Journal of the Minnesota Academy of Science

Volume 3 | Number 1 Article 19

1886

The Water of Artesian Wells; Its Quality and the Possibility of its Becoming a Source of Supply in Minnesota

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[*Paper S.*]

I. THE WATER OF ARTESIAN WELLS; ITS QUALITY AND THE POSSIBILITY OF ITS BECOMING A SOURCE OF SUPPLY IN MINNESOTA.—*C. N. Hewitt.*

II. THE GEOLOGICAL CONDITIONS WHICH CONTROL ARTESIAN WELL BORING IN SOUTHEASTERN MINNESOTA.—*C. W. Hall.*

I.

[ABSTRACT.]

The speaker presented the analyses of thirty-two artesian or drilled well waters, made in the laboratory of the State Board of Health of Minnesota under his direction, and presented a brief study of their history, quantity and composition, as bearing upon the question of such water for domestic water supply. He preferred the term "drilled" wells, as implying the essential fact that the water supply was obtained from beneath one or more strata of soil or rock, impermeable to surface water, and, therefore, comparatively free from the dangers of surface wells, or even deep wells not so protected. It will be seen, too, that the question of depth is not of so much importance as that of character of soil or rock penetrated. The "drive well" is excluded from this list, as not fulfilling the conditions, i. e. supply below impenetrable strata of soil or rock, and wells so tubed as to prevent the entrance of surface water to the supply. As to tubing, he advised the iron pipe, thoroughly coated with asphaltum inside and outside, or coated with black oxide of iron by one of the several processes used for that purpose. Galvanized iron was condemned as almost always imperfectly made, and as adding salts of zinc to the water. The so-called kalamein pipe was also objected to as not proved to be safe.

The plain wrought iron pipe is safe and good. The iron compounds which it adds to the water are harmless and may serve a good purpose (in pipes not directly connected with pumps) by precipitating the part or whole of organic matter. To prevent surface water trickling down through the bore, outside the pipe, into the water supply, tamping around the pipe after it is in place with pure clay or water cement, should be carefully done, and the pipes should come well above the ground.

As to the chemical composition of the artesian or drilled wells in Minnesota, the analyses afford some important conclusions not in accord with the pre-conceived notions of those best qualified to judge.

Those analyses and the average analysis of seventy-five good, ordinary wells in the same districts as the drilled wells (taken from the records of the State Board Laboratory) are given at the end of this paper.

Studied from this side, it appears (in grains per Am. gallon) that the "total solids" are: drilled wells, 29,590; common wells, 24,791. Loss by ignition: drilled wells, 3,439; common wells, 4,136. "Chlorine" drilled, 1,680; common, 1,005. "Oxygen used:" drilled, 0.0707; common, 0.0687. "Hardness total:" drilled, 16.6 degrees; common, 14.50 degrees. "Permanent hardness:" drilled, 4.4 degrees; common, 4 0 degrees. "Removable hardness:" drilled, 12.20 degrees; common, 10.5 degrees.

The differences are so slight that in the present state of the inquiry they may be ignored. Both are good domestic supply waters.

A comparison of drilled well waters by region shows some differences worthy of note: (In estimating permanent and removable hardness, the averages represent the majority but not all of the waters. This determination was not made in a few of the early analyses.)

	Solids	Vol.	Chlor.	O. used	Hardness Total	Hardness Rem.	Hardness Per.
1. Red River Valley,	35.815.	3.185	3.288	.0751	13.5	3.	10.5
2. H. P. Region	32.894	5.139	0.315	.1309	19.1	4.7	14.4
3. Minnesota R.	32.173	2.725	0.300	.0627	21.4	7.3	14.1
4. Mississippi R.	17.733	3.263	.856	.0329	16.6	4.4	12.2
Gen'l average 75 common wells	24.791	4.136	1.005	.0687	14.5	4.	10.5

The marked character of the Red River Valley series indicates clearly the geology of the district, as do those of the Minnesota River Valley. The majority of the Mississippi River Valley specimens came from cities, and do not perhaps fairly represent the averages of the whole district. This work is going on steadily in the Laboratory of the Board. This paper was written to answer the frequent inquiries as to the prospect and character of the "drilled well" water supply. As these statistics show, it has been favorable, and the drilled well may yet solve the question of water supply for families and smaller towns, if not for cities in Minnesota.

The comparison of good common well water with the drilled well supply, is not at all unfavorable to the common well, so far as the figures go, but to one familiar with this study, there is a solid satisfaction in the aid which a well made drilled well gives in answering the question, Is the "organic matter" of animal origin, and whether plant or animal, is it recent? In deciding whether to class a common well water as fair or doubtful; the history of the well enters largely into the problem, and it is often very difficult to get all the facts required for accurate judgment. By the assistance of Prof. C. W. Hall, of the University, the geological history of the drilled wells, so far as known, will be furnished hereafter with the analysis. Much aid in this direction is expected from the firms engaged in the business of drilling.

The railroads are making these wells for station and engine supply. Some of the waters are used to clean engine boilers of "scale." Those most efficient are alkaline, and contain a considerable proportion of the alkalies.

AVERAGE OF ARTESIAN WELLS.

Depth, feet	Solids		Hardness			Chlorine	Oxygen Used
	Total	Volatile	Total	Perm.	Rem.		
Red River Valley.							
169	35.815	3.185	14.5	3.	10.8	3.288	.0751
(12)	(12)	(11)	(14)	(11)	(11)	(14)	(11)
Minnesota River Valley.							
48	32.173	2.725	19.5	7.3	14.1	.300	.0627
(5)	(6)	(6)	(6)	(5)	(5)	(6)	(5)
Mississippi River Valley.							
308	17.733	3.263	15.4	4.4	12.2	.856	.0329
(7)	(9)	(8)	(7)	(6)	(6)	(9)	(5)
High Prairie Region.							
95	32.894	5.139	16.7	4.7	14.4	.315	.1309
(5)	(5)	(5)	(5)	(3)	(3)	(5)	(3)
Whole state.							
164	29.590	3.439	16.	4.4	12.2	1.680	.0707
(29)	(32)	(30)	(32)	(25)	(25)	(34)	(24)
For comparison, are given averages of good ordinary wells throughout the state.							
	24.791	4.136	12.7	4.	10.5	1.005	.0687
	(75)	(75)	(92)	(39)	(39)	(85)	(44)

Figures in parenthesis, number of specimens averaged.

Hardness in degrees of Clark's scale.

Other figures, grains per American gallon.

II.

Almost the first thing which a community demands is a supply of wholesome and abundant water. This demand is often a factor which locates centers of population and commercial interests. To bring from a distant and uncontaminated supply enough water for human needs, always requires the expenditure of large sums of money, as population increases and local supplies have become contaminated.

In our western states, with their level surface over large areas, and the consequent scarcity of springs, the question of a sufficient water supply becomes a very serious one in every community. Along our streams the excessive cost of a large supply is put off by the pumping station or the conduit from a higher level. The objections against such a supply have led some communities and several private individuals to attempt to secure, by boring artesian or deep wells, a supply free from those objectionable qualities which our river water is universally admitted to possess. A number of artesian wells in the upper Mississippi valley is the successful result of their efforts, and as this mode of securing a supply of water will be more and more followed, it is proposed in this paper to give a hurried outline of the geology of the Mississippi river valley so far as that valley lies in Minnesota, and tell what experience has pointed us toward, rather than what it has proved to us in the matter of deep wells in the southeastern portion of the state.

Around the headwaters of the Mississippi and around all its tributaries southward from Lake Itasca to a point this (south) side of Saint Cloud, the underlying rock is Archean. In part it consists of schists and slates, usually regarded as Huronian, and in part of gneisses of Laurentian time with eruptive granites and diabases. From the northeast to the southwest these rocks stretch entirely across the state. In all these areas experience gives no hope whatever that water will be found by boring into these rocks. They are covered however, by a layer of glacial drift, which reaches in places a thickness of 250 feet. This drift covering can contain vast quantities of water from that supply percolating into it from the yearly rains and snows. In this drift, then, must lie the chief supply of spring and well water for the whole region.

But to the south and east of the area named, younger rocks occur. They are of Cambrian and Silurian age. Their limit in

Minnesota may in general terms be said to be on the east the eastern boundary of the state, on the south Iowa, and on the north and west a line from Iowa to Duluth, so drawn that it would pass through New Ulm, Elk River and Hinckley. Very likely in the northern part of this territory the Cambrian rocks stretch beyond Anoka and Hinckley: that area is not yet fully explored. These rocks are made up of alternating sandstones, shales, limestones and dolomites, whose position is nearly horizontal. Again, no profound movements of the earth's crust have occurred here in the northwest since these rocks were laid down as Cambrian and Silurian sea sediments; therefore no shattering of the rocks has produced great fissures through which streams of water may escape.

Therefore, any water settling down into the porous portions of these strata naturally seeps along for great distances without passing to a level greatly lower than that which it strikes when first starting on its underground course. These sandstones, shales and limestones* vary in thickness from thin, interstratified beds to formations hundreds of feet in thickness. They vary, too, in composition in different portions of the state. The limestones in places become shaly, and the shales give place to sandstones as the beds are followed from one end to the other, or more exactly, as one follows the beds from the southeastern corner of the state towards the north and west, where the formations thin out and give place to the Archean rocks of the upper Mississippi and Minnesota river valleys.

Yet most of the formations are very persistent. The sandstones and the limestones which are exposed along the river gorges can be followed from one gorge to another, or from one deep well to another, over nearly all southeastern Minnesota, and are known to occur in Wisconsin and Iowa. The sandstones are the waterbearing strata, and this persistence is important to the well borer. It enables him to calculate to a very close figure the depth in any part of this area to which he must bore in order to reach a formation that everywhere, according to experience, yields an abundant supply of water.

*The term "limestone" is used here in its generic rather than in its specific sense to include the carbonates. Strictly speaking, a limestone is a carbonate of lime, or, more modernly expressed, a calcium carbonate. The Silurian carbonates of Minnesota contain magnesium carbonate in amount from 5.40 per cent. (p. 120) upwards, while the Cambrian carbonates are in places almost typical dolomites, and no where are they free from considerable magnesium carbonate.

By consulting the accompanying plate (Plate II) it will be seen that there five or six of these layers of sandstone. All of them yield water, the lower ones very freely.

Successful well boring for water depends on certain conditions, partly physical and partly geological. They may be briefly summarized as follows:

A. There must be a porous stratum of rock lying between two impervious strata.

B. There must exist an area at the surface of the ground, where the porous stratum is exposed to saturation from rainfall.

C. There must be a sufficient fall from this exposed area to the region of the wells to insure a steady and abundant flow of water.

D. There must be a sufficient freedom from fissures, faults and dikes to insure a steady flow without great loss of water from the rainfall district to the region of the wells.

It is not necessary that the porous stratum be a sandstone further than the natural qualities of the rocks themselves determine the question. No other rock species is sufficiently porous to permit a free flow through it of large quantities of water, save by fissures, and these form an unreliable passageway, even more likely to cause defeat than to insure success in the search for water.

The sandstones of southeastern Minnesota can very easily be parallelized by means of the deep wells already bored; and their general relations to each other, and to the interbedded limestones and dolomites can be made out.

Mr. Warren Upham has of late given considerable attention to the stratigraphic relations of these sandstones, and he has generously placed his manuscript at my disposal. In preparing these statements, and in sketching the accompanying plate, I have drawn freely from Mr. Upham's notes.

1. The Glacial Drift.—In enumerating briefly the formations in the southeastern portion of our state with reference to their water-bearing qualities, it is not necessary to do more than mention the glacial drift. This deposit, scattered almost entirely over the state, is the universal source of our ordinary well water. This is usually secured by excavating, rather than by boring. Yet where boring is done, it is no unusual thing to secure a flowing well by penetrating the rock to where a layer of clay covers the

sand or gravel over an area sufficiently large to catch and carry a supply of water.

2. THE CRETACEOUS.—Cretaceous rocks are found in a few places in this state. They are sandstones, shales, clays and carbonates. The extent of these rocks is not great, and mere isolated areas have thus far been found. This formation is not distinguished as a water-bearing one for deep wells.

3. THE DEVONIAN is equally insignificant from the standpoint of the well-borer. It occurs only in the southern portion of the state, so far as known. Its outcrops lie in Fillmore and Mower counties, with possibly some beds to the east and west of this central location. Doubtless the rocks of this formation are limestones and dolomites.

4. THE TRENTON.—The Lower Silurian represented by the Trenton limestones and shales is the next in order of the Palcozoic rocks. This is a bed of 30 feet in thickness, more or less, and it is a persistent one. The upper part of it is very impure limestone, containing some fossils* and lying nearly horizontal over a considerable portion of southeastern Minnesota. Its extent is not so great as that of the underlying Cambrian rocks, although it is found in Hennepin, Ramsey and Washington counties and thence southerly in Dakota, Goodhue, Rice, Steele, Dodge, Olmsted, Winona, Fillmore and Houston counties, and very probably in Wabasha and Mower. While this formation is quite impervious, it is interrupted through the erosion of streams and thus does not afford a satisfactory covering for the porous stratum beneath it.

5. THE ST. PETER sandstone lies next beneath the Trenton limestone. To the north this formation reaches beyond Minneapolis on the Mississippi, but it is too high to be seen in the banks of the St. Croix river. It is found in the central portions of Washington county, where it is protected from erosion by the overlying Trenton limestone. For some miles southward from St. Paul it has been eroded to a considerable extent, but still remains in a few isolated knolls or buttes in Dakota county. It again comes in as a quite persistent formation in eastern Rice, Goodhue, Steele, Dodge, Olmsted and Fillmore counties. It is more than likely that this rock may underlie parts of the following counties in addition: Waseca, Winona, Houston, Mower and Freeborn. It certainly occurs in the western part of Winona and Houston, and must run

*This Bulletin page 115.

under the Devonian in Mower and to the westward. The thickness of this formation at Minneapolis is 164 feet, and in the southern counties, in those locations where it can be measured, it has been found by N. H. Winchell to be as thin as 115 feet.* It may be said in passing, that Professor Chamberlin has found this same formation in Wisconsin, where it is widely distributed, varying in thickness "from two hundred and twelve feet down to a single layer of sand grains."†

The porous condition of this sandstone enables large quantities of water to percolate through it and saturate it, but its high position in this state prevents a flow from it. Yet by means of pumps and stationary engines large quantities of water may be drawn.

6. The Shakopee A.—All geologists of the northwest are not agreed to refer the St. Peter sandstone to the Silurian; indeed, the burden of opinion inclines to the Cambrian age as its true reference. But immediately below it is the Shakopee, a great formation which is undoubtedly Cambrian. This was first noted as a distinct bed of dolomite and dolomitic limestone at Shakopee in 1873.‡ "Its thickness in Minnesota varies from 90 feet at Shakopee to 200 feet in Houston county; in southeastern central Wisconsin it is from 50 to 250 feet; in eastern Wisconsin 62 to 141 feet; in Missouri, as the Second Magnesian limestone of Swallow, it is 230 feet in thickness. In the Minnesota reports this is the limestone of the Minnesota valley, and both the Shakopee and St. Lawrence in the southeastern counties, e. g. Houston, Winona, Olmsted and Fillmore, except the limestone referred to the St. Lawrence at Whalen and Lanesboro. It is the Shakopee of well borings at Minneapolis, Mendota, St. Paul and Hastings."

7. Elevator B Sandstone.—"This formation (the Shakopee) encloses a more or less persistent layer of sandstone 20 feet in thickness in the well at Elevator B, St. Paul, which is probably the Jordan sandstone of Houston and Fillmore counties, except perhaps Lanesboro; of Olmsted county, except perhaps Quincy.

"The sandstone found in this formation at Elevator B may be the cause of the terrace made by the lower part of this

*Geological and Natural History Survey of Minnesota. Final report, Vol. I, p. 656, and at other places in the county descriptions.

†Geology of Wisconsin, Vol. ii, p. 285.

‡Geol and Nat. Hist. Sur. Minn., 2nd An. Rep't. 1873, p. 138.

limestone* at Shakopee and Louisville, where a terrace is made by the upper part of the Shakopee limestone, and between Kasota and Mankato. The three divisions may be called, in descending order:

1. Shakopee or Lower Magnesian limestone A.
2. Elevator B sandstone.
3. Shakopee or Lower Magnesian limestone B."

Well-borers have not found the Elevator B sandstone in other wells bored in this valley, although from Mr. Upham's statements we may suppose it to be spread very widely through this Upper Cambrian dolomite.

8. THE SHAKOPEE B.—It need only be mentioned here that this layer is essentially the same in lithologic characters as number six and has already been described in Mr. Upham's own words.

9. THE JORDAN SANDSTONE.—Beneath Upham's Shakopee B layer which at Elevator B is a "buff magnesian limestone, 55 feet in thickness," lies the Jordan sandstone. This formation is almost identical with the St. Peter and Elevator B sandstones in lithologic characters. "It is 116 feet thick at East Minneapolis, 103 feet at Elevator B, and 95 feet at Hastings. It has a wide distribution in the Mississippi valley, occurring in Missouri as the Second sandstone of Swallow, 115 feet thick, and in Wisconsin as the Madison sandstone of Irving, in thickness from 35 to 60 feet. The white, evenly granular, medium textured, easily crumbling Jordan sandstone is found at Jordan, St. Peter, Kasota, Mankato

*Mr. Upham calls this rock a limestone in conformity with the usage of several other geologists. Analyses by Professor Dodge and Mr. Sidener give from 54.78 per cent. calcium carbonate and 42.53 per cent. magnesium carbonate in the building stone at Frontenac to 50.68 per cent. and 33.61 per cent. respectively, in the Red Wing stone. As a mean between those two extremes the following analysis of the rock at Ottawa made for the writer by Professor Dodge in January 1886. is given:

Carbonate of lime. $CaCO_3$	50.46 percent.
Carbonate of magnesia, $MgCO_3$	36.26 "
Silica, SiO_2	8.58 "
Alumina, Al_2O_3	3.18 "
Peroxide of iron, Fe_2O_3	1.72 "
Soda and potassa	traces
Chlorides, sulphates and phosphates	traces
Total	100.20

Amount of the stone not soluble in hydrochloric acid, 10.61 per cent.

Consisting of SiO_2	8.50 percent.
" " Al_2O_3	2.00 "
" " Fe_2O_3	traces

Since a typical dolomite has the proportion of 54.35 per cent. calcium carbonate and 45.65 per cent. magnesium carbonate, and Dana's list of analyses of the mineral dolomite (System of Mineralogy, 5th edition, p. 683) shows a greater variation from the type than do the analyses of Professor Dodge and Mr. Sidener, there can be no serious objection to calling these beds dolomites or dolomitic limestones.

and Minneopa in the Minnesota river valley; probably at Lanesboro and Quincy; in Barn bluff at Red Wing; and in the bluffs of eastern Winona county and of Hokah."

It yields more water than either of the layers above it.

10. THE ST. LAWRENCE.—Then comes the St. Lawrence formation of dolomitic limestone and shales underlying an equally large area with the Jordan sandstone above. "Thickness in Minnesota, 128 feet in E. Minneapolis well; 213 in Hastings; 160 feet in Mankato; and 170 in the old quarry east of Hokah; in Wisconsin, the Mendota limestone of Irving, with 30 feet of strata below, 60 to 75 feet; in Missouri, the Third magnesian limestone, 350 feet. This is the St. Lawrence of the Minnesota geological reports at St. Lawrence, Hebron and Jordan, but not in Houston, Olmsted, Fillmore and Winona counties, where this name is applied to the same formation that is called Shakopee in the Minnesota river valley, lying above the limestone at St. Lawrence; excepting perhaps at Whalen and Lanesboro, where apparently the true St. Lawrence is found." Upham.

11. THE DRESBACH SANDSTONE (The upper Saint Croix).—The fourth sandstone is the one that Mr. Upham locates "at the top of the Saint Croix." It is the formation which appears in the banks of the Mississippi at Dresbach, Dakota, etc., and is called in Minnesota the Dresbach sandstone. Its color is at Dresbach a light, rather pleasant gray, and its thickness in Minnesota is 50 feet or more; in Wisconsin near Madison, 54½ feet; in Missouri the Third sandstone of Swallow, 60 feet.

12. THE SAINT CROIX SHALES (The middle Saint Croix).—Below the preceding number, called the Dresbach sandstone, the second member of the great Saint Croix series consists of shales and shaly sandstones. A calciferous character is taken on in places as near St. Croix Falls, Wis.; and in Missouri it becomes the Fourth Magnesian limestone, 200 or 300 feet thick. In this state, so far as determined by well borings, its thickness is 115 feet at Hastings; 75 feet at Mendota; and 170 feet at East Minneapolis.

13. THE SAINT CROIX SANDSTONES (The lower Saint Croix).—This formation consists chiefly of white sandrock which at Hastings is 230 feet thick, and 395 feet at Brownsville. "This is the sandstone of the Chippewa, Black and Wisconsin rivers, 50 to 100 feet thick." Upham. Water is always found in this layer, and so far as tested, the supply is a large one, as shown by the

Brownsville well and by several Iowa wells which have penetrated what I presume is the same sandrock.*

The St. Croix series, as a whole, is of great extent and thickness. In southeastern Minnesota it is found everywhere that the overlying rocks occur, and whenever it has been penetrated, water has been found in it. It measures up to 478 feet in thickness at East Minneapolis, and over 400 feet at Hastings. In Wisconsin, according to Professor Irving, the rocks which in Minnesota are included in the St. Croix, reach a thickness of 700 feet† and are chiefly sandstones. Large quantities of water are obtained in the city of Madison by boring into these sandstones.

14. The Potsdam Sandstone. — Beneath these three formations which constitute the Saint Croix series, sandstones still continue. They possess a red color, and vary considerably in texture; some of them are coarse enough for conglomerates, and others are fine like shales. This series is waterbearing like those above it; indeed it could not well be otherwise. These rocks are conformable with those above them so far as our investigations enable us to determine.

Mr. Upham regards this series as the westward extension of what is called in New York the Potsdam formation, and he would give it the same name in this state which it has carried in New York and along the south shore of Lake Superior for so many years. It "constitutes a floor upon which the lowest member of the Saint Croix was laid in nearly uniform thickness" throughout southeastern Minnesota and over a large extent of Wisconsin and Iowa and other western states.

The thickness of the Potsdam is difficult to make out. At East Minneapolis it must be at least 1,050 feet. At Mankato the borings from 915 feet to the bottom, 2,204 feet, disclose these red sandstones and shales, a thickness of 1,289 feet, and the underlying rocks were not reached. But to the southeast the sandstones

*I take the following notes from Upham:

It is 550 feet to the granite at La Crosse, Wis.
" " 750 " " " " " Lansing, Ia.
" " 1,475 " " " " " Mason City, Ia.

There is here no flow, but water in abundance comes within 28 feet of the surface. It is 1,250 feet to the granite at Decorah, Ia. No flow of water, but it comes within 20 feet of the surface. At Calmar, 10 miles from Decorah, and 300 feet higher, boring ceased at 1,223 feet in sandrock. An inexhaustible supply of water, not, however, rising to the surface.

†Geology of Wisconsin, Vol. ii, p. 534.

are thinner. At Brownsville granite is struck at 590 feet, at La Crosse at 550 feet, and on the high prairie at Mason City the granitic rocks are 1,475 feet below the surface. So it would appear that there is but little room for the Potsdam in this section between the white sandstone of the lower Saint Croix and the granitic floor beneath the Cambrian of the Northwest. It is quite likely that during the early part of the period of sedimentation which followed the forming of the Lake Superior trough, the highland of northern central Wisconsin extended down to and across the Mississippi river at La Crosse, and that the shore debris did not cover it until the Saint Croix deposits of white sand were formed.

15. Below these red sandstones and shales lie the crystalline rocks which have in the northwestern states an enormous development. It is not necessary here to enumerate their sub-divisions, nor the rock species representing them. We will designate them simply as Pre-Cambrian. They are permeated with water throughout, but it percolates so slowly that no supply can be secured from that which ordinarily seeps through the rocks. Exceptionally, wells penetrating these rocks furnish a water supply, but it is when fissures are struck through which the water runs in streams.

It will be seen, if now we glance back, that the formations numbered 1, 5, 7, 9, 11, 13 and 14 are water-bearing. For ordinary well supply number one is universally used; for deep wells numbers five, nine and eleven are the most important sources of supply, because of their texture, which permits them to hold large quantities of water reservoired, and allows it to seep through them with great rapidity. Judging from experience, a well borer who reaches either one of these layers will never fail to secure a permanent supply of water, while his supply will very likely be increased if he goes beyond the layers named and into those below them.

The quality of this water supply is high. The great depth from the surface from which it is drawn prevents contamination from organic impurities and insures constant uniformity in composition. It is not pure water—pure water is an unknown thing in nature—but it is wholesome and at all times safe. The doctor has just told us of the composition of these waters as compared in bulk with those of surface wells, page 127; he has given the analyses of a great number of wells to show what artesian water is, as a rule. Let me give two analyses from well known wells, that we may see

how these two localities compare with the general results just given you.

1. Deep well water from Hastings, furnished the writer by W. H. Holden; analysis by Professor J. A. Dodge:

Silica, SiO_2	0.62	grains	per gallon
Carbonate of lime, $CaCO_3$	9.29	"	"
Carbonate of iron, $FeCO_3$	0.17	"	"
Sulphate of magnesia, $MgSO_4$	5.84	"	"
Chloride of magnesia, $MgCl_2$	1.82	"	"
Chloride of potassium, KCl	1.15	"	"
Chloride of sodium, NaCl	26.15	"	"
Total	45.04	"	"

The large amounts of sulphate of magnesia and chloride of sodium make this water a peculiar one. The action of these substances on locomotive boilers has proved very injurious.

2. West Hotel water, Minneapolis. Analysis by C. F. Sidener:

Silica, SiO_2	0.81	grains	per gallon
Alumina, Al_2O_3	0.02	"	"
Carbonate of lime, $CaCO_3$	12.88	"	"
Carbonate of magnesia, $MgCO_3$	6.04	"	"
Carbourte of iron, $FeCO_3$	0.12	"	"
Sulphate of magnesia, $MgSO_4$	0.14	"	"
Sulphate of potash, K_2SO_4	0.33	"	"
Sulphate of soda, Na_2SO_4	1.25	"	"
Chloride of sodim, NaCl	0.06	"	"
Phosphates	traces		
Nitrates and nitrites	traces		
Total	21.65	"	"
Free ammonia	.02	"	"
Albumenoid ammonia	traces		

Hardness, 15 degrees.

To show before the eye the succession of strata just named with the relative thickness of each, as well as the comparative depth of the wells thus far bored in the Mississippi river valley Plate II has been prepared. To make it clear to all, the following synopses are given:*

I. Lakewood Cemetery Well—*C. W. Hall.*

Formation 1. Extends from the surface, about 925 above the sea, to a depth of 256 feet. Consists of gravel with large bowlders of granite and diabase with some sand stone, sand and clay.

2. Not known to occur in this portion of the state.

3. Not known to occur in this portion of the state.

4. Not detected in the borings, save as pieces in No. 1; very likely absent at this place.

*The Roman numerals in these synopses refer to the well numbers; the Arabic numerals correspond with those of the formations described on the preceding pages.

5. From 256 to 302 feet. Not the entire thickness of this bed as shown by the other wells in this city, so this is undoubtedly the lower portion.

6. From 302 to 314 feet. At 302 feet the borings consisted chiefly of grains of white sand, but mingled with them were numerous light brown chips of dolomite.

The formation seems to be quite thin at this locality, the drillings from 302 to 314 feet being dolomitic, and below that becoming very sandy. The bottom of Shakopee A is estimated to be 320 feet from the surface.

7. At 323 the drillings were mostly a white sand, which continued very uniformly to 360 feet; the lower portion takes on a yellowish to light brown color.

8. The drillings between 360 and 403 feet show a dolomite which is referred to this formation, the Shakopee B.

9. The Jordan is represented by the white sands, sometimes fine and sometimes coarse, and at the top with some dolomitic chips lying between 403 and 558 feet in depth.

10. Green shales and sands extend down to the depth of 607 feet. [Compare the Mendota and Elevator B wells].

11. This formation, the Dresbach sandstone, characterized for its white sands, occupies the depth between 607 and 780 feet; towards the bottom it becomes somewhat green.

12. As green shales we have this bed reaching down to 844 feet.

13. Sand again occurs at 844 feet, which has a somewhat greenish color at the top; becomes white and clean at 960 feet and assumes a reddish tint at 1,010 feet.

14. From 1,010 feet to the last drillings taken from the well the material was a red sand, mingled towards the bottom with a light green shale. At 1,560, 1,850, 1,975, 2,100 feet, there was no perceptible change in the appearance of the drillings; at 2,150 feet a sample was referred to the writer by the superintendent of the cemetery. An examination showed pieces of quartz, hornblende, feldspar, both orthoclase and plagioclase, and some chloritic mineral. As those minerals were evidence of granitic material, the opinion was given that the Pre-Cambrian rocks were reached. The well was sunk no further and the hole was allowed to fill, as no flow of water was secured.

Total depth of the well, 2,150 feet.

II. The Washburn C Well*—*N. H. Winchell.*

Formation 1. From 825 feet above the sea, the first 10 feet downwards is made up of soil and glacial drift material.

2 and 3. Not represented.

4. Twenty-six feet in thickness; the last two feet of a blue shale.

5. In varying shades of color; this sandstone is 168 feet in thickness.

6. This formation was penetrated only one foot.**

Total depth of the well, 205 feet.

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*See also Tenth An. Rep. Geol. Nat. Hist. Sur. Minn., p. 211.

**Compare note on this well; this Bulletin, p. 123.

III. The West Hotel Well.—*C. W. Hall.*

[Compare this Bulletin, p. 122. The slight discrepancies which may be noted arise from the fact that the former summary was made up from Mr. Swan's written notes, while this synopsis is compiled from a series of drillings preserved for the writer by Mr. Swan at the time the well was sunk. N. H. Winchell received a series of drillings.]*

Formation 1. Consisting of ordinary drift material, from 835 feet above the sea, downwards to a depth of 18 feet.

2 and 3. Not represented.

4. Limestone and shale 20 feet.

5. White and yellow sand 164 feet. At 164 feet from the surface a layer of red shale four feet in thickness was penetrated. The first flow of water came from beneath this shale. The supply was not sufficient.

6. Dolomitic limestone 82 feet thick. At the top the color is reddish and the rock contains many grains of sand. (This Bulletin, p. 123.) Below a yellowish drab color prevails.

7. Below the preceding, a layer 15 feet in thickness occurs, which is referred to Upham's Elevator B sandstone. The drillings seem to contain about 30 per cent. of dolomite chips.

8. Thirty-six feet of dolomite, or dolomitic limestone underlies the preceding.

9. A bed of sandstone 96 feet in thickness yielded the second flow of water. This rock varies from fine to coarse in texture, the coarser lying near the bottom.

10. A thickness of 161 feet is grouped as this number of the series. The first 45 feet in descending order, is a fine white sand with some light gray calcareous material intermingled. It is quite near No. 9 in general characters, and it is not certain but it should be grouped with the sands of that formation rather than with the shales of this. The following 116 feet consists of green shales quite hard and firm at the bottom.

11. The clear white sand of this formation "at the top of the Saint Croix," was penetrated 30 feet. A supply of water running 300 gallons per minute was struck, when boring ceased.

Total depth of this well 622 feet.

IV. The East Minneapolis Well.**—*From Warren Upham's Notes.*

Formation 1. First 42 feet "sand and till" from 850 above the sea downwards.

2 and 3. Not present in this vicinity.

4. From 42 to 70 feet; 28 feet in thickness.

5. To 234 feet, clear white sand; 164 feet thick.

6. To 352 feet; first 102 feet red limestone, then 16 feet of gray limestone.

7 and 8. Not distinguished in this well from No. 6. No. 8 may lie however, in the "gray limestone" of the lower portion.

9. In this well is 116 feet thick; from 352 feet to 468 feet. The sand is white and clean.

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*Fourteenth An. Rep. Geol. and Nat. Hist. Sur. Minn., p. 11.

**Compare N. H. Winchell, these Bulletins, vol. I, p. 187.

10. The "blue shale" of the well borer between 468 and 596 feet in depth is regarded as Saint Lawrence.

11. The white sandstone which was next penetrated through 82 feet, represents this number, the Dresbach sandstone, at East Minneapolis.

12. What is termed the Upper Saint Croix in Mr. Upham's stratigraphy occupies a thickness of 170 feet. It consists chiefly of a blue shale.

13. Then comes a white sandstone 217 feet in thickness, in the middle of which a layer of sandy marl 12 feet in thickness was detected.

14. At 1,074 feet a red marl layer 57 feet thick was passed, and a red sandstone was reached. Boring continued in this rock until work ceased.

Total depth reached, 1,421 feet.

V. The Elevator B Well.—*Warren Upham.*

Height 855 feet above the sea.

Formation 1. Represented by 58 feet of modified drift.

2 and 3. Not present.

4. The Trenton limestone is 25 feet thick.

5. As clean white sand this number is 152 feet thick.

6. Calcareous sandrock 30 feet; buff magnesian limestone 35 feet; total 65 feet.

7. White medium grained sand 20 feet in thickness.

8. Buff magnesian limestone like the lower part of No. 6, 55 feet in thickness.

9. This formation, a white sand, is 103 feet thick.

10. The Saint Lawrence as shales and calciferous sandrock is 194 feet thick.

11. As white and gray sandstone 66 feet thick.

12. The gray and green shales of No. 12 were penetrated 100 feet or more and the boring ceased.

Depth reached 850 feet.

VI. The Saint Paul Harvester Works Well.*—*Warren Upham.*

Formation 1. As stratified gravel and sand from 871 feet, downward 235 feet.

2, 3, 4 and 5. All wanting.

6. "Buff magnesian limestone and sandrock 125 feet."

7. A sandstone layer 10 feet thick.

8. "Light yellowish buff magnesian limestone 10 feet."

9. A gray sandstone 100 feet.

10. Shales calciferous sandrock and dolomitic limestones down to the bottom of the well, 191 feet.

Total depth of the well 871½ feet. Two wells have been drilled by the Harvester Works company. The first part of each, between 500 and 600 feet, was drilled in the ordinary way, but the last part was penetrated by a diamond drill, and a core rather than pulverized drillings was examined. Water stands in both wells at 35 to 40 feet below the surface, and yields a constant supply.

*Also Geol. and Nat. Hist. Sur. 13th An. Rep., p. 59.

VII. The Mendota Well*—*Warren Upham.*

Formations 1, 2 and 3. Not present.

4. Twenty-two feet in thickness.

[This must be drift i.e. fallen pieces of the Trenton, as the well was bored at the edge of the bluff, along which in many places large slabs of limestone are broken down. Standing on the north side of the river, the Mississippi, the white St. Peter sandstone can be seen to the eastward of the station at a higher level than the roofs of the buildings. —C. W. Hall.]

5. Consists of brown sand rock 60 feet; blue shale 30 feet, and sand rock 35 feet; total, 125 feet.

6, 7 and 8. These thin formations are not here separated; total, 145 feet.

9. A white sandstone 95 feet thick.

10. A series of layers made up as follows: Gray shale, 50 feet; green shale, 110 feet; limestone, 10 feet; blue shale, 30 feet. Total, 200 feet.

11. This sandstone "at the top of the Saint Croix" is 50 feet thick.

12. As gray shale, 40 feet; green shale, 35 feet. Total, 75 feet.

13. This does not appear.

14. As a "very hard, red sandrock enclosing beds of shale." The Potsdam was penetrated 145 feet.

Total depth 857 feet.

VIII. The Hastings Well.** *Warren Upham.*

Height, 700 feet above the sea.

Formations 1, 2, 3, 4 and 5. Not represented.

6. A thickness of 80 feet was passed. This dolomite is seen in the streets of Hastings at a height considerably above the top of this well.

7. Sandstone 15 feet in thickness.

8. A dolomite or dolomitic limestone 12 feet thick. [Winchell designates this as a "dolomitic grit."]

9. "Sand rock" 95 feet.

10. "Shales; doubtless also calciferous sandstone." Colors, gray and green; 213 feet.

11. A sandstone containing pyrites. From the last 20 feet of this formation came the first flow of water; thickness 60 feet.

12. This formation, while consisting chiefly of blue shale (70 feet), contains also some green sand (20 feet), and dolomitic grit (5 feet). Total thickness, 115 feet.

13. A series of sandstones of varying coarseness, with some shale towards the bottom, having a total thickness of 230 feet.

14. From 820 feet down to the bottom of the well the rocks were chiefly sandstones, but with some red shales; thickness of these beds 340 feet. These are grouped by Upham as Potsdam.

Depth of well, 1,160 feet. Flow of water 100 gallons per minute, which reaches only a few feet above ground. The quality of this water is not satisfactory for railroad uses. Note this Bulletin, p. 137.

*N. H. Winchell has also copied Mr. Swan's notes. Geol. and Nat. Hist. Sur. Minn., 13th An. Rep., p. 55.

**See also N. H. Winchell, Geol. and Nat. Hist. Sur. Minn., 13th An. Rep. p. 56.

IX. The Red Wing Well*—*C. W. Hall.*

Height above the sea, 686 feet.

Formation 1. Wanting. A heavy deposit of river silt and gravel, probably to a large extent made up of No. 1, was passed through. Thickness, 40 feet.

2, 3, 4, 5, 6, 7, 8 and 9. All wanting.

10. One hundred and forty-five feet of blue shale sands and mingled sandstone, quartz—and limerock are assigned here. These would form only the lower part of the St. Lawrence, which at Hastings, 20 miles away, shows a thickness of 213 feet.

11. From the bottom of the preceding, 185 feet deep, to the bottom of the well, no material variation in the drillings was noted; all were "sandstone, white and soft." The drilling stopped in a hard streak possessing a red color, probably the top of the Potsdam formation.

"Total depth of the well 500 feet. Great abundance of water, slightly impregnated with iron. Pressure at the R. R. depot 40 lbs. per square inch." —W. E. Swan.

X. The Lake City Well†—*C. W. Hall.*

Height of Lake City depot above the sea, 705 feet.

Formation 1. Wanting. Here also as at Red Wing, a river deposit is passed. Thickness, 207 feet.

2, 3, 4, 5, 6, 7, 8 and 9. Wanting.

10. "Blue sand shale, 68 feet."

11. Gray sand and shale, 25 feet.

12. Gray sandstone and gray sandy shale, 112 feet.

13. Red and yellow sandstones and gray sandy shales, 88 feet.

14. "Red shale and quartzite, 320 feet."

The above references are based on Mr. W. E. Swan's notes to the writer. Water comes to within 45 feet of the surface. Well bored for the C., M. & St. P. Ry. Depth, 820 feet.

XI. The Brownsville Well‡—*C. W. Hall.*

Height above the sea about 640 feet.

Formation 1. Wanting. A blue clay, probably river deposit, occurs, 40 feet in thickness.

2, 3, 4, 5, 6, 7, 8, 9 and 10. Wanting.

11. Limestone,§ 25 feet.

12. Blue shale 60 feet and a green shale 70 feet; total thickness of the Saint Croix shales 130 feet.

13. Sandstone 395 feet.

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*Mr. Swan's notes are also given in the 13th An. Rep. Geol. and Nat. Hist. Sur. Minn., p. 57.

†Als Geol and Nat. Hist. Sur. Minn 18th An. Rep. p. 58.

‡From notes given Warren Upham by W. E. Swan, who drilled the well. Some changes have been made, for which Mr. Upham should not be responsible.

§As N. H. Winchell observes, 13th An. Rep. p. 59, this is a doubtful determination. If it be based on an acid test it could be only partially satisfactory, for even the Dresbach sandstone effervesces to a considerable extent in hydrochloric acid. A little further admixture of carbonates into this sandstone would form a rock answering to what are presumed to be the conditions of this layer.

14. No red sandstones or shales were reported by Mr. Swan.

15. Below the sandstones of formation 13, granite was reached. Possibly this was quartzite (see Lake City well, formation 14), and so, formation 14 instead of 15. Unfortunately no borings are at hand.

The well was bored to increase the water supply at the grist mill. Flow, 1,000 gallons per minute of soft water. Total depth, 590 feet.

XII. The Mankato Well*—*C. W. Hall.*

Formation 1. Ordinary bowlder clay or till 290 feet.

2, 3, 4, 5, 6, 7 and 8. Wanting.

9. This formation is present beneath quarries and in all the surrounding bluffs. It is quite possible that a part of the material referred to formation 1 belongs here.

10. The borings at 380 feet show a dolomitic rock, possibly somewhat shaly. At 390 feet a green shale and sandstone comes in. Estimated thickness of this formation 160 feet.

11. The drillings from 450 feet to 850 feet show a clear white sand having at the top a slightly pinkish tint. Thickness of these white sands 400 feet and more.

12. At 915 feet a red shaly sandstone appears which may be the representative of this formation in the southwest.†

13. From 1,010 to 1,240 feet the drillings are entirely sands and rather coarse in texture. The color at 1,010 feet is pink, at 1,240 feet nearly white. Thickness not less than 230 feet.

14. At 1,265 feet a pink color comes in which at 1,340 becomes red. The red color with an occasional fading into pink continues to the bottom of the well. The drillings saved from 1,875 feet down to the bottom, seemed to show a fine red shale at every point. Total depth 2,204 feet. The well is not at present used for water supply.

[*Paper T.*]

On the Reproduction of Lost or Mutilated Limbs of Insects.—*O. W. Oestlund.*

The reproduction of a lost limb is a fact well known to take place among the lower arthropods, especially the crustaceans and spiders. Such a lost limb is not produced by a gradual growing out, as might be supposed, like the growth of a limb or twig of plants, but the growth is internal and the limb does not appear

*See further details by Warren Upham in Geol. and Nat. Hist. Sur. Minn. Final report vol. I. pp. 422 et seq.

†Another view is that this rock may represent the top of the Potsdam, and that here, near the margin of the Saint Croix sea, no shales corresponding to formation 12 of the Mississippi river valley were formed. In that case No. 11 above would stand for the entire thickness of the Saint Croix, or formations 11, 12 and 13. There is no sufficient geologic reason why the Potsdam may not contain white and gray sandstones as well as pink and red.

PLATE II.

[To accompany Paper 8.]

Figure I. The Lakewood Cemetery Well, Minneapolis: bored in 1884-5 by Gray Brothers: depth, 2,150 feet.

Fig. II. The Washburn C Well, Minneapolis: bored in 1880 (?) by C. C. Whelpley: depth, 205 feet.

Fig. III. The West Hotel Well, Minneapolis: bored in 1884 by W. E. Swan; depth, 622 feet.

Fig. IV. The East Minneapolis Well; bored in 1874-75, City Engineer J. B. Clough in charge; depth, 1,421 feet.

Fig. V. The Elevator B Well, Saint Paul: bored in 1883 (?) by N. W. Carey; depth, 850 feet.

Fig. VI. The Saint Paul Harvester Works Well; bored in 1882-83 by N. W. Carey, (the diamond drill work was done by Mr. Joseph Susor); total depth, 871½ feet.

Fig. VII. The Mendota Well; bored by W. E. Swan; depth, 857 feet.

Fig. VIII. The Hastings Well; bored in 1880 by W. E. Swan; depth, 1,160 feet.

Fig. IX. The Red Wing Well; bored by W. E. Swan: depth, 500 feet.

Fig. X. The Lake City Well; bored in 1881 by W. E. Swan; depth, 820 feet.

Fig. XI. The Brownsville Well; bored by W. E. Swan; depth, 590 feet.

Fig. XII. The Mankato Well; bored in 1874-75 for the city; depth, 2,204 feet. [The writer's series of borings was presented partly by the Mankato high school, A. F. Bechdolt, superintendent, and partly by W. Hodapp].

Fig. XIII. A generalized section through Southeastern Minnesota from Stearns county to Iowa.