Water-Mineral Relations of Quaternary Deposits in the Lower Platte River Drainage Area in Eastern Nebraska

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1859-D

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By IVAN BARNES *and* RAY BENTALL

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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Relation of local environmental controls to chemical composition and selected properties of shallow ground water

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WATER-MINERAL RELATIONS OF QUATERNARY DEPOSITS IN THE LOWER PLATTE RIVER DRAINAGE AREA IN EASTERN NEBRASKA

By IVAN BARNES and RAY BENTALL

ABSTRACT

The partial pressure of carbon dioxide (P_{CO_2}), the degree of saturation with respect to calcite (IAP/K_{calcite}), the pH, and the concentrations of selected constituents in solution were determined for water from 52 wells and the Platte River. Compared to the P_{CO_2} in the atmosphere, the average P_{CO_2} in the ground water was many times greater and that in the river water was about twice as great. The high P_{CO_2} in the ground water probably results from the absorption, by infiltrating precipitation, of carbon dioxide produced in the soil by respiration of plant roots and microorganisms. The values for IAP/K_{calcite} for the ground water ranged from 0.141 to 1.29 and for the river water the average was 9.6. Water from each of the 10 sampled wells on the terrace plain in southeastern Saunders County was unsaturated with respect to calcite, whereas water from seven of the 42 wells on the Platte River flood plain was nearly saturated or supersaturated. Of the seven, two were in the Lincoln city well field where hydrologic relations indicate that a large fraction of the water yielded by the wells is induced seepage from the river. That more of the city wells did not yield supersaturated water is surprising in view of the high IAP/K_{calcite} values for the river water. Supersaturation of water from five of nine sampled wells downvalley from the well field probably is due to the presence of numerous limestone fragments in the Quaternary deposits in that part of the area. Also surprising was the finding that the average pH of the water from the city wells was 1 unit lower than that of the river water. The presence of both dissolved iron and dissolved oxygen in the water from several of the city wells probably reflects derivation of the water from two distinct sources: ground water naturally in the aquifer and induced seepage from the river.

INTRODUCTION

The purpose of the study described in this report was to relate the local environmental controls to the chemical composition and selected properties of shallow ground water in the lower Platte River drainage basin (fig. 1). Among the controls considered were the partial pressure of carbon dioxide (P_{CO_2}) in the atmosphere, the oxygen and carbon

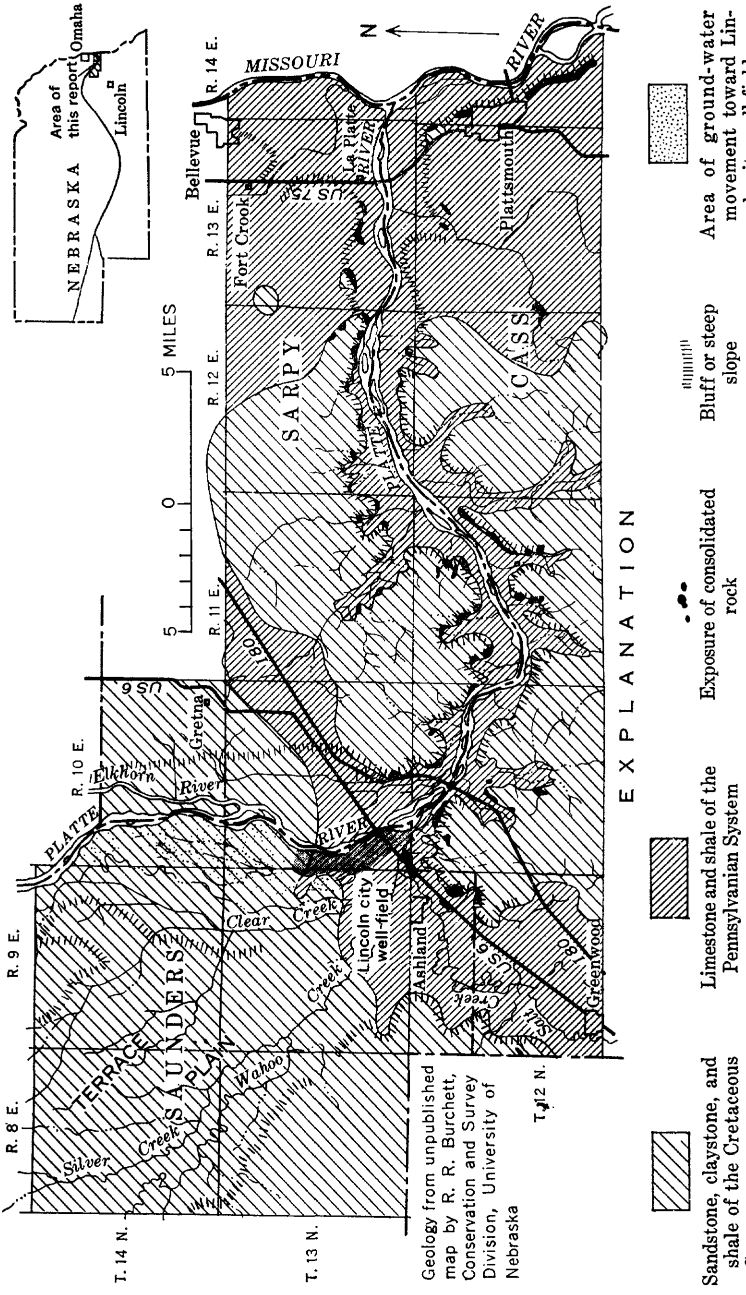

FIGURE 1.—Generalized geologic map.

dioxide content of the water, and the minerals with which the water has come into contact. Some tentative conclusions regarding the history of the ground water are based on petrographic analyses of the unconsolidated sediments through which the ground water percolates, on determinations of the ratio of the ion activity product (*IAP*) to the equilibrium constant for calcite (K_{calcite}) and on determinations of certain properties of the ground water.

The field and laboratory work was done by Edwin C. Schuett, Jr., who also prepared a preliminary interpretation of the data as a thesis for a Master of Science degree at the University of Nebraska. Ivan Barnes, who proposed the investigation, conferred with Schuett several times while the study was in progress and made most of the geochemical interpretation as it appears in this report. Ray Bentall compiled the remainder of the text, drawing on Schuett's thesis and on information in the files of the Conservation and Survey Division of the University of Nebraska.

Acknowledgment is due E. C. Reed, V. H. Dreeszen, V. L. Souders, and F. A. Smith of the Conservation and Survey Division, University of Nebraska, and S. B. Treves of the Department of Geology, University of Nebraska, for information and advice. Suggestions made by Mr. Souders were especially valuable and are greatly appreciated. The study, including preparation of this report, was under the general direction of D. M. Culbertson of the U.S. Geological Survey.

Each well and test hole referred to in this report has been assigned a compound number that indicates its location within the Federal survey from the sixth principal meridian and base line. The first segment of the number identifies the township north, the second the range east, and the third the section and location within the section. The lowercased letters indicate, in order, the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section. These letters are assigned to the subdivisions of the section in counterclockwise direction, as shown in figure 2. Thus, well 13–9–6dbc is in the SW¼NW¼SE¼ sec. 6, T. 13 N., R. 9 E.

GEOGRAPHIC SETTING

The area described in this report includes small parts of Saunders, Sarpy, and Cass Counties, Nebr. (fig. 1). Its general location is northeast of Lincoln and south and southwest of Omaha. Because it is traversed by the lowermost reach of the Platte River, a major drain in Nebraska, and is in large part underlain at shallow depth by saturated deposits of sand and gravel that yield water freely to wells, it has developed into an important water-supply area.

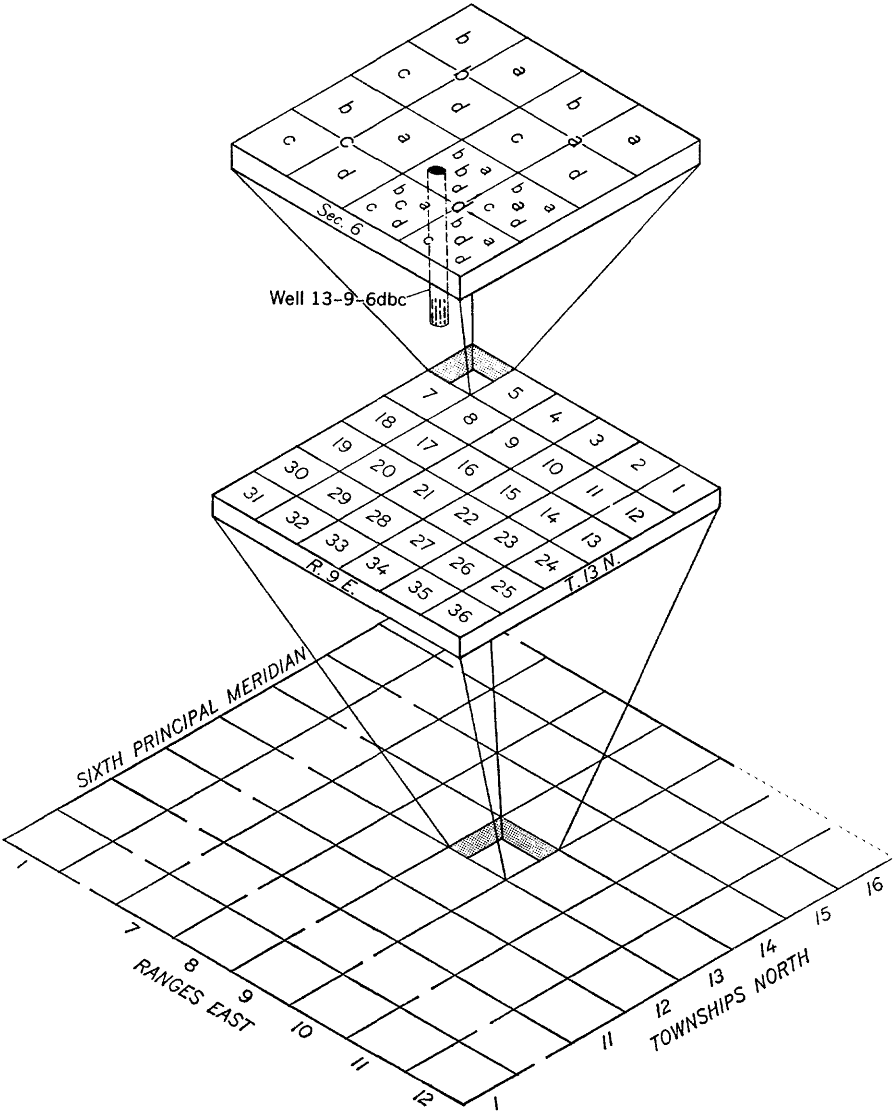

FIGURE 2.—System of numbering test holes and wells.

A well field alongside the Platte River near Ashland is the principal source of water for the city of Lincoln, which is about 30 miles southwest of Ashland. Another near the Platte River at La Platte supplies water to the Allied Chemical Corp. A third well field which will supply South Omaha is being developed on an island in the Platte River and alongside the north riverbank a short distance west of La Platte. At the time of the fieldwork for this study (1963), water supplies for about 200,000 people were obtained from wells in this area. When the well field for South Omaha is developed, the number of people supplied will increase to about 350,000.

The climate of the report area is typical of the middle part of North America. The mean annual temperature is about 52°F. On about 10 days during the winter the temperature drops to below zero, and on several days each summer it climbs to 100°F or a little higher. About four-fifths of the mean annual precipitation of about 28 inches falls during the period of April through September. Monthly amounts of precipitation differ widely because a large part of the summer precipitation is in the form of thundershowers, which may be numerous and well distributed or infrequent and scattered. During field operations in June and July 1963, temperatures ranged from 80° to 97°F and precipitation was above normal. Fieldwork was interrupted in late June because extensive flooding resulted from a rain of 2.47 inches at Ashland and 6.81 inches at Lincoln during a single 24-hour period on June 24–25.

The principal physiographic features of the area are rolling uplands, a broad gently sloping terrace plain, and nearly flat valley lands. Moderately steep to steep slopes or bluffs separate these features from each other. All the points for which information is presented in this report are on either the terrace plain or in the Platte River valley.

The terrace plain is a remnant of a formerly more extensive constructional plain. It is 75 to 100 feet lower than the bordering uplands and about 50 feet higher than the flood plain in the Platte River valley. Except where it broadens abruptly to the north to form a terrace on the west side of the Platte River valley, the terrace plain is a southeast-trending linear feature and resembles an abandoned river valley; it is referred to as the Todd Valley in some reports on the geology and geography of the area, but this name is not in general use among the local residents. The terrace plain is about 5 to 7 miles wide and has an average southeastward slope of 6 to 7 feet per mile. There are several shallow depressions having no surface outlet. About two-thirds of the part of the terrace plain shown in figure 1 is within the area drained by Wahoo Creek, and the remainder is within the area drained by Clear Creek.

The Platte River valley above Ashland differs considerably from the Platte River valley below Ashland. The upper segment is 6 to 8 miles wide and has an average gradient of about 7 feet per mile, whereas the lower segment is 1 to 2 miles wide and has a slightly steeper average gradient. Moreover, no bedrock is exposed along the valley sides of the upper segment, whereas bedrock is exposed in many places along the valley sides of the lower segment (fig. 1).

The soils on the terrace plain, like those on the uplands, developed principally on loess (wind-deposited silty clay), and those in the Platte River valley developed on silty or sandy alluvium that in places was shifted by the wind before vegetation became established. The soils differ in their ability to absorb and hold moisture.

In most places on the terrace plain, the surface layer of soil is a very dark silty clay loam that has a granular structure and is 6 to 16 inches thick. It grades downward to a dark-brown silty clay loam that has a blocky structure and is hard when dry and plastic when wet. Runoff from these soils is slow to rapid, depending on the degree of slope. The infiltration rate ranges from about 0.2 to 0.8 inch per hour, and the amount of water that can be stored for extraction by vegetation is 0.17 to 0.18 inch per inch of soil.

The soils in the Platte River valley generally are dark gray or dark grayish brown. In places the soils are so rich in organic material that they are referred to as muck, whereas in other places they are almost devoid of organic material. Generally the silty or sandy material extends to a depth of more than 20 inches and the substratum is sand and gravel. As well-defined surface drains are few, the soils of the flat-lying bottomlands are imperfectly drained, whereas the soils on the higher hummocks are well drained. Where soils are poorly drained, alkali conditions are common. Infiltration rates for the more silty soils range from 0.2 to 2.5 inches per hour and for the sandy soils from 2.5 to more than 10 inches per hour. The capacity for storage of water that can be extracted by vegetation is 0.16 to 0.18 inch per inch of silty soil and 0.06 to 0.15 inch per inch of sandy soil.

GEOLOGIC SETTING

The uppermost bedrock (consolidated rock) in the area is of either Pennsylvanian or Cretaceous age (fig. 1). The Pennsylvanian rocks consist of a succession of limestones, shaly limestones, and calcareous shales, and the Cretaceous rocks consist of sandstones, sandy shales, shales, and claystone. Lacking significant interstitial permeability, the Pennsylvanian rocks transmit water only through secondary openings such as solution channels along fracture planes. On the other hand, some of the Cretaceous sandstone layers retain a degree of their original interstitial permeability and can transmit small to moderately large quantities of water to wells or natural outlets. Mantled by an almost continuous sheet of unconsolidated sediments of Quaternary age, the bedrock is exposed only in places along the rather steep sides of the Platte River valley south and east of Ashland.

The available evidence, obtained by drilling, indicates that the bedrock surface, like the present-day surface, is characterized by hills and valleys and that the irregularities of the two surfaces are not parallel. Consequently, the depth to bedrock differs widely from place to place within the area. In general, the depth to the bedrock surface below the terrace plain ranges from 50 to 175 feet, and below the Platte River flood plain, from 50 to 100 feet. The greatest depths, as much as 250 feet, are along a buried valley that trends northeastward beneath the uplands in northeastern T. 13 N., R. 10 E., and northwestern T. 13 N., R. 11 E.

Because the area is only a short distance east of the western maximum extent of the Nebraskan and Kansan continental ice sheets, it was a site for accumulation of both periglacial and glacial deposits during both of these glaciations of the Pleistocene Epoch. Some of the deposits of the Nebraskan Glaciation were reworked or removed by erosion before and during the earlier part of the Kansan Glaciation; similarly, some of the Kansan deposits were reworked or removed during post-Kansan time. The continental ice sheets of the Illinoian and Wisconsin Glaciations did not override this area; instead, post-Kansan time in this part of Nebraska was characterized by alternating cycles of erosion and deposition. The coarser grained deposits, and possibly some of the finer grained, are of fluvial origin; they were derived partly from sediments carried into the area by streams draining the unglaciated area to the west and partly from rock debris transported into the area by the Nebraskan and Kansan ice sheets expanding from centers of accumulation to the northeast. The greater part of the finer grained sediments consists of loess. Probably the loess originally was almost uniformly calcareous, but infiltrating precipitation has leached most of the calcium carbonate from its upper layers.

As pointed out by V. H. Dreeszen of the Conservation and Survey Division of the University of Nebraska (oral commun., 1965), it is remarkable that such a large volume of unconsolidated sediments was deposited in eastern Nebraska during times when the continent stood generally high above sea level and so was especially vulnerable to stream erosion. Increases in precipitation, blocking of drainageways by glacial ice, and depression of the earth's crust beneath and peripheral to the tremendously thick ice sheets may have been the principal factors that combined to create a local environment favoring thick accumulation of sediments.

The Quaternary deposits underlying the terrace plain have an average thickness of about 100 feet and range in texture from clay to coarse sand and gravel. The uppermost deposits consists of loess having an average thickness of about 20 feet; the underlying deposits consists of silt, sand, and sandy gravel mostly of fluvial origin.

The nearly flat flood plain of the Platte River is underlain by Quaternary deposits averaging about 60 feet in thickness. Although lenses of fine-grained sediment are present in places, these deposits are, for the most part, moderately coarse grained. Loess, such as mantles the coarse-grained deposits beneath the terrace plain, is not present in the Platte River valley; instead, the surficial deposits in the valley consist of silty sand of alluvial origin. Downstream from Ashland numerous angular to subrounded fragments of limestone derived from the valley sides are present in the sand and gravel below a depth of 35 to 40 feet.

GRAIN SIZE AND MINERALOGIC COMPOSITION OF THE QUATERNARY FLUVIAL SEDIMENTS

Samples of the fluvial sediments underling the terrace plain and the Platte River flood plain were obtained by rotary drilling eight test holes. (See fig. 3 for locations and p. D36 for logs.) All the samples were sieved mechanically to determine the percentage of each within seven different ranges of particle size. Then the fraction for the size range ⅛ to $\frac{1}{16}$ millimeter was used for the mineralogic examination. Bromoform of specific gravity 2.87 was used to separate the light and heavy minerals, which subsequently were mounted in Canada balsam for examination by means of a petrographic microscope equipped with a recording micrometer.

The particle-size determinations (tables 1, 2) revealed that the fluvial sediments beneath the terrace plain differ in grain-size distribution from those beneath the Platte River valley. Beneath the terrace plain, sand is dominant between the base of the loess and depths of 85 to 95 feet, and gravel is either dominant or at least common at greater depths. Beneath the Platte River valley, however, gravel is common at nearly all depths, and the sand tends to be coarser than that beneath the terrace plain.

The mineralogical analyses show that light minerals constitute about 95 percent of the fluvial sediments beneath both the terrace plain and the Platte River flood plain. As shown in tables 3 and 4, these light minerals are mostly quartz, much of which is characterized by inclusions of liquid or gas, and the remainder consists wholly of feldspar or of feldspar and calcite. Both the feldspar and calcite grains are mainly cleavage fragments. No calcite was found in any of the samples

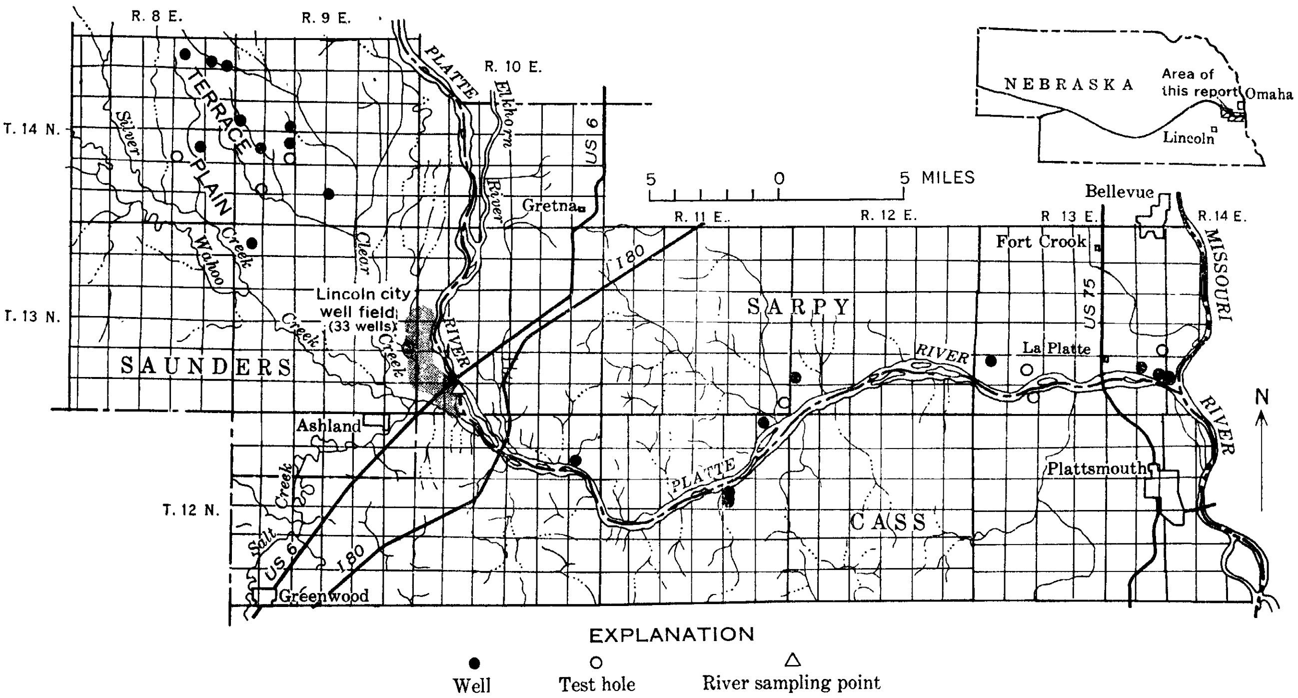

Figure 3.—Locations of test holes, sampled wells, and river sampling point.

TABLE 1.—*Mechanical analyses of unconsolidated deposits beneath the terrace plain*

Depth (feet)	Percent of sediment						
	Gravel (>2 mm)	Very coarse sand (2–1 mm)	Coarse sand (1–½ mm)	Medium sand (½–¼ mm)	Fine sand (¼–⅛ mm)	Very fine sand (⅛–1/16 mm)	Silt (<1/16 mm)
Test hole 14-8-23ccc							
8.8–10	1.6	3.9	19.0	52.0	21.0	0.8	1.8
10–15	.1	1.1	10.3	51.2	32.5	2.6	2.2
15–20	.2	1.7	13.1	47.8	33.5	2.6	1.2
20–25	.6	3.5	12.6	43.6	35.8	3.1	.9
25–30	1.0	6.5	21.0	39.7	28.3	3.0	.7
30–35	1.9	7.9	13.7	52.4	22.5	1.2	.5
35–40	1.4	5.9	14.6	53.9	22.1	1.4	.8
40–45	2.4	7.2	15.7	43.6	28.1	2.3	.8
45–51	.7	2.4	7.8	31.0	48.0	8.2	2.0
51–56	5.3	25.9	22.4	24.9	18.9	2.2	.4
56–60	1.9	7.9	11.7	36.0	37.2	4.9	.5
60–65	2.9	5.3	15.3	34.3	35.0	6.2	1.0
65–70	.3	1.0	6.1	43.6	44.1	4.6	.3
70–75	.2	.9	5.0	32.2	50.8	9.5	1.6
75–80	.0	1.4	12.1	48.7	33.5	3.4	1.1
80–85	11.1	19.4	21.5	32.5	13.6	.8	1.3
85–90	29.8	24.4	19.6	19.0	6.6	.4	.2
90–95	37.3	29.7	20.8	10.7	1.2	.1	.1
95–101	64.4	27.6	4.9	2.4	.6	.1	.1
101–105	58.2	23.9	12.3	4.9	.6	.1	.1
105–108.9	63.3	25.0	7.5	2.8	1.1	.1	.2
Test hole 14-9-20ddd							
16–21	0.6	0.5	4.8	44.9	41.5	5.3	2.7
21–26	.7	1.4	8.3	47.9	34.2	3.7	3.7
26–31	.5	5.6	14.7	41.8	33.7	2.7	.9
31–36	.8	12.4	22.6	40.4	19.4	2.3	2.1
36–41	.3	7.8	17.8	45.3	24.5	2.3	2.0
41–46	2.2	10.8	32.9	42.1	9.9	.9	1.4
46–51	2.4	11.0	26.1	43.3	14.9	.7	1.6
51–56	3.8	21.3	48.0	22.5	2.6	.4	1.4
56–61	5.8	26.2	42.1	21.6	3.4	.4	.6
61–66	.1	2.0	18.5	56.5	21.2	.9	1.0
66–71	.6	16.5	23.2	42.0	15.4	1.0	1.3
71–76	.6	15.4	13.5	48.6	19.8	1.1	1.1
76–81	.5	15.9	14.8	45.9	20.6	1.2	1.0
81–86	.6	31.7	26.6	29.4	10.1	.6	1.0
86–90	1.3	32.5	23.3	33.2	8.4	.5	.8
90–95	1.2	17.5	21.0	27.8	31.6	.3	.7
95–101	37.6	55.3	4.8	.9	.8	.3	.5
101–106	12.3	40.0	25.6	14.7	5.9	.7	.9
106–110	3.4	27.3	18.8	30.5	17.8	.8	1.5
Test hole 14-9-30ddd							
12.5–15	1.3	1.6	4.0	22.8	58.8	8.0	3.5
15–20	.0	.8	3.5	22.8	61.7	10.0	1.4
20–25	.6	3.1	4.8	24.5	54.6	10.9	1.5
25–30	2.3	4.7	10.8	44.7	32.5	3.7	1.4
30–35	.4	2.7	8.5	33.2	48.2	5.9	1.1
35–40	.6	3.1	11.7	33.3	42.5	8.4	.6
40–45	1.8	8.9	12.0	26.2	45.3	4.9	.9
45–50	1.0	4.1	9.5	37.7	42.7	4.6	.5
50–55	1.2	3.0	10.6	46.2	35.4	3.3	.5
55–60	9.4	4.4	10.4	33.2	37.9	4.4	.8
60–65	.9	2.6	5.3	22.4	52.6	14.6	1.7
65–70	.2	1.1	6.5	28.8	55.1	7.9	.5
70–75	2.2	10.3	11.1	30.5	39.7	5.3	1.1
75–80	24.2	26.4	9.8	17.5	18.6	3.2	.3
80–86	48.4	23.5	7.3	10.3	9.1	1.2	.4
86–90	2.2	2.7	13.2	35.9	38.4	7.2	.6
90–95	65.2	16.5	4.7	7.5	4.9	.8	.5
95–100	56.3	14.0	6.8	10.8	9.5	2.0	.6
100–105	52.1	8.6	7.3	18.1	12.1	1.5	.3
105–111	97.6	2.1	.0	.0	.2	.1	.1

TABLE 2.—*Mechanical analyses of unconsolidated deposits beneath the Platte River flood plain*

Depth (feet)	Percent of sediment						
	Gravel (>2 mm)	Very coarse sand (2-1 mm)	Coarse sand (1-½ mm)	Medium sand (½-¼ mm)	Fine sand (¼-⅛ mm)	Very fine sand (⅛-1/16 mm)	Silt (<1/16 mm)
Test hole 13-9-24ddc							
12.4-15	14.2	27.2	35.3	16.6	2.6	1.1	3.2
15-20	7.5	27.1	39.2	20.6	4.0	1.1	.6
20-23.2	3.1	14.5	46.3	28.6	5.2	.8	1.5
23.2-23.5	----------	----------	----------	----------	----------	----------	100.0
23.5-25[1]	----------	----------	----------	----------	----------	----------	----------
25-30	21.5	27.9	27.9	18.1	3.0	.6	1.1
30-35	19.2	17.4	38.9	19.0	4.3	.3	1.0
35-40	11.5	17.9	33.6	31.2	5.0	.4	.4
40-45	25.6	19.2	31.2	20.3	2.8	.1	.7
45-50	12.7	48.0	25.8	10.9	2.1	.1	.4
50-55	24.6	24.0	25.8	19.3	6.0	.1	.3
55-60	11.6	11.6	25.0	41.0	10.3	.1	.5
60-68.5	20.2	23.9	35.1	13.2	4.3	.1	.4
68.5-70	10.5	6.9	26.7	45.4	10.0	.4	.2
70-75	8.5	20.3	34.5	25.4	9.7	.7	.9
75-80	18.7	32.8	31.7	14.3	2.3	.2	.1
80-84.5	36.5	35.5	23.3	3.4	.5	.1	.5
Test hole 13-11-36dad							
1.5-5	1.1	1.8	9.5	53.4	29.4	3.2	1.6
5-10	.4	.8	4.6	28.1	57.5	8.3	.4
10-15	5.0	14.9	19.1	36.7	22.3	1.7	.4
15-20	12.3	16.1	21.3	34.0	15.3	.7	.4
20-25	21.4	24.4	22.0	23.3	7.7	.7	.4
25-30	34.1	30.9	18.7	11.5	4.0	.4	.4
30-35	33.5	27.5	18.8	12.8	6.3	.6	.5
35-40	34.5	35.5	13.4	12.2	3.7	.4	.3
40-45	46.0	31.7	15.0	6.0	.8	.3	.3
45-50	30.6	23.9	24.1	14.7	6.0	.6	.3
50-55	11.7	23.9	37.4	21.7	4.6	.4	.4
55-60[1]	----------	----------	----------	----------	----------	----------	----------
60-65	30.8	47.3	12.5	6.4	2.4	.3	.3
65-70	31.7	46.9	12.9	6.6	1.4	.4	.3
70-75	30.6	37.3	12.9	10.9	7.3	.8	.3
75-80	27.1	46.7	10.7	8.3	5.9	.8	.5
80-85	75.5	19.0	3.3	1.7	.3	.2	.1
85-90	70.9	23.5	4.0	1.0	.4	.2	.2
90-93	49.4	32.4	9.6	6.0	2.3	.2	.2
93-95	74.2	23.6	1.8	.2	.2	.1	.1
Test hole 13-13-24ddd							
10-15	0.0	0.2	0.4	1.4	48.0	44.7	5.4
15-20	.0	.3	.3	3.5	66.7	25.0	4.2
20-25	.3	.9	.9	10.2	73.2	12.7	1.9
25-30	.0	.3	.3	3.9	69.4	23.5	2.7
30-35	23.3	26.1	19.7	7.8	16.8	4.5	1.9
35-40	35.4	20.4	18.0	10.8	11.4	2.5	1.5
40-45	43.3	34.6	15.1	4.3	2.2	.4	.2
45-50	36.5	24.6	23.8	9.0	4.5	.8	.8
50-58	32.1	21.4	21.3	12.9	8.1	2.5	1.8
58-60	7.4	3.5	10.5	16.5	47.4	12.4	2.2
60-65	11.5	13.5	7.9	18.4	41.2	6.1	1.5
65-70	52.8	20.6	9.0	6.6	7.9	2.1	1.1
70-75	29.0	34.1	12.5	7.0	12.7	3.5	1.2
75-80	35.1	24.9	15.0	9.4	10.9	3.3	1.5
80-85	51.1	32.5	8.8	2.5	2.9	.8	1.4

[1] No sample.

TABLE 2.—*Mechanical analyses of unconsolidated deposits beneath the Platte River flood plain*—Continued

Depth (feet)	Percent of sediment						
	Gravel (>2 mm)	Very coarse sand (2–1 mm)	Coarse sand (1–½ mm)	Medium sand (½–¼ mm)	Fine sand (¼–⅛ mm)	Very fine sand (⅛–1/16 mm)	Silt (<1/16 mm)
Test hole 13-13-24ddd—Continued							
85–90	46.6	21.8	20.3	4.6	3.9	1.4	1.3
90–95	28.3	34.3	26.9	7.2	2.2	.7	.4
95–100	38.7	37.0	15.7	3.4	3.3	1.0	1.0
100–105	63.6	16.8	7.3	7.0	4.6	.4	.3
105–110	62.6	13.2	7.8	7.9	7.5	.8	.1
110–114.2	18.4	17.2	33.0	24.8	6.1	.3	.3
Test hole 13-13-29db							
2.6–7	7.5	7.9	14.2	32.8	32.8	3.5	1.4
7–11	9.9	13.2	21.8	37.6	16.1	1.2	.3
11–15	9.8	18.1	31.3	32.5	7.4	.8	.1
15–19	15.0	16.6	31.5	23.6	12.6	.5	.3
19–23	22.2	15.1	21.9	23.9	15.4	1.2	.4
23–27	25.1	14.1	24.3	17.9	14.7	3.5	.5
27–31	11.6	19.6	31.2	27.4	8.5	1.5	.2
31–35	10.5	13.4	25.7	36.0	13.2	1.1	.1
35–39	27.8	21.8	20.5	20.0	8.9	.7	.3
39–42	31.1	25.8	20.9	14.6	6.6	.7	.4
42–46	20.8	38.0	26.4	8.7	5.3	.6	.1
46–50	37.5	27.3	23.1	9.7	2.0	.1	.3
50–51.5	49.1	25.5	15.4	8.4	1.4	.1	.1
51.5–52.5 [1]	---	---	---	---	---	---	---
52.5–54	20.2	27.6	25.5	17.8	6.6	1.4	.9
54–54.5	9.6	26.7	28.9	18.9	9.9	3.5	2.5
Test hole 13-13-32ad							
18–22	2.8	4.3	19.2	41.0	25.4	5.3	2.0
22–26	11.2	14.4	22.4	28.0	19.9	2.8	1.2
26–30	21.2	17.7	23.4	22.0	13.1	1.7	.9
30–34	21.4	22.9	29.9	19.1	5.2	.9	.5
34–38	18.9	17.6	28.5	26.0	7.8	.7	.6
38–42	33.7	20.2	22.1	16.5	5.9	1.0	.5
42–46	3.8	7.6	16.2	33.3	34.5	3.8	.8
46–50	11.6	18.0	23.7	26.4	17.1	2.4	.8
50–54	16.0	18.4	28.7	24.8	11.0	.9	.3
54–58	15.2	17.9	22.4	26.5	15.4	2.1	.5
58–62	14.5	14.4	16.5	31.5	20.5	2.0	.7
62–66	49.8	18.3	12.3	11.8	6.7	.8	.4
66–70	41.3	21.9	21.6	12.2	2.5	.3	.1
70–72 [1]	---	---	---	---	---	---	---
72–76	34.3	25.4	20.3	15.9	3.6	.5	.1
76–80	33.9	29.9	20.9	11.9	3.0	.3	.2
80–84	30.7	24.3	21.9	18.6	3.8	.4	.2
84–88	36.7	34.0	19.8	7.7	1.6	.1	.1
88–92	40.3	32.2	15.7	8.2	2.8	.3	.5
92–94	41.1	24.0	13.8	11.3	8.5	.9	.3

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[1] No sample.

from the fluvial deposits beneath the terrace plain. However, as V. L. Souders (oral commun., 1965) identified crystalline calcite in samples from a hole drilled on the terrace plain a short distance north of the report area, it is likely that calcite is present in at least a few places beneath the part of the terrace plain within the report area. Samples from test hole 13–9–24ddc (about 2 miles north of Ashland and a very short distance downstream from the contact between Cretaceous and Pennsylvanian rocks) contained a few traces of calcite, but samples from the other test holes (all downstream from test hole 13–9–24ddc) contained considerably more. Calcite constituted more than 50 percent of the light minerals in samples from the base of the sand and gravel penetrated by test hole 13–13–29db. It is assumed the calcite grains were derived from limestone fragments that were crushed by the rotary action of the bit when the holes were being drilled. Calcite was the only carbonate mineral identified in any of the samples.

Although constituting a minor percentage of the sediment, the heavy-mineral fraction is more varied in composition. In samples from both the terrace plain and the Platte River valley, the chief heavy minerals were magnetite-ilmenite, zircon, garnet, and hornblende. Other amphiboles, pyroxenes, epidote, tourmaline, sphene, leucoxene, and hematite complete the suite of heavy minerals common to the sand and gravel in both parts of the area. Hematite is less abundant in samples from test holes drilled on the terrace plain than in samples from test holes drilled in the Platte River valley. Moreover, pyrite and limonitic pseudomorphs after pyrite were noted in the Platte River valley samples but were not seen in any of the terrace-plain samples.

OCCURRENCE OF GROUND WATER

The unconsolidated deposits underlying the terrace plain and the Platte River valley are water saturated below a level that ranges in depth from as little as a fraction of a foot to as much as 60 feet below the land surface. The average depth to the water table, or top of the zone of saturation, is considerably greater beneath the terrace plain than beneath the Platte River valley. All the ground water is regarded as under water-table, or nonartesian, conditions even though locally it may be confined under very slight artesian pressure.

As the soils in the area are highly permeable for the most part, they readily absorb rain and meltwater from snow. However, soil permeability is only one of the factors that determines the amount of rain or meltwater that infiltrates to the zone of saturation. The amount of water and the length of time it is available for absorption, the temperature and relative humidity of the air just above the land surface, the moisture content of the soil, and vegetal activity all may be factors

TABLE 3.—*Light and heavy minerals in the*

[Tr.,

Depth (feet)	Heavy minerals (percent)														
	Opaques				Nonopaques										
					Zircon						Tourmaline				
	Magnetite-ilmenite	Leucoxene	Hematite	Total	Colorless	Yellow	Brown	Pink	Total	Sphene	Black	Green-brown	Hypersthene	Hornblende	Actinolite
Test hole															
8.8–10	41	2	2	45	19	8	2	------	29	Tr.	1	2	3	6	------
10–15	34	------	1	35	24	10	2	1	37	Tr.	1	2	1	11	------
15–20	29	2	2	34	23	13	1	------	37	Tr.	1	1	1	14	------
20–25	27	1	3	31	20	12	1	------	33	Tr.	3	2	1	12	------
25–30	42	1	1	44	13	9	1	Tr.	23	------	2	3	1	6	------
30–35	31	------	1	32	18	11	Tr.	------	29	Tr.	1	4	3	14	------
35–40	56	Tr.	1	57	11	9	------	------	20	------	Tr.	1	1	4	------
40–45	38	------	1	39	14	11	Tr.	------	25	Tr.	1	1	1	16	------
45–51	27	------	1	28	20	16	1	------	36	Tr.	1	1	------	16	------
51–56	31	1	4	36	15	12	------	------	27	Tr.	1	2	1	18	------
56–60	39	Tr.	1	40	21	15	Tr.	Tr.	36	Tr.	Tr.	1	Tr.	14	------
60–65	21	Tr.	1	22	23	11	------	Tr.	34	Tr.	1	2	1	22	------
65–70	34	------	1	35	16	18	9	------	43	Tr.	1	2	2	9	------
70–75	35	Tr.	1	36	16	12	4	------	32	Tr.	2	4	3	8	------
75–80	38	Tr.	Tr.	39	18	11	5	------	34	Tr.	2	------	1	7	------
80–85	35	1	2	38	16	9	7	------	32	Tr.	1	------	1	9	------
85–90	34	------	Tr.	34	13	9	6	------	28	Tr.	3	Tr.	------	9	------
90–95	38	Tr.	Tr.	39	16	10	6	------	32	Tr.	4	------	------	8	------
95–101	54	------	------	54	15	3	6	------	24	------	------	------	------	9	------
101–105	26	1	------	27	13	17	11	------	41	------	------	1	1	6	------
105–108.9 [1]	------	------	------	----	----	----	------	------	----	------	------	------	------	----	------
Test hole															
16–21	45	Tr.	1	46	17	10	3	Tr.	30	Tr.	1	5	1	6	------
21–26	41	1	1	43	21	10	1	1	33	Tr.	2	6	------	5	------
26–31	30	1	Tr.	31	22	10	3	------	35	1	2	6	------	9	------
31–36	48	1	3	52	13	7	------	------	20	Tr.	1	2	2	6	Tr.
36–41	32	2	2	36	19	8	3	------	30	Tr.	Tr.	5	Tr.	8	------
41–46	46	3	4	53	17	7	Tr.	------	24	Tr.	1	2	Tr.	3	------
46–51	38	3	3	44	15	9	2	Tr.	26	------	1	3	1	7	------
51–56	30	1	3	34	24	3	1	Tr.	28	1	1	3	Tr.	8	Tr.
56–61	42	------	4	46	13	6	5	------	24	Tr.	1	5	1	5	Tr.
61–66	43	1	3	47	18	6	7	------	31	Tr.	1	5	1	5	Tr.
66–71	54	2	4	60	10	8	6	------	24	Tr.	Tr.	3	------	3	------
71–76	52	------	4	56	15	5	3	------	23	Tr.	2	4	------	4	------
76–81	52	2	2	56	13	7	4	------	24	Tr.	1	4	Tr.	4	------
81–86	41	1	2	44	18	5	4	------	27	1	1	7	Tr.	10	------
86–90	58	1	1	60	9	6	4	------	19	Tr.	1	3	Tr.	4	------
90–95	38	3	3	44	24	2	6	Tr.	32	------	------	4	Tr.	7	------
95–101	50	Tr.	2	52	16	6	7	------	29	Tr.	1	3	------	3	------
101–106	42	------	2	44	12	6	7	------	25	------	------	4	3	7	------
106–110	34	4	2	40	19	5	3	Tr.	27	Tr.	Tr.	3	2	8	------

[1] Heavy-mineral sample lost during analysis.

unconsolidated deposits beneath the terrace plain

trace]

Heavy minerals (percent)—Continued												Light minerals (percent)					
Nonopaques—Continued																	
				Rutile		Garnet						Quartz					
Tremolite	Augite	Diopside	Epidote	Red-brown	Yellow-brown	Colorless	Pink	Total	Biotite	Staurolite	Apatite	Plain	Inclusions	Total	Feldspar (undifferentiated)	Plagioclase	Microcline
14-8-23ccc																	
------	1	------	----	3	------	9	------	9	------	Tr.	------	63	25	88	12	------	----
------	Tr.	------	1	3	------	8	1	9	1	Tr.	------	63	22	85	15	------	----
------	Tr.	------	4	2	------	9	1	10	------	Tr.	------	62	27	89	10	1	----
------	1	1	3	3	------	11	3	14	------	------	------	67	23	90	10	------	----
------	1	Tr.	4	3	------	10	------	10	------	1	------	66	20	86	12	2	----
------	3	------	4	5	------	8	1	9	------	------	------	63	23	86	11	1	----
------	Tr.	------	1	1	------	5	1	6	------	Tr.	------	64	21	85	13	Tr.	Tr.
------	Tr.	------	3	4	------	9	2	11	------	Tr.	------	62	29	91	9	1	----
------	1	------	3	3	------	8	1	9	------	Tr.	------	62	25	87	13	------	Tr.
------	1	------	3	3	------	9	1	10	1	Tr.	------	67	19	86	12	1	1
------	Tr.	------	2	5	Tr.	6	1	7	------	Tr.	Tr.	64	19	83	14	1	----
------	3	------	3	7	------	6	------	6	------	Tr.	Tr.	66	22	88	12	2	----
------	1	------	1	3	------	7	1	8	------	Tr.	------	62	26	88	11	1	----
Tr.	1	------	1	4	------	6	2	8	------	Tr.	------	64	23	87	13	------	----
------	Tr.	------	1	3	------	11	1	12	------	Tr.	------	68	22	90	9	Tr.	Tr.
------	------	------	4	2	------	10	Tr.	10	2	1	------	63	24	87	12	Tr.	Tr.
------	1	------	8	1	------	13	3	16	Tr.	Tr.	Tr.	64	22	86	12	Tr.	1
------	------	------	6	1	------	10	3	13	------	------	Tr.	64	23	87	12	1	1
------	------	------	3	------	------	9	------	9	1	------	------	64	22	86	13	1	----
1	------	------	3	2	------	14	------	14	------	1	------	64	23	87	12	1	Tr.
------	------	------	----	------	------	----	------	----	------	------	------	64	20	84	14	1	Tr.
14-9-20ddd																	
1	1	------	2	2	------	6	1	7	------	Tr.	Tr.	----	----	88	9	2	----
1	1	------	2	3	------	7	1	8	------	------	Tr.	----	----	95	5	------	----
------	1	------	3	1	Tr.	9	2	11	------	Tr.	Tr.	----	----	94	4	1	Tr.
Tr.	1	------	2	1	------	10	3	13	------	Tr.	Tr.	----	----	94	6	1	----
Tr.	Tr.	------	3	Tr.	------	14	2	16	------	Tr.	------	----	----	93	5	3	----
------	1	Tr.	2	------	------	8	2	10	------	Tr.	------	79	14	93	7	------	----
Tr.	Tr.	------	2	2	------	7	2	9	------	Tr.	------	67	28	95	4	4	Tr.
------	1	Tr.	2	1	Tr.	11	2	13	Tr.	Tr.	------	61	30	91	9	------	----
------	1	------	4	2	------	8	2	10	------	Tr.	Tr.	63	30	93	6	------	----
------	1	Tr.	1	2	------	8	1	9	------	------	------	63	27	90	9	------	----
------	1	------	1	2	------	7	2	9	------	Tr.	------	62	29	91	9	Tr.	Tr.
------	1	------	2	2	------	7	1	8	------	------	------	71	19	90	9	1	----
Tr.	1	------	2	2	------	6	2	8	------	Tr.	------	73	23	96	6	------	----
------	1	------	4	2	------	3	------	3	------	Tr.	Tr.	63	27	90	10	------	Tr.
------	1	------	2	Tr.	------	5	2	7	------	1	------	66	23	89	9	2	----
------	Tr.	------	3	1	------	7	3	10	------	1	------	72	20	92	8	------	----
------	1	------	1	1	------	4	2	6	Tr.	Tr.	Tr.	70	25	95	5	------	----
1	1	------	3	1	------	7	1	8	------	------	Tr.	77	19	96	4	------	----
------	1	------	3	3	------	9	2	11	------	1	------	76	19	95	4	Tr.	1

TABLE 3.—*Light and heavy minerals in the unconsolidated*

[Tr.,

Depth (feet)	Heavy minerals (percent)														
	Opaques				Nonopaques										
					Zircon						Tourmaline				
	Magnetite-ilmenite	Leucoxene	Hematite	Total	Colorless	Yellow	Brown	Pink	Total	Sphene	Black	Green-brown	Hypersthene	Hornblende	Actinolite
															Test hole
12.5–15	32	Tr.	1	33	18	15	2	------	35	1	3	------	1	9	------
15–20	25	2	2	29	34	9	1	------	44	------	1	5	Tr.	6	------
20–25	26	1	3	30	23	7	1	------	31	Tr.	1	4	Tr.	8	------
25–30	51	1	1	53	16	8	1	------	25	------	Tr.	2	Tr.	5	------
30–35	34	Tr.	2	36	19	12	3	------	34	1	------	5	Tr.	6	------
35–40	33	------	1	34	23	14	1	------	38	------	------	3	Tr.	7	------
40–45	29	3	2	34	12	9	9	------	30	Tr.	------	8	Tr.	8	------
45–50	34	1	3	38	16	7	4	------	27	------	1	5	1	8	------
50–55	48	Tr.	2	50	18	5	6	------	29	Tr.	3	5	Tr.	4	------
55–60	36	------	2	38	23	7	5	------	35	1	1	5	------	5	Tr.
60–65	19	Tr.	2	21	25	13	12	------	50	Tr.	2	4	Tr.	6	------
65–70	31	1	3	35	13	10	10	------	33	------	2	8	Tr.	8	Tr.
70–75	30	3	2	35	24	8	8	------	40	Tr.	------	5	Tr.	4	------
75–80	24	3	3	30	15	7	11	------	33	Tr.	1	7	Tr.	11	Tr.
80–86	26	3	2	31	28	7	10	1	45	1	1	6	Tr.	5	Tr.
86–90	29	2	1	32	15	8	13	------	36	------	1	9	1	6	Tr.
90–95	33	------	1	34	18	8	9	------	35	1	2	4	Tr.	6	Tr.
95–100	35	1	3	39	19	7	8	------	34	Tr.	Tr.	6	2	4	------
100–105	29	2	3	34	11	11	9	------	31	------	1	6	Tr.	4	------
105–111	48	------	Tr.	48	13	7	6	------	26	------	1	5	2	5	------

deposits beneath the terrace plain—Continued

trace

Heavy minerals (percent)—Continued												Light minerals (percent)					
Nonopaques—Continued																	
				Rutile		Garnet						Quartz					
Tremolite	Augite	Diopside	Epidote	Red-brown	Yellow-brown	Colorless	Pink	Total	Biotite	Staurolite	Apatite	Plain	Inclusions	Total	Feldspar (undifferentiated)	Plagioclase	Microcline
14-9-30ddd																	
------	1	------	7	2	------	8	1	9	------	Tr.	------	66	19	85	14	1	----
Tr.	1	------	4	1	------	9	3	12	------	Tr.	------	63	24	87	13	------	1
Tr.	1	------	6	3	------	13	1	14	------	Tr.	------	62	25	87	10	1	----
------	1	------	3	1	------	7	2	9	Tr.	------	------	66	22	88	11	2	----
------	1	------	3	2	------	7	3	10	------	Tr.	------	62	26	88	11	1	----
Tr.	1	------	3	2	------	12	2	14	------	Tr.	Tr.	67	20	87	11	1	----
Tr.	Tr.	------	5	2	------	8	1	9	------	------	------	68	21	89	11	1	----
------	Tr.	------	4	2	------	10	1	11	------	Tr.	Tr.	59	26	84	14	1	----
------	Tr.	------	3	2	------	9	Tr.	9	------	Tr.	------	69	18	87	12	1	----
Tr.	1	------	3	2	------	6	3	9	------	------	------	59	25	84	14	1	Tr.
Tr.	------	------	4	2	------	9	2	11	Tr.	Tr.	------	62	23	85	13	Tr.	1
------	1	Tr.	3	2	------	10	1	11	------	------	------	58	26	84	16	1	Tr.
------	1	------	2	2	------	8	1	9	------	1	Tr.	68	19	87	11	1	Tr.
------	------	------	4	1	------	17	Tr.	17	------	Tr.	1	69	17	86	13	1	Tr.
Tr.	Tr.	------	2	1	------	7	2	9	------	------	Tr.	66	19	85	13	1	Tr.
1	1	Tr.	3	4	------	8	2	10	------	------	------	63	22	84	13	1	Tr.
Tr.	1	------	4	2	------	7	2	9	------	Tr.	Tr.	64	20	84	14	2	1
------	2	------	3	3	------	6	1	7	------	Tr.	Tr.	56	28	84	14	1	----
------	1	------	4	1	Tr.	10	2	12	------	Tr.	Tr.	61	23	84	15	2	----
------	2	------	4	2	------	9	1	10	------	------	1	65	22	87	12	1	1

TABLE 4.—*Light and heavy minerals in the unconsolidated*

[Tr.,

Depth (feet)	Heavy minerals (percent)																
	Opaques						Nonopaques										
							Zircon						Tourmaline				
	Magnetite-ilmenite	Leucoxene	Hematite	Pyrite	Limonite	Total	Colorless	Yellow	Brown	Pink	Total	Sphene	Black	Green-brown	Hypersthene	Hornblende
Test hole																
12.4–15	14	Tr.	14	7	1	36	16	6	4	-----	26	1	-----	2	Tr.	16
15–20	36	-----	2	3	-----	41	12	5	4	-----	21	1	-----	1	-----	13
20–23.2	31	Tr.	8	8	2	49	15	3	3	Tr.	21	1	Tr.	3	1	14
23.2–25 [1]	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
25–30	24	-----	5	10	2	41	17	7	6	-----	30	2	Tr.	4	Tr.	12
30–35	25	-----	4	8	1	38	19	5	3	-----	27	1	Tr.	3	Tr.	10
35–40	43	1	4	3	2	53	15	1	3	-----	19	2	1	1	Tr.	10
40–45	32	-----	5	2	1	40	10	7	6	-----	23	2	-----	2	-----	11
45–50	30	Tr.	Tr.	4	4	39	16	8	2	Tr.	26	1	-----	1	Tr.	11
50–55	38	Tr.	3	2	Tr.	44	14	4	2	-----	20	1	-----	3	1	18
55–60	51	1	2	1	1	56	10	8	4	-----	22	1	-----	1	-----	7
60–68.5	41	1	1	1	-----	44	14	3	3	-----	20	1	Tr.	3	-----	21
68.5–70	35	3	1	2	-----	41	14	7	4	Tr.	25	2	-----	5	1	15
70–75	25	3	3	Tr.	-----	31	11	6	4	-----	21	-----	-----	2	3	24
75–80	24	2	5	-----	Tr.	31	14	3	4	-----	21	Tr.	-----	4	Tr.	26
80–84.5	19	-----	6	1	1	27	6	7	5	-----	18	-----	-----	1	1	33
Test hole																
1.5–5	22	1	4	1	-----	28	15	11	7	-----	33	-----	-----	3	2	22
5–10	21	3	1	-----	-----	25	10	4	4	-----	18	1	-----	4	Tr.	30
10–15	26	3	4	-----	-----	33	10	6	4	-----	20	-----	-----	3	-----	16
20–25	36	2	3	-----	-----	41	12	9	4	1	26	-----	-----	5	1	16
25–30	23	1	5	Tr.	Tr.	29	22	7	3	1	33	-----	Tr.	2	1	13
30–35	24	1	6	-----	Tr.	31	16	9	3	Tr.	28	Tr.	-----	3	2	18
35–40	36	1	4	Tr.	-----	41	17	8	1	1	27	Tr.	-----	5	Tr.	13
40–45	10	3	3	-----	-----	16	18	8	3	-----	29	-----	-----	6	Tr.	32
45–50	27	2	4	-----	-----	33	18	6	3	Tr.	27	Tr.	-----	2	1	21
50–55	25	1	3	-----	Tr.	29	22	8	4	-----	34	Tr.	-----	4	1	13
55–60 [1]	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
60–65	40	Tr.	1	-----	-----	41	22	4	3	1	30	Tr.	Tr.	3	1	9
65–70	35	2	1	-----	-----	38	21	8	1	-----	30	1	-----	2	1	10
70–75	22	1	5	-----	-----	28	20	8	4	Tr.	32	1	-----	2	1	13
75–80	33	1	4	-----	-----	38	12	4	1	Tr.	17	-----	Tr.	3	1	23
80–85	19	2	6	-----	-----	27	18	6	5	-----	29	-----	-----	6	2	25
85–90	39	1	2	1	-----	43	10	4	5	1	20	-----	-----	4	1	14
90–93	33	3	1	-----	-----	37	19	8	1	-----	29	1	-----	3	1	12
93–95	5	1	7	1	-----	14	9	4	1	-----	14	-----	-----	4	3	35
Test hole																
10–15	14	1	9	-----	5	29	13	7	4	Tr.	24	1	-----	1	2	9
15–20	12	-----	8	-----	4	24	14	Tr.	3	-----	17	1	-----	2	3	18
20–25	11	-----	10	-----	4	25	7	4	4	-----	15	Tr.	-----	2	1	17
25–30	12	-----	12	Tr.	5	29	5	2	4	-----	11	-----	-----	Tr.	3	14
30–35	23	-----	4	Tr.	-----	27	7	1	3	Tr.	11	Tr.	-----	Tr.	2	13
35–40	37	Tr.	2	Tr.	-----	39	6	1	-----	-----	7	-----	Tr.	2	2	8
40–45	26	-----	10	Tr.	3	39	8	1	1	-----	10	-----	-----	1	1	8
45–50	28	Tr.	3	1	-----	32	8	2	3	-----	13	Tr.	-----	Tr.	1	6
50–58	23	1	6	Tr.	-----	30	4	2	1	-----	7	Tr.	-----	2	4	8
58–60	22	1	9	Tr.	Tr.	33	5	1	1	-----	7	-----	-----	2	5	10

[1] No sample.

deposits beneath the Platte River flood plain

trace]

Heavy minerals (percent)—Continued												Light minerals (percent)						
Nonopaques—Continued																		
						Garnet						Quartz						
Actinolite	Tremolite	Augite	Diopside	Epidote	Rutile (red-brown)	Colorless	Pink	Total	Biotite	Staurolite	Apatite	Plain	Inclusions	Total	Feldspar (undifferentiated)	Plagioclase	Microcline	Calcite
13-9-24ddc																		
------	Tr.	------	------	4	Tr.	6	2	8	Tr.	2	------	56	34	90	9	------	Tr.	------
------	Tr.	Tr.	------	4	3	8	2	10	------	2	Tr.	58	34	92	7	------	------	------
1	Tr.	------	------	5	2	5	1	6	Tr.	1	Tr.	57	34	91	8	------	------	------
------	1	------	------	3	2	5	------	5	------	1	------	56	37	93	8	------	------	------
1	Tr.	Tr.	------	3	1	12	1	13	Tr.	1	------	52	40	92	7	------	------	------
------	------	2	------	1	1	7	1	8	------	1	1	50	39	89	10	------	------	Tr.
Tr.	------	------	------	2	1	12	1	13	------	1	Tr.	51	38	89	10	------	------	Tr.
------	Tr.	Tr.	------	2	1	8	1	9	------	1	1	46	39	85	13	------	------	1
------	------	Tr.	------	2	2	8	2	10	------	Tr.	Tr.	48	40	88	10	Tr.	------	2
------	------	Tr.	------	1	1	8	4	12	------	Tr.	------	45	41	86	12	Tr.	------	1
------	Tr.	------	------	5	1	4	2	6	Tr.	1	------	49	40	89	11	------	------	Tr.
------	------	1	------	3	1	6	2	8	------	1	Tr.	48	41	89	11	------	Tr.	1
Tr.	------	2	------	4	1	8	1	9	------	1	------	49	38	87	12	------	------	------
------	Tr.	Tr.	------	5	Tr.	6	2	8	Tr.	Tr.	------	47	42	89	10	------	1	------
------	1	------	------	4	1	7	1	8	------	1	1	50	40	90	10	------	------	------
13-11-36dad																		
------	------	Tr.	------	4	2	7	3	10	------	Tr.	------	44	45	89	10	------	------	------
------	------	------	------	5	3	12	3	15	------	Tr.	------	50	36	86	14	------	------	Tr.
Tr.	------	2	------	5	1	16	3	19	------	Tr.	------	49	40	89	11	------	------	Tr.
------	------	------	------	2	2	5	3	8	Tr.	1	------	55	36	91	8	------	------	Tr.
------	Tr.	3	------	2	1	12	3	15	Tr.	2	Tr.	49	40	89	10	------	------	------
------	------	1	Tr.	2	2	7	4	11	------	Tr.	------	48	40	88	12	------	Tr.	Tr.
------	------	------	------	2	1	5	2	7	Tr.	Tr.	------	48	40	88	12	------	Tr.	------
------	------	------	------	6	2	5	------	5	------	Tr.	------	48	41	89	9	1	------	1
------	------	2	------	3	2	7	1	8	Tr.	1	------	54	36	90	10	------	------	Tr.
------	------	1	------	2	4	5	1	6	------	1	Tr.	56	30	86	11	Tr.	------	Tr.
------	------	------	------	1	1	8	2	10	Tr.	Tr.	Tr.	58	30	88	11	------	------	1
------	Tr.	1	------	1	1	9	3	12	------	Tr.	------	58	31	89	11	------	Tr.	------
------	------	1	------	3	2	12	5	17	------	Tr.	------	58	32	90	10	------	------	------
------	------	------	------	3	2	9	3	12	1	1	------	60	28	88	12	------	------	------
------	------	2	------	4	4	3	2	5	------	------	------	56	29	85	15	------	------	------
------	------	------	------	1	------	8	2	10	1	1	1	61	27	88	12	Tr.	------	1
------	1	------	------	3	2	10	2	12	------	------	1	58	30	88	11	Tr.	Tr.	1
------	------	3	------	7	7	7	------	7	1	------	1	56	29	85	10	1	------	3
13-13-24ddd																		
1	------	11	------	3	3	13	3	16	1	3	------	57	30	87	12	------	Tr.	------
1	------	19	------	3	3	8	2	10	1	2	------	62	28	90	10	1	------	Tr.
------	------	23	------	3	2	7	2	9	1	Tr.	1	54	30	84	13	------	------	Tr.
------	------	34	------	1	3	6	1	7	Tr.	Tr.	------	54	31	85	11	1	------	1
------	------	36	------	1	2	6	Tr.	6	Tr.	Tr.	Tr.	57	30	87	13	Tr.	------	Tr.
Tr.	------	28	------	1	3	5	1	6	Tr.	1	1	59	29	88	12	------	------	Tr.
------	------	31	------	Tr.	1	5	------	5	------	Tr.	------	58	30	88	13	1	------	2
------	------	36	------	Tr.	2	4	1	5	------	Tr.	Tr.	59	27	86	12	------	------	1
------	------	40	------	2	2	7	1	8	Tr.	------	Tr.	52	30	82	12	------	------	6
------	------	37	------	Tr.	2	5	3	8	Tr.	Tr.	------	51	32	83	10	Tr.	------	7

TABLE 4.—*Light and heavy minerals in the unconsolidated*

[Tr.,

Depth (feet)	Heavy minerals (percent)															
	Opaques						Nonopaques									
							Zircon						Tourmaline			
	Magnetite-ilmenite	Leucoxene	Hematite	Pyrite	Limonite	Total	Colorless	Yellow	Brown	Pink	Total	Sphene	Black	Green-brown	Hypersthene	Hornblende
Test hole																
60-65	22	3	10	Tr.	1	36	2	1	2		5			1	3	10
65-70	24	3	6	Tr.		33	7	1	3		11	Tr.		1	1	8
70-75	25	2	12	Tr.		39	7	1	1		9			2	3	9
75-80	14	2	11	Tr.		27	6	3	2		11	1		1	2	8
80-85	14	4	18	Tr.	1	37	4	Tr.	2		6	1		1	Tr.	12
85-90	29	3	4			36	4	2	2	Tr.	8	1		1	2	13
90-95	29	3	9	Tr.	Tr.	42	7	4	3		14	1	Tr.	2	1	11
95-100	26	1	10	5	3	45	10	1	4		15	1		Tr.	2	8
100-105	29	1	9	2		41	11	1	3		15	Tr.		1	1	7
105-110	22	1	8	Tr.		31	7	1	2		10	Tr.		1	2	9
110-114.2	27	1	8			36	12	2	2	Tr.	16	Tr.		2	3	11
Test hole																
2.6-7	29	1	2			32	11	9	2		22	1		4	1	17
7-11	32	1	1			34	10	6	3	Tr.	19			1	2	19
11-15	29	1	4			34	15	6	2		23			3	1	30
15-19	36	1	3			40	14	6	3	Tr.	23	1		4		18
19-23	25	Tr.	2			27	12	4	2	Tr.	18	1		2	2	31
23-27	18	1	2			21	12	6	5		23	Tr.	Tr.	1	1	30
27-31	26	1	4			31	13	6	5		24	Tr.	Tr.	3	2	27
31-35	31	1	4			36	10	3	5		18		Tr.	2	2	26
35-39	35	1	5			41	8	4	1		13			1	2	25
39-42	21	2	4			27	10	5	4	Tr.	19			2	2	30
42-46	20	2	7			29	22	6	2		30	Tr.		1	Tr.	18
46-50	26	4	7	Tr.		37	13	3	1		17	Tr.		3	1	21
50-51.5	55	1	7			63	7	4	1	Tr.	12			2	1	9
51.5-52.5 [1]																
52.5-54	25	Tr.	22	1	1	49	7	4	2	Tr.	13			Tr.	Tr.	18
54-54.5	23	2	22			47	8	1	1	Tr.	10			1	1	31
Test hole																
18-22	23	1	1			25	16	4	4		24		Tr.	5	1	22
22-26	31	1	1	Tr.		33	14	6	4	Tr.	24	Tr.		4	3	19
26-30	34	1	2	Tr.		37	13	5	2	Tr.	20	1		4		20
30-34	41	Tr.	2	Tr.		43	10	5	3	Tr.	18	1		4	Tr.	21
34-38	47	Tr.	2	Tt.		49	10	5	3	1	19	1	1	3	1	14
38-42	28	1	3	Tr.		32	9	7	7		25		Tr.	4	1	19
42-46	24	1	4			29	15	6	5		26	Tr.		3	Tr.	16
46-50	47	1	3			51	12	5	4	Tr.	21	1	Tr.	2	2	10
50-54	28	2	4			34	18	4	5	Tr.	27	Tr.		2	2	20
54-58	35	Tr.	1	1		38	14	7	4	Tr.	25	Tr.		4	1	13
58-62	31	1	3	Tr.		35	11	4	4	Tr.	19		Tr.	3	1	22
62-66	36	2	5			43	9	4	4	Tr.	17		Tr.	2	1	24
66-70	28	1	8	Tr.		37	9	5	5		19			4	1	20
70-72 [1]																
72-76	16	1	18	Tr.		35	11	1	3		15	Tr.		4	1	28
76-80	20	1	22	Tr.		43	7	1	5	Tr.	13	Tr.		1		31
80-84	9	1	27			37	10	3	1	Tr.	14			2	Tr.	34
84-88	12	1	23			36	7	3	1		11			1	Tr.	34
88-92	21	Tr.	16	Tr.		37	11	6	3	1	21	Tr.		1	1	24
92-94	28	1	14			43	12	5	4	Tr.	21			1		22

---

[1] No sample.

deposits beneath the Platte River flood plain—Continued

trace]

Heavy minerals (percent)—Continued												Light minerals (percent)						
Nonopaques—Continued																		
						Garnet						Quartz						
Actinolite	Tremolite	Augite	Diopside	Epidote	Rutile (red-brown)	Colorless	Pink	Total	Biotite	Staurolite	Apatite	Plain	Inclusions	Total	Feldspar (undifferentiated)	Plagioclase	Microcline	Calcite
13-13-24ddd—Continued																		
------	------	34	------	2	3	5	3	8	1	Tr.	------	55	29	84	9	------	------	6
------	------	38	------	1	1	4	2	6	------	Tr.	Tr.	59	26	85	9	------	------	5
------	------	31	------	2	2	3	3	6	------	Tr.	Tr.	61	25	86	10	------	------	4
------	------	38	------	1	6	3	4	7	1	Tr.	1	65	22	87	12	------	------	3
------	------	34	------	1	2	4	3	7	Tr.	Tr.	Tr.	55	29	84	10	------	------	6
------	------	28	------	1	2	5	1	6	------	Tr.	Tr.	60	25	85	9	------	------	6
------	------	22	------	1	1	5	2	7	1	Tr.	Tr.	57	24	81	9	Tr.	------	9
------	------	24	------	1	Tr.	2	1	3	Tr.	------	Tr.	55	28	83	8	1	------	8
Tr.	------	26	------	2	1	4	3	7	Tr.	------	Tr.	53	29	82	10	------	------	7
------	Tr.	35	------	1	1	3	2	5	1	Tr.	Tr.	56	25	81	8	------	Tr.	10
------	------	13	------	2	1	13	3	16	Tr.	1	------	56	24	80	6	------	------	13
13-13-29db																		
------	------	3	Tr.	2	2	11	4	15	------	Tr.	Tr.	72	19	91	8	------	------	Tr.
------	------	2	------	1	2	12	6	18	------	Tr.	Tr.	61	30	91	8	------	------	1
------	------	1	------	3	2	4	2	6	Tr.	Tr.	Tr.	57	32	89	9	------	------	1
------	------	2	------	2	1	7	1	8	Tr.	Tr.	------	62	30	92	5	------	1	1
------	------	2	------	4	1	7	1	8	Tr.	1	Tr.	58	30	88	10	------	------	1
Tr.	------	4	------	5	3	8	2	10	Tr.	Tr.	Tr.	57	31	88	9	------	1	1
------	------	3	------	4	3	5	3	8	------	Tr.	Tr.	54	34	88	10	------	2	1
Tr.	------	3	------	3	2	5	5	10	------	Tr.	------	54	34	88	8	1	1	2
------	Tr.	4	------	3	1	4	2	6	------	Tr.	1	52	36	88	9	------	1	2
Tr.	------	4	------	3	2	7	3	10	Tr.	1	Tr.	51	33	84	10	------	1	5
------	------	3	------	4	3	7	3	10	Tr.	1	------	53	34	87	10	------	------	3
------	------	3	------	5	3	7	2	9	------	Tr.	Tr.	52	33	85	10	------	1	5
------	Tr.	------	------	2	3	2	2	4	------	1	Tr.	52	28	90	11	------	Tr.	7
Tr.	Tr.	------	------	2	2	7	4	11	------	1	------	32	8	40	5	1	1	54
Tr.	------	4	------	2	1	1	Tr.	1	Tr.	Tr.	Tr.	28	2	30	5	1	Tr.	64
13-13-32ad																		
------	------	------	------	6	5	11	2	13	Tr.	2	------	68	22	90	9	Tr.	Tr.	1
------	------	------	------	6	2	9	3	12	Tr.	Tr.	------	77	14	91	8	------	------	1
Tr.	Tr.	------	------	6	1	12	1	13	------	1	------	73	16	89	7	1	Tr.	1
------	------	1	------	6	2	6	1	7	Tr.	Tr.	------	80	13	93	7	------	------	Tr.
Tr.	------	1	------	3	2	6	2	8	Tr.	1	------	63	29	92	7	------	------	------
------	Tr.	1	------	5	1	9	4	13	Tr.	1	------	75	16	91	10	------	------	Tr.
Tr.	------	1	------	6	3	10	5	15	------	1	Tr.	71	20	91	8	------		------
------	------	1	------	3	1	9	2	11	Tr.	1	------	76	16	92	7	1	Tr.	------
------	------	1	------	4	2	9	2	11	------	Tr.	------	67	24	91	8	------	------	1
------	------	Tr.	Tr.	5	4	9	2	11	Tr.	1	Tr.	73	19	92	7	------	Tr.	1
------	------	2	------	6	3	7	1	8	Tr.	Tr.	------	68	22	90	8	------	------	2
------	Tr.	Tr.	------	4	2	7	1	8	Tr.	Tr.	------	65	28	93	7	------	------	1
------	Tr.	1	Tr.	7	2	7	3	10	1	Tr.	------	66	25	91	6	------	Tr.	2
Tr.	Tr.	1	------	6	------	3	2	5	Tr.	Tr.	Tr.	72	19	91	8	------	1	Tr.
------	------	Tr.	------	4	2	3	1	4	Tr.	Tr.	------	71	18	89	8	------	------	3
------	Tr.	Tr.	Tr.	5	2	4	1	5	1	Tr.	------	75	13	88	6	------	------	5
Tr.	Tr.	1	------	8	1	6	1	7	1	1	Tr.	68	22	90	7	------	------	2
------	Tr.	1	------	3	2	5	1	6	1	1	Tr.	72	16	88	7	------	------	6
------	------	------	------	4	3	3	3	6	1	1	------	65	20	85	7	------	2	6

in varying degree. Even rather light precipitation can be an effective source of recharge if the soil is already moist, vegetation is dormant, and humidity is high. Conversely, heavy rain may result in little or no recharge if the soil is deficient in moisture, plants are growing rapidly, and the evaporation potential is high. The amount of recharge ranges widely from year to year and from one part of the area to another within the same year.

Most of the valley lands are subject to flooding. Where flooding occurs, the unconsolidated deposits generally become saturated to the land surface, but when the flood water recedes, the water table soon lowers to its more usual position owing to the combined effects of evaporation, transpiration of vegetation, and subsurface drainage.

The Platte River and the lower reaches of the other streams in the area are, in most places, hydraulically continuous with the zone of saturation in the unconsolidated deposits. Thus, whenever the stage of the river is higher than that of the water table, water percolates out of the stream and into the unconsolidated deposits. Because the Platte and Elkhorn Rivers and Wahoo and Salt Creeks are never completely dry within this area, they are a potential source of recharge in any reach where, for a time, the adjacent water table is lowered below stream level. The quantities of water that move out of the streams into the unconsolidated deposits cannot be determined from currently available information. It has been variously estimated that more than 50 percent and possibly as much as 90 percent of the water yielded by wells in the Lincoln well field is induced seepage from the Platte River.

Inflow from the adjacent bedrock also may be a source of water in the unconsolidated deposits. Although, compared to recharge from other sources, the quantity of such inflow is likely of little significance, it may account for some local differences in the chemical quality of the water. Probably, however, differences in the quality of the water in the unconsolidated deposits are due far less to inflow from the bedrock than to differences in the mineral composition of the unconsolidated deposits through which the water has percolated.

As shown by a water-table-configuration map prepared by Souders (1967), the ground water in the Quaternary deposits beneath the terrace plain percolates generally southeastward. Apparently, however, none percolates far enough to merge eventually with the underflow in the Platte River valley. Instead, part is discharged by evapotranspiration where the water table is within the reach of plant roots, and the remainder discharges directly into Clear, Silver, and Wahoo Creeks.

Souder's map also shows that the ground water in the area between the Platte River valley and Clear Creek percolates south and south-southwestward. Near the Platte the direction of percolation is nearly parallel to the river and farther westward it is toward Clear Creek. As pumping at the Lincoln city well field has created a trough in the water table, the direction of percolation in the vicinity of the well field is toward the axis of that trough. The approximate extent of the area throughout which ground water moves toward the well field is indicated by stippling in figure 1.

Elsewhere in the Platte River valley the direction of ground-water movement presumably is either parallel to or toward the principal surface drainage channels. Withdrawals for Allied Chemical Corp. and evaporation from the several gravel pits excavated below the water table result in local deviations from the natural direction of ground-water movement.

GEOCHEMICAL METHODS

A study was made of reactions involving the atmosphere, the ground water, and the solid phases identified in the petrographic study. Also considered was the possibility of reactions with organic matter.

The pertinent reaction for the effect of the atmosphere is

$$CO_{2(aq)} = CO_{2(g)}. \tag{1}$$

For any particular concentration of $CO_{2(aq)}$ (undissociated carbon dioxide in solution) there would be, at any temperature, a partial pressure (P_{CO_2}) in the gas in equilibrium with the solution. As shown by Keeling (1960), the concentration of carbon dioxide in the atmosphere is uniform. For the calculation of the P_{CO_2} in the atmosphere, only the barometric pressure (or air temperature and elevation) needs to be known. The P_{CO_2} in equilibrium with a water sample may be calculated according to the equation

$$H^+ + HCO_3^- = H_2O + CO_{2(g)} \tag{2}$$

from

$$P_{CO_2} = K_1 \cdot 10^{-pH} \cdot \gamma_{HCO_3^-} \cdot m_{HCO_3^-}, \tag{3}$$

where

γ = activity coefficient,

m = molality,

and

$pH \equiv -\log \alpha_{H^+}$,

where

α = activity.

A comparison of the $P_{\mathrm{CO_2}}$ in the atmosphere with the $P_{\mathrm{CO_2}}$ in the water sample provides a test for equilibrium.

A test for chemical equilibrium between calcite and coexisting water is provided by the following equations:

$$\mathrm{CaCO_3\ (calcite)=Ca^{+2}+CO_3{}^{-2}} \qquad (4)$$

$$\mathrm{CO_3{}^{-2}+H^{+1}=HCO_3{}^{-1}} \qquad (5)$$

$$\mathrm{HCO_3{}^{-1}+H^{+1}=CO_2+H_2O} \qquad (6)$$

$$\mathrm{H^{+1}+OH^{-1}=H_2O} \qquad (7)$$

For reaction 4 the ion activity product, *IAP*, is defined as

$$IAP \equiv \alpha_{\mathrm{Ca}}{}^{+2} \cdot \alpha_{\mathrm{CO_3}}{}^{-2} \qquad (8)$$

The activities of the ions were calculated from the concentration of the ions by the equation

$$\alpha = m\gamma.$$

The ion activity coefficients were determined from the Debye-Hückel equation (Klotz, 1950, p. 328–336). The activity of the carbonate ion, $\alpha_{\mathrm{CO_3}}{}^{-2}$, is calculated from the equation

$$K_2 = \frac{\alpha_{\mathrm{H}}{}^{+1} \cdot \alpha_{\mathrm{CO_3}}{}^{-2}}{\alpha_{\mathrm{HCO_3}}{}^{-1}} = \frac{10^{-\mathrm{pH}} \cdot \alpha_{\mathrm{CO_3}}{}^{-2}}{\alpha_{\mathrm{HCO_3}}{}^{-1}}$$

where K_2 is the equilibrium constant of the second dissociation of carbonic acid and its value is a function of temperature. The pH was determined by the method described by Barnes (1964). Both pH and $m_{\mathrm{HCO3}}{}^{-1}$ were measured in the field to avoid changes that might occur during storage. Samples for calcium analyses were acidified to preclude losses by precipitation in the sample bottles. Values used for the equilibrium constants of equations 4, 5, and 6 are from Larson and Buswell (1942, p. 1673), Harned and Scholes (1941, p. 1706), and Harned and Davis (1943, p. 2030), respectively.

The equilibrium constant, K_{calcite}, for reaction 4 can be compared with the ion activity product, *IAP*, for the same reaction to test for saturation with respect to calcite. At any temperature, a solution is saturated if the *IAP* equals K_{calcite}, unsaturated if IAP/K_{calcite} is less than 1, and supersaturated if IAP/K_{calcite} is more than 1.

The ion activity products of reactions for the solution of dolomite, calcite, aragonite, magnesite, and gypsum can be calculated by a computer program of the U.S. Geological Survey. Accurate data as to the pH of the water, temperature of the water, barometric pressure at time of analysis, and concentrations of the major ions in solution (especially calcium, carbonate, and bicarbonate ions) are necessary if the results are to be meaningful. Because calcite is the only carbonate mineral found in the unconsolidated deposits, the saturation of the water was considered only in terms of calcite.

Water from 10 wells on the terrace plain, 42 wells on the Platte River flood plain, and one location on the Platte River was sampled during this investigation; of the 42 wells on the Platte River flood plain, 33 were in the Lincoln city well field (fig. 3). Dissolved oxygen analyses were made in the field. The other chemical constituents (calcium, magnesium, sodium, potassium, sulfate, and chloride) were determined in the laboratory.

GEOCHEMICAL INTERPRETATIONS

GROUND WATER BENEATH THE TERRACE PLAIN

The water from each of the 10 wells on the terrace plain was unsaturated with respect to calcite, the most probable $IAP/K_{calcite}$ values ranging from 0.141 to 0.881 (table 5). Although water from well 14–8–1dcc approached saturation with respect to calcite, the maximum $IAP/K_{calcite}$ for all the other samples was 0.671. The unsaturation with respect to calcite could be expected because calcite is such an uncommon constituent of the unconsolidated deposits within the zone of saturation beneath the terrace plain. If generally present in the unconsolidated deposits earlier, the calcite has been leached from them in the meantime.

TABLE 5.—*Selected properties and constituents of ground water beneath the terrac plain*

Well	Temperature (°F)	pH	P_{CO_2} (most probable value)		Dissolved CO_2 (ppm)	Ca^{+2} (ppm)	$IAP/K_{calcite}$			SO_4^{-2} (ppm)	Dissolved O_2 (ppm)
			Atmosphere (atm × 10^{-3})	Ground water (atm × 10^{-3})			Maximum	Minimum	Most probable value		
13–9–6dbc	55.0	7.21	0.29	8.97	19.28	42	0.204	0.165	0.185	25	6.8
14–8–1cac	56.7	7.14	.29	19.5	40.80	76	.543	.443	.497	36	1.4
1dcc	55.9	7.29	.29	13.5	28.59	103	.968	.791	.881	122	1.3
2caa	57.7	7.13	.29	22.0	45.23	84	.671	.548	.616	36	.0
23daa	54.7	7.01	.29	17.6	38.13	50	.187	.145	.167	27	3.9
14–9–17dda	54.9	7.11	.29	15.5	33.47	63	.335	.237	.285	45	3.4
18cbc	55.6	7.00	.29	25.7	54.77	80	.392	.320	.359	46	.7
19daa	54.0	7.09	.29	16.4	35.98	62	.296	.219	.258	43	2.4
20add	55.8	6.98	.29	18.1	38.58	57	.211	.134	.171	55	5.7
34bbd	54.0	7.11	.29	10.9	24.02	46	.157	.121	.141	64	5.8

No areal pattern of variation of $IAP/K_{calcite}$ was apparent, possibly because too few samples were collected. Factors that may affect the ratio are differences in the permeability and mineral composition of the unconsolidated deposits, in type of soil, and in vegetation. If consideration is given to each of these, it is not surprising to find variation in the properties of the ground water.

The calcium concentration ranges from 42 to 103 ppm (parts per million) and generally increases as IAP/K_{calcite} increases. Because the water-bearing unconsolidated deposits beneath the terrace plain contain almost no calcite or other calcium carbonate minerals, the major source of calcium ions in the ground water probably is the unsaturated deposits through which recharge to the zone of saturation must filter. These unsaturated deposits consist largely of loess, which still is calcareous at depth even though its upper part is leached deeply throughout much of the area. Solution of calcium carbonate in the loess by infiltrating water may be sufficient to account for much of the calcium in the ground water. Low values of IAP/K_{calcite} may reflect recharge through loess from which most of the calcite has been leached, and high values may reflect recharge through loess that has not been leached so deeply.

As the unconsolidated deposits beneath the terrace plain are in direct contact with water-bearing Cretaceous sandstones, inflow from those rocks possibly could account for some of the dissolved minerals in the water from the sampled wells. However, the chloride content of water in the Cretaceous sandstones generally is moderately high, whereas the maximum in the samples was only 14 ppm. Therefore, either inflow from Cretaceous sandstones is insignificant in amount or, if significant, the water in the Cretaceous sandstones is much less saline in this vicinity than elsewhere. None of the water in the unconsolidated deposits beneath the terrace plain has been in contact with Pennsylvanian limestones or shales, so no part of the dissolved-mineral content can be attributed to that source.

Table 5 shows that the P_{CO_2} in the ground water beneath the terrace plain was 30 to 90 times greater than the P_{CO_2} in the atmosphere and that the maximum dissolved oxygen in the ground water was 6.8 ppm. No relation was apparent between the P_{CO_2} and dissolved oxygen in the water. Possibly the P_{CO_2} in the ground water can be attributed to absorption of carbon dioxide by infiltrating water. Generally carbon dioxide is produced and concentrated in the soil by a variety of plant and microbiologic processes. Baver (1956, p. 199–223) reported a definite increase of carbon dioxide with depth and a corresponding decrease of oxygen in the air of most soils. The fact that no relation was found between oxygen and carbon dioxide in this study supports the view that the source of carbon dioxide is probably biologic activity such as respiration by plant roots rather than the decay of organic matter. Decay reactions not only produce carbon dioxide but also consume oxygen.

The concentration of the sulfate ion in ground water from beneath the terrace plain ranged from 25 to 122 ppm; water from well

14–8–1dcc had the only sulfate concentration in excess of 64 ppm (table 5). An areal pattern of sulfate concentration is not apparent. As no sulfate or sulfide minerals were found in the test-hole samples that were examined, it is thought that organic compounds or sulfur-bearing minerals in the loess or soil may be the source of the sulfate ions in the ground water.

GROUND WATER BENEATH THE PLATTE RIVER FLOOD PLAIN

The most probable values of IAP/K_{calcite} for water from the 33 wells in the Lincoln city well field ranged from 0.188 to 1.08 and averaged 0.548; for water from the nine downvalley wells the most probable values ranged from 0.352 to 1.29 and averaged 0.841 (table 6). Water that was nearly saturated or supersaturated with respect to calcite was yielded by only two wells in the well field, but was yielded by five of the downvalley wells. It is of special interest that the river water (table 7) differs from the water yielded by the city wells in that it is about 10 times supersaturated with respect to calcite, contains much less dissolved carbon dioxide, and has a significantly higher pH than the average for water from the city wells.

As a large fraction of the water pumped at the well field probably is derived from the river, it is surprising that the chemical quality of the water from the wells is not more like that of the river water. In fact, one might wonder whether the fraction of river water in the yield of the wells is actually much less than is indicated by other evidence.

Obviously, the IAP/K_{calcite} values for water naturally in the aquifer at this location must be rather low, as the value for water from one well was only 0.188 and for water from 11 others was less than 0.5. Low values would be expected because limestone fragments in the water-bearing material at this location are rather uncommon (see log of test hole 13–9–24ddc) and a loess mantle (such as is present on the terrace plain) that could be a source of calcium ions is lacking.

As the dissolved carbon dioxide content of water from six of the city wells exceeded 20 ppm, it seems reasonable to assume that the water naturally in the aquifer generally contains that much or more. Infiltrating precipitation, which has dissolved carbon dioxide from the atmosphere and from the soil, is the most likely source of the carbon dioxide in the ground water. The lowest concentration of carbon dioxide in water from the city wells was more than four times that in the river water. The average P_{CO_2} in the water from the wells was nearly 10 times that in the river water.

Seven of the city wells yielded water having a pH less than 7.3, so the average pH of the water naturally in the aquifer probably is no

TABLE 6.—*Selected properties and constituents of ground water beneath the Platte River flood plain*

[Values for total iron determined by city of Lincoln. All measurements are for June and July 1963 except as indicated]

Well	Temperature (°F)	pH	P_{CO_2} (most probable value)		Dissolved CO_2 (most probable value, in ppm)	Ca^{+2} (ppm)	$IAP/K_{calcite}$			SO_4^{-2} (ppm)	Dissolved O_2 (ppm)	Total iron (ppm)				Fe^{+2} (ppm) Oct. 11, 1963
			Atmosphere (atm×10^{-3})	Ground water (atm×10^{-3})			Maximum	Minimum	Most probable value			Sept. 1958–Jan. 1959	June 1959	Oct. 1959	Apr.–May 1963	
							Lincoln city well field at Ashland									
32.1	54.0	7.21	0.29	10.2	22.37	54	0.274	0.223	0.251	62	0.5	0.01	0.04	0.02	0.03	0.03
32.1A	54.3	7.87	.29	2.08	4.53	48	1.22	.717	.940	66	.6	.22	.21	.18	.05	.32
32.2	57.6	7.08	.29	13.1	26.92	54	.207	.168	.188	80	2.1	.07	.07	.02	.05	.07
32.2A	58.1	7.53	.29	4.67	9.51	53	.596	.484	.544	79	1.8	.02	.01	.02	.03	.04
32.3	57.9	7.60	.29	3.98	8.13	54	.731	.566	.647	79	2.5	.02	.01	.03	.02	.03
32.3A	59.0	7.54	.29	4.60	9.22	56	.648	.527	.592	88	2.2	.17	.17	.03	.03	.04
32.4	57.7	7.21	.29	9.83	20.14	55	.294	.239	.270	74	.2	.07	.02	.06	.03	.07
32.4A	56.1	7.36	.29	7.15	15.07	55	.430	.318	.374	72	1.2	.02	.02	.02	.04	.03
32.5	53.6	7.28	.29	8.68	19.13	59	.361	.266	.315	72	.4	.10	.11	.15	.04	.14
49.6	54.3	7.33	.29	9.45	20.56	73	.564	.459	.515	100	.5	.01	.01	.04	.01	.05
49.7	53.6	7.54	.29	4.34	9.58	55	.543	.441	.497	74	1.1	.02	.04	.04	.02	.02
49.8	54.5	7.60	.29	5.34	11.57	79	1.22	.949	1.08	104	.5	.09	.09	.09	.13	.13
49.9	55.4	7.64	.29	3.73	7.96	56	.800	.621	.709	67	.8	.04	.01	.02	.02	.02
54.1	52.3	7.47	.29	5.06	11.42	50	.417	.323	.370	63	.3	.01	.00	.02	.02	.02
54.2	52.3	7.57	.29	4.31	9.72	55	.622	.460	.540	79	2.7	.03	.01	.03	.00	.00
54.3	55.0	7.62	.29	3.72	8.00	50	.678	.477	.576	69	.2	.01	.01	.01	.01	.02
54.4	50.7	7.68	.29	3.21	7.46	51	.645	.525	.586	73	1.2	.01	.00	.01	Tr.	.05
54.5	53.8	7.68	.29	3.39	7.46	56	.815	.663	.739	73	.4	.05	.01	.01	.01	.06
54.6	52.0	7.53	.29	4.73	10.74	54	.534	.414	.475	77	1.3	.02	.00	.01	.06	.06
54.7	54.7	7.44	.29	6.10	13.19	57	.500	.407	.455	70	.4	.01	.01	.01	.02	-------
54.8	52.3	7.76	.29	2.56	5.79	51	.800	.650	.728	78	1.1	.05	.05	.04	.01	.06
54.9	55.6	7.52	.29	4.63	9.85	52	.536	.415	.475	71	.5	.03	.01	.01	.02	.03
54.10	54.1	7.80	.29	2.41	5.27	49	.881	.716	.803	68	.9	.06	Tr.	.04	Tr.	.06
54.11	57.2	7.31	.29	8.04	16.63	56	.386	.314	.353	73	1.2	.01	.00	.01	Tr.	.02
56.1	59.5	7.71	.29	3.16	6.27	52	.957	.742	.852	73	.9	.04	.09	.09	.02	.05
56.2	55.6	7.35	.29	9.70	20.62	74	.694	.540	.617	99	.0	.93	1.05	.97	.58	1.05
56.3	53.8	7.45	.29	6.00	13.19	61	.634	.370	.489	68	.0	.50	.59	.55	.34	.62
56.4	66.2	7.69	.29	3.34	5.94	50	.988	.803	.898	75	.4	.14	.03	.11	.13	.11
56.5	50.0	7.65	.29	3.40	8.01	54	.633	.515	.573	79	1.2	.01	.02	.02	.01	.05
56.6	60.3	7.68	.29	3.35	6.57	53	.939	.694	.813	71	.2	1.67	.95	.15	.89	.46
56.7	55.0	7.23	.29	9.65	20.72	58	.309	.251	.281	71	.1	.01	.04	.09	.02	.07
56.8	61.3	7.25	.29	8.79	16.94	54	.341	.277	.310	74	.0	.01	.00	.10	.07	.16
56.9	54.7	7.28	.29	8.67	18.75	60	.355	.289	.323	75	.1	.01	.00	.04	.07	.10

Down valley from Ashland

12-10-12cbc	68.4	7.53	0.29	6.37	10.93	60	1.12	0.919	1.03	51	0.4	-------	------	------	------
12-11-1bac	54.1	7.30	.29	10.9	23.80	75	.585	.478	.531	77	.3	-------	------	------	------
14bcb	55.0	7.78	.29	3.03	6.50	62	1.28	1.04	1.16	72	.1	-------	------	------	------
14bcc	54.3	7.69	.29	3.90	8.49	60	1.10	.743	.916	66	.0	-------	------	------	------
13-12-30ccb	55.8	7.00	.29	27.1	57.50	73	.402	.298	.352	16	6.4	-------	------	------	------
13-13-25cbb	57.7	7.52	.29	7.11	14.55	95	1.42	1.16	1.29	108	.2	-------	------	------	------
25dca	46.8	7.70	.29	3.52	8.80	62	.815	.664	.741	72	.0	-------	------	------	------
25ddd	61.0	7.71	.29	3.43	6.64	54	1.06	.866	.967	63	.0	-------	------	------	------
30acc	55.8	7.45	.29	6.65	14.11	63	.718	.461	.581	63	.1	-------	------	------	------

TABLE 7.—*Selected properties and constituents of water in the Platte River near Ashland*

Time of collection (Oct. 11, 1963)	Temperature (°F)	pH	P_{CO_2} (most probable value)		Dissolved CO_2 (most probable value, in ppm)	Ca^{+2} (ppm)	$IAP/K_{calcite}$			CO_3^{-2} (ppm)	SO_4^{-2} (ppm)	Dissolved O_2 (ppm)	Fe^{+2} (ppm)
			Atmosphere (atm×10^{-3})	River water (atm×10^{-3})			Maximum	Minimum	Most probable value				
6:00 a.m.	62.6	8.52	0.29	0.615	1.16	59	10.6	6.55	8.37	4.0	52	--------	--------
6:30 a.m.	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	8.8	0.03
1:00 p.m.	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	10.1	.03
2:00 p.m.	70.9	8.56	.29	.591	.97	57	13.3	8.62	10.8	4.7	50	--------	--------

greater than that value. The river water has a pH of about 8.5, or more than one unit higher.

If the river water normally is as supersaturated with respect to calcite as the values for IAP/K_{calcite} indicate it to be, a large decrease in degree of supersaturation occurs during transit of the water from the river to the city wells. The specific factors involved in this decrease are not known but probably are related to environmental change. Water that had been flowing freely must now follow a tortuous path through intergranular openings, and, compared to the rate of riverflow, its rate of percolation through the aquifer is very slow. Moreover, the conditions of temperature and pressure are not the same, and the water comes into contact with a variety of minerals. Eventually the water derived from the river becomes mixed with water naturally in the aquifer.

Deposition of calcite on the grains of the material through which the river water must percolate to reach the wells could account for the decrease, but then the similar values for concentration of calcium in the river water and in water yielded by the wells would need to be explained. The decrease in degree of saturation most likely involves addition of carbon dioxide to the water, and such addition would account for the well water having a lower pH than the river water. Whether the difference in the dissolved carbon dioxide values for the river water and the assumed average for water naturally in the aquifer is a significant factor in the change from supersaturation to unsaturation is not known. Before the change can be explained satisfactorily, the seasonal range in values of IAP/K_{calcite} for the river water and the areal range in values of IAP/K_{calcite} for ground water moving toward the well field need to be determined.

The distribution of the IAP/K_{calcite} values for water from wells in the Lincoln city well field is shown in figure 4. Instead of indicating a progressive decrease with distance from the river, the distribution of the ratio lacks obvious pattern and thus probably is a function of more than a single factor. Heavy pumping undoubtedly has altered the natural paths and rate of ground-water travel, and pumping at different rates at different times in different parts of the well field probably precludes establishment of a fixed new pattern of flow paths. Furthermore, the permeability of the water-bearing materials through which water percolates from the river to the well is not uniform, so the routes of least resistance to water movement may be more devious than direct.

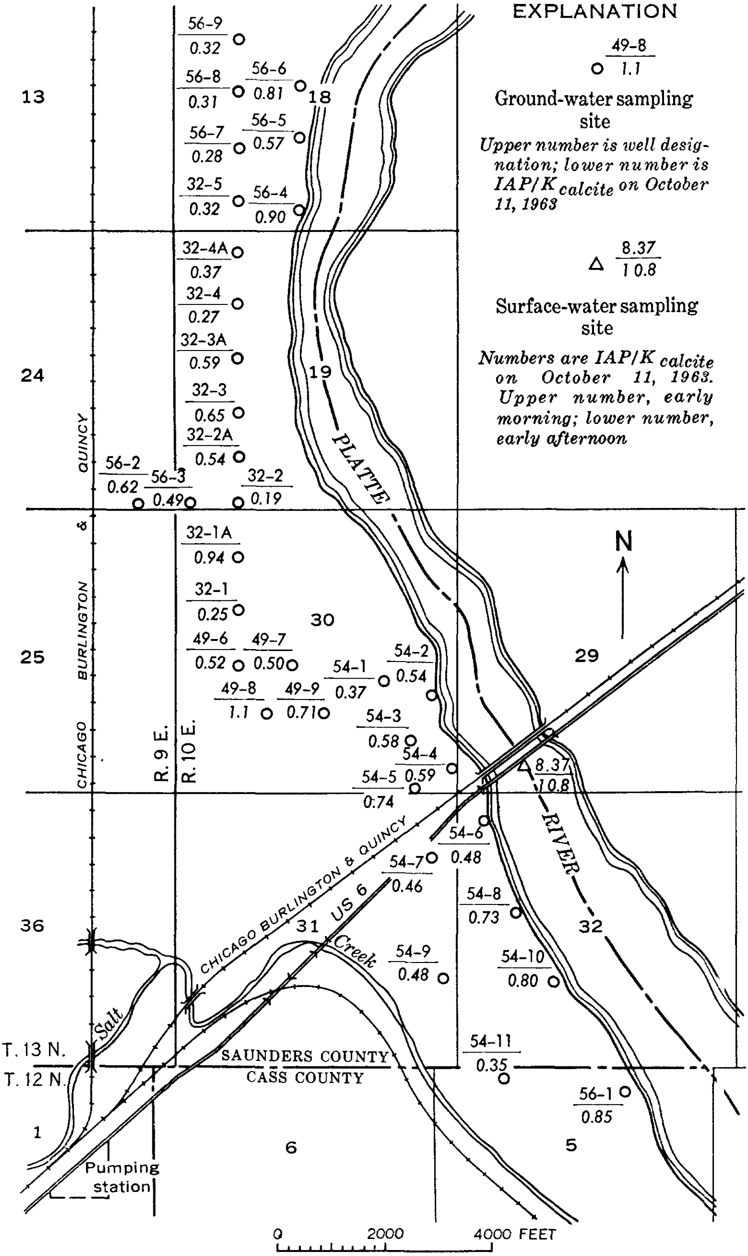

FIGURE 4.—Distribution of IAP/K_{calcite} values, Lincoln city well field.

The data on dissolved oxygen and dissolved iron (figs. 5, 6) show some interesting relationships. The two constituents are not compatible, as shown by the stepwise reactions

$$O_2+4H^++4e^-=2H_2O$$

$$4Fe^{+2}=4Fe^{+3}+4e^-$$

$$4Fe^{+3}+12H_2O=4Fe(OH)_3+12H^+$$

which, when added, give

$$O_2+4Fe^{+2}+10H_2O=4Fe(OH)_3+8H^+,$$

the last reaction being a summary statement of the oxidation of the dissolved iron and precipitation of a ferric hydroxide. (More detailed discussions are presented by Hem and Cropper (1959) and Hem (1960).) The hydroxide dehydrates on aging, so it would be expected that wells yielding water containing both dissolved iron and dissolved oxygen would become encursted with various hydrated iron oxides and that over a period of years the yield of the wells would decline.

Generally, wells discharging water containing both iron and oxygen in solution are drawing water from two sources—one a body of ground water containing dissolved oxygen and negligible dissolved iron and the other a body of ground water containing dissolved iron and negligible dissolved oxygen. The former probably is the induced seepage from the river and the latter the water naturally present in the aquifer. To reach the wells, river water percolates only a short distance through the aquifer and moves at a fairly fast rate owing to the heavy withdrawal by pumping. Although it loses some of its dissolved oxygen in transit, it has little opportunity to dissolve more iron before it is mixed, when entering the wells, with water derived from that naturally in the aquifer. On the other hand, most of the ground water naturally in the aquifer is derived from precipitation that has passed through sediments containing organic matter; furthermore, it has traveled a considerably longer distance at a much slower rate through sediments containing pyrite and hematite and so has had greater opportunity to dissolve iron as it approached the well field. The differences in total iron concentrations (table 6) with time may reflect changes in the proportion of water derived from the two sources.

As indicated in table 7, one of the samples of Platte River water was collected in the early morning and the other in the early afternoon of October 11, 1963. The concentration of dissolved oxygen in the river

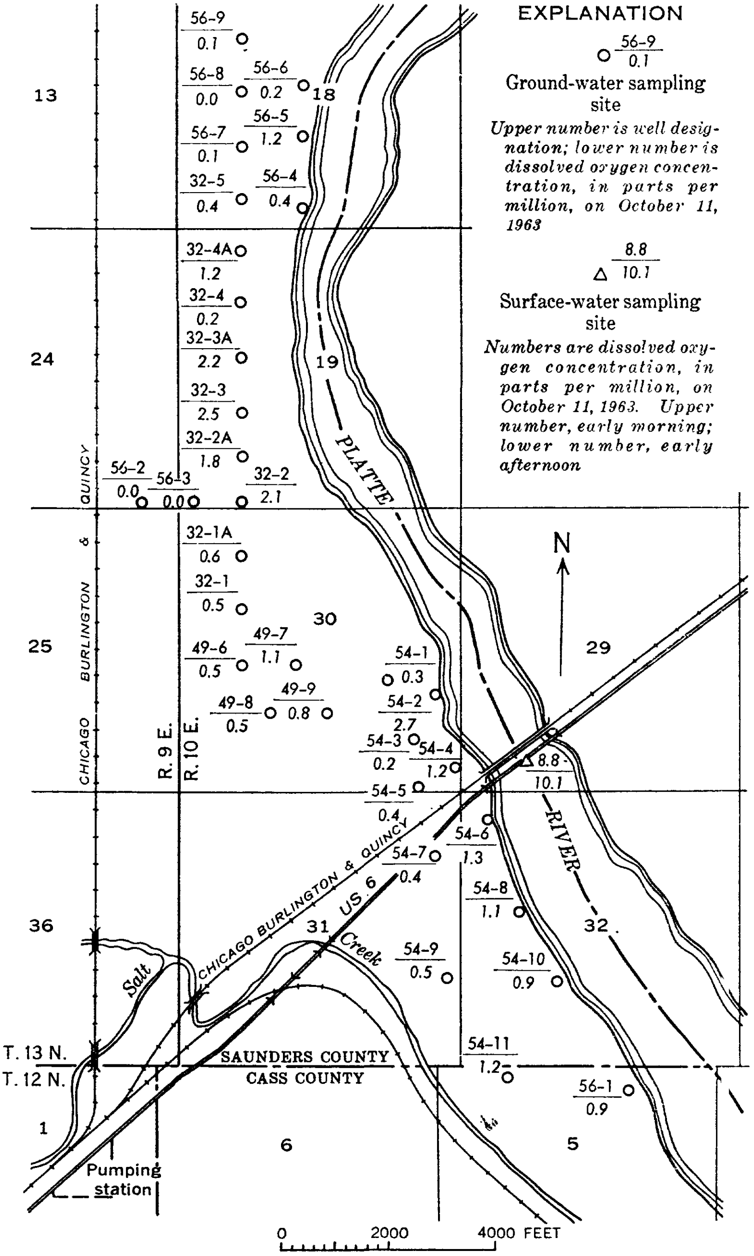

FIGURE 5.—Distribution of dissolved oxygen concentrations, Lincoln city well field.

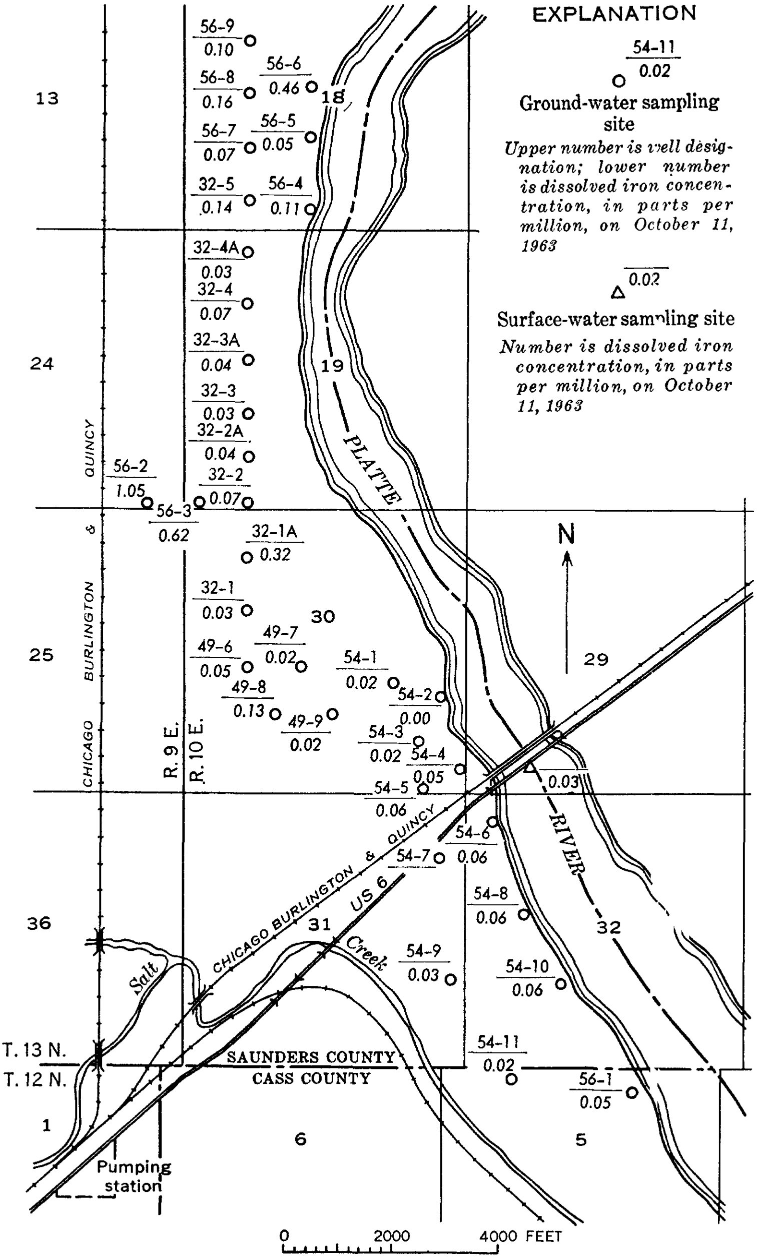

FIGURE 6.—Distribution of dissolved iron concentrations, Lincoln city well field.

water was lower in the early morning owing to respiration of organisms and higher in the afternoon owing to photosynthesis. That the controlling factor was biologic is indicated by the temperature variations, the dissolved oxygen being lower at a lower water temperature; the controlling factor could not be inorganic because solubility of oxygen increases with decreasing temperature. Even the lower of the two values for the concentration of dissolved oxygen in the river water was much higher than the values for the concentration of dissolved oxygen in the ground water.

The samples of water from wells downvalley from the well field probably contain little or no water derived from the Platte River and so are representative of water naturally in the aquifer in that reach of the valley. The higher average concentration of calcium in the water and the higher average value of IAP/K_{calcite} probably are related to the greater abundance of calcite in the water-bearing sediments in this reach compared to the well-field vicinity. The generally lower values of dissolved oxygen in the water probably are explained by the lack of water derived from the river. No other significant differences between water from the city wells and from wells downvalley from the well field were noted.

SUMMARY

Environmental conditions are reflected by the chemical quality of the ground water contained in Quaternary sand and gravel aquifers within the lower Platte River drainage basin.

In the terrace-plain area in southeastern Saunders County, the sand and gravel aquifer is mantled by a thick deposit of loess, and the principal source of recharge to the aquifer is local precipitation that infiltrates the loess. Even though the sand and gravel aquifer contains little or no calcite or sulfate minerals, the ground water contains both calcium and sulfate in solution. Furthermore, the P_{CO_2} in the water is many times greater than the P_{CO_2} in the atmosphere and is generally greater than in the ground water in the other two areas. Although the upper part of the loess is leached, the lower part is calcareous and so may be the principal source of the calcium ions. Similarly, organic compounds or sulfate-bearing minerals in the soil or loess may be the source of the sulfate ions. Respiration by plant roots and other biologic activity in the upper part of the loess probably account for most of the carbon dioxide in the water.

In the Lincoln city well field in the Platte River valley near Ashland, no loess overlies the sand and gravel, and recharge from precipitation enters the aquifer almost directly. As pumping induces seepage from the Platte River, the water yielded by the wells is a blend of water naturally in the aquifer and of water derived from the river. Rather large differences in degree of saturation with respect to calcite were detected, and the water from two of the 33 sampled wells was close to saturation. That more of the water was not saturated with respect to calcite is surprising in view of the river water being eight to ten times supersaturated. Possibly the great decrease in degree of saturation results from calcite deposition before the river water reaches the wells. Significantly, however, the average concentration of calcium ions in the water yielded by the wells was nearly the same as that in the river water. It was noted that water from many wells contained more dissolved iron than the river water; furthermore, the water from the wells also contained dissolved oxygen, which is not compatible with dissolved iron in the same solution. Water naturally in the aquifer probably contains dissolved iron, and the river water is known to contain dissolved oxygen; the water from one source probably has little or no opportunity to mix with the water from the other source before entering the wells. As the carbon dioxide content of the water yielded by the wells was much higher than that of the river water, the water naturally in the aquifer must be the source of carbon dioxide. Different proportions of water from the two sources probably account for the differences in the chemical quality of the water yielded by different wells.

Of the nine sampled wells on the Platte River flood plain downvalley from the well field, five yielded water either nearly saturated or slightly supersaturated with respect to calcite. Pebbles and larger fragments of limestone, which are abundant in the aquifer in this area, are a likely source of the calcium ions.

LOGS OF TEST HOLES

Test holes were drilled as part of the ground-water studies made cooperatively by the Conservation and Survey Division of the University of Nebraska and the U.S. Geological Survey. Samples of the cuttings may be examined at the Conservation and Survey Division.

Test hole 13–9–24ddc:	*Depth (feet)*
Quaternary deposits:	
Soil, silty, calcareous, gray; some sand and clay	9.6–12.4
Sand, medium to coarse, tan to brown; abundant feldspar; some silt and clay lenses below 20 ft	12.4–23.2
Silt, sandy, dark-gray	23.2–23.5
No sample	23.5–25
Sand, coarse, brown; some siliceous root fragments; some gravel and silt	25–35
Sand, medium to coarse, tan; abundant feldspar; siliceous root fragments	35–55

	Depth (feet)
Test hole 13–9–24ddc—Continued	
Quaternary deposits—Continued	
Sand, medium to coarse, tan; increasingly gravelly with depth; some limestone fragments; silty from 70 to 80 ft	55–84.5
Pennsylvanian rocks:	
Shale, clayey, fossiliferous, gray to green	84.5–?
Test hole 13–11–36dad:	
Quaternary deposits:	
Soil, silty, slightly calcareous, gray to brown; contains some sand and sparse orthoclase pebbles	0.4–1.5
Sand, medium to coarse, tan to brown; grades downward to coarse sand containing 5–10 percent gravel; clay and silt lenses between 20 and 25 ft	1.5–25
Sand, coarse, brown; contains 25 percent gravel; some siliceous and calcareous nodules; sparse orthoclase and quartz pebbles	25–50
Sand, coarse, brown, and some gravel; some siliceous and calcareous nodules	50–80
Gravel, tan to brown; predominantly orthclase and quartz; some rock fragments	80–95
No sample; probably Pennsylvanian rocks	95–100
Test hole 13–13–24ddd:	
Quaternary deposits:	
Soil, silty with some clay, gray to brown; increasingly sandy with depth; slightly calcareous and ferruginous with depth	0–10
Sand, fine to medium, brown to gray; abundant dark minerals	10–30
Sand, fine to coarse, tan to brown; some gravel	30–40
Sand, fine to coarse, tan to brown; contains some gravel and limestone fragments; some silt and clay lenses below 45 ft	40–58
Sand, fine to medium, brown to gray; some gravel, mostly quartz and feldspar; a few limestone fragments	58–65
Sand and gravel, tan; abundant feldspar fragments; some siliceous nodules	65–100
Gravel, tan; abundant feldspar and rock fragments; crinoid stem	100–110
Sand, coarse, yellowish-tan; some gravel; 10 percent limestone fragments	110–114.2
Test hole 13–13–29db:	
Quaternary deposits:	
Soil, silty with some clay, dark-brown; noncalcareous	0–2.6
Sand, medium to coarse, tan; scattered quartz and orthoclase pebbles; limestone fragments below 31 ft	2.6–35
Sand and gravel, tan; gravel contains orthoclase and quartz pebbles and scattered limestone fragments	35–46
Gravel, tan; contains orthoclase and quartz pebbles and limestone fragments	46–51.5
No sample	51.5–52.5
Gravel, light tan; 20–30 percent limestone fragments	52.5–54.5
Pennsylvanian rocks:	
Shale, clayey, gray; maroon inclusions	54.5–?

	Depth (feet)
Test hole 13–13–32ad:	
Quaternary deposits:	
Soil, silty, noncalcareous, brownish-gray; some clay and sand	0.5–1.5
Silt, clayey and sandy, calcareous, brownish-gray	1.5–15
No sample	15–18
Sand, medium to coarse, tan; increasingly gravelly with depth; some silt and clay lenses	18–42
Sand, medium to coarse, tan; limestone cobbles below 50 ft	42–62
Sand and gravel, tan; scattered limestone cobbles	62–70
No sample	70–72
Gravel, tan to brown; some coarse sand; scattered limestone and rock fragments	72–94
Pennsylvanian rocks:	
Shale, clayey, slightly calcareous; yellowish brown grading downward to green gray	94–98
Test hole 14–8–23ccc:	
Soil, tan, silty; includes small amount of clay; leached	1.0–1.5
Loess, silty, calcareous, friable, tan	1.5–8.8
Sand, fine to coarse, gravelly with depth, tan; contains siliceous root fragments; silt and clay lenses from 56 to 65 ft	8.8–65
Sand, fine to coarse	65–80
Sand and gravel, tan; gravel fraction increases from 10 to 40 percent with depth; mostly orthoclase and quartz	80–95
Gravel, predominantly feldspar and quartz; some coarse sand; some rock fragments coated with Fe_2O_3 from 105 to 108.9 ft	95–108.9
Test hole 14–9–20ddd:	
Soil, silty, brown; little organic material	0–0.5
Soil, silty, tan, leached	0.5–5
Loess, silty, tan, friable; somewhat calcareous from 7 to 16 ft	5–16
Sand, fine to coarse, tan; increasingly coarser with depth; 5 percent gravel from 56 to 61 ft; siliceous root fragments throughout	16–61
Sand, fine to coarse	61–95
Sand and gravel, brown; considerable well-rounded orthoclase; siliceous root fragments from 95 to 101 ft; broken ironstone fragments (Cretaceous?) from 106 to 110 ft	95–110
Cretaceous rocks:	
Sand, fine, yellow-tan; apparently uncemented	110–?
Test hole 14–9–30ddd:	
Soil, silty, dark-gray, leached	0–2
Loess, silty, slightly calcareous, buff, friable	2–12.5
Sand, fine to medium, tan; coarser with depth; contains siliceous root fragments	12.5–60
Sand, fine to medium	60–75
Sand and gravel, tan; gravel mostly quartz and orthoclase	75–86

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