DEEP WELLS OF IOWA
(A Supplementary Report)

By

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WITH A CHAPTER ON

Well Water Recessions in Iowa

By

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AND A TABLE OF IOWA TOWNS GIVING

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Introduction

Since its organization in 1892 the Iowa Geological Survey has recognized the importance of underground water resources and has made them one of the chief objects of its investigation. Three special reports[1] have been published setting forth the development of these resources up to 1912. The county reports have treated more or less fully of the wells and springs of their respective districts. Moreover, advice has frequently been sought and given to well drillers and contractors, municipalities, railways, and other corporations and private individuals as to the underground water supplies available to them.

The present paper is intended only to supplement the reports already published. Since the publication of the latest report in 1912 at least 150 deep wells and prospect holes have been drilled in Iowa, areas have been explored whose water resources were little known, and in some of the oldest drilling territory, where well records had been singularly wanting or imperfect, new and complete data have now been obtained for the first time. In some instances the conclusions of earlier reports have been modified, in many instances confirmed, by new facts deserving permanent record.

Of all the mineral resources of a state, underground water ranks among the first in amount of output and in the value of its product as measured by the indispensable services it renders. The wells of Iowa may be regarded as its most valuable mines. The deeper wells, now numbering at least 400, have an annual output running into billions of gallons, while the hundreds of thousands of shallow farm wells and house wells, ending in drift or country rock, yield in the aggregate an output of a value perhaps as great.

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1 Norton, W. H., Thickness of the Paleozoic Strata of Northeastern Iowa: Iowa Geol. Survey, vol. III, pp. 169-210, Des Moines, 1895.

Norton, W. H., Artesian Wells of Iowa: Iowa Geol. Survey, vol. VI, pp. 115-428, Des Moines, 1897.

Norton, W. H.; Hendrixson, W. S.; Simpson, H. E.; Meinzer, O. E.; and others, Iowa Geol. Survey, vol. XXI, pp. 29-1214, Des Moines, 1912.

The period covered by this investigation has been one of urban development in Iowa and has witnessed the change in the water supply of towns from house wells to a municipal supply. It has witnessed also the wide introduction of sewerage and therefore the vastly increased amount of water required for urban uses. It has also seen an increasing pollution of streams. Rivers which half a century ago might have been considered for public supply have become common sewers. Their waters if used require unintermittent and thorough filtration and chemical disinfection.

In the location of the towns of Iowa water supply was probably never even considered as a deciding factor. The eminently proper place for the county seat was often held to be the geographic center of the county even if on a high and dry divide. The site of towns on streams was fixed by a mill site, the convergence of traffic at a ferry, but perhaps never by the advantage of abundant water for public and private uses. Pioneer Iowa depended on shallow house wells and cisterns for water supply.

But with the infection of the soil shallow house wells became unfit for use. And with the installation of sewerage and growth in population shallow wells also became entirely inadequate to meet the increased demand, except in a few favored localities. Hence the problem of water supply for Iowa municipalities during recent decades—a problem by no means yet completely solved.

Naturally the first resort for towns whose shallow well supply proved insufficient was the sinking of deep wells to tap the stores of artesian water in pervious rocks lying perhaps a thousand, perhaps two or even three thousand feet beneath the surface. At this point the Iowa Geological Survey has been able to give first aid.

For the distribution, amount and quality of the available underground waters at any locality depend on the composition, structure and attitude of the rock formations. These characteristics have been learned from field studies in areas of outcrop. The experience of drillers in Iowa and adjacent states has been gathered, so that over a very large part of the state the deep geology is fairly well made out even to greater depths than the drill can profitably go. Thus the Saint Peter sandstone, one of the most readily identified of the water beds, has been traced from its outcrops in northeastern Iowa where it stands about 1200 feet above sea level, to the southwestern corner of the state where it has sunk to 1853 feet below sea level. Contour maps are drawn (Plate I) showing the probable approximate elevation above or below sea level of this reliable formation at almost any locality. To obtain the probable distance which it is necessary to drill in order to reach the Saint Peter, one needs only to subtract its elevation above sea level, as shown approximately by the Contour map, from the elevation of the locality obtainable for any railway station, or to add the elevation of the Saint Peter if that formation lies below sea level.

In the report of 1912 on Underground waters, forecasts were made also for the towns not already supplied with artesian water whose size and location made not improbable the sinking of deep wells in the near future. These forecasts showed the depth to the various water beds of the artesian field and the nature and thickness of the formations through which the drill would pass. And on consultation by drillers or by their clients additional facts have also been given as to deep well prospects. The general reliability of these forecasts has been confirmed on the whole by the numerous wells drilled the last fourteen years.

Because of the very large body of facts at its disposal the Survey has been able to render a unique service to all concerned in problems of water supply. The advantage of disinterested and reliable advice to municipalities and others who have the sinking of deep wells under consideration is evident.

For well drillers and contractors the Survey offers a clearing house by which any firm can draw upon the experience of all for many years, as well as the technical knowledge and skill of geologists.

It is a pleasure to find that well-men often consult the Survey, have read thoroughly its reports, are well acquainted with the deep geology of the state, and have even adopted the rather formidable and changing scientific nomenclature of the formations. Drillers are thus able to base their bids on pretty well assured geologic conditions. It is unnecessary to increase these bids to cover improbable contingencies, or to lose on contracts by reason of unexpected difficulties. Over a good deal of Iowa, well drilling is fairly well standardized, a condition which makes for the benefit of well drillers and their employers.

Before making bids and signing contracts, drillers have asked the advice of the Survey as to the depth of the different water beds—an important matter where a contract specifies casing to the Saint Peter—and as to the lengths of casing necessary to case out caving shales and deleterious waters.

After drilling has gone deep both drillers and their employers sometimes refer the question of going deeper to the Survey. In some instances the advice has been given to stop work at once, and thousands of dollars have been saved in a single well when the advice as been followed. In certain cases the advice has been disregarded and the drilling continued with good results, namely, proving the accuracy of the forecast, increasing respect for the judgment of geologists, and confirming and extending our knowledge of the deeper strata of the state. In other cases the advice has been given to go on to still deeper-lying water beds and some very large flows have thus been secured.

It is well to remember the limitations of our knowledge of the subsurface rocks. They are not open to inspection. They can be photographed by no rays. Their nature, and the valuable minerals, such as oil and water, which they may contain are everywhere a matter of inference, and the accuracy and extent of the inference must depend on the accuracy and fullness of the data from which the inference is drawn.

These data are, first, the observations made of the outcrops of the formations where they form the country rock. The facts obtained by this field study of the geological formations of Iowa are reliable and definite, though not exhaustive. But it is not to be expected that the formations will carry their outcrop characteristics unchanged for scores and hundreds of miles as they sink deeper and deeper below the surface. Rather is it probable that they will thicken or thin, change in their dip, and become altered in composition. And formations quite unknown from surface outcrops may appear among the deeper strata. Where a water-bearing sandstone, for example, lies on an old erosion surface it may differ in thickness from a few grains where it rests on a buried hill-top to many feet where it fills a pre-existing valley. A sandstone, water-bearing at its outcrop because of open texture, may with distance become impervious as its interstices are filled with clay or cemented with lime. And although the lie of the strata in Iowa is singularly uniform—a fact that tends to make the state rich in artesian waters, but poor in oil and gas and monotonous in scenery—upfolds and downfolds may occur in the deeper strata without any surface expression. All these variations are unpredictable and can be discovered only by the drill.

To a very large extent, therefore, our knowledge of the deep geology of Iowa must depend on the second group of data—the information secured from deep well drilling. It is believed that in large measure this information is dependable and the general accuracy of the forecasts based upon it confirms its reliability. Our debt, therefore, to the drillers and to the owners of deep wells is very great for the painstaking efforts they have often made to place their facts at the disposal of the Survey.

But it must be remembered that all of this group of data is second-hand and not open to correction by personal investigation. Such data must vary widely in fullness and accuracy. The statistics of a city well furnished by officials may be set down from complete original, and well-kept records, or perhaps from a generalized memory called into hurried and reluctant action by repeated solicitations. It is sometimes evident that the owner of a well just completed knows little or nothing about his valuable property except possibly its depth.

Drilling firms are necessarily the ultimate sources of information, and often are the most reliable and ready. Yet practice differs widely. A firm may regularly keep full and accurate records of a well, submit them to a competent geologist along with a complete set of samples of the drill-cuttings, and furnish the owner of the well and the Geological Survey the full statistics of the well, its depth, diameters, casings, packings, water beds, results of tests for capacity, and log of the rocks passed through. Other firms may keep full records of the wells they drill on the time sheets of their foremen, but although these firms are usually ready to place such facts at the disposal of the Survey, it requires considerable uncompensated time and trouble on the part of busy men. And still other firms apparently keep no records and give their employers nothing beyond a receipted bill for payment. When the well needs repairs this lack of information will be found regrettable for financial reasons.

All owners of deep wells should recognize their right to this information, and if necessary should make it a matter of the contract. And all well drillers should recognize the advantage of imparting it. All statistics are, or should be, at hand on completion of the well. Taking frequent samples of the cuttings involves much time and pains on the part of workmen, but it is well worth the trouble, and either the drilling firm or its employer can have the samples examined in laboratory by the Iowa Geological Survey without expense.

Drillers' logs are an essential part of the geologist's data. Only the driller knows and can record the hardness of a given rock as tested by the time taken to drill a unit distance and by the wear on the bit. In his time sheets he sets down, or should set down, any slight change in the rock, so that streaks of shale in limestone, or of limestone in shale, for example, are defined, which escape notice if the only data are samples of cuttings taken at intervals of even as little as ten feet. The driller usually records the presence of water in any bed as evidenced by fluctuations of water level or the washing away of cuttings. He sets down the kind of rock in which the drill is working. He can give the depth more exactly than ordinarily can be determined from sample cuttings taken at regular intervals.

Yet drillers' logs often require interpretation and confirmation. The practical, hard-working, skilful well driller is not a lithologist. He has neither the time, the experience, or the laboratory equipment for accurate determinations of the materials of his slush bucket. If a rock, the Galena dolomite for example, crushes under the drill to a crystalline sparkling sand he may, and sometimes does, set it down as "sand", "sandrock" or "sandstone". And a geologist working without samples of the cuttings may suppose it the Saint Peter sandstone, for example, or that here the Saint Peter consists of upper and lower members separated by limestone. Hard shale is labelled "slate", soft shale often "soapstone", "mud rock", or "gumbo". Well cemented fine-grained sandstone cutting to chips, is often called "lime". Granite may be called "red sandrock" and schist "black lime". Quartzite may be labelled "granite" because of color and hardness.

Even in so simple a matter as color, it must be remembered that the cuttings as the driller sees them are usually covered with a wash of fine rock flour. This the geologist in laboratory removes, or judges the color by fresh broken surfaces.

As to such ambigous rocks as those of the Franconia, the driller is no more infallible or consistent than are geologists.

The driller's log should always be confirmed by a full set of sample cuttings, but even here there are possibilities of error. A sample taken from the slush bucket represents the rock in which the drill is working, but it may also contain a larger or smaller amount of material fallen from higher levels in the well. From any uncased portion of the drill-hole rocks may be dislodged by the vibration of rods or ropes and by the drill and slush bucket as they are hoisted and lowered. Rocks such as shales and loose sandstones and conglomerates may at any time cave for structural reasons until cased out. Thus shale from the Decorah and Glenwood formations may be found at lower levels, and when the drill is working in the Saint Peter may simulate streaks of interbedded shale. Sand from friable sandstone may thus mingle with the fresh cuttings of lower limestones and shales. It must often be left undecided as to what material of a sample is native and what foreign, especially when it is not known when the casing was inserted which cased out caving layers. In the description of samples, therefore, the mention of any material does not necessarily imply that the material was present in the rock at the given depth.

When there is reason to believe that the different materials of a sample of cuttings are all native, there still may remain some uncertainty as to the manner of their association. A sample made up of quartz sand and minute chips of dolomite may represent streaks of sandstone in dolomite or of dolomite in sandstone, a dolomitic sandstone, or an arenaceous dolomite. In case of a dolomitic matrix, however, some imbedded grains may usually be found if the cuttings are not too fine.

Occasionally there is some ground for suspicion that the depth label is incorrect. If it has been copied from that of the first container, the original figures may have become nearly illegible and may have been misread. Original containers may have become misplaced before labelling. If the workman at the derrick should attempt to label a number of containers from memory the result is apt to be highly unsatisfactory to the workman in the laboratory. Whatever may be the cause of such errors, labels are not convincing when Pleistocene clays are labelled as occurring hundreds of feet deep in solid rock, or sands of Saint Peter facies far above the depth of other samples of that formation, or samples of nonmagnesian limestone among the dolomites of the Prairie du Chien.

Sometimes there is reason to believe that the sample has not been taken directly from the slush bucket, but has been scraped up from the dump, introducing bits of coal and cinder and cuttings from earlier emptyings. Suspicion may attach to a long run of samples singularly alike in their heterogeneity.

Subject to these possibilities of error and misinterpretation the cuttings from Iowa deep wells are accepted as on the whole reliable and authentic. It is upon them that the chief dependence has been placed since the organization of the Survey. While the drilling of deep wells is now less of an event locally than in the closing decades of the last century, and citizens are less apt to possess the collector's passion for cuttings as rare specimens, yet drilling firms recognize as fully as ever the importance of taking these samples and their scientific value.

It may be added that sets of samples should always be complete, taken from start to finish every ten feet at least, and at every change in the rocks. Little can be done with a few samples taken many feet apart. Even when such samples can be referred to individual formations, they give neither their upper nor lower limits, and important formations may be omitted.

A sample is sometimes labelled as representing a body of rock scores or hundreds of feet thick, while its own depth is not stated. In this case the assumed uniformity of the body of rock is sometimes quite probable, sometimes highly improbable, but it can neither be proved nor disproved.

Cuttings should be emptied from the slush bucket directly into the containers. They should never be washed, as the fine material of them is quite as valuable for identification as the coarse. Cheap and good containers are found in cigar boxes and glass fruit jars, and the Iowa Geological Survey is glad to furnish cloth bags with stout tags attached for labels. Labels should be written with a common pencil, not an indelible pencil, and every care should be taken that the figures are legible and remain so. Wet cuttings should not be placed directly in the cloth bags but should first be drained or the water is very likely to stain the labels and make their legends illegible.

The Geological Formations

Underground waters, their distribution and the amount and quality of them obtainable at any place depend largely on the structure and composition of the rocks. Of first importance, therefore, are the geological formations, not only in their areas of outcrop, but also in the larger areas where they are buried from view and are accessible only to the drill. The various members of the geologic column in Iowa in their relations to underground water have been treated in earlier reports and it is now necessary to summarize only the more important facts obtained in the preparation of the present paper. A list of these members is given herewith.

GENERAL SECTION OF IOWA STRATA

Group	System	Series	Formation		Character
CENOZOIC	Recent				Soil, geest, alluvium
	Quaternary, patches of Tertiary	Pleistocene	Wisconsin		Bowlder clay
				Peorian	Loess, forest bed, sand, gravel
			Iowan		Bowlder clay
				Sangamon	Gumbotil, soils, forest bed, sand, gravel
			Illinoian		Bowlder clay
				Yarmouth	Gumbotil, peat, soil, sand, gravel
			Kansan		Bowlder clay, gravel
				Aftonian	Gumbotil, peat, soil, gravel
			Nebraskan		Bowlder clay, gravel

GENERAL SECTION OF IOWA STRATA (Continued)

Group	System	Series	Formation	Character
MESOZOIC	Cretaceous	Upper Cretaceous	Colorado	Shale, limestone
			Dakota	Sandstone
PALEOZOIC	Permian	Fort Dodge		Gypsum, shale
	Pennsylvanian	Missouri	Wabaunsee Shawnee Douglas Lansing Kansas City	Limestones, shales, coal
		Des Moines	Pleasanton Henrietta Cherokee	Shales, coals, sandstones, limestones
	Mississippian	Iowa Series: Meramec	Ste. Genevieve (Pella) St. Louis Spergen Warsaw	Limestones, marls, sandstones
		Iowa Series: Osage	Keokuk Burlington	Limestones
		Iowa Series: Kinderhook		Shale, limestones
	Devonian	Upper Devonian	Lime Creek—State Quarry Cedar Valley Wapsipinicon { Davenport Independence Otis	Shale, limestones Limestone, shale Limestone Shale Limestone
	Silurian	Cayugan?	Salina ? nowhere exposed	Limestone, gypsum
		Niagaran	Gower Hopkinton	Dolomites
		Alexandrian	Waucoma	Limestone
	Ordovician	Cincinnatian	Maquoketa	Shale, dolomite
		Mohawkian	Galena Decorah Platteville	Dolomite Shale, limestone Limestone, shale
		Canadian	Glenwood St. Peter Prairie du Chien { Shakopee New Richmond Oneota	Shale Sandstone Dolomite Sandstone Dolomite
	Cambrian	Croixan	Jordan St. Lawrence { Trempealeau Franconia Dresbach Eau Claire Mt. Simon Red clastic beds (unnamed) } Not exposed in Iowa	Sandstone Dolomite, marls Shale, glauconite, marl Sandstone Shale,sandstone Sandstone, shale Sandstone, shale, conglomerate
PROTEROZOIC	Algonkian	Huronian	Sioux	Quartzite
ARCHEOZOIC	Laurentian?		Nowhere exposed	Granite, schist

PLEISTOCENE SYSTEM

Few facts relating to the glacial drift are obtainable from deep well records beyond its depth and thickness. Glacial tills and water-bearing sands and gravels are of prime importance to the driller of farm wells and the house wells of villages and towns and to the many hundreds of thousands of people in Iowa who derive their supply from them. But the deep well driller usually pays little attention to the drift. He goes through its water sands without testing their capacity, and all too frequently takes no samples until bed-rock is reached. Hence no attempt is made in this report to distinguish the different drift sheets.

Pleistocene deposits are found of abnormal thickness in old buried channels and deep filled valleys of present rivers at Washington, Riverside, Audubon, Denison, and perhaps at Van Horne, Grinnell and Stuart. At all these points it is more than 200 feet to bed rock.

The thickest drift in the state is usually supposed to exist in northwestern Iowa, but uncertainty has attached to many well records because of the possible failure of the driller to distinguish glacial clays from Tertiary clays and from Cretaceous shales. The wells of this area here reported give nothing exceptional for the drift except at Holstein, where, if the samples are authentic, glacial tills are found as deep as 380 feet and may extend to the first sample of bed rock at 420 feet.

CRETACEOUS SYSTEM

In northwestern Iowa the drill normally pierces below the drift the shales and limestones of the Colorado group of the Cretaceous, passing thence into the well known water bed of the Dakota sandstone. The Colorado group is well developed at Orange City, where it attains a thickness of 330 feet. At Inwood none of the Cretaceous can be identified from an imperfect log. At Sioux City the Colorado and a large part of the Dakota lie above the level of the rivers and of the well curbs. As at many towns in northwestern Iowa, the Dakota sandstone furnishes part or whole of the supply at Sioux City and Orange City.

Beneath the sandstones of the Dakota group shales whose rank is undetermined are found at several places. Some may belong to the Dakota group; others to Paleozoic systems. At Sioux City shales, red and whitish, 70 feet thick occupy this horizon. At Orange City 8 feet of red shale with 37 feet of underlying gray shale rests on a sandstone attributed to the Saint Peter. As the sand grains included in the red shale are well rounded both shales may be classified plausibly as Glenwood.

At Emmetsburg the Dakota sandstone is parted from Paleozoic dolomite by bright brick-red ochreous shale of finest grain, 22 feet thick, with some angular included grains of sand, and black nodular grains of ironstone up to five millimeters diameter. At West Bend a "red marl" separates the Dakota sandstone from Mississippian cherts and at Ayrshire a red shale is reported as underlying the Dakota sandstone. At Algona a "fine sandstone" attributed to the Cretaceous rests on 5 feet of limestone which in turn overlies 10 feet of "red shale". At Holstein shales 170 feet thick intervene between the exceptionally thick drift and the Mississippian. Here the Cretaceous sandstone is wanting and the shales may be Pennsylvanian, although at Cherokee a thick body of shale and sandstone at the same horizon has been placed with the Cretaceous.

In western Iowa heavy shales beneath the drift and the Dakota sandstone may be Pennsylvanian in age. The red shales of the Pella beds at Fort Dodge suggest that some of the red shales above mentioned may even be Mississippian.

PENNSYLVANIAN SYSTEM

Data as to the character and thickness of the Pennsylvanian, or Coal Measures, will be found in the records of several new wells located on the widespread area of outcrop of this system. In a number of instances the logs of the drillers will be found more complete and accurate than data from the samples of the cuttings. In the Missouri series frequent changes in the character of the strata are common, and samples taken every ten feet miss thin beds of sandstone, shale, limestone, fire clay and coal, which a carefully taken log records.

In wells of the Des Moines series it is unfortunately rather common for drillers to take no samples until the somewhat monotonous shales which constitute the bulk of this stage are passed through. The abnormal record of the deep well at Manson (p. 246) is interpreted as probably that of the fill of a pre-Pennsylvanian valley—or possibly of a pre-Cretaceous valley—by deposits in part continental.

MISSISSIPPIAN SYSTEM

According to the classification of Weller and Van Tuyl,[2] the Mississippian system of Iowa includes the following subdivisions: the Meramec group, consisting of the Ste. Genevieve (Pella), St. Louis, Spergen, and Warsaw formations, the Osage group, consisting of the Keokuk and Burlington, and at base the Kinderhook group, embracing a heavy basal shale and various formations of limestone, shale and sandstone not discriminated in this report.

In deep well sections the Mississippian is approximately demarked from the Pennsylvanian where the shales of the Des Moines or its basal sandstones give place to the cherts and limestones of the earlier system. Pella shales or St. Louis sandstones occurring at the summit of the Mississippian might easily be wrongly included in the Pennsylvanian.

The delimitation of the Mississippian at base from the Devonian is even more difficult in deep well sections than in the field, where in the northeast part of the area of outcrop the place of the Sheffield shale, ranked at present as Mississippian, may perhaps be decided by fossils to be Devonian, and in the southeast, where some doubt still attaches to the place of the Sweetland Creek shales, now ranked as Devonian.

In several deep well sections in Illinois Udden has successfully discriminated the Kinderhook shale from the Sweetland Creek by the presence of microscopic *sporangites* in the latter. In Iowa deep well sections this discrimination has not been made, and it is probable that some shales attributed to the Kinderhook include Devonian shales also, Sweetland or Lime Creek.

In the well sections of southeastern Iowa the Kinderhook shale (including perhaps Upper Devonian shale at base) carries the thickness of its outcrops and of the well sections of earlier reports. At Fairfield this shale is 250 feet thick, at Morning Sun

2 Van Tuyl, Mississippian Strata of Iowa: Iowa Geol. Survey, vol. XXX, pp. 42, 43.

and Brighton about 280 feet, and at Winfield and Donnellson about 325 feet. At Riverside in Washington county it measures 175 feet, but here the upper part may be cut away by the filled valley of English river. At Keokuk it measures 204 feet.

To the northwest the Kinderhook shale thins. At Nevada it measures 80 feet, at Des Moines 185 feet, at Rippey 45 feet. At Webster City it is represented perhaps by argillaceous limestones and at Fort Dodge it is about 60 feet thick and contains beds of limestone. At Gowrie it measures 50 feet. Further to the northwest, at Holstein and Algona, it is not recognized.

In southwestern Iowa it has but a moderate thickness, at Audubon 50 feet, at Stuart 41 feet and at Greenfield 55 feet. At Oakland a shale 97 feet thick struck at 1486 feet may be the Kinderhook. In that case the entire Mississippian at Oakland has the not excessive and yet sufficient thickness of 396 feet.

DEVONIAN SYSTEM

The upper limit of the Devonian terrane is usually drawn in deep well sections at the summit of the limestones which underlie the body of shale whose upper portion at least is Kinderhook. The lower limit is difficult to define except where nonmagnesian or slightly magnesian limestones, perhaps with shaly beds, give place to typical Niagaran dolomites. But the Wapsipinicon stage of the Devonian contains dolomitic beds and the Salina of the Silurian is by no means fully dolomitized, and west of Marshalltown it is usually the Salina on which the Devonian rests.

Near the western edge of the area of outcrop the Devonian is assigned a thickness of 165 feet at Waterloo, 231 feet at Van Horne, and 220 feet at Oakdale. Farther west, at Nevada, it is probably at least 240 feet thick and 120 feet thick at Des Moines. At Stuart and Rippey a thickness of 155 feet is assigned to this system.

In southeastern Iowa the Devonian rocks appear to be about 140 feet thick at Brighton and 100 feet thick at Washington. At Donnellson no more than 140 feet can be given to both the Devonian and Silurian.

SILURIAN SYSTEM

The Silurian system of Iowa is of special interest in its relations to ground water. The Niagaran limestone throughout its area of outcrop and along its western edge forms a capacious reservoir within easy reach. Its solution channels are many and large and it has the advantage of an impervious floor in the Maquoketa shale. Over this area wells of about 300 feet or less which reach the base of the formation may yield an adequate supply for villages and towns. Such wells are as safe as any where the limestone has an impervious cover of boulder clay. But where the limestone is not thus protected its solution channels may carry contaminating surface waters too deep to be shut out by casings. The recent Niagaran well at Manchester is but one of several examples of this danger.

As the Niagaran limestone dips beneath the surface to the west and south there is evidence that it comes to be overlain and replaced by gypsum-bearing limestones, which probably belong to the Salina group of the Silurian. These beds are of importance to the driller for any water they contain is likely to be objectionable on account of its permanent hardness and should be cased out. To the north the Niagaran limestone thins abruptly and it can not be certainly identified at Charles City, Mason City or Osage.

The Silurian in parts of the state beyond its area of outcrop contains also arenaceous beds which may be water-bearing and in western Illinois form reservoirs for oil.

SALINA

Gypsum-bearing beds referred to the Salina were found in Iowa wells drilled before 1910 at Marshalltown, Des Moines, Grinnell, Pella and Mount Pleasant. At Glenwood also and at Bedford gypsiferous limestones were found apparently below the horizon of the Permian, the probable horizon of the gypsum of Fort Dodge, and below also the stratigraphic level of the Mississippian, to which the gypsum of Centerville belongs. These also were tentatively referred to the Salina.

The inferences of the earlier reports have been confirmed by new wells at various points. At Des Moines, in the well of the

Northland Milk and Ice Cream Co., the gypseous beds of the Salina appear in considerable force 140 feet below the base of the Kinderhook shales. At Webster City gypsum associated with nondolomitic limestone is found in distinct beds 80 and 140 feet above the summit of the Maquoketa shales, and chips of gypsum with limestone occur in cuttings to 250 feet above that datum. At Nevada and Ogden well marked gypseous deposits were found at the Silurian horizon and they probably were found at Ames also. In southeastern Iowa gypseous beds occur 140 feet below the base of the Kinderhook at Brighton. The beds of gypsum and anhydrite at Mount Pleasant lie 120 feet below the base of the same shales.

At Stuart and Greenfield the gypseous beds of the Salina form a stepping stone between those at Des Moines and those at Glenwood and Bedford. Gypsum begins to appear in the cuttings of the Stuart well at 1375 feet and is found at intervals in chips with limestone to 1759 feet, 106 feet above the summit of the Maquoketa. At Greenfield gypsum occurs in the cuttings from a body of dolomite found 130 feet below the well defined horizon of the base of the Kinderhook shales.

HOING SANDSTONE

Sandy beds at the base of the Silurian were discovered by Calvin[3] in 1888 in a deep well section at Washington, Iowa, and this has been confirmed by the cuttings of the deep wells since drilled at this locality. At Sigourney also a bed 6 feet thick and composed of chert, limestone, and much quartz sand occurs at the base of the Silurian. At Des Moines in the Greenwood Park well a similar formation 22 feet thick was disclosed 55 feet above the top of the Maquoketa shale and separated from it by a bed of limestone. The same sandy bed was reached by the recent well of the Northland Milk and Ice Cream Company (p. 166).

At Stuart quartz sand and limestone chips form the cuttings representing the basal 24 feet of the Silurian. At Centerville a sandstone 50 feet thick overlies 60 feet of sandy limestone, which rests on shales assigned to the Maquoketa. At Shellsburg a fine-grained sandstone 30 feet thick rests on the Maquoketa shales.

3 Calvin, S., American Geologist, vol. 1, pp. 28-31.

Probably the basal sandy rocks of the Silurian at some of the above localities are the equivalent of the sandstone discovered by the drill in the Colmar oil field in western Illinois and called the Hoing sand.[4] The Hoing formation is described as spotty and discontinuous in distribution and lenticular in its deposits, with a thickness ranging from 5 to more than 30 feet. It is supposed to lie unconformably on the Maquoketa shale and to occupy hollows in the erosion surface developed on the shale during the erosion interval preceding the deposition of the Niagaran limestone. It thus consists of land deposits reworked by the transgressing Niagaran sea.

The arenaceous deposits at the base of the Silurian in Iowa well sections bear this interpretation. At Des Moines, where they rest on limestone, it is quite possible that, as in its outcrop in northern Iowa, the Maquoketa includes a limestone bed as its upper member.

ORDOVICIAN SYSTEM

MAQUOKETA SHALE

The facts gathered from recent wells as to this formation, so important as a confining bed in the artesian system, and so reliable as a marker in the interpretation of well sections, confirm the conclusions of earlier reports, but offer little that is new.

Considerable range in the thickness of the Maquoketa is found even in nearby sections. This is attributable to the variations in level of the land erosion surface developed on the shale before the deposition of the Niagaran limestones, and no doubt also to various classifications of transition beds and to various interpretations of sample cuttings. The interpretation of washed samples of the cuttings of shale and shaly limestone, from which the clayey constituents have been removed, may easily differ from that of unwashed sample cuttings of the same beds in a different well.

[4] Morse, W. C., and Kay, F. H., Bull. No. 31, State Geol. Surv. of Illinois, pp. 40-42.

Thickness of the Maquoketa Shale

Well section	Thickness in feet
Cresco	120
Oelwein	215
Preston (upper part perhaps cut away)	120
Delmar	225
Dewitt	201
Waterloo	230
Cedar Rapids	260
Shellsburg	170
Oakdale	145
Bettendorf	200
Van Horne	193
Nevada	50
Grinnell	240
Des Moines (Greenwood Park)	33
Stuart	119
Rippey	150
Denison	40
Audubon	90
Webster City	70
Fort Dodge	210, 190
Algona	40
Washington	200
Winfield	210
Brighton	110
Donnellson	5

To the north, as at Calmar, Cresco and Charles City, shale has been replaced by impure dolomites.

To the northwest the Maquoketa thins and at Emmetsburg may be represented by a shale only 4 feet thick. At Cherokee and Holstein it has apparently either feathered out or has been removed by erosion. To the southwest the shale was not recognized in the Council Bluffs and Omaha wells and probably was not reached at Glenwood and Bedford. At Nebraska City, however, the driller's log records a shale 114 feet thick at 2160 feet, which is pretty certainly the Maquoketa.

In the extreme part of southeast Iowa the Maquoketa feathers out and at Donnellson is but 5 feet thick.

GALENA, DECORAH AND PLATTEVILLE FORMATIONS

Beneath the Maquoketa shale the drill enters a group of limestones and shales which rests on the Saint Peter sandstone. In descending order this group consists of the Galena limestone, the Decorah shale, the Platteville limestone, and the Glenwood shale. The Glenwood shale is transitional to the Saint Peter sandstone and while here grouped with the formations which succeed it, is reserved for description in a later section.

In well sections where the Decorah is absent or unrecognized the group above the Glenwood is designated as the Galena-Platteville.

This group of formations is one of the most extensive in the Iowa geologic column, underlying all the state except a few townships in the northeastern county, and an undefined area in the northwest, where the Cretaceous rests directly on the Saint Peter or on still older rocks.

The lithologic characteristics of these beds are fairly constant throughout the state. While they are not of themselves sufficient for identification in the absence of fossils, in well sections where the Maquoketa and Saint Peter are present the group is identified with certainty, although its component formations may not be clear.

The cavernous nature of the Galena and the numerous powerful springs which issue from it at its juncture with the Decorah shale along its outcrops, suggest the fact that it is an important water bed, but that the circulation of ground water in it is through irregular and unpredictable solution channels and not in sheets.

Among the older wells such irregular waterways in the Galena were struck at Clinton, Davenport, Fort Madison, Sumner, Osage, Mason City, Hampton, Pella, Grinnell and Holstein. To this list are now added Algona, Calmar, Donnellson, Van Horne and Webster City. At Calmar, Donnellson, Mason City and Iowa City the Galena-Platteville furnishes the main supply.

GLENWOOD FORMATION

In the Geology of Allamakee County Calvin[5] described as a basal shale of the Trenton a shale five or six feet thick resting conformably on the Saint Peter sandstone. Later, in his survey of Winneshiek county, Calvin[6] found this shale more fully developed. He gave it a formational name from Glenwood township, where it reaches a thickness of 15 feet, and because of streaks and bands of sand of Saint Peter facies which it contained he classified it along with the Saint Peter sandstone as a formational member of the Saint Peter stage.

5 Calvin, S., Iowa Geol. Survey, vol. IV, pp. 73, 74, Des Moines, 1895.
6 Calvin, Iowa Geol. Survey, vol. XVI, pp. 61, 74, Des Moines, 1906.

Leonard[7] in his report on the geology of Clayton county finds this shale but 2 or 3 feet thick and nonarenaceous. He classifies it as the basal shale of the Trenton.

Norton, in his report on the Underground Water Resources of Iowa,[8] describes the Glenwood shale as widely distributed over the state. It is included in the Platteville formation, since from the point of view of the driller of deep wells it seemed best to retain the term *Saint Peter* in its most restricted sense and in well sections at a distance from the area of outcrop heavy shales above the Saint Peter sandstone might include the equivalents of the Decorah shale and of the Platteville limestone, there become predominantly shaly. Yet it is stated that "if studied in the field some of these arenaceous transition beds would be classified with the Saint Peter".

For the same reasons in the present investigation the Glenwood is placed with the Platteville, the Decorah and the Galena. If the sand which it carries in places aligns it with the Saint Peter the clay which is its constant constituent relates it to the Platteville, which in its lower beds has a tendency to become argillaceous.

The Glenwood probably has some economic value as a containing bed for the sandstone aquifer on which it rests. It forms a trusted marker as a member of the unique sequence of the Platteville earthy limestone, the hard dark green shale of the Glenwood, the clean sand of the Saint Peter and the dolomites of the Prairie du Chien.

In the deep well sections of northeastern Iowa the Glenwood has about the thickness of its outcrops. At Decorah, Monona, Calmar, Manchester, Waverly and Sumner its thickness does not exceed 10 feet. At Frederika the driller's log reports at this horizon 8 feet of "gumbo" overlain by 32 feet of "blue shale", probably in part Platteville.

To the west, in north-central and northwestern Iowa, the formation either thickens or merges with a shaly Platteville, perhaps also with the Decorah shale. At Charles City the shale overlying the Saint Peter sandstone is 73 feet thick and the up-

7 Leonard, A. G., Iowa Geol. Survey, vol. XVI, p. 251, Des Moines, 1906.

8 Norton, Iowa Geol. Survey, vol. XXI, pp. 82-84, Des Moines, 1912.

per layers of the sandstone apparently are somewhat argillaceous. At Osage and Hampton a thickness of about 40 feet is maintained, while at Mason City the shales immediately above the Saint Peter reach a thickness of 90 feet, including a thin bed of limestone. At Algona the driller's log records at this horizon shale 112 feet thick with three streaks of limestone aggregating but 11 feet. At Emmetsburg these shales are 95 feet thick and at Cherokee they may reach 50 feet. At Holstein (p. 225) there is an interesting succession of 90 feet of argillaceous dolomites, sandstone, shale and limestone.

In east-central Iowa the Glenwood is thin—10 feet or less—at Clinton, Maquoketa and Anamosa and is absent or unreported at Green Island, Cedar Rapids, Tipton and Vinton. At Oakdale the Glenwood is separated from the Saint Peter by a thin bed of limestone. At De Witt, where it is 13 feet thick, it consists of sandstone with inflammable oil shale overlying the typical green shale of its outcrops. At Bettendorf the Glenwood includes 15 feet of sandstone and 15 feet of subjacent shale. The same succession is reported by Udden at Rock Island.[9] At Sabula 25 feet of limy, clayey sandstone is parted from the clean sandstone of the Saint Peter by 25 feet of green fissile shale. At Letts the same succession lies within the limits of 30 feet.

In central Iowa the Glenwood is thin at Des Moines and Van Horne. At Grinnell it includes a thin basal bed of limestone. At Jefferson, Ames, Ackley, Webster City, Fort Dodge, Rippey and Gowrie its thickness lies between 25 and 35 feet. At Boone the place of the Glenwood in the stratigraphic column is occupied by 50 feet of shale arenaceous at base and with a thin layer of sandstone 15 feet from the top.

In southeastern Iowa the Glenwood is arenaceous or includes an upper layer of sandstone at Morning Sun, Winfield, Brighton and Washington. At Sigourney it is absent and at Donnellson it is represented only by a thin dolomitic sandstone. At Centerville it is 10 feet thick and contains no sand.

In west-central and southwestern Iowa the shales overlying the Saint Peter attain something of their thickness in north-central Iowa. At Denison and Audubon this body of shale is 80

9 Udden, J. A., Some Deep Borings in Illinois: Illinois State Geol. Survey, Bull. 24, p. 62, Urbana, 1914.

feet thick, including at Denison a bed of limestone not more than 10 feet thick and parted from the Saint Peter by a layer of limestone which comes within the same measure. At Stuart the Saint Peter is overlain by three beds aggregating 16 feet—a highly calcareous shale, a fine dolomitic sandstone of rounded grains, and at bottom a very sandy, limy shale. Sixty-four feet higher occurs a 5 foot bed of dark green shale with rounded grains. Some sandy shales are found also at several lower levels in the midst of limestones of Platteville facies. If these samples are authentic the shaly beds which represent the Glenwood may reach the thickness given the formation at Audubon and Denison.

SAINT PETER SANDSTONE

The Saint Peter sandstone is not only an important water bed, it is also a most valuable marker on account of its lithologic peculiarities as a clean soft sandstone of rounded and frosted grains. It underlies the entire state excepting a small area in the northwest which extends at least as far south as Inwood and, judging by the Worthington, Minnesota, deep well section (p. 366), as far east as Osceola county. In the northeastern corner of the state it stands at an elevation of about 1200 feet above sea level on the high divides between Upper Iowa and Yellow rivers. Gradually it sinks to the southwest until in a drill hole section at Nebraska City, opposite the southwestern corner of the state, it was identified in 1912 by the writer at 1853 feet below sea level. To the east of Nebraska City it probably lies still deeper and in the southwestern counties of Iowa the Saint Peter and the water beds below it are quite too far below the surface for profitable exploitation.

Because of the easy recognition of the Saint Peter and its statewide extent a contour map is inserted (Plate I) showing the probable elevation of its surface above sea level. Where the elevation is highly hypothetical the contours are drawn with broken lines. The data on which the map is based are the logs of hundreds of wells, and although the accuracy of the map can not exceed the accuracy of the data, it is believed that it will be found helpful. It must be remembered, however, that the map is based necessarily on the assumption that the dip of the formation between two given points is constant. Local upfolds and downfolds which find no surface expression can not be predicted in advance of the drill.

The Saint Peter is a fairly reliable water bed. Yields are reported from it at Brighton, Gowrie, Donnellson, Fort Dodge, Morning Sun, Orange City, Oakdale, Van Horne, Washington and Waterloo. The Saint Peter seldom furnishes the main supply and it is usually advisable to drill deeper to tap the more copious flows of lower water beds.

Basal Beds of the Saint Peter.—Normally in Iowa both at outcrops and in well sections the clean white sands of the Saint Peter rest directly on the dolomite of the Prairie du Chien. In several wells, however, the drill has struck at the base of the Saint Peter sandstone of normal type anomalous beds—chert conglomerates, red shales and red sandstones of special importance to the driller because of their exceptional facility in caving. To the geologist these basal conglomerates and other residual materials produced by the secular decay of the Prairie du Chien dolomites are of interest since they are records of a long erosion interval between the Prairie du Chien and the Saint Peter.

In the study of Iowa well sections these anomalous deposits were first noticed in Holstein city well no. 1. Here the beds below the Saint Peter sandstone include caving red and green shale and chert, with dolomite and sandstone and marl, either in distinct layers or as pebbles and matrix of a conglomerate. The thickness is undetermined but can hardly exceed 255 feet and probably is much less. For in city well no. 2 drilled 160 feet from well no. 1 the beds below the Saint Peter are quite normal and no caving material was encountered. The red shale and chert of well no. 1 are to be construed as a lenticular deposit and, if thick, as fill in a steep-sloped valley.

The section in well no. 1 from the base of the Saint Peter at 1485 feet to 1740 feet, where we have a bed of plastic blue shale resting on glauconiferous marl referred to the Saint Lawrence (Franconia beds) is described as follows:[10]

10 Norton, W. H., Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, pp. 1006 and 1048.

Limestone (?) marly, arenaceous; described by driller as a "sandy rock which wears the drill; sand grains brought up in slush bucket; other drillings very light and float up in water; rock drills about one foot an hour, and does not cave" 1485–1520
Shale, red; "at about 1520 red marl was coming in and could not tell much about the formation from there down to 1890 feet as it was caving very badly all the way and caved more or less from there down to 2000 feet" 1520
Sandstone, fine-grained, blue-gray, dolomitic cement 1575
Sandstone and dolomite; quartz sand, considerable red shale and some green shale from above, and a little gray siliceous dolomite .. 1670
Chert, dark reddish brown, ferruginous, in small chips, arenaceous with minute particles of crystalline quartz; as similar chert and reddish argillaceous powder are found in nearly all the drillings below, this may have fallen in from 1520 1700
Sandstone and chert; sandstone fine-grained, in detached grains of clear quartz, many imperfectly rounded, and minute white cuttings showing quartz particles in dolomitic cement; chert, dark brown, ferruginous, dolomitic 1720

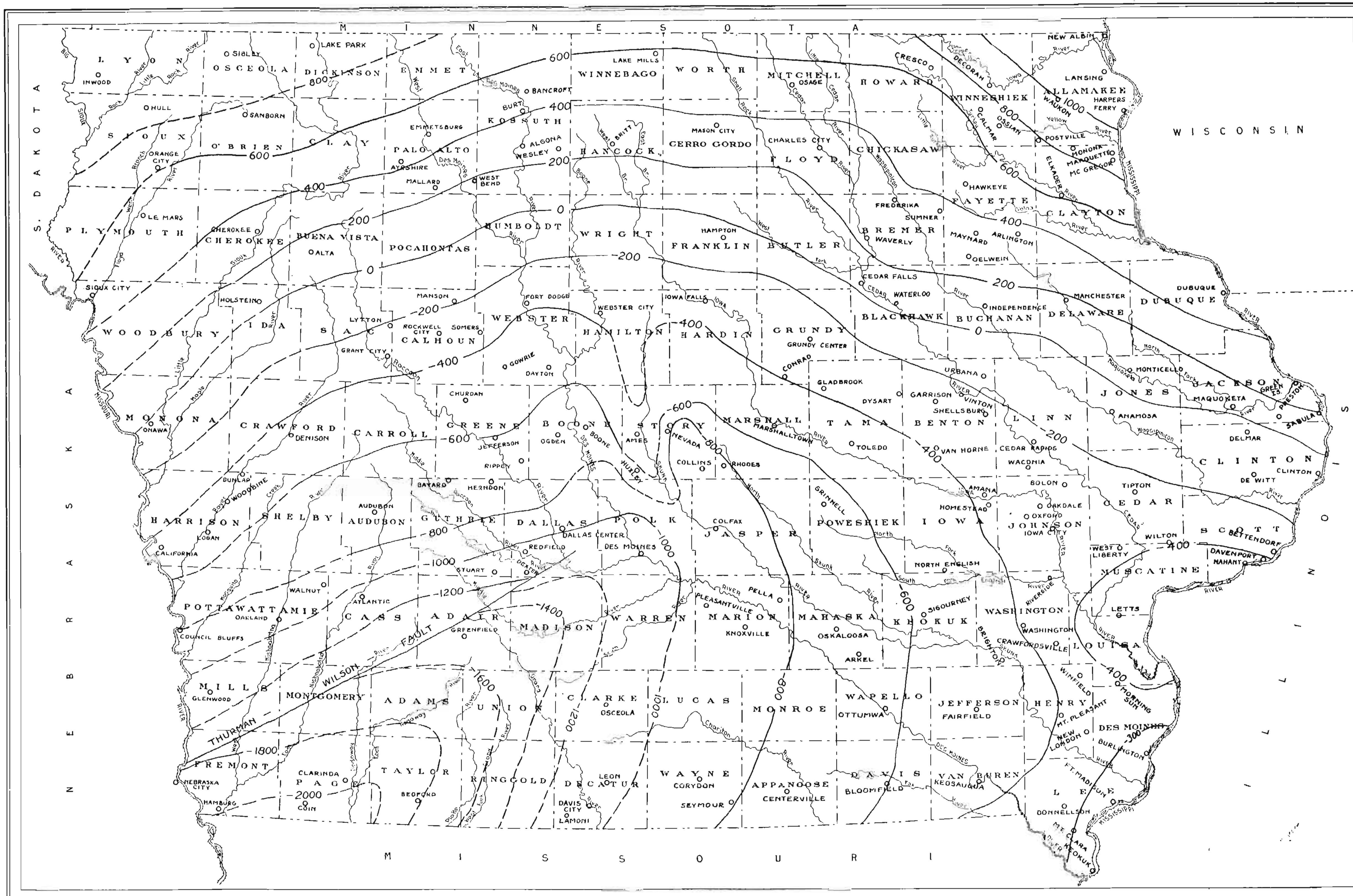
A prospect hole drilled in 1907 near Maquoketa afforded more satisfactory evidence of the nature of these anomalous beds beneath the Saint Peter sandstone, and here these beds were interpreted by the writer as continental deposits recording an unconformity.[11] The record of these beds and of a sample of cuttings of dolomite beneath them, referred to the Oneota, is as follows:

Sandstone, fine, brick red, considerable red argillaceous or ferric admixture; when washed in hot water drillings remain pink owing to the films of ferric oxide on grains of quartz sand; grains rounded, many broken; sand said by driller to contain seams of red shale; in log "red sandstone" 815–1056
Dolomite, light yellow gray, with much dark red and dark brown hard fine-grained shale; some light green shale; a fine yellow quartz sand; a fragment of red fine-grained sandstone set with pieces of green shale; all except dolomite probably foreign, at 1056

From the sample taken at 1056 feet it seemed clear to the writer that the drill was here working in dolomite, but the material assumed to have fallen in from the continental deposits above is also noteworthy, especially the fragment of red sandstone set with pieces of shale. This fragment is quadrate, its diagonal diameter 2 cm., and the sandstone incloses as a matrix a central mass of shale with bent and broken laminæ about its edges. The sample of the cuttings also furnishes a piece of laminated green shale in which two laminæ each about 2 mm. thick inclose a lamina of the same thickness of white sandstone.

While only one sample was supplied of the entire 241 feet described as "red sandstone with seams of shale" it was noted[12]

11 Norton, W. H., op. cit., p. 496.
12 Norton, W. H., op. cit., p. 79.



Map of Iowa showing contours at top of Saint Peter sandstone, and the location of deep wells and borings. By W. H. Norton. Figures show estimated elevation in feet above or below sea level. Contour lines in dashes are hypothetical.

that "the log was made out with unusual care by the foreman in charge of the work" and that an inspection of the slush piles after the well was nearly completed "showed so large an amount of the red sandstone as to give much support to the statement of the log."

A number of instances on record of similar red deposits discovered at this horizon in deep wells were cited: in Minnesota reddish deposits of limestone in a well at East Minneapolis and in one at the West Hotel[13] and in Illinois red marls at Lake Bluff and Winnetka,[14] Joliet,[15] Moline and East Moline.[16]

The basal beds of the Saint Peter shown in some deep well sections are inconspicuous or wanting in the Iowa area of outcrop. Yet Trowbridge[17] has observed that "in several places, notably in the vicinity of Church, the basal portion of the Saint Peter sandstone contains fragments of chert which came from the Prairie du Chien dolomite". Trowbridge also notes two phases of the Saint Peter in Iowa, an upland phase and a valley phase, the latter "highly and variously colored" as at Pictured Rocks, McGregor, and he goes on to say that "these differences within the formation are due doubtless to the different conditions which existed in the valleys and on the divides during the early part of the Saint Peter stage".[18]

In the states adjoining Iowa on the north, east and south the differences between the basal beds of the Saint Peter and its normal facies have been noted by a number of observers. Reference has already been made to typical well logs in Illinois and Minnesota. In Missouri, the basal member of the Saint Peter group, as described by Dake, the Everton, consists of an upper limestone and a lower group of sandy beds including a basal conglomerate of chert pebbles and sometimes of dolomitic pebbles as well, all in a sandy matrix. In one section this conglomerate is 10 feet thick.[19] Dake in commenting on Norton's interpreta-

13 Hall, C. W., Bull. Minnesota Acad. Nat. Sci., vol. 3, p. 139.

14 Stone, Leander, Bull. Chicago Acad. Sci., vol. 1, p. 96.

15 Leverett, Frank, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 799.

16 Udden, J. A., ibid, p. 848.

17 Trowbridge, A. C., The Prairie du Chien-Saint Peter Unconformity in Iowa: Proc. Iowa Acad. Sci., vol. XXIV, p. 180, Des Moines, 1917.

18 Trowbridge, op. cit., p. 181.

19 Dake, C. L., Problem of the Saint Peter Sandstone: Bull. Missouri School of Mines, vol. VI, no. 1, p. 16, Rolla, 1911.

tion of the Maquoketa red sandstone as a continental deposit states that "this solution is also directly in line with the presence of red residual soils discovered by the writer at the base of the Saint Peter sandstone in Missouri."[20]

In Wisconsin, both Chamberlin and Wooster early noted at the base of the Saint Peter, conglomerate, chert and kaolinic masses.[21] Alden in 1918 recorded 12 deep wells in which red marl, red shale, red sandstone, grey and red chert occupy this horizon.[22] He also states that "at very many places throughout the belt of outcrop * * * there are small exposures of reddish, purplish, bluish, greenish or white clayey shale or sandy shale at or near the contact between the limestone and the overlying sandstone". "At Albany in Green County 3 to 5 feet or more of this loose chert was seen occupying a rounded and weathered surface of the limestone and underlying the undulating basal layers of sandstone, in whose lowest layers fragments of chert were included".[23] Referring to the red sandstone Alden notes that "at what exposures there are it differs from most of the Saint Peter formation in that infiltration of silica-bearing waters has led to the rejuvenation of a large part of the quartz crystals * *".[24]

In the Tomah and Sparta quadrangles, Wisconsin, Twenhofel and Thwaites[25] found that the basal parts of the Saint Peter involve "a variable thickness of red and green noncalcareous shales and fine-grained shaly yellow sandstones". "At any place where the base of the Saint Peter was observed it rests on a residuum of red clay and chert which is altogether without stratification. This residuum was derived from the weathering of the Oneota and possibly higher formations. In this article this unstratified material is assigned to the Saint Peter, although it developed during the time of erosion which intervened in this area between the Oneota and the Saint Peter and thus might be considered a distinct formation."

To the evidence from outcrops Thwaites has added that de-

20 Dake, op. cit., p. 68.

21 Geol. of Wisconsin, vol. 2, p. 287; vol. 4, p. 129.

22 Alden, W. C., Quaternary Geology of Southeastern Wisconsin: Prof. Paper no. 106, U. S. Geol. Survey, p. 79.

23 Alden, ibid, p. 81.

24 Alden, ibid, p. 82.

25 Twenhofel, W. H., and Thwaites, F. T., Journ. Geol., vol. XXVII, pp. 632-633, 1919.

rived from deep well sections.[26] In summation he states "The Saint Peter is dominantly a light gray * * * * * sandstone; below the sandstone are beds of purplish red and green shale, interstratified with layers of white disintegrated chert, and conglomerate with chert and limestone pebbles in a matrix of fine to coarse sand. These basal beds cave very badly in wells and must be cased off. At Shullsburg, Wisconsin, Galena, Illinois, and elsewhere they are a very difficult horizon to penetrate with the drill. The caved material mixes with cuttings from lower horizons making some records very hard to interpret." Again, speaking of the base of the Saint Peter Thwaites remarks, "The shales at this horizon are virtually all noncalcareous and appear to be more or less oxidized residuum from the underlying dolomites. The chert beds and conglomerates represent assortment of residual deposits by water."

Thus it appears that in Iowa as well as in Minnesota, Wisconsin, Illinois and Missouri the Saint Peter sandstone of normal type is underlain in places by beds largely made up of residual materials, the product of secular rock weathering and erosion of earlier formations and resting on an erosion surface of considerable relief. At least in part these materials may be regarded as continental deposits, such as valley fill, and color and oxidation, together with the apparent presence of pebbles of dolomite in the conglomerates, suggest accumulation under conditions of aridity. In deep well sections it is impossible to say to what extent such materials have been reworked by a transgressing sea.

To the writer it seems that these basal beds deserve to be distinguished from the Saint Peter by a formational name, both on account of their lithologic difference and the time and manner of their deposit. At least such a distinction would subserve the interests of well drillers and of geologists who deal with deep well sections, and it is hoped that an outcrop of the formation may be found which will supply a suitable name.

In the present report two additional deep well sections of these anomalous deposits are given, Preston and De Witt, both in northeastern Iowa and not far from the Maquoketa oil prospect. At Preston the Saint Peter sandstone of normal facies is under-

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26 Thwaites, F. T., Paleozoic Rocks Found in Deep Wells of Wisconsin and Northern Illinois: Journ. Geol., vol. XXXI, p. 529 et seq.; 1923.

lain by basal deposits, 365 feet thick, described by the driller as red sandstone, red shale, and clay and sand, which cut out entirely the Prairie du Chien formation.

At De Witt, the Saint Peter sandstone has an abnormal thickness of 223 feet and is underlain by 295 feet of conglomerates, red sandstones, red and green shale which extend to some depth into the Trempealeau. Detailed description will be found on pages 172 to 176. While some doubt exists as to the thickness of these basal deposits, because of extensive caving, there is no question that at both localities, as at Maquoketa, the drill was working in deep basal beds of the same nature as those of the outcrops in Wisconsin.

CAMBRIAN SYSTEM

The Cambrian rocks outcrop in but three counties of northeastern Iowa and their deeper strata are nowhere exposed to view, so that necessarily the first accounts of this great body of rock were incomplete. In the report on the geology of Allamakee county Calvin in his synoptic table recognizes only the Saint Croix stage of the Cambrian system, without any formational subdivisions. "The whole assemblage of Cambrian strata, so far as Iowa is concerned, represent continuous deposition under practically unchanged conditions."[27] Yet he identifies the equivalents of the Jordan sandstone and the Saint Lawrence limestone as defined by Winchell in Minnesota.

Norton in his first paper on the deep wells of Iowa[28] finds the succession of a sandstone, termed by him the upper Saint Croix, and dolomites, shales and sandstone, termed the lower Saint Croix. In his report on the Artesian Wells of Iowa,[29] however, Norton subdivides the Cambrian of Iowa in descending order into the Jordan sandstone, the Saint Lawrence dolomite and shales, and the Basal sandstone, the latter term including the Dresbach sandstone of the Minnesota geologists "with the unnamed shale beneath it and the Hinckley sandrock and the unnamed red shales and red sandrock beneath it" to the summit of the Algonkian.

27 Calvin, Geology of Allamakee County: Iowa Geol. Survey, vol. IV, p. 60, Des Moines, 1895.
28 Norton, Thickness of the Paleozoic Strata of Northeastern Iowa: Iowa Geol. Survey, vol. III, pp. 169-210.
29 Norton, Iowa Geol. Survey, vol. VI, pp. 140-142, 1897.

In the reports on Winneshiek and Clayton counties Calvin,[30] and Leonard[31] recognize the Jordan sandstone, the only Cambrian formation outcropping in the counties, and Leonard in his deep well sections follows the classification used by Norton as to the deeper Cambrian strata.

In his report on the Underground Water Resources of Iowa Norton[32] discards the term "basal sandstone," recognizes the Dresbach as the first clean sandstone below the Saint Lawrence dolomites and shales, and leaves undifferentiated the Cambrian strata below the Dresbach. It was noted, however, that these undifferentiated beds comprise two divisions in several well sections, as those at Dubuque, Manchester, Anamosa and Tipton, viz., upper marls or sandy and limy shales, and heavy underlying sandstones.

This historic resumé shows that Iowa geologists, not venturing to propose names for recognized formations without outcrop in their state, have adopted from time to time the nomenclature of geologists of adjacent states where these formations occur as country rock.

It now seems well to follow this precedent and designate the upper dolomitic beds of the Saint Lawrence dolomite and shales as the *Trempealeau* and the lower shales and shaly sandstones as the *Franconia.* The clean sandstone below the Franconia beds is already known as the Dresbach. The beds below the Dresbach so far as they are characterized by shales and shaly or dolomitic sandstones are now known as the *Eau Claire,* while the cleaner sandstones beneath are now termed the *Mount Simon.* In Minnesota the Saint Croix series is underlain by the Hinckley sandstone and the Red Clastics of Hall and Meinzer. Evidence that the latter formation is Middle Cambrian has recently been offered by Stauffer.[32a]

JORDAN SANDSTONE

The Jordan sandstone remains one of the chief aquifers of the Iowa artesian field. Of the wells listed in the present report

30 Calvin, Geology of Winneshiek County: Iowa Geol. Survey, vol. XVI, p. 62, Des Moines, 1906.

31 Leonard, Geology of Clayton County: Iowa Geol. Survey, vol. XVI, p. 237, Des Moines, 1906.

32 Norton, Iowa Geol. Survey, vol. XXI, 1912.

32a Stauffer, C. R., Bull. Geol. Soc. of America, vol. 38, p. 469 seq., 1927.

those of Algona, Bettendorf, Charles City, Delmar, Dubuque, Garrison, Grinnell, Hampton, Oakdale, Preston, Shellsburg, Stuart, Van Horne and Waukon found this formation water bearing.

Yet it must be said that the Jordan sandstone in places is so well cemented, so dolomitic, that its capacity as a water sand is slight or nil. At Waterloo it is highly dolomitic in its basal beds. Yet it was here in city well no. 1 that the main flow was found, perhaps in crevices. Much the same conditions prevailed at Shellsburg. At Oelwein the Jordan was found dry in the city well. In the well of the Chicago Great Western Railroad most of the water was found below the Saint Peter, but the exact horizon is unknown. At Washington, in city well no. 5, the Jordan is not reported as a water bed. At De Witt the Jordan sandstone is cut out by unconformity and apparently it yielded little at Nevada and Ogden.

In western Iowa, at Holstein, this formation is dubiously represented by a sandstone not more than 20 feet thick and it is unrecognized at Sioux City.

TREMPEALEAU DOLOMITE

The Trempealeau formation is rarely water bearing. Yet where its dolomites are sufficiently pure and the circulation of underground water favors, it may contain solution channels, such as are much more commonly found in the dolomites of the Prairie du Chien. The Trempealeau is reported as a water bed at Dubuque, at Washington and with some doubt at Waterloo. In eastern Iowa when sufficient water is not obtained above the Trempealeau, drilling may well be carried through it to the glauconitic shales and marls of the Franconia.

FRANCONIA BEDS

The shaly beds of the Franconia are well demarked in the wells which reach their depth, but they are seldom pierced through except in eastern Iowa, especially in the Mississippi valley where the Dresbach and Mount Simon sandstones are the objectives.

The Franconia forms a valued marker, with its greensands rich in glauconite, with its "marls," whose large quartzose constituents may be too fine to polarize with the usual brilliant colors of quartz—ambiguous beds which Winchell has well described as "greenish and shaly and yet not a shale, calcareous and not a limestone, magnesian but not a dolomite, finely siliceous but not a sandstone."[33]

The Franconia is thus identified at Waukon, Marquette, Dubuque and Bettendorf, De Witt, Delmar, Nevada, Grinnell, Ogden and as far west as Algona, Holstein and Sioux City. At Holstein, however, it is not demarked from similar beds of the Eau Claire as the Dresbach sandstone is here absent. In the deeper wells of the state listed in earlier reports the division of the Saint Lawrence between the Trempealeau dolomite and the Franconia shales is clearly made out for the most part, as in deep well sections at Anamosa, Clinton, Manchester, Mason City, Sumner, Tipton and Waverly. At Boone, where the Jordan apparently is absent, it is difficult to draw the line between the Prairie du Chien, which begins at 1900 feet, and the Trempealeau, which probably ends at 2425 feet, where the glauconitic beds of the Franconia appear. These glauconitic beds continue to 2840 feet, where clean sandstones come in which may be assigned to the Dresbach. At 2900 feet shales were struck, perhaps the EauClaire, which continue to the bottom of city well no. 2 at 2914 feet. But the red marls and shales reported by Beyer at the bottom of well no. 1 at 3000 feet lend some color to the classification of the beds below 2840 feet as Mount Simon. In that case the series of glauconitic shales, marls and sandstones from 2425 feet to 2846 feet embraces both the Franconia and the EauClaire, the Dresbach being absent as at Holstein.

At Des Moines the clean Oneota dolomites give place at 2418 feet to the Jordan sandstone. The lower limit of this sandstone is in some doubt but its thickness probably does not exceed 40 feet. The glauconitic beds of the Franconia begin at 2565 feet and similar beds with marls continue to the bottom of the well at 3000 feet. The deeper Cambrian sandstones either were not reached or have feathered out. The thickness of these glauconitic beds and marls, 435 feet, favors the supposition that they in-

33 Winchell, N. H., Geol. and Natural Hist. Survey of Minnesota, vol. i, p. 255, 1884.

clude both the Franconia and the EauClaire, and that the Dresbach is here absent.

DRESBACH SANDSTONE

The clean sandstones of the Dresbach make it a dependable water bed along the Mississippi at least as far south as Davenport. At New Albin it is cut away by the old channel of Mississippi river. At Marquette it yields bountifully. At Decorah, in the oil prospect drill hole, the Dresbach is pretty clearly marked in the driller's log. At Dubuque, Clinton and Bettendorf it produces generously. It is water-bearing at Delmar and De Witt.

West of the counties bordering Mississippi river it usually has not been necessary to drill as deep as the Dresbach sandstone. At Manchester it was found to be 152 feet thick, at Anamosa 180 feet, where it is recorded as the softest sandstone in the well, and at Tipton 150 feet thick. It was also gone through at Cedar Rapids in city well no. 1, but the records of the well do not discriminate the formations below the Jordan. From none of these wells is the Dresbach reported as water-bearing. If any flow was secured from it, it was unnoticed either because of having the same static level as flows from higher beds, or for other reasons.

The Dresbach is 30 feet thick at Algona, but there is no evidence of its presence at Holstein, and its place is uncertain at Des Moines and Boone. At Nevada the water-bearing sandstone at the base of the section may be the westward extension of the Dresbach.

EAU CLAIRE BEDS

The Eau Claire resembles the Franconia in texture and constituents, although with less glauconite, and may be expected to be dry. Yet crevices or exceptionally clean sands within it may yield water, as at Bettendorf.

MOUNT SIMON SANDSTONE

The Mount Simon furnishes the supply of the New Albin wells and at several levels yields generously to the deeper wells at Dubuque. At Clinton, where it was penetrated in city well no. 6, it furnishes a phenomenal supply. At Rock Island (Mitchell and

Lynde Building), the driller's log indicates, the Mount Simon was penetrated some 97 feet beginning at 2185 feet from the surface. In his generalized section of Rock Island and vicinity, Udden[34] states that this sandstone is water-bearing.

But of the Mount Simon as of the Dresbach it must be said that it is seldom advisable to drill to its depth except in the immediate valley of the Mississippi or the counties bordering upon it.

RED CLASTICS

These beds and the Archeozoic granites and schists on which they rest have been penetrated by the drill at a few localities since the preparation of the report of 1912 on the Underground Waters of Iowa. As was to be expected they were found dry.

SALT POOLS IN THE CAMBRIAN

Local pools of saline water are found rarely in the Cambrian strata of Iowa. In the northeastern district 27 wells footing in the Cambrian, excluding two wells at McGregor, have, according to Hendrixson's report of 1912, an average chlorine content of only 17.4 p.p.m. But a local pool at McGregor tapped by city well no. 2, apparently in the Eau Claire sandstone, gave its water 968 p.p.m. of chlorine and at Prairie du Chien salt water was found at about the same reported depth.

In the three deep wells at and in the vicinity of Lansing chlorine rises to an average of 59.7 p.p.m. This amount, although inconsiderable from the point of potability, is markedly high when compared with the average of the Cambrian waters of the district.

In north-central and northwestern Iowa Cambrian chlorine remains low: e.g. at Mason City 23, at Charles City 0, at Algona 9, at Holstein 12 p.p.m. In this area the chlorine of the Manson well, 206 p.p.m., is as exceptional as is its chemical analysis as a whole and its geological section also. The Manson well, however, does not enter Cambrian rocks.

In the east-central district the stratigraphically deepest well, that at Tipton, drilled 1240 feet below the top of the Cambrian,

34 Udden, J. A., U. S. Geol. Survey, 17th Ann. Rept., pt. 2, p. 842.

has but 2 p.p.m. of chlorine. Wells at Anamosa and Vinton, footing deep in the Cambrian, carry but 1 and 15 p.p.m. Grinnell, Homestead and Belle Plaine also are low in chlorine—34, 33 and 7 p.p.m.

At Cedar Rapids salt and heavily mineralized water is found at some point below 1450 feet, the base of the Jordan, but the Jordan and upper waters have a chlorine content of only 0,4 to 14 p.p.m.

In the Davenport area, however, lies a Cambrian pool of saline water of great importance, which will be described in detail later.

In southeast Iowa the percentage of chlorine in the deeper well waters is higher than in the districts mentioned, but in no case does it reach any marked concentration. Here the Cambrian water is in many cases less saline than that from upper horizons. At Burlington the park well, 2430 feet deep, has 161 p.p.m. of chlorine while wells in the city about 500 feet deep contain about 275 p.p.m. At Washington the city well reaching the Saint Lawrence contains 71 p.p.m. of chlorine, while another reaching only the Saint Peter contains 123 p.p.m. At Ottumwa the deepest well has a chlorine content of 119 while a mineral spring from the Mississippian has 533. The Keokuk wells, about 700 feet deep, are high in chlorine—632 to 674 p.p.m., but they draw their water from above the Saint Peter.

The deepest wells of central, south-central and southwestern Iowa show a moderate but by no means an excessive salinity. The wells about 3000 feet deep at Boone and Des Moines carry 128 and 124 p.p.m. The Mississippian and Pennsylvanian may yield water much saltier than the Cambrian. Three wells less than 800 feet deep, at Flagler, Knoxville and Pella, have a chlorine content of 925 to 1803 p.p.m. Deep wells in southwest Iowa penetrating the gypsum-bearing beds attributed to the Salina show an exceptional amount of salt—at Glenwood 282 and at Bedford 1420 p.p.m. At Bedford, however, a still saltier water with 2545 p.p.m. of chlorine was found at 1300 feet at the base of the Coal Measures.

Salt Water in the Davenport Artesian Field.—It has long been known from chemical analyses that the artesian waters of Davenport, Moline, Rock Island and their satellite towns contain a comparatively high percentage of common salt, although by no means enough to make them unpalatable or injurious. Of the six Davenport wells whose analyses are given in volume XXI of the Iowa Geological Survey the average chlorine content is 307 p.p.m. and the range is from 272 to 396 p.p.m. Well no. 2 of the Bettendorf waterworks showed on completion in 1925 391 p.p.m. and the Davenport swimming pool well on completion in 1922 showed 363 p.p.m. Wells at Moline and East Moline whose analyses are at hand show a range of 250 to 322 p.p.m. in chlorine.

The formations in which these wells foot range from the Galena to the Eau Claire, and the high percentage of salt is confined to no single aquifer. In fact the highest percentage in the analyses made before 1926 is found in a well footing in the Saint Peter.

At Silvis, Illinois, however, a well 1987 feet deep penetrating the Dresbach or below gave on completion in 1912 a somewhat higher chlorine content, 550 p.p.m. This amount, as stated by the analyst of the Illinois Department of Public Health, "might give the water a slightly salty taste but would not affect its sanitary quality".

In June, 1928, the Bettendorf Water Company informed this office that the water of well no. 2, drilled in 1925, had changed for the worse and was also injuring the water of their well no. 1, with which it communicates through porous strata. It was the inference of the company's officials that the change had not been a gradual one, but "must have come in all at one time". An analysis showed that the chlorine content had risen from 391.7 to 889.0 and the sodium chloride content from 553.82 to 1441.157 p.p.m. The common salt had risen 2.6 times and the total solids had nearly doubled. It now became necessary to cut off the highly mineralized water. The well was filled to the depth of 25 feet. A preliminary analysis indicated that the total mineral content was reduced from 2284 to about 1900 p.p.m. The well was then filled to 50 feet from the original bottom. The results are shown in the table below. The sodium chloride had now been reduced nearly one-half and the sulphate radicle more than one-third. But this betterment in quality had been purchased at high cost in quantity. The pumping capacity with the centrifugal pump in use had been reduced from about 400 to 150 g.p.m.

Analyses of Bettendorf Waterworks Well No. 2

Constituent	1925*	1928†	1928 After filling 50 feet†
	Parts per million		
Silica	16.00	....	5.8
Oxides of Fe and Al	4.40	0.60 (Fe ion)	12.20
Potassium	....	17.38	23.58
Sodium	321.80	617.92	332.52
Calcium	50.80	147.75	82.04
Magnesium	45.20	17.12	27.25
Chloride radicle	391.70	889.0	480.0
Nitrate radicle	00.00	0.6	0.1
Sulphate radicle	194.50	360.22	213.18
Carbonate radicle	192.50	0.0	0.0
Bicarbonate radicle	90.00	302.56	309.88
Total solids	1245.		
Total hardness gr.p.gal.	16.85		
Hypothetical combinations			
Magnesium carbonate	155.89	....	....
Calcium carbonate	126.89	....	....
Sodium carbonate	10.84	....	....
Sodium sulphate	287.64	158.471	111.951
Sodium chloride	553.82	1441.157	756.678
Potassium nitrate	....	.989	.162
Potassium chloride	....	32.423	44.859
Ferrous bicarbonate	....	1.910	....
Magnesium sulfate	....	84.758	134.911
Calcium sulfate	....	262.172	41.940
Calcium bicarbonate	....	285.606	282.081
Silicon oxide	....	6.500	5.8
Ferric oxide	....	....	.43
Aluminum oxide	....	10.340	11.77
Total solids		2284.326	1390.58

It will be noted that the filling of the well proved that the main flow came from below the Dresbach sandstone and considerably deeper than had been reported on the completion of the well.

This rapid and ruinous change in the Bettendorf well was unprecedented in the history of the wells at Davenport, some of which had been used for 40 years. Up to this time new wells, although drilled to maximum depth, had failed to disclose any saltier waters than earlier and shallower wells had tapped. But clearly there lies in or below the Eau Claire beds a water entirely too salt to be potable. Heavy pumping at Bettendorf at

* Made by Chemist of the Bettendorf Water Co.

† Made in Chemical Laboratories of State University of Iowa by R. K. Lewis.

length disturbed the equilibrium between the heavy salt water of this pool and the fresher and lighter waters of the overlying strata. As the fresh water was drawn off the salt water rose under artesian pressure, perhaps broke through, into the higher water beds with ruinous results.

A similar increase in saltness is on record in the case of numbers of deep wells near the ocean. After long and heavy pumping the normal flow of fresh land water seaward is reversed and gives place to invading brine. The frequent rise of salt water in depleted oil pools is well known.

A slight increase in salinity is seen in the Davenport city swimming pool well. In 1922 the chlorine content was 363 p.p.m. according to an analysis by the Hygienic Laboratories at Iowa City. In 1926 this had risen to 423 p.p.m. according to the same analysts.

The city officials of Silvis, Illinois, supply some data as to the city well under date of August 27, 1928. After mentioning the fact that "A few months ago the Continental Ice Company put a deep well pump into it and it has been pumping steadily ever since", the mayor states: "It is the opinion of some that the water has grown saltier since it is being pumped constantly, but we have had no analysis made to determine if this is true". Analyses by the State Water Supply Division were also inclosed which show that the chlorine content changed from 550 p.p.m. in 1912 to 592 in 1918, 650 in 1923, and 620 in January, 1924, and 590 in February, 1924. The increase in total solids was more considerable.

At Canton, Illinois, deep well water shows an increase in chlorine from 245 p.p.m. in 1898 to 885 in 1924 according to the analyses of the Illinois State Water Supply Division in their Bulletin no. 21. The source of this more saline water, however, is not necessarily from below. Coal mine wells in the vicinity give chlorine contents as high as 1010 p.p.m.

It is clearly shown by the experience at Bettendorf that hereafter in the Davenport field wells should not be sunk below the Dresbach sandstone. If the invasion of saline water should continue or spread, wells may be limited to the Jordan and higher aquifers. Furthermore, the equilibrium between the salt and fresh water in the field should not be endangered unnecessarily by the continued leakage of unused wells.

It is an interesting question how far the salt pool at Davenport extends into Iowa. It cannot reach De Witt to the north, whose deep well shows but 39 p.p.m. of chlorine, or to Tipton to the northwest, where the chlorine content is only 2 of a well which was sunk far below the strata of the footing of the deepest wells at Davenport. To the south the chlorine curve falls to 161 p.p.m. at Burlington and to the west to 200 at Wilton and to 102 at West Liberty. (See also Nahant, page 267.)

By consulting the analyses of public supplies in Illinois* it is seen that the Davenport salt pool lies at the northwestern corner of a large area in Illinois in which artesian waters show considerable salinity. North of the latitude of Davenport, in Whiteside and Lee counties the chlorine content is as low as in northeastern Iowa, e.g. 7 p.p.m. at Morrison, 22 at Amboy, 3 at Sublette. But to the south of this favored area, as the Saint Peter sandstone dips to 500 and 1000 feet below sea level in Henry, Bureau and LaSalle counties, and the Pennsylvanian forms the country rock, the chlorine curve rises sharply, e.g. to 470 p.p.m. at Atkinson, 412 at Buda, and 322 at Oglesby, all drawing on Saint Peter water. These contents, it will be noted, are approximately the same as that of the Davenport wells with the same footings. The deep well at Aledo, Mercer county, footing 1205 feet below the top of the Cambrian, reached a salt pool and was plugged at 1450 feet, but the water still carries 439.7 p.p.m. of chlorine. In Henderson, Warren and Knox counties, where the Saint Peter apparently does not sink below 500 feet below sea level, its water ranges in chlorine from 155 p.p.m. at Abingdon to 259 at Stronghurst. But as the Saint Peter dips toward Illinois river the chlorine curve rises again to an exceptional maximum of 825 p.p.m. at Ipava.

Deep Wells As Oil Prospects

For the most part the deep wells of Iowa have gone through the formations in which there was any probability of finding oil, and have therefore served as prospect holes for oil and natural

* Buswell, A. M., Illinois State Water Survey, Bull. no. 21.

gas, as well as for other valuable minerals. The importance of this secondary service is suggested by an editorial some years since in a leading daily newspaper advising the legislature to sink drill holes 5000 feet deep in all parts of Iowa to discover the rich stores of oil, copper and other minerals which without doubt lay hidden beneath the prairies. Compared with such a project the sinking of the hundreds of deep wells of Iowa has been simple and inexpensive. As a rule they have gone deep enough—although the deepest of them hardly exceed 3000 feet—to find any mineral wealth there possibly can be, and they have been amply paid for by the water they deliver. Still more simple and inexpensive is the maintenance of the Geological Survey, which collects and collates the facts regarding these wells, including those which bear upon the presence or absence of valuable minerals in the rocks of the state.

As to copper and iron and the precious metals, the futility of prospecting for them in Iowa is shown by an elementary knowledge of the geology of the state. As to coal, the areas where it may be found have long since been mapped. But in the case of oil the conditions of its accumulation are such that each deep well sunk has had some value as a prospect hole for that locality. Oil and natural gas are found throughout the world in a number of geological formations from the Pleistocene back to the Cambrian, and several of these formations, elsewhere oil-bearing, occur within the limits of the state. Nor as a rule will the geologist affirm in advance of the drill that in any given locality all the other necessary conditions for the accumulation of oil and gas are wanting. These conditions may be briefly stated as (1) an oil producing rock as source, usually a shale, (2) a porous rock as reservoir, usually a dolomite or sandstone, (3) an upfold, dome, or lens which, with (4) an impervious cover commonly a bed of shale, forms a trap within which the hydrocarbons accumulate under the pressure of artesian waters.

As each deep well is drilled in Iowa it is carefully examined for the presence or absence of these conditions. Laboratory study of deep well cuttings shows that several formations include in various places thin beds charged sufficiently with hydrocarbons to be inflammable. While these shales prove that locally the processes of petroleum making and leaching have been arrested, they yet suggest the possibility that elsewhere the same beds may have given rise to oil and gas which may have been leached out into containers in the overlying rocks.

In the wells described in the present report the Kinderhook shale at Donnellson shows traces of hydrocarbons; the Maquoketa shale carries near its base an inflammable shale at Bettendorf, Fort Dodge and Winfield; and the Glenwood shale includes inflammable layers at Oakdale, where a similar shale occurs higher up in the Platteville formation. Such instances suggest that possibly at other localities in Iowa the Kinderhook, Maquoketa or Glenwood shales may prove to be rich sources whose oil has leached into oil pools in overlying reservoir rocks.

Several formations, as the Niagaran and Galena dolomites, are sufficiently porous to form adequate reservoirs for oil and gas. The discovery in a few well sections in southeastern Iowa of arenaceous beds at the base of the Niagaran, which represent the Hoing sands of the Colmar oil field of western Illinois, suggests a possibility that somewhere in the state these sands may yet be found of sufficient thickness for oil accumulation, and that all other conditions may concur. This possibility, however, is so faint, and the distribution of the Hoing sands even in the Colmar field is so discontinuous, that no encouragement is given to any prospecting of them by the drill.

Deep well drilling has also shown the wide extent of shales thick and impervious enough to form the necessary covers for oil reservoirs. Such are the Kinderhook, the Maquoketa and in some areas the Glenwood, and the shales of the Des Moines and Missouri group of the Pennsylvanian system.

In general, the lie of the strata of the state is proved by its deep well sections to be too uniform to favor the structures necessary for oil accumulation. Yet occasionally, as at Oakdale, Ames, and perhaps at Fairfield, the drill has found marked upwarps of the deeper beds.

The outstanding fact remains that of the hundreds of wells drilled in Iowa scarcely one has shown even a trace of oil. They may have shown some of the necessary conditions for oil accumulation, but never oil. This is in marked contrast with some oil prospect holes, which are said to have yielded a barrel or so of oil before they were abandoned. Most of these prospects have kept their geologic facts under impervious cover. In summation, deep well drilling in Iowa offers little encouragement for oil prospecting, although it points out various favorable conditions. The field in Iowa regarded by Howell[35] as the one area which merits in any degree a test for oil, viz., the extreme southwestern part, is the area least prospected by deep wells.

The relations of an artesian circulation to the accumulation of oil and gas are not entirely clear. But of two areas—one with a permanently vigorous circulation of sweet artesian water for urban supply, the other with rich oil pools, to be replaced after a brief period by salt water—the former certainly is in the long run preferable for human habitation.

Deep Wells and Other Municipal Supplies

Deep wells form but one of several types of municipal water supplies in use in Iowa. The supplies of the state are drawn from static waters—lakes and the artificial lakes known as impounding reservoirs; from the flowing waters of rivers and smaller streams; from ground water rising in springs or tapped by various types of wells at different depths and reaching various water beds.

But few lakes large and deep enough for town supply are found in Iowa. The state is largely covered by the older drift sheets, and over these areas the topography is so mature that the indices of infancy such as lakes have been outgrown, effaced. In contrast the neighboring states of Minnesota and Wisconsin, surfaced very largely with the younger drift, still linger in the lake stage and are able to supply their largest cities and many of the smaller towns with lake water.

Only seven Iowa municipalities draw their water supply from lakes, and the population thus served is less than 10,000.

Impounding reservoirs, collecting the run-off from limited areas, supply sixteen towns, with a total population of 55,470. But two of these towns have populations above 10,000. Three

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35 Howell, J. V., Petroleum and Natural Gas in Iowa, Iowa Geol. Survey, vol. XXIX, p. 36.

other towns have populations between 10,000 and 3,000, while no town thus served has a population less than 1200. The larger cities seem to be excluded by the amount of water thus obtainable under Iowa conditions and the smaller towns and villages by the cost of installation and operation.

Ten Iowa municipalities, population, 176,220, draw directly on rivers. Among these municipalities are Burlington, Council Bluffs, Davenport, Keokuk and Ottumwa, whose aggregate population is 167,381. River supply is thus favored by the larger rather than by the smaller cities and towns.

One hundred and sixty-one municipalities, ranging in size from the largest city in the state to some of the smallest villages, use the ground water of the alluvial sands of present rivers or of ancient glacial streams—ground water to which in some cases river water contributes by seepage. Water is obtained by shallow dug wells of large diameter, infiltration galleries, and driven and drilled wells, commonly less than 100 feet in depth. Thus are supplied Boone, Des Moines, Iowa City, Marshalltown and Muscatine (aggregate population, 181,985), a group of 14 cities between 3,000 and 10,000 population (aggregate population 64,478), 42 towns between 1,000 and 3,000 population, and about 100 towns and villages of less than 1,000 population.

Common wells in drift or country rock serve a larger number of Iowa communities than any other supply. This is the favorite supply of villages and smaller towns and is used also by nine towns with populations ranging from 3,000 to 10,000 (total population, 45,000) and by 25 towns from 1,000 to 3,000. One hundred and forty-eight communities using this supply have a population of less than 1,000.

Deep wells, setting the minimum depth of this class rather arbitrarily at 300 feet, supply 125 municipalities. This group includes six of the larger cities, Sioux City, Dubuque, Cedar Rapids (in part), Waterloo, Clinton, Mason City and Fort Dodge, with populations ranging from 20,000 to 71,000 in round numbers, total population 255,451. This group also includes 13 towns from 3,000 to 10,000 population, and 47 towns between 1,000 and 3,000 population. While this supply is among those favored by large cities and towns, the villages are precluded from it by its cost.

The statistics just given do not indicate any universal preference for any single type of water supply. No type can unqualifiedly be said to be "the best," the most desirable. Even the large cities of Iowa divide their choices between deep wells, shallow wells and rivers. Each type has its disadvantages and its advantages, and ratios and preponderances vary with the locality. Thus deep wells have been abandoned for shallow wells and shallow wells for deep wells. River supplies have been superseded by both deep and shallow wells and vice versa. Wells of both types have been replaced by impounding reservoirs, and a town with an impounding reservoir is now attempting to replace it with a deep well. The problem of water supply is essentially a local one for each community to solve as best it can. There are no general formulæ, applicable to the entire state, which will solve it.

It remains to sketch briefly some of the various superiorities and defects of different supplies under Iowa conditions as shown by the experience of Iowa towns.

Lake supply.—The general advantages of lake supply are the clarity of the water, since the lake acts as a settling basin and besides is often fed by springs, the bacterial purity of the water of feeding springs, the constancy and adequacy of the supply, and the low cost of delivery. In many shallow lakes of Iowa with mud bottoms several of these advantages are absent, and the bacterial purity of feeding springs does not insure against contamination by feeding streams and run-off and the sewerage of hotels and settlements along the shore. Two of the six Iowa towns using lake water have found it advisable to pass it through filters.

Impounding reservoirs.—The Iowa towns making use of this supply are all situated in south-central and southwestern Iowa on areas of maturely dissected Kansan drift underlain by the Coal Measures. The problem of water supply is thus difficult. Wells in drift tapping the Aftonian interglacial sands and any pre-Nebraskan sands on rock are commonly inadequate for the larger towns. The country rock is usually dry. The Cambro-Ordovician aquifers lie too deep for profitable drilling. The quality of deep well water also is poor on account of heavy mineralization. River towns are left a choice between taking water directly from the stream or from shallow wells sunk in flood plain sands. Fortunately the valleys of the mature streams of this region are commonly floored with wide flood plains, where cut in drift. Upland towns, however, situated on the high divides of the Kansan drift plain may be quite too far from streams for this resource. The impounding reservoir may be the last resort.

In various regions of rugged topography with droughtless summers the use of storage waters is very common. Iowa, however, has the inherent disadvantages of a prairie state, of deep fertile soil, and lying near the semiarid west. Long summer droughts, perhaps during a succession of dry years, occasionally occur. The relief of the land is low. Sites for deep reservoirs are few. Secure rock foundations for dams may be difficult to find. The gentle slopes of the hillsides are covered deep with easily washed soils. The land of the watershed is costly, for as a rule it is arable and its price is enhanced by nearness to the town. It is clear that in Iowa impounding reservoirs will have far less vogue than in a region like New England, for example. So far, they are confined, as we have said, to a single drift sheet and a single rock terrane. The driftless area in Iowa offers excellent sites for reservoirs, but here the artesian aquifers lie near the surface. The areas of the younger drift sheets are little dissected and offer accessible stream and well supplies. Where the Kansan drift overlies other rocks than those of the Coal Measures, the supply from wells in the country rock is open. Outside the area of outcrop of the Coal Measures with a cover of Kansan drift, no impounding reservoir has yet been built in Iowa.

In comparison with wells, storage waters have the disadvantage of all surface waters in that they have not undergone the natural filtration to which all ground water has been subjected. They are more turbid, more liable to bacterial infection and organic growths. On the other hand storage waters are soft and adapted to industrial purposes and locomotive supply.

Compared with underground waters, the impounding reservoir has the further disadvantage of rapid evaporation over a large surface with maximum depletion on this account at the time of minimum replenishing by rain and maximum municipal consumption. In the upper Mississippi valley loss by evaporation has been estimated at somewhat more than four feet per annum. In Iowa, reservoirs are necessarily comparatively shallow and the required supply is sometimes obtained only by two reservoirs. Compared with deep reservoirs, especially those of more humid climates, the large ratio of surface to cubic contents gives rise to an excessive percentage of evaporation loss.

In comparison with a river supply the impounding reservoir has the advantage that the drainage area is small, and can therefore be kept under strict sanitary supervision and control, and for the same reason the disadvantage that replenishment fluctuates with the local rainfall. The inevitable silting up of the reservoir is another disadvantage.

The impounding reservoir in Iowa is constructed like the "tanks" of the arid west by building a dam across a valley to collect and store the water of the run-off. Fortunately the flat divides of the Kansan upland in southern Iowa are narrow, and towns located upon them can usually find suitable valleys at negotiable distances along the dissected margins of the upland, locally termed "the breaks." The greatest reported distances of reservoirs from the towns do not exceed two and three miles. But as the reservoirs are commonly at a lower level than the towns, in two instances as much as 85 and 150 feet (measured from the reservoir floor), the operating expense is increased considerably by the lift.

The impounded lake is commonly fed only by the run-off of the watershed but at What Cheer a small stream and at Tabor springs contribute also. The low relief of the areas is seen by the fact that the hills immediately about the reservoirs stand only from 40 to 100 feet above the reservoir bottoms.

In every instance in Iowa the dams are constructed of earth. In some cases (e.g. Corydon, Lenox, Tabor) they are built with a core of cement, or (Osceola) of "rock," in order to prevent infiltration and the burrowing of animals. They are sometimes faced with concrete or riprap.

Iowa dams are built low, because of the relief of the land and the small storages required. The maximum height is at Centerville, 60 feet, the minimum at What Cheer, 6 feet, but these heights for the most part fall between 25 and 40 feet. At Fairfield and Lenox two reservoirs with comparatively low dams furnish the storage that in a single reservoir would require a higher dam.

The capacity of reservoirs in Iowa varies from 5 million gallons at Mount Ayr (population 1750) and 3 million gallons at What Cheer (population 1626) where there appears to be a rapid and fairly constant replenishment, to maxima of 110 million gallons at Centerville (population 10,000), 135 million gallons at Albia (population 6,000), and 180 million gallons at Fairfield (population 5948).

The amount in storage in dry seasons of course may be much less than the total capacity of the reservoir. Thus at Lenox the maximum depth of water, 28 feet, may be drawn down in drought to 10 feet, and at Osceola from 40 to 15 feet. Albia is reported to experience serious shortage in drought and to maintain an emergency supply in a small creek. In 1923 it was reported by the Iowa Insurance Service Bureau that at Centerville the total storage water available fell to 30 million gallons. "The emergency was met by reducing the consumption to 225,000 gallons a day, and to meet the consumption pumps were installed at a railway reservoir, at a mine and in a well, so that the water in storage should not be depleted. If the situation does not improve, water will be hauled in tank cars."

No other shortages, however, have been reported by Iowa towns.

The watersheds of Iowa reservoirs are all small, ranging from 40 acres to one or two square miles. They are owned by the municipality. With one or two exceptions, the land is kept under grass or forest. In these exceptional cases, portions are under plow or in pasture, conditions which make for turbidity in the stored waters, contamination, and rapid silting up of the reservoir.

In the best practice in the state separate settling basins are installed with rapid mechanical filters and chemical treatment of the water. Aeration plants are also under consideration. The need of settling basins is illustrated by the case of a reservoir holding but 5 million gallons, whose water is so turbid that pipes are continually clogged. In some cases the water is reported to have a disagreeable taste or odor in summer, but the number is few considering the organic growths common in shallow waters along the margins of reservoirs. In nearly all cases the supply is said to be satisfactory. The one exception is a town now using raw water, but this is to be remedied by filtration. Lamoni, which has used storage, has recently (1927) drilled a deep well.

It is expected that the number of impounding reservoirs will continue to increase and that the supply, when treated as are flowing waters, will prove satisfactory. It is hoped that generally larger reservoirs may be provided, securing storage amply adequate to long and recurring droughts, with the added advantages of deeper water in promoting clarification, bleaching, and the destruction of pathogenic germs, and in limiting the growth of shallow water organisms.

River supplies.—In contrast with the run-off impounded in reservoirs, rivers offer a supply constant and unfailing, owing to their far larger watersheds and their replenishment by springs during times of drought. Because they are always fed by ground water in part, the water of rivers is harder than that of the impounded run-off, but less heavily charged with calcium, magnesium and iron salts than is the water of most wells. As a rule river water is better than well water for manufacturing purposes, boilers, and for domestic use in cooking and the laundry.

In the matter of sedimentation, the river has no advantage over the reservoir when a dam is necessary to provide depth of water for the intake. Otherwise, as in the case of the Mississippi and Missouri river towns whose intake pipes are laid in open channel, the advantage is with the river, which continually sweeps its silt down stream.

No machinery is buried deep in ground inaccesible to inspection and difficult to repair. The cost of delivery to the distribution system is low, except in certain instances where upland towns have resorted to rivers flowing some distance away and considerably below their level.

It may be claimed for river supplies that they are dependable, permanent, equal to any present emergency or future requirement.

On the other hand, river water has the defect of its quality. The run-off from plowed fields, pastures and forested hillsides, the tributary streams which bring it their loads of silt, render it turbid with the inorganic waste of the land. By the same means it is contaminated with organic refuse. Moreover, lowly organisms which grow in the water may give it an unpleasant taste and odor.

There is now added in the case of Iowa rivers defilement by the sewage and industrial offal of the towns upon their banks. In testing these waters there is now often found the bacteria-coli group of micro-organism indicating fecal pollution. Iowa river water has become a dilute sewage effluent.

This does not signify that river water may not be so treated as to be safe. It is said that the sewage effluent of Paris, after treatment, issues potable and healthful, as clear, sparkling, and delicious as the water of springs. It may be added, however, that it is not used as a public supply.

The water of Iowa rivers is usually allowed to settle in settling basins; then treated with coagulants and chemical bactericides and forced through rapid mechanical filters. Bacteriological tests are made to insure efficiency. Such treated waters show at the state laboratories a very high per cent of safety (p. 69).

No slow sand filters have been built within the state and yet there have been typhoid epidemics in Iowa cities to warn against the possible consequences of carelessness at the gate at which the enemy is seeking entrance. As has been said by Simpson in his report on the water supply of Cedar Rapids, "The chief difficulty in connection with the use of river water arises from the fact that the organic matter in the water may unite with the chlorine used for purifying the water * * * and form certain organic compounds which impart very unpleasant tastes and odors to the water. * * * There is no known way to avoid these tastes and odors in surface water supplies."

Raw river water is used in Iowa only by some small towns on the Lower Des Moines river, which do not employ it for domestic supply, and by Council Bluffs, drawing on the Missouri river, the least dangerous, perhaps, of all rivers within or bordering upon the state.

There is no question that the use of rivers as water supply has been retarded and restricted by the function imposed upon them of carrying the sewage of the riparian cities and towns. At the present time one of the cities of the state which has long used river water is turning for this reason to a ground water supply. When the pollution of Iowa streams is no longer lawful, much larger populations no doubt will make use of river supply, the most copious, accessible and permanent of all.

Springs.—Little need be said of this supply, so few are the towns in Iowa which can avail themselves of it. Strong springs occur in considerable numbers, as for example the contact springs of northeastern Iowa at the junction of the Niagaran limestone and the Maquoketa shales and that of Galena limestone and the Decorah shales. Such springs may issue well up the hillside and afford considerable head when piped to the valley floor, but they are seldom near enough to towns for use as public supplies.

The purity of spring water commonly goes without question, yet the purest water is liable to contamination as it approaches the surface and issues from the ground. Some years ago Cedar Falls drew its supply from copious springs rising from Devonian limestone in the valley of Dry Run. In 1911 an epidemic of typhoid fever was attributed to the city supply and it was supposed that the springs had become infected through solution channels in the closely jointed limestone or by back water from the river. This supply was then superseded by 5 wells about 125 feet deep, sunk in the country rock, 1400 feet distant from the springs.

It will be noted that according to the table of page 69 springs furnish to the state water laboratory the largest per cent of unsatisfactory waters of all classes of public and private supplies.

Infiltration galleries and shallow wells.—Extensive deposits of sand and gravel at or near the surface, as on river flood plains, furnish natural storage basins of great capacity, rapid recharge and easy access. They act as natural filtration plants for ground water derived from the soak-in of the rain and for any percolating water from the stream. Wells sunk at the river bank, as at Bellevue and Guttenberg on the Mississippi, or on islands in the river, as the wells of the Boone plant on the Des Moines, and infiltration galleries, as those of the city of Des Moines on the flood plain of the Raccoon, may draw largely or even at times wholly on the river, but in contrast with the water of a river intake, the water of such wells and galleries has been more or less clarified by its passage through even a few feet of sand.

The normal movement of water in flood plain deposits is toward the stream. But at stages of high water and under heavy pumping the movement may be reversed, as the tests made by Kiersted at Muscatine illustrate.[36] For 3300 feet from the river there was found a slope of the ground water surface toward the river of 0.8 foot in 1000 feet and a rate of flow in this direction of at least two and one-half feet a day. But with the rise of the Mississippi the normal flow of ground water was first dammed and then reversed, reaching a slope inland of 0.84 foot in 1000 feet, and a flow from the river at about the rate just mentioned.

Water percolating from the stream brings in fine sediment, clogging the porous transmitting beds and diminishing the yield of wells and galleries. Excellent examples of the process are supplied by dams of impounding reservoirs, built of sand and fine gravel. "The initial leakage was high, but the embankment eventually became silted tight."[37] The same process goes on with ground water flowing toward the stream, but far more slowly, inasmuch as ground water carries very little sediment. Even deep artesian waters may in the same way clog their aquifers about the well tube, causing a diminishing yield.

The only example of infiltration galleries in Iowa is at Des Moines. The galleries are located on a tract of 1200 acres on the flood plain of Raccoon river. They are 11,821 feet in length and are sunk to a depth of 20-25 feet in uniform and coarse deposits. The newer galleries are constructed of rings of concrete. In addition the system includes 2375 feet of tunnel which will be increased soon by 2000 feet. The average daily pumpage in 1927 was 12,781,345 gallons, with some days' pumpage reaching 19 or

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36 Norton, Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, pp. 563-566.
37 Flinn, Weston and Bogert, Waterworks Handbook, p. 193, New York, 1927.

20 millions. Flooding has been resorted to in times of drought. The pumps have a capacity of 85,000,000 gallons daily.

The principle of the collecting gallery is employed by several Iowa water works by leading into the city shallow well one or more pipe lines with open joints constructed of vitrified clay or cement tile.

The capacity of the natural sand reservoirs tapped by galleries and shallow wells depends on the extent, thickness, and porosity of the beds. The chief factor in their adequacy for a city supply is the ratio of replenishment to draft. Any reservoir natural or artificial, no matter how large, must in time go dry if the draft upon it exceeds by ever so little the amount by which it is recharged. Patches of flood plain under consideration by cities for water supply have been examined by the writer which no doubt would yield generously for a time, so long as storage exceeded draft. But they were not favored as the site of wells, for they were found to be cut off from replenishment from up valley by spurs of rock and their hinterlands apparently would be able to supply too little ground water on its way to the river.

For sanitary reasons, though not for yield, flood plains standing at some height above the river are preferable for well fields to lower bottom lands. There is less danger from overflow and consequent pollution. Above the water table there is a thicker zone, which is alternately dry, filled with air, and wet with vadose water. This zone of aeration and oxidation acts as a natural filter in which nitrites and ammonia are decomposed and pathogenic bacteria destroyed.

While this natural filter may be able to take care of the ordinary surface contaminations of pastures and forest lands and even for those of fertilized cultivated fields, it is not to be considered competent to disinfect the waste of a thickly settled area with perhaps leaky sewers. Cities built on flood plains may find cheap supplies within their residential districts, but ground water in need of chemical treatment has little to commend it over river water.

Not all flood plains are available for ground water supply for towns. Some are carved by the lateral cutting of the stream and consist of a bench of rock veneered with a thin layer of alluvial soil, as that of the Mississippi at Davenport and of the Cedar at Waterloo. Some are cut partly in rock and partly in dry glacial stony clays, as that west of the Cedar at Cedar Rapids, which happens to be traversed by a sand filled ancient channel. The most suitable flood plains are those built up by the torrential waters of Pleistocene rivers. Here deep beds of coarse sand and gravel are often overlain and sealed with finer deposits. Flowing wells may sometimes be obtained, as on the lower course of Prairie creek in Linn county, the Wapsipinicon valley in Bremer county, and the artesian basin of Belle Plaine.

Pleistocene sands outside present or ancient river valleys should be carefully tested for extent, thickness and replenishment. Unless adequate in these respects their first yield may be fallacious, and as at Boone they may have to be abandoned. The history of Iowa waterworks shows that it is fairly common for the shallow wells of the first installation to be found inadequate. New wells are put down, perhaps in a new well field served by a second pumping station. Or the town goes over to a deep well, river, or impounding reservoir.

But seldom do the towns which make use of the flood plain waters of the river valleys need any additional supply except that readily obtained by sinking other wells in the same water bed.

Several types of shallow wells are in use in Iowa. There are dug wells with diameters sometimes more than 20 feet, with sides of brick or concrete, drawing their water from the bottom. A gang of driven wells, with sand points, set at right angles to the line of ground water flow may discharge into a common suction pipe.

From the sanitary view-point shallow wells are looked on more favorably than rivers, but are held inferior to wells in drift and country rock and to artesian wells.

As Hinman has pertinently said,[38] "The shallow wells share the dangers of the deep well and have additional dangers of their own as a consequence of their being dependent upon shallower sources for their water. They are more dependent upon local weather conditions for their supply. Unusually wet or unusually

38 Hinman, J. J., Twenty-first Biennial Rept. Iowa State Board of Health, p. 79, Des Moines, 1925.

dry weather may bring a change from the normal quality. Most of the trouble of the shallow well comes from the conditions of the top and the upper part of the casing, which are often constructed in such a way that the surface water is not excluded. The upper ten or twelve feet of the curbing and the top of the well at least, ought to be water-tight. Surface drainage is likely at any time to carry with it material of a sewage-like nature and sewage, especially town sewage, is very likely to contain the bacteria which are the cause of typhoid fever and other intestinal disorders.''

From the viewpoint of production and cost of installation and operation, shallow wells are often the best investment. If another supply is chosen, it should only be after they have been given full consideration and ample tests, as at Dubuque, p. 79.

Wells in glacial drift and country rock.—This supply, as we have seen, is peculiarly adapted to small upland villages and towns. Wells in drift commonly have but a small yield. Wells in country rock may yield enough for towns of one or two thousand population and in exceptional cases for much larger towns. The areas of outcrop of the Galena, Niagaran, Devonian and Mississippian limestones offer many examples, and where at a moderate depth the limestone is underlain by an impervious floor of shale the prospect for a successful well is very promising. Yet two towns, De Witt and Delmar, under the most favorable conditions for wells in country rock, have recently superseded them with deep artesians.

The geologic sequence which results in some of the favorable conditions for wells in the country rock is clearly stated by Meinzer:[39] ''Obviously an ideal sequence of events has occurred where a limestone was exposed to leaching until it became cavernous and was then subjected to changes which raised the water table and immersed the cavernous part in the zone of saturation. This sequence of events has occurred in the north-central United States and has made excellent aquifers out of some of the prominent limestones of that region, such as the Galena limestone and the Niagara limestone. Before the glacial epoch these limestones lay at the surface over wide areas and

[39] Meinzer, O. E., Occurrence of Ground Water in the United States: U. S. Geol. Survey, Water Supply Paper 489, p. 132, Washington, 1923.

were subjected to extensive weathering. Then they were overridden by successive ice sheets and became covered with glacial drift. Today the water table in most places passes through the drift mantle leaving the underlying cavernous limestone within the zone of saturation. In these areas limestone is considered an excellent water bearer and many limestone wells will yield from 100 to several hundred gallons a minute. Where these formations are so deeply buried that they have never been leached they are often not regarded as aquifers by deep well drillers, who search for the water bearing sandstones below the limestones.''

Wells in drift and the country rock are usually drilled through a heavy cover of impervious glacial till, which effectually seals their water beds from surface contamination. In contrast to shallow wells and surface waters, the purity of this supply is assured under these conditions.

But the fact that the water is pure when it enters the well does not guarantee its purity when pumped into the mains. In some known instances surficial water has freely entered the well through rusted casings. Pollution from privy vaults and leaky sewers may find access also where the seal of glacial till is wanting or imperfect, and the casing is not effectively bedded and packed, or by means of crevices in the rock. If in conjunction with these conditions a sporadic case of typhoid fever occurs in the vicinity the epidemic which follows need not be attributed to an inscrutable Providence.

The recent experience of Manchester shows the possibility of wells in country rock both for good and evil. The first deep well for city supply was put down in 1896, is 1870 feet deep, and foots in the EauClaire beds of the Cambrian. After 30 years of use this deep well failed to meet satisfactorily the increasing demands upon it. In the language of the local press, ''During the hot dry season of the year the demand made upon the pumping system is exceedingly heavy and it is with great difficulty that the engineer at the pumping station can keep the stand pipe filled as it should be.''

After the selection of a proper site by dowsing with the witch willow, a new well, 212 feet deep and 14 inches in diameter, was drilled in the northeastern part of the city. Below 10 feet of soil this well penetrated the Niagaran limestone nearly to the impervious floor of the Maquoketa shale. At about 175 feet, in a crevice, a yield of 300 g.p.m. was obtained. The well was cased to 100 feet. The static level was 30 feet below the curb. The total cost of this supply, including pump and electric motor, pump-house, and connections with the city mains, was less than $10,000.

Unfortunately, although this well seemed to promise to provide so cheaply "a tremendous and inexhaustible flow of water of the highest purity * * * alone sufficient for local needs", it could not be used. The disadvantages soon became apparent of a supply drawn from a well in a country rock which is pierced by a network of crevices and solution channels, and is protected from the contamination of the surface waters of the surrounding town by only a ten foot cover of soil. The water of the well failed to permanently clear. Pumping still brings in "a brownish clay, like flour, matting up like clay". Three times the water has been found bacteriologically "unsatisfactory" by the State Board of Health. In November, 1928, the city is considering either drilling a new well to reach below the Maquoketa shales or installing an air lift in the well of 1896 and bringing it up to maximum yield by necessary repairs.

Artesian wells.—Perhaps the chief excellence of this supply is its purity. Artesian waters require no clarification, filtration, aeration, or chlorination. Without treatment they are potable and safe. They can not bring upon the community any of those diseases whose germs are water borne.

The high rank of artesian and other deep well waters is indicated by the following table supplied by Mr. J. J. Hinman, Jr., Chief of the Water Laboratory Division of the State Board of Health. It summarizes the results of more than 30,000 bacterial examinations of Iowa supplies.

Summary of Results of the Water Laboratory
Percentage Satisfactory

Type of Source	Public Supplies		Private Supplies	
	Feb. 1914, to June 30, 1926	Biennium 1924-26	Feb. 1914, to June 30, 1926	Biennium 1924-26
Springs	38.03	48.00	27.16	23.08
Shallow wells	39.32	46.65	18.35	17.47
Deep wells	66.40	73.35	66.10	56.55
Treated waters	86.18	90.81		
Filter plant effluents	94.84	92.94		

It will be noted that the excess percentage of safety of deep wells used as public supplies over shallow wells is about twenty-seven and the minimum depth of "deep wells" as the term is used by the Board of Health and generally by water engineers is 100 feet. No statistics are at hand as to the comparative safety of artesian wells, or of those deeper than 300 feet.

The comparative safety of deep wells is recognized in the regulations of the State Board of Health governing the examination of public water supplies. Water supplied by wells less than 100 feet in depth is to be analyzed at least once during each three months period; water from wells more than 100 feet in depth is to be analyzed at least once during each six months period, . . the water in both cases having been found satisfactory at the last examination.

While the artesian water which enters a deep well is no doubt organically pure, artesian wells are not necessarily perfectly safe wells. Like wells in the drift and country rock they may be contaminated with surface waters. Several typhoid fever epidemics have been traced to infected artesian wells. In a recent instance noted by Hinman,[40] a sewer communicating with the well pit through a drain pipe was able to back up into the well. At Waterloo and Manchester artesian wells have been found contaminated, but happily without infection by pathogenic bacteria. At Waterloo the water from a contaminated soil found entrance through the upper rusted casing. At Manchester the well is located on the bank of the Maquoketa river and heads in the Niagaran limestone. As was pointed out by the writer when the well was drilled,[41] it receives near the surface a supply of water from the same source as that of a powerful Niagaran spring near by, as well as from the deep lying Jordan sandstone. The water of the sandstone is above suspicion, that of the surface limestone has become polluted and is liable to dangerous infection. The remedy is to dissolve the partnership by replacing a short wooden temporary casing with a water-tight iron casing extending to or near the base of the limestone, which here is 225 feet thick.

No statistics are at hand as to the comparative safety of arte-

[40] Iowa State Board of Health, Biennial Report, 1924, p. 78.

[41] Norton, W. H., Artesian Wells of Iowa, vol. VI, Iowa Geol. Survey, p. 214, Des Moines, 1897.

sian wells and deep wells sunk in the drift and country rock. Both alike are liable to pollution by surface waters through defective casings and packings. But, on the whole, the artesians have the advantage of better construction. They are put down by highly skilled workmen with all appliances at hand. Casings are generally made of the best materials. Within the upper casing, which reaches through surface deposits to solid rock, there is often placed an inner casing extending hundreds of feet, carefully packed, and occasionally the space between the casings is filled with concrete.

Deep wells in the country rock which do not penetrate a cover of impervious clay are little if any safer than shallow wells, especially if their casings are short, since surface waters may descend and find access to the well through crevices and solution channels in the rock. A number of infected wells of this class are on record in Iowa.

A summary of the results of the examination of upwards of 33,000 samples of city water supplies of Iowa from April, 1914, to May 1, 1927, has been prepared for the writer by Jack J. Hinman Jr., Director of the Laboratories of the State Board of Health. From this report it appears that at no time the samples submitted from the following deep well supplies have been found "unsatisfactory:" Ayreshire, Donnellson, Hull, Huxley, Lansing, Manson, Marcus, Nevada, Pleasantville, Pocahontas, Rockwell, Wilton.

The following supplies have been found "unsatisfactory" but once during their history: Anamosa, Charles City, Dunlap, Dysart, Elkader, Lake Mills, Lytton, North English, Oakland, Tipton, Winfield. In the remainder of the deep well public supplies the water has been found definitely "suspicious" or worse two or more times, or is regularly chlorinated. It must be remembered, however, that a number of towns draw on both deep and shallow wells, and no data are at hand to show from which wells the contaminated water came.

But the fact that in 63 per cent of the towns of Iowa using deep wells in part or whole for water supply contamination has been proved on two or more occasions shows conclusively that deep wells, like shallow wells, may be polluted by surface waters. The advantage of deep wells lies in this. The shallow well, whose aquifer is unprotected by an impervious covering stratum, may draw on waters widely and hopelessly polluted. The deep well draws on a sealed aquifer whose water is above suspicion. If the water of a deep well is found contaminated it may be taken for granted that the contamination enters the well through the defective mechanism of the well, such as an imperfectly sealed or rusted casing, and therefore can be remedied.

It hardly need be added that an artesian supply does not confer immunity against epidemics of the typhoid group caused, as in some Iowa examples, by infected river water drawn into the mains on some emergency.

A second advantage of artesian wells is the capacity of the reservoir on which they draw. The Cambrian and Ordovician sandstones of the upper Mississippi artesian field are hundreds of feet thick in the aggregate and underlie thousands of square miles. There are, besides, vast volumes of water stored in the Prairie du Chien and other limestones belonging to the same artesian system. It is assumed that this reservoir, replenished by the rainfall over the area of outcrop of the several aquifers, is practically inexhaustible.

No doubt early estimates of the amounts of underground water were excessive. And a large part of underground water even of the most conservative estimates of its total amounts, is held too closely in the fine pores of rocks to be available for wells. The reports of drillers indicate that even the Saint Peter, the Jordan, the Dresbach and the Mount Simon sandstones are not filled throughout with gravity water ready to flow into the tube as soon as the formation is entered by the drill. While definite facts as to the precise depths at which water has been struck are regrettably few, it seems that even the leading aquifers supply water freely only at certain horizons, which vary in different wells, horizons at which the texture of the rock is sufficiently open to allow pressure flow. And any one of these ordinarily generous aquifers may locally yield no water from top to bottom, so far as drillers' reports give evidence. Any calculation, therefore of the amount of artesian water held in storage, based on estimates of the volume of aquifers, and their average per cents of pore space, and on the assumption that all pore spaces are water filled, is clearly excessive. Yet since in the artesian field of the Upper Mississippi valley the Cambro-Ordovician system of aquifers yields generously to practically all wells which tap it, we may conclude that, throughout this field, artesian water is moving slowly under pressure. Considering the vast area of the field and its constant replenishment by a copious rainfall over an extensive intake area it may be assumed that artesian water in Iowa is too great in amount to be exhausted or seriously depleted.

Objection is sometimes made to artesian waters because of hardness. It is true that as a rule they are more highly mineralized than the water of streams. Compared with other ground waters, the water of deep wells is less highly mineralized, as was found by Hendrixson[42], in the northeast, east central and north central districts of the state. In the remaining districts of the state the opposite obtains.

In general mineralization is excessive where the Cambro-Ordovician aquifers lie deep and are covered by Mississippian and Pennsylvanian strata, especially in southwestern and south central Iowa.

When the water of any well supply is found excessively or even moderately hard a chemical treatment of the water by a softening plant is often to be recommended on the score of economy.

The initial cost of artesian wells makes against their use by the smaller municipalities and against their duplication for emergency supply, as when a well is thrown out of commission for repairs. A large recent increase in cost may be noted by comparing the cost of the wells listed in the present report with the cost of those of the report of 1912. This is the natural result of the greatly increased price of labor and materials due in part to a depreciated currency. The competitive prices for drilling for oil is said also to be a factor. Contractors' bids take account not only of depth but also of the material to be penetrated, ease of drilling, risks of losing tools and the amount of required casing. Wells which pierce heavily bedded limestones for the most part, cost less than those in which there is much caving shale. Bids are apt to run high in order to cover uncertainties where the

42 Underground Water Resources of Iowa, vol. XXI, Iowa Geol. Survey, p. 165.

formations to be passed through, their character and thickness, are little known. Prices must be large enough to cover risks where the contractor assumes in any part the responsibility for the success of the well. Any dependable information as to the deep geology of the state, which diminishes these uncertainties and risks, must lower the cost of wells in the highly competitive market by which prices are now fixed.

Operation and maintainance of deep wells may also be expensive, operation when the static head is low and the lift large, maintainance when corrosive waters rapidly rust out casings and when wells tend to fill with sand.

A recent example is the well of the Sinclair Packing Company, Cedar Rapids, drilled in 1911 and 1471 feet deep. After fifteen years of use rusted casing allowed the Maquoketa shale to cave and partially block the well, reducing the pumping capacity from 900 to 300 g.p.m. In 1926 the well was recased and the pumping capacity was then found to be around 900 to 1000 g.p.m. However, while repairs were in progress a well 72 feet deep and 21 inches in diameter, of the Layne-Bowler patent, was sunk in the flood plain sands of the Cedar river. This shallow well yielded at first 1500 g.p.m., dropping in a few months to 1000 g.p.m., and as the water is somewhat colder and much less expensive to pump than that of the artesian, the deep well, though not abandoned, has been superseded at least for a time, and a second Layne-Bowler shallow well added.

Perhaps the chief objection made to an artesian public supply, especially for the larger towns, is that of deterioration, overdraft and ultimate inadequacy. Deep wells, it is said, suffer gradual decline, the static level lowers from year to year, pumping cylinders are hung at greater depths. Air compressors are installed with pipes reaching deeper and deeper in the well. The cost of pumping steadily increases while air lift pumps become less and less efficient with reduction in submergence. The delivery declines. New wells are drilled but because of interference do not add to the output in proportion to their cost. Finally the deep well supply will have to be supplemented or superseded by one of another type.

This melancholy forecast is hardly justified by the history of

Iowa deep wells. Some of the oldest city wells are still giving good service. But seven towns have abandoned an artesian well supply and this for various reasons. At Monticello a crooked drill hole made needed recasing impracticable, and a cheap supply was found in a well in the country rock. At Boone the inadequate yield of two wells, 3000 feet deep, was apparently due in part to the small diameters with which the drill hole was able to reach the deep lying aquifers. Shallow wells in glacial sands were substituted and when these failed a permanent if distant and expensive supply was found in island wells at the Des Moines river. At Sigourney the artesian water was found so heavily mineralized in 1882 that it was never put to use. Yet a still deeper artesian was drilled in 1923 for city supply. Centerville seems to have abandoned deep wells on account of the quality of the water and finally has gone over to the impounding reservoir. At Newton two deep drill holes failed to reach the Saint Peter sandstone on account of difficulties in drilling and the water obtained from upper aquifers was poor. At Mallard the city well filled with sand.

Fourteen towns using artesian wells for their municipal supply report diminishing yield or receding static level (1925), and there are probably other instances not reported. The deterioration of these wells in some instances signifies nothing of more general importance than the clogging of the aquifer immediately about the drill hole, or leakage or cave because of a rusted casing. In other cases an overdraft is evidenced. More water is drawn from the aquifer than can locally be transmitted in a given time. There is produced within and for an unknown distance about the well field an area of diminished pressure comparable to the cone of depression in the water table about a shallow well.

Conservation

The need of conservation of deep well waters is less obvious than that of oil, natural gas and coal. These resources once consumed, are not replaced; ground water is continually replenished, much as lumber supply is renewed by forest growth. Yet just as in a country's forests cutting may exceed growth, so in a well field the draft on ground water may be greater than recharge.

The fact that artesian water is already overdrawn in several Iowa cities and towns proves that its conservancy must be considered.

When a public well supply shows signs of overdraft blame is occasionally placed on private wells which draw on the same water beds. In Dubuque, Clinton, Mason City, Fort Dodge and Cedar Rapids and Sioux City there are, it is true, numbers of private wells, besides those of the municipal supply. But so far as artesian water is legitimately used and not wasted the total amount of water consumed by the inhabitants of the city and its industries is not thereby increased. It makes no difference to the static level and the adequacy of the supply whether a given amount of water is drawn from public wells or from both public and private wells. A consumer may find it to his advantage to sink a well of his own and discontinue the public service, but he does not thereby increase the draft or overdraft on the artesian reservoirs.

"The first adequate attempt to conserve artesian waters on a large scale," as has been said by Meinzer, is being made in North Dakota under Dr. Howard E. Simpson, State Water Geologist. In this artesian field 6,000 artesian wells have been drilled and form a very valuable asset of the farming communities of this area. For several years unchecked flowing wells have dissipated the pressure and over wide belts the static head has fallen below the surface. Since 1921 laws have been passed and campaigns of education conducted designed to prevent discharge from flowing wells beyond beneficial use, to prevent leakage, and to secure the sealing of disused wells. As a result the decline of the pressure has been checked and wells have been kept flowing that otherwise would have failed to flow.

Another region where the decline of artesian water of great economic value has brought about conservation by legislative measures is Oahu, one of the Hawaiian islands. Here about 600 wells form the main domestic supply of 100,000 people and are indispensible to the irrigation of sugar lands of great productive value. The maximum daily draft upon these wells is 350,000,000 gallons.

The laws of the territory of Hawaii are designed to prevent all waste of artesian water not only by flow without beneficial use but also by leakage underground. How great can be the leakage loss of an artesian well is shown by the tests made here for the first time with the current meter. In Honolulu alone the total leakage thus discovered amounted to 7,750,000 gallons a day, an amount equal to one-third the total daily consumption of the city. Of this loss 5,900,000 gallons were saved by suitable repairs.

In the Iowa artesian field the need for conservation is less in evidence than in the Dakota basin or Oahu. Water is little used for agricultural purposes. There is practically no waste from uselessly flowing wells. Only in a few areas is there any dangerous overdraft. But in these local well fields the need of conservation is serious and urgent. The static level has already receded far. Abandoned wells should not merely be capped to prevent flow; they should be plugged deep enough to effectively seal the aquifers. The nature of the rocks pierced by the Iowa wells does not lead to the anticipation of such an amount of leakage as that found in Oahu, but it is highly probable that a thorough investigation with a current meter in several Iowa well fields would disclose a large and continuous loss and that the stoppage of lateral escape of artesian waters would go far in maintaining their static level. The well owners in an artesian field share in a common supply. They are stock holders in a common property. The waste of one is the loss of all, and waste as defined in legislative statutes includes subsurface leakage. It may be that only by the strictest conservation will there remain enough for all, enough for any.

Artesian Supply of Iowa Cities

The experience of the larger Iowa cities which have used artesian wells for public supply is believed to be of special value and will therefore be given in some detail. Further data will be found under each of these cities in this report and in earlier water reports of the Survey. In every instance except one, Waterloo, there is a considerable use of artesian water drawn from private wells, so that the artesian yield is larger than the public consumption indicates. At Clinton the number of private deep wells is 18, at Dubuque 27, at Mason City 9. As the preference of some large consumers for private supplies can not be due to difference in quality, it is assumed to be due to difference in cost. And probably the cost factor, rather than quality, has led to the sinking of the private deep wells of Burlington (12), Davenport (20), Keokuk (14) and Ottumwa (8), and other towns, which use another type of supply.

CLINTON

The city of Clinton (population 24,151) is supplied by the Clinton Waterworks Company with water drawn from artesian wells, of which six have been drilled and five are now in use. These wells are described in the writer's report of 1912.

The first public supply at Clinton is said to have been water of the Mississippi river strained through compartments filled with sand and gravel. As early as 1886 the first two artesian wells were drilled, marking the installation of the present system, and three additional wells had been added by 1902. All these wells discharged into the reservoir by natural flow.

But as the initial head of the wells, which had been 44 feet above the curb in the case of first wells drilled, declined and their delivery under natural flow decreased, fears were entertained as to the permanence of the artesian system. It was thought that any additional wells would diminish the yield of those already drilled, and would not increase the total delivery in proportion to the expense. The water company therefore installed as a supplemental supply a mechanical filtration plant drawing on the water of the river and with a capacity of 1,000,000 gallons daily. This, however, proved unsatisfactory, and at the writer's suggestion the deeper water beds of the Cambrian, the "basal sandstones," were tapped in 1911 by a deep well, no. 6, which secured a phenomenal flow, lifting by lateral leakage the static level of several deep wells of the Clinton area.

In 1917 there again developed a need of increase of supply. One well, inconveniently situated, had been abandoned, and the five wells in use were piped directly to the pumping basin. Aided by a vacuum pump which removed the air from the connecting pipe, these wells were then giving a flow of 2,483,000 gallons daily. At the advice of Mead and Seastone, consulting engineers, an air lift system was installed in wells 2 and 3. Tests in 1917 showed in these wells alone an increase in delivery of 900,000 gallons daily. In 1925 well no. 6 also was put under air and in 1926 with 100 feet of compressed air was capable of furnishing the entire supply of 4,000,000 gallons daily, while in emergency four wells could be operated at once with a combined daily pumpage of 8,500,000 gallons.

It was the opinion of Mead and Seastone published in 1917 that "the artesian supply of Clinton can be made available for a city of at least 100,000 inhabitants and fully adequate not only for domestic but for all necessary fire service." This favorable forecast, which nothing has as yet invalidated, probably was based on the capacity of the Mount Simon artesian reservoirs, which so far have been tapped only by the waterworks wells.

Eighteen deep wells have been drilled in the Clinton area and two at Fulton, Illinois, in addition to the six drilled for public supply. Seven have been abandoned. In 1925 the head of wells still in use averaged 12 feet below the curb, a total fall of 56 feet since the first wells were drilled.

DUBUQUE

Dubuque (population 39,141) draws its supply from five deep wells, whose capacity of 6,476,000 gallons daily under air with a lift of 128 feet is more than twice the average daily consumption.

In 1910 the supply was obtained from four deep wells. Later two of these at a distance from the Eagle Point pumping station were disconnected and two additional wells were put down at Eagle Point.

In 1922 it became evident that steps must be taken to increase the supply. At this time the four deep wells delivered under a motor driven centrifugal pump 1,779,840 gallons daily, while a group of wells about 100 feet in depth penetrating the sands of the flood plain of the river added under pump 1,570,000 gallons.

In choosing between the extension of the deep well system and that of the shallow wells, it was taken into consideration that tests over a period of years had shown large interference among the shallow wells and a constant decrease in their capacity. Although few flood plains would seem to offer more advantageous water beds than those of Upper Mississippi river it was decided to develop the artesian wells, using the present shallow wells only for emergency supply. A fifth deep well was drilled (p. 183) and air lifts were installed, giving the combined pumpage, as stated, of nearly six and one-half million gallons daily. Apparently the deep wells of Dubuque will continue adequate for a number of years.

There are now in the local Dubuque field thirty-two deep wells, including seven which have been abandoned, all of which draw on the artesian reservoirs by leakage, pumping or natural flow. A discussion of the progressive loss of head due to local overdraft will be found on page 184.

FORT DODGE

In the report for 1912 on the Underground Water Resources of Iowa there were listed three city artesian wells, which furnished a flow supply adequate to the city's peak consumption of 1,600,000 gallons daily. During the ensuing seven years it was found necessary to drill four additional wells because of the filling up of the chief well and to meet an ever increasing demand.

In 1919 the supply had so far fallen short that, according to an official report, an old filtration gallery supplying river water was frequently drawn upon. It was said that the discharge of the wells had been growing weaker year by year, and it could be foreseen that in time they would cease to flow. The experiment of pumping well no. 1, tried in 1909, had not been a success. It was held that the other wells were of too small a diameter for the use of either centrifugal or plunger pumps, and they were separated too far for the use of the air lift. The hardness of the water was also offered as an objection to its continued use.

It was proposed, therefore, to entirely abandon the artesian supply and erect a mechanical filtration plant for the use of the Des Moines river water at an estimated cost of $400,000.

At the request of the city Council and the Webster County Medical Association the case was taken under advisement by the writer, who, after visiting the city, submitted the following report:

Mount Vernon, Iowa
June 7, 1919

To the Mayor and Council of the City of Fort Dodge, Gentlemen:

Your city is fortunate in having the privilege of a choice between several adequate sources. There are towns in Iowa which can not get water from deep artesians, or from artesians of moderate depth, or from shallow wells. There are towns too remote from rivers to utilize this source of supply, and some unfortunate towns have only the Hobson's choice of impounding surface waters.

Shallow Wells

If I may judge from a brief inspection of your area, this source of supply is not available at Fort Dodge, although it yields a large supply to a number of cities and towns, as, for example, Muscatine, Marshalltown and Boone. The requisite conditions for this supply are thick and extensive beds of pervious material and the water table. or saturation surface, near the surface of the ground. Those conditions are best met on flood plains of aggrading rivers, where stream-laid sands and gravels form natural water beds.

Unfortunately the upper Des Moines river has not been an aggrading stream. It is still so young that its valley is narrow and steep sided. There are no extensive bottoms built up of sand and gravel from which to draw ground water on its way to the river, or "the underflow," more closely connected with the stream.

At Fort Dodge the narrow flats below the water-works on the left bank are inadequate in area and are so built over that there would be danger of pollution. A more promising area, at first sight, for a gang of shallow wells is found on the right bank above the dam. But inspection shows that this flat is underlain slightly above water level in the river with a rock floor on which rest river deposits too fine to transmit water in any considerable quantity. Ground water supply from shallow wells may therefore be excluded.

Infiltration Galleries

For the same geologic reasons—the youth of the river and the consequent lack of heavy deposits of coarse waste on its bed and banks—there does not appear any very good opportunity for drawing on the water of the river by means of infiltration galleries. The most promising location is Duck Island. * * * * Bed rock, however, is so near, the alluvium of the island is so disconnected from the pervious deposits on the land, that the outlook is by no means as promising as when islands of sand and gravel rise from deep beds of the same material which extend beyond the river's banks.

Deep Artesians

Another source to be considered is that of the deep lying water beds of the Upper Mississippi artesian basin, especially the Saint Peter sandstone, the Prairie du Chien formation and the Jordan sandstone. This is the source of supply drawn upon by Mason City, Charles City, Waverly and Waterloo. It is that drawn upon by your city well no. 1.

As to the quantity of water to be obtained from these deep horizons we have on record the following facts. * * * * These tests indicate that under the pump, and using all the water beds, two or three wells tapping the Jordan sandstone would furnish enough water for a long term of years.

Quality of the Deep Artesian Waters

Unfortunately when well no. 1 was drilled no analyses were made of the waters coming in at different depths. We have, however, the analysis made by Hendrixson about 1910 (Iowa Geol. Survey, vol. XXI, p. 188). If this was made before the caving of the well it represents all waters coming into the bore-hole including those of the Jordan sandstone. Comparing this with Knight's analysis of the present water of the well in the table below it will be noted that the well water of 1910 was superior to that of 1919. It contained 26 parts per million less of calcium and magnesium, and 119 (about one-third) less of the sulphate radicle, and one-third less of iron and aluminum. On the other hand it contained somewhat more of common salt and chloride of magnesia. The basal waters, then, are somewhat better than the upper waters, if the first analysis was made when the well was still of its original depth.

It hardly need be said that the waters of artesian wells are bacterially pure. They offer immunity so far as water supply is concerned from those diseases whose germs are carried in drinking water so long as the casings are kept in repair and surface waters do not get into the well.

Cost of Deep Artesians

The cost of two or three deep wells reaching the Jordan sandstone is great, especially at the present time with the high price of labor and material. As with any machinery, that of a deep well needs repairs from time to time, and the deeper the well the greater the cost of needed repairs. For this reason you will no doubt seriously consider the cost of this supply as well as the difficulties and cost of maintainance.

I am aware of the mechanical difficulties in a deep artesian supply. Your deep well has seriously caved. Sand in the water is reported as being ruinous to your pumps. But it is my belief that both of these difficulties can be obviated both in the repairing of well no. 1 and in sinking other wells to the Jordan sandstone. Difficulties with corroded casings can be obviated, although at large expense, by the use of cast iron casings.

Artesians of Moderate Depth

The next supply to be considered is that from artesians tapping the Mississippian strata and perhaps the Devonian also. Mississippian rocks, exposed in the immediate vicinity of Fort Dodge, are widely extended over the upper Des Moines basin. Undoubtedly they carry large amounts of ground water which are under considerable head at low levels, such as the bottom of the Des Moines river valley. The Mississippian is composed of alternating beds of limestone, shale and sandstone. The shale beds are dry, but serve as covers to maintain artesian pressure. Much of the limestone is but slightly magnesian and is highly soluble. We may expect that ground water has worked out by solution a good system of branching channels. But it is impossible to predict the depth at which any such a channel will be struck by a well at any given point. Sandstones are few and in thin beds. If the records of the different wells are reliable, these sandstones are also discontinuous.

The Mississippian strata have been explored already by the city wells and by other wells sunk by private parties. The quantity obtainable by natural flow is thus pretty well ascertained. The initial flows and those of today are shown in the following table from estimates by Superintendent Pray.

Flow of City Wells of Fort Dodge

	Initial Flow in gallons per minute	Present Flow (1919) in gallons per minute
Well No. 2	80	50
Well No. 3	600	200
Well No. 4	60	15
Well No. 5	48	20
Well No. 6	80	50
Well No. 7	80	50
Total	948	385

The natural flow has thus diminished more than one-half—from 1,365,000 gallons per day to 554,400 gallons. Even with the present flow of well no. 1 added, estimated at 300 gallons per minute, or 432,000 gallons per day, we have a total well supply by natural flow of less than one million gallons per day, from 600,000 to 700,000 gallons short of the requirement.

To secure this extra amount two methods are to be considered, (1) pumping the present wells, (2) the sinking of additional wells. A cylinder pump, or an air lift, increases the discharge of water from a well in proportion to the depth at which it is placed. Thus at Charles City the yield of the city artesian, under natural flow 200 gallons per minute, was increased to 900 gallons per minute with a vacuum of seven pounds. At the State College at Ames the discharge was increased from 3525 gallons per hour to 7400 gallons by lowering the pumping cylinder from 105 feet below the curb to 270 feet. It seems probable that in accordance with the experience of other wells a large increase in supply from the Fort Dodge wells can be obtained by pump or air lift. The amount of this increase can not be definitely stated, but it can be ascertained by actual tests at comparatively little expense.

If an adequate supply can be obtained by pumping the present wells no additional wells will be needed as long as the pumped supply holds out. When it falls below the requirements of the city, new wells can be drilled. The present wells are admirably located to secure the maximum head and discharge. * * * * Additional wells can be placed up river from the waterworks on the low ground adjacent to the hydro-electric plant and up Lizard creek. Other wells could be sunk also in the valley of Soldier creek. * * * * It is my opinion that by pumping the present wells and by drilling new wells from 200 to 600 feet in depth from time to time a sufficient supply for Fort Dodge can be obtained for an indefinitely long period of years or at the least, for a period so long as amply to realize on the cost of the investment.

There are certain objections to the quality of this supply. It contains considerable iron. In the Municipal building a gelatinous rusty red deposit forms rapidly below the taps where the iron is apparently extracted from the water by plant slimes. A meter which had been in use for some time showed considerable deposit of this sort. The extent to which these iron deposits give trouble in basins and to laundries is no doubt well known to your citizens. The analyses indicate that it may give considerable trouble and annoyance. It would therefore be well to take the matter up with engineers to find the cost of removing the iron by aeration or filtration.

A second objection to the water of the wells is its hardness. The degree and kind of hardness is shown in the following table taken from analyses made for this investigation by Dr. Nicholas Knight of Cornell College. The numbers are parts per million.

Hardness of Fort Dodge Waters

Well	No. 1	No. 2	No. 3	Des Moines River
Lime and magnesia carbonates (temporary hardness)	161.90	326.00	222.6	238.8
Lime sulphate (permanent hardness)	455.9	235.3	270.8	316.2
Total	617.8	561.3	493.4	555.0

We may compare the hardness of the Fort Dodge wells with that of other deep wells in Iowa, as shown by the amounts of calcium (Ca.) and magnesium (Mg.) present, in parts per million.

	Ca. and Mg.
Fort Dodge, average of the three wells	171.4
Fort Dodge, well no. 1, when drilled	154.
Dubuque	88.
Charles City	91.
Clinton	92.
Waverly	96.
Mason City	115.
West Liberty	115.
Waterloo	116.
Ottumwa	127.
Cherokee	273.
Keokuk	279.
Burlington	457.
Belle Plaine	481.

Certainly the lime and magnesia present in the Fort Dodge well water is not so great as to be deleterious to public health. To persons unaccustomed to its use it might cause slight temporary digestive disorders, but again those accustomed to it might suffer similar troubles of the digestive tract on changing to softer drinking water. There is no valid or accepted evidence that such hard waters are the cause either of goiter or of urinary calculi.

As an industrial water, the water of the Fort Dodge wells is not to be commended. It has other disadvantages which no doubt you have considered. It will clog heaters and hot water pipes. It makes necessary the use of much larger quantities of soap than would a water entirely soft, and is less pleasant in bathing. Altogether, the cost of a hard water supply in plumbers' bills, in soap, and in the cisterns, tanks and lifts that many citizens install in order to secure soft water must amount in the aggregate to a very pretty sum.

Comparing the quality of the water of the shallower wells with that of the deep well we find no advantage with the latter. If therefore sufficient water can be obtained from wells from 200 to 600 feet deep there is no need of incurring the expense of drilling wells 1400 and 1800 feet in depth.

Filtered River Water

As a source of supply the Des Moines river has several points in its favor. This supply is abundant, inexhaustible, permanent. Machinery is accessible for repairs. The water is bacterially impure, yet the upper Des Moines doubtless contains less sewage than the middle Cedar, for example. Filtration is necessary for this supply. With care a filtration plant may be maintained at a high point of efficiency, as is shown by the history of the filter systems of several Iowa cities. The records of typhoid fever epidemics in Iowa cities also show how fatal may be a lack of care. As Turneaure and Russell state, "to obtain uniformly good results with economy requires very careful operation. The coagulant must be closely regulated to correspond with the quality of the water." These authors emphasize also the great care involved on the part of the attendants and the importance of having the whole plant under the control of regular and frequent bacteriological tests. With these precautions mechanical filtration can be made successful and efficient.

This supply is better than that of the wells for industrial purposes: iron is present in so small amounts in the river water at Fort Dodge that it will give no trouble in laundries or elsewhere.

Yet it will be carefully noted that the water of the Des Moines river at Fort Dodge, as shown by Knight's analyses, is by no means a soft water. At the time when the sample analyzed was taken, it contained 555 parts per million of calcium and magnesium carbonates and calcium sulphate, while the average contents of the three well waters in these salts was 557.5. Comparing the calcium and magnesium contents of the river water, 160.37 parts per million, with the waters of the deep wells listed in the foregoing table, it will be seen that the Des Moines river sample was more heavily charged with these elements than many of these wells. The following table taken from Hendrixson in vol. XXI, Iowa Geol. Survey, shows the comparative rating of the river water:

	Ca. and Mg. in parts per million
Average of 30 deep wells in ne. Iowa	94
Average of 35 deep wells in east central Iowa	150
Average of 16 deep wells in se. Iowa	199
Average of 13 deep wells in sw. and south central Iowa	223
Average of 10 deep wells in central Iowa	236
Average of 9 wells nw. Iowa	277
Des Moines river, May, 1919, Fort Dodge	160.

The reason for the hardness of the water of the upper Des Moines (which thus is about the average hardness of the deep wells in eastern Iowa) is not far to seek. The river is largely fed by ground water issuing from springs. Owing to the youth of the stream and the consequent lack of well developed tributaries there is a larger soak-in of the rainfall and less run-off reaches the streams than in the older rivers of eastern Iowa. Spring fed, the river thus contains large quantities of lime and magnesia carbonates and gypsum dissolved by ground water in its passage through the rocks and soils.

It must not be inferred that the river water is equally hard at all times of the year. When the proportion of run-off is greater, as at times of flood, the proportion of calcium and magnesium will be less (the water softer). At low water, in time of summer drought, when the supply will still more largely be from springs than in May when the sample was taken, it may be expected that the water will be still harder than the sample analysed. Some idea of the range in hardness may be gotten from the following table:

Analysis of Des Moines river water at Keosauqua, 1906-7 on the last week of the month.
in parts per million

	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	March	Apr.	May	June	July	Aug.
Ca and Mg	59	100	108	138	40	53	?	96	72	79	56	86

We have here an annual range from a minimum of 40 parts per million to a maximum of 138. The range at Fort Dodge will probably be as great. And at any given time of the year the water of the river at Fort Dodge will probably be considerably harder than at Keosauqua as the lower Des Moines river is more largely fed by the run-off.

Analyses of Fort Dodge Waters
in parts per million

A Des Moines River, May, 1919, Knight
B City well No. 1, May, 1919, Knight
C City well No. 1, 1910 (?) Hendrixson
D City well No. 2, May, 1919, Knight
E City well No. 3, May, 1919, Knight

	A	B	C	D	E
Total Solids	530.6	846.00	867.	618.6	561.6
Ca, Calcium	93.12	134.10	114.	135.28	112.52
Mg, Magnesium	67.25	46.25	40.	45.94	40.2
Cl, Chlorine	14.7	120.70	144.	14.7	14.7
HCO_3, Bicarbonate radicle	173.0	117.57	410.	217.64	152.12
SO_4, Sulphate radicle	224.55	323.75	205.	167.09	193.3
N, Nitrogen	2.2	0.1		0.05	0.1
Combined					
SiO_2, Silica	14.6	6.00		8.0	7.6
Fe_2O_3 and Al_2O_3, Ferric oxide and alumina	0.6	3.00	2.	14.0	8.6
NaCl and KCl, Sodium and potassium chloride	23.1	198.90	239.	23.1	23.1
Calcium carbonate	3.4	0.00		165.2	81.9
Magnesium carbonate	235.4	161.90		160.8	140.7
Calcium sulphate	316.2	455.90		235.3	270.8

In matters of engineering it is not my province to advise. The suggestions offered from the viewpoint of the geologist may, I trust, make somewhat easier your choice between the different sources of supply as you weigh their advantages and disadvantages, their relative cost of installment, their permanence and cost of upkeep.

In accordance with the tenor of the above report and the recommendation of Assistant State Geologist Lees and Dr. Kime of the County Medical Association, the city abandoned the filtration project and turned to the development of the artesian system. Well no. 1 was cleaned to depth of 1247 feet, which left it footing in the Galena limestone. In October, 1919, five of the wells were tested with the air lift with the following results:

Well	Natural Flow, G. P. M.	Air Lift Discharge, G. P. M.	Drop, Feet
No. 1	300	600	50
No. 2	55	200	140
No. 3*	350	......	......
No. 4	7	60	135
No. 5*	10	......	......
No. 6	90	250	75
No. 7	20	80	135
Total	832	1190	

* Not tested with air lift.

The judgment of the report as to the adequacy of the existing wells was thus verified. Five of the wells under the air lift, supplemented by the natural flow of no. 3, could supply 2,793,000 gallons per diem, over a million gallons in excess of the peak consumption.

In 1921 well no. 3, 8 inches in diameter, was abandoned and on its site a new well was drilled with a diameter of 17 inches and a natural flow of 750 gallons per minute.

After four years of successful use of the air lift it appeared in 1923 that it could be economically dispensed with if the natural artesian flow could be increased by drilling another well. Accordingly in 1923 well no. 8 was drilled, yielding a flow of 740 gallons per minute. Since that time wells nos. 1, 3, 6 and 8 have furnished alone the entire city supply. These four wells discharge 1480 gallons per minute by natural flow into a two million gallon reservoir, from which the water is picked up by high service pumps.

City wells nos. 1, 2 and 3 were described in the Underground Water Report of 1912.

City wells nos. 4 and 5 were drilled in 1914 by J. J. Becker, of Garner, Iowa. Well no. 4 has a depth of 400 feet, diameters, 8 and 6 inches. The principal supply was found at 200 feet. In 1919 the initial head of 20 feet above the curb had lowered to 9 feet and the original flow of 60 gallons per minute had decreased to 7.

Well no. 5 has the same diameters as no. 4 and a depth of 624 feet. Water was found at 300 to 400 feet, with a small vein at 100 feet.

In 1919 the initial head of 20 feet above the curb and the flow of 48 gallons per minute had diminished to 15 feet and 10 gallons.

Wells nos. 6 and 7 were drilled in 1916 by Thorpe Bros. of Des Moines. Well no. 6 has a depth of 283 feet and diameters of 10 and 8 inches. Water was found at 260 feet and the natural discharge was 190 gallons per minute.

Well no. 7 was drilled on Duck Island; depth 498 feet, diameters, 8 and 6 inches; water beds, 70-80, 315 and 473 feet. The initial head was 30 feet and the flow 80 gallons per minute.

Well no. 8 was drilled in 1923 by Thorpe Bros. Well Co. of Des

Moines. The depth is 1436 feet, diameters from 16 to 8 inches. The principal supply was found at 400 feet, and other water beds at 900 and 1400 feet. The head is 40 feet above the curb, and the discharge is 750 gallons per minute. The temperature is 52° Fahr. and the cost was $18,000.

At the close of 1928 the city has under favorable consideration the installation of a plant for water softening and removal of the iron.

MASON CITY

Mason City (population 20,065) draws from deep wells not only an ample public supply, but also the supply for industrial plants and railways equipped with their private wells. In 1910 the city obtained from six wells an average of 400,000 gallons daily with a maximum of 650,000 gallons. These wells were from 616 to 651 feet in depth and tapped the water beds of the Galena-Platteville limestones.

In 1910 it was found necessary to explore the lower water beds and city well no. 7 was drilled to the depth of 865 feet, penetrating the Shakopee dolomite to a depth of 40 feet. Five wells of corporations now drew on the same supplies as the city, the depth of these wells ranging from 405 to 816 feet.

As the increasing consumption by the waterworks and industrial plants pressed close on a supply apparently overdrawn, it was advised by this office to sink an additional well or wells to tap the lower waters of the Prairie du Chien and the Jordan. Accordingly city well no. 8 was drilled in 1912 to a depth of 1219 feet with a delivery of 1200 gallons per minute. In 1913 this office was again consulted as to deepening one or more of the shallower wells sunk in the reservoir. It was advised to avoid interference by drilling at a distance a well of the same depth as no. 8, and well no. 9, drilled in 1913, footing in the Jordan sandstone, also proved a capacity of 1200 gallons per minute.

The large yield of these lower aquifers has led to the abandonment of the shallower wells, nos. 1, 2, 3, 4 and 5, and the pulling of their equipment. Wells nos. 6 and 7 have been deepened to about 1200 feet and under air together with wells 8 and 9 have a combined delivery of 3900 gallons per minute. The city consumption averages about 1,300,000 gallons daily and under normal demands the entire public supply can be drawn from a single well. The city is thus far within its reserves, while railways and industrial plants draw on the artesian water beds by means of nine deep wells.

SIOUX CITY

Sioux City (population 71,227) draws its supply from 13 wells, from 323 to 341 feet deep and from 16 to 26 inches in diameter. The aquifer embraces heavy beds of porous sandstone (the Dakota) sealed by beds of clay or shale. (See logs, pp. 326-330.)

There are three pumping stations, one of which, the Main Street station, is held in reserve. At the Lowell station the wells are spaced 600 feet apart.

The pumping capacity of the individual wells differs, the highest being 3,000,000 g.p.d. Together they meet an average daily consumption (Venturi meter) of 6,000,000 g.p.d. and a maximum consumption of 13,000,000 g.p.d.

The present static level is 40 feet below the surface and is reported (1927) as falling at the rate of four inches yearly. In 1921 the recession for the previous 14 years was stated to be at the rate of one foot per year.

WATERLOO

Waterloo (population 36,230) draws its water supply exclusively (1927) from four deep wells. Previous to 1904, the supply was drawn from Cedar river, when a severe epidemic of typhoid fever traced to the city water led to the abandonment of the filtration plant and, on the advice of this office after a careful survey, to the installation of artesian wells. Wells no. 1, sunk in 1905, no. 2 (1907) and no. 3 (1911) are described in the writer's report of 1912. The description of wells nos. 4 and 5 will be found on pages 350-353 of the present report.

Well no. 1 has been abandoned because of "a chemical condition of the soil, causing casing to deteriorate so rapidly that it was cheaper to drill a new well in another location." Another report assigns infection as the cause. No trouble of this kind has occurred with the other wells.

The four wells now in use are located on a practically straight line about 5700 feet in length. The tested capacity at present of the four is more than 5,000,000 gallons daily while the peak consumption is but 3,000,000 gallons and the average daily consumption 1,500,000 gallons. The industrial plants of the city largely make use of the river water for boiler supply.

The usual lowering of the initial static level has taken place. In well no. 1 (1905) this level was found at 20 feet above the curb. In well no. 4, drilled nine years later, the head had fallen, but was still above the surface. Well no. 5 (1922) failed to flow. The static level in 1927 is reported at 40 feet below the curb for wells nos. 2 and 3 and 34 feet for well no. 4, while for well no. 5, whose curb is 8 feet higher, the static level apparently since its drilling has been 50 feet below the surface.

Since the above was written well no. 6 has been completed (December, 1928) and will be found described on page 352.

CEDAR RAPIDS

The city of Cedar Rapids, population 56,000, has a daily average consumption (1927) of 4,237,357 gallons, a daily average per capita consumption of 80 gallons, and a maximum daily consumption of 6,462,120 gallons.

While the main supply of Cedar Rapids is obtained from Cedar river, it has also been drawn largely from deep wells, and a supply from shallow wells has recently been under consideration. The water supply question of the city is at present writing still undecided, but it is believed that its experiences with different supplies are of sufficient value to warrant their relation here at some length.

The first public supply of the city, 1875-1888, was taken from a filter well on the river bank. In 1888 three artesian 5 inch wells were drilled from 144 to 160 feet apart at the apices of a triangle. The first of these wells was sunk to a depth of 2225 feet, reaching the Sioux quartzite, and thus piercing all the Cambrian aquifers. As a salty and corrosive water entered the well somewhere below 1450 feet, the well was plugged at that depth in 1894. The other wells were 1450 feet deep, footing in the Jordan sandstone, and no artesian since drilled has ventured below that aquifer. Unlike Dubuque and Clinton, Cedar Rapids is thus unable to draw on the deeper Cambrian water beds. Fortunately the Jordan sandstone here is thick and generous in yield.

The initial head of the Jordan water was 761 feet above sea level, 28 feet above the curb. The discharge was 250 g.p.m. from each well by flow under its own pressure.

In 1894 an artesian well, drilled for the Y. M. C. A. to the same depth as the city wells, showed a head of but 735½ feet above sea level. The flow of the city wells had now for some years been insufficient, and had been supplemented by raw river water. The water company had also lost much of its manufacturing patronage because of the hardness of the water. It was therefore decided not to further extend the deep well supply, but to seek a main supply from the river, continuing the deep wells only to supplement it. A mechanical filter plant was erected in 1895-6 at the site of the three deep wells. Had it then been known that deep wells could easily be made to yield 1000 g.p.m. at Cedar Rapids the decision might have been different.

By 1911 waterworks well no. 3 had been abandoned, the head of the city wells had fallen to 2 feet below the curb and their yield each to 150 g.p.m. The capacity of the filter plant was 10,000,000 g.p.d. and the average daily consumption 2,500,000 gallons. The deep wells were still used, as they are used today, chiefly when filtration is made more difficult or unsatisfactory, as during spring floods and the heat of summer.

In 1914, perhaps owing to dissatisfaction with river water, a tentative move toward an artesian supply was made by drilling, on the West Side, city well no. 4, 1591 feet deep, and 10 inches in diameter at bottom. The initial head of this well was 721 feet above sea level, 15 feet below the curb, about the head of Silurian waters in several wells. This well is now pumped by a vertical rotary pump and yields 1055 g.p.m., with the pump at 84 feet. The draw down is not known as the well is closed by the pump head, but of course can not exceed the limit of the intake.

Of the three original city wells situated on the small triangle at the waterworks nos. 2 and 3 are now abandoned owing to serious interference. Well no. 1 now shows a static level of 14 feet below the curb, lowering to 18 feet when the distant deep well of the Sinclair Packing Co. is pumped. It delivers under air from 900 to 1000 g.p.m. This well and well no. 4 now furnish about 2,500,000 gallons daily.

A change in water supply has been under careful and thoughtful consideration by the officials of the city and under vehement discussion by the people and the press since 1926. The filtration plant is old and must be rebuilt soon if the river is continued as the main supply.

As shallow wells were under advisement in October, 1926, the writer was consulted as to the proposition of a supply from proposed wells about 100 feet in depth tapping sands of the Cedar river flood plain within the city on the West Side, wells whose sufficiency was guaranteed for one year. It was then pointed out that the chief factor in sufficiency is not the capacity of the reservoir but the rate of its replenishment; that the flood plain, encircled by rock hills, has little replenishment except from rain and river; that the flood plain is largely cut in rock and glacial till and its water-bearing sands are limited to the course of a buried channel. In case shallow wells were to be considered as a supply it was advised to explore thoroughly the possibilities of the buried preglacial or interglacial channel underlying the flood plain of Prairie creek south of the city with its drainage area of over 200 square miles. The wide continuous flood plains of the Cedar river above Covington were also suggested.

The test well put down by the guaranteeing company on the West Side flood plain proved a failure, and several test holes were then sunk in the Prairie creek valley, some of which developed a large flow.

The writer was again called to advise in the situation and after a cursory reconnaissance pointed out the complex nature of the valley fill and the need of further tests to determine the extent and thickness and capacity of the water beds.

The City now employed Professor Howard E. Simpson of the University of North Dakota, Water geologist of that state, and consulting expert on municipal supply, to make a complete ground water survey. His report of December, 1927, discusses fully five local sources of ground water and also Cedar river.

The following synopsis of Simpson's report is as far as possible in excerpts.

1 *Springs.* A supply from the springs north of the city and on Indian creek rising from Devonian limestone is inadequate as the maximum supply available is 3,000,000 gallons daily. In common with all springs they are liable to surface contamination. When drawn off in large amounts by collecting basins and galleries, it would be necessary to watch the supply very carefully and take frequent sanitary analyses.

2 *The Silurian limestone.* A number of wells in the city foot in Silurian limestone at depths of from 150 to 450 feet. Their head is from 15 to 30 feet below the curb and their yield, depending in part on size of well and pump, reaches a maximum of 600 g.p.m. But no quantity sufficient for city supply could be taken without greatly lowering the head, drawing in shallow and probably contaminated water and endangering the supply. This source in Cedar Rapids should remain for industrial uses, where a cheap, cold, sanitary water is highly desirable.

3 *The Cedar River Gravels.* The gravels of the flood plain up river about Palo are probably the largest available source of a supply of this type to be found in the vicinity. With the growth and industrial development of the city these gravels may prove to be a most valuable water supply. Their distance from the city, however, makes it inadvisable to give them further consideration at this time.

The gravels of the buried channel of the flood plain within the city limits are not recommended for sanitary reasons, although in some wells they now deliver 1000 g.p.m. continuous service. There is no impervious clay cover and the river in some places at least, flows in a bed cut directly in this gravel deposit. This water is, however, highly satisfactory for cooling purposes, for which it is chiefly used, since it is the coldest water available and the most economical to pump. Its temperature is reported at 48° to 52° F., depending in part on the season and the amount of pumpage. The fact that heavy pumping sometimes runs the temperature up as high as 56° or 58° F. in certain of these wells clearly indicates that very shallow waters, possibly from the river itself, are drawn down into the intake under the heavy pumpage of summer. The taking of this supply within or below the city would necessitate treatment to make it safe for public use. It would offer little advantage over river water and should be considered only as an alternative of the river itself.

The Prairie Creek Gravels. A very complete survey was made by Simpson of the Prairie creek flood plain and its ancient buried channel. The character of the fill is indicated by the log of test hole no. 17:

Material	Thickness feet	Depth feet
Loam and clay	5	5
Sand and clay	10	15
Bluish white clay	15	30
Sand	5	35
Light blue clay	60	95
Blue clay	28	123
Sand and gravel	47	170
Fine sand	5	175
Clean sand and gravel	27	202
Coarse gravel	10	212
Rock		

The geological interpretation by Simpson of this log and of the ten samples of material taken from this hole is as follows:

Formation	Thickness feet	Depth feet
Alluvium, loess, etc.	30	30
Buchanan gravel	5	35
Kansan boulder clay	88	123
Aftonian gravel	89	212
Silurian limestone	2	214

Test holes nos. 9 and 8 with diameters of 5⅝ inches and 4 inches, with static heads of 28 and 20.7 feet, flowed on completion at the rate of 350 g.p.m.

The conditions which prevail in the Prairie creek artesian basin are very similar to those of the Belle Plaine artesian basin which gave rise to the most famous artesian well in America, the "Belle Plaine Jumbo". This basin, however, is neither as large nor as deep as that of Belle Plaine and we may not expect so great a head nor as large a yield as were found there. The Prairie creek basin is also a smaller duplicate of that of the Iowa river in the Amana colony and is possibly a part of the same artesian system.

The mineral quality of the Prairie creek gravel water is good, though it is moderately hard and unfortunately it appears to carry a larger amount of iron than any of the others considered. This would at least require treatment by aeration or otherwise for the removal of the iron. The sanitary quality is good, owing to the thick boulder clay deposited over the Aftonian gravel, and there would be no danger of contamination except through the well holes.

The quantity of water passing very slowly down valleyward through these Prairie creek sands and gravel is large, but how large is uncertain owing to the number of variable factors, the extremes of which even cannot be ascertained with accuracy. Just how much the yield obtainable may be is the most difficult problem encountered in this survey and the only one which cannot be solved with a reasonable degree of certainty. The amount, however, is large, amounting at least to several million gallons per day. It is possible that these gravels may yield a sufficient amount of water for the entire city supply. It cannot be depended upon as an exclusive source unless proved by further testing to yield much larger amounts than have yet been demonstrated.

The Deep Artesian Formations offer for the city the best available source of ground water supply in its natural state. It is an excellent drinking water and the only objection to its use from the standpoint of quality is its hardness. This is true, however, of all available water supplies. Deep artesian wells could undoubtedly be made to yield an abundant supply for the city for some years to come. The necessary consideration would be the number, the size, and the spacing of the wells. With wells finished at least 12 inches in diameter, and at least one-half mile apart, a yield of about 1000 g.p.m. per well could undoubtedly be secured. Eight million gallons daily could be secured from six of these wells. Two wells should be allowed in reserve, making eight wells in all. These should be spaced as widely as possible and located preferably in the city parks.

The possibility of deep artesian waters for city supply in eastern Iowa is fully demonstrated in Waterloo, Clinton, Dubuque and other cities. To take the entire supply from deep artesians, would, however, be so great a drain upon the deep artesian formations in the immediate vicinity of the city, when continued through a long period of years, that it does not seem advisable on account of cost to make this the exclusive supply.

As to Cedar river as a surface water supply Simpson states: The quality of the water from the mineral point of view, especially as respects hardness, is superior to that of any available ground water. The average total hardness of the year as calculated by the U. S. Geological Survey is 185.8 parts per million, or 10.85 grains per gallon, most of which is temporary. The river, however, is always polluted, and it must be purified before it is fit for domestic use. It may, however, be made entirely safe for domestic use at the same time that it is being clarified and softened, if softening is desired. The chief difficulty in the use of river water arises from the fact that the organic matter in the water may unite with the chlorine used for purifying the water, especially when it is necessary to use this in excess, and form certain organic compounds which impart very unpleasant tastes and odors to the water. This is especially noticeable in warm tap water, and water from a surface supply is always warm in summer. This warmth, which is frequently above 70° F., is also one of the chief objections to the river water.

The use of the rivers for sewer purposes in the past, and increasingly so in the present, is largely depriving the cities of this valuable source of water supply. It seems highly probable that within the next fifty years, possibly within twenty-five, the people will abolish the grosser forms of stream pollution and make this, the most abundant, economical and permanent of all water supplies, more readily available for public use. Pollution can never be entirely avoided, however, and the organic compounds characteristic of surface waters will necessarily be present with their tastes and odors. There is no known way to avoid these tastes and odors in surface water supplies.

The Future Supply. The Industrial Survey recently made by the Chamber of Commerce estimates that the population of Cedar Rapids in 1950 will be 100,000. The future needs of this increased population with its increased industrial needs may therefore be anticipated in the selection of a water supply at the present time. There should be 8,000,000 gallons per day immediately available and at least 10,000,000 gallons per day in sight for 1950.

This future water supply must be bacteriologically pure; it should be clear, cool, and free from unpleasant tastes and odors. It should also be relatively free from iron in solution and from corrosive minerals. I believe that the people of Cedar Rapids will also say that it should be soft.

While it may not be possible to meet all these requirements and have a perfect water, it is possible to closely approach this ideal and that within a very moderate cost. Low cost is only of less importance than quality and quantity, since low cost means larger usage and resulting cleanliness and beauty of the city.

A slight increase in cost in order to soften the public supply is more than repaid in cash to the average householder in the saving of soap consumption, the repairs of plumbing, the renewal of hot water tanks and boilers and above all in the saving of fuel for the heating of water in unscaled and sludge-free pipes. We need not mention what soft water means to the housewife in sanitation, comfort and beauty of the home.

Cedar Rapids may have quality water, clean, soft and abundant. It is recommended that the decision be first made whether the future water supply will be hard or soft. If the water is used without softening it is recommended that deep artesian formations be utilized as the primary source and the Prairie creek gravels as a secondary source. If soft water is desired any supply should be softened to about 138 parts per million and it is recommended that the Prairie creek gravels be selected as the primary source, provided on further prospecting and development it be found to yield in excess of 5,000,000 gallons per day, and that deep artesian wells be continued as a supplementary supply.

In accordance with specifications in the report of Professor Simpson another trial well was sunk in the Prairie creek valley. This well, 180 feet deep, was 24 inches in diameter. It yielded under the pump 1,500,000 gallons per day for 30 days with a draw down to 36 feet below the surface, or 42 feet below static level. By increasing the speed of the pump a discharge was obtained of

2,000,000 gallons per day for three weeks with a draw down to 55 feet below the surface of the ground.

Water was not struck in this test well until after an election was held as to a proposed bond issue for new water works. The proposition failed to carry. The firm of Alvord, Burdick, and Howson of Chicago was now employed as engineering experts. In their report it is stated as to the artesian supply:

"The entire region about Cedar Rapids is underlaid with water-bearing sandstones capable of yielding a supply adequate for either present or future needs if the wells are sufficiently distributed. The water is hard but could be readily softened."

As to the Prairie creek gravels as the source of the city supply this firm of engineers was less optimistic. "We have made a two months test of the J Street well (the last one drilled) and have observed the effect on the water levels in that well and others as far distant as two and one-half miles. From the data thus secured we conclude that the Prairie creek sands are too limited to furnish an adequate supply unless possibly by locating a number of pumping stations at intervals of several miles. We do not consider this a practicable source of supply for present and probable future requirements of Cedar Rapids." The requirements of the city had already been placed by the firm at 12,000,000 gallons per day, to supply the maximum consumption of ten years hence.

The firm therefore recommended that the existing plant be abandoned and a modern plant be built up valley opposite Ellis Park at a total expenditure, exclusive of land, of $640,000. Their estimate as to the costs of the supplies considered is as follows, each to be used as sole supply.

Supply	First Cost	Annual Cost
Deep wells	$ 885,000	$168,850
Prairie Creek gravels	1,250,000	200,000
Cedar River, steam	864,000	131,000
Cedar River, electricity	640,000	111,000

In November, 1928, the City in an election approved the issue of bonds for $660,000 for the proposed new water works.

ANALYSES OF WATER AVAILABLE FOR PUBLIC SUPPLY AT CEDAR RAPIDS

The following analyses were made in December, 1927, for Professor Howard E. Simpson by Professor G. A. Abbott, head of the Department of Chemistry, University of North Dakota. They are reproduced here with permission because of their value as an addition to our knowledge of the chemistry of Iowa waters.

Analyses of Waters from Cedar Rapids

Laboratory Number 2340. No. 1. Testhole no. 9. South side Prairie Creek. Artesian gravel. Depth 212 feet.

	Parts per million		Parts per million
Residue on evaporation	320	Sodium (Na)	5.06
Alkalinity to phenolphthalein	None	Calcium (Ca)	38.80
Total alkalinity (as $CaCO_3$)	278	Magnesium (Mg)	43.46
Total hardness (as $CaCO_3$)	278	Iron (Fe)	1.40
Temporary hardness	278	Chlorine (Cl)	7.80
Permanent hardness	0	Carbonate (CO_3)	166.80
		Sulphate (SO_4)	Trace

Hypothetical Combinations

Sodium chloride (NaCl)	12.87	Magnesium carbonate ($MgCO_3$)	152.04
Calcium carbonate ($CaCO_3$)	97.00	Iron oxide (Fe_2O_3)	1.62

A water of only moderate hardness, practically all of which is carbonate or "temporary" hardness. It is slightly corrosive, owing to the release of carbonic acid on boiling. In a boiler it would produce a sludge rather than a hard scale. It could be softened by boiling, or by addition of a little hydrated lime. I have reported the calcium and magnesium as carbonates, but they really exist in the water in the form of bicarbonates, which are decomposed by boiling.

Laboratory Number 2342. No. 3. City Waterworks Well No. 4. West Side Artesian. Depth 1450 feet.

	Parts per million		Parts per million
Residue on evaporation	642	Sodium (Na)	123.81
Alkalinity to phenolphthalein	None	Calcium (Ca)	71.56
Total alkalinity (as $CaCO_3$)	285	Magnesium (Mg)	34.51
Total hardness (as $CaCO_3$)	323.5	Iron (Fe)	0.10
Temporary hardness	285	Chlorine (Cl)	24.00
Permanent hardness	38.5	Carbonate (CO_3)	171.00
		Sulphate (SO_4)	248.12

Hypothetical Combinations

Sodium chloride (NaCl)	39.54	Magnesium carbonate ($MgCO_3$)	89.46
Sodium sulphate (Na_2SO_4)	314.53	Magnesium sulphate ($MgSO_4$)	44.70
Calcium carbonate ($CaCO_3$)	178.90	Iron oxide (Fe_2O_3)	0.14

A moderately hard water, somewhat corrosive, but non-scale forming. High in total solids due to a large amount of sodium sulphate.

Laboratory Number 2343. No. 4. Penick and Ford Company 429 foot well.

Silurian limestone.

	Parts per million		Parts per million
Residue on evaporation	434	Sodium (Na)	41.89
Alkalinity to phenolphthalein	None	Calcium (Ca)	84.20
Total alkalinity (as $CaCO_3$)	285	Magnesium (Mg)	25.33
Total hardness (as $CaCO_3$)	316	Iron (Fe)	0.20
Temporary hardness	285	Chlorine (Cl)	30.00
Permanent hardness	31	Carbonate (CO_3)	171.00
		Sulphate (SO_4)	46.91

Hypothetical Combinations

Sodium chloride (NaCl)	49.14	Magnesium carbonate ($MgCO_3$)	89.40
Sodium sulphate (Na_2SO_4)	25.27	Magnesium sulphate ($MgSO_4$)	37.26
Calcium carbonate ($CaCO_3$)	210.50	Iron oxide (Fe_2O_3)	0.28

Moderately hard water. Nearly all of the hardness due to calcium bicarbonate and removable by boiling. Slightly corrosive, owing to release of carbonic acid on boiling. Low in iron. Should give a sludge or soft scale in a boiler.

Laboratory Number 2344. No. 5. City Waterworks Well No. 1. Station Well.

Depth 1450 feet.

	Parts per million		Parts per million
Residue on evaporation	731	Sodium (Na)	75.14
Alkalinity to phenolphthalein	None	Calcium (Ca)	105.24
Total alkalinity (as $CaCO_3$)	285.0	Magnesium (Mg)	46.95
Total hardness (as $CaCO_3$)	480.6	Iron (Fe)	Trace
Temporary hardness	285.0	Chlorine (Cl)	52.48
Permanent hardness	195.6	Carbonate (CO_3)	171.00
		Sulphate (SO_4)	239.18

Hypothetical Combinations

Sodium chloride (NaCl)	86.58	Magnesium carbonate ($MgCO_3$)	18.39
Sodium sulphate (Na_2SO_4)	106.99	Magnesium sulphate ($MgSO_4$)	208.50
Calcium carbonate ($CaCO_3$)	263.10	Iron oxide (Fe_2O_3)	Trace

A very hard water. Forty per cent of the hardness is permanent hardness. A corrosive, scale forming water requiring softening to make it suitable for public supply.

Laboratory Number 2346. No. 7. Sinclair Packing Company gravel well.

Depth 72 feet.

	Parts per million		Parts per million
Residue on evaporation	1,469	Sodium (Na)	441.78
Alkalinity to phenolphthalein	None	Calcium (Ca)	120.00
Total alkalinity (as $CaCO_3$)	257.0	Magnesium (Mg)	33.54
Total hardness (as $CaCO_3$)	435.5	Iron (Fe)	.60
Temporary hardness	257.0	Chlorine (Cl)	603.50
Permanent hardness	178.5	Carbonate (CO_3)	154.20
		Sulphate (SO_4)	276.53

Hypothetical Combinations

Sodium chloride (NaCl)	994.50	Calcium sulphate ($CaSO_4$)	58.48
Sodium sulphate (Na_2SO_4)	155.49	Magnesium sulphate ($MgSO_4$)	162.50
Calcium carbonate ($CaCO_3$)	257.00	Iron oxide (Fe_2O_3)	1.14

A very hard salty water. The large amount of sodium chloride (common salt) suggests strongly the possibility that the well is receiving surface contamination, such as salt from the packing plant. Of course it might come from salt beds, but these are usually found at greater depths. The water is too salty for suitable water supply.

Laboratory Number 2347. No. 8. Penick and Ford Co. 70 foot gravel well.

	Parts per million		Parts per million
Residue on evaporation	575	Sodium (Na)	49.68
Alkalinity to phenolphthalein	None	Calcium (Ca)	155.80
Total alkalinity (as $CaCO_3$)	363	Magnesium (Mg)	30.58
Total hardness (as $CaCO_3$)	511.5	Iron (Fe)	.60
Temporary hardness	363.0	Chlorine (Cl)	92.00
Permanent hardness	148.5	Carbonate (CO_3)	217.80
		Sulphate (SO_4)	120.58

Hypothetical Combinations

Sodium chloride (NaCl)	122.44	Magnesium chloride ($MgCl_2$)	30.04
Calcium carbonate ($CaCO_3$)	363.00	Magnesium sulphate ($MgSO_4$)	129.60
Calcium sulphate ($CaSO_4$)	36.04	Iron oxide (Fe_2O_3)	.85

High in total solids and very hard. Twenty-nine per cent of the hardness is permanent hardness. A corrosive, scale forming water. Would require softening to make it suitable for public supply.

Laboratory Number 2348. No. 9. Marion Springs. Composite.

	Parts per million		Parts per million
Residue on evaporation	296	Sodium (Na)	14.79
Alkalinity to phenolphthalein	None	Calcium (Ca)	69.44
Total alkalinity (as $CaCO_3$)	218	Magnesium (Mg)	21.40
Total hardness (as $CaCO_3$)	262.5	Iron (Fe)	Practically none
Temporary hardness	218	Chlorine (Cl)	6.00
Permanent hardness	44.5	Carbonate (CO_3)	130.80
		Sulphate (SO_4)	20.57
		Iron oxide (Fe_2O_3)	Practically none

Hypothetical Combinations

Sodium chloride (NaCl)	9.99	Magnesium carbonate ($MgCO_3$)	37.88
Sodium sulphate (Na_2SO_4)	33.65	Magnesium sulphate ($MgSO_4$)	53.40
Calcium carbonate ($CaCO_3$)	173.60	Iron oxide (Fe_2O_3)	Practically none

Only moderately hard. Most of the hardness is carbonate or temporary hardness. Sludge forming rather than scale forming. Slightly corrosive to boilers. Fairly satisfactory for public supply. Could be softened by hydrated lime treatment.

Laboratory Number 2349. No. 10. McLeod Spring.

	Parts per million		Parts per million
Residue on evaporation	281	Sodium (Na)	17.91
Alkalinity to phenolphthalein	None	Calcium (Ca)	71.56
Total alkalinity (as $CaCO_3$)	213	Magnesium (Mg)	12.67
Total hardness (as $CaCO_3$)	237.65	Iron (Fe)	None
Temporary hardness	213	Chlorine (Cl)	6.00
Permanent hardness	24.65	Carbonate (CO_3)	127.80
		Sulphate (SO_4)	51.44
		Iron oxide (Fe_2O_3)	None

Hypothetical Combinations

Sodium chloride ($NaCl$)	9.88	Sodium sulphate (Na_2SO_4)	43.31
Calcium carbonate ($CaCO_3$)	178.90	Iron oxide (Fe_2O_3)	None
Magnesium carbonate ($MgCO_3$)	24.38		

Very similar to No. 9. Only moderately hard, and most of the hardness is temporary hardness. Sludge forming rather than scale forming. Slightly corrosive to boilers. Fairly satisfactory for public supply. Could be largely softened by treatment with hydrated lime.

Laboratory Number 2350. No. 11. Cedar River Water.

	Parts per million		Parts per million
Residue on evaporation	303	Sodium (Na)	.71
Alkalinity to phenolphthalein	None	Calcium (Ca)	71.56
Total alkalinity (as $CaCO_3$)	210	Magnesium (Mg)	32.04
Total hardness (as $CaCO_3$)	241.5	Iron (Fe)	.60
Temporary hardness	210	Chlorine (Cl)	24.00
Permanent hardness	31.5	Carbonate (CO_3)	126.00
		Sulphate (SO_4)	67.07
		Iron oxide (Fe_2O_3)	.85

Hypothetical Combinations

Sodium chloride ($NaCl$)	1.81	Magnesium carbonate ($MgCO_3$)	26.46
Calcium carbonate ($CaCO_3$)	178.90	Magnesium sulphate ($MgSO_4$)	83.70
Magnesium chloride ($MgCl_2$)	30.64	Iron oxide (Fe_2O_3)	.85

This river water is only moderately hard, most of the hardness being temporary. It is fairly high in iron. It is somewhat corrosive, due to magnesium chloride. A sanitary analysis would probably show that the water is somewhat polluted with organic matter and bacteria and it would probably require filtration or sterilization to render it fit for public supply.

Descriptions of Deep Wells

ALGONA

(Altitude 1204 feet, C. & N. Ry.)*

CITY WELL NO. 3

The third well for the city of Algona was put down by Thorpe Brothers Well Company of Des Moines in 1924-25. The depth is 1885 feet. Water was found from 250 to 300 feet in limestone, probably Mississippian in age, and from 500 to 650 feet in the Galena-Platteville limestones, yielding in a test at 800 feet 150 gallons per minute. The main supply was obtained from the Shakopee dolomite at 1063 feet and from the horizon of the Jordan from 1240 to 1270.

The static level of the water in the well is 100 feet below the surface of the ground. The well pumps 200 gallons per minute with the pumping cylinder at 200 feet. Under continuous pumping at this rate there is a draw down of 100 feet.

* Slight differences between altitudes of towns and of wells are due to the use of later data for the towns. See Ia. Geol. Survey, vol. XXXII.

Twelve inch casing extends to 206 feet and is succeeded by 958 feet of 10 inch casing and 741 feet of 8 inch casing. The casing is perforated at the water beds. The cost of the well is approximately $22,000.

When the well had reached the depth of about 1700 feet this office was consulted as to going deeper. In reply it was stated that it was highly improbable that another water bed would be found. ''You may strike the red clastic series anywhere from the present bottom of the well to 1800 feet, or granite anywhere between where you are now and 2000 feet.'' ''If you should take the gambler's chance and go on, stop when you come to the red clastics—red shales and sandstones—or to the granite.'' The advice to stop was repeated when at 1810 feet the red clastics were struck.

Notwithstanding these advices, the work was continued and as the red series proved unexpectedly thin (its thickness north of Algona in Minnesota measures 200 feet) granite was reached at 1830 feet. This obdurate rock was entered to the depth of 55 feet. The rate of drilling from 1812 to 1860 feet, 1.8 feet per hour, indicates some secular decay of the ancient land surface to a depth of at least 30 feet. From 1860 to 1885 feet the rate fell to 6 inches per hour in the sounder rock.

Record of Strata

	Depth in Feet
Pleistocene and Recent (130 feet thick; top 1200 feet above sea level):	
''Yellow clay''	0–35
''Black clay''	35–130
Cretaceous (71 feet thick; top 1070 feet above sea level):	
''Fine sandstone''	130–186
''Limestone''	186–191
''Red shale''	191–201
Mississippian, Devonian?, Silurian? (209 feet thick; top 999 feet above sea level):	
''Limestone''	201-204
Limestone, reddish buff, saccharoidal, rather slow effervescence in cold dilute HCl	204–212
Limestone, gray, compact, some pinkish, some whitish, rapid and moderately rapid effervescence	213–223
Limestone, brownish drab, rapid effervescence, in flaky chips	223–235
Dolomite, gray, crystals of calcite; bright green shale in large chips; some white chert	235–250
Limestone, light yellow and gray, rather slow effervescence	250–270
Limestone, dark gray, rather slow reaction; some limestone with rapid effervescence	270–325
Dolomite, drab, compact; 2 samples (darker from 360–400)	325–400

Ordovician:
  Maquoketa (40 feet thick; top 800 feet above sea level)—
    Shale, greenish, calcareous, in concreted masses 400–440
  Galena to Glenwood inclusive (480 feet thick; top 760 feet above sea level)—
    Limestone, gray, earthy, argillaceous, rapid effervescence; shale 440–460
    Limestone, drab and light yellow, rapid reaction 460–495
    Limestone, blue gray, argillaceous, rather slow effervescence; much white chert 495–550
    Limestone, rather slow response to acid; blue gray 550–665
    Limestone, light buff, rather slow response 665–715
    Shale, light blue; cuttings of limestone; residue of minute quartzose particles 800–820
    Shale, dark greenish, calcareous, in hard concreted masses 820–860
    Shale, as at 800 860–870
    Shale, as at 820 870–890
    Shale, greenish, fissile 890–900
    Shale, as at 820 900–910
    Limestone, dark drab and light gray, rapid reaction; much green fissile shale; a little quartz sand of well rounded grains 910–920
  Saint Peter sandstone (80 feet thick; top 280 feet above sea level)—
    Sandstone, fine, white, Saint Peter facies; with some green fissile shale 920–940
    Shale, green 940–950
    Sandstone, fine, rusted 950–960
    Sandstone, blue-gray, fine, grains well rounded, highly argillaceous with concreting powder; 2 samples 960–1000
  Shakopee (90 feet thick; top 200 feet above sea level)—
    Dolomite, with much quartz sand 1000–1010
    Dolomite and shale; in concreted masses of powder and fine chips; much quartz sand 1010–1020
    Dolomite, light gray; much quartz sand 1020–1030
    Dolomite, gray, in small chips 1030–1040
    Dolomite, gray, vesicular; siliceous oölite; sandstone white, fine 1040–1050
    Dolomite, light gray; 3 samples 1050–1090
  New Richmond (70 feet thick; top 110 feet above sea level)—
    Sandstone, fine, white, larger grains well rounded; some flakes of calciferous sandstone at 1100; 3 samples 1090–1120
    Dolomite, light drab, in minute chips; quartz sand and powder of shale; 2 samples 1120–1140
    Sandstone, very fine, buff, calciferous 1140–1150
    Sandstone, white, fine, rounded grains 1150–1160
  Oneota (90 feet thick; top 40 feet above sea level)—
    Dolomite, light yellow-gray and gray, drab at 1210-1230; 8 samples 1160–1250
Cambrian:
  Jordan sandstone (90 feet thick; top 50 feet below sea level)—
    Sandstone, white, fine, larger grains well rounded; fragments of arenaceous dolomite; shale 1250–1260
    Sandstone, with much dolomite in fine powder; 2 samples 1260–1280
    Sandstone, white, clean, fine, larger grains rounded; 2 samples 1280–1300
    Sandstone, whitish, fine; much microscopic angular quartzose material and dolomitic powder 1300–1320
    Sandstone, gray, fine, rounded grains; 2 samples 1320–1340
  Saint Lawrence—
    Trempealeau (50 feet thick; top 140 feet below sea level)—
      Dolomite, buff, in powder; some quartz sand 1340–1350
      Dolomite, gray, in fine chips 1350–1360
      Dolomite, argillo-arenaceous, in concreted masses 1360–1370
      Dolomite, gray, hard, in small chips concreted with argillo-calcareous powder in light blue-gray masses 1370–1380
      Dolomite, light blue-gray, argillaceous 1380–1390

Franconia (160 feet thick; top 190 feet below sea level)—
- Dolomite, gray, in chips and sand; highly glauconitic; with argillo-calcareous powder 1390–1400
- Dolomite, glauconitic; 2 samples 1400–1420
- Shale, light greenish, highly quartzose and dolomitic, glauconitic, quartzose matter minute and angular, in concreted powder and chips; 7 samples 1420–1500
- Shale, greenish and light purplish; slightly dolomitic; 5 samples 1500–1550

Dresbach (30 feet thick; top 350 feet below sea level)—
- Sandstone, white and gray, fine, larger grains rounded, some green, paper shale and glauconite at 1550; 3 samples 1550–1580

Eau Claire (230 feet thick; top 380 feet below sea level)—
- Sandstone, light greenish yellow, argillaceous, calciferous; 2 samples 1580–1600
- Sandstone, very fine, imperfectly rounded grains 1600–1610
- Sandstone, as above, light greenish yellow, argillaceous; 2 samples.. 1610–1630
- Shale, light blue, slightly calcareous 1630–1640
- Shale, dark green, glauconitic, arenaceous; 2 samples 1640–1660
- Shale, blue and green, plastic, at 1710 glauconitic and minutely arenaceous; 8 samples 1660–1730
- "Shale, blue"; no samples 1730–1770
- Sandstone, buff, fine-grained, in sand; some chips of soft light gray sandstone, as below 1770–1780
- Sandstone, gray, rather soft, of microscopic angular particles of quartz, argillaceous, slightly calcareous, in chips 1780–1790
- Shale, green-gray, non-calcareous, in hard concreted masses 1800–1810

Red Clastic series (20 feet thick; top 610 feet below sea level)—
- Sandstone, red and reddish brown, some grains 2 mm. in diameter, of clear quartz, surface stained; some black round grains, non-crystalline, harder than glass, opaque, brownish when pulverized; 3 samples 1810–1830

Archean (penetrated 55 feet; top 630 feet below sea level):
- Granite, or arkose, in fine sand of reddish feldspar, angular grains of quartz, and black mica; some rounded grains of quartz perhaps from above; 3 samples 1830–1860
- Granite: quartz, orthoclase feldspar, biotite mica 1860–1885

Driller's Log

	Depth in Feet		Depth in Feet
Yellow clay	0–35	Sandstone	1038–1063
Black clay	35–130	Limestone	1063–1091
Fine sandstone	130–186	Sandstone	1091–1121
Limestone	186–191	Limestone	1121–1254
Shale, red	191–201	Sandstone	1254–1342
Limestone	201–223	Shale	1342–1360
Shale	223–225	Shale	1360–1380
Limestone with shale	225–816	Limestone	1380–1424
Shale	816–833	Shale	1424–1469
Limestone	833–836	Limestone, very hard	1469–1480
Shale	836–856	Shale	1480–1483
Limestone	856–859	Limestone	1483–1487
Shale	859–915	Shale	1487–1551
Limestone	915–920	Sandstone	1551–1604
Shale	920–928	Shale	1604–1671
Sandstone	928–940	Shale	1671–1756
Shale	940–950	Sand rock	1756–1768
Sharp sand	950–960	Lime, brown, sandy	1768–1785
Shale and hard sharp sand	960–980	Shale, blue	1785–1808
Sandy shale	980–1020	Red shale, cavy	1808–1812
Sandy lime	1020–1038	Sandy red rock	1812–1885

*Mineral Content of City Well, No. 3, Algona**

	Parts Per Million
Bicarbonate	456.3
Chloride	9.
Sulfate	146.6
Silica	8.4
$Fe_2O_3+Al_2O_3$	14.8
Calcium	104.4
Magnesium	39.6
Na + K as Na	38.5
Total solids	589.4

ALTA, BUENA VISTA COUNTY

(Altitude 1514 Feet, I. C. R. R.)

The deep well of this city was completed in 1916 by Kiskadden and Anderson of State Center. The depth is 1465 feet and the diameters from 12 to 4 inches. A fair supply of water was found at about 500 or 600 feet. The main water bed was struck at about 1390 feet, 124 feet above sea level, and probably is the Saint Peter sandstone, since this aquifer would be expected at about this depth. The static level is 320 feet below the surface. On pumping there is an almost immediate draw down to 360 feet, where the water level remains constant under continuous pumping of 100 gallons per minute. The first pump installed was an air lift pump, but this has been replaced by a double cylinder pump, the cylinder hung at a depth of 390 feet. The water is reported as "soft."

An earlier well 72 feet deep supplies a very hard water at the pumping rate of 46 g.p.m. This well supply is used as far as possible on account of the cheaper lift. The cost of the deep well was about $6,000.

*Mineral Content of City Well, Alta**

	P.P.M.
Bicarbonate	422.1
Chloride	5.
Sulfate	354.8
Silica	13.2
$Fe_2O_3+Al_2O_3$	4.0
Calcium	231.7
Magnesium	33.3
Na + K as Na	63.2
Total solids	916.2

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon. 1927.

ARKEL, MAHASKA COUNTY

(Altitude 855 feet, C. & N. W. Ry.)

WELL OF CHICAGO & NORTH WESTERN RAILWAY COMPANY

Driller's Log

	Depth in Feet
Soil	0–1
Yellow clay	1–53
Sand and Gravel	53–71
Yellow clay	71–90
Blue clay	90–122
Yellow gravel and sand	122–124
Blue clay	124–154
Shale mixed with sand	154–172
Limestone	172–198
Sandstone	198–203
Limestone	203–207
Sandstone	207–211
Limestone	211–223
Sandstone	223–226
Limestone	226–230
Sandstone	230–241
Limestone	241–252
Sandstone	252–255
Limestone	255–273
Shale, blue	273–282
Limestone	282–285
Blue shale	285–317
Limestone	317–327

ARLINGTON, FAYETTE COUNTY

(Altitude 1112 feet, C., M. & St. P. Ry.)

The well drilled for the town of Arlington in 1923 by B. Sharff of Oelwein is 823 feet deep and has diameters from 8 to 5½ inches. It is reported that the Saint Peter sandstone was struck at a depth of 775 feet (about 337 feet above sea level) and was 45 feet thick. The only other fact that is known of the well is that from 820 to 823 feet the drill was working in very hard limerock.

There seems to be some deviation from the normal dip of strata in this area, as the Saint Peter was estimated to lie about 400 feet above sea level and was so mapped in the report of 1912 on the Underground Water Resources of Iowa.

*Mineral Content of City Well, Arlington**

	P.P.M.
Bicarbonate	290.4
Chloride	5.
Sulfate	53.0
Silica	12.2
$Fe_2O_3+Al_2O_3$	3.2
Calcium	72.9
Magnesium	21.7
Na + K as Na	18.1
Total solids	331.3

AUBURN, SAC COUNTY

(Elevation 1232 feet above sea level)

An oil prospect drilled at the village of Grant City, a mile north of Auburn, by Calvin Reed of Bowling Green, Kentucky,

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

was unfinished at the end of 1928. It had then reached the depth of 1315 feet. As the Pennsylvanian shales caved badly, no samples of the cuttings were saved until the Mississippian limestones were struck at 470 feet. The driller's log to this depth is as follows:

	Depth in Feet
Gravel	0–10
Shale	10–85
Glacial sand (water)	85–90
Blue shale	90–210
Black shale	210–250
Blue shale	250–450
Red shale	450–455
Brown sand (water, head 170 feet below curb, would lower by bailing)	455–470

Record of strata

	Depth in Feet
Mississippian (385 feet thick):	
Limestone, gray in mass, rapid effervescence in cold dilute HCl; white chert	470–475
Limestone, drab and gray, fine-crystalline, rather slow effervescence; 3 samples	475–535
Limestone, light blue-gray and yellow-gray, rapid effervescence; white chert	535–555
Limestone, buff, fine crystalline-granular, rather slow effervescence	555–560
Limestone, light yellow-gray, calcilutite, rapid effervescence; 3 samples	560–575
Limestone, light cream color, very fine of grain, in sand, rapid effervescence; 5 samples	575–600
Limestone, gray	600–605
Limestone, cream color or light yellow-gray, fine-grained or calcilutite, rapid effervescence; 11 samples	605–665
Limestone, gray	665–670
Limestone, light yellow-gray, fine-grained, rapid effervescence, some slow	670–680
Dolomite, light yellow-gray, in fine meal; 2 samples	680–695
Dolomite, light brown, in fine sand, speckled white with fine particles of chert	695–705
Limestone, gray, rather slow effervescence	705–710
Limestone, blue-gray, fine-grained, argillaceous, slow effervescence; 2 samples	710–720
Dolomite, brown; some white chert	720–725
Dolomite, gray; white chert	730, 733
Limestone, gray or blue-gray, slow effervescence; with gray or blue-gray chert; 4 samples	740–760
Chert, dark blue-gray and lighter; 4 samples	765–780
Limestone, gray and blue-gray, slow effervescence; chert of same color	785, 790
Dolomite, yellow-gray, fine crystalline-granular, in sand	800
Sandstone, gray, fine irregular grains, calcareous, with brisk effervescence; limestone, light yellow-gray, rapid effervescence	805
Dolomite, mottled dark and light gray, macrocrystalline, siliceous and argillaceous residue; shale concreting chips of dolomite into hard masses	815
Dolomite, drab, siliceous, argillaceous, macrocrystalline, in clean chips	820
Dolomite, very light gray, some gray and mottled, very fine grain; 4 samples	825–845
Shale, green-gray, pyritic, dolomitic, in lumps with fine chips of light gray dolomite; also shale, light gray, soft, noncalcareous, siliceous, best seen in fragments fallen from this stratum in samples below	850

Devonian-Silurian (295 feet thick):	
Dolomite, light yellow-gray and buff, fine crystalline-granular; 3 samples	855–865
Dolomite, light yellow-gray and buff, cryptocrystalline, very slow effervescence; 8 samples	870–905
Dolomite, blue-gray and yellow-gray, as above	910–915
Dolomite, yellow-gray and blue-gray and buff, cryptocrystalline; large fragment from 935; dolomite, buff, cryptocrystalline, with small cavities drusy with pearl spar; 7 samples	915–945
Dolomite, light blue-gray, soft, crystalline-earthy, somewhat vesicular, pyritic; some drab finely laminated shale	945–955
Dolomite, buff, gray and yellow-gray, some vesicular; 5 samples	955–980
Shale, light blue-gray, some drab, calcareous, pyritic, in lumps, inclosing fine chips of light yellow-gray limestone of rather slow effervescence	980–985
Dolomite, blue-gray, light blue-gray, and drab, rather slow effervescence; 6 samples	985–1020
Dolomite, brown and buff; 3 samples	1030–1050
Dolomite, light gray and yellow-gray	1060, 1070
Dolomite, brown, crystalline-granular, some in fine meal; 7 samples	1085–1140
Ordovician:	
Maquoketa (60 feet thick)—	
Shale, blue-gray, in chips; with dolomite	1150
Shale, dark greenish, noncalcareous, in hard masses inclosing chips of buff dolomite	1155
Shale, hard, light blue and green; light buff dolomite in fine chips	1160, 1170
Dolomite, buffish gray mottled darker, argillaceous, much green shale in chips	1180
Dolomite, buff, argillaceous, much light blue and green shale in chips	1200
Galena-Platteville (penetrated 105 feet)—	
Dolomite, brown and buff, fine-grained	1210
Dolomite, drab and gray, very fine of grain	1220, 1230
Dolomite, light yellow-gray and gray; 6 samples	1240–1315

Notes.—This prospect was drilled over the body of Cretaceous shales which have been used at Auburn for making clay wares and it seems probable that the "shale" of the driller's log from 10 to 85 feet is Cretaceous, probably Benton, and that the underlying "glacial sand" is in reality the Dakota sandstone. Both of these formations were recognized by Macbride in his survey of Sac county.[42a] The blue, black and red shale beneath probably is Pennsylvanian. The "brown sand, water bearing", at the base of the Pennsylvanian may be compared with the interesting brown arkosic sands at the same horizon in the deep well at Manson.

No attempt is made to subdivide the Mississippian. The heavy beds of cream-colored calcilutites and fine-grained light gray nonmagnesian limestones are noteworthy. The underlying blue and gray cherts and argillaceous dolomites from about 700 to 850 feet may represent the Kinderhook. As to the shale of the

[42a] Iowa Geol. Survey, vol. XVI, pp. 526-531.

Kinderhook the driller reports: "We did not get any Kinderhook shale to amount to anything; just a few streaks of it a foot or two thick." At Rockwell City a sample of shale and dolomite is supposed to represent a bed 220 feet thick, footing at about the same level, and is referred to the Kinderhook.

The shaly beds from 1150 to 1210 feet seem to mark the Maquoketa, although the shale is lithologically different from the "mud rock" Maquoketa shale of eastern Iowa. This leaves the dolomites 295 feet thick lying between the Maquoketa and the Kinderhook horizons to the Devonian-Silurian. Dolomites also characterize the strata below the Kinderhook at Rockwell City.

AUDUBON

(Altitude 1325 feet, C. & N. W. Ry.)

The city well at Audubon was drilled in 1912 by the J. P. Miller Artesian Well Company of Chicago. Much water was found in quicksand from 26 to 31 feet and was cased off. At 1510 feet in "blue limestone" above the Maquoketa shale water stood 240 feet below the curb and tested 120 gallons per minute with a six-inch pump. Some more water with the same head is reported at 1584 feet in argillaceous dolomite below the main body of Maquoketa shale. Below this depth more water was found but at what levels is not stated. On completion the well pumped 208 gallons per minute and the static level had risen to 225 feet from the curb.

Record of strata in city well, Audubon, with driller's log to 1040 feet

	DEPTH IN FEET
Pleistocene and Recent (252 feet thick; top 1300 feet above sea level):	
"Clay	0–26
"Quicksand	26–31
"Clay	31–250
"Rock, perhaps a boulder	250–251
"Clay, yellow	251–252
Pennsylvanian (323 feet thick; top 1048 feet above sea level):	
"Shale	252–377
"Coal and sulphur	377
"Shale, gray	377–475
"Shale, black	475–480
"Shale, light colored	480–575
Mississippian (520 feet thick; top 745 feet above sea level):	
"Streaks of lime and shale	575–610
"Sandy lime 7, green shale	610–630
"Sand	630–636
"Lime, clear, brown	636–653
"Streaks of lime and shale with some spar	653–654
"Shale, sandy	654–657
"Shale, green	657–660
"Lime with quartz in it	660–725
"Shale, green	725–736

"Lime"	736–745
"Streaks of lime and shale"	745–790
"Lime, clear, white"	790-820
"Shale"	820–860
"Marl, yellow"	860–865
"Lime, gray, full of quartz"	865–1040
Shale, highly calcareous, blue gray, in friable concreted masses; 5 samples	895–935
Limestone, light yellow-gray, soft, earthy, rapid effervescence in cold dilute HCl; green shale, chalcedonic silica	945
Chert, blue-gray, and limestone	955
Dolomite or magnesian limestone, light brown, crystalline-granular, slow effervescence, large chips of blue shale	965
Limestone, gray, rapid effervescence, cherty	975
Chert, blue	985
Limestone, gray, rapid; blue chert	995
Limestone and shale, limestone gray, rapid effervescence, much chert; in friable concreted masses	1005–1015
Limestone, blue-gray and yellow, oölitic, rapid, some blue chert	1025
Shale, light blue and greenish, calcareous, in chips and concreted masses; 6 samples (Kinderhook)	1035–1085
Devonion (?), Silurian (445 feet thick; top 205 feet above sea level):	
Dolomite, light blue-gray, argillaceous; 5 samples	1095–1135
"Shale, green"	1140–1143
Dolomite, light yellow-gray, blue-gray and whitish, some chips in cuttings with rather brisk effervescence, some gray shale; 11 samples	1145–1390
Dolomite, light buff, crystalline, in sand	1435
"White lime"	1440–1480
"Lime, bluish"	1480–1485
"Shale"	1485–1489
"Lime, bluish"	1489-1540
Ordovician:	
Maquoketa shale (90 feet thick; top 240 feet below sea level)—	
"Green shale"	1540–1557
Dolomite, blue-gray, earthy, argillaceous, some green shale; 2 samples	1540, 1600
Galena and Platteville (335 feet thick; top 330 feet below sea level)—	
"Lime, flinty at 1740 and 1791, white shale at 1865 to"	1980
"Shale"	1980–2015
"Shale, green"	2015–2052
Dolomite, light gray, light buff	1630, 1665
Dolomite, whitish, argillaceous, in concreted masses	1675, 1685
Dolomite, light gray, in fine sand and small chips; 3 samples	1695–1715
Chert and dolomite, white	1725, 1735
Dolomite, in whitish flour and concreted masses, highly argillaceous, or dolomitic shale	1745
Chert and dolomite; 3 samples	1755–1775
Dolomite, light yellow and whitish, cherty; 4 samples	1785–1815
Dolomite, whitish, highly argillaceous, in flour and concreted masses; 3 samples	1825–1845
Dolomite, blue-gray and buff and drab, in sand, cherty at 1885–1905, argillaceous at 1915 to 1935; 11 samples	1855–1955
Glenwood (80 feet thick)—	
Shale, bright blue-green, in flaky chips	1965, 1975
Shale, light blue-gray, highly calcareous, nonplastic; 3 samples	1985–2005
Shale, bright blue-green, plastic, in flakes and concreted masses; 3 samples	2015–2035
Saint Peter sandstone (60 feet thick; top 715 feet below sea level)—	
Sandstone, whitish, fine, rounded grains; considerable green shale; 5 samples	2045–2085
Sandstone, highly argillaceous, calciferous, grains fine, some with secondary enlargements; in concreted masses	2095

Prairie du Chien (penetrated 295 feet; top 805 feet below sea level)—	
Dolomite, buff, highly arenaceous, in fine sand of dolomite, crystalline and cryptocrystalline quartz	2105-2110
Dolomite, gray	2125
Dolomite, brownish gray, highly vesicular with minute spheroidal cavities as if from the removal of oölite grains; in large chips	2135
Dolomite, buff in mass, much fine quartz sand	2145
Dolomite, gray	2155–2165
Dolomite, highly arenaceous, or sandstone; cuttings in buff sand of dolomite and rounded grains of quartz (New Richmond? Jordan?)	2175–2185

Notes.—In the above section, the carefully kept driller's log fills out the first 895 feet, of which no samples of the cuttings were taken, and also bridges an occasional gap below that depth and inserts thin beds of which the samples taken at wider intervals give no evidence.

The base of the Mississippian is drawn with considerable uncertainty at the bottom of the 50 foot bed of shale struck at 1035 feet, since this bed seems to represent the Kinderhook shale of southeastern Iowa.

The shale and argillaceous dolomite at 1540 feet hold about the position at which the Maquoketa might be expected. If this identification of the Maquoketa is correct the dolomites above it are probably largely, if not wholly, Silurian, and those beneath it are Galena and Platteville, together with the basal shales (the Glenwood) immediately overlying the Saint Peter.

Whether the calciferous sandstone at 2095 feet belongs with the Saint Peter as a basal transition bed or with the Prairie du Chien is a matter of doubt, but the dolomites beneath it are clearly the latter in both place and facies.

Driller's log of Audubon deep well, below 1040 feet

	Depth in Feet
Green shale	1040–1103
Lime, chalky, with little white balls at 1115	1103–1140
Shale	1140–1182
Lime, at 1193 hard and soft streaks of chalky lime	1182–1405
Crevice of 8 inches at	1405
Brown lime	1405–1440
White lime	1440–1480
Bluish lime	1480–1485
Shale	1485–1489
Bluish lime	1489–1540
Green shale	1540–1557
Lime, flinty at 1740 and 1791, streak of white shale at 1865	1557–1980
Shale	1980–2015
Green shale	2015–2052
Sand	2077–2105
Lime	2105–2400

*Chemical analysis of water of Audubon city well**

Acids and Bases		Parts per 100,000	Probable Combination in the Water		Grains per U. S. gallon
Sodium Oxide	Na_2O	35.61	Calcium Carbonate	$CaCO_3$	11.37
Calcium Oxide	CaO	23.97	Calcium Sulphate	$CaSO_4$	18.49
Magnesium Oxide	MgO	9.92	Magnesium Sulphate	$MgSO_4$	17.36
Iron Oxide	Fe_2O_3 }		Iron Oxide	Fe_2O_3 }	
Alumina	Al_2O_3 }	0.16	Alumina	Al_2O_3 }	0.09
Silica	SiO_2	0.84	Silica	SiO_2	0.49
Sulphuric Acid	SO_3	61.40	Suspended Matter		0.74
Chlorine	Cl	20.45			
			Incrusting Solids		48.54
Hardness, Etc.			Sodium Sulphate	Na_2SO_4	23.74
Hardness		69.00	Sodium Chloride	$NaCl$	19.65
Alkalinity		19.5			
Metacidity		1.7	Non-Incrusting solids		43.39
			Free Carbon Dioxide	CO_2	0.44
			Half Bound Carbon Dioxide	CO_2	5.00
			Volatile Matter		5.44

AYRSHIRE, PALO ALTO COUNTY

(Altitude 1315 feet, M. & St. L. R. R.)

A well 878 feet deep was drilled for the town of Ayrshire in 1921 by Bert Sharff, artesian well contractor of Oelwein. The diameters are 10 inches to 346 feet, 8 inches to 800 feet, and 6 inches to 878 feet. Water stands at 116 feet from the surface of the ground. The capacity as measured by a 24 hour test with the pump 46 feet below the surface of the water was 120 gallons per minute. As the well is cased to the Saint Peter sandstone at 852 feet, it is assumed that the supply tested was entirely from that formation. A flow of 22 gallons was found at 360 feet in "sand" and a flow untested but apparently much larger was found at 650 feet.

Driller's Log

Formation	Depth in Feet	Formation	Depth in Feet
Soil	0–3	Brown lime, very hard	694–702
Clay, yellow	3–13	Gray rock	702–711
Gravel, coarse	13–15	Blue shale	711–714
Clay, blue	15–100	Lime rock	714–732
Sand	100–105	Green shale	732–734
Clay, blue and brown	105–295	Lime, brown	734–740
Sand	295–346	Shale, bluish	740–753
Sandrock	346–352	Rock	753–756
Sand	352–370	Blue shale	756–840
Shale, brown	370–378	Black shale	840–846
Sand, very fine	378–515	Hard rock	846–848
Limestone	515–560	Blue shale	848–852
Blue shale and shelly rock	560–640	Saint Peter sandrock	852–878
Dakota sandstone	640–694	Shale	878

* L. M. Booth Co., Engineering Dept., Jersey City, 1917.

Notes.—The above log was evidently taken with care, and to a considerable extent the rocks described can be referred to their respective geological formations with assurance, although no samples of the cuttings were saved. The workmen were familiar with the Saint Peter sandstone from their experience in eastern Iowa and their identification of the sandstone at 852 feet (463 feet above sea level) may be taken as correct. A forecast for Ayrshire had given the depth of the Saint Peter as 400 feet above sea level. As at Algona and Emmetsburg to the northeast and Hartley to the northwest, the very heavy shales above the Saint Peter are referred to the Glenwood and perhaps include the Platteville and Decorah. As far up as the brown limestone at 694 feet (621 feet above sea level) we have evidently the Galena limestone. But the 54 feet of "Dakota sandstone" from 640 to 694 feet is difficult to interpret. No such sandstone occurs at this horizon at Emmetsburg and Algona. Comparing the Ayrshire section with the Emmetsburg section the summit of the Saint Peter occurs at Ayrshire 33 feet lower than at Emmetsburg and the summit of the Glenwood-Decorah is some 16 feet lower. But if the sandstone whose base is at 694 feet (621 feet above sea level) is the Dakota, then that sandstone declines from Emmetsburg to Ayrshire the extraordinary amount of 297 feet. And if the sandstone in question is Dakota, the 125 feet of "limestone," "blue shale and shelly rock" immediately overlying it are left quite in air. Under these circumstances, the possibility must be considered that the fine sand to which Galena dolomite often cuts has been mistaken for true sandstone, a mistake often made, and that, unaccustomed, perhaps, to the Dakota sandstone of western Iowa, the drillers labelled the formation as Dakota. If the Galena extends upward, then, to 640 feet, the "blue shale and shelly rock" above it may represent in part the Maquoketa.

The "sandstone, very fine" from 378 to 515 feet is pretty surely Cretaceous and its base at 800 feet above sea level is 118 feet lower than the base of sandstone of the Dakota at Emmetsburg. The drift probably extends to the base of the "blue and brown clay," which is here taken to be till, giving it a thickness of 295 feet, and may also include the "sand" beneath, which would make the total depth 346 feet.

*Mineral Content of City Well, Ayrshire**

	P.P.M.
Bicarbonate	383.1
Chloride	12.
Sulfate	572.9
Silica	15.6
$Fe_2O_3+Al_2O_3$	5.2
Calcium	133.4
Magnesium	66.3
Na + K as Na	105.7
Total solids	1103.0

BANCROFT, KOSSUTH COUNTY
(Altitude 1174 feet)

The city well of Bancroft, drilled in 1928 by Bert Sharff of Oelwein, is 626 feet deep. Rock was struck at 165 feet and was "shelly" to 275 feet. The Saint Peter sandstone was not reached, but according to the gradient between Algona and Blue Earth, Minnesota, it should be encountered at about 675 feet from the surface. The static level of the well is 24 feet below the surface, with a draw down of five feet after a 24 hour test pumping of 150 g.p.m.

BAYARD, GUTHRIE COUNTY
(Altitude of curb about 1080 feet)

In the autumn of 1926 a group of Guthrie Center citizens organized the Central Oil and Gas Company and began drilling an oil prospect near Bayard. Sample drillings were sent to the Survey by the driller, Mr. Calvin Reed of Bowling Green, Kentucky. The record of the drillings follows, with interpretations by Dr. James H. Lees, Assistant State Geologist. Work on this prospect was discontinued at 1320 feet, in August, 1927, but was resumed in January, 1929, with G. H. Rose and Son of Maryville, Missouri, as drillers.

Samples from Bayard Well

	DEPTH IN FEET
Pleistocene:	
Till, glacial, with pebbles	20–30
Gravel, glacial, pebbles up to one-half inch diameter; "flowing water"	30–50
Sand, very fine, uniform, gray	50–100
Same as above; "gas at 110 feet"	100–150
Clay, probably glacial, gray, fine-textured, a few pebbles	150–155
Sand and gravel, rather fine, probably glacial	155–170
Sand, fine, uniform, light gray, a few specks probably mica	170–180

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

Clay, fine, uniform, brownish gray, probably glacial	180–205
Clay, black, very fine, some siliceous pebbles	205–220
Des Moines:	
Shale, very fine, smooth feel, gray, probably Des Moines	220–300
Sand, fine, uniform, light gray; "Water"	300–312
Shale, fine, dark gray	312–330
St. Louis and Osage:	
Limestone, gray, fine-grained	330–340
Limestone, gray, with fragments of dark chert	340–350
Limestone, finely sandy, gray	350–358
Sandstone, limy, fine-textured, dark gray	358–368
Limestone, gray, fine-grained	368–375
Limestone, dark gray	375–385
Limestone, similar to above, with lighter fragments	385–395
Limestone, dark gray, with fragments of fine-grained sandstone and clayey sand	395–400
Limestone, dark gray, fine-grained, with large amount of sand in rather coarse white grains	400–410
Limestone, dark gray, similar to above; blue chert	410–420
Sandstone, fine-grained, much chert and lime	420–425
Limestone, dark gray, some fine-grained, some coarser	425–440
Limestone, similar to above, some chert and quartz grains	440–450
Sandstone, fine, dark, some lime, probably as matrix. "Water"	450–453
Limestone, dark gray, in coarse chips, sugary texture, much chert and quartz	453–460
Limestone, dark gray; chert, gray to white; shale, black	460–470
Limestone in chips and powder, the former responding slowly to acid at first, more briskly later; shale, black; some chert, white and gray	470–480
Limestone, gray; chert, bluish white and gray; all in small angular chips. A little dark shale	480–490
Limestone, etc., similar to above	490–500
Limestone, gray, some fine sand, much gray to white chert in fragments	500–510
Shale, dark gray, very fine-textured, calcareous	510–520
Shale, similar to above, and fragments of limestone and of flint which contain some lime as shown by reaction	520–530
Limestone and chert, gray, in fine grains and powder	530–540
Same as above	540–550
Limestone, dark gray, in small chips, with chert and some shale	550–560
Limestone, light gray, with much chert, in fine grains	560–570
Same as above	570–580
Limestone, light gray, in fine powder, ready effervescence in acid	580–590
Limestone, gray, in fine grains, with much chert and clear quartz grains	590–600
Same as above	600–610
Limestone, light tan color, in fine grains, a little chert	610–620
Limestone, gray, in small flakes and grains, very finely granular, some grains and powder of chert	620–625
Limestone, dark gray, in small grains, some chert	625–630
Limestone, light gray, chips and powder, vigorous effervescence, considerable residue. Fragments of limestone are made up of small rounded grains with fine matrix	630–640
Limestone, similar to above	640–650
Same as above	650–660
Limestone, similar to above, some chert and pyrite	660–670
Limestone, gray, in angular chips, which are almost entirely soluble in acid. Some grains of chert	670–680
Limestone, similar to above but more chert	680–690
Limestone, with much chert	690–700
Same as above	700–710
Limestone, dark gray, in fine grains; some chert and a good deal of fine sand	710–715
Limestone, similar to above, only in larger grains; finely granular texture, mostly soluble in acid	715–720

Similar to above, some chert	720–730
Limestone, dark gray, finely sugary texture, rather slow reaction to acid, probably dolomitic; some gray chert	730–735
Limestone, similar to above but with more fine sand, which is insoluble in acid	735–740
Limestone, similar to above, but with less sand	740–745
Kinderhook:	
Shale, fine-textured, gray-green, some lime present	745–775
Shale, very finely gritty, blue-green, somewhat limy	775–800
Shale, very finely gritty, light gray, calcareous	800–825
Shale, dark green when damp, very fine-textured, little lime present; some harder nodules with calcareous matrix	825–835
Devonian and Silurian (?):	
Limestone, dark gray, sugary texture, in small chips and granules; almost entirely though slowly soluble in acid	835–840
Limestone, light tan, finely crystalline with sparkling facets; almost entirely soluble in acid. Some darker chips	840–845
Limestone, light tan, very similar to above	845–850
Limestone, gray, similar to above, except for slightly darker color. Some chips of shale may be from above. Driller says rock below Kinderhook shale drilled as if there were streaks of shale a foot or so thick, but that Kinderhook was caving, so could not be sure	850–860
Limestone, very light tan, somewhat sugary texture, but finer grained than samples above. In chips one-fourth to three-fourths inch in diameter. A few of these show pyrite	860–865
Limestone, similar to above, but in smaller chips and grains; a little pyrite; some shale. Responds readily to acid and is almost entirely soluble	865–870
Limestone, a little darker and more coarsely crystalline than sample above. Some fragments of calcite and some shale	870–880
Limestone, in small crystalline grains, mostly gray, some white and some transparent. Responds rather slowly to cold acid, more strongly to hot acid; entirely soluble	880–885
Limestone, similar to above, in uniformly small gray granules; evidently dolomitic, but entirely soluble	885–890
Limestone, dark gray, in chips and coarse powder. Effervesces rapidly in cold acid—finely granular	890–895
Limestone, similar to above; considerable shale	895–905
Limestone, similar to above, but somewhat more definitely crystalline; in fine grains; much shale	905–910
Limestone, gray, finely granular and sugary, strong response to acid, a little very fine siliceous residue. Considerable shale in bluish chips, very fine-textured, very slightly limy	910–915
Limestone, similar to above, but with somewhat coarser sugary texture. Much shale as above	915–920
Limestone and shale, as above	920–925
Limestone, light bluish gray, finely crystalline, slow response to acid, but almost complete solution. Not much shale	925–930
Limestone, light gray, similar to above sample	930–935
Limestone, dark gray, very finely granular, slow response to acid, with a little whitish residue. Some shale	935–945
Limestone, similar to above	945–950
Limestone, similar to above	950–960
Limestone, light gray, very fine-grained, readily and almost completely soluble in acid	960–965
Limestone, rather dark gray, distinctly sugary texture, a little fine-grained shale	965–970
Limestone, similar to above. Numerous shale chips	970–980
Limestone, similar to above but finer in texture—not much shale	980–985
Limestone, rather dark gray, finely to coarsely crystalline	985–990
Limestone, similar to above. Some shale	990–995
Limestone, similar to above	995–1000

Limestone, rather dark gray, in fine gritty powder. Reaction of acid is rather slow at first, considerable residue of fine clear quartz sand grains 1000–1010
Limestone, similar to above but in larger grains; some sand grains 1010–1020
Limestone, similar to above. The rock has a fine sugary texture and this and its slow response to acid probably indicate that it is magnesian 1020–1030
Limestone, similar to above, but again in rather fine powder with much fine clear sand 1030–1040
Limestone, similar to above, coarser grains. Some quartz sand and some fragments of clear calcite 1040–1050
Limestone, similar to above 1050–1060
Limestone, similar to above 1060–1070
Limestone, somewhat lighter gray than samples above, otherwise similar 1070–1080
Limestone, similar to above. Ready response to acid. Considerable quartz in small grains 1080–1090
Limestone, similar to above, only finer grains 1090–1100
Limestone, gray, evidently dolomitic, action with acid slow but long continued, with almost complete solution of the sample. In very fine grains, very little silica 1100–1120
Limestone, like that above 1120–1140
Limestone, or dolomite, gray, in grains and fine powder, finely granular, slow response with acid, but nearly complete solution 1140–1180
Limestone, darker gray, in medium sized, finely granular grains; response with acid rather more brisk than sample above, few sand grains but otherwise material is almost entirely soluble 1180–1190
Limestone, dark gray, in coarse grains, some white calcareous material in fine powder. Nearly all soluble. Much blue noncalcareous shale in small chips and powder. Driller says the shale seems to be in layers six to twelve inches thick and two to five feet apart 1190–1195
Limestone and shale, similar to above 1195–1200
Limestone, similar to above but shale less abundant 1200–1210
Limestone, similar to above sample, in fine grains, some white calcite, some shale 1210–1220
Limestone, dark gray, in coarse grains, rapid reaction with acid. Much shale 1220–1235
Limestone, like above 1235–1240
Limestone, very dark gray, in coarse grains and chips, ready response with acid. Perhaps one-fourth shale 1240–1245
Limestone, and shale as above but in smaller fragments 1245–1250
Limestone and shale, similar to above, cuttings fine 1250–1260
Limestone, dark gray, in fine crystalline granules; shale, dark blue-green in small chips, constitutes perhaps one-fourth of mass. Fairly brisk response to acid, solution of limestone nearly complete 1260–1270
Limestone and shale, similar to above 1270–1280
Limestone and shale, similar to above 1280–1290
Limestone, gray, some very fine-grained, some rather finely granular. Very little shale. Considerable cherty residue 1290–1300
Limestone, similar to above 1300–1315
Limestone, gray, granular, and shale, blue-green. Both are in fine powder to small chips, up to one-fourth inch diameter. Response to acid very brisk, much residue of shale and chert. A few chips from 1320 feet are dark gray hard noncalcareous shale 1315–1320
Limestone, brownish gray, in fine sand, dolomitic, some residue of very fine siliceous material and small chips of chert; shale, blue-green, brittle, in small chips 1338–1342
Limestone, similar to above but in finer more uniform crystalline sand; response to cold acid fairly brisk; residue very finely divided silica; no shale present; 2 samples 1340–1343
Limestone, similar to above but in somewhat coarser fragments; numerous smoothly rounded clear grains of quartz 1346–1355

Limestone, light gray and grayish tan, in fine crystalline sparkling granules which dissolve rather readily in cold acid and leave a residue of very fine siliceous material; 4 samples	1355–1380
Limestone, medium gray, coarse to fine granules, sugary texture, response in cold acid fairly brisk, more rapid in hot acid, long continued, residue small	1385
Limestone, light gray, in very fine powder of crystalline granules of rather slow response to cold acid; 4 samples	1390–1405
Dolomite, dark tan, small angular chips of chert and fewer rounded, rather clear dolomitic grains. Response to acid not very brisk, residue large	1408
Dolomite, similar to above but in coarser fragments; chert, gray, comprising greater part of sample, some white, chalcedonic; 2 samples	1415, 1420
Dolomite, bluish gray at 1425 and 1435, dark gray at 1445 and 1448, in powder and chips, response to hot acid somewhat more ready than in two preceding samples; abundant gray chert; 4 samples	1425–1448

Notes.—The driller notes: Struck gas in a "sea mud" at 110 feet. This formation was real soft and would heave up the hole from 30 to 40 feet. I had to drive the casing ahead of the tools in order to drill the well. The last ten feet of (Kinderhook) shale seemed to be harder and there may be quite a lot of lime in it, but it was about the same color as the shale. The strata seemed to change at about 1160 or 1180 feet as if the drill were passing from Devonian to Silurian strata.

BETTENDORF, SCOTT COUNTY

(*Altitude 572 feet*)

WELL NO. 2 OF THE BETTENDORF WATER COMPANY

The first deep well of the Bettendorf Water Company was sunk by the Bettendorf Improvement Company, and was described in the report of 1912 on the Underground Water Resources of Iowa. The second well was drilled in 1925 by Thorpe Brothers Well Company of Des Moines. The depth is 2122 feet; the diameters are from 20 to 10 inches. Water was found from 1505 to 1565 feet in the Jordan sandstone, when a distinct fall of the static level was noted, the water dropping in the tube to 30 feet below the curb. The advice of this office was asked as to going deeper and the company was strongly urged to not stop the work until the water bed of the Dresbach had been tapped. A higher head from this Cambrian aquifer was also predicted. The main supply of the well was reported in the Dresbach sandstone from 1868 to 1990 feet and water was found also at 2100 feet in the Eau Claire. The pumping capacity of the well is 1000 gallons per minute, and the natural flow is 200 gallons per minute.

The relations of the two wells 100 feet apart are of special interest. Well no. 1, 1650 feet deep, taps no water beds below the Jordan sandstone. In well no. 2 the Saint Peter is cased out. Yet the amount of leakage from well no. 2 into well no. 1 is so great that for some time it was not necessary to install a pump in well no. 2. "On pumping no. 1 at the rate of about 600 gallons per minute the draw-down is about 12 feet. The draw-down on no. 2 while pumping no. 1 is about 5 feet. Pumping out of no. 2 at the rate of 1000 gallons per minute, the draw-down was about 15 feet. The draw-down on no. 1 while pumping no. 2 is nothing. Pumping both wells at the same time does not change the draw-downs as stated above, that is, 15 feet on no. 2 and 12 feet on no. 1."

These facts illustrate the well known law that the water of a lower aquifer discharges laterally into any higher aquifer whose water is under less pressure. At Clinton in well no. 6 of the Waterworks Company, the strong flow from the Mount Simon horizon of the Cambrian had such an enormous leakage that according to the officials of the company it lifted some 3 feet the head of other artesian wells within an area extending 2000 and 3000 feet from the well. At Bettendorf the company fortunately is able to retrieve a portion of the leakage through well no. 1.

The drill hole is cased with 20 inch cast iron casing to 120 feet, 12 inch from 391 to 644 feet, 10 inch from 946 feet to 1127 feet, and 10 inch from 1573 to 1855 feet. The cost of the well was $26,000. The data as to the well and as to several wells at Davenport were supplied by Mr. W. Z. Schneider, general manager of the company, who also donated to the Survey an exceptionally complete set of samples of the cuttings.

Record of Strata of Well No. 2 of the Bettendorf Water Company

	Depth in Feet
Pleistocene and Recent (35 feet thick; top 586 feet above sea level):	
Soil, dark	10
Sand, lighter, some grains of limestone	20
Sand as above, some particles of gray sandstone	30
Devonian:	
Wapsipinicon limestone, Lower Davenport beds (35 feet thick; top 551 feet above sea level)—	
Limestone, whitish, rapid effervescence in cold dilute HCl; 3 samples	40–60

Silurian:	
Niagaran (350 feet thick; top 516 feet above sea level)—	
Dolomite, cream-gray and light blue-gray, compact, slow effervescence	70, 80
Dolomite as above, some buff and brown; 5 samples	90–130
Dolomite, light gray, in small chips and whitish powder, in larger chips and vesicular from 260 down; with some white flint at 350 and 360; with much white flint from 370 to 410; 28 samples	140–410
Ordovician:	
Maquoketa shale (200 feet thick; top 166 feet above sea level)—	
Shale, bluish, highly calcareous, with microscopic quartzose particles, in small chips, with some dolomite; 3 samples	420–440
Shale, blue, in powder, with chips of hard dark argillaceous limestone	450
Shale, in powder and chips; 3 samples	460–480
Limestone, dark drab, argillaceous, in small chips	490, 500
Shale, blue, in powder and chips; 7 samples	510–570
Shale, olive green	580
Shale, light brown, fissile, feebly inflammable	590
Shale, brown, strongly inflammable	600, 610
Galena and Platteville limestones and Glenwood shales (365 feet thick; top 34 feet below sea level)—	
Dolomite, light brown, vesicular, in small chips	620
Dolomite, gray and buff; 10 samples	630–720
Dolomite, brown and buff, much white chert; 6 samples	730–780
Dolomite, gray, some chert; 3 samples	790–810
Dolomite, brown, cherty	820
Dolomite, blue-gray, cherty	830
Dolomite, brown, cherty; 4 samples	840–870
Limestone, in large flakes, earthy, rapid effervescence; some bright green shale in flakes	880
Limestone, blue-gray and whitish, in sand, rapid effervescence, earthy	890
Dolomite, light buff, cherty (misplaced ?)	900
Limestone, as at 890; 4 samples	910–940
Glenwood formation—	
Sandstone, white, fine, grains well rounded, some limestone	950
Sandstone, white, clean, as above	960
Shale, dark green, pyritiferous, noncalcareous, in flakes and concreted masses	970
Shale, dark green, in splintery flakes; and white sandstone, coarser than at 950	980
Saint Peter sandstone (75 feet thick; top 399 feet below sea level)—	
Sandstone, white rounded grains, with small friable whitish masses of sand of minute angular grains with calcareous cement; shale in dark green flakes; laminated greenish argillaceous sandstone	990
Sandstone, white, clean, St. Peter facies, larger grains at 1050 1 mm. in diameter; 6 samples	1000–1050
Prairie du Chien (440 feet thick; top 474 feet below sea level)—	
Dolomite, whitish to light brownish gray; with siliceous oölite at 1240, 1250, 1260; with chert at 1130, 1300-1390, 1410, and 1470; with considerable quartz sand at 1250, 1260 and 1290; with some quartz sand in cuttings at 1130, 1170, 1240, 1250, 1290; 44 samples	1060–1490
Cambrian:	
Jordan sandstone (80 feet thick; top 914 feet below sea level)—	
Sandstone, white, calciferous, rounded grains, in chips, with whitish dolomite and much siliceous oölite	1500, 1510
Sandstone, white, fine, larger grains rounded; with dolomite and chert	1520–1530

Dolomite, gray, in small chips, with much quartz sand	1540
Chert; gray siliceous dolomite; sandstone, fine, in chips; and much quartz sand, rounded	1550–1560
Sandstone, in small chips, showing dolomitic cement; grains rounded	1570
Saint Lawrence:	
Trempealeau beds (170 feet thick; top 994 feet below sea level)—	
Dolomite, blue-gray and drab; in fine chips and powder; 16 samples	1580–1740
Franconia beds (110 feet thick; top 1164 feet below sea level)—	
Dolomite, dark buff in mass, quartzose and slightly glauconitic, some purplish shale as below	1750
Shale, purplish, highly arenaceous with minute angular quartzose particles, highly calcareous; some glauconite	
Shale, green-gray, highly arenaceous, with finest angular particles, glauconitic, calcareous	1760
Shale, green-gray, highly arenaceous, calcareous, glauconitic (or sandstone, of finest angular grains); 3 samples	1770–1790
Dolomite, gray, minutely arenaceous, sparingly glauconitic; with green shale	1800–1810
Sandstone, gray, dolomitic, of minute grains, sparingly glauconitic	1820
Dolomite, as at 1800	1830
Sandstone, gray, of minute angular particles, dolomitic, glauconitic	1850
Dresbach sandstone (140 feet thick; top 1274 feet below sea level)—	
Sandstone, cream-colored in mass, larger grains well rounded	1860
Sandstone as above, coarser, in chips and loose grains	1870
Sandstone, white, fine, rounded grains, in loose sand; and minute chips of microscopic angular particles in dolomitic cement	1880
Sandstone, cream white, fine, larger grains well rounded; some particles of coal at 1970 and 1980; 11 samples	1890–1990
Eau Claire beds (penetrated 122 feet; top 1414 feet below sea level)—	
Sandstone, green-gray, in small chips, microscopic angular particles, dolomitic, slightly argillaceous; some glauconite; considerable brownish cryptocrystalline silica	2000
Sandstone, fine, larger grains rounded, some green pyritiferous shale	2010
Sandstone, gray, fine, dolomitic, in chips	2020
Sandstone, gray, fine, grains poorly rounded, a little glauconite	2030
Sandstone, light buff, very fine angular grains, a little glauconite	2040
Sandstone, gray, in chips, grains minute; dolomitic, glauconitic; some green shale; much shale at 2090; 5 samples	2050–2090
Sandstone, light buff, of minute angular particles, dolomitic, glauconitic	2100, 2110
Shale, drab, plastic, in difficultly friable masses, microscopically quartzose, dolomitic	2122

Driller's Log of Bettendorf Water Company Well No. 2

	Depth in Feet
Black soil	0–10
White fine sand	10–25
Broken lime and light colored shale	25–40
Hard gray lime	40–400
Blue shale	400–480
Hard gray lime	480–530
Blue shale	530–600
Hard white lime	600–945
Sand and shale	945–960
Light green shale	960–985
Sandstone, white fine sand	985–995
Saint Peter sandstone. Soft white fine sand	995–1045

Shale and sand	1045–1055
Lime and red shale	1055–1085
Very hard white lime	1085–1505
White hard sand	1505–1565
White limestone, medium hard	1565–1732
Red lime and shale	1732–1765
Sand, gray lime and shale	1765–1780
Sand and gray lime, very hard	1780–1868
White fine soft sand	1868–2018
White fine sand with black specks	2018–2045
White fine sand and shale	2045–2068
Mixture, sand, shale and black specks	2068–2100
Gray limestone	2100–2120
Red shale	2120–2122

BRIGHTON, WASHINGTON COUNTY

(Altitude 740 feet, C., B. & Q. R. R.)

In 1923 a deep well was drilled for the town of Brighton by Floyd Alspach, contractor, of Nowata, Oklahoma. The depth is 1815 feet and the diameters may be inferred in part from the casings, of which a 12 inch pipe is set at 97 feet, an 8 inch pipe at 209 feet and a 6 inch pipe at 1492 feet. Water was found in Meramec sandstone at 120 feet; at 655 and 775 feet in Devonian limestone; from 1260 to 1265 feet in a sandstone stratum of the Glenwood; in the Saint Peter sandstone, 1287 to 1322 feet; in arenaceous dolomite of the Shapokee and New Richmond; and in the Oneota dolomite, from 1500 to 1530, from 1550 to 1650 and from 1665 to 1685 feet.

On completion, water stood 90 feet below the surface.

Record of Strata

	Depth in Feet
Pleistocene and Recent (90 feet thick; top 748 feet above sea level):	
Sand, yellow, clayey	30
Clay, yellow, sandy	40
Clay, yellow	50
Clay, yellow, sandy	60
Sand, gray, grains irregular, moderately fine, mostly of clear quartz, also black, yellow and purplish	70, 80
Mississippian:	
Meramec, Osage and Upper Kinderhook beds (290 feet thick; top 658 feet above sea level):	
Shale, gray, unctuous; some sand	90
Sandstone, light gray, clear quartz, fine, irregular grains, calcareous matrix at 100, noncalcareous at 110, with some limestone particles at 120, argillaceous and calcareous at 130	100–130
Limestone, light blue-gray, slow effervescence in cold dilute HCl, siliceous with minute particles of clear quartz and some grains of quartz sand; pyritiferous; in sand	140
Chert, dark gray and white, some banded, bands up to 4 mm. wide; sandstone, gray, fine, with sporadic coarse grains; calciferous	150
Sandstone, blue-gray, highly argillaceous, grains very fine, irregular; in friable masses	160

Shale, blue-gray, calcareous	170
Limestone, blue-gray, macrocrystalline-earthy, rapid effervescence, soft, friable, in large chips	180
Shale, blue-gray, calcareous, in concreted masses	190, 200
Shale, highly calcareous, blue-gray, in chips; chalcedonic silica	210
Limestone, whitish, rapid effervescence, macrocrystalline-earthy; in large chips	220
Limestone, light gray, rapid effervescence, earthy, with some greenish specks of included shale; much white chert	230, 240
Limestone, whitish, fine granular-crystalline, rapid effervescence, hard; much white chert	250, 260
Chert, white; limestone, light yellow-gray, fine granular, rapid effervescence, in sand	270, 280
Limestone, light gray, moderately rapid and rapid reaction to acid; chert, chalcedony; blue gray shale	290, 300
Limestone, light yellow-gray, rapid effervescence; brown limestone, with rather slow reaction	310
Limestone, brown-gray, fossiliferous, rapid effervescence, fine crystalline-granular; white chert	320
Limestone, brown and yellow-gray, rapid effervescence, cherty	330, 340
Sandstone, drab, minute angular grains, argillaceous, calcareous	350
Shale, blue, calcareous	360
Sandstone, as at 350	370
Kinderhook shale (280 feet thick; top 368 feet above sea level):	
Shale, blue, plastic, calcareous	380, 390
Shale, blue, in powder and small highly siliceous chips, calcareous and composed largely of microscopic particles of quartz	400
Shale, blue, plastic; 6 samples	410–450
Shale, brown, in flakes and powder, noninflammable, empyreumatic ordor on heating	460
Shale, brown, as above, and blue	470
Shale, drab, plastic; 3 samples	480–500
Shale, blue-gray, plastic; 8 samples	510–580
Shale, drab	590, 600
Shale, blue-gray, plastic; 5 samples	610–650
Devonian (140 feet thick; top 88 feet above sea level):	
Limestone, blue-gray, earthy, rapid reaction, argillaceous, in chips	660, 670
Shale, chocolate-brown, burns white but noninflammable, noncalcareous	680
Shale, blue, plastic	690, 700
Limestone, brownish buff, finely mottled, fine crystalline-granular, rapid effervescence	710
Limestone, buff, rapid and slow response to acid	720
Limestone, blue-gray, earthy, fossiliferous at 730, rapid reaction	730, 740
Limestone, light gray, rapid effervescence, cherty at 760 and 770; 4 samples	750–780
Limestone, buff-gray, moderately slow reaction, considerable residue of particles of cryptocrystalline silica and a few fine grains of clear quartz	790
Silurian (100 feet thick; top 52 feet below sea level):	
Gypsum, in white hard tough concreted mass with limestone	800
Gypsum, in hard concreted gray-white mass, with some yellow limestone of rapid effervescence	810
Chert; limestone, some rapid effervescence; gypsum; a few grains of clear quartz; yellow-gray in mass	830
Limestone, light blue-gray, rapid reaction, with gypsum, some chips of limestone and gypsum together; some gray shale in chips	840, 850
Dolomite, brown-gray, compact, subcrystalline	860, 870
Dolomite, green-gray, highly argillaceous, a little fine rounded quartz sand imbedded	880
Dolomite, blue-gray, in fine meal; much gypsum in meal and larger grains	890

Ordovician:

Maquoketa shale (110 feet thick; top 152 feet below sea level):

Shale, dark blue-gray, hard, dolomitic, in chips	900
Shale, red, plastic	910
Shale, drab	920, 930
Shale, light blue-gray; 4 samples	940–970
Shale, brown-gray; with chips of dolomite, soft, buff, argillaceous	980
Shale, light gray, plastic	990
Shale, light brown-gray, dolomitic with microscopic crystals	1000

Galena to Glenwood inclusive (280 feet thick; top 262 feet below sea level):

Dolomite, brown-gray, with light yellow-gray limestone at 1020, 1030; 3 samples	1010–1030
Limestone, light gray, rapid effervescence; dolomite, brown-gray	1040
Dolomite, brownish or buff; limestone, gray, rapid reaction; cherty at 1090; 5 samples	1050–1090
Limestone, light blue-gray, rapid; mottled brown, showing under microscope crystals of dolomite in matrix of brown, rapidly effervescing limestone; green shale in flakes; white chert	1100
Dolomite; chert; limestone; 3 samples	1110–1140
Dolomite, buff	1150
Limestone, moderately rapid and rapid effervescence, buff and light yellow	1160
Limestone, light gray and light brown-gray, rapid effervescence, highly cherty at 1180	1170, 1180
Dolomite, buff; limestone, light gray, rapid reaction; chert	1190
Dolomite, buff, a little cryptocrystalline silica and fine irregular grains of clear quartz; a little limestone	1200
Limestone, light gray, rapid response; some dolomite	1210
Limestone, chocolate-brown, rapid effervescence, inflammable	1220
Dolomite, gray; some limestone showing rapid reaction with acid; some quartz sand in fine well rounded grains	1230
Limestone, gray, earthy, rapid reaction, in small chips	1250
Dolomite, gray, in fine meal	1260
Sandstone (Glenwood beds), fine grains well rounded and frosted; much limestone and dolomite in small chips	1270
Shale (Glenwood), dark gray-green, pyritiferous	1280

Saint Peter sandstone (40 feet thick; top 542 feet below sea level):

Sandstone, white, grains up to 1 mm. in diameter, usual facies of Saint Peter; dark fissile shale from above	1290
Sandstone, as above, very fine at 1300; at 1320 fine and coarser up to 0.8 mm. in diameter; with some chert	1300–1320

Prairie du Chien:

Shakopee (210 feet thick; top 582 feet below sea level)—

Dolomite, gray	1330
Dolomite, yellow-gray; a little quartz sand and white chert	1340
Dolomite, with more or less quartz sand; oölitic at 1410, cherty at 1390, 1410-1450, 1500; 16 samples	1360–1530

New Richmond (100 feet thick; top 792 feet below sea level)—

Dolomite, yellow gray, cherty, siliceous-oölitic, with much quartz sand, 5 samples	1540–1580
Dolomite, gray, much quartz sand	1590
Sandstone, fine, secondary enlargements; gray dolomite with imbedded grains of quartz	1600
Dolomite, buff, highly arenaceous, secondary enlargements	1610
Sandstone, buff, secondary enlargements, with some dolomite	1620
Dolomite, highly arenaceous, imbedded grains	1630

Oneota (penetrated 170 feet; top 842 feet below sea level):

Dolomite, gray, much cryptocrystalline silica in minute translucent flakes; a little fine quartz sand; all in fine meal	1640
Dolomite, light gray, cherty at 1750, 1760, 1780; usually some residue of cryptocrystalline silica and sand of clear quartz; 14 samples	1650–1810

Driller's Log

	Depth in Feet		Depth in Feet
Clay	0–30	Lime, gray	880–895
Blue mud	30–37	Lime, gray	895–905
Quicksand	37–60	Red mud	905–910
Sandy mud	60–90	Shale, blue	910–930
Blue mud	90–97	Shale, brown	930–1005
Lime	97–120	Lime, brown	1005–1015
Sand	120–123	Lime, gray	1015–1040
Shale	123–125	Lime, brown	1040–1100
Lime	125–127	Lime, gray	1100–1216
Shale	127–165	Lime, red	1216–1222
Blue mud	165–180	Shale, blue	1222–1224
Shale, white	180–215	Lime, red	1224–1229
Lime, gray	215–230	Lime, gray	1229–1260
Lime, soft	230–350	Sand, gray	1260–1265
Shale, blue	350–365	Lime	1265–1271
Sand, soft	365–371	Shale, blue	1271–1287
Shale, blue	371–385	Sand, St. Peter	1287–1322
Shale, brown	385–400	Lime, gray	1322–1475
Shale, white	400–600	Sand	1475–1482
Shale, brown	600–605	Lime, brown	1482–1500
Shale, white	605–655	Sand, white	1500–1530
Lime, broken	655–675	Lime, sandy	1530–1550
Shale, white	675–702	Sand	1550–1650
Lime, white	702–775	Lime, white	1650–1665
Sand, white	775–780	Sand, white	1665–1685
Lime, brown	780–800	Sand and lime	1685–1785
Lime, white	800–865	Lime, brown	1785–1798
Lime, brown	865–880	Lime, brown	1798–1815

*Mineral Content of City Well, Brighton**

	P.P.M.
Bicarbonate	300.1
Chloride	69.
Sulfate	470.8
Silica	12.8
$Fe_2O_3+Al_2O_3$	7.1
Calcium	64.3
Magnesium	37.9
Na + K as Na	156.5
Total solids	968.8

BURLINGTON

(*Altitude 530 feet, C., R. I. & P. Ry.*)

WELL OF THE HOTEL BURLINGTON

This deep well was drilled in 1924 by E. F. Jones of Burlington. The depth is 585 feet and the diameter 5 inches. The head is 25 feet above the curb. Casing is driven about 150 feet into rock, The water is used only for the coils of an ice-making machine. The cost of the well was about $1100.

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

WELL OF THE BURLINGTON FRUIT COMPANY

In 1924 a well was completed for this company by E. F. Jones. The depth is 675 feet and the diameter 5 inches. The principal supply was found at about 300 feet. The head is stated to be 50 to 60 feet above the curb. The well is cased to above 250 feet; its total cost was $1350.

WELL OF THE JOHN BLAUL'S SONS COMPANY

This well, 613 feet deep and 5 inches in diameter, was drilled by E. F. Jones in 1924. Water was found at 550 feet. The original head was 18 feet above the curb and in 1926 it was 14 feet. The flow per minute is 25 gallons. The cost of the well was $1200.

Chemical Analysis of Water by Dearborn Chemical Co., Peoria, Ill.

Mineral	Grains per gallon
Silica	.991
Oxides of iron and aluminum	.070
Carbonate of lime	trace
Sulphate of lime	61.451
Carbonate of magnesia	11.220
Sulphate of magnesia	19.432
Sodium and potassium sulphates	80.258
Sodium and potassium chlorides	23.800
Total mineral solids	197.392
Total incrusting solids	73.732
Total nonincrusting solids	123.660

The directing chemist of the Dearborn Company reports that the water is very difficult to handle from a scale-forming and also a foaming standpoint, and is not recommended for boiler purposes under any conditions.

BURT, KOSSUTH COUNTY

(Altitude 1177 feet)

CITY WELL NO. 1

This well was drilled in 1916 and is 517 feet deep. The diameters are 8 and 6 inches. A little water was encountered at 95 and 165 feet, but the principal supply was found at 517 feet. The static level on completion was 24 feet below the surface, where it still remains. The pumping capacity is 95 gallons per minute—two and one-half times the maximum consumption of the town. The casing is 8 inches to 184 feet and 6 inch casing to rock at 264 feet.

CALIFORNIA, HARRISON COUNTY

OIL PROSPECT OF H. R. COULTHARD

This drill hole was sunk about a quarter mile north of the station on the Missouri river flood plain at an elevation of about 1010 feet above sea level. The upper strata represented by the samples are evidently Mississippian. The Saint Peter sandstone was not reached, but the lowest dolomites may belong to the Galena.

Record of Strata

	Depth in Feet
No samples	0–360
Limestone, light yellow-gray, oölitic, brisk effervescence in cold dilute HCl; in sand	360–365
Limestone, light gray, earthy, rapid effervescence, with imbedded calcite crystals; in rather large chips	464–481
Limestone, light yellow-gray, oölitic (?), rapid effervescence; in sand	595–614
Dolomite, light buff in mass, in fine sparkling crystalline sand	614–628
Dolomite, or magnesian limestone, buff, in fine crystalline sand, rather slow effervescence	655
Dolomite, brown, fine crystalline-granular; much white chert	662
Dolomite, buff, in fine sparkling sand; limestone, drab, fine crystalline-granular, argillaceous, rather rapid reaction in acid, with sporadic calcite crystals, in chips	692
Shale, blue; limestone, blue-gray, and yellow-gray, rather slow effervescence; some flint and chalcedonic silica; all in chips	780
Shale, blue-gray, calcareous	780–790
Dolomite, light gray, in fine crystalline sand	810–816
Dolomite, light gray, crystalline-granular, soft, cherty, somewhat more rapid effervescence than LeClaire dolomite; 2 samples	967, 978
Dolomite, buff, in coarse sand, some grains of rapid effervescence	970–1045
Limestone, drab and yellow-gray, rapid effervescence, much bright green shale in waterworn chips	1145–1150
Dolomite, light gray, in sand, with shale as above	1150–1190
Dolomite as above, and shale as above	1209–1228
Dolomite, gray, much white chert, some chalcedonic silica	1228–1300
Chert, white; dolomite, light gray	1360–1460

CALMAR, WINNESHIEK COUNTY

(Altitude 1258 feet)

In 1922 a well 398 feet deep was completed for the Chicago, Milwaukee and Saint Paul Railway Company by James Kushar of Plymouth, Iowa.

The static level is 77 feet below the surface of the ground, and is lowered 11 feet when the well is pumped at its capacity of 165 gallons per minute. At 376 feet a test was made which showed a static head of 84 feet with a draw down of 34 feet, when the well was pumped at the rate of 160 gallons per minute. At 177 feet the well was tested at 25 gallons per minute and the static level of 85 feet was lowered within 2 feet of the bottom.

Driller's Log

	Depth in Feet
Pleistocene (64 feet thick):	
Yellow clay	0–30
Blue clay	30–64
Maquoketa (123 feet thick):	
Limestone	64–110
Lime and soapstone mixed	110–120
Brown limestone	120–132
Brown lime and sandstone	132–141
Limestone	141–148
Shale and limestone	148–177
Limestone and a little shale	177–187
Galena and Platteville (penetrated 221 feet):	
Hard limestone	187–248
Limestone and shale in layers	248–268
Hard limestone	268–276
Hard limestone and a few layers of shale	276–308
Hard brown limestone and some shale	308–318
Hard brown limestone	318–378
Soft porous brown limestone	378–395
Hard brown limestone	395–398

Notes.—Comparing the above section with those of wells nos. 1 and 2 of the railway company at Calmar[43] it will be seen that the thickness of the Maquoketa in wells nos. 2 and 3 is precisely the same and is 23 feet less than that recorded for well no. 1.

The interval from 248 to 310 feet is reported in well no. 2 as "shale," in well no. 1 as "limestone," and in well no. 3 more accurately, no doubt, as "limestone and shale in layers," "limestone and a few layers of shale" and "limestone and some shale."

Well no. 1, drilled to the depth of 1223 feet, found the Saint Peter at 608 feet, the Prairie du Chien at 675, the Jordan at 1000 and the Trempealeau dolomite of the Saint Lawrence at 1120 feet.

CEDAR RAPIDS

(*Altitude 725 feet*)

WELL OF T. M. SINCLAIR COMPANY

This well was drilled by the J. P. Miller Artesian Well Company of Chicago in 1911. The depth is 1471 feet, the diameters are 12 inches to 415 feet, 10¼ inches to 682 feet and 8 inches to the bottom.

At 301 feet (Niagaran limestone) water stood 4 feet below the surface and yielded 200 gallons per minute.

43 Underground Water Resources of Iowa, vol. XXI, Ann. Rept.: Iowa Geol. Survey, pp. 414-15.

At 410 feet (Niagaran limestone), the static level remaining the same, a tee was placed 9 feet from the surface and the water flowed 50 gallons per minute into the reservoir. At 1130 feet (Prairie du Chien) an additional supply was struck and at 1225 (Prairie du Chien) the flow into the reservoir was 85 gallons per minute. At 1300 feet the flow measured 125 gallons, and at 1330 feet 260 gallons. Crevices were encountered at 1370 feet with an increase in flow to 300 gallons per minute. At 1430 (Jordan) the flow decreased to 200 gallons per minute and remained unchanged to the completion of the well. The well was later found to have a pumping capacity of 900 g.p.m.

Temperature of Water

At 301 feet	54° Fahr.
At 875 feet	59° Fahr.
At 1225 feet	59½° Fahr.
At 1330 feet	60½° Fahr.

Driller's Log

	Depth in Feet
River sand deposit, quicksand on rock	0–70
Lime rock, gray-blue (Devonian and Silurian)	70–420
Shale (Maquoketa)	420–680
Lime, white, with trace of shale at 910	680–925
Quartz and iron pyrite, at	925
Lime, grayish	925–985
Sand (Saint Peter)	985–1015
Lime (Shakopee)	1015–1050
Sandy lime (New Richmond included)	1050–1225
Lime (Oneota)	1225–1400
Sand (Jordan)	1400–1471

WELL OF PENICK AND FORD, LTD.

This well is one of several of about the same depth which have been drilled in the business district of Cedar Rapids and which tap the waters of the Niagaran limestone.

The well, 430 feet deep and 6 inches in diameter, was drilled by Chas. D. Nolan of Cedar Rapids in 1924. The principal supply was found at 400 feet ''above Maquoketa shale'', and other viens were struck at 65, 145 and 240 feet. The static level is 7 feet below the curb; the pumping capacity under air is 110 g.p.m. The cost of the well was $1290.

CHARLES CITY

(Altitude 1011 feet)

CITY WELL OF 1928

The first artesian well of this city was drilled in 1906 and is described in the report on the Underground Water Resources of Iowa. The natural flow on completion was 200 g.p.m. and the discharge under a vacuum of 7 pounds 900 g.p.m. In 1928 the discharge is reported as 250 g.p.m. under a centrifugal pump.

Increased consumption as well as the decreased yield of the old well made a new well necessary. The second well was drilled 1540 feet from well no. 1 in order to prevent interference as far as conveniently possible. It was completed in 1928 by the McCarthy Well Co. of St. Paul and Minneapolis. The depth is 1385 feet, 202 feet less than that of well no. 1, which penetrated the St. Lawrence formation to the depth of 337 feet, at least 187 feet of which were the dry Franconia beds. The diameters are 20 inches to 70 feet, 16 inches to 122 feet, 13 inches to 593 feet, and 10 inches to bottom. The principal supply was found at 1190 feet in the Jordan sandstone. Another water bed was struck at 718 feet near the top of the Saint Peter sandstone.

The static level is 13 feet below the surface. The pumping capacity is 300 g.p.m. with a draw down to 100 feet below the surface of the ground with a turbine pump set at 120 feet. The head of the Jordan sandstone water is lower than that of the Saint Peter sandstone, as the well flowed after a day's shut down, when it had reached the depth of 735 feet. The well is cased with 70 feet of 20 inch pipe outside the 16 inch pipe which extends from the surface to 122 feet. A 10 inch liner extends from 593 to 787 feet.

Record of strata of City well no. 2, Charles City

	Depth in Feet
No samples	0–70
Devonian (114 feet thick, first sample at 941 feet above sea level):	
Limestone, yellow, fine-grained, earthy, slow effervescence in cold dilute HCl	70
Limestone, light brown-gray, crystalline, rapid effervescence	80
Limestone, gray and dark drab, fine crystalline-granular, rapid effervescence	90
Limestone, gray, earthy, rather slow effervescence, some rapid	100
Shale, light blue-gray, calcareous, in friable masses	109
Shale, blue-gray, plastic, in hard concreted masses, calcareous	114
Dolomite, yellow-gray, soft, fine-granular, compact	124
Dolomite, gray, fine crystalline-granular, slightly porous, soft, some blackish spots	134

Limestone, magnesian or dolomite, fine crystalline-granular, porous, moderately slow effervescence	144
Limestone, blue-gray, argillaceous, obscurely fossiliferous with calcite casts, rather slow effervescence; some chert	154
Dolomite, fine crystalline-granular, gray	164
Limestone, light and dark gray, argillaceous, earthy, moderately rapid effervescence	174
Ordovician:	
Maquoketa (90 feet thick; top 827 feet above sea level)—	
Shale, light gray, calcareous, in friable masses; considerable fine sand of clear quartz in irregular grains and a few crystals	184, 194
Dolomite, gray, porous; and light blue, highly argillaceous	204
Dolomite, gray, argillaceous at 224, drab at 244 feet; 4 samples	214–244
Dolomite, light brownish drab, some vesicular, argillaceous	254
Sandstone, blue-gray, argillaceous, dolomitic, in chips, grains fine, fairly well rounded	264
Galena-Platteville (361 feet thick; top 737 feet above sea level)—	
Limestone, gray and brown-gray, soft, argillaceous, fine-granular, rather slow effervescence, obscurely fossiliferous in white calcite	274
Limestone, in mass yellow-gray, rapid effervescence; much white chert; fine rounded grains of quartz sand; all concreted in friable masses	284, 294
Limestone, light yellow-gray, granular, rapid effervescence	304
Limestone, light and darker gray, argillaceous, rather coarse-granular, rapid effervescence, in concreted masses	324
Shale, gray, in rather difficultly friable masses concreting gray limestone and white chert	334
Limestone, gray, earthy, fine-grained, rapid effervescence, in chips; 3 samples	344–364
Limestone, gray, earthy, in large flakes, fossiliferous, rapid effervescence	374, 384
Limestone, gray and light yellow-gray, rapid effervescence, fossiliferous at 404, gray flint at 494 and 504; 20 samples	394–584
Limestone, light yellow-gray, earthy, rapid effervescence, in sand concreted with argillo-calcareous powder; 5 samples	594–634
Glenwood shale (73 feet thick; top 376 feet above sea level)—	
Shale, in light blue-gray concreted mass, highly calcareous with grains of limestone; residue of fine grains of quartz sand, larger ones rounded; chert; pyrite	635
Shale, light gray, in concreted mass with some light gray limestone	645
Shale, dark brownish drab and greenish gray, unctuous, hard	665
Shale, brown-gray in mass, some greenish flakes	675
Limestone, yellow-gray, earthy, rapid effervescence, with some flakes of dark shale, all concreted with argillo-calcareous powder into tough mass	685
Shale, rather dark blue-green and drab, slightly calcareous, with some quartz grains at 705; in tough masses	695, 705
Saint Peter sandstone (68 feet thick; top 303 feet above sea level)—	
Sandstone, grains of Saint Peter facies, larger ones 1 mm. diameter, concreted in sample with powder of shale in blue-gray mass	708
Sandstone, as above, but a little finer, concreted with argillo-calcareous powder in light gray, rather difficultly friable mass at 718, blue-gray at 728, a little green shale at 738; 3 samples	718–738
Sandstone, light gray in mass, larger grains less than 0.5 mm. in diameter, some concreting powder but easily friable	758, 768
Prairie du Chien (404 feet thick; top 235 feet above sea level)—	
Dolomite, brown-gray, in chips, with much quartz sand	776
Dolomite, brown-gray, in chips	786
No sample	796
Dolomite, gray, in small chips; some quartz sand and shale	806

No sample	816
Dolomite, gray; 4 samples	826–856
Sandstone, fine rounded grains of clear quartz; some dolomite with imbedded grains	862
Sandstone, highly dolomitic, pyritic	872
Dolomite, gray, in clean chips	874
Dolomite, with quartz sand concreted with powder of light green shale	884
Dolomite, gray	894, 904
Dolomite, gray, with quartz sand and powder of shale concreted in rather difficultly friable light gray mass; a little white chert	914, 924
Dolomite, gray, in chips	934
Sandstone, grains rounded, with dolomite chips showing imbedded grains	940
Dolomite, gray, showing minute round holes as from removal of oölites; considerable quartz sand, larger grains about 1 mm. in diameter	950
Dolomite, gray, imbedded grains of quartz sand; siliceous oölite; much loose quartz sand; powder of shale; all in hard light-gray concreted mass	960
Dolomite, gray	970
Sandstone, larger grains 1.5 mm. diameter, with much gray dolomite	980
Sandstone, with gray dolomite; some white chert	990
Dolomite, gray, blue-gray, yellow-gray, whitish; cherty at 1010, 1020, 1070, 1080; considerable quartz sand at 1030, 1050, 1150, 1170; 18 samples	1000–1170
Cambrian:	
Jordan sandstone (90 feet thick; top 169 feet below sea level)—	
Sandstone, grains of clear quartz, rounded, frosted, larger grains slightly over 1 mm. diameter; some chips of dolomite	1180
Sandstone, white, grains as above	1190, 1200
Sandstone, white, some chips of fine blue-gray sandstone with dolomitic cement	1210, 1220
Sandstone, dolomitic	1230
Sandstone, in loose grains; some chips of fine sandstone, dolomitic	1240, 1260
Saint Lawrence (Trempealeau formation) (penetrated 20 feet; top 259 feet below sea level)—	
Dolomite, whitish, blue-gray and gray, pyritic, arenaceous	1270
Shale, light blue-gray, in hard concreted masses, inclosing much quartz sand and particles of dolomite, some with imbedded grains; perhaps a highly argillaceous, arenaceous dolomite	1280, 1290

Notes.—The limits of the formations for the first 274 feet in the above section are highly uncertain and are rendered more problematic by some grave disagreements between the samples of the first and second city wells. The Devonian clearly extends at least as far down as 109 feet, and the Galena-Platteville clearly begins as high up as 284 feet. But as basal layers of the Devonian may be dolomitized, the magnesian beds from 124 to 164 feet inclusive are assigned to that formation, since the underlying stratum of limestone appears too slightly magnesian for either the Niagaran or the Maquoketa.

At Waverly the Niagaran has thinned to 50 feet at most. At

Charles City it appears to have feathered out, leaving the Devonian to rest directly on the Maquoketa, as in the counties to the east. And as to the east the Maquoketa may be expected to have lost in part its clayey shales and to have become much more calcareo-magnesian. The argillaceous sandstone at 264 feet is an unusual feature, but better placed at the base of the Maquoketa than with the Galena-Platteville.

The Galena-Platteville is left with a normal thickness of 361 feet and is undolomitized, as in the well-sections of Bremer county.

The shales referred to the Glenwood are abnormal in thickness when compared with the Glenwood to the south and east, but lack nearly 20 feet of the thickness they hold at Mason City. At Osage they are 45 feet thick. At Charles City they embrace not only the usual dark blue-green shale at base, but also gray, blue-gray, drab and brownish shales with two seams of limestone. They extend upward to the horizon of the Decorah shales of the counties to the east, but their arenaceous content at top seems to link them rather to the Glenwood.

The Saint Peter sandstone is of special interest because of the clayey content (evident in the unwashed samples) of the upper layers. This clay appears as a cement concreting the contents of the slush bucket when dry into tolerably tenaceous light gray or blue-gray masses, and is to be distinguished from the flakes of greenish shale, fallen from the Glenwood, common at this horizon in any well. In the first city well these argillaceous sandstones were placed by the writer with the Glenwood and the contour line of the Saint Peter in Floyd county in the report of 1912 was thus given a local convexity to the northeast, interrupting its normal curve. The cuttings now available lead to a correction and show clearly, as the cuttings of the first well did not, that the dolomites of the Prairie du Chien begin at 776 feet.

The Jordan sandstone was struck at about the same level in both wells and was found to be of about the same thickness.

The Saint Lawrence beds were penetrated but 20 feet in well no. 2. The drill of well no. 1 had explored them to a depth of 337 feet, of which the lower 187 feet at least is referable to the Franconia. A gap of 120 feet in the sample cuttings made it impossible to demark the Trempealeau and the Franconia. As at Waverly and Sumner the Saint Lawrence, so far as cuttings show, is here composed mainly of shales.

CHURDAN, GREENE COUNTY

(Altitude 1121 feet)

Log of Wm. Becker, driller

	DEPTH IN FEET
Soil	0–18
Sand and a little water	18–23
Blue clay	23–186
Rock	186–200
Shale and slate and a little water	200–412
Cap rock, very hard	412–440
Lime rock and more water	440–495
Brown rock almost as hard as granite	495–640
Sand rock with more water; head 70 or 80 feet below curb	640–705
Gray rock, more water; head 65 feet below curb	705–773

This well was drilled a year or two previous to 1915. Its diameters were 9 to 6 inches and it was cased to 413 feet. It failed to yield a satisfactory supply and two wells 160 feet deep, with diameters, one of 4 inches, the other of 8 inches, were drilled later. These wells end in sand and yield an abundant supply. The town has nearly a mile of mains.

CLARINDA

(Altitude, 1012 feet)

On Nevember 5, 1928, Iowa's First Oil Developing Company of Clarinda began the drilling of Wilson no. 1 oil prospect hole. It is on the bottom lands of Nodaway river four miles south of Clarinda, on the Wilson farm, in the southeast quarter, southeast quarter, section 24, T. 68 N., R. 37 W., in Page county. The drillers were G. H. Rose and Son of Maryville, Missouri. The well was begun with a diameter of 15½ inches and was lined with 15½ inch casing to 25 feet. Thence the hole is 12½ inches in diameter to 506 feet and is cased with 12½ inch pipe to that depth. Below this point the diameter is 10 inches to 912 feet with 10 inch casing. At 912 feet the well was reduced to 8 inches with casing of the same size and was still at this size at 1530 feet.

Record of strata of Wilson No. 1 oil prospect of Iowa's First Oil Developing Co., Clarinda

	DEPTH IN FEET
Pleistocene and Recent (25 feet thick; top about 988 feet above sea level):	
Glacial clay, yellow, sandy, noncalcareous	0–10

Pennsylvanian: Missouri series (690 feet thick; top 963 feet above sea level):

Limestone, gray, fine-textured, in light gray powder and chips, responds readily to acid; 25 to 31 and	33–36
Shale, blue, gray, drab, sandy	36–40
Shale, dark gray, calcareous, some small clear specks may be selenite (gypsum)	51–60
Limestone, light gray, finely crystalline	70–80
Limestone, dark gray, finely granular, some Fusulina	80–83
Limestone, or limy shale, in fine strongly calcareous concreted powder, light gray, some sand grains which may be from above	83–94
Limestone, light gray, fine-grained	94–102
Shale, bluish gray, very fine-grained, very slightly calcareous	102–140
Limestone, dark gray, very finely granular	140–144
Limestone, light gray, finely sugary, many small specks of pyrite	144–150
Shale, very smooth feel, rather light gray, noncalcareous	150–160
Limestone, light gray, finely sugary	160–165
Shale, dark gray, very finely gritty, limy; 2 samples	340, 349
Limestone, dark gray, very fine-grained	353
Shale, bluish, purplish, fine-grained, limy; 4 samples	355–372
Limestone, gray, in fine powder and grains. Label says "salt water". Sample of water is decidedly salty	385–392
Shale, gray, limy, chips of limestone at 435; some bluish and whitish at 450; 6 samples	418–450
Limestone, light gray, finely sugary, some darker flakes are hard shale like that at 440; "top of lime below No. 27"	450
Shale, light and dark gray, finely gritty, limy; 3 samples	452–460
Limestone, dark gray, soft, very fine-grained, much very fine dark clay residue	462–465
Shale, dark gray, fine-textured, very little lime	465–467
Limestone, light gray, finely sugary	467–470
Limestone, white and light gray, in fine powder which is almost entirely soluble in cold acid	470–473
Limestone, gray, sugary texture; 2 samples	473–477
Limestone, blue-gray, fine texture	477–480
Limestone, gray, finely sugary texture	480–484
Limestone, dark gray, almost black when wet, finely sugary texture, some shale; 2 samples	484–493
Shale, finely gritty, dark gray, limy; sand grains 495-499; 3 samples	493–499
Shale, light gray, very finely gritty, limy; 2 samples	499–504
Limestone, light gray, in coarse powder, effervesces very freely in cold acid, some residue probably siliceous	504–505
Shale, limy, dark gray, soft, very smooth feel, also dark green, very finely granular, hard	505–510
Shale, light gray, finely gritty, limy	510–515
Limestone, light gray, in chips and powder, briskly effervescent, a very little light colored residue	515–519
Limestone, light gray, in grains and chips, packed with Fusulina and spines	519–523
Shale, dark gray, gritty with very fine sand; grains of limestone mingled in shale	523–530
Limestone, dark gray, somewhat shaly, granular, several specimens of Fusulina	530–535
Shale, dark gray, very finely gritty, quite limy	535–540
Limestone, dark gray, crystalline-granular	540–545
Limestone, dark gray, fragments oölitic, strong effervescence, some dark residue	545–550
Limestone, light gray, crystalline-granular, in grains and chips, some of which contain Fusulina and other light colored masses, numerous black specks, 565-571: 4 samples	550–571
Shale, dark gray, finely gritty, limy	571–577

Limestone, dark gray, in small chips; some black fragments which do not respond to acid probably are black shale 577–581
Limestone, light gray, granular, ready effervescence, darker gray, 594-604; 4 samples 581–604
Shale, black, hard, laminated, numerous specks, probably mica, on parting planes 604–610
Shale, very limy, or limestone, shaly, dark gray, ready response to acid but much dark very finely divided residue 610–615
Limestone, light gray, fine-grained 615–621
Limestone, light gray, sugary texture 621–627
Limestone, similar to above, and shale, black, hard, very fine-textured, mica specks 627–634
Shale, black, similar to above, noncalcareous, some reaction from mingled limy matter 634–640
Shale, light gray, noncalcareous, finely gritty, hard 640–645
Limestone, light gray, crystalline; 2 samples 645–652
Shale, gray, hard, finely gritty, nonlaminated 652–655
Limestone, light gray, similar to that at 645-652 655–660
Shale, gray, noncalcareous, hard, some effervescence from powder in sample 660–665
Limestone, brown, crystalline, briskly effervescent; a little dark residue perhaps silica 665–670
Limestone, brown, with large clay content; and shale, greenish, fine-textured, limy, hard; much of sample is in powder concreted to hard masses; 2 samples 670–680
Limestone and shale, greenish gray, limestone subcrystalline, shale finely gritty, rather hard 680–685
Shale, gray, fairly hard, very fine-textured, very small lime content; some gray powder is briskly effervescent 685–691
Limestone, dark gray, fine-grained, with large clay content 691–695
Limestone, gray, and shale, dark gray and brown, slightly calcareous 695–702
Limestone, in white and gray crystalline granules very freely responsive to cold HCl; shale, blue-gray, chocolate-colored, hard, not limy; pyrite; 2 samples 702–712
Limestone, some clayey, some granular, readily soluble in cold HCl, light to dark gray; much shale, soft, greenish, reddish, gray, limy 712–715

Pennsylvanian: Des Moines series (penetrated 725 feet; top 273 feet above sea level)—

Shale, gray and chocolate-colored, finely gritty, somewhat calcareous; samples contain some fragments of bright shiny brittle coal at 735-741 (bag says "Hit coal at 738-743, no cap rock") and at 741-745; 4 samples 715–745
Limestone, gray, clayey, fine-grained, in angular chips and flakes, brisk effervescence; shale, gray, finely gritty, perhaps one-fourth of sample 745-748, one-half of samples 748-750 and 750-755, some dark gray and brown in second sample; 3 samples 745–755
Shale, black and dark gray, laminated, strongly calcareous above, less below; 5 samples 755–785
Shale, dark brown, hard, slightly limy; some fragments of hard gray finely granular limestone 785–791
Limestone, light gray, fine-grained, very brisk effervescence, slight residue; shale, dark gray, limy, carbon streaks, mica specks; 4 samples 791–804
Shale, light gray, soft, calcareous, some flakes of dark gray limestone 804–808
Limestone, dark gray, hard; shale, dark gray, hard, limy; darker 822-827; probably some differences were detected by the driller, as noted in his log, but the samples are very similar; 7 samples 808–841
Shale, light and dark gray, some calcareous, some not, very fine-textured; 5 samples 841–876
Shale, similar to above, noncalcareous; sandstone, fine, light gray, noncalcareous; 2 samples 876–885

Shale, black, finely laminated, noncalcareous, some in large flakes; limestone, light gray, fine-textured	885–894
Shale, gray, very fine-textured, mostly noncalcareous; calcareous with some dark brown noncalcareous 904-906, mostly dark brown, noncalcareous 906-915, some gray limestone 915-920, somewhat calcareous 924-928, almost black 928-955, a few fragments limestone and sandstone 955-964; 18 samples	894–990
Sandstone, medium gray, composed of fine subangular clear grains of quartz, numerous white mica specks; shale, very dark gray, fine-grained, a few large chips 990-1000, abundant small chips 1000-1005, 1010-1018; 5 samples	990–1021
Sandstone, like that of sample above; shale, a few dark gray flakes, noncalcareous, but mostly in concreted masses of light gray, limy, fine-textured material	1021–1025
Shale, light and dark as above but noncalcareous; a few grains of quartz sand, perhaps from above	1025–1034
Shale, light tan to light bluish, gritty, calcareous; limestone, some small light gray chips	1034–1044
Limestone, light gray, fine-grained, briskly effervescent in cold HCl; shale, light and dark gray, very fine-textured, noncalcareous; residue fine, hard, whitish grains probably chert	1044–1050
Shale, black, very fine-textured; a few fragments of bright coal (log says "Coal, very inferior, 1044-1057"); powder of sample gives some reaction with acid, residue includes chert	1050–1057
Shale, as above; sandstone, gray, fine-grained, in grains and small pebbles; a few grains of limestone	1057–1065
Shale, light to dark gray, finely gritty, calcareous 1065-1075, mostly noncalcareous below; some sandstone 1113-1119; thin films and lenses of limestone 1119-1125; concreted calcareous masses 1130-1140, quartz sand 1145-1170, 1193-1206; nearly black 1206-1245; 25 samples	1065–1245
Sandstone, medium gray, composed of fine subangular clear quartz grains; some bluish black shale, nearly gritless	1245–1251
Shale and sandstone as above, in approximately equal amounts	1251–1265
Shale, dark gray, similar to above, no sandstone; calcareous 1287-1292; some samples concreted into hard masses, some in small chips; powder slightly calcareous 1320-1330, strongly so 1340-1350, but chips noncalcareous; black 1345-1350, dark tan 1350-1357, mixed black and tan 1364-1371, tan 1371-1377; 20 samples	1265–1384
Shale, gray and black, former finely gritty, latter almost gritless, all noncalcareous; sandstone, similar to those above, nearly equal to shale in amount; powder contains some effervescent particles; 4 samples	1384–1410
Shale, very dark gray, finely gritty, noncalcareous, pyrite, a few small chips of coal 1417-1422; in small chips and grains, with some sand in fine rounded to subangular grains 1422-1427; more sandstone, in small gray pebbles 1427-1433; 4 samples	1410–1433
Sandstone, gray, grains fine to very fine, subangular to rounded, clear to translucent, a few white; a very little black shale 1433-1435; tan, grains more even in size 1435-1461; somewhat calcareous 1468-1474; some black shale and pyrite 1490-1495; 8 samples	1433–1495
Shale, black and dark gray, in small chips, almost noncalcareous, some pyrite; sandstone, grains similar to those in sandstones above, small amounts 1495-1503, equal to shale 1503-1512; mostly black shale, with much pyrite 1512-1530; 4 samples	1495–1530

Driller's log, Wilson No. 1 oil prospect

Character	Thickness, feet	Depth, feet
Soil	10	0–10
Sand and gravel, lots of water	15	10–25
Lime	6	25–31
Shale, dark	2	31–33
Lime	3	33–36
Shale, dark	4	36–40
Shale, light	3	40–43
Shale, blue	3	43–46
Lime	5	46–51
Shale, gray	19	51–70
Lime	10	70–80
Coal and shale (inferior coal)	3	80–83
Light shale	11	83–94
Lime	8	94–102
Black shale	38	102–140
Limy shale	4	140–144
Lime	6	144–150
Dark shale	10	150–160
Lime	5	160–165
Shale	1	165–166
Lime	6	166–172
Shale, gray and black	8	172–180
Lime	28	180–208
Dark shale	16	208–224
White lime	4	224–228
Light shale	8	228–236
Red rock	14	236–250
Light shale	70	250–320
Brown shale	20	320–340
Dark sandy shale	9	340–349
Lime and shale, broken	7	349–356
Brown shale	19	356–375
Lime	10	375–385
Water sand, salty	12	385–397
Black shale	8	397–405
Blue shale	4	405–409
Brown shale	4	409–413
Blue shale	31	413–444
White shale	1	444–445
Broken white lime	2	445–447
White hard lime	4	447–451
Dark shale	11	451–462
Black lime	7	462–469
White shale	4	469–473
Hard lime (white to gray to black to brown)	15	473–488
Shale, light and sticky	11	488–499
Shale, light and sticky	5	499–504
White lime	6	504–510
Light shale	4	510–514
White lime	10	514–524
Dark shale	14	524–538
Lime	36	538–574
Dark shale	4	574–578
White lime	30	578–608
Dark shale	8	608–616
White lime	18	616–634
White shale	12	634–646
Lime	14	646–660
Dark shale	10	660–670

Light shale	10	670–680
White lime	10	680–690
Light shale	12	690–702
Shale, brown and red	23	702–725
Shale, light blue	10	725–735
Shale, blue	3	735–738
Coal	5	738–743
Lime	2	743–745
Shale	2	745–747
Hard lime	8	747–755
Black shale	25	755–780
Blue shale	5	780–785
White lime	17	785–802
Light gray shale	20	802–822
Lime shale and dark shale	8	822–830
Lime (water enough to drill with)	22	830–852
Light shale	53	852–905
Dark shale	7	905–912
White lime	6	912–918
Shale, light to dark	77	918–995
Water sand (salty)	25	995–1020
White shale	14	1020–1034
Dark shale	4	1034–1038
Soft sandy lime	4	1038–1042
Light shale	2	1042–1044
Coal (very inferior)	13	1044–1057
Dark shale	188	1057–1245
Water sand (break in the middle)	15	1245–1260
Dark shale	65	1260–1325
Lime shell	2	1325–1327
Black shale	64	1327–1391
Lime shell	1	1391–1392
Dark shale	18	1392–1410
Light sandy shale	10	1410–1420
Coal	2	1420–1422
Dark shale	13	1422–1435
Water sand (show of oil in top of sand)	42	1435–1477
Black shale	2	1477–1479
Water sand	3	1479–1482
Brown shale	2	1482–1484
Water sand	46	1484–1530

Notes.—The driller's log shows that the Missouri series begins at a depth of 25 feet below the surface. The top of the Des Moines series is placed at 715 feet on the shale which seems to have some of the features of Des Moines shale, such as color and the presence of coal. The coal at 80 to 83 feet doubtless is the Nodaway bed, as its elevation corresponds quite well with that in the mines at Clarinda—900 to 920 feet above sea level. Salt water was encountered at 385 to 397 feet and again in the sandstones at 995 to 1020 and 1245 to 1260 feet. The driller says of the coal logged at 738 to 743 feet: "It drilled very fast and while it showed some coal I rather think it was just a small streak." The same was true of the coal recorded between 1044 and 1057 feet. A shale at 670 to 680 feet caused much trouble and delay by repeatedly squeezing into the hole. Finally the 10 inch casing was driven past it. The well caved a little also between 1340 and 1410. The sandstone between 1245 and 1260 feet showed enough gas to be detected by the odor.

Drilling was still being prosecuted in February, 1929, when this report went to press.

CLINTON

(Altitude 590 feet)

WELL OF THE WESTERN ICE COMPANY

In 1927 C. W. Varner of Dubuque completed a well for this company, the first deep well drilled in the city since 1912. The depth is 1500 feet, the diameters 17, 12, 10 and 8 inches. The discharge is approximately 300 g.p.m. The static level is 10 feet above the surface. The well started to flow at 1060 feet and continued to increase to about 1330 feet. Below this level no further increase was noticed. The following casing was inserted: 12 inches to 90 feet, 10 inches from 83 to 403 feet, 8 inches apparently from 710 to 750 feet, casing out the shales above the Saint Peter.

Driller's Log

	Depth in Feet
Soil	0–3
Niagaran limestone	3–173
Maquoketa shale	173–495
Galena lime	495–730
Shale (Glenwood)	730–740
Saint Peter sandstone	740–780

"The rest of the formation is about the same as at the American Sugar Beet Company's well."

COLLINS, STORY COUNTY

(Altitude 1007 feet)

Previous to 1926 Collins had been supplied from a well 180 feet in depth. A second well was drilled in that year by E. A. Ford of Marshalltown. The depth is 384 feet. The drill passed through 278 feet of clay, with thin streaks of shale at bottom and it foots in rock at the depth mentioned. The capacity of the well is 40 g.p.m.

CONRAD, GRUNDY COUNTY

(Altitude 992 feet)

CITY WELL NO. 1

The depth of this well is 606 feet and its diameters are 10 and 8 inches. It was completed in 1915 by Edgar Ford of Marshalltown. Water was found at 125 feet and the principal supply came from 606 feet. Water stands at about 160 feet from the surface. The pumping capacity with the cylinder hung at 240 feet is 40,000 g.p.d.; the consumption of the town averages 5,000 g.p.d., with a maximum of 10,000 g.p.d. The water can not be used in boilers.

Driller's Log

	Depth in Feet
Clay	0–22
Sand	22–172
Shale and rock	172–322
Rock	322–606

CORYDON

(Altitude 1083 feet)

In 1911 a well was sunk by the city of Corydon to a depth of 1240 feet, when the work was abandoned as the yield was but 20 gallons per minute. The log and some further description of the drill hole was published in the report of 1912 on the Underground Water Resources of Iowa, but since that time a set of cuttings has been received, which may be described as follows:

Record of Strata

	Depth in Feet
Pleistocene, Pennsylvanian (top 1110 feet above sea level):	
No record, no samples	0–610
"Shale, sandy"	610–663
"Sandstone, some water"	663–731
Mississippian (444 feet thick; top 379 feet above sea level):	
Sandstone, light yellow-gray in mass, grains fine, of clear quartz, poorly rounded; limestone whitish, rapid effervescence in cold dilute HCl	742–748
Chert, white, in large chips; limestone, light gray, rapid effervescence, in sand; chalcedonic silica	770
Limestone, dark buff, crystalline-earthy, moderately rapid reaction, in large flakes	810
Limestone, whitish, rapid effervescence, calcite	821–831
Limestone, blue-gray, soft, rapid reaction, in small flakes	835–841
Limestone, blue-gray, crystalline-earthy, soft, rapid effervescence, in flakes; cherty at 875	854, 875
Shale, blackish; chert, brown; limestone, argillaceous	895–898
Limestone, whitish and bluish gray, macrocrystalline; white chert ..906,	918–925
Limestone, light cream colored, macrocrystalline, rapid effervescence; chalcedonic silica and limpid quartz	925–928

Chert, white; limestone as above	928–930
Chert, white, chalcedonic silica; limestone whitish and light yellow gray, rapid effervescence	950–953
Limestone, light gray, cherty	970–975
Dolomite, or magnesian limestone, brownish gray, moderately slow effervescence; some cryptocrystalline silica	1000
Dolomite, as above, in fine sand; white chert; chalcedonic silica; chips of clear quartz; pyrite; 3 samples	1018–1036
Limestone, blue-gray, rapid reaction, in fine sand; blue flint	1036-1039
Chert, white and blue-gray; limestone, light gray; some dolomite, brownish gray; some grains of clear quartz; pyrite; 3 samples	1039–1056
Limestone, gray, rapid response to acid; white chert; chips of crystalline quartz	1056–1077
Limestone, light blue-gray, macrocrystalline-earthy, in flaky chips	1077–1088
Shale, bluish drab, calcareous, plastic, in concreted masses, 4 samples (Kinderhook)	1088–1145
Limestone, light brown-gray, earthy, rapid effervescence	1145–1160
Shale, blue, plastic, calcareous	1160–1175
Devonian (penetrated 55 feet; top 65 feet below sea level):	
Limestone, dark blue-gray, rapid reaction, in fine sand; much blue fissile shale in flakes probably from above; some flint and pyrite; 2 samples	1175–1183
Limestone, gray, rapid effervescence, in sand	1183–1210
Limestone, light gray, rapid response	1210–1220
Limestone, light gray and whitish, rapid reaction	1220–1230

COUNCIL BLUFFS

WELL NO. 3, IOWA SCHOOL FOR THE DEAF

A well 1012 feet in depth was drilled for this school in 1885 and a second well, 1100 feet deep, in 1889. In July, 1927, a third well was completed by Thorpe Brothers Well Company of Des Moines. The depth is 2155 feet, the diameters from 16 to 5 and 5/16 inches. Water was found at 55 feet and the main supply at 1585 feet. Small veins were struck at 707, 1815 and 1900 feet. Water rises within 59 feet of the surface. On test pumping with the pumping cylinder at 370 feet 150 gallons per minute were delivered, with a draw down to 360 feet below the surface. The well is cased throughout, with the exception of 500 feet of the lower 525 of the well. The cost of the well was $20,000 and of the pumping machinery $3500.

Chemical analysis of water of Well no. 3, Iowa School of the Deaf

An analysis made by William T. Bailey shows the following mineral content:

	Parts per million (p.p.m.)	Grains per U. S. Gallon (gr. per gal.)
Residue on evaporation	1389	81.705
Volatile matter	122	7.176

Calcium (Ca)	81.17	4.770
Magnesium (Mg)	95.33	5.607
Sodium & potassium (Na+K)	197.10	11.594
Iron (Fe)	2.00	.117
Aluminum (Al)	18.17	1.068
Silica (SiO_2)	41.6	2.447
Chlorine (Cl)	85.0	5.000
Normal carbonate (CO_3)	28.0	1.647
Bicarbonate (HCO_3)	283.04	16.636
Sulfate (SO_4)	658.25	38.720
Nitrates (NO_3)	0.30	.017
Total	1489.96	87.623

Hypothetical Combinations:

Calculated	p.p.m.	gr. per gal.
Sodium nitrate ($NaNO_3$)	.41	.024
Sodium chloride (NaCl)	127.52	7.501
Sodium sulfate (Na_2SO_4)	452.45	26.615
Magnesium sulfate ($MgSO_4$)	440.59	25.917
Magnesium carbonate ($MgCO_3$)	21.83	1.284
Calcium carbonate ($CaCO_3$) equivalent to 328.19 p.p.m. or 19.306 gr. per gal. calcium bicarbonate	202.58	11.917
	1245.28	73.258

Determined:	p.p.m.	gr. per gal.
Silica (SiO_2)	41.6	2.447
Iron oxide (Fe_2O_3)	5.72	.336
Aluminum oxide (Al_2O_3)	34.28	2.016
Total calculated	1326.98	78.057
Residue on evaporation	1389.00	81.705
Excess residue above calculated & determined	62.02	3.648

Record of strata, Well no. 3, Iowa School for the Deaf

	DEPTH IN FEET
Pleistocene and Recent (55 feet thick; top 1010 feet above sea level):	
Soil, dark, pulverulent	0–6
Loess-like silt, buff, calcareous	6–20
Silt, bright buff, slightly calcareous, a little coarser than above, in friable masses, ''muddy quicksand'' of log, almost impalpable grain; 2 samples	20–40
Sand and gravel, yellow-gray, some grains of pink quartzite; 2 samples	40–55
Pennsylvanian (675 feet thick; top 955 feet above sea level):	
Limestone, gray and buff, rapid effervescence in cold dilute HCl; much quartz sand	55–65
Shale, black, in hard concreted masses with fragments of gray limestone included	65–75
Limestone, blue-gray, rapid effervescence; gray chert	75–88
Shale, drab and dark drab	88–90
Shale, blue	90–95
Shale, red	95–100
Limestone, light gray, macrocrystalline-earthy, rapid effervescence	100–109
Shale, blue	109–113
Limestone, dark gray, fine-grained, crystalline-earthy, minute yellowish calcite nests, in large chips	113–120
Limestone, drab, earthy, fossiliferous; fragments of bryozoa, cyathophylloids, crinoid stems, brachiopods	120–130
Shale, blue	130–142

Limestone, gray, earthy	142–150
Shale, blue-gray	150–155
Limestone, blue-gray, minutely fossiliferous	155–160
Limestone, gray, earthy, siliceous	160–166
Shale, drab, fossiliferous	166–170
Shale, blue-gray	170–172
Limestone, gray and whitish	172–181
Shale, black, inflammable, and blue	181–191
Limestone, light gray and whitish, earthy, fossiliferous with fragments of brachiopods and crinoid stems; some gray flint	191–200
Limestone, light gray, earthy, soft; 2 samples	200–220
Shale, black, coaly, inflammable; shale, drab	220–229
Limestone, gray and light gray, some soft, some harder with irregular fracture; 3 samples	229–243
Shale, green-gray	243–248
Limestone, light gray, soft, earthy, laminated, in flakes	248–261
Shale, cinnamon red; 3 samples	261–290
Limestone, gray, earthy, rather soft	290–303
Sandstone, blue-gray, argillaceous, calcareous, micaceous, grains minute; 2 samples	303–320
Shale, red	320–335
Limestone, gray, laminated, earthy	335–344
Sandstone, as at 303	344–355
Shale, black, inflammable	355–364
Limestone, gray, earthy	364–366
Shale, drab, in concreted masses	366–375
Limestone, gray and drab, earthy	375–380
Limestone, yellow-gray, earthy, some speckled; 3 samples	380–404
Shale, blue-gray, in concreted masses	404–410
Shale, drab and black, in chips	410–420
Shale, drab and blue-gray; 5 samples	420–461
Limestone, gray, earthy; 2 samples	461–472
Shale, red	472–480
Shale, red, buff, blue	480–490
Sandstone, gray, fine, irregular grains; 4 samples	490–525
Shale, red, some drab at 540 and 570; 8 samples	525–600
Shale, drab or blue with some red; caving at 630; 4 samples	600–640
Shale, blue	640–648
Shale, sandy, brown; some limestone	648–650
Shale, sandy	650–653
Shale, blue	653–658
Shale, black; 3 samples	658–680
Shale, drab and gray	680–690
Shale, blackish; 2 samples	690–707
Sandstone, gray, fine irregular grains; much pyrite; some limestone, gray and drab, rapid effervescence; 3 samples	707–730
Mississippian (430 feet thick; top 280 feet above sea level):	
Limestone, light gray, rapid reaction in sand; some white opaque chert and quartz sand; some shale	730–740
Limestone, whitish and light gray, soft, crystalline-earthy, rapid effervescence, in flakes; 2 samples	740–760
Limestone, brown, slow effervescence, argillaceous, microscopically arenaceous	760–770
Limestone, gray, some of moderately slow response, some with rapid; fine crystalline	770–780
Limestone, gray, rapid reaction, much light blue-gray chert; and hard very fine-grained sandstone	780–790
Limestone, brown, moderately slow effervescence; whitish and brown chert; chalcedonic silica, some grains of quartz sand; 4 samples	790–826
Shale, blue, plastic, calcareous	826–829
Limestone, buff and gray, fine crystalline-granular, effervescence mod-	

erately slow, some white chalcedonic silica and brown chert; 2 samples	829–850
Limestone, gray, response rapid and moderately slow, much chert, chalcedonic silica, and vein quartz	850–860
Limestone, gray, rapid effervescence; silica, chert and quartz as above	860–870
Limestone, gray, fine crystalline-granular, and earthy, rapid reaction, in flakes	870–880
Limestone, whitish, highly siliceous or cherty	880–885
Shale, blue-gray	885–889
Chert, gray; chalcedonic silica; gray cherty limestone	889–900
Limestone, gray, yellow-gray and buff, rapid reaction, much chert and chalcedony as above; 4 samples	900–940
Limestone, light yellow-gray, crystalline-earthy, reaction rapid, in large flakes	940–950
Chert, light gray and whitish, granular, in chips, some large; limestone, light yellow-gray, rapid effervescence, in sand	950–960
Limestone, yellow-gray and light buff, oölitic, rapid reaction, in sand; 3 samples	960–990
Limestone, buff, response rapid; much white and gray chert, some chalcedonic silica	990–1000
Limestone, gray and buff, rapid effervescence, fine-granular; much blue gray chert	1000–1010
Limestone, dark brownish, reaction rapid and moderately rapid, fine crystalline-granular, some blue-gray chert	1010–1020
Limestone, buff-gray, rapid response, chert as above	1020–1030
Limestone, buff-gray and light gray, rapid reaction, fragments of brachiopods, gray chert; 2 samples	1030–1050
Limestone, mottled gray and whitish, response rapid, flaky chips	1050–1070
Limestone, yellow-gray, calcilutite, rapid effervescence; some white, soft, earthy	1070–1080
"Limestone, gray and white"	1080–1086
"Shale"	1086–1090
Shale, light blue, green-blue and drab, calcareous, plastic; 7 samples (Kinderhook)	1090–1160
Unassigned; below 1592 probably Ordovician (Galena) (thickness 995 feet, top 150 feet below sea level):	
Limestone, whitish and light gray, rapid reaction, in flaky chips, larger chips mottled; earthy-fine-crystalline, some macrocrystalline; 6 samples	1160–1220
Limestone, white and light yellow-gray, earthy-fine-crystalline; some shale in concreted masses	1220–1230
Limestone, gray and white, soft, rapid effervescence	1230–1233
Shale, dark gray, strongly calcareous; one large chip of finely crystalline, fragmental limestone	1233–1236
Limestone, brown-gray	1236–1240
Limestone, buff-gray, rather slow reaction, much shale, some in concreted masses	1240–1250
Limestone, buff, some with rapid reaction, some rather slow; much shale	1250–1260
Limestone, medium dark brown, response rather slow, some drab shale; 2 samples	1260–1280
Chert, white and light blue-gray, in large flakes; chalcedonic silica, limestone and shale	1280–1290
Shale, blue-gray, calcareous, plastic; 2 samples	1290–1310
Shale, drab, in large flakes	1310–1320
Limestone, brown, rather slow effervescence; gray, rapid; large chips of blue shale from above	1320–1330
Limestone, drab, fine-grained, somewhat clayey, response rather slow	1330–1340
Limestone, brown, rapid effervescence	1340–1350
Limestone, light buff and light yellow-gray, rapid reaction	1350–1360
Limestone, drab and buff, rather slow response	1360–1370
Limestone, drab, fine-grained, rather rapid response	1370–1380
Limestone, buff, hard, fine crystalline-granular, rapid reaction	1380–1390

Limestone, buff, earthy, soft, argillaceous, reaction rather rapid 1390–1400
Limestone, brown and buff, fine crystalline-granular, effervescence rather slow; 5 samples 1400–1445
Limestone, dark blue-gray, compact, in fine chips, rapid effervescence; a little shale 1445–1455
Limestone, brown and buff; much shale; 2 samples 1455–1480
Limestone, buff, soft, argillaceous, fine crystalline-granular, reaction rather slow, disintegrating under weak HCl into fine flour; shale in chips from above 1480–1490
Dolomite or magnesian limestone, buff, in fine chips, much shale in fine chips; driller's log: "1455-1490 shaly lime" 1490–1500
Limestone, buff, crystalline, compact, rapid effervescence 1500–1501
Shale, blue-green, hard, feebly calcareous, in concreted masses 1501–1510
Limestone, brown, compact, reaction rapid; with shale 1510–1520
Limestone, buff-gray, some light gray, reaction rather slow; much white chert at 1520 and at 1540; 3 samples 1520–1550
Limestone, buff-gray, soft, rather slow response, disintegrating into fine flour under weak HCl, earthy; 2 samples 1550–1570
Dolomite, buff-gray 1570–1580
Dolomite, light gray; some whitish limestone of rapid effervescence 1580–1585
Sandstone, fine grains ill-rounded, larger about 0.7 mm., some secondary enlargements, some grains pinkish 1585–1592
Dolomite, light gray and whitish, some imbedded quartz grains; loose quartz sand fine and poorly rounded; some whitish rapidly effervescing limestone; much gray and white chert and some chalcedonic silica 1592–1600
Limestone, light gray, very fine-grained, reaction rather rapid, in flaky chips; dolomite, gray, in small chips; a little shale and quartz sand..1600–1610
Dolomite, light gray and gray, considerable chert; 5 samples 1610–1660
Dolomite, gray; a little chert; 4 samples 1660–1700
Dolomite, light blue-gray, in small chips, white chert, a little translucent chalcedonic silica and fine ill-rounded grains of quartz sand; 2 samples 1700–1720
Dolomite, light brownish gray and yellow-gray; white chert, chalcedonic silica, ill-rounded grains of quartz sand, pyrite, much light blue shale in concreted masses inclosing chips and grains of the other materials; 2 samples 1720–1740
Dolomite, gray and yellow-gray, chert, pyrite and silica as above; a little blue and greenish shale in small chips 1740–1750
Dolomite, light gray, a little white chert, quartz sand and blue shale; 4 samples 1750–1790
Dolomite, light gray and gray, in fine chips and sand, a few chips of decayed chert, some blue shale; a little whitish limestone 1790–1800
Dolomite, gray and light yellow-gray and whitish, in fine crystalline sand, cherty at 1810, 1890, 1910, 1920; 13 samples 1800–1930
Chert, gray and white, in chips, with gray dolomite in fine sand; 3 samples 1930–1960
Dolomite, whitish; much white chert 1960–1970
Chert, gray and white, with some dolomite in fine sand 1970–1980
Dolomite, light gray; much gray and white chert 1980–1990
Dolomite, light gray; a little chert; all in fine sand 1990–2000
Dolomite, light buff, in fine crystalline sand, with some fine angular particles of quartz; 2 samples 2000–2020
Dolomite, light buff and yellow, hardly any quartz sand; 3 samples 2020–2050
Dolomite, light buff and light gray, in fine sand and powder, somewhat arenaceous with minute angular particles of quartz; pyrite; some hard fissile shale, blue-green, in flakes; 3 samples 2050–2080
Dolomite, light gray, highly arenaceous with minute angular particles of quartz; much pyrite in microscopic crystals; hard fissile shale in small flakes 2080–2090
Dolomite, buff and light gray, in fine crystalline sand; a little limestone of rapid effervescence; 2 samples 2090–2110

Shale, dark blue-green, fissile, slightly calcareous, in flakes 2110–2120
Shale, medium light blue-green, hard, in minute flakes 2120–2122
Dolomite, gray, in fine sand; some limestone, of rather rapid reaction, coarser 2122–2130
Shale, medium light blue-green, unctuous, slightly calcareous, pyritiferous 2130–2135
Dolomite, gray, in fine sparkling crystalline sand; quartz in broken particles and some ill-rounded grains, some with secondary enlargements; cryptocrystalline silica in grains containing microscopic crystals of pyrite; much pyrite in fine opaque particles; some minute lumps of blue shale pyritiferous; 3 samples 2135–2155

Notes.—In the above section at Council Bluffs the base of the Pennsylvanian is pretty clearly determined at 280 feet above tide. This is 264 feet higher than the Pennsylvanian floor at Oakland, but according to the driller's log is 177 feet lower than the same horizon at Walnut. South from Council Bluffs the Pennsylvanian floor sinks to 148 feet below tide at Glenwood, a fall of 428 feet. But in the short distance from the School for the Deaf at Council Bluffs to Miller Park, Omaha, and Fort Crook there is a sharp ascent, for at these points the floor of the Coal Measures occurs respectively at 532 and 550 feet above sea level, or at Fort Crook 270 feet higher than at the School for the Deaf.[44]

Assuming this strong eastward dip we may correlate the thick shale at Council Bluffs which we have assigned to the Kinderhook with the thin shale at 212 feet above sea level at Fort Crook. And perhaps the hard green shale 150 feet below sea level at Fort Crook is the same as the shale found at Council Bluffs at 491 feet below sea level.

The dolomites below this horizon are much the same in both wells, crushing under the drill to finest sparkling sand, and strongly suggest the horizon of the Galena. If this reference is correct, the shales near the bottom of the Council Bluffs well, at 2110-2120 and 2130-2135 feet, are probably the Decorah or Glenwood, and the Saint Peter sandstone lies not far below the footing of the well. It will be recalled that at Nebraska City the shales above the Saint Peter with their distinctive fossils were found at 2754 feet, 1824 feet below sea level, and the Saint Peter sandstone was struck at 2783 feet.

44 Norton, Iowa Geological Survey, vol. XXI, pp. 1172-75.

CRAWFORDSVILLE, WASHINGTON COUNTY

(Altitude 731 feet)

Crawfordsville, Washington county, population 340, is supplied by two wells, one 240 feet in depth and capable of furnishing 15,000 g.p.d. and the other 695 feet deep and capable of furnishing 20,000 g.p.d. The latter well was drilled in 1915 by Edward Fass. The principal supply was found at 145 feet in rock and no other water bed of importance was encountered. The depth of the cylinder is 160 feet and the pumping capacity is 14 g.p.m.

CRESCO

(Altitude 1300 feet)

In 1924 a well 670 feet deep was completed for the city of Cresco by the Sewell Well Company of Saint Louis. Sixteen inch casing extends to a depth of 258 feet, where it is bedded in a concrete seal 15 inches thick poured when the well had reached that depth. This casing cuts off any cave from the drift sands and from the Maquoketa shales. The diameter of the drill hole is 15¼ inches from 258 feet to 597 feet, where it is constricted to 12½ inches. Casing of 12¼ inches diameter is inserted from 494 to 597 feet, cutting off the Decorah and Glenwood shales.

A strong flow was struck at 415 feet in the Galena limestone and another in the Saint Peter sandstone. The static level is 151 feet below the surface and the tested capacity is 250 gallons per minute with a draw down of 49 feet, below which it could not be lowered. On stopping the pump the static level was recovered in 20 minutes.

Record of strata of the Cresco city well of 1924

	Depth in Feet
Pleistocene and Recent (30 feet thick; top 1300 feet above sea level):	
Clay, brownish yellow, very sandy, in hard moulded masses	0–10
Sand, gray, and gravel, greenstones abundant	10–20
Sand, yellow, and gravel	20–30
Devonian (50 feet thick; top 1270 feet above sea level):	
Limestone, yellow, soft, earthy, rapid effervescence in cold dilute HCl	30–40
Limestone, yellow, earthy, black specks of manganese oxide and ferruginous stains and crusts, in large chips, rapid effervescence, fossiliferous	40–50
Limestone, light yellow-gray and buff, crystalline-granular and earthy, rapid reaction; 3 samples	50–80
Maquoketa (120 feet thick; top 1220 feet above sea level):	
Dolomite, light brown-gray and yellow-gray, very fine grain, conchoidal fracture, sparsely vesicular; shale, blue-green, hard, dolomitic, in small chips; 2 samples	80–100

Limestone, whitish, fine crystalline-granular, rapid and moderately rapid effervescence	100–110
Dolomite, light brown-gray, drab and gray, fine grained, vesicular, earthy, response rather slow; 4 samples	110–150
Shale, blue, hard, calcareous, in large chips and concreted masses; much dolomite gray and yellow-gray; in sand; 2 samples	150–170
Shale, light blue-gray, calcareous, minutely arenaceous, in friable concreted masses; some selenite	170–180
Dolomite, brown, soft, fine crystalline-granular, large argillaceous residue, empyreumatic odor on heating; 2 samples	180–200
Galena (310 feet thick; top 1100 feet above sea level):	
Limestone, brownish, drab and gray, earthy, in flaky chips, effervescence rapid; 10 samples	200–300
Limestone, light yellow-gray and gray, earthy, rapid reaction, 21 samples	300–510
Decorah (50 feet thick):	
Shale, olive; limestone; in moulded masses	510–520
Shale, blue-gray and greenish, calcareous, in moulded masses; 4 samples	520–560
Platteville (20 feet thick):	
Limestone, gray, rapid reaction	560–570
Limestone, as above, a few flakes of green calcareous fissile shale	570–580
Glenwood (10 feet thick):	
Shale, in hard moulded masses, some in flakes, gray-green, fissile, non-calcareous; some quartz sand of St. Peter facies	580–590
Saint Peter (70 feet thick, top 710 feet above sea level):	
Sandstone, light gray in mass, grains rounded and frosted, up to 1 mm. in diameter, some grains cemented; some shale in gray-green flakes, non-calcareous, fissile	590–600
Sandstone, light gray in mass, finer than above	600–610
Sandstone, white, medium to fine; some flakes of shale; 5 samples	610–660
Shakopee (top 640 feet above sea level):	
Dolomite, gray (some limestone of rapid effervescence), cuttings mostly of Saint Peter sand	660–670

Driller's log, Cresco city well, 1924

	DEPTH IN FEET
Surface solution	0–5
Clay, gravel and sand	5–15
Blue mud	15–25
Yellow clay and boulders	25–80
Shale and limestone	80–89
Limestone	89–170
Shale	170–180
Limestone and some shale	180–195
Limestone	195–255
Limestone, water at 280	255–520
Shale and limestone, water at 415	520–525
Shale	525–557
Limestone	557–582
Shale	582–592
Sandy shale	592–597
St. Peter sandstone	597–667
Limestone	667–670

*Mineral analysis of water from Cresco city well**

	Parts per million
Nitrate (NO_3)	21.3
Chlorine (Cl)	29.0
Sulfate (SO_4)	50.0

* Dr. E. W. Bartow, State University, Iowa City, Oct. 20,1924.

Bicarbonate (HCO_3)	314.8
Sodium (Na) (Calc'd)	36.3
Magnesium (Mg) (Calc'd)	36.0
Calcium (Ca) (Calc'd)	56.6
Iron (Fe)	Trace

Hypothetical combinations	Parts per million	Grains per gallon
Sodium nitrate ($NaNO_3$)	29.2	.71
Sodium chloride (NaCl)	48.8	2.85
Sodium sulphate (Na_2SO_4)	28.5	1.67
Magnesium sulfate ($MgSO_4$)	38.5	2.25
Magnesium carbonate ($MgCO_3$)	97.8	5.72
Calcium carbonate ($CaCO_3$)	142.0	8.30
Undetermined	21.2	1.24

Notes on the Cresco section.—Comparing the log of the driller with the depths given on the samples of the cuttings it will be seen that in several instances the former is more precise, and the thickness and position of some of the formations may be accordingly corrected.

The deposits of the drift represented by the cuttings do not agree entirely with the log, as the "blue mud" of the log is not confirmed by any samples. Taken by itself the log would lead to the inference of a deposit of yellow clay (till) with boulders extending from 25 to 80 feet. The cuttings, however prove that this deposit is limestone and the impression of the drill working in a boulder bed may have been given by the condition of the strata: deformation, crushing, close and irregular joints and pitching courses, such as Calvin records at the local quarry.[45] The Maquoketa shales outcrop in the valley of Silver creek northeast of Cresco, so that with the gentle dip of the rocks in this area no great thickness of the Devonian is to be expected, unless the Maquoketa is cut away owing to erosion before the deposit of the Devonian.

The Maquoketa section in the vicinity of Cresco was found by Calvin to embrace shales and calcareo-magnesian beds in alternating layers, crystalline dolomites, light yellow magnesian shales, and non-magnesian, fossiliferous limestones. Owing to the absence of the heavy beds of plastic shales which make up the larger part of the Maquoketa in the area of outcrop to the southeast, the entire thickness of the formation in this county is estimated by Calvin at not to exceed 100 feet.[46]

45 Calvin, S., Geol. of Howard Co., Iowa Geol. Survey, vol. XIII, p. 59, Des Moines, 1903.
46 Op. cit., pp. 48, 49.

In accordance with these field determinations the upper bed of the Maquoketa is taken to be the dolomite and shale at 80 feet. A thickness of 120 feet brings the formation to the horizon where a brown argillaceous dolomite gives place at 200 feet to heavy nonmagnesian earthy limestone, evidently Galena limestone which has escaped dolomitization, a common feature of the Galena of this area.

DALLAS CENTER, DALLAS COUNTY

(Altitude 1073 feet)

CITY WELL OF DALLAS CENTER

This well was drilled by Thorpe Brothers Well Company of Des Moines and is a little over 2000 feet deep. Its diameters range from 12 to 6 inches. It is cased with 12 inch pipe to 131 feet, with 10 inch pipe to 498 feet, with 8 inch pipe from 469 to 1048 feet and with 6 inch pipe from 960 to 1900 feet.

The formations encountered by the drill were glacial drift to 130 feet and shale to 840 feet, where limestone, presumably of the Mississippian system, was reached. The top of the Saint Peter sandstone is reported as approximately 1941 feet below the curb, or about 868 feet below sea level.

An analysis of water from this well was made recently by Howard C. Maffitt of Des Moines and the results are given below.

Analysis of water from the present town well at Dallas Center

Constituents	Parts per million by weight	Grains per U. S. Gallon
Sodium and potassium	316.0	18.3
Calcium (as Ca)	537.0	31.2
Magnesium (as Mg)	138.0	8.0
Iron (as Fe)	5.6	0.32
Aluminum (as Al)	3.7	0.21
Manganese	none	
Sulphate (as SO_4)	2251.0	131.0
Nitrate	none	
Phosphate	none	
Bicarbonate (as HCO_3)	216.0	12.5
Chloride (as Cl)	177.0	10.3
Silica (as SiO_2)	30.0	1.74

Hypothetical Combinations	P.P.M.
Sodium chloride	292.0
Sodium sulphate	622.0
Magnesium sulphate	683.0
Calcium sulphate	1818.0
Calcium bicarbonate	8.0

The iron had precipitated from the water before the sample was received.

WELL OF MINNEAPOLIS AND SAINT LOUIS RAILROAD

This well was drilled by the McCarthy Well Company of Minneapolis. It is approximately 900 feet deep, but very little else is known about it. Little use is made of the water on account of its high mineral content, as is true also of the city well. The analyses of these two well waters were furnished by Messrs. W. E. Buell and Company, Municipal Engineers of Sioux City, who suggested that possibly the similarity in the analyses may be due to a break in the casing of the city well permitting the influx of sulphate waters from the Coal Measures, which probably supply the railroad well.

*Analysis of water from the M. & St. L. Railroad well at Dallas Center**

Constituents	P.P.M.	Gr. per Gal.
Total solids	3495.0	204.5
Silica (SiO_2)	11.0	.64
Iron and aluminum oxides	7.5	.44
Calcium (Ca)	568.0	33.20
Magnesium (Mg)	109.8	6.32
Alkalinity (as $CaCO_3$)	175.6	10.27
Chlorides (Cl)	166.2	9.73
Sulphates (SO_4)	2015.0	117.70
Hypothetical Combinations		
Sodium chloride (NaCl)	275.5	16.10
Sodium sulfate (Na_2SO_4)	568.0	33.20
Magnesium sulfate ($MgSO_4$)	541.8	31.65
Calcium sulfate ($CaSO_4$)	1698.0	99.35
Calcium carbonate ($CaCO_3$)	175.2	10.24

No determination of iron alone could be made since by the time water reached the laboratory the iron had all settled out.

DAVENPORT

(*Altitude C., M., St. P. & P. R. R. Sta. 560 feet, U. S. G. S.*)

WELL OF CITY OF DAVENPORT

In 1922 a well 1905 feet deep was completed for the municipal swimming pool at Davenport by the McCarthy Well Co. of Minneapolis and Saint Paul.

The diameters are from 12½ to 10 inches. The well is a flow-

* Made by the State Chemical Laboratory of the State of South Dakota.

ing well with a natural discharge of approximately 200 g.p.m. The log of the well is as follows:[47]

	Depth in Feet		Depth in Feet
Drift	0–28	Shale	1752–1768
Limerock	28–400	Shale and lime	1768–1780
Shale	400–625	Limerock	1780–1785
Limerock	625–950	Shale and lime	1785–1790
Shale	950–970	Limerock	1790–1798
Sandrock	970–1150	Lime and shale	1798–1808
Shale and rock	1150–1200	Limerock	1808–1817
Limerock	1200–1460	Shale and lime	1817–1821
Sandrock	1460–1471	Limerock	1821–1845
Limerock	1471–1476	Lime and shale	1845–1851
Sandrock	1476–1532	Limerock	1851–1880
Limerock	1532–1752	Sandrock	1880–1905

The log permits the following assignment to formations:

	Thickness	Depth in Feet
Pleistocene	28	0–28
Devonian and Silurian	372	28–400
Maquoketa	225	400–625
Galena-Platteville	325	625–950
Glenwood	20	950–970
St. Peter (and upper Shakopee)	180	970–1150
Prairie du Chien	310	1150–1460
Jordan	72	1460–1532
Trempealeau	220	1532–1752
Franconia	128	1752–1880
Dresbach, penetrated	25	1880–1905

DAVIS CITY, DECATUR COUNTY

(Altitude 913 feet)

The city well of Davis City was drilled by the Thorpe Bros. Well Co. of Des Moines about 1914 and is reported to be 950 feet deep. The diameters are from 10 to 5 inches. Water stands within 200 feet of the surface. No other facts as to the well are now obtainable.

DECORAH

DRILL HOLE OF THE PIONEER OIL AND GAS COMPANY

This well is on Bakke no. 1 lease, Twp. 98 N. R. 7 W. Se. qr. of sw. qr. Sec. 30 Glenwood township, Winneshiek county. (Altitude about 1100 feet.)

47 Lindly, J. M., Proceedings Iowa Acad. of Science, vol. XXXIV, p. 247.

Driller's log, with assignment to formations

	Depth in Feet
Pleistocene and Recent (28 feet thick):	
Mud, soft	0–28
Galena limestone (222 feet thick):	
Lime, hard	28–250
Decorah shale (38 feet thick):	
Shale	250–260
Sandy shale (water)	260–275
Shale, blue	275–288
Platteville limestone (22 feet thick):	
Lime	288–310
Glenwood shale (5 feet thick):	
Mud	310–315
Saint Peter sandstone (90 feet thick):	
Saint Peter sandstone (water)	315–405
Prairie du Chien (290 feet thick):	
Blue mud	405–408
White lime	408–465
Sand (water)	465–470
Hard lime	470–500
Shale	500–505
Lime sand	505–695
Jordan sandstone (105 feet thick):	
White sand	695–800
Saint Lawrence dolomite and shales (218 feet thick):	
Black lime and sand	800–830
White sand	830–835
Lime	835–845
Shale	845–850
Lime	850–860
Sand	860–870
Lime	870–890
Sand	890–910
Blue shale	910–920
Sand	920–950
Shale	950–1018
Dresbach sandstone (137 feet thick):	
Sand	1018–1155
Eau Claire beds (85 feet thick):	
Shale	1155–1165
Sand shale	1165–1195
Mud	1195–1205
Sand shale	1205–1240
Mount Simon beds (410 feet thick):	
Sand	1240–1650
Red clastics (70 feet thick):	
Mud (red bed)	1650–1720
Archean, dark igneous or metamorphic rocks (penetrated 1580 feet):	
Black lime	1720–2512
Black lime	2512–3000
Salt water lime	3000–3300
Black lime	3300
Black sand in place of lime	

Remarks.—The Decorah oil prospect has several claims to distinction. Among them is the fact that it is the deepest drill hole in the state both stratigraphically and by measurement in feet. No oil or gas was found, and shooting the well in the summer of

1926 with 80 quarts of explosive at 3300 feet and with 160 quarts at 2560 feet did not bring to light any evidence that the Archean rocks of Iowa are more petroliferous than the Archean of other areas.

No samples of the cuttings were obtainable above the Archean, but the driller's log falls in rather easily with the normal geologic section to be expected in northeastern Iowa. Samples of the cuttings of the "black lime" were submitted, and have been examined petrologically by Professor J. R. Van Pelt, Jr., of Cornell College.

Minerals present	DEPTH OF SAMPLE IN FEET
Quartz (35 to 45 per cent), oligoclase (35 to 45 per cent), magnetite (10 to 15 per cent), biotite (trace)	2990
Quartz, plagioclase, probably albite or oligoclase; calcite (from a higher horizon?); magnetite; hematite	3000
Material much finer-grained than other samples; nearly every grain deeply iron-strained; quartz, feldspar, minor amount of biotite	3140
Similar to preceding sample but coarser; both notable for deep brown rust color. Quartz abundant, fine; biotite 5 to 10 per cent, in flakes up to 2 mm.; small amount of fine-grained magnetite	3200
Quartz; plagioclase (much of it twinned on the albite law); biotite; magnetite; a light green translucent mineral unidentified	3300

None of the fragments in the samples was large enough to show the texture of the rock.

DELMAR, CLINTON COUNTY

WELL OF CHICAGO, MILWAUKEE AND SAINT PAUL RAILWAY

This well was drilled in 1917 by W. H. Gray and Brothers of Milwaukee. The depth is 1216 feet; the diameters are from 16 to 6 inches. The static level is 80 feet below the surface. The pumping capacity is 200 gallons per minute and with the pumping cylinder at 140 feet the water is lowered but slightly when pumped at the rate of 108 gallons per minute. The well is cased to top of rock and from 763 to 861 feet.

*Water Analysis**

	GRAINS PER U. S. GALLON
Oxides	1.00
Calcium carbonate	10.88
Magnesium carbonate	7.01
Alkali sulphate	.71
Alkali chloride	.64
Total	20.75

* H. W. Ostrom, Railway Chief Chemist.

Driller's Log

	Depth in Feet
Pleistocene and Recent (57 feet thick; top 810 feet above sea level):	
Yellow clay	0–30
Blue clay	30–50
Gravel	50–57
Niagaran limestone (163 feet thick; top 753 feet above sea level):	
Yellow limestone	57–145
White limestone	145–220
Maquoketa shale (225 feet thick; top 590 feet above sea level):	
Hard sandy shale	220–445
Galena limestone, Glenwood shale and St. Peter formation (416 feet thick; top 365 feet above sea level):	
Limestone, very hard	445–763
Shale	763–771
Sandy shale	771–800
Medium sandy shale	800–807
Hard shale	807–830
Caving shale	830–861
Prairie du Chien (368 feet thick; top 3 feet above sea level):	
Limestone	861–1006
Streaks of lime and sandstone	1006–1175
Jordan sandstone (35 feet thick; top 365 feet below sea level):	
Sandstone, water bearing	1175–1210
Saint Lawrence, Trempealeau dolomite (penetrated 6 feet; top 400 feet below sea level):	
Limestone, to bottom of the well	1210–1216

Notes.—The shale at 220 feet is doubtless the Maquoketa, altho it is quite exceptional to have this "mud rock" shale described either as "hard" or "sandy." The run of limestone from 445 to 763 feet seems to include both the Galena and the Platteville, and the Decorah is not distinguished. The Glenwood shale appears at 771 feet, but its thickness and base are somewhat uncertain.

DELMAR WATERWORKS WELL, 1927

This well, 1592 feet deep, was completed in 1927 by the Gray Well Drilling Company of Milwaukee and Chicago. The diameters are from 13 to 8 inches. The well is cased with a 12½ inch drive pipe to rock, and a 10 inch casing extends from the surface to 458 feet, casing out Niagaran and drift waters and preventing caving from the Maquoketa shale. An 8 inch liner is inserted from 745 feet 8 inches to 875 feet, shutting out caving shales both above and below the Saint Peter sandstone.

The original contract provided for a well 1250 feet deep, sufficient to tap not only the Saint Peter and other Ordovician aquifers, but also the Jordan sandstone of the Cambrian. At this depth, however, the well was found to yield but 75 g.p.m. and the drilling was continued through the Dresbach sandstone. On completion at 1592 feet the well delivered on test 100 g.p.m. with the pumping cylinder at 278 feet.

Until after passing the Jordan sandstone the static level stood abnormally high. At 1250 feet it was 70 feet (with a draw down to 140 feet). The head, therefore, of the Jordan and higher water beds was 737 feet above sea level. This may be compared with the original head at Sabula from the Jordan, 658 feet above tide, Green Island 665 feet, Clinton water works no. 1 632 feet, and of more recent wells, Clinton water works well no. 5 (1902) 602 feet and De Witt city well (1923) 617 feet. On continuing the drilling the static level had fallen to 170 feet (637 feet above sea level) at 1309 feet, in the Trempealeau dolomite, and to 190 feet (617 feet above tide) at 1380 feet, in the Franconia beds. After piercing the Dresbach sandstone the static level stood on the completion of the well at 196 feet (611 feet above sea level) or at about the present static level of the De Witt and Clinton wells.

Record of strata, Delmar waterworks well, 1927

	Depth in Feet
Pleistocene and Recent (54 feet thick; top 807 feet above sea level):	
Clay, yellow, sandy, noncalcareous, in hard masses; 2 samples	0–30
Till, blue-gray, calcareous; 3 samples	30–54
Niagaran dolomite (158 feet thick; top 753 feet above sea level):	
Dolomite, buff, large chips; 3 samples	54–85
Dolomite, bright buff, in sand and powder, argillaceous	85–95
Dolomite, bright buff, large chips	95–105
Dolomite, bright buff; at 115 also some dark olive-gray clay, unctuous, noncalcareous; at 125 feet fragment of cast of *Halysites catenulatus ?*; 3 samples	105–135
Dolomite, very light gray or whitish, crystalline-granular, some slightly vesicular; at 135 considerable clay or shale as at 105; from 175 to 195 much white chert; 6 samples	135–195
Dolomite, blue-gray, cryptocrystalline, cherty	195–205
Dolomite, blue-gray, argillaceous, some siliceous with microscopic particles of quartz; some blue gray shale	205–212
Maquoketa shale (228 feet thick; top 595 feet above sea level):	
Shale, blue, hard, dolomitic, pyritic, some laminated, in chips; some light colored dolomite	212–220
Shale, blue, plastic	220–230
Shale, blue-gray, in chips and concreted masses	230–240
Shale, blue, dolomitic, plastic; 16 samples	240–410
Shale, drab, in concreted masses; included chips brownish drab	410–420
Shale, dark brown, inflammable, in chips	420–430
Shale, brown and drab	430–440
Galena-Platteville limestones; Glenwood shale (325 feet thick; top 367 feet above sea level):	
Dolomite, drab and light brown-gray, argillaceous, pyritic, crystalline-earthy, compact; in flaky chips; much brown inflammable shale	440–445
Dolomite, gray and yellow-gray, crystalline, in chips; 2 samples	445–460
Dolomite, light gray, in sand and fine chips; 5 samples	460–510
Limestone, rapid effervescence in cold dilute HCl, white, soft, earthy, fossiliferous, in flaky chips; most of sample dolomite as above	510–520

Limestone, whitish and buff, in chips and powder, effervescence rapid; 5 samples	520–570
Limestone, as above; dolomite, buff	570–580
Dolomite, yellow-gray; white chert; 2 samples	580–600
Dolomite, brown and buff, cherty; 2 samples	600–620
Dolomite, buff; limestone, light yellow and whitish, earthy, effervescence rapid, in large flakes; 2 samples	620–640
Limestone, yellow gray and whitish, some mottled, earthy, response moderately rapid; some buff dolomite; 3 samples	640–670
Limestone, brown, rapid effervescence	670–680
Shale, brown, highly inflammable, calcareous, hard, in chips; much whitish limestone	680–690
Limestone, buff and gray, effervescence rapid, moderately rapid and slow	690–696
Shale, green, hard; chips of limestone	696–701
Limestone, buff and whitish, response rapid; shale, brown, inflammable; shale, bright green	701–710
Limestone, drab and gray, response rapid; 5 samples	710–755
Shale, greenish, in concreted masses; inclosed chips of limestone	755–765
Saint Peter sandstone (95 feet thick, top 42 feet above sea level):	
Sandstone, yellow in mass from rusted grains (magnetic iron from drill in cuttings), grains well rounded and frosted, larger grains up to 1 mm. in diameter; some hard green shale in flakes	765–775
Sandstone, white, finer	775–785
Sandstone, light yellow-gray; whitish clayey powder feebly calcareous	785–795
Sandstone, whitish; 2 samples	795–815
Sandstone, rusted light yellow, secondary enlargements	815–825
Sandstone, yellow-gray in mass; siliceous chips white, with imbedded transparent grains of quartz; some whitish shale	825–835
Sandstone, white; shale, light green, fissile, noncalcareous	835–845
Shale, light bright green, noncalcareous, concretionary structures; concreted masses of white dolomitic powder; a few chips of gray dolomite and of light greenish gray dolomite argillaceous and siliceous; white unctuous clay with microscopic particles of white chert; two chips of yellow jasper with minute globular structures, oölitic or fossiliferous	845–855
Shale, light bright green; one large chip indurated, light greenish gray, apparently concretionary	855–860
Prairie du Chien dolomites (295 feet thick; top 53 feet below sea level):	
Dolomite, light yellow-gray, fine-grained, compact, soft; chert, white; much green shale	860–870
Dolomite, light yellow-gray and brown; shale, green	870–880
Dolomite, gray, in small chips; whitish from 970 to 1030; 14 samples	880–1030
Dolomite, blue-gray	1030–1040
Dolomite, as above, cherty; 2 samples	1040–1060
Dolomite, blue-gray; 4 samples	1060–1100
Dolomite, buff, cherty	1100–1105
Dolomite, light yellow-gray, highly cherty, arenaceous	1105–1115
Dolomite, light gray	1115–1125
Dolomite, whitish, arenaceous, a little hard green fissile shale; a little fine-grained sandstone	1125–1135
Dolomite, buff; 2 samples	1135–1155
Jordan sandstone (30 feet thick; top 348 feet below sea level):	
Sandstone, light yellow in mass, fine, well-rounded grains, some crystalline enlargements, considerable dolomite with embedded grains; some dark brown argillaceous sandstone with buff flint at 1165; 3 samples	1155–1185
Saint Lawrence, Trempealeau dolomite (145 feet thick; top 378 feet below sea level):	
Dolomite, whitish, in fine sand, a very little quartz, some drusy	1185–1195
Dolomite, whitish	1195–1205
Dolomite, light gray, crystalline; a very little quartz sand; 2 samples	1205–1225

Dolomite, light gray, much sand in fairly well rounded grains but no imbedded grains found in dolomite chips; 2 samples 1225–1245
Dolomite, light gray, some quartz sand; some chert; 2 samples 1245–1260
Dolomite, buff in mass, in fine sand; 2 samples 1260–1280
Dolomite, whitish, in very fine sand 1280–1290
Dolomite, gray, cherty 1290–1300
Dolomite, gray; a little quartz sand 1300–1310
Dolomite, light red-brown, rusted by iron from drill; some quartz sand; 2 samples 1310–1330

Saint Lawrence, Franconia beds (100 feet thick; top 523 feet below sea level):
Dolomite, brown in mass, minutely arenaceous, glauconitic 1330–1340
Sandstone, reddish gray, minute grains, glauconitic; shale, purplish and green, hard, fissile 1340–1350
Sandstone, gray, grains minute, speckled with glauconite 1350–1360
Shale, green, highly arenaceous, grains minute; glauconitic, dolomitic; 2 samples 1360–1380
Sandstone, gray, of minute grains, speckled with glauconite, dolomitic cement; green shale; 3 samples 1380–1410
Sandstone, gray, minute grains, slightly glauconitic; gray shale; 2 samples 1410–1430

Dresbach sandstone (110 feet thick; top 623 feet below sea level):
Sandstone, clean, white, diverse in size of grains, maximum up to 1.2 mm. diameter, grains well rounded, frosted; 2 samples 1430–1450
Sandstone, 2 samples, one as above; the other, argillaceous, crystalline enlargements of grains 1450–1460
Sandstone, white, some rusted buff, medium to fine, at 1520 largest grains reach 1.3 mm.; 8 samples 1460–1540

Eau Claire sandstone (penetrated 52 feet; top 733 feet below sea level):
Sandstone, gray, argillaceous, fine, grains rounded, feebly dolomitic; 2 samples 1540–1560
Sandstone, greenish gray, fine, glauconitic, feebly dolomitic; 2 samples..1560–1580
Sandstone, greenish gray, fine to medium, glauconitic, grains rounded ..1580–1592

Notes.—It will be noted that thin transition beds, argillaceous dolomites, occur both above and below the Maquoketa shales. As in some other deep well sections a brown inflammable shale is found at the base of the formation.

The upper 70 feet of the Galena-Platteville are typical dolomites. The lower 245 feet are undolomitized with the exception of a 40 foot bed of dolomite well up the column. Within 75 feet of the base occurs a layer of brown inflammable shale and a few feet below is 5 feet of green shale.

The Glenwood shale is thin, rests directly on the Saint Peter sandstone and contributes by caving to the first cuttings of the sandstone.

At the base of the Saint Peter occurs anomalously a caving shale, 15 feet thick, which may be compared to the shales and conglomerate found at this horizon at Maquoketa, Preston and De Witt. The cuttings at Delmar do not clearly indicate a conglomerate as at the towns just mentioned, but they strongly suggest such an origin by the mingling of shale, dolomite, chert, decayed chert and jasper.

The Prairie du Chien has its normal thickness for northeastern Iowa but does not here carry a well defined medial sandstone, the New Richmond.

The Jordan is exceptionally thin and its texture as evidenced by the cuttings shows the reason for its scanty yield.

The underlying Trempealeau dolomite is in places somewhat sandy. Possibly the Jordan might be mistaken for the New Richmond, the Trempealeau for the Oneota of the Prairie du Chien and the Dresbach for the Jordan, were it not for the typical glauconitic shaly dolomitic sandstones so easily and clearly identified as the Franconia.

The Dresbach sandstone, 100 feet thick, gives cuttings which suggest a more generous yield than the tests on completion proved. It rests on typical Eau Claire beds.

DENISON

(Altitude 1170 feet)

The deep well at Denison, completed for the city in 1916 by W. H. Gray and Brother of Chicago, is 1810 feet in depth, with diameters from 14 to 8 inches. The pumping capacity is 200 g.p.m. and is sufficient for the normal demand. Two dug wells, yielding 60,000 g.p.d. are in reserve. The static level is 88 feet with a draw down to 170 feet. The main supply comes from the Saint Peter and the Prairie du Chien, from 1680 feet and below, the lower beds furnishing the larger amounts.

The upper casing, 14 inch, is 262 feet in length. A 10 inch casing 261 feet long is bedded at 500 feet. The shales above the Saint Peter sandstone are cased out with 8 inch casing, 46½ feet long, bedded at 1665 feet.

The cost of the well was $6613.

Driller's Log

	Depth in Feet
Struck shale at	245
Drift and shale	245–485
Brown limerock	485–950
Lime rock with traces of shale	950–1600
Shale and rock, caved and had to be cased out	1600–1665
Lime rock	1665–1680
Sandstone	1680–1730
Brown lime	1730–1810

Below the sandstone there seemed to be many crevices, as we drilled 35 feet, from 1740 to 1775 feet, without being able to get a sample.

Record of strata in City well no. 1, Denison

	Depth in Feet
Pleistocene and Recent (210 feet thick; top 1170 feet above sea level):	
Alluvium, silts, clay, sand and glacial tills; 20 samples	10–200
Pennsylvanian (170 feet thick; top 960 feet above sea level):	
Shales, gray, brown, black; 17 samples	210–370
Mississippian, Devonian (?), Silurian (780 feet thick; top 790 feet above sea level):	
Limestone, whitish and light yellow-gray, crystalline-earthy, rapid effervescence in cold dilute HCl, in flaky chips; with some chips of black shale	380
Flint, yellowish; limestone of same color; a little shale	390
Limestone, buff and gray, fine-grained, effervescence moderately slow	400, 410
Shale, gray, calcareous, in concreted masses	420, 430
Chert, white; limestone, gray; some brown ferruginous limestone; shale in concreting powder	440
Shale, gray; with some limestone, white crystalline-granular and light yellowish, cryptocrystalline, rapid effervescence; white chert	450
Shale, gray; limestone, white, gray and buff, reaction rapid; chert, chalcedonic silica, and quartz sand in fine irregular grains; 3 samples	460–480
Limestone, gray, fine crystalline-granular, much blue-gray flint	485
Flint, blue-gray; and limestone, yellow-gray and whitish, crystalline-granular, rapid reaction	490
Limestone, whitish and yellow-gray, rusted buff, encrinital, rapid response to acid	500
Limestone, blue-gray and whitish, subcrystalline and earthy, reaction rapid; at 520 laminated and with chips of vein or geodic quartz; 4 samples	510–540
Limestone, light yellow-gray, calcilutite, and buff, fine crystalline-granular	550
Limestone, light yellow-gray, whitish and gray, crystalline-earthy and fine crystalline-granular, oölitic at 580, cherty at 570 and 690, rapid effervescence, with considerable quartz sand in cuttings at 610 and 630, and some in all; 14 samples	560–690
Limestone, light yellow-gray, slow reaction, some rapid	700
Limestone as above, cherty; 3 samples	710–730
Limestone, light yellow-gray, fine grained, rapid effervescence; light gray chert	740
Limestone, drab, cherty, argillaceous, rapid response	750
Limestone, light buff, fine crystalline-granular, rapid effervescence; cherty	760
Limestone, buff, rather slow response to acid	770
Limestone, light gray, rather rapid reaction	780
Dolomite, light blue-gray, fine crystalline-granular, in fine sand; 4 samples	790–820
Limestone, gray, earthy, rather rapid reaction, some chips slow	830
Dolomite, light blue-gray; 3 samples	840–860
Dolomite as above, with some limestone chips of rapid effervescence	870
Dolomite, light yellow-gray, fine crystalline-granular, with some chips of rapid effervescence; 5 samples	880–920
Dolomite, light gray, somewhat argillaceous	930
Limestone, whitish and blue gray, earthy, in flaky chips, reaction rapid; some dark gray, finely laminated, highly argillaceous; some green shale, fissile, calcareous	940
Dolomite, light buff	950
Shale, blue-gray, highly calcareous, in hard concreted masses	960
Dolomite, light yellow-gray, unwashed cuttings in friable concreted masses, washed cuttings in crystalline sand	970, 980
Dolomite and shale; dolomite, light yellow gray in sand; shale, blue-gray	990, 1000

Dolomite as above, some flakes of gray-green shale; in hard concreted masses	1010
Dolomite and shale; dolomite, light yellow-gray, in sand; shale in concreting powder	1020
Dolomite, in light buff sand; 4 samples	1030–1060
Dolomite, light yellow-gray and buff, crystalline-granular, effervescence somewhat more rapid than LeClaire dolomite; at 1100 majority of grains of cuttings show rapid effervescence; 9 samples	1070–1150
Ordovician:	
Maquoketa shale (40 feet thick, top 10 feet above sea level)—	
Dolomite, blue-gray, earthy, moderately slow effervescence	1160
Dolomite and shale, dolomite dark blue-gray, moderately slow reaction, in sand; shale in powder, considerable pyrite	1170
Shale, light drab, in hard concreted masses gritty with fine limestone particles	1180, 1190
Galena and Platteville (480 feet thick; top 30 feet below sea level)—	
Dolomite, buff, subcrystalline, considerable pyrite at 1220; 3 samples	1200–1220
Chert, white, gray and blackish, mottled; and dolomite	1230
Dolomite and chert, as above	1240
Chert and dolomite, light gray	1250
Dolomite and chert	1260
Dolomite, light gray; 3 samples	1270–1290
Dolomite, gray, vesicular, crystalline-granular, rough, cherty	1300
Dolomite, gray and dark gray, subcrystalline and white, cherty; some cuttings with pepper and salt appearance; 8 samples	1310–1380
Dolomite, gray, argillaceous; cherty	1390, 1400
Dolomite, light gray, with flint of same color	1410
Dolomite, whitish, in flour, argillaceous, cherty; with particles of crystalline quartz too minute to polarize in strong colors	1420
Dolomite, gray and buff, mostly in fine crystalline sand, cherty at 1440-1470, 1510-1540; 15 samples	1430–1570
Limestone, blue-gray and yellow-gray, in small chips, rapid reaction	1580
Shale, light blue-gray, highly calcareous, in hard concreted masses, quartzose with minute grains and angular particles; 3 samples	1590–1610
Limestone, light yellow-gray, earthy, soft, rapid response, in flaky chips; and chips of green-gray, fissile calcareous shale	1620
Shale, blue-gray, green-gray and drab, calcareous; 4 samples	1630–1660
Limestone, light gray, reaction rapid; pyrite; chips of gray shales	1670
Saint Peter sandstone (60 feet thick; top 510 feet below sea level)—	
Sandstone, white, fine, grains well rounded, frosted; a few chips of limestone of brisk effervescence at 1680; a little green shale in chips at 1710-1720; 5 samples	1680–1720
Sandstone, minute ill-rounded grains of pure quartz, some stained with iron; chert; much pyrite	1730
Prairie du Chien (penetrated 70 feet, top 570 feet below sea level)—	
Dolomite, whitish, light yellow-gray and pink, somewhat rusted, sparsely arenaceous with imbedded grains; cuttings in coarse sand with considerable quartz sand and green shale	1740
"Drillings washed away"	1750, 1760
Dolomite, light gray and oölitic chert	1775
Dolomite, light yellow-gray, in sand, arenaceous, particles of dolomite largely in excess of quartz grains	1785
Dolomite as above, some quartz grains with secondary enlargements	1795–1805
Dolomite, as above, arenaceous, grains of quartz sand, rounded, coarser and more numerous than above; considerable chert	1810

Notes.—In the Denison section the Coal Measures may seem exceptionally thin, but it must be taken into account that their base lies 45 feet higher than at Audubon, for example, of points southeast, while the preglacial surface stands 88 feet lower.

The base of the Mississippian is undetermined. If it lies at about the same distance above the top of the Saint Peter as at Audubon, it may occur at 790 feet (380 feet above sea level) where dolomites or magnesian limestones begin in heavy beds.

The thickness of the Silurian at Stuart, where it is believed to be marked by gypsiferous beds, leads to the inference that the dolomites at Denison from 790 to 1160 feet may belong to that system. The shales and argillaceous limestones at the latter depth seem to correspond stratigraphically with the Maquoketa at Stuart. The underlying dolomites and limestones and basal shales to the Saint Peter sandstone at 1680 feet are thus assigned to the Galena and Platteville and to the Glenwood.

The Saint Peter is here too fine of grain to be a bountiful water-bed. The main supply comes from the creviced dolomites and sandy layers of the Prairie du Chien. The upper beds of these dolomites, and perhaps all of them, belong to the Shakopee, but possibly the highly arenaceous stratum struck at 1810 represents the New Richmond sandstone.

It may be added that the cuttings were unwashed. The colors given are those of the individual chips after washing and are thus different from the color of the cuttings in mass, which was pretty uniformly a gray.

*Chemical Analyses of Cuttings from deep well at Denison**

DEPTH IN FEET	720	780	790	870	1070	1300	1540	1580
Fe_2O_3	7.24	.92	1.31	1.59	.90	.63	2.26	4.82
Al_2O_3	.44	.62	0.00	.49	.34	1.51	.57	.53
$CaCO_3$	52.30	60.80	57.34	61.01	64.40	56.52	57.02	80.10
$MgCO_3$	40.23	37.57	41.63	37.27	34.43	41.77	40.20	14.60
Total	100.21	99.91	100.28	100.16	100.07	100.43	100.06	100.05

DES MOINES

WELL OF NORTHLAND MILK AND ICE CREAM COMPANY, EAST 6TH AND DES MOINES STREETS

This well was drilled in 1925 by Thorpe Bros. of Des Moines. The flow over the top, when the well was completed, was approximately 100 g.p.m.

* Silica omitted, because of chert and quartz sand in cuttings.

*Record of strata**

	Depth in Feet
Pleistocene and Recent (26 feet thick; top 833 feet above sea level):	
"Yellow clay"	0–26
Pennsylvanian (209 feet thick; top 807 feet above sea level):	
"Gray shale"	26–60
"Brown shale"	60–70
"Light shale, seep water"	70–95
"Black shale"	95–105
"Light shale"	105–115
"Dark blue shale"	115–170
"Light blue shale"	170–213
"Dark shale"	213–217
"Light blue shale"	217–222
"Sandstone, shaly"	222–230
"Light shale"	230–235
Mississippian:	
Meramec, Osage and Upper beds of the Kinderhook (400 feet thick; top 598 feet above sea level)—	
"Limestone"	235–275
"Shale, blue"	275–280
"Limestone"	280–295
"Brown shale"	295–335
"Limestone"	335–345
"Shale, with lime streaks"	345–365
"Limestone"	365–380
"Lime, with shale streaks"	380–410
"Limestone"	410–460
"Shale, blue"	460–470
"Limestone"	470–510
Limestone, with large amounts of chert	505
Limestone with sand, limestone dark gray, in fine chips ranging up to one-fourth inch in diameter, finely granular, responds rather slowly to acid; residue quite large, very fine-textured, gritty; chips of white granular quartz	515, 530
Limestone, similar to above, more ready response to acid, residue cherty, only a little sand	540, 550
Limestone, as above, more dolomitic; white flint	560
Limestone, shaly, gray, in friable concreted lumps; response to acid very brisk; residue abundant, of exceedingly fine white sand grains and clay	570
Limestone, light gray, in concreted lumps which break up readily into fine powder and small chips, response to acid very ready; cherty; a little very fine sand; 3 samples	580–600
Limestone, lighter gray than above, very readily soluble	610, 620
Kinderhook shale (185 feet thick; top 198 feet above sea level)—	
Shale, gray, red, chocolate colored, etc., soft; fine; somewhat limy	635
Shale, gray, soft, very limy; some finely gritty; 9 samples	640–720
Shale, light tan, soft, very limy, finely gritty; 3 samples	730–740
Shale, similar to above, more gritty with chips of gray limestone and blue gray shale	750
Shale, light tan, limy, finely gritty, and with small chips of light gray and dark gray limestone, very responsive to acid, finely crystalline	755, 760
Shale, tan, limy, finely gritty, noncalcareous; flakes of limestone, dark gray, fairly ready response to acid; flakes of selenite	770
Shale, brownish tan, and dark blue, soft, only slightly gritty, noncalcareous	775
Shale, as at 770	790
Shale, brownish, in rather coarse powder; flakes of selenite; dark	

* By Dr. James H. Lees, Assistant State Geologist.

sand grains; yellowish calcite. A small chip disintegrates in acid leaving abundant sand	800
Devonian (120 feet thick; top 13 feet above sea level):	
Limestone, light gray, in flakes, grains and powder, noncrystalline; effervesces freely in acid; considerable fine siliceous residue; dark round flat masses like flax seed which probably are ironstone	820
Shale, very light gray, readily effervescent, finely gritty; very fine grains of silica, some dull, some sparkling	830
Limestone, dark gray, very fine-grained; calcite; crystalline fragments of quartz; ironstone concretions as above; flakes of white chert; little clay present in the limestone but much silica in fine grains in addition to the flint. Another sample marked 840 is a light gray, highly calcareous, very fine powder and evidently represents a streak of limy, finely siliceous shale	840, 850
Limestone, gray, in powder and small grains, very ready response to acid; some transparent granules of quartz; considerable sandy residue	860, 870
Limestone, light tan, in fine gritty powder, highly calcareous, some sandy residue	880
Limestone, light gray, dolomitic, in very fine grains, which under the glass are seen to be almost white and translucent with many small shining fragments of calcite	890
Limestone, gray, crystalline, as above, but somewhat more responsive to cold acid	900
Limestone, darker gray, crystalline, responds vigorously to cold acid	910, 920
Limestone, as at 900	930
Silurian (penetrated 414 feet; top 107 feet below sea level):	
Limestone, a little darker than above, readily soluble; with insoluble white subcrystalline flakes of the hardness of anhydrite	940
Limestone, light gray, in grains and small chips; flakes of white fibrous selenite three-fourths inch long	950
Limestone, gray, in grains and chips, noncrystalline, some crystalline, effervesces freely in cold acid; (at 980 in very small grains, white to dark brown, action in acid brisk); large clayey and sandy residue; 4 samples	960–990
Limestone, gray, in fine sugary grains, free effervescence in acid; 6 samples	1000–1060
Limestone, as above; large residue of gypsum or anhydrite	1070
Limestone, light gray; large admixture of gypsum, some in flakes one-fourth inch in diameter; response to cold acid slow at first but increasing	1080–1090
Limestone, darker gray than above, response to acid fairly ready, residue small; some gypsum	1100
Limestone as above, action in acid brisk	1110
Limestone, dark gray, sugary texture, action in acid slow at first; some flakes of selenite	1120
Limestone, dark gray	1130
Limestone, light gray, in fine powder concreted into masses	1140
No samples, ''lime'' of driller's log	1140–1210
Limestone, gray, sugary texture, action in acid brisk; 7 samples	1210–1270
Limestone, gray, action in acid starts rather slowly	1280
Limestone, gray, sugary, dolomitic, solution nearly complete	1290
Limestone, as above, sandy residue	1300
Limestone, yellowish, in fine sugary grains, moderate response to acid; residue fine clear grains of sand and fragments of gypsum	1310
Limestone, as above. Another sample taken from the drill bit at 1320 feet is shale, red, yellowish, blue, purple, etc., slightly limy, somewhat gritty. Just above the shale is a thin bed of sand which runs very freely and gave the drillers a good deal of trouble. Sample effervesces freely; large residue of clear quartz grains	1320
Shale, like that in sample above	1330
Limestone, light gray, in small grains and larger chips ranging up to	

one-fourth inch in diameter, effervesces readily; numerous flakes of bluish shale; flint, pink and white; clear grains of quartz which may come in part from bed above	1340
Dolomite, light gray, sugary; much quartz sand in small clear well-rounded grains, with some white and pink flint. The quartz composes probably two-thirds the entire mass	1350

Driller's Log

	DEPTH IN FEET
Given above in *Record of strata*	0–510
Lime, sandy	510–555
Limestone	555–630
Shale	630–748
Limestone	748–775
Lime, white, medium hard	780–860
Hard gray lime	860–888
Hard sandstone	888–890
Hard sand and lime	890–907
Hard lime	907–990
Broken lime, some salt water overflowed at surface	990–1010
Hard lime	1010–1020
Broken lime	1020–1080
Lime	1080–1222
Lime streaked with shale	1222–1272
Hard lime	1272–1310
Yellow shale with sand	1310–1320
Red shale	1320–1325
Light shale	1325–1336
Sand and lime mixed, strong flow of water	1336–1355

Analysis of water by Dearborn Chemical Co., Chicago, D. K. French, Chemical Director.

Mineral Analysis

HYPOTHETICAL COMBINATIONS	GRAINS PER U. S. GALLON OF 231 CU. IN.
Silica	1.168
Oxides of Iron and Aluminum	.116
Carbonate of Lime	Trace
Sulphate of Lime	94.196
Carbonate of Magnesia	11.550
Sulphate of Magnesia	7.674
Sodium and Potassium Sulphates	119.435
Sodium and Potassium Chlorides	12.240
Sodium and Potassium Nitrates	Trace
Loss, etc.	.069
Total Soluble Mineral Solids	246.448
Organic Matter	Trace
Suspended Matter	2.336
Total Soluble Incrusting Solids	107.030
Total Soluble Nonincrusting Solids	139.418
Pounds Soluble Incrusting Solids per 1000 U. S. gallons	15.29
Pounds Soluble Nonincrusting Solids per 1000 U. S. gallons	19.92

DEEP WELL OF WOOD BROTHERS, DES MOINES

This well was drilled by Thorpe Brothers Well Company in 1926. On completion it tested 250 gallons per minute and during this test of between three and four days the water, which had stood at 67 feet below the curb at the beginning of the test, lowered but 11 feet. The elevation of the curb is 840 feet above sea level.

*Driller's log of well of Wood Brothers**

	Depth in Feet
Pleistocene and Recent (85 feet thick; top 840 feet above sea level):	
Soil	0–15
Sea mud and sand	15–85
Pennsylvanian (145 feet thick; top 755 feet above sea level):	
Shale, yellow	85–230
Mississippian above Kinderhook shale (390 feet thick, top 610 feet above sea level):	
Lime	230–300
Shale, green	300–330
Lime	330–405
Shale, green	405–425
Lime	425–485
Shale, light	485–490
Lime	490–620
Kinderhook shale (65 feet thick; top 220 feet above sea level):	
Shale, green	620–645
Lime	645–660
Shale, green	660–685
Devonian and Silurian (665 feet thick; top 155 feet above sea level):	
Lime	685–1295
Shale, red	1295–1315
Sandy lime, sharp (Hoing sands of Silurian)	1315–1350
Maquoketa shale (100 feet thick, top 510 feet below sea level):	
Shale, red	1350–1375
Shale, blue	1375–1450
Galena, Decorah, Platteville, Glenwood (455 feet thick; top 610 feet below sea level):	
Lime shale	1450–1555
Sand shale	1555–1575
Lime	1575–1850
Shale, green (Decorah)	1850–1860
Lime (Platteville)	1860–1890
Shale, green (Glenwood)	1890–1905
Saint Peter (25 feet thick; top 1065 feet below sea level):	
Sand, soft, white	1905–1930
Prairie du Chien, 430 feet thick; top 1090 feet below sea level):	
Lime	1930–2085
Sandy lime	2085–2140
Sand, white	2140–2185
Lime	2185–2360
Jordan (penetrated 63 feet; top 1520 feet below sea level):	
Sand, brown and white	2360–2395
Sand, soft, white	2395–2423

Notes.—Comparing the sections of the two wells described above and that of the deeper well at Greenwood Park[48] it will be

* Assignment to formations by W. H. Norton.

48 Norton, W. H., Iowa Geol. Survey, vol. XXI, pp. 893-894.

seen that at the park well the Coal Measures are much thicker than at the others, while the Mississippian is correspondingly thinner.

The gypsum found by Lees at Silurian horizons in the Northland well, like that found at the same levels in the Park well, is referred to the Salina rather than the Niagaran.

The Hoing sands at the bottom of the Northland well may be the same as the arenaceous dolomite occurring 21 feet higher in the Park well and overlying 55 feet of cherty dolomite. In the Wood Brothers' well, the Hoing is apparently represented by the "sandy lime, sharp" at 1315 feet, immediately above the shales assigned to the Maquoketa.

The top of the Maquoketa appears 63 feet higher in the Wood Brothers' well than in that of Greenwood Park and the formation is 67 feet thicker, the base of the shales in both being at about the same elevation. In both wells the Galena, Decorah, Platteville and Glenwood are well made out. The thickness assigned to the underlying formations is as close as is to be expected, and the top of the Jordan is but 26 feet higher at Greenwood Park than in the well of Wood Brothers.

DE WITT, CLINTON COUNTY

(Altitude 719 feet, C., M. & St. P. Ry)

Previous to 1923 the city supply of De Witt was drawn from two wells, 274 and 524 feet deep. In the first water was obtained from the Niagaran limestone immediately above the floor of the Maquoketa shale; in the second from the Galena limestone immediately below the ceiling formed by the base of the same impervious shale, with a yield of 50 gallons per minute.

In January, 1923, a well 1646 feet deep was completed by the F. M. Gray, Jr., Well Company of Milwaukee. The diameters are 12½ inches to 70 feet, 12 inches to 283 feet, 10 inches to 1256 feet and 8 inches to bottom. The well is cased to 70 feet, from 283 to 526 feet, casing out the Maquoketa shales, and from 877 to 1256 feet.

The chief supply was found in the Dresbach sandstone at 1646 feet. The Saint Peter also was water bearing at 1100 feet.

The static level is 101 feet below the surface. At the test, pumping 225 gallons per minute gave a draw down of but one foot. The cost of the well was $10,000 and of the pumping machinery $5,000.

Record of Strata

	DEPTH IN FEET
Pleistocene and Recent (30 feet thick; 718 feet above sea level):	
"Clay and drift"	0–30
Niagaran (295 feet thick; top 688 feet above sea level):	
Dolomite, bright buff and yellow, pale cream color at 220; slightly cherty at 220 and 240, very cherty at 260; 14 samples	30–280
Dolomite, blue-gray	280–295
Maquoketa (201 feet thick; top 423 feet above sea level):	
Dolomite, blue-gray, crystalline; greenish drab, earthy, argillaceous; in chips; shale, light blue and drab, calcareous	295–305
Dolomite, blue-gray, crystalline in chips; shale, light blue	305–325
Shale, blue, plastic; 5 samples	325–425
Shale, gray; 2 samples	425–465
Shale, brownish gray	465–485
Shale, blue	485–496
Galena-Platteville (333 feet thick; top 222 feet above sea level):	
Dolomite, pale brownish gray and dark gray, crystalline, in clean chips; 4 samples	496–525
Dolomite, light buff-gray, in fine sand; an occasional well rounded grain of fine quartz sand	525–535
Dolomite, light brown-gray	535–555
Dolomite, buff and brown-gray, in fine sand, and chips; 3 samples	555–600
Dolomite, brown in mass, crystalline	600–620
Clay, yellow, slightly calcareous, very fine-grained; a little white sandstone of microscopic angular particles of clear quartz	620–625
Limestone, light gray and brownish gray, brisk effervescence in cold dilute HCl; a little brown dolomite; some white chert; 3 samples	625–680
Limestone, whitish and brownish gray, rapid effervescence, cherty; 3 samples	700–755
Shale, green, fossiliferous; pyrite; impure limestone (Decorah)	755–760
Limestone, drab and gray, finely laminated and fossiliferous at 760; 3 samples	760–820
Limestone, medium dark blue-gray	820–829
Glenwood (13 feet thick):	
Sandstone, whitish gray in mass, grains well rounded, some with secondary enlargements; a little brown inflammable shale	829–833
Shale, green, fissile, feebly effervescent	833–842
Saint Peter sandstone (223 feet thick, top 124 feet below sea level):	
Sandstone, whitish gray in mass, grains rounded, frosted, up to 0.8 mm. diameter; some green shale; on one chip sandstone and shale in apposition	842–850
Sandstone, white, clean, very fine	850–860
Sandstone, white, medium; 4 samples	860–915
Sandstone, white, some rusted grains; 4 samples	915–970
Sandstone, light gray and cream colored; 3 samples	970–1015
No samples, "sandstone"	1015–1050
Sandstone, light yellow from iron stained grains; secondary enlargements	1050–1065
Basal beds of the Saint Peter formation: conglomerates, shales and sandstones (295 feet thick; top 347 feet below sea level):	
Sandstone, light pink, fine to medium, some secondary enlargements, color due to pinkish and reddish grains and remains after boiling in acid	1065–1070

Sandstone, yellow, some grains rusted; some secondary enlargements, a very little dolomite, "chert pebbles" (Thwaites) 1070–1080
Shale, dark purplish red, hard, fine-grained, noncalcareous; a little shale light greenish, noncalcareous; chert pebbles up to 1 cm. diameter, surfaces softer than interior 1080–1140
Shale, dark purplish red, noncalcareous, nonarenaceous except for a small amount of minute angular quartzose matter; shale light greenish, noncalcareous, nonarenaceous; pebbles of chert; some whitish aggregates of quartz sand and particles of cryptocrystalline silica 1120–1135
Dolomite, gray, in fine chips; a little shale green and purplish red as above, in small rounded chips as if water-worn in the well; chert, white; much gray sand of rounded medium fine grains; one fragment of black coal at 1135; two samples 1135–1161
Shale, light blue-green, in moulded masses including rounded quartz sand and chips of chert 1161–1173
Chert, white and brownish gray, white, in large angular chips, some decayed; some rounded fragments of green and red shale; quartz sand 1173–1190
Chert, in small chips, quartz sand; much water-worn green and red shale 1190–1200
Chert, white and gray, some brownish gray; shale as above 1200–1210
Chert, white, and some quartz sand; much rusted; an occasional grain of dolomite; some white soft masses of decayed chert; very little shale 1210–1220
Chert and sand as above, some soft decayed chert; considerable dolomite, gray, in sand; green shale, at 1220 very abundant and in large flakes; 2 samples 1220–1240
Chert, oölitic, arenaceous, some pyrite; sand as above; considerable green shale; some dolomite; 2 samples 1240–1260
Sandstone, in rounded grains, secondary enlargements; chips of fine noncalciferous white sandstone; oölitic chert, white, brown, yellow, purplish; whitish dolomite in sand; some green shale; 2 samples 1260–1280
Sandstone, as above, chips of hard fine sandstone abundant; chert; dolomite; shale 1280–1290
Sandstone, as above, coarse, grains up to 1 mm. diameter, secondary enlargements; grains much broken; chips of fine sandstone; chert; pyrite; some light green shale and a little red shale in small chips..1290–1300
Dolomite, light purplish; sandstone as above but finer; some green shale in small rounded chips; pyrite 1300–1310
Sandstone, fine, gray, as above; dolomite, gray, highly siliceous with microscopic quartzose particles; shale and pyrite as above 1310–1320
Dolomite; sandstone, gray in mass; all in fine grains; shale as above; pyrite; a cinder 1320–1340
Dolomite, yellow-gray, minutely siliceous with crystalline and cryptocrystalline quartz; much sandstone in grains, some sandstone with cherty material; some chips of chert; much green and red shale; two large bits of coal 1340–1360

Trempealeau (80 feet thick; top 642 feet below sea level):
Dolomite, buff, arenaceous with fine rounded grains; clean, in fine sand; 3 samples 1360–1400
Dolomite, whitish, in fine flour; siliceous with minute particles of clear and crytocrystalline quartz; slightly argillaceous 1400–1410
Dolomite, gray and yellow-gray, in chips and sand, highly siliceous as above; 3 samples 1410–1440

Franconia (100 feet thick; top 722 feet below sea level):
Sandstone, gray, of minute quartzose particles, dolomitic, glauconitic....1440–1450
Sandstone, gray, very fine-grained but coarser than above, dolomitic, glauconitic; 6 samples 1450–1520
Sandstone, brown in mass, from medium fine rounded grains to minute quartzose particles, highly glauconitic, dolomitic 1520–1530
Sandstone, light gray in mass, grains up to 0.8 mm. diameter; some

grains of dolomite with quartz grains imbedded; a little glauconite 1530–1540

Dresbach (105 feet thick; top 822 feet below sea level):

Sandstone, yellow, clean, a little finer than above; some glauconite 1540–1545

Sandstone, yellow in mass; grains white, frosted, rounded, larger grains up to 1 mm. diameter, mass color due to slight iron stain 1545–1555

Sandstone, light yellow, finer than above; 2 samples 1555–1575

Sandstone, light yellow-gray in mass, medium, in grains and chips, dolomitic; much fine material in cuttings 1575–1605

Sandstone, light yellow-gray, medium, rounded grains; 3 samples 1605–1645

Eau Claire (penetrated 1 foot; top 927 feet below sea level):

Dolomite, buff, in chips, siliceous with minute particles of quartz; much quartz sand in cuttings 1645–1646

Notes on the De Witt section.—The samples of Niagaran dolomite show the characteristic colors and textures of the Hopkinton stage and the cherty beds at the base which are so well exhibited in the outcrops at Clinton.

The dolomite and shale at the summit of the Maquoketa may represent interbedded transitional layers.

In the Glenwood, the presence is to be noted of a thin top layer of sandstone, separated from the Saint Peter sands by the usual green fissile shale. There is some doubt whether the sandstone from 842 to 850 feet should not go with the Glenwood, as it is placed by Dr. F. T. Thwaites of the Wisconsin Geological Survey, who has examined these samples for the drilling company. On the whole, however, it seems preferable to regard the green shale of the cuttings as derived from the shale above, and this is also the interpretation of the driller's log.

Between the clean Saint Peter sandstone ending at 1065 feet and the clean samples of dolomite of the Trempealeau which begin at 1360 feet, the rocks in which the drill was working are represented by anomalous and somewhat ambiguous samples which are taken by both Thwaites and the writer to represent conglomerates and shales with some sandstone. As will be noted from the detailed description given above, the samples consist of shales of various colors, chert, much of it decayed, dolomite chipped to fine sand, and sandstone either in loose sand or chips. The conglomeratic nature of much of this rock is confirmed by the characteristic caving of it, a feature often noted in other wells. In the driller's log as given on the blue print of the consulting engineer the rock from 1080 to 1256 is set down as "176 feet caving dolomite, brown and gray in various shades." The Gray Well Drilling Company writes "We underreamed this well from the 1100 ft. point to the point where the casing now rests" (1256 feet). "This was due to the fact that it was impossible for us to make any headway due to the bad caving nature of the formation." The casing referred to is an 8 inch pipe bedded at 1256 feet and extending to 877 feet, high up in the Saint Peter sandstone. It is on account of this extensive and continued caving that the interpretation of the cuttings is difficult both for drillers and geologists.

There is no doubt that the Saint Peter sandstone, with 15 feet of transitional sandstone, is underlain by 55 feet of shale, dark purplish red and light green, with chert pebbles, some with surfaces decayed. As the chert is unstained, and for other reasons, the pebbles are held to occur in distinct beds and not sporadically.

The samples between this shale and the clean dolomite at 1360 feet show much intermingling of material. From 1135 feet, the base of the shale referred to, to 1161 feet, the samples consist of shale, water-worn and probably largely due to caving, chert, quartz sand and dolomite. It is assumed that the drill here was working in a conglomerate of pebbles of chert and dolomite set in a sandstone matrix, perhaps with seams of shale. But we can not be sure that in part the drill was not working in dolomite and that the presence of shale, chert, and sand is not due to extensive caving. From 1161 to 1173 feet, a 12 foot bed of light blue-green shale is represented by a fairly clean sample.

The samples from 1173 to 1260 feet are heterogeneous, composed of the same ingredients as are those taken to represent the conglomerate above. They are given the same interpretation.

From 1260 to 1360 feet the samples continue heterogeneous and ambiguous. It is to be supposed that the casing bedded at 1256 feet cut off all caving from above. If, then, all the materials of the samples are native it may be assumed that the drill was still working in conglomerate. The presence of sandstone, here in chips, shows that the matrix of the conglomerate was more indurated than that at higher levels. However, the possibility is not to be excluded from consideration that sandstone and dolomite were supplied from bedded layers instead of from matrix and included pebbles. The explanation of shale in the samples below the footing of the casing offered by the drilling firm is "that after the 8 inch pipe was set at 1256 feet depth several streaks of shale weren't counted and did cave a little, thereby causing these shale cavings to appear in these samples."

The upper limit of the Franconia is drawn where the siliceous dolomites of the Trempealeau give place to minutely quartzose glauconitic sandstones. The Franconia is less argillaceous than in many localities. The base is difficult to define. A gradual increase in coarseness of grain is shown as the Dresbach is approached. The sandstone from 1530 to 1540 is included on account of the dolomite present, and the sandstone from 1540 to 1545 is placed with the Dresbach, although glauconite is a constituent.

*Mineral Content of City Well, De Witt**

	P.P.M.
Bicarbonate	336.7
Chloride	39.
Sulfate	37.0
Silica	34.2
$Fe_2O_3+Al_2O_3$	4.2
Calcium	92.2
Magnesium	33.5
Na + K as Na	21.4
Total solids	429.8

DEXTER, DALLAS COUNTY
(Altitude 1148 feet)

The well of this city was started July 10, 1928, and finished December 10, 1928. It is specially noteworthy from the fact that an abundance of water was found at a moderate depth in an area where, as at Stuart, the deepest wells in the state are necessary to tap the dependable water beds. The Dexter well is 1245 feet deep and does not reach the Ordovician. Water was found in strata which apparently belong to the upper beds of the Silurian. The diameters of the well are from 16 to 8 inches. The well is cased throughout. Water was found at 1240 feet in limestone and yielded under test of 36 hours 200 g.p.m. with a draw down of but 15 feet. The static level is 242 feet below the curb, or about 902 feet above sea level. The static level of the St. Peter

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

water at Stuart, we may state for comparison, was found to be 325 feet below the curb, or about 880 feet above sea level, while the static level of the deeper water beds was 20 feet lower. The well was drilled by the Thorpe Bros. Well Co. of Des Moines. It cost over $12,000 and pumping equipment will cost about $3000 additional.

Driller's log

	Depth in Feet		Depth in Feet
Yellow clay	0–20	Shale	670–680
Yellow clay and gravel	20–40	Lime rock	680–820
Blue clay	40–190	Shale	820–826
Red shale	190–210	Lime rock	826–1015
Brown shale	210–265	Shale	1015–1060
Blue and red shale	265–285	Lime rock	1060–1140
Gray shale	285–335	Sand rock, some water	1140–1160
Blue shale	335–355	Shale	1160–1166
Black shale	355–498	Lime rock and shale	1166–1240
Blue shale	498–520	Lime rock, broken, took cuttings, water	1240–1245
Shale and lime rock	520–565		
Lime rock	565–670		

Record of strata, Dexter City well

	Depth, feet
Pleistocene and Pennsylvanian (680 feet thick; top 1144 feet above sea level):	
No samples, see log	0–680
Mississippian (370 feet thick; top 464 feet above sea level):	
No samples, see log	680–700
Limestone, drab and brownish, argillaceous, rapid effervescence in cold dilute HCl; gray and brown chert and whitish chalcedony; some clear quartz in fine irregular grains; much drab and blackish shale	700–710
Limestone, gray and brown, argillaceous, moderately rapid effervescence; gray chert; 2 samples	710–730
Limestone, gray, fine crystalline-granular, rapid effervescence; much gray chert	730–740
Limestone, gray, argillaceous, moderately rapid effervescence; much gray and brownish chert	740–750
Chert, gray and brownish, chalcedonic silica; limestone, gray; 2 samples	750–770
Limestone, gray, earthy, argillaceous, moderately rapid effervescence; gray and brownish chert and conspicuous white chalcedonic silica; 2 samples	770–790
Limestone, yellow-gray and gray, rapid and moderately rapid effervescence; gray chert, some mottled; 3 samples	790–820
Limestone, gray and yellow-gray, mottled, soft, macrocrystalline-earthy, in large flakes, rapid effervescence; some chert	820–830
Chert, light gray and gray, some limestone and whitish chalcedony; 3 samples	830–860
Limestone, gray, moderately rapid effervescence	860–870
Chert, gray; some gray limestone	870–880
Limestone, gray and yellow-gray, rapid effervescence; a little gray chert and chalcedony at 880; 2 samples	880–900
Chert; whitish chalcedony; gray limestone	900–910
Limestone, light yellow-gray, oölitic, rapid effervescence; 4 samples	910–960

Limestone, yellow-gray and brown, moderately rapid effervescence, fine crystalline-granular	960–970
Limestone, light and dark gray mottled, soft, in large flakes, macrocrystalline, encrinital, rapid effervescence	970–980
Limestone, drab, rather slow; whitish and gray chert	980–990
Limestone, gray, fine crystalline-granular, rather slow effervescence	990–1000
Shale (Kinderhook) light blue, in concreted masses, calcareous	1000–1010
Limestone, buff, rapid effervescence, in fine sand	1010–1020
Shale, light blue-gray, in chips strongly calcareous	1020–1030
No samples, ''shale'' in log	1030–1050
Devonian (150 feet thick; top 94 feet above sea level):	
Limestone, gray, fine crystalline-granular and calcilutite, rapid effervescence; 4 samples	1050–1090
Limestone, light yellow-gray, fine texture, rapid effervescence	1090–1100
Limestone, whitish, in fine sand, rapid effervescence; 2 samples	1100–1120
Limestone, light yellow-gray, somewhat rusted, rapid effervescence	1120–1130
Limestone, light gray, rapid effervescence	1130–1140
Shale, drab, calcareous, in tough concreted masses	1140–1150
Limestone, gray, rapid effervescence, some large chips of laminated light brownish calcilutite; much powder of shale	1150–1160
Limestone, light yellow-gray and dark gray, rapid effervescence	1160–1170
Dolomite, buff and brown	1170–1180
Dolomite, yellow-gray, rather slow effervescence	1180–1190
Dolomite, light yellow-gray, earthy, soft, rather slow effervescence	1190–1200
Silurian (penetrated 45 feet; top 56 feet below sea level):	
Shale, light blue-gray, in concreted masses inclosing chips of gray dolomite	1200–1210
Dolomite, gray and greenish gray, fine crystalline-granular	1210–1220
Shale, very light gray or whitish, quartzose; some minute grains of quartz sand; chips of light gray dolomite	1220–1230
No samples	1230–1245

Notes.—The upper strata assigned to the Mississippian are characteristic in their cherty argillaceous limestones and beds of cherts, and in the presence of chalcedonic silica. There is considerable shale in the samples, in part blackish and red or pink and evidently fallen from above, in part gray and less clayey and very possibly from layers in which the drill was working.

Equally characteristic of the lower strata of the Mississippian are the oölitic limestones beginning at 910 feet. The shales beginning at 1000 feet are taken to be Kinderhook.

The beds assigned to the Devonian are characteristic limestones of rapid effervescence including calcilutites, with some dolomitic beds at base which perhaps should go to the Silurian.

The shales at 1200 feet are taken to mark the top of the Silurian and may be compared with the gypseous shales and limestones of the Silurian at Stuart, although at Dexter they carry no gypsum. With these assignments of the Kinderhook and the Silurian, the Devonian at both Stuart and Dexter is given a thickness of about 150 feet.

The towns of Dexter and Stuart are less than six miles apart, so that the geologic sections of their logs should be closely parallel.

No samples of the cuttings of the Stuart well were saved above 1185 feet, and for this distance the samples at Dexter may be used for the interpretation and reinterpretation of the Stuart log, remembering that the town of Stuart is 61 feet higher than Dexter.

In the light of the Dexter cuttings, the "shale, light colored, calcareous" of the Stuart log from 765 to 815 feet may well be Mississippian instead of Pennsylvanian as assigned (p. 333), although the Mississippian floor on which the Pennsylvanian was laid is known to be one of rather large relief.

The shales referred to the Kinderhook at both Dexter and Stuart are about 50 feet thick, and as stated an equally close agreement is obtained for the Devonian. However, the top of the Kinderhook at Dexter is 144 feet above sea level, while at Stuart it is but 28 feet above the same datum. The same difference in level is found at top of the Silurian.

DONNELLSON, LEE COUNTY

(Altitude 708 feet)

A deep well was drilled for this town in 1925 by J. M. Schlicher, who furnished the facts given together with samples of the cuttings. The depth is 1095 feet, the diameters are 8¼, 7⅝, 6 and 4½ inches. The chief water bed is the Saint Peter sandstone. Water was found also at 136 feet in Mississippian sandstone and at 720 feet in Silurian or Devonian limestone. The lower 50 feet of the Galena and Platteville limestones are also water bearing.

The water struck at 720 feet had a static level of 150 feet below the curb. At 990 feet water began to rise in the drill hole, and the water from the Saint Peter sandstone lifted the level to 80 feet below the surface of the ground.

The well is cased with 8¼ inch casing to 67 feet, 6 inch to 285 feet, and 4½ inch to 708 feet.

The discharge is equal to the capacity of the pump, viz. 80 gallons per minute. This drill hole was put down in an old well 275 feet deep, at a cost of $3226. The casing cost $1137 in addition.

Chemical analysis

Probable Combinations	Grains per U. S. Gallon
Silica	0.607
Oxides of iron and aluminum	0.186
Calcium carbonate	2.350
Calcium sulphate	54.783
Magnesium carbonate	18.880
Sodium and potassium sulphate	33.099
Sodium and potassium chlorides	1.020
Total solids	110.960

Record of Strata

	Depth in Feet
Pleistocene and Recent (67 feet thick; top 696 feet above sea level):	
"Clay"	0–61
"Sand"	61–67
Mississippian:	
Meramec and Keokuk (208 feet thick; top 629 feet above sea level)—	
"Limestone"	67–136
"Sandstone"	136–138
"Limestone"	138–150
"Shale, blue"	150–275
Burlington group (93 feet thick; top 421 feet above sea level)—	
Limestone, whitish, macrocrystalline, soft, in large flakes	275–290
Limestone, whitish, crystalline-earthy; much blue-gray chert and chalcedonic silica	306
Chert; earthy whitish limestone; some gray shale	320
Chert, blue-gray	330
Limestone, whitish and blue-gray, macrocrystalline-earthy, in large thin chips	348, 360
Kinderhook shale (325 feet thick; top 328 feet above sea level)—	
Shale, greenish and blue, calcareous, in concreted masses	368, 380
Sandstone, gray, argillaceous, slightly calcareous, grains largely microscopic, in small chips	392, 400
Shale, bluish, in concreted masses	408
Sandstone, as at 392	419, 430
Shale, bluish, in concreted masses	440
Shale, blue-gray, calcareous, highly quartzose	448, 460
Shale, blue, in concreted masses; 6 samples	465–515
Shale, brownish drab, burns white with slight empyreumatic odor	520
Shale, drab, fissile	530
Shale, blue-gray	540
Shale, drab	550
Shale, blue; 10 samples	560–650
Shale, brownish drab, with pyrite	660
Shale, blue-gray	670–680
Devonian (and Silurian ?) (140 feet thick; top 3 feet above sea level):	
Limestone, blue-gray, highly argillaceous and arenaceous, grains minute, ill-rounded, in chips	693
Limestone, as above, somewhat arenaceous; pyrite	700
Limestone, yellow-gray, brisk effervescence in cold dilute HCl, in fine sand	711
Shale, blue, in chips; some limestone	720
Limestone, blue, argillaceous, soft, crystalline-earthy, rapid effervescence, in small flakes	730, 740

Limestone, blue-gray, calcilutite, laminated, some surfaces of laminæ dark brown, effervescence rapid, in flaky chips, with powder of blue shale	745
Limestone, as above, yellow-gray, but with no brown surface films	750, 760
Limestone, blue-gray, calcilutite, some dark and irregularly surfaced laminæ, reaction rapid, some chocolate brown shale	770, 780
Limestone, mottled brown-gray, in thin flakes, rapid response, fossiliferous, crystalline-earthy, some dark surfaces as above	790
Limestone, light yellow-gray, fine-grained, rapid reaction; 4 samples	800-830
Ordovician:	
Maquoketa shale (5 feet thick, top 137 feet below sea level)—	
Shale, light green-gray and blue-gray, fissile, somewhat calcareous, in chips and concreted masses	833–838
Galena and Platteville (202 feet thick; top 142 feet below sea level)—	
Dolomite, gray, crystalline, in small chips	840, 850
Dolomite, light buff and gray in crystalline sand; 14 samples	860–990
Dolomite, as above, with brown flint	996,1000
Dolomite, or magnesian limestone, buff and light brown, in crystalline sand and small chips, not so slow effervescence as LeClaire dolomite; 3 samples	1010–1030
Saint Peter sandstone (55 feet thick; top 344 feet below sea level)—	
Dolomite, buff, highly arenaceous, with imbedded grains fine, moderately well rounded, some showing secondary enlargements	1040
Sandstone, light yellow in mass, grains as above but without secondary enlargements, wide range in size; a little buff dolomite	1050
Sandstone, as above, clean, larger grains up to 0.7 mm. in diameter; 4 samples	1060–1090
Prairie du Chien (Shakopee dolomite, entered at 399 feet below sea level)—	1095

Notes.—The Kinderhook shales are present at Donnellson in great force, as at Burlington, Fort Madison and Mount Clara. Their summit shows a fall of 141 feet from Mount Pleasant, and of 247 feet from Burlington, and a continued fall to Keokuk of 50 feet, while it is about the same level as the top of the Kinderhook at Fort Madison.

The laminated calcilutite limestones with dark surfaces struck at 745 feet are of a rather rare type, and at once suggest the Otis horizon of the Wapsipinicon stage of the Devonian.

The shale at 833 feet is assigned to the Maquoketa with much uncertainty although its position is that of the shale, also thin, placed with the Maquoketa at Fort Madison, and that of the much thicker shales of the same stratigraphical position at Burlington and Mount Pleasant.

The Galena-Platteville has its usual facies, but the basal shale which so commonly rests upon the Saint Peter sandstone is absent as at Mount Pleasant and Keokuk.

The sandstone at 1040 feet is assigned with considerable confidence to the Saint Peter, as it agrees closely in position with the sandstones referred to that formation in the deep well sections of southeastern Iowa. On a cross section from Burlington to Baring, Missouri, the gradient of the Saint Peter intersects at Donnellson the location of the sandstone in question. Lithologically, however, it departs somewhat from type.

DUBUQUE

(Altitude 608 feet)

The city of Dubuque has long been one of the best developed local artesian fields of Iowa. In 1912 nineteen artesian wells were in service including four belonging to the city, while one had been abandoned. Since that date twelve deep wells have been drilled within the city limits. In 1910 our knowledge of the geologic section at Dubuque and therefore of artesian conditions was very incomplete. Now it is fairly adequate, through the careful efforts of Mr. C. W. Varner, artesian well contractor, who has preserved samples of the cuttings of several recent wells. The wells drilled since the compilation of the report on the Underground Water Resources of Iowa are as follows:

The well of the Fisher Ice Company, drilled in 1912, is 1325 feet deep.

The well of Swift and Company, drilled in 1922 by V. Garvey of Dubuque, is 1335 feet deep, with a diameter of 8 inches. It delivers 54 gallons per minute.

The well of the T. J. Mulgrew Ice Company, drilled in 1922, is 900 feet deep, discharges 300 gallons per minute and maintains a static level of 4 feet above the curb.

The Sanitary Milk Company's well, drilled in 1925 by C. W. Varner of Dubuque, is 515 feet deep, diameter 8 inches, discharge 150 gallons per minute, and head 12 feet below the curb.

The Consumers Ice Company's well, drilled in 1925 by C. W. Varner, is 1300 feet deep and discharges 225 gallons per minute. A 10 inch drive pipe extends to 165 feet, below which the well is uncased with these diameters: 10 inches to 414 feet, 8 inches to 503 feet, and 6 inches to the bottom.

The Farley and Loetscher Company's well, completed in 1926 by C. W. Varner, is 1438 feet deep, diameters: 12 inches to 500 feet, 10 inches to 1025 feet, 8 inches to bottom. Twelve inch casing extends to 193 feet. The discharge is from 700 to 800 gallons per minute when pumped down to 28 feet below the curb.

The following water levels were recorded as the well was drilled, showing the increase of height of head with depth:

DEPTH OF WELL IN FEET	DEPTH OF STATIC LEVEL BELOW CURB IN FEET
340	28
390	22
525	18
800	13½
1380	3
1400	flowed

As the height of the water did not increase between 1180 and 1280 feet the driller considers these beds dry.

Wells have also been drilled for the Iowa Dairy Company, the A. Y. McDonald Mfg. Company and the Brunswick Balke Collander Company, but no information regarding them can be obtained.

Since 1910 the city has added three deep wells to its Eagle Point equipment, making five deep wells now in service there.

Wells nos. 3 and 4 were drilled in 1919, depths 1460 and 1458 feet. Their diameters are each from 12 to 6 inches. Number 4 is cased with 12 inch casing to 136 feet, 10 inch 374 to 430 feet, 8 inch 550 to 593, and 6 inch 868 to 968 feet. Their static level is estimated at about 658 feet.

Well no. 5, drilled in 1924 by C. W. Varner, is 1500 feet deep, diameters 16 to 10 inches with 16 inch casing to 130 feet to shut out alluvial sands and 125 feet of 12 inch casing to protect from caving shales which occur in places between 390 and 445 feet. The location of water beds is indicated by the variations in static level and discharge as the drilling progressed.

At 420 feet, Jordan sandstone, water raised 2 or 3 feet.
At 550 feet, Trempealeau dolomite, water raised 7 or 8 feet.
At 700 feet, Dresbach sandstone, water raised within 8 feet of surface.
At 780 feet, Dresbach sandstone, water started to overflow.
At 1165 feet, Mount Simon sandstone, flow of 154 gallons per minute.
At 1350 feet, Mount Simon sandstone, flow of 240 gallons per minute.
At 1500 feet, Mount Simon sandstone, flow of 267 gallons per minute.

The average daily consumption of the city of Dubuque from the public supply is 3,000,000 gallons. The pumping capacity of the five artesian wells at Eagle Point under air lift of 128 feet is about 6,500,000 gallons and shallow sand wells can supply an additional 1,500,000 gallons. The water is pumped by electricity to a high level reservoir whose capacity is 7,500,000 gallons and a very low rate is obtained, as the pumping is done at off-peak periods except in emergencies.

Static level.—With the drilling of an increasing number of deep wells and the installation of powerful pumps, the static level has progressively lowered. The deeper wells drilled in the '80s and early '90s had a static level of more than 700 feet above tide. (Butchers' Association well, 1887, head 740 feet. Linwood cemetery well no. 2, 1891, 742 feet.) In 1908 the head of the Dubuque wells had generally sunk to levels not exceeding 625 feet. The initial head of the city wells at Eagle Point (1899) was reported at 649 feet and the measurement of the head of well no. 5 indicates that that head is still maintained. This is particularly gratifying in view of the large decline from the earliest levels to those of 1908 and especially in view of the large loss from disused wells. Yet the recommendations of our report of 1912 must be repeated with emphasis. Wells in this area should be kept effectively cased wherever permeable upper beds allow the lateral escape of the waters rising under high pressure from the deeper aquifers, and disused wells should be plugged above the Dresbach sandstone, i. e. in the Franconia or the Trempealeau beds of the Saint Lawrence.

Little information is obtainable as to the present condition of the Dubuque wells. Seven wells have been abandoned since 1912 for various reasons, among them the cheapness of the city water as compared with the cost of pumping. These wells are the two wells of Linwood cemetery and those of the Cushing factory, the Consumer's Steam Heating Company, Schmidt's brewery, and the wells of the city at 6th Avenue and at 8th Street.

In part the loss of head and of discharge has been due to leakage owing to defective casing rather than to any general overdraft. Thus the well of James Beach and Sons, 940 feet deep, with an initial head (1897) of 34.5 feet above the curb, now heads below curb owing to defective casing. In 1925 the well of the Bank and Insurance Building was repaired by C. W. Varner, the pumping capacity was increased 35 per cent, to 150 gallons per minute, and the initial head of 1894, 648 feet above tide, was restored.

Record of Strata in City well no. 5, Dubuque

	Depth in Feet
Pleistocene and Recent (118 feet thick; top 625 feet above sea level):	
Sand, alluvial, brown and buff; 4 samples	10–60
Sand, reddish, fine, with clay, in friable masses	60–75
Sand, brown, coarser, with clay	75–90
Clay, light buff	90–103
Sand, buff, coarse, of rocks of the drift, much of yellow chert and dolomite	103–118
Saint Peter sandstone (139 feet thick; top 507 feet above sea level):	
Sandstone, grains of clear quartz, well rounded, moderately fine, with some chips of yellow chert	118–127
Sandstone, white, light yellow-gray and buff, rounded grains; 9 samples, all in loose sand	127–249
Sandstone, yellow, fine, not friable, and red, friable, both in chips	250–257
Prairie du Chien (Oneota dolomite, 93 feet thick; top 368 feet above sea level):	
Shale, dark red, hard; and dolomite, light gray, both in chips	257–260
Dolomite, light gray, with some red shale and green shale	260–265
Dolomite, light gray, small residue of minute quartz particles and grains	265–280
Sandstone, fine, with some chips of dolomite and red shale	293
Dolomite, light brownish gray	293–308
Dolomite, gray, pinkish chert, considerable quartz sand	308–315
Dolomite, gray	315–325
Dolomite, gray, some highly arenaceous, with much gray chert	325–340
Cambrian:	
Jordan sandstone (95 feet thick; top 275 feet above sea level)—	
Sandstone, buff, hard, in chips	350
Sandstone, fine, light reddish, larger grains well rounded, in loose sand	363
Chert, white, large chips stained pinkish	370
Chert, with much red shale, in small chips	385–388
Dolomite, highly arenaceous with thickly imbedded grains, in large chips	388–395
Sandstone, fine, pinkish from surface stains	395–405
Sandstone, yellow, moderately coarse	407–415
Sandstone, pinkish, fine; 2 samples	415–445
Saint Lawrence (Trempealeau dolomite, 120 feet thick; top 180 feet above sea level)—	
Dolomite, gray and brown; 7 samples	445–550
Dolomite, purplish brown, arenaceous	560–565
Saint Lawrence (Franconia beds, 90 feet thick)—	
Sandstone, buff and reddish, fine grained, calciferous, glauconitic, in chips; with shale, green, arenaceous, glauconitic	565–580
Sandstone, gray, of minute grains and particles, calciferous, argillaceous, glauconitic, with some green shale, glauconitic and minutely arenaceous; 4 samples	580–640
Sandstone, moderately coarse grains, with highly arenaceous dolomite, glauconitic	640–655
Dresbach sandstone (195 feet thick; top 30 feet below sea level)—	
Sandstone, white and gray, of clean quartz sand, grains well rounded, frosted, maximum diameter about 1 mm.; 11 samples	655–850
Eau Claire beds (100 feet thick; top 225 feet below sea level)—	
Sandstone, gray, very fine irregular grains, calciferous, glauconitic, micaceous, in friable chips	850–865

Sandstone, light buff, fine	865–880
Shale, green-gray	880–895
Sandstone, red, of minute angular grains, some dark red shale	900–905
Sandstone, buff, fine-grained	905–920
Sandstone, reddish and buff, very fine irregular grains, slightly calciferous, sparsely glauconitic, in small chips	920–935
Sandstone, as above, with a little white chert	935–950
Mount Simon beds (penetrated 550 feet; top 130 feet below sea level)—	
Sandstone, whitish, fine-grained, maximum up to 0.7 mm. in diameter, larger grains rounded (light pinkish at 980); 8 samples	950–1079
Sandstone, buff, grains up to 1 mm. diameter; 5 samples	1079–1147
Sandstone, reddish brown cuttings, grains irregular, secondary enlargements, heavily stained and cemented with ferruginous material with some magnetic iron; 3 samples	1147-1187
Sandstone, cuttings blackish, coatings dissolve in hot HCl, leaving sand white, larger grains rounded, some secondary enlargements, a little flint	1187–1201
Sandstone, light reddish buff, fine	1201–1214
Sandstone, cuttings brown, much magnetic iron, a little flint, secondary enlargement of grains, surface of some fragments of cemented grains smooth and shining, as if developed in contact with surface of glass receptacle; 2 samples	1214–1241
Sandstone, buff, somewhat rusted, secondary enlargements; 2 samples	1241–1270
Sandstone, cuttings brown, heavily rusted, secondary enlargements	1270–1285
Sandstone, buff, somewhat rusted, secondary enlargements, chips of sandstone of minute grains, argillaceous, well cemented at 1300 feet; 4 samples	1285–1335
Sandstone, cuttings brown, deeply rusted, in detached grains, some chips of well cemented sandstone of minute grains, and some mottled sandy shale	1335–1350
Sandstone, buff, moderately coarse, and chips of cream yellow friable fine-grained sandstone with secondary enlargements	1350–1355
Sandstone, light reddish buff	1355–1370
Sandstone, fine and very coarse, with some gravel of clear quartz up to 6 mm. diameter, fine grains show secondary enlargements	1375–1380
Sandstone, light pinkish, fine-grained, many grains broken, crystalline enlargements	1390–1395
Sandstone, light reddish brown, grains imperfectly rounded	1405–1410
Sandstone, fine, with chips of reddish argillaceous sandstone of very fine grain	1410–1414
Sandstone, light yellow and light pink, grains ill-assorted, some up to 2 mm. diameter; 2 samples	1425–1445
Sandstone, reddish buff, fine; 3 samples	1445–1490
Sandstone, pinkish, ill-assorted, grains up to 2.2 mm. diameter, some chips of unrusted sandstone, light yellow, friable, imperfectly rounded ill sorted grains	1500

Record of Strata in Farley and Loetscher's well, 8th and White Streets, Dubuque

Pleistocene and Recent (193 feet thick; top 639 feet above sea level):	
"To bed rock"	0–193
Ordovician:	
Saint Peter sandstone (top 446 feet above sea level)—	
"Sandstone, small amount; shale, 3 feet below sandstone"	
Prairie du Chien (270 feet thick; top 439 feet above sea level)—	
Dolomite, light blue-gray, crystalline, rather soft in chips, with some green shale	200–210
"Limestone"; no samples	210–260
Dolomite, light blue-gray, hard, subcrystalline, white chert and some siliceous oölite, some with imbedded grains of quartz sand, some pyrite	260–270

Dolomite, light gray, macrocrystalline, vesicular	300–310
Chert, light gray, some dolomite; 4 samples	330–375
Dolomite, gray, cherty; 2 samples	375–390
Dolomite, gray	390–400
Dolomite, gray, some sparse imbedded grains of quartz	400–410
Dolomite, light yellow-gray; 2 samples	410–450
Dolomite, light yellow-gray, subcrystalline, cherty, arenaceous, in chips	450–460
Dolomite, light yellow-gray, cuttings in sand, arenaceous	460–470
Cambrian:	
Jordan sandstone (70 feet thick; top 169 feet above sea level)—	
Sandstone, calciferous, light gray, in small chips and sand, grains rounded; 2 samples	470–520
Sandstone, whitish, fine-grained, calciferous, argillaceous, secondary enlargements	520–530
Marl, whitish, highly arenaceous, calcareous, argillaceous, quartz grains rounded, but some with secondary enlargements; in friable concreted masses	530–540
Saint Lawrence (Trempealeau dolomite, 60 feet thick; top 99 feet above sea level)—	
Dolomite, light yellow-gray and brown, fine crystalline granular; 6 samples	540–600
Saint Lawrence (Franconia beds, 160 feet thick; top 39 feet above sea level)—	
Marl, pink, calciferous, and red, argillaceous, highly arenaceous, glauconitic, grains of quartz sand fine and ill-rounded with much material of angular quartz particles, in friable concreted masses; 6 samples	600–660
Marl, as above, green, highly glauconitic	660–670
Shale, gray and greenish and brown, calcareous, glauconitic and highly arenaceous, in hard concreted masses; 5 samples	670–720
Shale, red, calcareous and highly arenaceous	720–730
Sandstone, gray and yellow, calciferous, argillaceous, glauconitic, rounded grains up to 1 mm. diameter; 2 samples	740–760
Dresbach sandstone (180 feet thick; top 121 feet below sea level)—	
Sandstone, light yellow and white, clean, grains up to 1 mm. diameter; 2 samples	760–790
Sandstone, light yellow, in chips and sand, a few chips of drab arenaceous dolomite	790–800
Sandstone, light yellow and white, in clean quartz sand, grains well rounded, very diverse in size up to 1 mm. diameter; 10 samples	800–900
Sandstone, gray, in chips, very fine of grain, some argillaceous and calciferous, with much coarse whitish sand	900–910
Eau Claire beds (100 feet thick; top 301 feet below sea level)—	
Shale, blue, noncalcareous, in concreted masses, with considerable buff quartz sand and chips of fine calciferous, glauconitic sandstone; 2 samples	940–960
Sandstone, yellow-gray, in chips, some large and thin, fine-grained	970–980
Sandstone, gray, in sand, fine-grained	980–990
Sandstone, red, argillaceous, calciferous, grains minute, in friable concreted masses; 2 samples	990–1010
Sandstone, buff, of minute grains and particles	1010–1020
Sandstone, gray, glauconitic, some grains rounded, some with secondary enlargements, some pink and yellow	1020–1030
Mount Simon beds (penetrated 398 feet; top 401 feet below sea level)—	
Sandstone, light buff, rounded grains up to 0.8 and 1 mm. in diameter, many rusted; 3 samples	1040–1070
Sandstone, buff, grains much rusted, coarser than above, some chips of blue-gray calciferous sandstone	1070–1080
Sandstone, as at 1040	1080–1090
Sandstone, as at 1070	1090–1100

Sandstone, light yellow, white and red, grains rounded, largest up to 0.8 mm. or less, at 1220 feet up to 2 mm. diameter, deeply rusted at 1100; 24 samples	1110–1350
Shale, red, in hard concreted mass	1350–1355
Sandstone, as at 1100; 8 samples	1355–1438

Record of strata in well of the Consumer's Ice Company

	Depth in Feet
Pleistocene and Recent:	
Sandy clay and humus	12–15
River sand, gray, moderately fine, fragments of shells	15–30
Gravel and coarse sand, up to 1¾ inches diameter	30–45
Clay, red, plastic	45
Sand, yellow	75–105
Clay, drab, sandy	145–165
Prairie du Chien:	
Dolomite, light yellow-gray, arenaceous, cherty; 3 samples	170–195
Chert, white, and dolomite, whitish	345–360
Dolomite, yellow-gray, oölitic	400–450
Jordan:	
Sandstone, well rounded grains, calciferous, in chips	450–470
Sandstone, light buff, fine, calciferous	500–525
Saint Lawrence (Trempealeau dolomite):	
Dolomite, light yellow-gray, in chips, considerable quartz sand in cuttings	525–540
Dolomite, light buff and pink; 3 samples	540–620
Saint Lawrence (Franconia beds):	
Sandstone, red, in powder and concreted friable masses, grains minute, argillaceous, calciferous, with some glauconite; some chips of pink dolomite	620–650
Sandstone, drab and red, as above, no dolomite chips	650–690
Sandstone, bluish, as at 650	690–730
Dresbach sandstone:	
Sandstone, white, in clean loose sand, grains rounded, maximum diameter 1 mm.; 9 samples	730–930
Eau Claire sandstone:	
Sandstone, drab, argillaceous, of fine quartz particles, glauconiferous; some blue shale; some loose rounded grains of quartz; 2 samples	930–970
Sandstone, light pink, clean, of fine grains	970–1000
Mount Simon sandstone:	
Sandstone, buff, rather coarse, rounded grains	1235
Sandstone, white and buff (rusted), grains up to 1.2 mm. at 1255 feet, rounded; 3 samples	1235–1300

Notes.—The three wells whose logs are given above are sunk in the fill of an ancient channel of Mississippi river. Its maximum depth as here disclosed is about 160 feet below the present water surface. It will be noted that the fill consists of river deposits only—no glacial till is present.

By this ancient erosion channel, the Galena and Platteville limestones are entirely cut away, and the Saint Peter also in the Ice Company's well; while only a trace remains in the well at 8th and White Streets. In the Eagle Point well, the Saint Peter is 139 feet thick. Here the ancient channel is more shallow, and the highly irregular bed of the sandstone descends 70 feet below its level at Eighth and White Streets. In the well at Schmidt Brewery[49] the the Saint Peter was struck at about its level in the Eagle Point city wells, and was found to be overlain by 66 feet of limestone and dolomite of the Platteville, while the base of the sandstone was approximately at the same level as in the Eighth and White Streets well.

In the Eagle Point well the unconformity at the base of the Saint Peter cuts deep into the Prairie du Chien, leaving it here but 93 feet thick.

It is of special interest that the Jordan sandstone, one of the chief aquifers of the Upper Mississippi artesian field, is here fine of grain, largely calciferous, and yields little or no water.

The Saint Lawrence runs true to type, presenting first the body of dolomite, which the Wisconsin Geological Survey has called the Trempealeau, and second the body of shales and shaly sandstones of finest grain, in many instances glauconitic, designated by the same Survey as the Franconia.

In strong contrast to these beds is the clean, water-bearing Dresbach sandstone which underlies them.

Until now the Iowa Cambrian beds beneath the Dresbach have been undifferentiated, but we may follow again the Wisconsin geologists in designating the beds present in the Dubuque wells as the Eau Claire and the Mount Simon. The Eau Claire consists here of shaly sandstones and sandy shales overlying the clean sandstones of coarser grain of the Mount Simon. The same succession obtains widely in northeastern Iowa, in the well-sections of McGregor, Manchester, Anamosa, Clinton and Tipton, and in southern Minnesota also.

In City well no. 5 the cuttings from 1147 to 1350 feet are deeply rusted. Magnetic iron, doubtless from the drill, bespeaks special wear by some hard substance. The contractor reports especially slow drilling here and that more time was taken in drilling this distance of 203 feet than in drilling all the remainder of the well. The steel bit became deeply grooved. The cuttings show little flint, and this brittle though hard substance rarely gives much trouble. Pyrite, the only other common hard mineral

49 Iowa Geol. Survey, vol. XXI, p. 384.

to be expected, is suggested by the presence of iron oxide in large amount, since grains of iron sulphide, especially if in the form of marcasite, might be altered to limonite under the conditions which obtained, since the cuttings taken from the slush bucket were kept wet for months in glass jars. No pyrite is found now in the samples of the cuttings, but the blue print made by the engineer in charge records between the depths mentioned "intermittent thin layers of iron pyrites imbedded in flint."

It is the belief of the contractor, however, that some hard substance was struck which followed the tools down, grooving the tempered edge of the bit when in the right position at the bottom of the well, a mass which did not change its shape or wear out, but at last was pounded into the walls of the drill hole.

Pyritiferous beds "in which pellets and crystals of iron sulphide constitute a considerable portion of the material" are reported from the Eau Claire horizon in southern Minnesota.[50]

DYSART, TAMA COUNTY

(Altitude 973 feet)

The city well of Dysart was drilled about 1917 and is 1600 feet in depth, with a diameter from top to bottom of 10 inches. On completion the static level was 120 feet below the surface and the pumping capacity 60 g.p.m. Both have remained unchanged to the present time. There is no draw down under continuous pumping. The quality of the water is reported as soft. No log has been preserved of the well. At Dysart the Saint Peter sandstone is to be expected at about 300 feet below sea level, or 1275 feet in round numbers below the level of the railway station. The well probably draws on the Prairie du Chien as well as the Saint Peter, and possibly enters the Jordan sandstone.

ELKADER

WELL OF TOWN OF ELKADER, 1927

This well, 659 feet deep, was drilled by C. W. Varner, Dubuque. The diameters are from 15 to 10 inches. The main supply was found from 350 to 400 feet, and other water beds were struck at 175, 350 and 550 feet. The static level was estimated to be about

50 Hall, Meinzer and Fuller, U. S. Geological Survey, Water Supply Paper no. 256, p. 48.

20 feet above the curb. The well discharges under natural flow 190 g.p.m. This and the two wells of the town already in use discharge into a surface reservoir about 300,000 gallons in 24 hours. The well is cased with 65 feet of 12 inch pipe and 216 feet of 10 inch pipe, "separating the flow from the Saint Peter sandstone."

The cost of the well was $5,950.

Record of strata, Elkader well, 1927

	DEPTH IN FEET
Soil	0–5
Galena limestone (60 feet thick, top 733 feet above sea level):	
Limestone, yellow-gray, rapid effervescence in cold dilute HCl	5–50
Limestone, blue-gray, rapid effervescence	50–65
Decorah shale (25 feet thick):	
Shale, light blue-gray, in concreted masses; limestone, yellow-gray, reaction rapid; gray chert; pyrite	65–90
Platteville limestone (48 feet thick):	
Limestone, blue-gray, rapid effervescence, fossiliferous, in flaky chips	90–138
Glenwood shale (7 feet thick):	
Shale, hard, green-gray, laminated	138–145
Saint Peter sandstone (30 feet thick, top 593 feet above sea level):	
Sandstone, white, grains well rounded, frosted, up to 1 mm. diameter; much fine material of broken grains	145–175
Prairie du Chien (315 feet thick; top 563 feet above sea level):	
Dolomite, yellow-gray, cherty at 200 feet; 3 samples	175–215
Dolomite, gray, some closely and minutely vesicular, considerable quartz sand in cuttings	215–230
Dolomite, brown	230–250
Dolomite, yellow-gray, cherty	250–270
Dolomite, whitish, some quartz sand	270–300
Dolomite, gray, cherty at 360; 4 samples	300–380
Dolomite, brown, cherty	380–400
Dolomite, yellow-gray, buff at 470, slightly cherty at 400, considerable quartz sand at 450; 4 samples	400–490
Jordan sandstone (40 feet thick; top 248 feet above sea level):	
Sandstone, white, grains rounded, frosted, larger up to 1 mm. diameter, most of material fine or broken grains	490–500
Sandstone, rusted to light yellow, very fine, "hard"	500–510
Sandstone, light yellow, very fine, irregular grains, dolomitic cement; in chips and sand	510–530
Saint Lawrence, Trempealeau dolomite (penetrated 80 feet or more; top 208 feet above sea level):	
Dolomite, gray, in chips; quartz sand in cuttings	530–550
Shale, gray, in friable concreted masses, dolomitic, highly arenaceous with minute angular grains of quartz	550–570
Dolomite, yellow-gray, in clean chips; 2 samples	570–610
No samples, reported to be no change in material	610–659

*Mineral Content of City Well, Elkader**

	P.P.M.
Bicarbonate	319.6
Chloride	4.
Sulfate	47.4
Silica	8.4

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

$Fe_2O_3 + Al_2O_3$	2.6
Calcium	66.4
Magnesium	42.6
Na + K as Na	14.8
Total solids	346.0

FAIRFIELD

(Altitude 766 feet)

WELL OF JEFFERSON COUNTY GAS, OIL AND MINERAL COMPANY

This well was sunk in 1910 about one-quarter mile east of the business center of Fairfield by J. D. Shaw of Davenport. The depth is 1685 feet or more and the diameters are from 12 to 8 inches. The main flow was struck at 1135 feet and other water beds were found at 200 and 500 feet. The head of water is 88 feet from the surface (680 feet above sea level).

A few samples of the cuttings were obtained and are described as follows:

Record of Strata

	Depth in Feet
Mississippian, Meramec, Osage and Upper Kinderhook:	
Limestone, blue-gray in mass, fine-grained, earthy, rapid effervescence in cold dilute HCl	150
Chert, white and blue; chalcedonic silica; some limestone as above	210
Limestone, light blue and yellow-gray, macrocrystalline, rapid effervescence; limestone, magnesian, buff, fine crystalline-granular, rather slow effervescence; much bluish chert	275
Chert and limestone, whitish	310, 345
Kinderhook shale (250 feet thick; top 180 feet above sea level, bottom 70 feet below sea level):	
No samples except the following	600–850
Limestone, blue-gray, earthy, argillaceous, siliceous, reaction rapid	815
Silurian:	
Limestone, light brownish gray, compact; gypsum plentiful, in white chips	940
Limestone and gypsum as above; gypsum in small amount	1000
Galena-Platteville:	
Dolomite, light yellow-gray and blue-gray, in chips	1100
Dolomite, buff, in fine sand	1135
Dolomite, yellow-gray, in fine chips	1400
Glenwood:	
Shale, bluish green and drab, in flakes and moulded masses	1450
Saint Peter, sample, 714 feet below sea level:	
Sandstone, white, fine, Saint Peter facies	1480
Prairie du Chien:	
Dolomite, gray, cherty; some fissile shale	1530, 1680
Dolomite, light yellow-gray, cherty; considerable quartz sand of rounded grains	1685

WELL OF THE FAIRFIELD PURE ICE COMPANY

This well, 1325 feet deep, was completed in 1912 by J. E. Foss of Washington, Iowa. The diameters are from 10 to 6 inches. The chief supply was found at 1275 feet in "sandstone" unusually soft and easily drilled. The capacity of the well under an air compressor was found to be 100 gallons per minute maintained for 18 hours without lowering the water below its static level of 116 feet from the surface of the ground.

Samples of the cuttings were taken by the company "when we met with different formations" and the following description of them is furnished by the manager.

"No. 1, 500 feet, Gray limestone
No. 2, 550 feet, Brown limestone
No. 3, 575 feet, Gray limestone
No. 4, 600 feet, Blue shale
No. 5, 725 feet, Black shale
No. 6, 760 feet, Blue shale
No. 7, 800 feet, Black shale
No. 8, 825 feet, Blue shale
No. 9, 850 feet, Brown limestone
No. 10, 900 feet, White limestone, continuing to
No. 11, 1125 feet, St. Peter sandstone, from 1125 to 1325 feet."

FORT DODGE

(Altitude 1111 feet, C. G. W. R. R.)

*Record of Strata of City Well No. 4**

Located on Duck Island in Des Moines river. Altitude of city well is about 6 feet above river level or about 976 feet above sea level.

	Depth in Feet
Sand and cobbles, size of walnut to baseball	0–20
Blue clay	20–35
Red shale or clay, called fire clay by driller	35–70
White shale	75–105
Lime rock, gray or brown	105–125
Lime rock, brown	125–220
Sand rock	220–328
Limestone, in fine powder, gray-buff, effervescence very ready with cold HCl; considerable residue	357–360
Limestone, gray, in coarse powder and small chips which show granular, sugary surfaces; effervescence slight in cold HCl, rapid in hot acid	365
Limestone, in gray powder, sugary fracture, response with cold HCl fairly ready, more so with hot HCl	370
Limestone in fine light gray powder, some clear, translucent sand grains present. Responds very readily to cold HCl	375
Limestone, in coarse dark gray powder and fragments, fractured faces dull, lusterless, a few small sparkling fragments of calcite. Response to cold acid fairly ready, considerably accelerated on slight application of heat. One lump of light gray dolomite enclosed	380
Sample similar to that at 380, with some small fragments of light gray limestone	385

* By Dr. James H. Lees, Assistant State Geologist.

Limestone in light gray, fine powder, responds to acid very readily after slight heating. Small concreted masses readily friable. Powder almost entirely soluble	390
Limestone, powder slightly darker than at 390, effervescence slightly less ready	395
Very similar to 390, small insoluble residue of sand grains	400

*Record of Strata of City Well No. 5**

	Depth in Feet
Shale, dark gray, very finely gritty, no response to acid; at 30 feet contains some small rounded pebbles which evidently are of foreign origin; 3 samples	0–30
Limestone, gray, in small chips, easily attacked by acid; much fine residue apparently of quartz, together with some larger grains	30–40
Shale, dark gray, very finely gritty, some slightly calcareous, a few fragments of limestone at 70 and 120 feet; 8 samples	40–120
Limestone, gray, powder reddened by iron rust. Ready effervescence	120–125
Shale, light gray, limy; 2 samples	125–140
Limestone, dark and light gray, in fine chips, grains and powder, pyrite, ready effervescence, magnesian 400 to 450 feet, chert at 410, clayey residue at 468; 33 samples	140–468
Shale, blue-gray, very slightly calcareous, finely gritty; 3 samples	468–490
Limestone, drab and blue-gray, in small chips; almost no response to cold acid, vigorous effervescence in hot acid; 2 samples	490–510
Limestone, bluish gray, rapid effervescence; 4 samples	510–550
Limestone, light gray, subcrystalline, strongly magnesian, in small sand, fragments present many glistening facets	550–560
Limestone, light gray, bluish at 590, in very fine sparkling sand, freely effervescing; 3 samples	560–590
Limestone, like the preceding, but quite magnesian; 2 samples	590–610
Limestone, medium dark to bluish gray, fine powder, free effervescence; 2 samples	610–624

Drillers' Log, City Well No. 6

	Depth in Feet
Surface	0–16½
Shell rock	16½–18
Soft shale	18–78
Lime rock, small amount of water	78–110
Shale and slate, cavy	110–167
Sandstone	167–188
Red shale	188–224
Lime rock	224–227
Shale	227–252
Lime rock	252–257
Sand rock	257–264
Lime rock	264–283
Shale, entered at	283

Driller's Log, City Well No. 7

	Depth in Feet
Surface	0 – 19
Red shale	19 – 33
Lime rock	33 – 37
Red and blue shale	37 – 62
Lime rock	62 – 73
Sand rock, small flow	73 – 80
Lime rock	80 –123

* By Dr. James H. Lees, Assistant State Geologist.

Shale	123 –126
Soft limestone	126 –163
Very hard lime rock	163 –200
Limestone	200 –299½
Rock, very difficult drilling	299½–309
Limestone	309 –315½
Sandrock (increased flow)	315½–427
Blue limestone	427 –448
Blue limestone	448 –468
Limestone	468 –473
Limestone (increased flow)	473 –485
Blue shale	485 –498

Record of Strata, City Well No. 8

	Depth in Feet
Mississippian:	
Dolomite, buff, limestone, buff and light gray; shale	53
Shale, drab and purplish; a very little limestone; "mixed with cave;" 3 samples (Pella beds?)	150–170
Shale, light greenish yellow; limestone, rapid effervescence in cold dilute HCl	180
Shale, light greenish gray; much finely divided cryptocrystalline silica; pyrite; a flake or so of selenite	190
Limestone, dolomite, buff, slow effervescence; limestone, lighter colored, rapid effervescence	200
Limestone, gray, oölitic, rapid effervescence; shale	210
Limestone, gray; much finely divided cryptocrystalline silica; pyrite; shale	220
Limestone, buff, rather rapid reaction, crystalline-granular, in coarse chips	230
Limestone, gray, rapid reaction, in fine meal; sandstone, fine, grains ill-rounded; quartz crystals; much cryptocrystalline silica	240
Limestone, light buff and light gray, rapid response; 3 samples	250–270
Shale, greenish	280
Limestone, light cream colored, oölitic, rapid effervescence	290, 300
Limestone, light yellow-gray; macrocrystalline, rapid reaction	310
Dolomite, buff, in fine sand; some light yellow-gray limestone of rapid effervescence, in larger chips	320, 330
Limestone, gray and buff, fine-grained, rapid reaction	340, 350
Limestone, buff, dolomitic, response slow and rather slow; some rapid	360, 370
Limestone, light gray, rapid reaction	380
Limestone, drab, fine-grained, rather slow reaction	390
Limestone, buff and light yellow-gray, fine-grained, rapid response	400, 410
Limestone, light yellow-gray, rather rapid effervescence	420
Dolomite, brown gray, fine crystalline-granular; gray chert; 3 samples	430–450
Chert and limestone, gray	460
Limestone, brown, fine-grained, earthy	470
Limestone, light yellow-gray	480
Shale, blue-gray, calcareous, in hard moulded masses	490
Limestone, light yellow, reaction rapid, in sand concreted with shale	500
Shale, yellow-gray, in concreted masses	510
Dolomite, light buff, in fine crystalline sand, with much shale	520
No samples	530, 540
Devonian and Silurian (360 feet thick; top 456 feet above sea level):	
Limestone, gray and buff; some chips of shale; 3 samples	550–570
Dolomite, light buff, subcrystalline	580, 590
Dolomite, whitish and light blue-gray, crystalline; 4 samples	600–630
Limestone, blue and yellow-gray, crystalline, rapid reaction, large flakes	640, 650
Limestone, buff, gray and brown, rapid effervescence	660
Dolomite, gray, fine crystalline-granular, soft	670, 680
Shale, greenish, slightly calcareous; whitish masses of powdered limestone	690

Dolomite, blue-gray, some laminated, compact, argillaceous 700
Dolomite, yellow-gray, crystalline 710
Shale, blue-green, fissile, with small chips of crystalline dolomite 720
Dolomite, blue and yellow-gray, fine crystalline; much blue-green shale 730, 740
Dolomite, buff and blue-gray, in sand; some blackish inflammable shale in fine grains 750, 760
Dolomite, gray 770
Dolomite, gray, some blackish inflammable shale 780, 790
Limestone, magnesian or dolomite, gray-buff, rather slow effervescence 800
Limestone, gray and buff, rapid effervescence 810
Limestone, magnesian, or dolomite, drab, buff and gray, rather slow reaction; some limestone, response rapid; 4 samples 820–850
Dolomite, gray, in fine sand; speckled with grains of blackish shale, non-inflammable, but giving distillate of oil 860
Dolomite, buff and light blue-gray; some limestone 870
Limestone, buff and light yellow-gray, rapid effervescence; some rounded grains of quartz sand 880

Ordovician:

Maquoketa shale (210 feet thick; top 96 feet above sea level)—

Shale, blue and blue-green, calcareous, laminated; 4 samples 890–920
Limestone, buff, crystalline, argillaceous, rapid reaction; considerable shale in powder 930, 940
Dolomite, brown 950
Dolomite, buff and blue-gray, in sand; some whitish limestone; considerable shale in flakes; 3 samples 960–980
Shale, greenish blue, soft, in flakes 990
Shale as above, with some sand of dolomite and white chert 1000, 1010
Dolomite, buff, in sand; some shale 1020
Shale, greenish, in flakes, sand of buff dolomite; whitish limestone; cinders 1030
Shale, drab 1040
Shale, drab; buff dolomite, effervescence rather slow, in sand 1050
Dolomite, rather slow reaction, buff 1060
Dolomite, gray, much white and gray chert; shale, dark drab and gray; quartz sand in rounded, corroded grains 1070
Dolomite, light buff 1080
Shale, greenish drab, plastic; white decayed chert 1090

Galena-Platteville (240 feet thick; top 114 feet below sea level)—

Dolomite, blue-gray, cherty; 7 samples 1100–1160
Shale, drab, calcareous, with dolomite and chert, in sand 1170
Dolomite, blue-gray, cherty 1180
No samples 1190, 1200
Dolomite, blue-gray 1210, 1220
Dolomite, gray; much chert; some whitish limestone 1230, 1240
Dolomite, rusted brown, in sand, a little chert 1250
Dolomite, buff; some whitish limestone 1260
Dolomite, heavily rusted; 4 samples 1270–1300
Dolomite, light buff and gray, in sand 1310
Dolomite, blue-gray; white chert 1320
Dolomite, buff, in crystalline sand; a very few rounded grains of quartz 1330

Glenwood shales (40 feet thick; top 354 feet below sea level)—

Shale, blue-green, in hard moulded masses and flakes; with some chips of blue-gray subcrystalline laminated dolomite; 3 samples 1340–1370

Saint Peter sandstone (penetrated 30 feet; top 394 feet below sea level)—

Sandstone, Saint Peter facies, rusted; chips of hard blue-green shale 1380, 1390
Sandstone, clean, light yellow in mass, larger grains up to 0.7 mm. in diameter 1400, 1410

*Record of Strata from Well No. 1 of Beaver Products Company, Fort Dodge**
Well at Mill. (Altitude about 1115 feet)

	Depth in Feet
Clay, gray, pebbly, calcareous, glacial till; 4 samples	0–40
Sand, light gray, medium fine-grained, concreted into lumps; noncalcareous. Some of the grains appear to be of gypsum	40–50
Sand, light gray, fine powder to grains ⅛ inch in diameter, concreted by calcareous powder. Some grains appear to be of gypsum. Some are too dark	50–60
Clay or shale, reddish or pale wine color, fine textured, but with minute sand grains and mica specks; noncalcareous	60–70
Shale, black, fine textured, smooth feel, somewhat calcareous	70–80
Shale, limy, or limestone, in grains most of which are black, a smaller number white. Some of the latter are strongly effervescent while others are not. Evidently the sample represents black shale with white streaks and with some bands of limestone. The white grains are not gypsum. Some of the black grains are concreted by a calcareous powder	80–90
Shale, black and gray, smooth textured, slightly calcareous	90–100
Shale, dark gray, gritty, calcareous; some black grains and some white ones, these latter noncalcareous; 2 samples	100–120
Shale, dark gray, reddish at 150 to 190, smooth textured, strongly calcareous, grains of limestone at 170; 7 samples	120–190
Limestone, gray, with some red and some black grains; strongly calcareous	190–200
Sandstone, reddish, very fine-grained	200–210
Limestone, gray in washed sample, reddish tinge perhaps due to shale above; mostly soluble in acid; a fragment of blue-gray, calcareous shale in sample at 240; 3 samples	210–240
Sandstone, reddish gray; fragments of limestone and red calcareous shale	240–250
Shale, red, or shaly limestone, in flakes and grains; some fragments of gray limestone and shale; all calcareous; 4 samples	250–290
Limestone, gray, in powder, fine grains, small chips and angular fragments; many granules of white or translucent chert at 320 feet, some at 360 feet and below; 11 samples	290–400
Sandstone, gray, fine-grained, some calcareous cement; 2 samples	400–416

WELL NO. 2 OF BEAVER PRODUCTS COMPANY

This well was drilled by Thorpe Bros. Well Co. of Des Moines in 1924. The depth is 450 feet, the diameters are 12 to 6 inches. Water was found at 100 and 400 feet, the latter being the principal supply. Water rises within 80 feet of the surface. The pumping capacity is about 25 gallons per minute, with the pumping cylinder set at a depth of 250 feet. The water is softened for boiler use.

WELL NO. 3 OF BEAVER PRODUCTS COMPANY

This well was completed in July, 1925, and was drilled by Thorpe Brothers of Des Moines. The elevation of the curb is 1114 feet above sea level. The diameter is 12 inches at the top and 6 inches at the bottom. Twelve inch casing extends to 205

* By Dr. James H. Lees, Assistant State Geologist, from samples submitted by the driller, J. J. Becker of Garner.

feet, 10 inch from 194 feet to 365 feet, 8 inch from 590 feet to 688 feet, and from 1434 feet to 1510 feet, 6 inch from 1485 to 1580 feet. Packing is set at 688 feet and at 1535 feet.

The principal supply of water was found in the Saint Peter sandstone from 1525 to 1586 feet. Water was found also in the Shakopee dolomite and the New Richmond sandstone.

On completion the water stood 62 feet below the curb, a static level which it has maintained to date. Before the Saint Peter aquifer was struck the water in the well headed about 50 feet below the surface.

The pumping capacity of the well is 275 gallons per minute with the cylinder set 132 feet below the surface. Continuous pumping does not draw down the head.

The temperature is 56° Fahr. The water is reported to have no bad effects on boilers. The cost of the well was $13,000.

*Analysis of Water**

	GRAINS PER U. S. GALLON
Volatile and organic matter	.25
Silica	1.55
Oxides of Iron and Aluminum	trace
Calcium oxide	8.96
Magnesium oxide	4.44
Sodium oxide	4.03
Sulphuric anhydride	10.24
Carbonic anhydride (fixed)	8.93
Chlorine	.35
Hardness as $CaCO_3$	27.10
Suspended matter (mostly iron)	.35
Alkalinity as $CaCO_3$	20.30
Probable combinations	
Volatile and organic matter	.25
Silica	1.55
Calcium carbonate	16.00
Magnesium carbonate	3.61
Magnesium sulphate	8.16
Sodium sulphate	8.52
Sodium chloride	.58
Total solids	38.67

Record of Strata of Well No. 3 of Beaver Products Company

	DEPTH IN FEET
Pleistocene and Recent (45 feet thick; top 1114 feet above sea level):	
Till, drab with a light yellowish tinge, predominantly clayey; 4 samples	10-40
Permian, Fort Dodge beds ("45 to 61 feet"):	
Gypsum, white and gray; limestone, buff; blue shale; much varicolored quartz sand, pebbles of drift	50, 60

* By Wm. B. Scaife & Sons Co.

	Feet
Pennsylvanian, Des Moines series (89 feet thick; top 1053 feet above sea level):	
Shale, dark blue, some red, plastic, noncalcareous	70
Shale, black, turns gray before the blowpipe; 2 samples	80, 90
Shale, dark gray	100
Shale, blackish; 4 samples	110–140
Mississippian (520 feet thick; top 964 feet above sea level):	
Pella beds (60 feet thick)—	
Shale, reddish and gray; and limestone, gray, rapid effervescence, in chips and powder; with a little coal	150
Shale, red, plastic; 4 samples	160–190
Shale, red with other colors, with limestone in chips	200
St. Louis beds (120 feet thick)—	
Limestone, white, earthy, rapid effervescence in cold dilute HCl, in flaky chips	210
Limestone, light buff, fine-grained, compact, argillaceous, moderately slow reaction, some rapid; with bluish chert, and some gray argillaceous sandstone of fine grain; 3 samples	220–240
Limestone, as at 210	250
Limestone, blue-gray, crystalline-earthy, argillaceous, reaction rapid	260
Limestone, yellow-gray and buff, fine-grained, earthy, or crystalline-granular, response moderately slow; 3 samples	270–290
Limestone, light blue, argillaceous, crystalline-earthy, rapid effervescence, with considerable pale yellow crystalline quartz	300
Limestone, gray, soft, earthy, rapid effervescence; 2 samples	310, 320
Kinderhook stage (340 feet thick)—	
Limestone, blue-gray, fossiliferous, rapid reaction, in flaky chips with considerable chalcedony and crystalline quartz intercrystallized with calcite	330
Limestone, calcilutite, light yellow-gray	340
Limestone, whitish, macrocrystalline, in large flaky chips, rapid effervescence, with some oölite	350
Limestone, whitish or light yellow-gray, fine crystalline-granular, rapid reaction, in flaky chips; 5 samples	360–400
Limestone, light yellow-gray, macrocrystalline-earthy, rapid response	410
Shale, blue, in flakes; and sandstone, gray, fine, ill-rounded grains, argillaceous, calciferous, pyritiferous; some limestone	420
Limestone, light yellow-gray, effervescence rapid; with white cryptocrystalline silica and grains of quartz sand; some pyrite	430, 440
Limestone, blue-gray, macrocrystalline, pyritiferous, rapid effervescence; and shale	450, 460
Limestone, white, soft, earthy, rapid reaction, in large flaky chips, gray, macrocrystalline at 490 and 500; 4 samples	470–500
Limestone, gray, crystalline-granular, some rapid, some slow effervescing; in sand and small chips; 2 samples	510, 520
Limestone, yellow-gray, soft, earthy, rapid response, flaky chips; 2 samples	530, 540
Limestone, gray, a calcilutite, rapid effervescence, large chips	550
Limestone, buff, rapid reaction; with white chert	560
Limestone, gray, fine granular, moderately slow reaction; with much white chert; 3 samples	570–590
Limestone, gray, rapid response; some white chert	600
Limestone as above, gray shale, much pyrite, a little quartz sand in fine grains, cuttings in sand	610
Shale, blue, plastic, calcareous; 2 samples	620,630
Limestone, blue-gray, reaction slow; and shale, greenish and drab, some blackish, with pyrite; 2 samples	640, 650
Shale, blue-green, plastic, calcareous	660
Devonian (190 feet thick; top 444 feet above sea level):	

Limestone, light yellow-gray, crystalline-granular, slow reaction, in chips	670
Limestone, buff, rapid effervescence, in sand and small chips	680
Limestone, buff and blue-gray, moderately slow	690
Limestone, blue-gray and light yellow-gray, crystalline-granular, moderately slow reaction, some buff and rapid	700
Limestone blue-gray, coarse-granular, moderately slow response	710
Limestone, blue-gray, coarse-granular, rapid reaction; 2 samples	720, 730
Dolomite or magnesian limestone, blue-gray or light yellow-gray, much in crystalline sand; 7 samples	740–810
Limestone, blue (at 850 light yellow-gray), moderately slow response, crystalline-granular; and much highly argillaceous limestone, hard, dark bluish, in small chips; 3 samples	830–850
Silurian (140 feet thick; top 254 feet above sea level):	
Limestone, light yellow-gray, fine crystalline-granular, effervescence moderately slow; 2 samples	860, 870
Dolomite, brown or buff, cherty at 930 and 940, in sand; 11 samples	880–980
Limestone, yellow-gray and brown, in small chips and sand, rapid reaction	990
Ordovician:	
Maquoketa shale (190 feet thick; top 114 feet above sea level)—	
Limestone, dark blue with moderately slow effervescence and light brown with rapid reaction; and shale, drab, hard, in chips; 2 samples	1000–1010
Limestone, drab and light gray, some mottled, earthy, some macrocrystalline-earthy, rapid response, in large thin chips; 4 samples	1020–1050
Limestone, brown, rapid effervescence	1060
Limestone, brown, some rapid reaction, mostly moderately slow, in sand	1070
Limestone, light yellow-gray, earthy, moderately slow response, in small chips	1080
Limestone, blue, argillaceous, moderately slow response, in small chips	1090
Limestone, light buff, earthy, moderately slow reaction, with some light greenish shale	1100
Limestone, light drab, earthy, moderately slow effervescence, hard, in small chips and sand; 6 samples	1110–1160
Shale, greenish, with a little brown inflammable and drab limestone as above	1180
Galena and Platteville limestones (thickness 310 feet, top 76 feet below sea level)—	
Dolomite, brown, subcrystalline, in small chips, with much white chert	1190
Dolomite, as above, with considerable greenish shale	1200
Dolomite, drab, cherty, with some powder of shale; 2 samples	1210, 1220
Dolomite, buff, in sand and meal, with some powder of shale	1230
Dolomite, buff and gray, cherty at 1240, 1330, 1340; argillaceous at 1270; 16 samples	1240–1390
Limestone, gray, rapid response, in small chips; 2 samples	1400, 1410
Limestone, gray, with some shale	1420
Shale, green, plastic, with some argillaceous limestone	1430
Limestone, brown, fossiliferous, crystalline-granular, some green shale	1440
Limestone, yellow-gray, rapid effervescence	1450
Shale, bright green, plastic	1464–1478
Limestone, whitish, fossiliferous, soft, earthy, rapid effervescence, in flaky chips; with much green shale; 2 samples	1480, 1490
Glenwood shale (20 feet thick; top 386 feet below sea level)—	
Shale, green, some brown at 1510; 2 samples	1500, 1510

Saint Peter sandstone (75 feet thick; top 406 feet below sea level)—
Sandstone, moderately fine, of usual Saint Peter facies, white except as rusted in container, with much green shale at 1520, 1580 and 1595; 8 samples 1520-1595
Shakopee dolomite (55 feet thick; top 486 feet below sea level)—
Dolomite, no samples, cuttings washed away 1600–1665
New Richmond sandstone—
Sandstone, white, moderately fine, rounded grains of pure quartz, to bottom of well 1665–1669

Driller's Log, Well No. 3, Beaver Products Company

Formation	Thickness feet	Depth feet
Dirt and clay	45	45
Gypsum rock	16	61
Shale	77	138
Limestone	17	155
Red shale	28	183
Limestone	3	186
Red shale	18	204
Limestone	86	290
Shaly limestone	35	325
Limestone	283	608
Shale	32	640
Limestone	15	655
Shale	10	665
Limestone	799	1464
Shale	12	1476
Limestone	18	1494
Shale	30	1524
Saint Peter sandstone	62	1586
Limestone	9	1595
No samples, open limestone	60	1655
New Richmond sandstone	14	1669

Notes.—This well on the upland penetrates higher beds than the city wells located on the Des Moines valley floor. The Pleistocene till is probably underlain by thin glacial sands and gravels not represented in the samples of the cuttings nor in the driller's log, but furnishing drift sand and gravel to the underlying cuttings at 50 and 60 feet. Some of the white sand of the cuttings of the Fort Dodge beds may be derived from an incoherent sandstone of that formation.

The section through the Coal measures and the Pella beds conforms to that of the local outcrops.

The characteristics of the Saint Louis beds are pretty clearly exhibited from 210 to 250 feet, and the argillaceous limestones from 300 to 320 feet are included in this formation with less evidence. This is also a distinctly argillaceous horizon in city well no. 1.

The upper limestones referred to the Kinderhook, some of them oölitic, perhaps represent the Alden beds. The base of the Kinderhook and the summit of the Devonian might be expected to be marked by distinct and heavy shales. Such, however, are reached only in shales and shaly limestones from 610 to 670 feet. This is also a particularly well marked horizon in city wells no. 1, no. 7 and no. 8. If this is taken as the base of the Mississippian it gives it an extravagant thickness. It may be assumed that these shaly beds represent the Sheffield shale of Franklin county, which, it must be remembered, while provisionally referred to the Kinderhook, may be shown by more thorough investigation in the field to be Devonian. Lithologically the limestones above this shale as high as 604 feet above sea level might also be Devonian. But if the Devonian begins at this height (510 feet deep) the shales from 610 to 670 feet are left in the middle of the Devonian instead of at either top or bottom where they should be expected.

The underlying dolomites, with some limestones, correspond stratigraphically with the beds at Webster City, which are pretty clearly defined as Silurian by their gypsum content.

The Maquoketa shale probably is represented by the earthy, argillaceous limestones with some shale occurring from 1000 to 1190 feet, although the samples afford no "mud rock shale," pounded into plastic clay under the drill, and the driller's log reports no shale between these limits. The lower limit of the Maquoketa is uncertain, as the upper beds of the Galena may be argillaceous. The unwashed samples from city well no. 1, described in the Report on the Underground Waters of Iowa, 1912, and the samples of well no. 8, show this horizon much more clearly. The underlying formations are plainly demarked.

The driller's log, which no doubt gives closer measurements than the sample cuttings, states that the Saint Peter is 62 feet thick and the subjacent limestone, the Shakopee, is 69 feet thick.

WELLS OF L. E. ARMSTRONG

In May, 1927, Mr. Armstrong had drilled on his farm in section 31, Cooper township, about a mile west of Fort Dodge, a well 407 feet deep. Water rose within 125 feet of the curb, which is about 1120 feet above sea level. The driller was J. J. Becker of Garner. In October, 1927, Mr. Becker drilled a second well for Mr. Armstrong, in the north half of the northeast quarter of section 35, Douglas township, two miles west of well no. 1. This well is 216 feet deep and water rises within 119 feet of the top, which is about 1130 feet above sea. In the following record samples from both wells are combined as indicated.

*Record of Armstrong Wells Nos. 1 and 2**

	Depth in Feet
Clay, gray, limy, probably glacial till (No. 2)	50
Shale, red with light blue streaks, limy, Coal Measures (No. 2)	80
Shale, similar to above (No. 2)	110
Shale, black, some fragments of coal (No. 1 ?)	125
Shale, red, like that at 80 feet (No. 2)	130
Shale, like that above (No. 2)	150
Shale, like above	165
Shale, like above	180
Shale, like above	190
Shale, light pinkish tan, limy	200
Shale, light tan, similar to above	205
Sandstone, fine-grained, with some shale	215
Sandstone, fine, white grains, red shale. Last sample marked "No. 2"	216
Shale, dark gray	225
Shale, black, very fine, marked "thickness 2 feet"	240
Shale, dark gray to black, numerous pebbles of various kinds which look like glacial gravel	260
Shale, red, limy, with mixture of pebbles as above	270
Shale, red as above	290
Shale, red like above but few pebbles	310
Shale, red, similar to above	320
Shale, similar to above	330
Sandstone, very fine colorless grains, pinkish from iron stain or shale	340
Sandstone, like above	350
Sandstone, like above, but tan color	360
Sandstone, like above	370
Sandstone, like above	380
Limestone, gray, powder to rather coarse crystalline grains which respond readily to acid. Some sand	390
Limestone, similar to above	400
Limestone, similar to above. These last three samples are St. Louis limestone	407

WELL OF FREDERIC LARRABEE

In May, 1927, Mr. Larrabee had drilled by Mr. J. J. Becker a well on his farm in the northwest quarter of section 13, Douglas township, two miles northwest of Fort Dodge. The well is 315 feet deep, the altitude about 1100 feet and water stands 100 feet below curb. The description of the samples follows. Probably all below the first one represent St. Louis limestone.

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* By Dr. James H. Lees, Assistant State Geologist.

*Samples from well of Frederic Larrabee**

	Depth in Feet
Gravel or coarse sand, clean, gray, with fine sand mixed	90
Limestone, dark gray, fine-grained to sugary texture	100
Sandstone, fine-grained, gray, with abundant limestone, perhaps as cement	110
Sandstone, coarse to fine, light gray; limestone in chips and powder, gray	120
Sandstone, very fine-grained, light gray; much limestone, also fine powder	130
Sandstone, similar to above	140
Shale, gray, almost gritless, somewhat limy	150
Sandstone, dark gray, rather fine-grained, much limestone in fine powder	160
Limestone, in powder and chips, light gray; considerable sand in small grains	170
Limestone, similar to above, a little sand and some clay	180
Limestone, dark gray, powder to chips, fine-grained for most part, some finely crystalline	190
Shale, dark gray, very finely gritty, limy	200
Limestone, dark gray, with some clay and chert	210
Limestone, light gray, fine-grained; some darker limy shale	220
Limestone, gray, very finely sugary; very ready effervescence in acid, nearly all soluble. Some shale, may be from above	230
Limestone, very shaly, dark gray, in soft powder and chips; ready action in acid but much residue	240
Limestone, light gray, in finely gritty powder, nearly all soluble in acid	250
Lmestone similar to above but in coarser grains. A little residue of clear grains, probably chert	260
Limestone and shale, gray, limestone in finely gritty powder, shale in chips	270
Limestone, light gray, entirely soluble in acid. In small fragments	280
Limestone, similar to above	290
Limestone, similar to above; some shale	300
Limestone, in nearly white, very finely gritty powder	310
Limestone, similar to above	315

GARRISON, BENTON COUNTY

(*Altitude 863 feet*)

WELL OF IOWA CANNING COMPANY

In 1926 a well at least 1435 feet deep was completed for this company by Charles D. Nolan of Cedar Rapids. The principal supply was found from 1375 to 1435 feet. During the drilling of the well, it is said, water stood about 12 feet below the curb until the main water bed was reached when it fell to 21 feet below the same level.

On testing the well yielded to the capacity of the pump, 125 gallons per minute, with the pumping cylinder set 80 feet below the curb and the draw down to 42 feet below the curb.

49 feet of 12 inch casing is set to rock, and 191 feet of 8 inch casing through the Maquoketa shales. The cost of the well was $8610.

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* By Dr. James H. Lees, Assistant State Geologist.

Description of samples of cuttings from well of Iowa Canning Company, Garrison

	Depth in Feet
Dolomite, in fine buff sand	450
Shale, blue, calcareous (Maquoketa)	529, 545, 595
Limestone, nonmagnesian, Galena facies; 14 samples	690– 975
Dolomite, Prairie du Chien facies, some rounded grains of quartz sand, chert at 1095	1090–1095
Dolomite and sand, as above; some blue-green shale, slightly calcareous	1150
Shale, in light blue-gray concreted masses, highly dolomitic with minute crystals of dolomite; some fine quartz sand and flakes of blue-green shale	1225, 1235, 1255
Dolomite, some grains of quartz sand	1315, 1340
Dolomite and chert, oölitic, Prairie du Chien facies	1400

GLADBROOK, TAMA COUNTY

(Altitude 850 feet)

The city well of Gladbrook was completed in 1914 by E. A. Ford of Marshalltown. The depth is 828 feet and the diameters are 10 and 8 inches. The capacity of the well is 125 g.p.m. The well is cased with 10 inch pipe to 168 feet and with 8 inch pipe from 160 to 412 feet.

Driller's Log

	Depth, feet
Wisconsin and Kansan drift	0–168
Mississippian lime, solid	168–258
Mississippian lime and shale	258–400
Devonian lime	400–685
Silurian lime	685–828

GLENWOOD

(Altitude 1031 feet)

CITY WELL NO. 2

In April, 1925, a well now about 2200 feet deep was begun by the Layne-Bowler Chicago Company of Chicago. The diameters are from 16 to 6 inches. The city officials state that the official test of the well, when 1990 feet in depth, showed that the well could produce about 60 g.p.m., about the present yield of each of the two deep wells at Glenwood, the city well and that of the Institution for the Feeble-Minded. As the contractors had agreed to bring in a well producing 200 g.p.m., the city refused to accept the well and brought suit to recover $14,000 advanced to the company. The company later drilled some 200 feet deeper, without success, so far as known, and it is stated that no appreciable work has been done since 1926.

This instance illustrates the unwisdom of contracts guaranteeing a certain supply, even "where a geologist would be reluctant to assume any financial risk in the case."[51]

Even in well exploited artesian fields the utmost which the contractor should guarantee is good materials and workmanship. Any guarantee of a specific amount of water is specially unwise and should never be asked in areas whose deep geology and water resources are little known. The best that can be said of such contracts is that they tend to distribute the cost of occasional failures to the entire clientele.

The following data as to water were supplied by the late Seth Dean, city engineer.

Water Beds in City Well No. 2, Glenwood

Depth	Formation	Capacity, g.p.m.	Head below curb, feet	Draw down, feet
15	Blue clay		15	
75–80	Sand and gravel	29	38	26
525	Shale (Pennsylvanian), cased out	----	......	----
630–640	Sandstone (Pennsylvanian), cased out	33	200	----
1065	Sandy limestone, cased out	----	125	----
1090	Sandy limestone, salt water rose from 165 to	----	140	----
1150	Hard limestone	----	133	----
1305	Mississippian	----	120	----
1345	Limestone	----	115	----
1600	Sandy limestone	----	75	----
1670	Sandy limestone	85	67	93

In the above table the formations are assigned on the basis of the section of the first deep well of Glenwood drilled in 1891.[52] In this well the Mississippian, reached at 1235 feet, extended probably at least to the base of a heavy shale at 1644 feet. The remainder of the well, 2000 feet deep, was attributed to the Silurian, because of the presence of gypsum from 1941 feet to the bottom, with the possible exception of some upper limestone which may be Devonian.

GOWRIE, WEBSTER COUNTY

(Altitude 1137 feet)

A deep well for the town of Gowrie was completed in March, 1926, by the Thorpe Brothers Well Company of Des Moines.

51 Norton, W. H., Artesian wells of Iowa, Iowa Geol. Survey, vol. VI, p. 418.

52 Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, pp. 1139, 1140, Pl. XVIII.

The depth is 1842 feet and the diameters range from 16 to 8 inches. Water was found from 500 to 600 feet in Mississippian limestones but the principal supply was struck from 1700 to 1785 feet in the Saint Peter and Upper Shakopee and at the bottom of the well. The static level is 81 feet from the surface. With the pumping cylinder set at 150 feet the pumping capacity is 300 gallons per minute. The cost of the well was $16,673.

Casing

Diameter in inches	Length in feet	Depth of bottom in feet
16	182	182
12	210	385
10	106	860
8	226	1300 (1st line) and 1678 (2nd line)
6	20	1693

Record of Strata

	Depth in Feet
Pleistocene and Recent (160 feet thick; top 1139 feet above sea level):	
Clay, brownish yellow, sandy, noncalcareous, with pebbles of drift, grass roots at 80 feet; 13 samples	0–130
Clay, as above, some masses of soft, decayed, buff limestone	140, 150
Pennsylvanian (230 feet thick; top 984 feet above sea level):	
Shale, hard, blackish, coaly on surface, 3 large chips	160
Shale, blackish and drab; 13 samples	170–310
Shale, blue and light blue-gray, calcareous, in moulded masses; at 350 feet when washed gives chips of soft, gray, earthy, argillaceous limestone; fine-grained sandstone; gray flint; pyrite; and some coarse grains of reddish silica 2 to 3 mm. in diameter; 7 samples	320–380
Mississippian (420 feet thick; top 749 feet above sea level):	
Limestone, light yellow-gray, very soft and friable, macrocrystalline-earthy, in large flakes; rapid effervescence in cold dilute HCl	390
Chert, blue-gray, in large chips; some limestone, gray, fine-grained, rapid effervescence	400
Limestone, buff, rapid effervescence, hard, fine-grained; shale, olive colored, noncalcareous, large chips	410
Limestone, as above	420
Limestone, light yellow-gray, encrinital; some limestone, hard, blue-gray	430
Limestone, cream colored, soft, earthy; limestone, gray, earthy, speckled, hard, pyritiferous; chalcedony, blue-gray	440
Limestone, yellow-gray, soft, earthy, with sporadic calcite crystals; some oölitic limestone; some yellow gray calcilutite; some shale	450
Limestone, buff, finely crystalline; yellow-gray calcilutite; gray chalcedonic silica	460
Chert, blue-gray; chalcedonic silica, gray; limestone, light yellow-gray, crystalline	470, 480
Limestone, blue-gray, light yellow-gray and mottled, soft, macrocrystalline	490
Limestone, whitish, macrocrystalline-earthy, soft, large flakes	500
Shale, drab; limestone, yellow-gray, mottled; white chalcedonic silica	510
Limestone, light yellow-gray, soft, coarsely crystalline	520
Limestone, light yellow-gray, fine-crystalline, rather slow reaction; some as above, rapid reaction	530, 540

Limestone, whitish, oölitic, response rapid, in large flakes	550
Chert, blue-gray; some yellow-gray limestone of rapid effervescence	560
Limestone, light yellow-gray and whitish, coarse crystalline-granular, some oölitic at 570; 3 samples	570–590
Limestone, yellow-gray, fine crystalline-granular, rapid effervescence	600, 610
Limestone, light yellow-gray, coarse crystalline-granular, some oölite	620
Limestone, light yellow-gray, cherty	630
Limestone, light yellow-gray and brownish, finely granular	640
Limestone, light yellow-gray and whitish, macrocrystalline-earthy, oölitic in large chips	650
Limestone, yellow and blue-gray, in sand	660
Limestone, light yellow-gray and whitish, oölitic; some drab shale	670
Limestone, light yellow-gray, finely granular; some large chips of coarse grained limestone	680
Dolomite or magnesian limestone, yellow-gray, fine crystalline, slow effervescence, in medium sized chips	690
Limestone, light yellow-gray and whitish, coarsely crystalline, rapid reaction	700
Limestone, light blue-gray and yellow-gray, finely crystalline-granular, rapid effervescence, in coarse sand	710
Limestone, blue-gray and yellow-gray, crystalline, rapid reaction, with considerable clayey powder; 3 samples	720–740
Limestone, as above, some fine quartz sand and flint	750
Shale, light blue, plastic, calcareous; 5 samples	760–800
Devonian to Galena-Platteville inclusive (850 feet thick; top 329 feet above sea level):	
Limestone, blue-gray, finely crystalline; some yellow limestone of slow effervescence; mottled flint; argillaceous powder	810
Limestone, blue-gray, rather rapid reaction	830
Limestone, buff and light blue-gray, crystalline-granular, rather slow reaction, cherty	840
Limestone, blue-gray, fine-grained, rather rapid response to acid	850, 860
Limestone, light buff-gray, coarser grained than above, rapid reaction	870
Limestone, light buff-gray, fine-grained, rather rapid effervescence; some chert	880
Limestone, gray, fine-grained, effervescence rather rapid; gray flint	890, 900
Limestone, yellow and blue-gray	910
Limestone, magnesian, or dolomite, light and dark gray, slow effervescence, some rather rapid; 4 samples	920–950
Limestone, light gray and buff, mostly of rapid effervescence; much argillaceous powder	960
Limestone, light gray and olive gray, very fine-grained, rather slow reaction; yellow gray, rapid effervescence; some shale, light blue-green, calcareous	970, 980
Limestone, gray, rapid response, some bright yellow, very fine-grained, slow; shale, drab and blue	990
Limestone, yellow-gray and drab, mostly rapid reaction; blue and blackish shale; cinders at 1030; 6 samples	1000-1050
Limestone, light gray and yellow, compact, fine-grained, rapid response; some white chert; some limestone in smaller chips of rather slow effervescence; argillaceous powder concreting whole into rather difficultly friable masses	1060, 1070
Chert, gray and whitish; some limestone of slow response; 3 samples	1080–1100
Limestone, light gray, both slow and rapid effervescence	1110, 1120
Chert, blue-gray; some limestone, slow reaction	1130
Limestone, blue-gray, argillaceous, rapid response to acid, highly arenaceous, grains fine, ill-rounded	1140
Limestone, blue-gray, argillaceous, rapid effervescence	1150
Limestone, blue-gray, some whitish, response rapid; some dolomitic	1160
Chert, gray; some dolomite, light gray, a little limestone	1170, 1180
Limestone, blue-gray, encrinital, rapid response; some light blue shale	1190
Limestone, finely crystalline, rapid effervescence	1200

Limestone, buff-gray, fine-grained, rapid reaction, some whitish, coarser, crystalline, rather slow; some light blue shale, pyritiferous; 3 samples	1210–1230
Limestone, light buff-gray and whitish, crystalline-granular, reaction rapid; some light blue shale; 3 samples	1240–1260
Limestone, light yellow-gray and whitish, crystalline, rather rapid effervescence; limestone, blue-gray, macrocrystalline, argillaceous	1270
Limestone, light yellow-gray, response rather slow; and blue-gray limestone of rapid reaction	1280, 1290
Limestone, whitish, crystalline, rather slow reaction, some gray and rapid, some blue-gray, finely laminated, siliceous; considerable shale	1300
Limestone, yellow, rather rapid effervescence; whitish, rapid, and blue gray, rather slow reaction	1310
Limestone, gray of various tints, some rapid reaction, some slow in same sample; 12 samples	1320–1430
Chert and dolomite, gray	1440
Dolomite, light yellow-gray; some limestone of rapid response, in larger chips	1450, 1460
Limestones, gray, rapid and slow response	1470, 1480
Dolomite, light gray, compact, fine-grained, in small chips; some chert; some gray limestone of moderately slow reaction; 17 samples	1490–1650
Glenwood shale (40 feet thick; top 521 feet below sea level)—	
Shale, blue-green, some drab, fissile, in moulded masses; 4 samples	1660–1690
Saint Peter sandstone (60 feet thick; top 561 feet below sea level)—	
Sandstone, white, clean, rounded and frosted grains up to 0.8 mm. diameter; some fissile green shale; 6 samples	1700–1750
Shakopee dolomite (penetrated 30 feet)—	
Dolomite, gray, much quartz sand and shale as above; 4 samples	1760–1790
No samples, to bottom of well	1800–1842

Driller's Log

	Depth in Feet
Yellow clay	0–62
Sand	62–66
Yellow clay	66–155
Red shale	155–166
Black shale	166–175
Gray shale	175–310
Shale and lime	310–385
Lime	385–750
Gray shale	750–790
Lime	790–1200
Broken lime	1200–1203
Lime	1203–1280
Shale	1280–1284
Lime	1284–1650
Blue shale	1650–1685
Sand	1685–1735
Lime and sand	1735–1785
Sand	1785–1842

Notes.—It is quite possible that the boundary between the Pennsylvanian and the Mississippian should be drawn at the top of the blue shales from 320 to 380 feet, instead of at their base.

The shale from 760 to 800 feet is assumed to define the frontier between the Mississippian and the Devonian.

The limestones which extend almost without a break from the top of the Devonian at 800 feet to the Glenwood at 1650 feet present no clear formational characteristics. The shale of the driller's log at 1280 and the siliceous limestone at 1300 are probably to be included in the Maquoketa, which here, as at Fort Dodge, seems to be represented largely by limestones instead of shales. Probably the lower 220 feet, at least, of this run of limestone is Galena-Platteville.

The mixture of limestones of various reactions to acid, and the presence of shale in limestone cuttings probably is due to falls.

The elevation of the Saint Peter sandstone, 561 feet below sea level, is somewhat above that of the forecast of the report of 1912 (Map, Plate I), which placed it at a little more than 600 feet below this datum.

*Mineral Content of City Well, Gowrie**

	P.P.M.
Bicarbonate	427.0
Chloride	14.
Sulfate	208.1
Silica	15.8
$Fe_2O_3+Al_2O_3$	3.6
Calcium	93.6
Magnesium	53.2
Na + K as Na	52.0
Total solids	653.7

GRAND JUNCTION, GREENE COUNTY

(*Altitude 1039 feet*)

The city well at Grand Junction was drilled by Thorpe Brothers Well Co., of Des Moines, being completed December 26, 1925. It is 320 feet deep and is cased with 12 inch pipe to 105 feet and with 10 inch pipe from 100 feet to 250 feet, 6 inches. Static level of the water is 15 feet below the surface. In testing the well the pump was set 40 feet below the surface and it pumped 150 gallons per minute for 24 hours.

Driller's Log

	THICKNESS FEET	DEPTH FEET
Clay	47	47
Sand, fine and mixed	53	100
Shale, mixed	150	250
Rock	24	274
Sand rock	46	320

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

GREENFIELD

(Altitude 1370 feet)

The deep well of the city of Greenfield at the close of 1928 had been drilled by Layne-Bowler Chicago Co. to the depth of 2505 feet. The diameters are from 20 to 8 inches. The static level is 505 feet from the surface, which may be compared with the head of the Stuart deep well, 350 feet. Some water was found in the sandstone near the base of the Pennsylvanian and also at about 1600 feet in Mississippian limestone. At 2130 feet, in the Silurian, according to press reports at the time, a water sandstone was reached. "From all appearances the sand resembles the St. Peters sandstone, which is supposed to be one of the best water bearing strata of sand. The sand is a solid formation and requires no casing. It is fine in texture and white in color and was found after a stratum of very hard rock was penetrated by the drill. When first taken from the well it resembles sugar sand in texture and color but gets darker after it is exposed to the air." The samples submitted to this office, however, were almost wholly of dolomite with some gypsum and showed no particular resemblance to the Saint Peter. They were referred to the same horizon—Silurian—which yields a supply for the Des Moines deep wells. The Saint Peter was not reached after 375 feet of deeper drilling and probably lies about 750 feet below the rock mistaken for it. The yield of this stratum does not seem to have been measured accurately, but to quote again from current press reports "This sandstone contains a large quantity of good water as test by the bailer revealed. The water coming up with the bailer was clear and suitable for drinking purposes. The water in the well "cleared" when this vein of sand was penetrated, showing a good inflow of water. * * * The striking of this stratum did not, however, raise the water level in the well, which still remains within 500 feet of the top."

Tests made after drilling was stopped at 2505 feet showed a capacity of 65 g.p.m. with the pumping cylinder at 600 feet. The report by city officials stated that it "pumps down to the cylinder and remains there if not more than 60 g.p.m. is pumped".

Casing was placed as follows: from the surface 20 inch to 207 feet, 16 inch to 285 feet, 12 inch to 980 feet and 10 inch to 1260 feet; from 1534 feet 8 inch to 1780 feet. The 8 inch casing was inserted to case out the Kinderhook shale and some of the overlying limestone and shale.

The latest report from Greenfield (Dec. 31, 1928) states that "the well is not completed and will probably be drilled to 3500 feet."

Mineral analysis (water believed to be entering well at 1600 feet)

	Grains per Gallon
Silica	0.700
Oxides of iron and aluminum	0.116
Carbonate of lime	15.611
Sulphate of lime	9.622
Carbonate of magnesia	5.839
Sodium and Potassium sulphates	82.195
Sodium and Potassium chlorides	6.800
Loss, etc.	0.005
Total mineral solids	120.888

Record of strata, Greenfield city well.

	Depth in Feet
Pleistocene and Recent (200 feet thick; top 1370 feet above sea level):	
Till, yellow, clayey, sand and pebbles of drift, in hard lumps; 5 samples	20–120
Peat, blackish and dark brown, inflammable, some fossil wood	120–140
Till, gray, calcareous, in hard lumps	140–160
Till, blue-gray, as above	160–180
Gravel, pebbles of drift up to 3 cm. diameter, with yellow clay sufficient to bind	180–200
Pennsylvanian (1130 feet thick; top 1170 feet above sea level):	
Limestone, yellow-gray, crystalline-earthy, rapid effervescence in cold dilute HCl; some drab flint; in chips	200–220
Shale, drab and blackish	220–230
Shale, dark gray, red and bluish gray; 3 samples	230–290
Limestone, drab, fossiliferous, in flaky chips, "lime shell 306-310"	290–310
Shale, red and gray	310–330
Limestone, drab and gray, hard, fine-grained, fossiliferous, argillaceous, somewhat siliceous	330–340
Limestone, gray; drab shale	340–360
Shale, blue-gray and red, drab, greenish gray; 3 samples	360–425
Limestone, gray, earthy, fossiliferous; 2 samples	425–460
Shale, drab; chips of light gray limestone	460–465
Limestone, light gray and whitish, some coarse granular, some calcilutite	465–475
Shale, drab, with chips of light gray limestone	475–500
Limestone, very light gray, macrocrystalline-earthy, soft	500–515
Shale, gray and blackish	515–525
Limestone, light yellow-gray, earthy	525–542
Shale, red; 2 samples	542–580
Shale, blue-gray, with chips of argillaceous drab limestone	580–600
Shale, red and blue-gray; 2 samples	600–640
Limestone, light brownish gray, rather hard, fossiliferous	640–645
Shale, blue-gray and drab	645–665
Shale, blue-gray; limestone	665–685
Shale, gray and drab; 4 samples	685–750

Limestone, gray, earthy, argillaceous	750–755
Shale, drab; some coal; 2 samples	755–800
Shale, blue-gray and drab; 5 samples	800–895
Limestone, yellow-gray, argillaceous, siliceous	895–905
Shale, gray and drab; 4 samples	905–965
Shale, blackish	965–985
Shale, drab	985–995
Sandstone, gray, fine, grains of clear quartz, highly irregular	995–1005
Shale, gray and drab; 5 samples	1005–1100
Shale, blackish; 2 samples	1100–1138
Sandstone, gray, irregular grains of clear quartz, larger about 0.5 mm. diameter; 2 samples	1138–1163
Shale, drab and blackish; 4 samples	1163–1235
Sandstone, as at 1138	1235–1250
Shale, gray, finely arenaceous, noncalcareous; some white chert; pyrite	1285
Mississippian (450 feet thick; top 40 feet above sea level):	
Limestone, drab and gray, slow effervescence, argillaceous, slightly arenaceous; considerable gray and white chert; sandstone, drab, very finely arenaceous, calcareous	1330
Limestone, light gray, crystalline-earthy, soft, in flaky chips	1350
Shale, medium blue-gray, micaceous, pyritic, in hard lumps	1390
Chert, brown and white; some limestone	1468
Shale, medium blue-gray, in hard lumps	1510
Chert, white and brown; chalcedonic silica; some limestone; 3 samples	1525–1590
Shale, medium blue-gray, in hard lumps	1600
Limestone, blue-gray and yellow-gray, rather slow effervescence; light gray chert; blue-gray shale; all in chips; 3 samples	1600–1640
Limestone, yellow-gray, rapid effervescence; 2 samples	1680, 1700
Shales (Kinderhook), light blue-gray, some brown at 1770; 6 samples	1720–1775
Devonian (125 feet (?) thick; top 410 feet below sea level):	
Limestone, light yellow-gray, rapid effervescence; 6 samples	1780–1860
Silurian (and underlying formations ?):	
Dolomite, brown, in sand, a little quartz sand and chert; a flake or so of selenite or gypsum	1905
Limestone, buff in mass, rather slow effervescence, some rapid; a little gypsum	1925
Limestone, buff, rather slow reaction, some rapid, in sand; considerable gray shale; 2 samples	1950, 1980
Dolomite, gray and buff-gray; 3 samples	2000–2060
Dolomite, brown, in sand; 3 samples	2070–2100
Dolomite, light brown and gray, in finer sand, considerable residue of gypsum; pyrite; gray chert; white clay; a little quartz sand; 2 samples	2120–2140
Dolomite as above, a little gypsum, some cryptocrystalline silica	2160, 2180
Dolomite, drab and gray; some gypsum; pyrite	2200
Dolomite, brownish; gypsum	2220
Dolomite, brownish and gray; gypsum in whitish grains; gypseous clay; 2 samples	2240, 2280
Dolomite or magnesian limestone, rather slow effervescence, soft, disintegrating under weak acid into crystalline finest grains, argillaceous residue; whitish gypseous calcareous clay in soft chips	2340
Dolomite or magnesian limestone, rusted, disintegrating under weak acid into finest crystalline sand; whitish gypseous clay	2355
Dolomite, gray, much quartz sand, fine grains rounded, some secondary enlargements	2380
Limestone, light gray, crystalline-earthy, rapid effervescence, argillaceous	2400
Shale, reddish, in concreted masses; white masses of limestone in powder with fine quartzose residue, and a little gypsum	2420
Chert, white, and chalcedonic silica, considerable quartz sand in fine rounded grains; a little limestone of rapid effervescence	2440

Dolomite, light gray and whitish; whitish cryptocrystalline silica, sandstone, fine, calcareous, larger grains well rounded	2455
No samples	2455–2505

Notes.—The gray sandstones occurring at or near the base of the Coal Measures (1138 to 1163 feet and 1235 to 1250 feet) may be compared with the similar sandstone found at the same horizon at Lamoni, Atlantic, Bedford and Glenwood. This sandstone furnished more or less of the meager yield of the well, as the casing was perforated from 1138 to 1168 feet.

The cuttings at 1285 are rather ambiguous and might be classed as Mississippian. But as the log records a black shale 15 feet thick at 1298, the top of the Mississippian is placed at 1330 feet, the depth of the first sample of typical Mississippian facies.

The samples of shale from 1720 to 1775 feet are Kinderhook in aspect and stratigraphically. With these assignments the thickness of the Mississippian foots up 450 feet, with which may be compared the thickness of the Mississippian at Lamoni, 453 feet, and at Des Moines (Wood Bros. well) 450 feet, at Atlantic probably at least 420 feet, and 405 feet at Stuart.

The limestones from 1780 to 1905 feet thus fall to the Devonian. The dolomites and limestones from 1905 to 2455 feet may be referred with plausibility to the Silurian on account of their position and their gypseous content. The thickness given the Silurian—it carries through to 2455 feet—is thus 550 feet, something less than at Bedford, where it shows much more gypsum, and a little thicker than at Des Moines.

Drilling was stopped at 2505 feet on account, in part at least, of mechanical difficulties arising from the loss of tools at the bottom of the drill hole.

The Saint Peter sandstone, it is inferred, was still several hundred feet below. At Stuart the distance from the top of the Mississippian to the top of the Saint Peter sandstone is 1561 feet, at Nebraska City 1763 feet; at Council Bluffs the Saint Peter had not been reached 1425 feet below the same datum. On the scale of the Stuart well the Saint Peter would be found at Greenfield at 2891 feet from the surface, 1521 feet below sea level, and on the scale of the Nebraska City well about 200 feet deeper. If the last sample is at or near the base of the Silurian, and the thickness of the Ordovician above the Saint Peter sandstone be given a minimum of 300 feet, the Saint Peter sandstone would lie at 2755 feet from the surface or 1385 feet below sea level.

Driller's log

	Depth in Feet		Depth in Feet
Yellow clay	0–120	Limestone	895–905
Black mud	120–140	Gray shale	905–920
Blue shale	140–180	Mottled shale	920–1020
Yellow clay	180–200	Gray shale	1020–1080
White limestone, medium soft	200–220	Pink shale	1080–1100
Black shale	220–230	Black shale	1100–1138
Mottled clay	230–250	Sandstone	1138–1163
Red shale	250–270	Black shale	1163–1235
Blue shale	270–290	Sandstone, soft	1235–1265
Blue shale and lime-shells, soft	290–310	Black shale	1265–1280
Red shale	310–330	Soft sandstone	1280–1295
White limestone	330–340	Black shale	1295–1310
Blue shale	340–380	Shale and sand	1310–1330
Gray shale	380–425	Lime	1330–1350
Gray limestone	425–460	Gray shale	1350–1390
Green shale	460–465	Lime	1390–1395
White limestone	465–475	Sandy shale	1395–1465
Blue shale	475–500	Lime	1465–1500
White limestone	500–515	Shale	1500–1510
Black shale	515–525	Lime	1510–1570
White limestone	525–542	Gray shale	1570–1640
Black shale	542–545	Lime	1640–1720
Red shale	545–580	Shale	1720–1785
Blue shale	580–600	Brown lime	1785–1790
Red shale	600–620	Shale	1790–1800
Blue shale	620–640	Hard lime	1800–1880
Limestone	640–645	Lime	1880–1890
Blue shale	645–700	Sandy lime	1890–1900
Mottled shale	700–750	Brown lime	1900–1930
Gray limestone	750–755	Hard lime	1930–2080
Mottled shale	755–780	Brown lime	2080–2108
Blue shale	780–820	No record, except about 4 feet of shale at 2445	2108–2505
Gray shale	820–875		
Mottled shale	875–895		

GRINNELL

(Altitude 1007 feet, C., R. I. & P. Ry)

CITY WELL NO. 5

This well, drilled in 1920 by the Thorpe Brothers Well Company of Des Moines, is 2000 feet deep and its diameters are from 16 to 8 inches. The principal supply was found at 1800 feet in the Shakopee dolomite; other water beds were encountered at 1500 feet in the Galena and at 1900 feet in the New Richmond.

The static level is 250 feet below the surface. The capacity under the air lift is 120 gallons per minute but continuous pump-