Clay, pinkish-tan |

* * * *

Test Hole No. 33
Location: 38-28-21dccc
Depth to water: 44 feet

| | |
|---|---|
| 0- 4 | Sand, gray |
| 4- 9 | Sand, light-gray, fine to medium |
| 9-14 | Sand, light grayish-green |
| 14-19 | Silt, light greenish-gray, sandy |
| 19-79 | Sand, light tannish-brown, fine to medium |

* * * *

Test Hole No. 34
Location: 38-28-23bbcb
Depth to water: 4 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-14 | Clay, brown, some sand |
| 14-29 | Clay, light tannish-green, some fine sand |
| 29-64 | Clay, greenish-gray |
| 64-79 | Clay, light pinkish-brown, some coarse sand |

* * * *

Test Hole No. 35
Location: 38-28-23cbbb
Depth to water: 9 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 9 | Silt, light blackish-brown |
| 9-19 | Sand, fine to medium, silty |
| 19-84 | Clay, light tannish-brown, sandy |

* * * *

Test Hole No. 36
Location: 38-28-24aadd
Depth to water: 21 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-21 | Silt, tannish-brown, some fine to coarse sand |
| 21-29 | Silt, tannish-brown |
| 29-44 | Clay, tannish-brown, some fine to medium sand |

* * * *

Test Hole No. 37
Location: 38-29-26aaaa
Depth to water: dry hole

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-14 | Clay, brown |
| 14-19 | Clay, whitish-tan |
| 19-24 | Sand, silty, drilled real hard |

* * * *

Test Hole No. 38
Location: 38-29-25aacb
Depth to water: 19 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 14 | Silt, brownish-tan, sandy |
| 14- 34 | Sand, tannish-brown, fine |
| 34- 44 | Sand, buffish-brown, coarse |
| 44- 90 | Clay, tannish-brown |
| 90- 94 | Gravel |
| 94-109 | Clay, greenish-brown |

* * * *

Test Hole No. 39
Location: 38-29-25adcc
Depth to water: 19 feet

| | |
|---|---|
| 0- 14 | Silt, brownish-tan |
| 14- 25 | Silt, dark-brown |
| 25- 29 | Sand, tannish-brown, medium |
| 29- 34 | Sand, grayish-brown, medium |
| 34- 61 | Sand, brownish-tan, fine to medium |
| 61-106 | Clay, greenish-brown |
| 106-108 | Gravel |
| 108-124 | Clay, brownish-tan |

* * * *

Test Hole No. 40
Location: 38-28-30baaa
Depth to water: 4 feet

| | |
|---|---|
| 0- 2 | Topsoil |
| 2- 4 | Clay, blackish-brown, some sand |
| 4- 9 | Clay, grayish-brown, some fine sand |
| 9-19 | Sand, grayish-brown, fine, some clay |
| 19-26 | Sand, grayish-brown, coarse, some clay |
| 26-79 | Clay, tannish-brown, some coarse to fine sand |

* * * *

Test Hole No. 41
Location: 38-28-30bddd
Depth to water: 4 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Sand, dark grayish-brown, very fine, silty |
| 4-14 | Sand, dark-gray, fine, silty |
| 14-21 | Sand, dark brownish-black, very fine, some clay |
| 21-49 | Clay, tannish-brown, sandy |

* * * *

Test Hole No. 42
Location: 38-28-29dbcd
Depth to water: dry hole

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 9 | Sand, light-brown, fine to medium |
| 9-24 | Sand, light-tan, silty |
| 24-29 | Sand, light-brown, silty, drilled real hard |

* * * *

Test Hole No. 43
Location: 38-28-28cabb
Depth to water: dry hole

| | |
|---|---|
| 0- 1 | Topsoil |
| 1-14 | Clay, greenish-yellow |
| 14-19 | Sand, tannish-green, fine, silty |
| 19-29 | Silt, buff, some very fine sand |
| 29-37 | Sand, tan, fine to medium |
| 37-38 | Gravel stringers |
| 38-47 | Sand, tan, fine to coarse, silty |

* * * *

Test Hole No. 44
Location: 38-28-27dacc
Depth to water: 27 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 4 | Sand, dark tannish-brown, fine, some clay |
| 4- 14 | Sand, tan, fine to medium, silty |
| 14- 27 | Silt, brownish-tan, some sand |
| 27- 48 | Sand, gray-brown, fine to medium |
| 48- 58 | Clay, tannish-brown, silty, some sand |
| 58-114 | Clay, greenish, silty |

* * * *

Test Hole No. 45
Location: 38-28-26bddd
Depth to water: 14 feet

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 9 | Clay, dark-brown |
| 9-14 | Sand, light-tan, fine to medium, some clay |
| 14-29 | Sand, gray, fine to medium, some clay |
| 29-44 | Sand, light tannish-brown, fine to medium |
| 44-54 | Clay, light tannish-brown |
| 54-64 | Clay, reddish-brown, some fine to coarse sand |

* * * *

Test Hole No. 46
Location: 38-28-26ddaa
Depth to water: 4 feet

| | |
|---|---|
| 1- 4 | Sand, light-gray |
| 4-12 | Sand, blackish-brown |
| 12-14 | Clay, brownish-black |
| 14-29 | Clay, yellowish-tan |
| 29-49 | Clay, reddish-tan |

* * * *

Test Hole No. 47
Location: 38-28-31bbaa
Depth to water: 1 foot

| | |
|---|---|
| 0- 1 | Topsoil |
| 1- 9 | Sand, light-brown, fine to medium, clay |
| 9-19 | Clay, light greenish-gray |
| 19-37 | Sand, light tannish-yellow, fine to medium |
| 37-49 | Clay, greenish-yellow, some coarse sand |

* * * *

Test Hole No. 48
Location: 38-28-32bbba
Depth to water: 4 feet

| | |
|---|---|
| 0- 4 | Sand, dark tannish-brown, silty |
| 4-14 | Sand, tannish-brown, some silt |
| 14-24 | Sand, coarse, some medium gravel |
| 24-34 | Clay, greenish, silty |
| 34-59 | Clay, pinkish-tan, some very fine sand |

* * * *

# APPENDIX B

## Logs of rotary test holes in the Mission area.

(for location see figure 3)

Test Hole No. R-1
Location: 38-28-21ddcd
Depth to water: estimated at 90 feet[1/]

| | |
|---|---|
| 0- 3 | Topsoil, black |
| 3- 16 | Sand, fine, ash with bentonite (?) |
| 16- 22 | Sand, with ash |
| 22-133 | Sand, tan, medium |
| 133-164 | Clay, olive-tan |
| 164-170 | Clay, red |

* * * *

Test Hole No. R-2
Location: 38-28-21dadd
Depth to water: estimated at 130 feet[1/]

| | |
|---|---|
| 0- 3 | Topsoil |
| 3- 33 | Sand, ash |
| 33- 37 | Sand |
| 37- 44 | Clay, greenish-white |
| 44-166 | Sand, tan, medium |
| 166-180 | Clay, white to light-gray |
| 180-185 | Clay, red |

* * * *

Test Hole No. R-3
Location: 38-28-28adaa
Depth to water: estimated at 53 feet[1/]

| | |
|---|---|
| 0- 52 | Ash, sand |
| 52-106 | Sand, tan, medium |
| 106-109 | Clay, greenish to light-gray |
| 109-163 | Sand; cemented layers of sand |
| 163-195 | Clay, greenish |
| 195-200 | Clay, red |

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1/ Water-level determinations in the rotary test holes were not measured because of the addition of water during the drilling process. Thus all water-level estimates give a minimum expected saturated thickness.

Test Hole No. R-4
Location: 38-28-28accc
Depth to water: estimated at 89 feet[1/]

| | |
|---|---|
| 0- 3 | Topsoil |
| 3- 15 | Sand, with cemented sand |
| 15- 33 | Ash |
| 33-138 | Sand, tan, medium |
| 138-178 | Clay, greenish-white |
| 178-185 | Clay, red |

* * * *

Test Hole No. R-5
Location: 38-28-27dddc
Depth to water: estimated at 30 feet[1/]

| | |
|---|---|
| 0- 2 | Topsoil |
| 2-10 | Silt, blackish-brown |
| 10-15 | Sand, buff, fine |
| 15-84 | Sand, fine to medium |
| 84-90 | Clay, whitish-gray |
| 90-95 | Clay, red |

* * * *

Test Hole No. R-6
Location: 38-28-28dddd
Depth to water: estimated at 32 feet[1/]

| | |
|---|---|
| 0- 2 | Sand, fine |
| 2- 22 | Ash, light-gray |
| 22- 60 | Sand, light-brown, loosely consolidated |
| 60-100 | Sand, light-brown, very loose |
| 100-177 | Sand, light-brown to gray, well-cemented |
| 177-180 | Clay, green |
| 180-185 | Clay, red |

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1/ Water-level determinations in the rotary test holes were not measured because of the addition of water during the drilling process. Thus all water-level estimates give a minimum expected saturated thickness.