CHEMICAL AND PHYSICAL CHARACTERISTICS OF NATURAL GROUND WATERS IN MICHIGAN: A PRELIMINARY REPORT

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ABSTRACT

Wide variations occur in the chemical and physical characteristics of natural ground waters in Michigan. Dissolved-solids concentrations range from 23 to 2,100 milligrams per liter. Waters having low dissolved-solids concentrations are calcium bicarbonate waters. Sodium, sulfate, and chloride increase as mineralization increases. Iron, aluminum, and titanium are higher at some locations than is common in most natural waters. Lead concentrations exceed those desirable in drinking water at some locations in the northern part of the Lower Peninsula. Generalized areal patterns of water quality variation suggest that geology is a primary cause of differences across the state. Examples of chemical associations in water suggest that chemical analyses may be valuable in tracing and identifying mineral deposits.

INTRODUCTION

Information on the natural[1/] chemical and physical characteristics of ground water, particularly with respect to substances that occur in trace amounts, does not meet needs in Michigan and in other parts of the nation. Such information is essential for establishing baseline conditions against which long-term changes in water quality can be judged, and for properly evaluating the degree and severity of contamination when it occurs. In addition to supporting management decisions relating to the protection of the water resource, a better definition of natural water quality is necessary for studies of the significance and relation of the geochemical environment to human health and disease. Water quality information is also important in the identification and development of mineral resources. As minerals become scarce, and as their value increases, chemical analyses of ground water will likely be used even more frequently for this purpose.

In 1974, the Geological Survey Division of the Michigan Department of Natural Resources and the U.S. Geological Survey began a cooperative program to investigate the natural characteristics of water in aquifers in the state. The program is a continuing one in which carefully selected wells are sampled each year. New wells are also drilled to the principal aquifers to monitor both water quality and water levels. The

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1/ The term "natural" is used to characterize water exhibiting no readily detectable modification by man's activity. It is probable that few, if any, of the ground waters normally sought as supplies are completely free of all cultural influence.

design and construction of these wells is such that they are suitable as long-term observation sites. Site selection is made in all cases so as to avoid known, or even suspected, contamination. Since 1974, about 30 samples have been collected each year, and 17 wells have been drilled. Information obtained through this program forms the basis of this report.

Purpose and Scope of Study

This report presents a preliminary evaluation of the natural chemical and physical characteristics of ground waters in Michigan. Because data are few, interpretations are intended to illustrate the direction that studies need to take when information has accumulated from the continuing program. For this study, maximum and minimum values of individual substances and properties have been determined, as well as how frequently values of a given magnitude may be expected. Water-quality characteristics have been related to geologic source, areal variations identified if possible, and geochemical associations noted. Chemical analyses from other data programs or sources have not been used in this evaluation, largely because it seemed preferable to confine the study to data obtained under the same uniformly strict conditions and because no prior analyses for some substances are available.

Method of Investigation

In conjunction with the Michigan Geological Survey, available information on wells was reviewed each year to select possible wells for sampling. Geologic source, well location, and the probability of obtaining representative water from an aquifer were considered in the selection. Wells were pumped from a half to one and a half hours before sample collection. While at the well site, specific conductance, pH, and temperature were measured. Filtration, treatment, or chilling was also done at the site, as appropriate.

Laboratory analyses of 86 substances or properties were normally made. The major anions and cations, trace metals, pesticides, and other substances of particular significance were included in analytical work. One hundred and fifty-five samples were collected, 39 of which were collected when wells were resampled. The second sample was obtained from some wells when a result was questionable, or to confirm an unusual quality characteristic. Analysis of water from three wells have not been used in this study because, in the author's judgment, modification of natural water quality is detectable. In tabulating maximum and minimum values, 152 analyses have been used. For all other evaluations of the data, only one analysis of water from a well has been used in order to prevent distortions in mean and frequency computations. Thus, most conclusions are based on analyses of 113 samples. Complete chemical analyses of water from each well and exact well locations have been published in annual reports by Huffman (1979a,b). These reports, available from the U.S. Geological Survey in Lansing, may be consulted for more complete and specific information. A description of laboratory methods used by the U.S. Geological Survey in the analysis of samples is given in Barnett and Mallory (1971), Goerlitz and Brown (1972), Thatcher and others (1977), and Skougstad and others (1979).

Samples were obtained from wells in 63 of Michigan's 83 counties at locations distributed throughout the state. Geologically, water samples were obtained from 23 different glacial and bedrock deposits. (See table 5.) If no firm characterization of the composition or texture of glacial deposits could be made, the source of water has been identified as "Glacial deposits, undifferentiated."

GENERAL WATER-QUALITY CONDITIONS

Considerable variation occurs in the quality of ground water from place to place throughout the state. Table 1 lists the maximum and minimum values for all substances and properties other than pesticides. Maximum and minimum dissolved-solids concentrations differ by a factor of about 100, although the range for individual substances may be much greater. Concentrations of most substances are within the range common for ground waters, with the exceptions of those of iron, aluminum, and titanium. The maximum concentrations of each were: iron, 29,000 μg/L (micrograms per liter); aluminum, 44,000 μg/L; and titanium, 3,600 μg/L.

Waters having a low dissolved-solids concentration are generally calcium bicarbonate waters, that is, the calcium constitutes more than 50 percent of the cations and bicarbonate constitutes more than 50 percent of the anions. As the dissolved-solids concentration of a typical water increases, the proportion of sodium, sulfate, and chloride increases. Figure 1 illustrates generalized changes in chemical composition as dissolved-solids concentration increases. Sulfate increases most rapidly as dissolved solids increase, accompanied by a proportional decrease in bicarbonate. A decrease in calcium is balanced by a corresponding increase in sodium. Magnesium does not change appreciably.

In general, the concentrations of major dissolved substances increase as dissolved solids increase. Concentrations of most trace substances, however, seem to be unrelated to the dissolved-solids concentration of the water. For example, no correlation was detected between dissolved-solids concentration and aluminum, barium, boron, cadmium, chromium, copper, iron, lead, manganese, nitrogen, silica, titanium, vanadium, uranium, or zinc. Strontium, an exception, does increase as dissolved solids increase.

Specific conductance, which is a measure of the ability of water to conduct an electrical current, is frequently used to estimate dissolved-solids concentration. The relation of dissolved solids to specific conductance is determined by the amount and type of substances in solution. Generally, water composed predominately of divalent ions will have a dissolved solids-specific conductance ratio greater than a water composed predominately of univalent ions. Figure 2 shows the relation of specific conductance and dissolved-solids concentration based on samples collected for this study. The nonlinear relation reflects the changing composition of the water shown in figure 1.

Polychlorinated biphenyls, polychlorinated napthalenes, and 23 pesticides were determined on each sample. Analyses were made for each of the following substances:

Table 1.--Maximum and minimum values of chemical and physical characteristics of ground water.

Constituent or property	Maximum	Minimum
Alkalinity (mg/L as $CaCO_3$)	484	7
Aluminum, Total Recoverable (µg/L as Al)	44,000	0
Arsenic, Total (µg/L as As)	32	0
Barium, Total Recoverable (µg/L as Ba)	300	0
Beryllium, Total Recoverable (µg/L as Be)	30	0
Bicarbonate (mg/L as HCO_3)	590	8
Bismuth, Total (µg/L as Bi)	<40	<1
Boron, Total Recoverable (µg/L as B)	2,000	0
Cadmium, Total Recoverable (µg/L as Cd)	21	0
Calcium, Dissolved (mg/L as Ca)	230	2.4
Carbon, Organic Dissolved (mg/L as C)	28	.4
Carbon Dioxide, Dissolved (mg/L as CO_2)	188	.3
Carbonate (mg/L as CO_3)	24	0
Chloride, Dissolved (mg/L as Cl)	830	.4
Chromium, Total Recoverable (µg/L as Cr)	180	0
Cobalt, Total Recoverable (µg/L as Co)	40	0
Color (Platinum Cobalt Units)	200	0
Copper, Total Recoverable (µg/L as Cu)	1,900	0
Cyanide, Total (mg/L as CN)	.02	.00
Fluoride, Dissolved (mg/L as F)	1.5	.0
Gallium, Total (µg/L as Ga)	<20	<1
Germanium, Total (µg/L as Ge)	<50	<1
Hardness (mg/L as $CaCo_3$)	900	9
Hardness, Noncarbonate (mg/L as $CaCo_3$)	840	0
Iron, Dissolved (µg/L as Fe)	12,000	0
Iron, Total Recoverable (µg/L as Fe)	29,000	10
Lead, Total Recoverable (µg/L as Pb)	220	0
Lithium, Total Recoverable (µg/L as Li)	90	0
Manganese, Dissolved (µg/L as Mn)	710	0
Manganese, Total Recoverable (µg/L as Mn)	1,100	0
Magnesium, Dissolved (mg/L as Mg)	80	0.7
Mercury, Total Recoverable (µg/L as Hg)	2.1	.0
Molybdenum, Total Recoverable (µg/L as Mo)	40	0
Nickel, Total Recoverable (µg/L as Ni)	50	0
Nitrogen, Total (mg/L as N)	2.9	.00
Nitrogen, Ammonia, Total (mg/L as N)	1.2	.00
Nitrogen, Nitrate, Total (mg/L as N)	2.9	.00
Nitrogen, Nitrite, Total (mg/L as N)	.04	.00
Nitrogen, Organic, Total (mg/L as N)	1.1	.00
pH (Units)	8.9	6.4
Phenols (µg/L)	7	0
Phosphorus, Total (mg/L as P)	.59	.00
Phosphorus, Ortho, Total (mg/L as P)	.40	.00
Potassium, Dissolved (mg/L as K)	14	.4
Selenium, Total (µg/L as Se)	1	0
Silica, Dissolved (mg/L as SiO_2)	21	.4
Silver, Total Recoverable (µg/L as Ag)	13	0
Sodium, Dissolved (mg/L as Na)	490	.5
Solids, Residue at 180°C, Dissolved (mg/L)	2,000	20
Solids, Sum of Constituents, Dissolved (mg/L)	2,100	23
Specific Conductance (micromhos)	3,500	37
Strontium, Total Recoverable (µg/L as Sr)	5,900	20
Sulfate, Dissolved (mg/L as SO_4)	760	.7
Tin, Total Recoverable (µg/L as Sn)	<40	0
Titanium, Total (µg/L as Ti)	3,600	0
Turbidity (JTU)	140	0
Uranium, Dissolved (µg/L as Ur)	1.4	.01
Vanadium, Total (µg/L as V)	50	<.5
Zinc, Total Recoverable (µg/L as Zn)	4,700	0
Zirconium, Total (µg/L as Zr)	80	<1

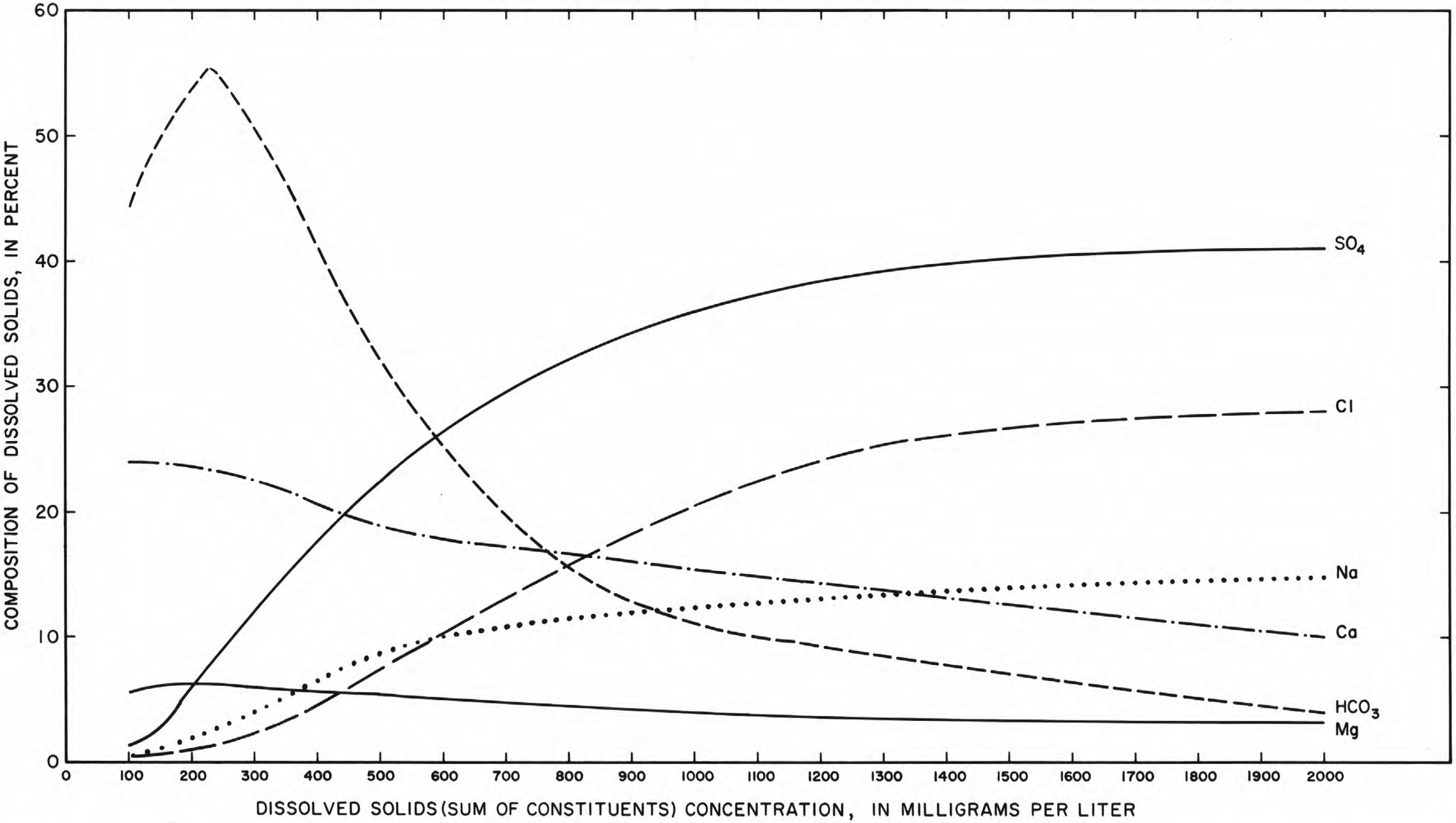

Figure 1.--Relation of dissolved-solids concentration to chemical characteristics of water.

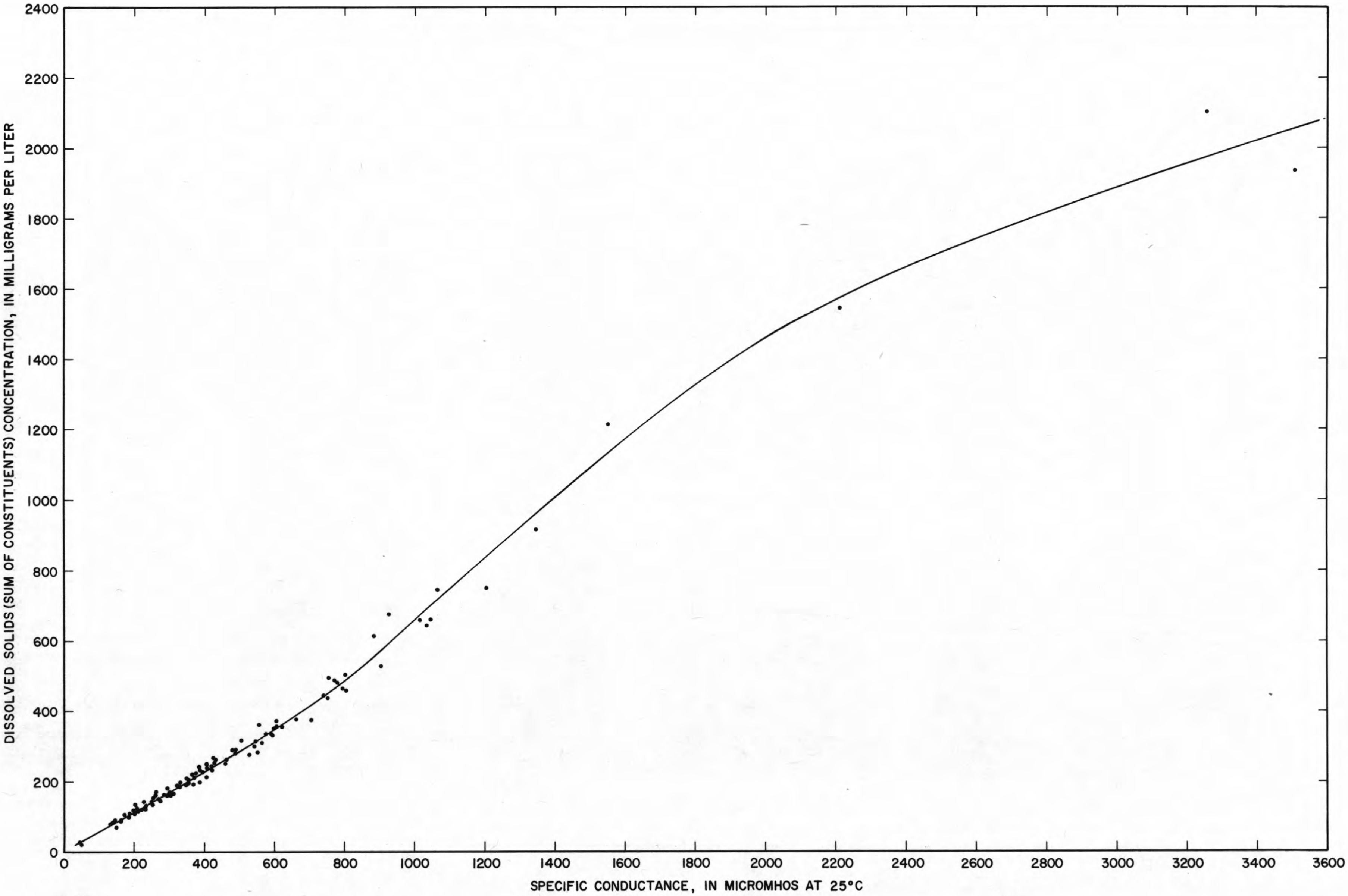

Figure 2.--Relation of specific conductance to dissolved-solids concentration of water.

Aldrin	Malathion
Chlordane	Methoxychlor
DDD	Methyl parathion
DDE	Methyl trithion
DDT	Parathion
Diazinon	Silvex
Dieldrin	Trithion
Endosulfan	Toxaphene
Endrin	2,4-D
Ethion	2,4,5-T
Heptachlor	Polychlorinated napthalenes
Heptachlor epoxide	Polychlorinated biphenyls (PCB)
Lindane	

Pesticides were detected in water from only two wells, both in the northern part of the state. Water from these wells contained trace amounts of PCB, 2,4-D, and 2,4,5-T. A resampling of the water showed no detectable levels. Other chemical characteristics of water from both wells indicated, however, that the water was not representative of natural conditions, and thus the analyses were not included in data summarized in this report.

Frequency distributions of data were prepared for most substances and properties, and curves were drawn showing the percentage of ground waters having a value equal to or less than a specified amount. From these curves, values occurring at the 10, 25, 50, 75, and 90 percentiles were determined and listed in table 2.1/ Results indicate how often values of a given magnitude may be expected in uncontaminated ground waters of Michigan, and thus provide a preliminary basis for judging the modification of water quality characteristics. For example, 10 percent of the chloride concentrations are equal to or less than 0.7 mg/L (milligrams per liter); 90 percent of the concentrations are equal to or less than 54 mg/L. Similarly, nitrate, which in high concentration commonly indicates contamination, is equal to or less than 0.24 mg/L in 90 percent of the waters.

A comparison of frequency data to drinking water standards of the U.S. Environmental Protection Agency (1977a,b) is shown in table 3. Both maximum contaminant levels for inorganic chemicals and secondary maximum contaminant levels were referred to frequency curves and the percentage of time the level was equaled or exceeded determined. Lead concentrations exceeded the 50 µg/L maximum contaminant level in 13 percent of the ground waters. Iron and manganese concentrations are frequently greater than secondary maximum levels; total dissolved-solids concentration exceeded the secondary maximum level in 15 percent of the

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1/ Bismuth, gallium, and germanium are reported as "less than (<)" values. For these substances, low concentrations are reported by the laboratory in a qualitative manner because of the expense of precise quantitative analyses. Frequency distributions prepared for these substances represent a distribution of the most frequently reported "less than" results, and thus values given in table 2 may or may not correspond to concentrations that occur at the indicated frequency.

Table 2.--Frequency data for chemical and physical characteristics of ground water.

Constituent or property	Percent of ground waters having a value equal to or less than that indicated				
	10%	25%	50%	75%	90%
Alkalinity (mg/L as $CaCO_3$)	76	115	163	220	300
Aluminum, Total Recoverable (μg/L as Al)	7	19	31	56	150
Arsenic, Total (μg/L as As)	0	0	1	2	5
Barium, Total Recoverable (μg/L as Ba)	0	0	0	84	127
Beryllium, Total Recoverable (μg/L as Be)	0	0	0	0	<2
Bicarbonate (mg/L as HCO_3)	87	135	196	268	370
Bismuth, Total (μg/L as Bi)	<1	<2	<3	<7	<17
Boron, Total Recoverable (μg/L as B)	0	8	25	70	235
Cadmium, Total Recoverable (μg/L as Cd)	0	0	1	2	9
Calcium, Dissolved (mg/L as Ca)	20	34	48	64	97
Carbon, Organic Dissolved (mg/L as C)	.9	1.6	2.9	4.9	8.0
Carbon Dioxide, Dissolved (mg/L as CO_2)	1.4	2.3	5.4	10	18
Carbonate (mg/L as CO_3)	0	0	0	0	0
Chloride, Dissolved (mg/L as Cl)	.7	1.1	2.2	14	54
Chromium, Total Recoverable (μg/L as Cr)	2	8	9	10	11
Cobalt, Total Recoverable (μg/L as Co)	0	0	1	2	5
Color (Platinum Cobalt Units)	0	1	4	9	25
Copper, Total Recoverable (μg/L as Cu)	1	2	5	10	20
Cyanide, Total (mg/L as CN)	.00	.00	.00	.00	.00
Fluoride, Dissolved (mg/L as F)	.0	.0	.1	.3	.6
Gallium, Total (μg/L as Ga)	<1	<1	<1	<2	<6
Germanium, Total (μg/L as Ge)	<2	<3	<4	<10	<23
Hardness (mg/L as $CaCo_3$)	75	119	178	244	375
Hardness, Noncarbonate (mg/L as $CaCo_3$)	0	0	7	29	99
Iron, Dissolved (μg/L as Fe)	4	48	220	780	1,800
Iron, Total Recoverable (μg/L as Fe)	51	160	740	2,400	4,300
Lead, Total Recoverable (μg/L as Pb)	2	5	11	21	78
Lithium, Total Recoverable (μg/L as Li)	0	0	0	6	18
Manganese, Dissolved (μg/L as Mn)	.0	6.0	23	59	130
Manganese, Total Recoverable (μg/L as Mn)	6.5	9.8	36	120	200
Magnesium, Dissolved (mg/L as Mg)	6.0	8.8	15	24	33
Mercury, Total Recoverable (μg/L as Hg)	.0	.0	.4	.5	.5
Molybdenum, Total Recoverable (μg/L as Mo)	0	0	1	4	10
Nickel, Total Recoverable (μg/L as Ni)	0	2	5	9	16
Nitrogen, Total (mg/L as N)	.05	.13	.27	.50	.92
Nitrogen, Ammonia, Total (mg/L as N)	.00	.00	.04	.16	.37
Nitrogen, Nitrate, Total (mg/L as N)	.00	.00	.00	.07	.24
Nitrogen, Nitrite, Total (mg/L as N)	.00	.00	.00	.00	.01
Nitrogen, Organic, Total (mg/L as N)	.00	.03	.10	.20	.34
pH (Units)	7.3	7.5	7.7	7.9	8.1
Phenols (μg/L)	0	0	0	0	2
Phosphorus, Total (mg/L as P)	.00	.00	.01	.03	.07
Phosphorus, Ortho, Total (mg/L as P)	.00	.00	.00	.00	.02
Potassium, Dissolved (mg/L as K)	.5	.6	1.0	1.8	3.6
Selenium, Total (μg/L as Se)	0	0	0	0	0
Silica, Dissolved (mg/L as SiO_2)	5.7	7.1	10	13	16
Silver, Total Recoverable (μg/L as Ag)	0	0	0	0	1
Sodium, Dissolved (mg/L as Na)	1.1	1.9	3.4	12	55
Solids, Residue at 180°C, Dissolved (mg/L)	106	145	223	360	630
Solids, Sum of Constituents, Dissolved (mg/L)	96	150	220	340	570
Specific Conductance (micromhos)	177	250	370	550	900
Strontium, Total Recoverable (μg/L as Sr)	31	52	120	500	1,200
Sulfate, Dissolved (mg/L as SO_4)	3.1	6.5	12	35	170
Tin, Total Recoverable (μg/L as Sn)	1	2	3	6	16
Titanium, Total (μg/L as Ti)	1	2	5	14	120
Turbidity (JTU)	0	0	2	6	28
Uranium, Dissolved (μg/L as Ur)	.00	.03	.11	.24	.46
Vanadium, Total (μg/L as V)	2	3	8	14	30
Zinc, Total Recoverable (μg/L as Zn)	6	13	65	240	710
Zirconium, Total (μg/L as Zr)	2	4	5	9	26

Table 3.--Comparison of water quality to drinking water standards of the U.S. Environmental Protection Agency.

Contaminant	Maximum contaminant levels for inorganic chemicals	Secondary maximum contaminant levels	Percent of values equaling or exceeding maximum level
Arsenic (As)	50 μg/L		0
Barium (Ba)	1,000 μg/L		0
Cadmium (Cd)	10 μg/L		4
Chloride (Cl)		250 mg/L	less than 2
Chromium (Cr)	50 μg/L		1
Color (Units)		15 units	13
Copper (Co)		1 mg/L	less than 1
Fluoride (F)	1.4 to 2.4 mg/L		less than 2 exceed 1.4 mg/L; no values greater than 2.4 mg/L
Iron (Fe)		300 μg/L	44 (Dissolved Fe) 67 (Total Fe)
Lead (Pb)	50 μg/L		13
Manganese (Mn)		50 μg/L	30 (Dissolved Mn) 42 (Total Mn)
Mercury (Hg)	2 μg/L		0
Nitrate (NO_3 as N)	10 mg/L		0
pH (Units)		6.5 to 8.5 units	less than 2 exceed 8.5 units; no values less than 6.5 units
Selenium (Se)	10 μg/L		0
Silver (Ag)	50 μg/L		0
Sulfate (SO_4)		250 mg/L	7
Zinc (Zn)		5 mg/L	0
Total Dissolved Solids		500 mg/L	15

waters. Concentrations of lead, and certainly those of iron and manganese, are likely to decrease if water is treated before use. However, more frequent chemical analyses of lead are desirable when evaluating the suitability of domestic water supplies, particularly in those parts of the state where lead concentrations are highest. Cadmium, color, chromium, copper, chloride, fluoride, pH, and sulfate also may not meet standards at some locations.

AREAL VARIATIONS IN WATER QUALITY

Geologic conditions are a principal factor determining the areal variation in quality of ground water throughout the state, although differences may also be due to varying hydrologic conditions. Examples of the areal predominance of some water-quality characteristics are shown in figures 3, 4, and 5. Areal patterns were determined by plotting values on maps, and noting areas of similarity. Dissolved-solids concentration of water tend to be highest in the central part of the Lower Peninsula (fig. 3). Many wells in this area obtain water from bedrock deposits, which normally contain more highly mineralized water. The major dissolved substances - calcium, magnesium, sodium, sulfate, and chloride - also tend to be highest in the same area. Hardness[1/] of water is highest in the southeastern part of the state and at some places in the Upper Peninsula (fig. 3).

Areal predominance of barium and ammonia is illustrated (fig. 4) because each substance has caused either concern or a problem in the past few years. In 1974, concentrations of barium in some ground waters in southeastern Michigan were found to be as high as 7,800 μg/L--an amount considered unsafe for human consumption. Although no concentrations of that magnitude were found during this investigation, higher barium concentrations seem to occur in the southeastern part of the state. More frequent analyses for barium in the area are probably warranted.

The ammonia concentration of ground water has been of major significance on at least one occasion during the past several years. Plans for a fish hatchery in southeastern Michigan were abandoned when ground water was found to contain ammonia in excess of that suitable for propagation of trout. Figure 4 shows that higher ammonia concentrations are likely in the south-central and southeastern part of the state. As information accumulates, more precise delineations of ammonia distribution may provide one of the initial bases for judging the suitability of a ground water for fish hatchery use.

1/ The U.S. Geological Survey classifies the hardness of water as follows: 60 mg/L or less, soft; 61 to 120 mg/L, moderately hard, 121-180 mg/L, hard; and 190 mg/L or greater, very hard. Using this classification, and based on data obtained for this study, 5 percent of the ground waters are soft, 20 percent are moderately hard; 25 percent are hard; and, 50 percent are very hard.

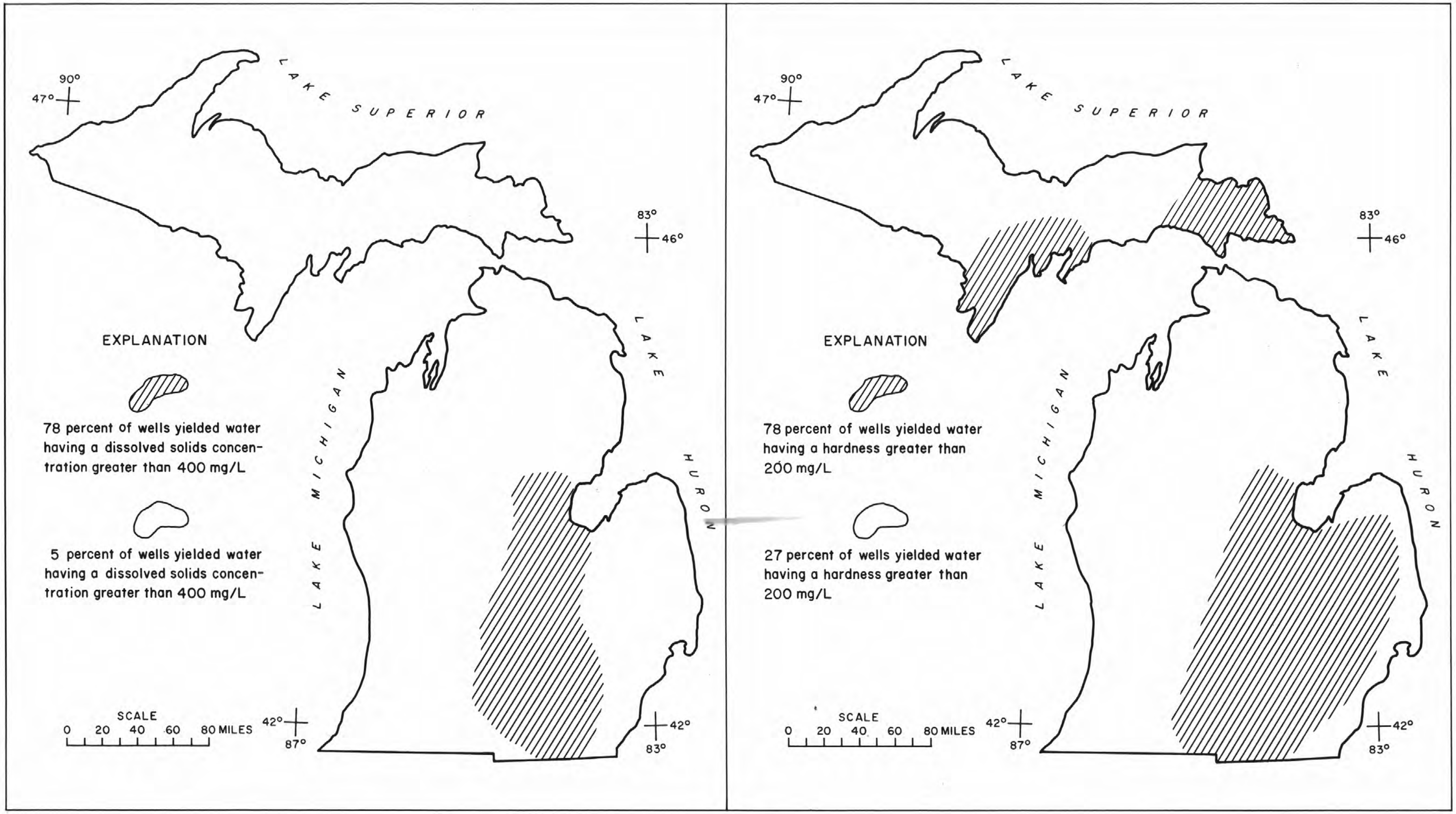

Figure 3.--Areal predominance of dissolved solids and hardness of water.

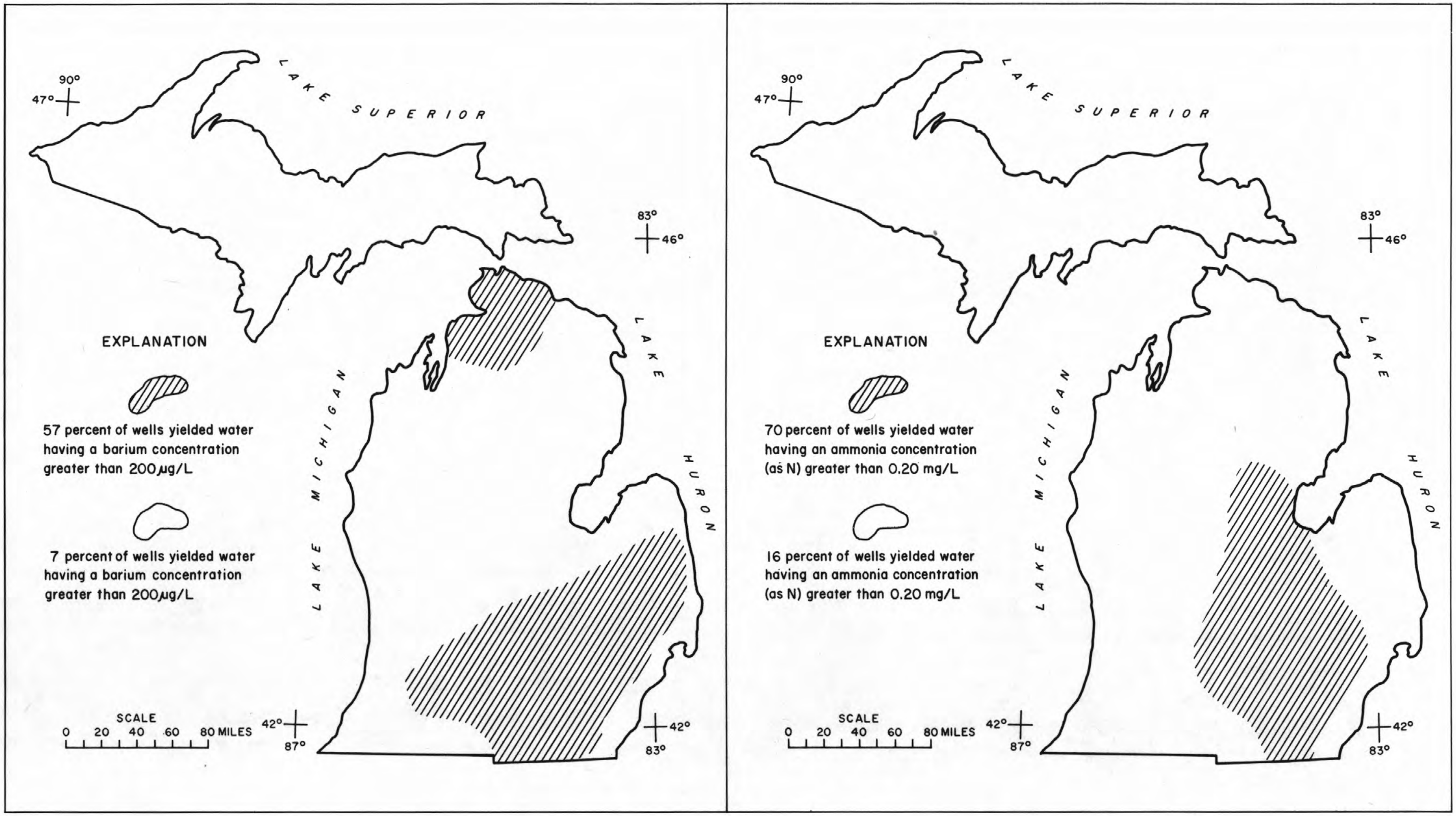

Figure 4.--Areal predominance of barium and ammonia in water.

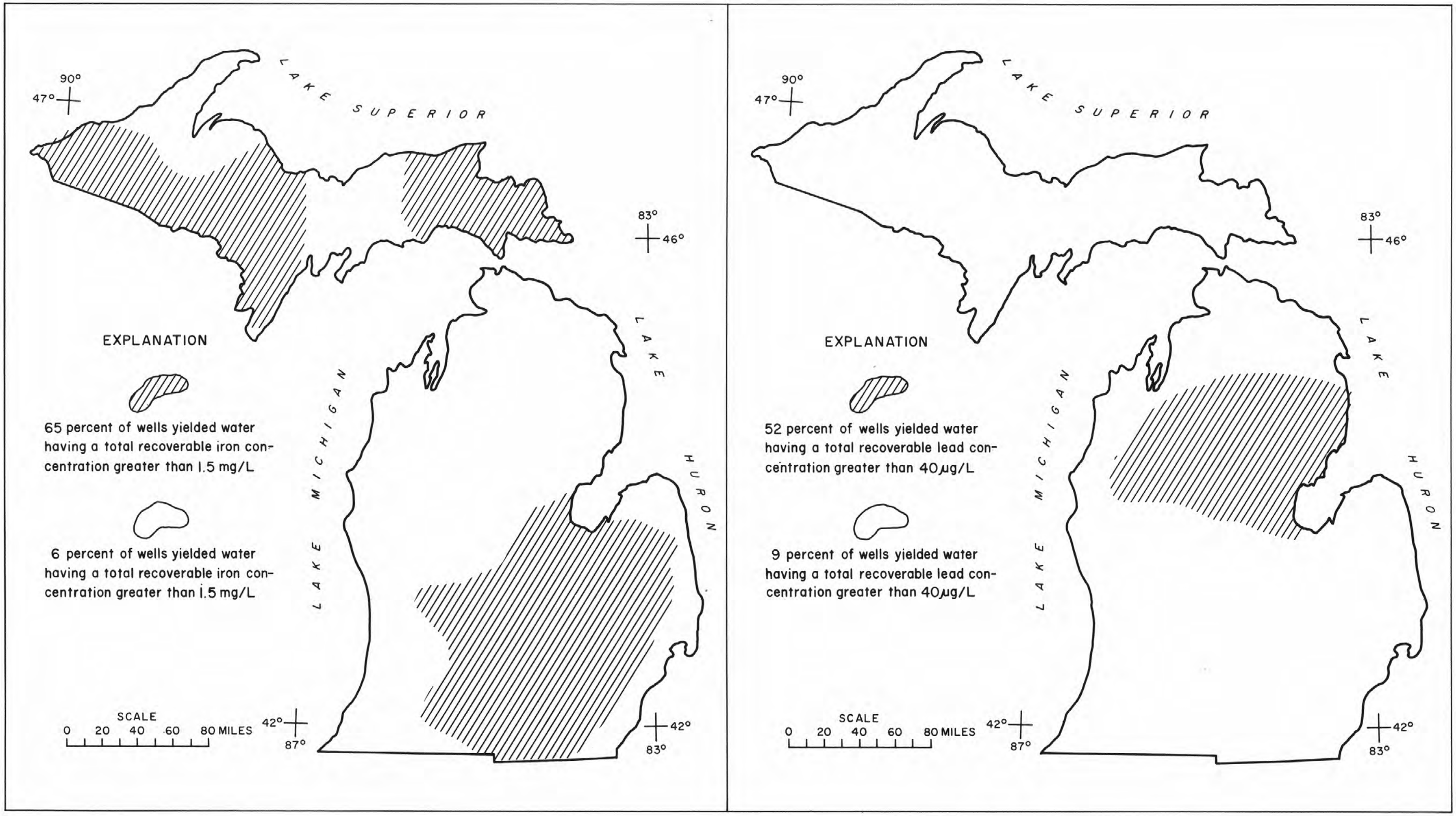

Figure 5.--Areal predominance of total recoverable iron and total recoverable lead in water.

Areal predominance of iron and lead is shown in figure 5. Iron concentrations are highest in the Upper Peninsula and in the southeastern part of the Lower Peninsula. Lead seems to be highest in the north-central part of the Lower Peninsula, where concentrations frequently approach the maximum permitted in drinking water supplies.

RELATION OF WATER QUALITY TO GEOLOGIC SOURCE

Chemical analyses were made on water collected from wells tapping seven glacial deposits (77 samples) and 16 bedrock deposits (36 samples). On the basis of lithology, nine bedrock deposits may be classified primarily as limestone or dolomite, five as sandstone, one as a shale, and one as a sandstone and shale. Some of the bedrock deposits, such as the Saginaw Formation, contain sandstone, shale, limestone, and coal. Table 5 lists the mean values of each chemical and physical property by geologic source. Interpretations based on the mean values should be made with caution because the number of samples of water obtained from each source is different.

The average depth of wells in glacial deposits (95 feet) is about half the average depth of wells in bedrock deposits (215 feet). Although no precise correlation can be demonstrated, the mineralization of water tends to increase as depth of wells increase (fig. 6). The mean dissolved-solids concentration of water from glacial deposits was 241 mg/L; the mean for bedrock deposits was 535 mg/L. Seventy-two percent of the maximum values given in table 1 are associated with water from bedrock deposits.

Figure 7, 8, and 9 illustrate the chemical characteristics of water from each geologic source by means of bar diagrams. If sufficient analyses were available from a geologic source, waters of both high and low mineralization are illustrated.

Among glacial deposits, outwash deposits generally contain water having the highest dissolved-solids concentrations. Higher than average concentrations of some trace metals also occur in water from outwash. Among bedrock deposits, water from the Saginaw Formation was more highly mineralized than that from other bedrock deposits. Some of the maximum concentrations of trace substances also occur in water of the Saginaw Formation. Table 4 shows mean concentrations for selected substances in water from glacial and bedrock deposits; mean concentrations computed by deleting data obtained from outwash deposits and the Saginaw Formation are also shown.

A comparison of water from limestones and dolomites, from sandstones, and from glacial deposits identified few distinguishing characteristics. For most substances, mean concentrations given in table 5 do not offer sufficient evidence to form firm conclusions regarding differences in the water quality of each geologic source. Figure 10 illustrates, however, how boron and sodium are related to lithology. Highest concentrations of each occur in water in the sandstones; lowest concentrations occur in water in glacial deposits. Areas delineated for each deposit encompass 80 percent or more of the boron and sodium concentrations available for plotting.

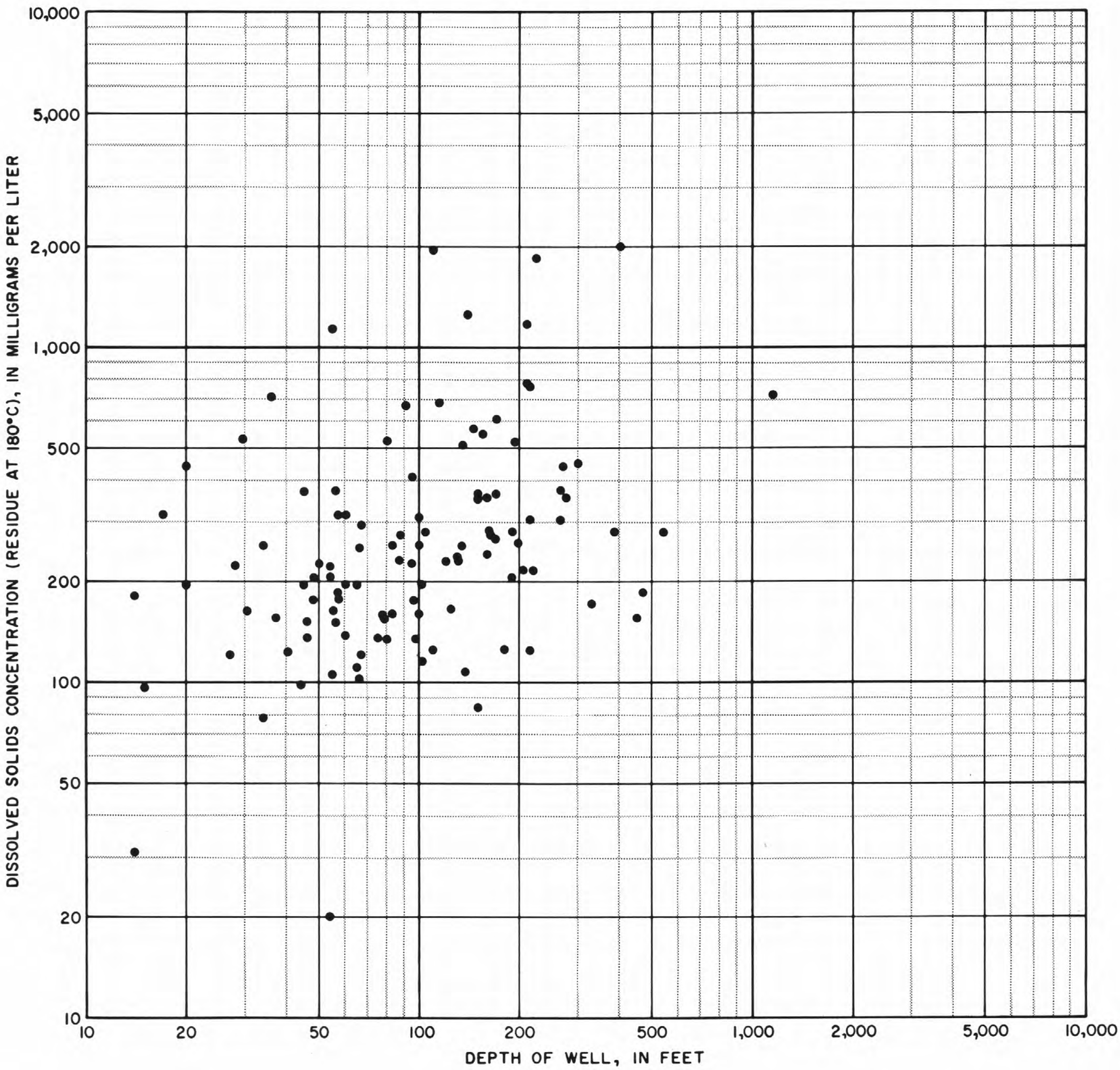

Figure 6.--Relation of depth of well to dissolved-solids concentration.

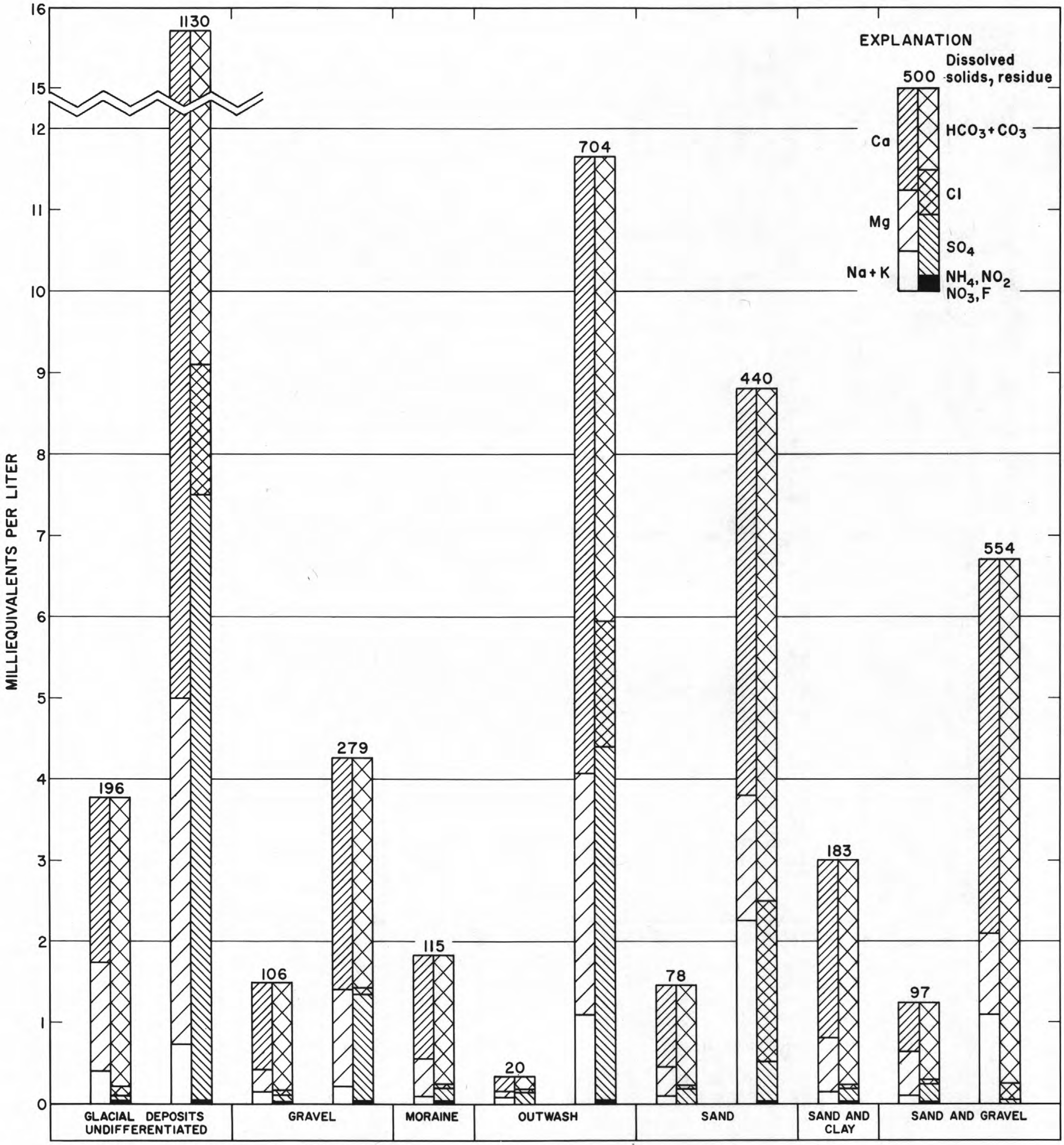

Figure 7.--Chemical characteristics of water from glacial deposits.

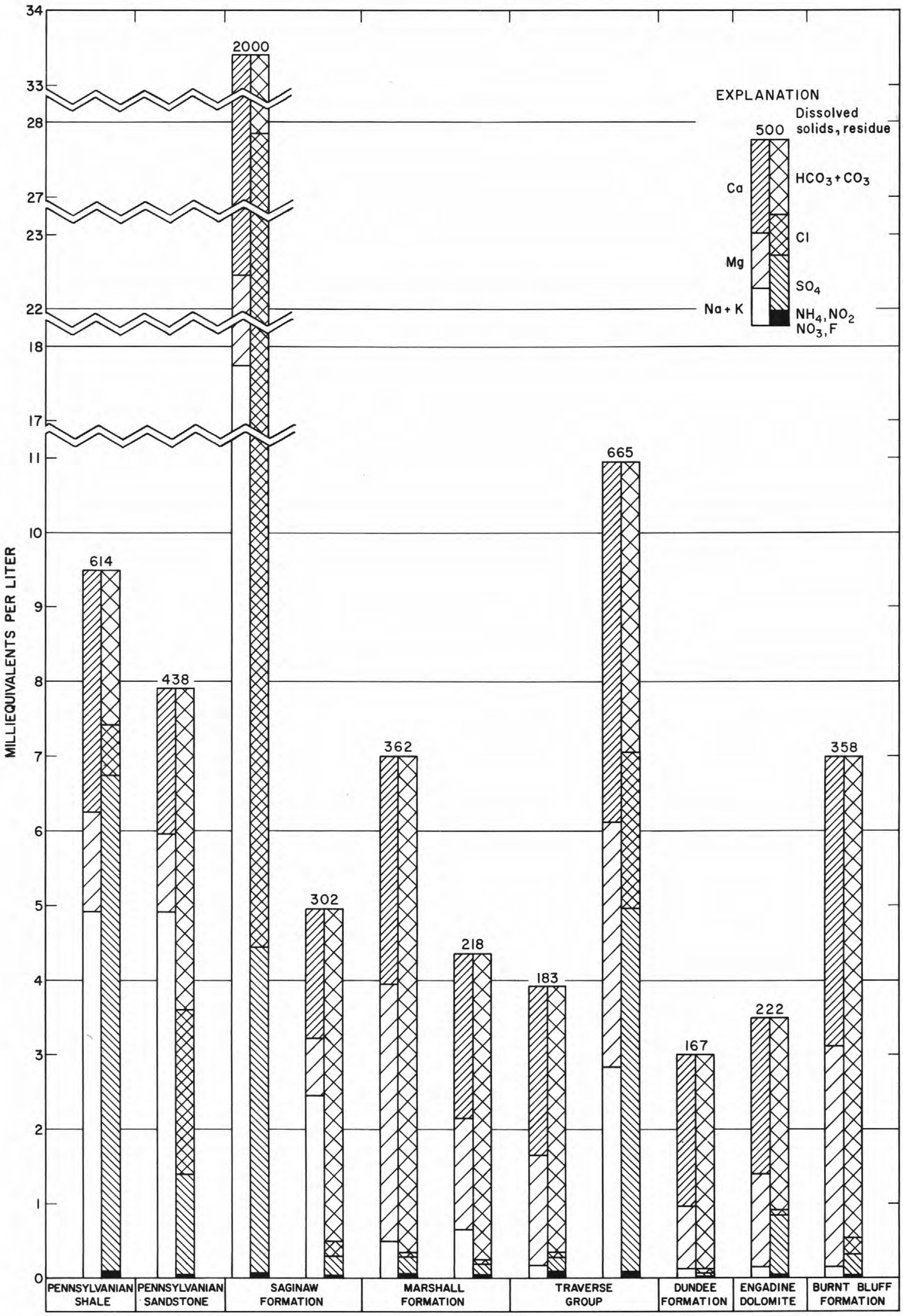

Figure 8.--Chemical characteristics of water from bedrock (Pennsylvanian, Mississippian, Devonian and Silurian).

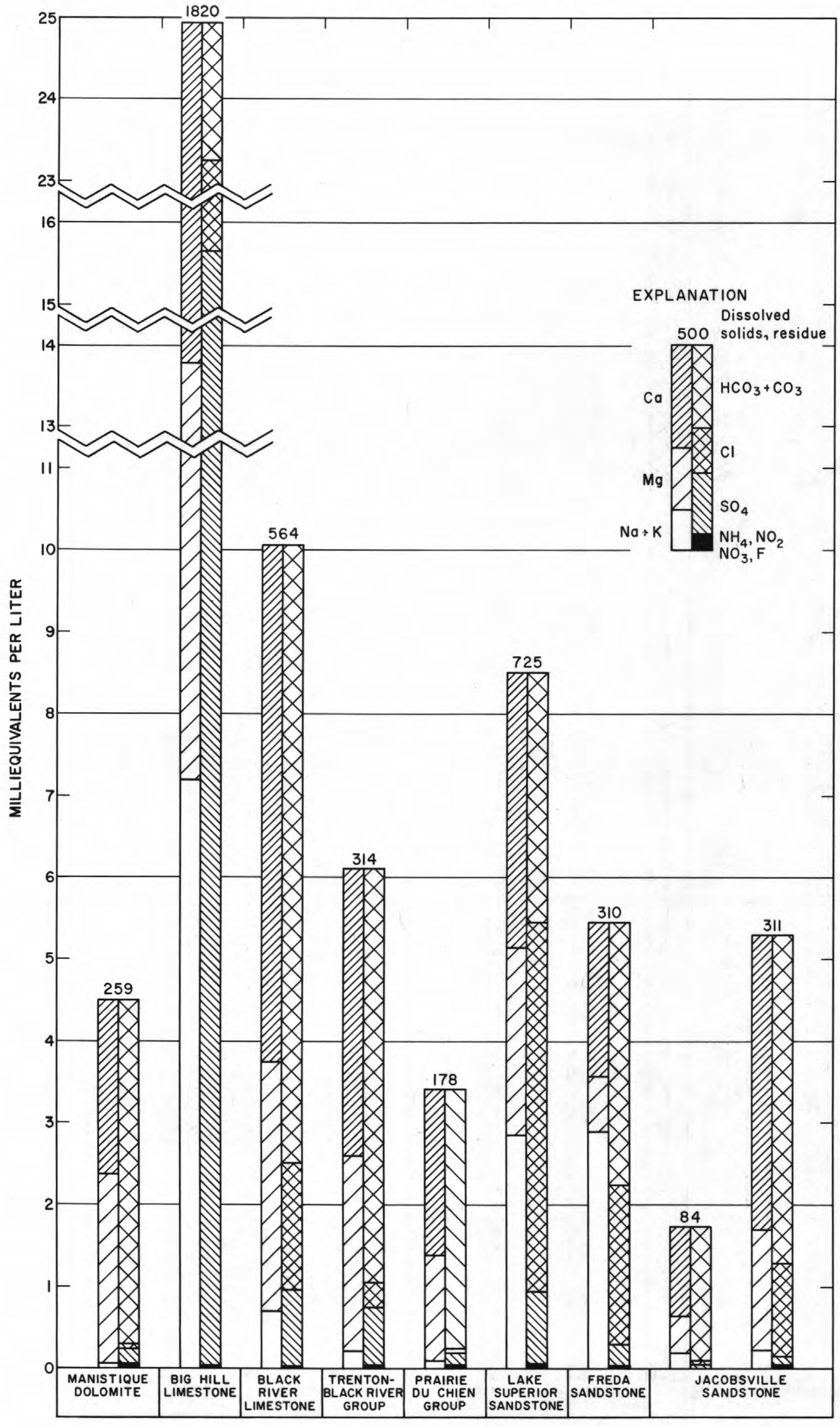

Figure 9.--Chemical characteristics of water from bedrock (Silurian, Ordovician, Cambrian, and Precambrian).

Table 4.--Comparison of chemical and physical characteristics of water from glacial and bedrock deposits.

Constituent	Mean Concentration			
	Bedrock	Glacial deposits	Bedrock (Saginaw Formation omitted)	Glacial deposits (outwash omitted)
Aluminum (µg/L)	1,693	197	584	209
Barium (µg/L)	78	43	65	42
Boron (µg/L)	254	55	197	43
Chloride (mg/L)	71	11	34	10
Chromium (µg/L)	16	8.9	15	9.2
Copper (µg/L)	22	35	18	12
Hardness (mg/L)	311	187	257	168
Iron, Total (µg/L)	3,340	1,760	2,170	1,220
Lithium (µg/L)	22	1.5	18	1.3
Manganese, Total (µg/L)	102	75	77	63
Nickel (µg/L)	10	5.9	8.3	6.4
Nitrogen, Total (mg/L)	.47	.39	.37	.42
Potassium (mg/L)	3.1	1.1	2.6	1.0
Silica (mg/L)	9.7	11	8.2	11
Silver (µg/L)	1.0	.36	1.0	.37
Sodium (mg/L)	56	11	28	8.9
Solids (Residue), Dissolved (mg/L)	535	241	384	211
Strontium (µg/L)	1,040	274	811	210
Sulfate (mg/L)	123	36	79	24
Tin (µg/L)	12	3.8	11	4.5
Titanium (µg/L)	414	21	299	19
Zinc (µg/L)	552	219	484	197

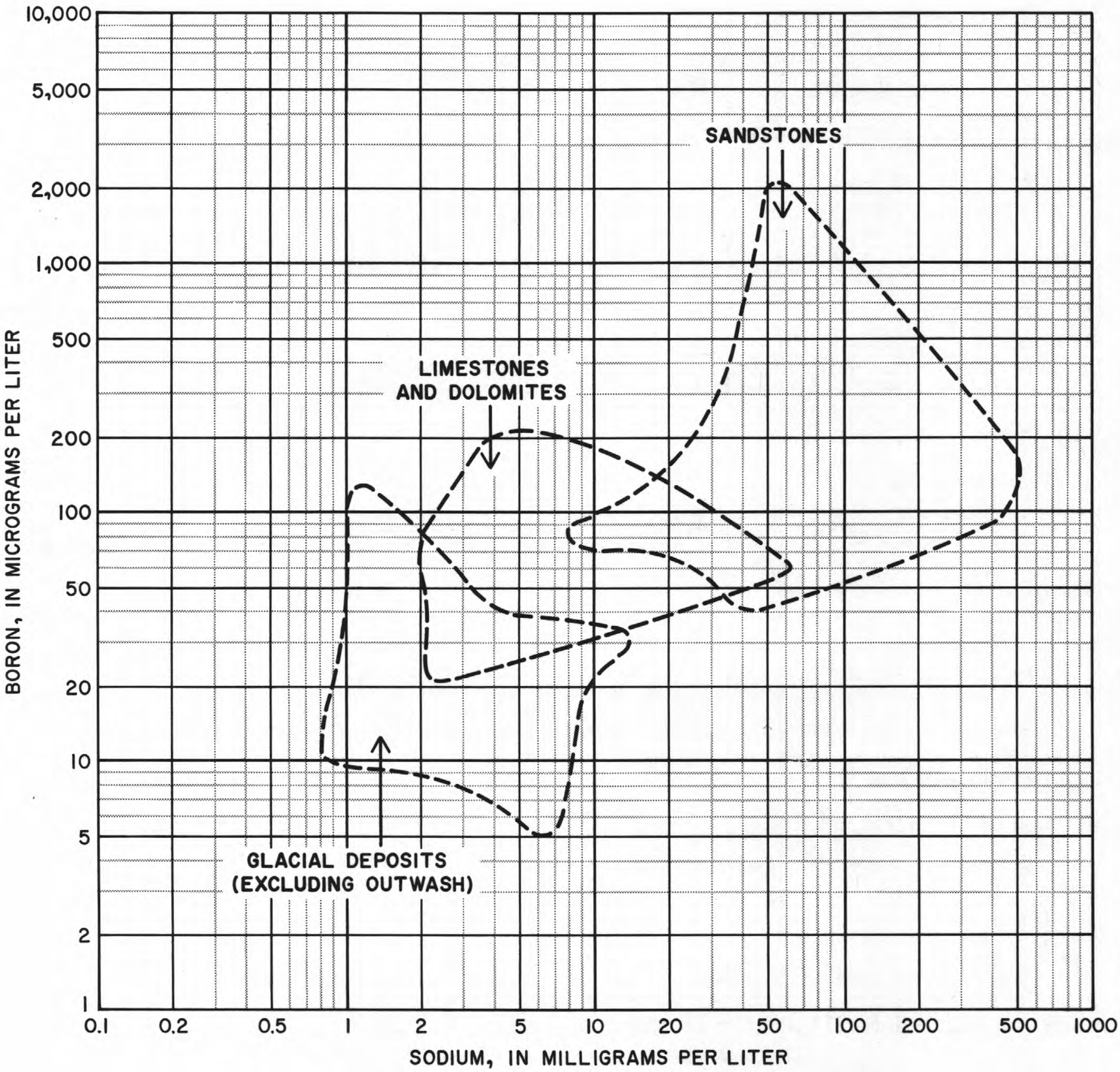

Figure 10.--Relation of boron and sodium to geologic source.

RELATION OF WATER QUALITY TO MINERAL ASSOCIATIONS

Mineral associations in geologic materials have been studied extensively. Frequently these associations are reflected in the chemical composition of water, and, for this reason, chemical analyses for trace substances serve as a prospecting tool. In the analyses of data for this report, about 40 possible relations between substances were investigated either by simple plotting of data or by regression analysis. As data are few and concentration ranges narrow for some substances, correlation was poor, even for some of the better known and understood associations. Extensive treatment is thus unwarranted in this report. Significant associations, involving aluminum and its relation to titanium and zirconium, are given as illustrations.

Aluminum is not commonly present in natural waters in concentrations greater than a few tenths of a milligram per liter. Its solubility is sometimes increased owing to the formation of complexes with fluoride and sulfate. Once dissolved from rocks, it rapidly forms aluminum hydroxide, which has a low solubility in the pH range of most natural waters. High concentrations of aluminum occur in water from several geologic sources in Michigan, and a relation between the concentration of aluminum and the composition or texture of deposits is not evident. Shale has been cited as having the highest average aluminum content among sedimentary rocks (Hem, 1972), and a well drilled in the Saginaw Formation, which is primarily sandstone and shale, did yield water having an aluminum concentration of 44,000 μg/L. Although the sample was clear when collected, much of the aluminum was probably in a finely divided particulate form. Water of the same well had a titanium concentration of 3,600 μg/L. The author is aware of only one higher concentration of titanium (5,400 μg/L), and that occurred in water associated with volcanos in Kamchatka, U.S.S.R. (White and others, 1963).

A plot of titanium concentrations versus aluminum concentrations is shown in figure 11. A regression analysis of the data gave a correlation coefficient of 0.91. The relation of the two constituents seems consistent with data of Migdisov (1960) who studied the titanium-aluminum ratio of sedimentary rock samples in Russia. Migdisov concluded, from an analysis of more than 1,900 samples, that the TiO_2/Al_2O_3 ratio was 0.053. Expressed as a Ti/Al ratio, the value is 0.06. Figure 11 suggests that the Ti/Al ratio for Michigan ground waters ranges from about 0.1 to about 0.06. This consistency indicates that the titanium-aluminum association in Michigan ground waters is a reliable one, and one that might have significance in investigating the occurrence of titanium deposits.

The relation of aluminum to zirconium in water (fig. 12) may also be of possible significance in geochemical investigations. Zirconium, like aluminum and titanium, seems to occur in concentrations higher than commonly reported. Il'ina and others (1970) found that the zirconium and titanium contents of sandstone, siltstone, and clay are related. This fact, and the apparent relationship of aluminum and titanium, suggest that a aluminum-zirconium relationship is to be expected.

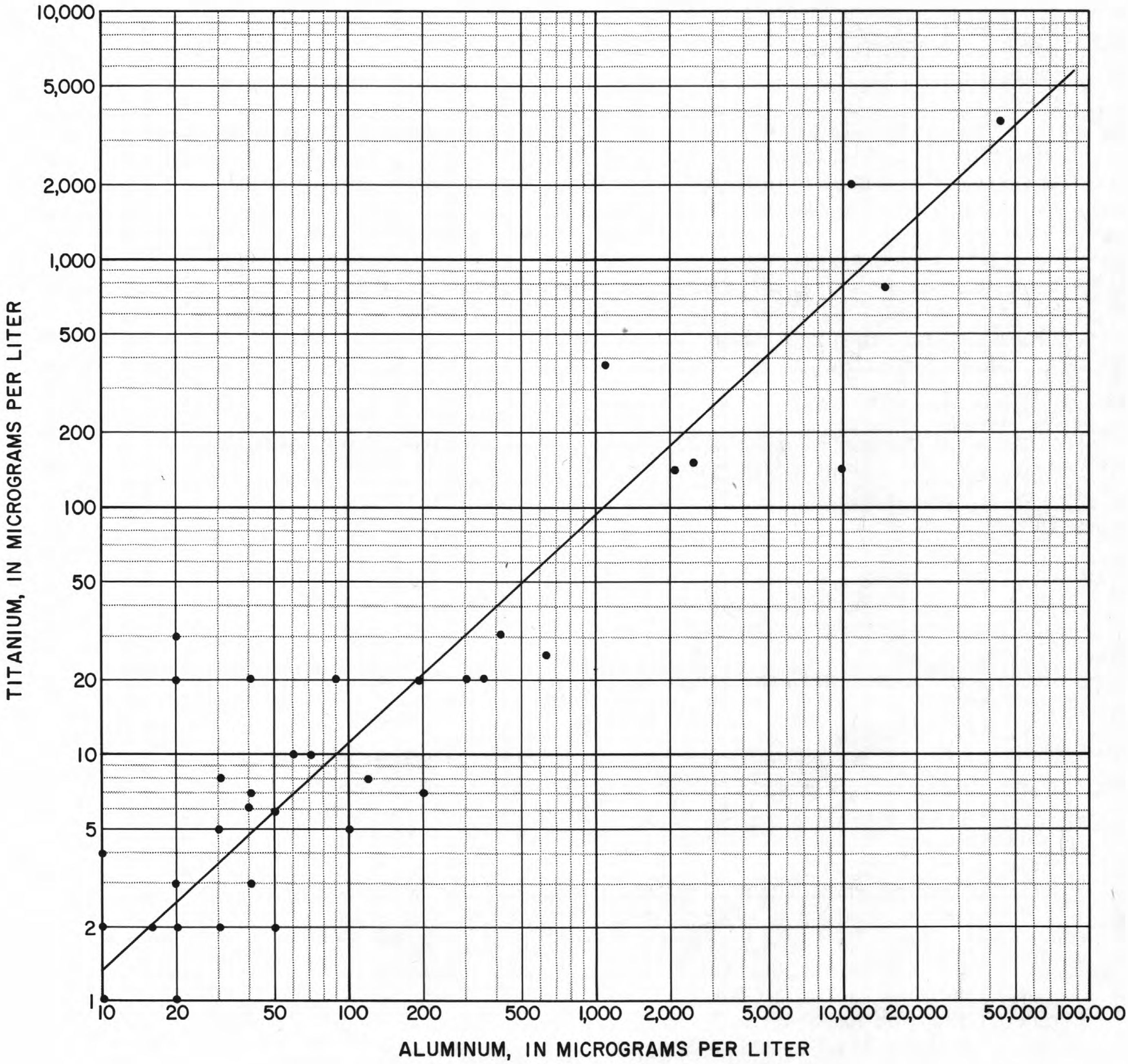

Figure 11.--Relation of titanium to aluminum in water.

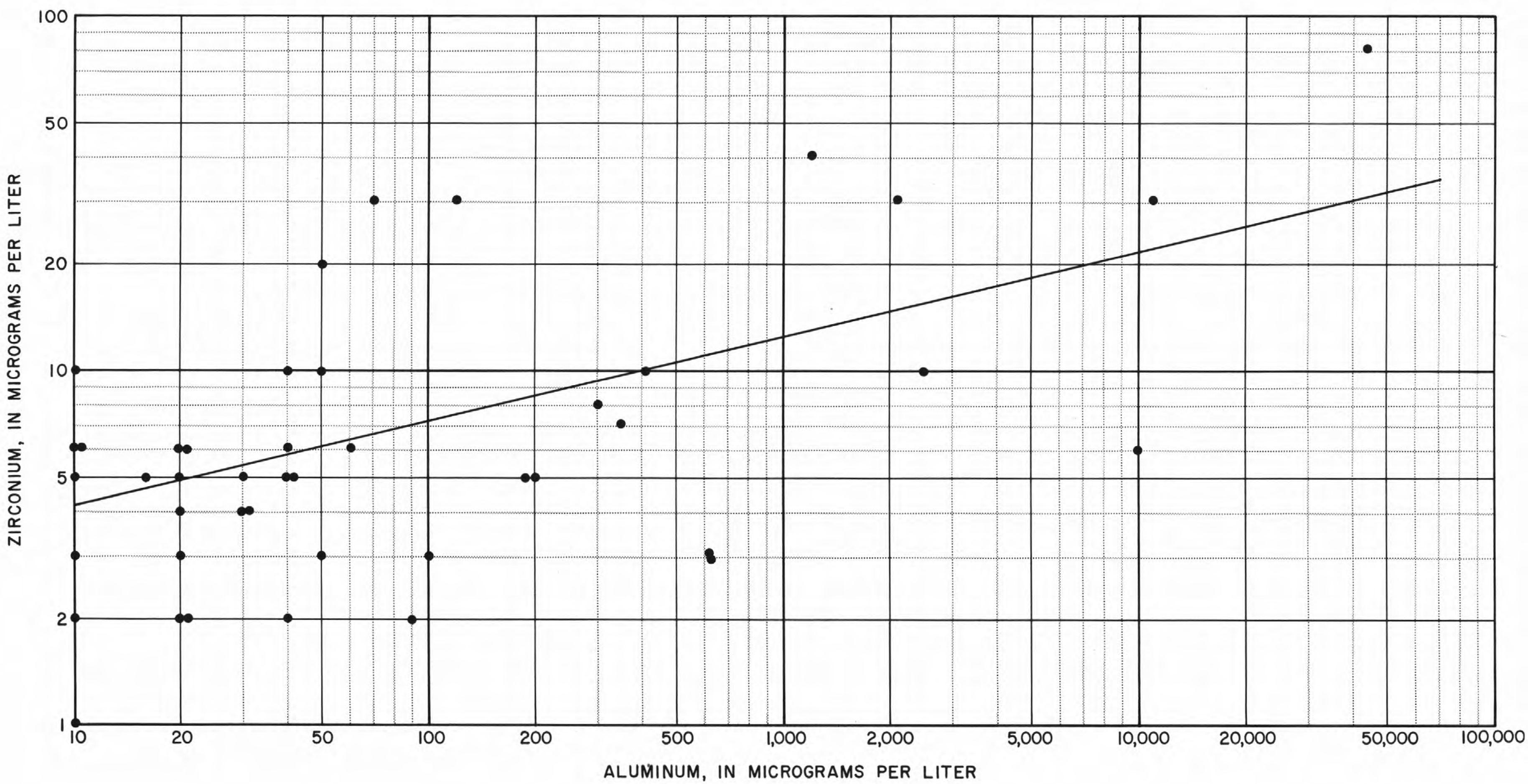

Figure 12.--Relation of zirconium to aluminum in water.

Analysis of data for this report, as well as ample geochemical literature, suggest that identification of other mineral associations may be possible as information accumulates. For example, relations between copper and titanium, manganese and iron, copper and zirconium, vanadium and iron, and boron and sodium are apparent but less definite. Further, relations between pH and higher lead concentrations and between pH and aluminum are suggested by data. Strontium, which is chemically similar to calcium and generally in close geochemical association with it, increases rapidly as calcium increases. The concentration of strontium in ground waters analyzed shows a closer relationship with magnesium, however. Strontium increases by a factor of about 100 as magnesium increases by a factor of about 5. Strontium also increases as sulfate increases.

CONCLUSIONS

Chemical and physical analyses of 152 samples collected from 1974 to 1979 indicate that the quality characteristics of ground water in Michigan vary widely. Water from bedrock deposits is more highly mineralized than that of glacial deposits. Among glacial deposits, outwash yields the most highly mineralized water. Among bedrock deposits, the Saginaw Formation yields the most highly mineralized water. Calcium and bicarbonate are generally the predominant ions in waters of lower mineralization, whereas sodium, sulfate, and chloride are the predominant ions in waters of higher mineralization. About 75 percent of ground waters may be classified as hard or very hard. Iron occurs in concentrations that are higher than common in many natural ground waters. Aluminum and titanium occur in unusually high concentrations, and their occurrence seems to be one of mineral association.

Frequency distributions indicate that a significant number of waters do not meet U.S. Environmental Protection Agency drinking water standards for iron, manganese, lead, total dissolved solids, and color. Sulfate, pH, fluoride, copper, chromium, chloride, and cadmium also do not meet standards at times. Scant data indicate that lead tends to be naturally higher in ground water in the upper part of the Lower Peninsula than in other areas. Dissolved-solids (sum of constituents) concentrations, which ranged from 23 to 2,100 mg/L statewide, are highest in the southern part of the Lower Peninsula.

Too few data are available to define conclusive differences in the chemical characteristics of water from each geologic source. Mean concentrations, computed for each glacial and bedrock deposit, do provide a basis for comparison.

Mineral associations, notably those of aluminum and titanium and aluminum and zirconium, are evident from data obtained. Further work will likely develop additional relationships that are only tentative at present.

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Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.

[The number of samples collected from each source and used in computing tabulated means is as follows: Glacial deposits, undifferentiated, 11; gravel, 5; moraine, 1, outwash, 13, sand, 35; sand and clay, 1; sand and gravel, 11; Pennsylvanian shale, 1; Pennsylvanian sandstone, 1; Saginaw Formation, 10; Marshall Formation, 5; Traverse Group, 2; Dundee Formation, 1; Engadine Dolomite, 2; Burnt Bluff Formation, 2; Manistique Dolomite, 1; Big Hill Limestone (of Hussey, 1926), 1; Black River Limestone, 1; Trenton-Black River Group, 2; Prairie du Chien Group, 2; Lake Superior Sandstone, 1; Freda Sandstone, 1; and Jacobsville Sandstone, 3. Single samples listed as mean values. Averages for bismuth, gallium, and germanium were calculated from reported "less than (<)" values, and thus may or may not correspond to true average concentrations.]

Source	Alkalinity (mg/L as $CaCO_3$)	Aluminum, Total Recoverable (μg/L as Al)	Arsenic, Total (μg/L as As)	Barium, Total Recoverable (μg/L as Ba)	Beryllium, Total Recoverable (μg/L as Be)	Bicarbonate (μg/L as HCO_3)	Bismuth, Total (μg/L as Bi)	Boron, Total Recoverable (μg/L as B)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	189	42	2	39	0.4	230	<4	61
Gravel Mean	114	70	1	52	.4	131	<4	36
Moraine Mean	84	60	4	0	.0	102	--	20
Outwash Mean	208	93	4	47	3.5	251	<2	116
Sand Mean	160	344	1	43	.1	195	<3	42
Sand and clay Mean	144	30	1	100	.0	175	--	20
Sand and gravel Mean	125	55	2	40	1.0	152	<3	32
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	107	60	1	0	.0	130	--	100
Pennsylvanian sandstone Mean	210	60	0	0	.0	260	--	610
Saginaw Formation Mean	272	4,476	5	101	4.7	332	<14	372
Marshall Formation Mean	215	2,214	9	140	1.0	260	<8	70
Traverse Group Mean	196	105	1	100	.0	239	--	30
Dundee Formation Mean	148	300	4	0	.0	180	--	20
Engadine Dolomite Mean	190	520	1	0	.0	231	--	60
Manistique Dolomite Mean	242	25	0	5	1.0	296	<7	20
Burnt Bluff Formation Mean	320	70	0	0	.0	390	--	0
Big Hill Limestone Mean	67	130	1	0	.0	82	--	560
Black River Limestone Mean	400	80	1	100	.0	482	--	160
Trenton-Black River Group Mean	220	70	1	135	10	274	<17	145
Prairie du Chien Group Mean	136	35	2	4	1.0	162	<5	0
Lake Superior Sandstone Mean	165	615	0	150	5.0	201	<10	1,055
Freda Sandstone Mean	159	510	6	100	2.0	194	<10	1,400
Jacobsville Sandstone Mean	192	43	2	67	.0	233	--	63

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	Cadmium, Total Recoverable (μg/L as Cd)	Calcium, Dissolved (mg/L as Ca)	Carbon, Organic Dissolved (mg/L as C)	Carbon Dioxide, Dissolved (mg/L as CO_2)	Carbonate (mg/L as CO_3)	Chloride, Dissolved (mg/L as Cl)	Chromium, Total Recoverable (μg/L as Cr)	Cobalt, Total Recoverable (μg/L as Co)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	3	68	5.4	10	0	19	8	2
Gravel Mean	4	34	4.6	5.3	5	1.5	7	2
Moraine Mean	2	25	1.7	1.6	0	1.1	10	3
Outwash Mean	.8	74	5.7	7.3	1	13	7	3
Sand Mean	3.4	44	4.1	6.3	0	7.8	9.9	1
Sand and clay Mean	2	42	.7	2.2	0	1.1	10	2
Sand and gravel Mean	1	41	3.6	4.8	0	17	9.4	1
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	5	65	1.2	2.6	0	24	10	2
Pennsylvanian sandstone Mean	6	39	7.7	5.2	0	79	10	1
Saginaw Formation Mean	.3	119	6.4	18	0	165	18	8
Marshall Formation Mean	2	58	3.0	7.6	0	7.7	12	3
Traverse Group Mean	1	68	2.6	9.6	0	38	10	2
Dundee Formation Mean	1	40	11	9.1	0	1.5	10	3
Engadine Dolomite Mean	1	52	2.6	5.8	0	1.4	15	2
Manistique Dolomite Mean	0	54	7.1	20	0	1.3	14	4
Burnt Bluff Formation Mean	0	79	2.9	39	0	7.4	10	0
Big Hill Limestone Mean	2	230	.6	2.1	0	270	10	2
Black River Limestone Mean	2	120	3.1	39	0	55	10	0
Trenton-Black River Group Mean	6	57	2.1	11	0	5.4	24	10
Prairie du Chien Group Mean	2	32	3.4	3.3	0	.6	8	3
Lake Superior Sandstone Mean	10	62	1.6	9.0	0	160	95	20
Freda Sandstone Mean	0	39	2.8	3.1	0	69	8	3
Jacobsville Sandstone Mean	1	45	2.7	14	0	16	10	1

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	Color (Platinum Cobalt Units)	Copper, Total Recoverable (µg/L as Cu)	Cyanide, Total (mg/L as CN)	Depth of Well (feet)	Fluoride, Dissolved (mg/L as F)	Gallium, Total (µg/L as Ga)	Germanium, Total (µg/L as Ge)	Hardness (mg/L as $CaCO_3$)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	5	9	.00	105	0.3	<2	<5	248
Gravel Mean	7	44	.00	71	.1	<1	<4	117
Moraine Mean	1	15	.00	103	.1	--	--	86
Outwash Mean	20	151	.00	89	.4	<6	<20	274
Sand Mean	8	10	.00	109	.1	<1	<5	164
Sand and clay Mean	5	5	.00	57	.1	--	--	140
Sand and gravel Mean	45	7	.00	64	.1	<1	<5	143
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	10	1	.00	172	.5	--	--	230
Pennsylvanian sandstone Mean	5	1	.00	270	.3	--	--	150
Saginaw Formation Mean	11	4	.00	243	.5	<7	<20	447
Marshall Formation Mean	3	8	.00	172	.3	<2	<9	246
Traverse Group Mean	10	4	.00	281	1.4	--	--	290
Dundee Formation Mean	85	2	.00	125	.1	--	--	140
Engadine Dolomite Mean	28	78	.00	60	.2	--	--	220
Manistique Dolomite Mean	2	4	.00	102	.6	<3	<10	250
Burnt Bluff Formation Mean	5	11	.00	160	.1	--	--	350
Big Hill Limestone Mean	5	5	.00	225	.0	--	--	900
Black River Limestone Mean	5	15	.00	147	.2	--	--	450
Trenton-Black River Group Mean	12	16	.00	41	.2	< 20	< 40	245
Prairie du Chien Group Mean	3	6	.00	136	.2	<2	<6	132
Lake Superior Sandstone Mean	4	12	.00	1,160	.4	<20	<50	270
Freda Sandstone Mean	15	80	.00	100	.3	<3	<10	130
Jacobsville Sandstone Mean	6	5	.00	244	.1	--	--	182

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	Hardness, Noncarbonate (mg/L as $CaCo_3$)	Iron, Dissolved (μg/L as Fe)	Iron, Total Recoverable (μg/L as Fe)	Lead, Total Recoverable (μg/L as Pb)	Lithium, Total Recoverable (μg/L as Li)	Manganese, Dissolved (μg/L as Mn)	Manganese, Total Recoverable (μg/L as Mn)	Magnesium, Dissolved (mg/L as Mg)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	61	545	1,370	21	4	43	58	20
Gravel Mean	10	428	1,266	16	2	56	72	8.1
Moraine Mean	2	40	160	1	0	0	0	5.6
Outwash Mean	73	1,442	4,415	32	3	115	134	22
Sand Mean	9.1	332	930	34	1	44	50	13
Sand and clay Mean	0	40	580	6	0	10	20	8.0
Sand and gravel Mean	21	1,553	2,070	11	0	116	118	9.5
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	120	250	320	160	60	50	50	16
Pennsylvanian sandstone Mean	0	550	890	150	40	20	20	13
Saginaw Formation Mean	206	2,382	6,536	14	31	106	176	36
Marshall Formation Mean	53	402	3,388	20	20	67	138	24
Traverse Group Mean	95	600	2,600	10	0	20	20	29
Dundee Formation Mean	0	2,400	2,400	7	0	90	90	10
Engadine Dolomite Mean	30	580	2,900	12	15	35	70	22
Manistique Dolomite Mean	5	10	80	5	10	5	8	28
Burnt Bluff Formation Mean	30	80	40	0	0	0	0	36
Big Hill Limestone Mean	840	50	600	15	50	50	50	80
Black River Limestone Mean	57	1,600	3,200	22	10	30	60	37
Trenton-Black River Group Mean	21	535	1,915	55	0	25	45	24
Prairie du Chien Group Mean	4	85	430	14	0	0	10	13
Lake Superior Sandstone Mean	106	105	265	130	35	40	100	28
Freda Sandstone Mean	0	200	10,400	16	90	20	160	8
Jacobsville Sandstone Mean	15	80	963	12	1	73	77	17

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	Mercury, Total Recoverable (μg/L as Hg)	Molybdenum, Total Recoverable (μg/L as Mo)	Nickel, Total Recoverable (μg/L as Ni)	Nitrogen, Total (mg/L as N)	Nitrogen, Ammonia, Total (mg/L as N)	Nitrogen, Nitrate, Total (mg/L as N)	Nitrogen, Nitrite, Total (mg/L as N)	Nitrogen, Organic, Total (mg/L as N)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	0.4	5	5	0.73	0.23	0.32	0.01	0.18
Gravel Mean	.5	2	7	.24	.08	.04	.00	.12
Moraine Mean	.5	2	10	.24	.00	.21	.00	.03
Outwash Mean	.3	5	4	.29	.18	.05	.00	.07
Sand Mean	.35	3	6	.36	.07	.11	.00	.17
Sand and clay Mean	.5	1	21	.45	.00	.28	.00	.17
Sand and gravel Mean	.23	.1	6	.41	.06	.14	.00	.20
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	.5	0	3	.98	.93	.00	.01	.04
Pennsylvanian sandstone Mean	.5	3	3	.83	.67	.00	.00	.16
Saginaw Formation Mean	.36	6	14	.72	.47	.01	.00	.24
Marshall Formation Mean	.02	3	9	.17	.07	.00	.01	.13
Traverse Group Mean	.2	2	6	.15	.05	.00	.00	.10
Dundee Formation Mean	.5	1	5	.47	.15	.00	.01	.31
Engadine Dolomite Mean	.2	3	7	.20	.06	.00	.00	.14
Manistique Dolomite Mean	.5	2	4	.54	.01	.40	.00	.12
Burnt Bluff Formation Mean	.0	3	4	1.2	.01	.92	.00	.24
Big Hill Limestone Mean	.5	4	11	.75	.17	.22	.00	.36
Black River Limestone Mean	.0	3	14	.27	.05	.07	.00	.15
Trenton-Black River Group Mean	.5	9	22	.26	.08	.04	.01	.14
Prairie du Chien Group Mean	.5	2	6	.52	.06	.40	.01	.08
Lake Superior Sandstone Mean	.6	10	12	.28	.06	.02	.01	.20
Freda Sandstone Mean	.3	2	15	.11	.03	.01	.04	.03
Jacobsville Sandstone Mean	.2	2	5	.21	.01	.11	.05	.08

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	pH (Units)	Phenols (µg/L)	Phosphorus, Total (mg/L as P)	Phosphorus, Ortho, Total (mg/L as P)	Potassium, Dissolved (mg/L as K)	Selenium, Total (µg/L as Se)	Silica, Dissolved (mg/L as SiO_2)	Silver, Total Recoverable (µg/L as Ag)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	7.7	0.5	0.02	0.00	1.6	0	9.9	0.5
Gravel Mean	7.8	.8	.03	.01	1.2	0	11	.0
Moraine Mean	8.0	.0	.01	.00	.9	0	15	.0
Outwash Mean	7.9	1.2	.03	.02	1.5	0	12	.3
Sand Mean	7.8	.3	.04	.02	.8	0	10	.4
Sand and clay Mean	8.1	.0	.01	.01	1.1	0	19	.0
Sand and gravel Mean	7.8	.1	.01	.01	1.1	0	12	.3
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	7.9	1.0	.01	.00	5.8	0	6.2	.0
Pennsylvanian sandstone Mean	7.9	.0	.00	.00	4.6	0	6.1	1.0
Saginaw Formation Mean	7.6	1.8	.06	.02	4.3	0	14	.8
Marshall Formation Mean	7.8	1.0	.02	.01	1.4	0	10	1.2
Traverse Group Mean	7.6	.0	.01	.00	2.6	0	9.4	.0
Dundee Formation Mean	7.5	.0	.01	.00	.6	0	11	1.0
Engadine Dolomite Mean	7.8	1.0	.18	.01	1.4	0	5.4	.0
Manistique Dolomite Mean	7.4	1.0	.01	.01	1.4	0	7.0	1.0
Burnt Bluff Formation Mean	7.2	.0	.04	.01	1.6	0	5.3	.0
Big Hill Limestone Mean	7.8	.0	.04	.01	9.0	0	.6	.0
Black River Limestone Mean	7.3	10	.00	.00	3.4	0	11	.0
Trenton-Black River Group Mean	7.6	1.0	.01	.01	2.0	0	12	4.0
Prairie du Chien Group Mean	7.9	.0	.02	.02	1.0	0	11	1.0
Lake Superior Sandstone Mean	7.6	.0	.01	.00	5.8	0	7.4	8.0
Freda Sandstone Mean	8.0	.0	.14	.11	7.0	1	9.2	1.0
Jacobsville Sandstone Mean	7.5	.0	.02	.01	2.8	0	11	.0

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	Sodium Dissolved (mg/L as Na)	Solids, Residue at 180°C, Dissolved (mg/L)	Solids, Sum of Constituents, Dissolved (mg/L)	Specific Conductance (micromhos)	Strontium, Total Recoverable (µg/L as Sr)	Sulfate, Dissolved (mg/L as SO_4)	Tin, Total Recoverable (µg/L as Sn)	Titanium, Total (µg/L as Ti)
GLACIAL DEPOSITS								
Glacial deposits, undifferentiated Mean	21	368	338	518	488	84	3	2
Gravel Mean	3.5	156	147	233	520	18	2	14
Moraine Mean	1.9	115	108	167	70	8.3	--	--
Outwash Mean	20	384	364	582	589	95	15	10
Sand Mean	7.4	182	193	341	127	13	3	41
Sand and clay Mean	2.7	183	168	280	60	7.9	--	--
Sand and gravel Mean	6.3	197	176	299	84	11	3	7
BEDROCK DEPOSITS								
Pennsylvanian shale Mean	110	614	612	880	1,000	320	--	--
Pennsylvanian sandstone Mean	110	438	445	735	700	64	--	--
Saginaw Formation Mean	128	1,629	1,583	1,363	1,627	233	13	542
Marshall Formation Mean	11	319	304	491	474	62	6	502
Traverse Group Mean	34	424	421	690	1,275	122	--	7
Dundee Formation Mean	2.2	167	159	268	100	2.4	--	--
Engadine Dolomite Mean	3.2	256	250	425	2,600	48	--	--
Manistique Dolomite Mean	.8	259	249	420	110	9.6	6	4
Burnt Bluff Formation Mean	2.4	358	338	584	60	14	--	--
Big Hill Limestone Mean	160	1,820	1,540	2,205	2,500	750	--	--
Black River Limestone Mean	14	564	526	900	700	46	--	--
Trenton-Black River Group Mean	2.9	256	262	440	210	22	25	8
Prairie du Chien Group Mean	2.8	150	150	251	120	8.1	5	3
Lake Superior Sandstone Mean	62	628	468	850	3,150	43	30	370
Freda Sandstone Mean	62	310	304	540	530	13	7	30
Jacobsville Sandstone Mean	10	225	224	393	193	5.0	--	--

Table 5.--Mean values of chemical and physical characteristics of water from geologic sources.--Continued

Source	Turbidity (JTU)	Uranium, Dissolved (μg/L as Ur)	Vanadium, Total (μg/L as V)	Zinc, Total Recoverable (μg/L as Zn)	Zirconium, Total (μg/L as Zr)
GLACIAL DEPOSITS					
Glacial deposits, undifferentiated Mean	3	0.2	3	61	5
Gravel Mean	6	.2	2	478	4
Moraine Mean	0	--	--	120	--
Outwash Mean	16	.04	12	197	30
Sand Mean	7	.18	2.9	272	4
Sand and clay Mean	2	--	--	210	--
Sand and gravel Mean	3	.13	10	146	5
BEDROCK DEPOSITS					
Pennsylvanian shale Mean	1	.01	--	20	--
Pennsylvanian sandstone Mean	1	.54	--	10	--
Saginaw Formation Mean	33	.29	19	716	29
Marshall Formation Mean	13	.16	8	178	12
Traverse Group Mean	2	.29	2.3	25	--
Dundee Formation Mean	--	.33	--	10	--
Engadine Dolomite Mean	36	--	--	1,070	--
Manistique Dolomite Mean	1	--	5	20	10
Burnt Bluff Formation Mean	1	--	--	310	--
Big Hill Limestone Mean	9	--	--	4,700	--
Black River Limestone Mean	3	--	--	3,200	--
Trenton-Black River Group Mean	2	--	33	60	30
Prairie du Chien Group Mean	1	.05	4	15	6
Lake Superior Sandstone Mean	1	--	40	15	40
Freda Sandstone Mean	95	--	26	60	10
Jacobsville Sandstone Mean	3	--	--	73	--

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