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**THE IRON ORE DEPOSITS NEAR  
WAUKON, IOWA**

**BY  
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## OUTLINE.

Introduction .....	37
Location .....	37
Relief .....	37
Drainage .....	40
Development .....	40
Field work and acknowledgments.....	40
Stratigraphic geology .....	41
The Prairie du Chien formation.....	41
The Oneota member .....	43
The New Richmond member.....	43
The Shakopee member .....	43
Fossils of the Prairie du Chien.....	43
Stratigraphic relations .....	44
The St. Peter formation.....	44
The Platteville formation .....	46
The Basal shale .....	46
The Platteville limestone .....	47
The Decorah shale .....	48
Fossils of the Platteville formation.....	48
The Galena formation .....	50
Lithologic character .....	51
Fossils .....	52
Structural geology .....	53
Physiographic geology .....	54
General statement .....	54
The upper plain .....	58
The lower plain .....	59
Ages of the peneplains.....	60
Economic geology .....	63
The iron ore .....	63
General character of the ore.....	63
Physical character of the ore.....	64
Fossils in the ore.....	68
Composition of the ore.....	70
Analyses .....	72
Origin of the ore.....	73
General features .....	73
The residuum .....	75
Nature of the residuum.....	76
Source of the iron.....	78
Concentration of the iron.....	79
Precipitation of the iron.....	80
Summary .....	82
Treatment of the ore.....	84
Present development .....	84
Mining .....	86
Haulage .....	87
Concentration .....	87
Results of the treatment.....	90
Disposition of the ore.....	90
Bibliography of the Waukon iron ore.....	92





## THE IRON ORES OF IRON HILL NEAR WAUKON, IOWA

### Introduction.

#### LOCATION.

Iron Hill lies in west-central Allamakee county, in the northeastern corner of Iowa, and is about two and one-half miles northeast of the town of Waukon. It is within the Waukon quadrangle of the United States Geological Survey.

Waukon, a town of about 2,000 population, and which is the county seat of Allamakee county, forms the terminus of a branch of the Chicago, Milwaukee & St. Paul Railway, connecting with the main line at Waukon Junction, on the Mississippi river. (See figure 1.)

#### RELIEF.

Iron Hill is the highest point in northeastern Iowa, and attains a height of 1,340 feet above sea level. The lowest land in the vicinity, in the southeastern corner of Makee township, is 960 feet above sea level. This indicates a maximum relief of 380 feet.

In the central and western parts of Makee township grades are low and the slopes relatively gentle, but in the eastern and northern portions the topography is markedly rugged, due to the proximity to the drainage lines. Waukon itself is located on a rolling plain whose greatest extent is to the southwest of the town. Owing to the absence of any considerable quantity of drift the topography has been controlled largely by erosion.

The district may be divided into two generally distinct topographic provinces, which differ not only in elevation but also in character and origin. These are:

- (a) The upland plain.
- (b) The valleys.



FIG. 1—Index map of northeastern Iowa showing location of area studied (small rectangle). Also the area covered by the Waukon sheet of the U. S. Geological Survey (larger rectangle).

The plain in general is rolling and well drained, and is covered by a thick residual soil overlain by a small amount of loess. Wherever the plain lies on the Galena formation of the Ordovician system, as it does throughout the small region to be considered, sinkholes are characteristic features. The soil is of fairly good quality and the farmers are prosperous.

The valleys are marked by outcrops of hard rock and represent an advanced stage of dissection. The larger ones have been filled with alluvium to a depth of ten to twenty-five feet, but cultivation has so increased the run-off of the hillsides that the present streams are now cutting out their old flood plains and destroying much of the arable bottom land.

The relation between the two provinces is shown by the sketch map, figure 2.

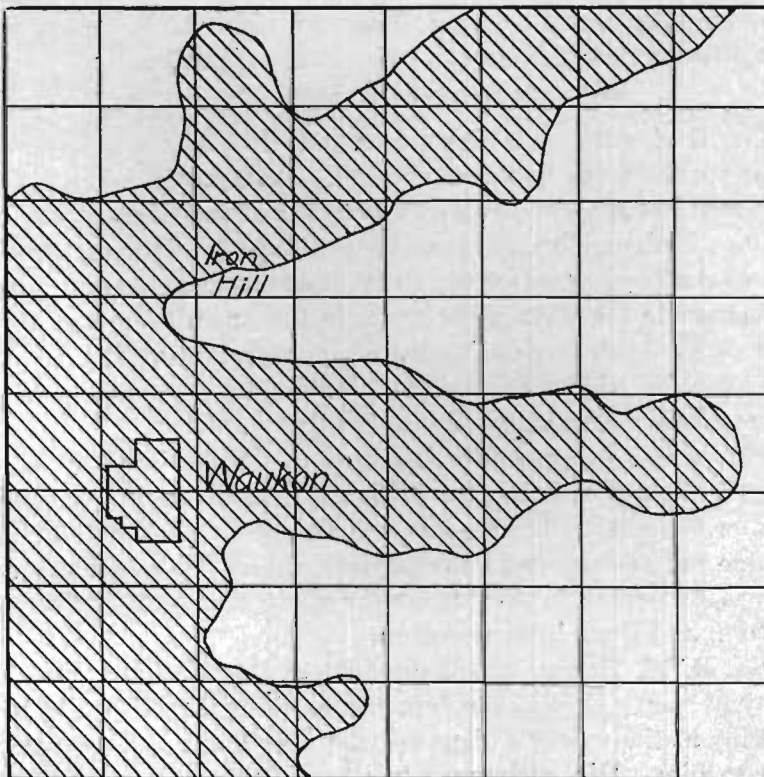


FIG. 2—Sketch map showing relation of upland and valley in vicinity of Iron Hill. Upland shaded.



## DRAINAGE.

The Waukon area is drained by three chief streams, the Upper Iowa river, Village creek and Paint creek. The ridge of which Iron Hill is the highest point, forms the divide between the basins of the two former streams.

Owing to the thinness of the soil on the hillsides all except the larger watercourses are more or less intermittent, flowing as mere brooks during ordinary times, but becoming swollen to torrents during each heavy rain. The many springs which rise over the shaly members of the Platteville formation tend to equalize the flow to a marked degree, and prevent any but the minor tributaries from becoming completely dry between rains.

## DEVELOPMENT.

The Iron Hill deposits are being developed by the Missouri Iron Company, of St. Louis, Missouri. Mr. R. W. Erwin is Superintendent and Manager of the local property.

## FIELD WORK AND ACKNOWLEDGMENTS.

The field work on which this report is based was carried on chiefly during the summer of 1914. Four weeks were spent in the driftless area of Iowa as a member of the field course given by the Universities of Iowa and Chicago. During this trip especial attention was given to Physiographic geology. Later in the summer ten days were spent in the examination of the ore deposit and the region immediately surrounding it. In April, 1915, a third visit was made to Waukon for the purpose of verifying certain conclusions and collecting new data.

The writer is especially indebted to Professor G. F. Kay of the University of Iowa, for criticism and advice in the preparation of the work. Thanks are due also to Professor A. C. Trowbridge for assistance in the physiographic phases of the work; and to Professor A. O. Thomas for aid in the identification of the fossils, and their interpretation.

Mr. R. W. Erwin, superintendent of the Missouri Iron Company property at Waukon, has rendered invaluable assistance by placing at the writer's disposal whatever maps and data were of use to him. His assistance has been especially helpful in the preparation of those chapters dealing with the deposit itself, and with the metallurgical treatment of the ore.



**GEOLOGY.****Stratigraphic Geology.**

All of the indurated rocks exposed in the neighborhood of Waukon are of Ordovician age, although the Cambrian rocks lie at only a short distance beneath the surface. The generalized section below shows the relations of the various formations, which are shown also on the geological map, figure 3.

SYSTEM	SERIES	FORMATION		THICKNESS	CHARACTER OF ROCK
Ordovician	Mohawkian	Galena		Feet 240	Limestone and dolomite
		Platteville	Decorah	5-30	Shale & limestone
			Platteville	50-60	Limestone
			Basal shale	2-5	Arenaceous shale
	Canadian	Saint Peter		100+	Soft, incoherent sandstone
		Prairie du Chien	Shakopee	80	Dolomite
			New Richmond	20	Sandstone
			Oneota	150	Dolomite
Cambrian	Potsdamian	Saint Croix	Jordan	Not exposed	Sandstone
			St. Lawrence		Sandstone & shale
			Dresbach		Sandstone

**THE PRAIRIE DU CHIEN FORMATION.**

The Prairie du Chien has but a limited distribution in the district. However, it is prominent in the valley of Village creek in the eastern part of Makee township, and also in the northwest corner of Makee township along a tributary of the Upper Iowa river. An unconformity between the St. Peter and the Prairie du Chien renders these outcrops highly variable. It is a common occurrence along Village creek to find one wall of the valley

composed of Prairie du Chien dolomite, while the opposite wall is of soft St. Peter sandstone. The two formations appear and disappear along the valley in a most striking manner.

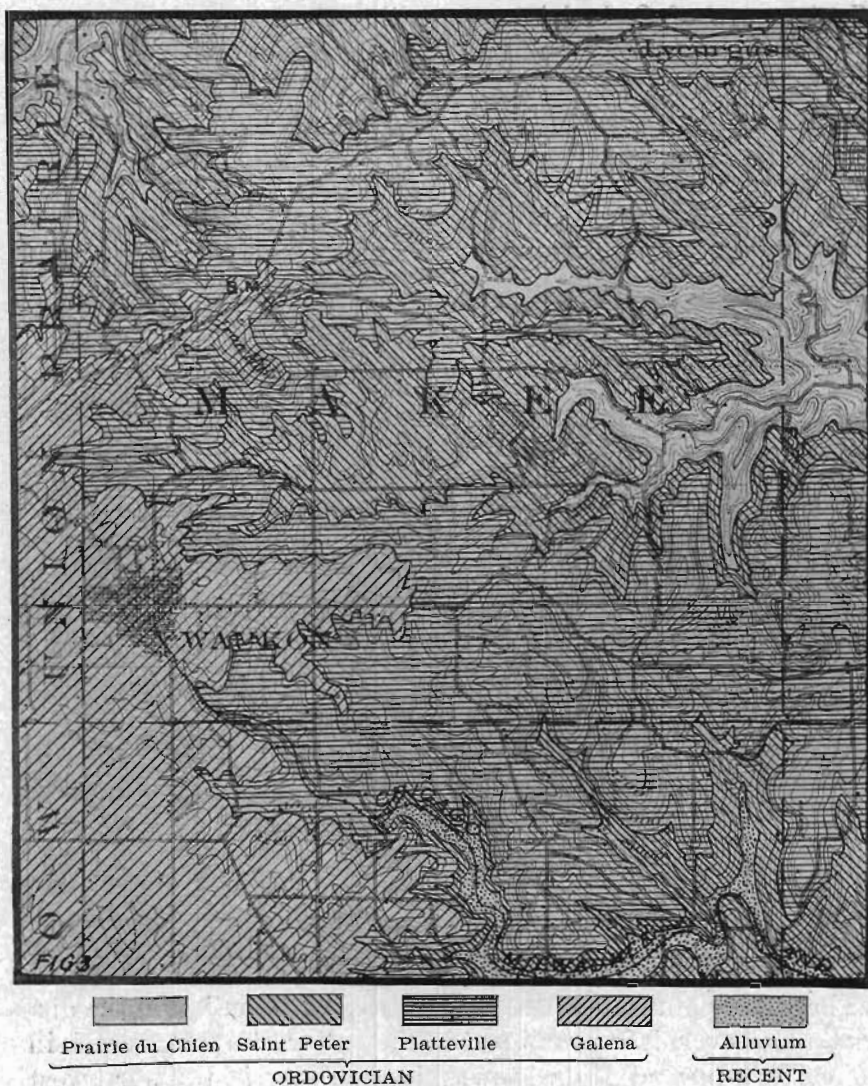


FIG. 3—Geological Map Iron Hill and Vicinity.

The Prairie du Chien formation of Iowa has been subdivided into three members, named, from the bottom up, Oneota dolomite, New Richmond sandstone, and Shakopee dolomite. The two

upper members are very irregular in occurrence and in places are absent. In the limited number of outcrops found near Waukon only the Oneota and Shakopee were identified, but blocks of New Richmond float were scattered profusely in the deeper alluvium of Village creek and the Upper Iowa river.

*The Oneota Dolomite.*—The Oneota member is here a thick-bedded, buff-colored dolomite. It has the characteristic open texture and the sandy, crystalline appearance of a true dolomite and contains a considerable amount of chert, usually as nodules and arranged in rather definite bands. Small cavities in the rock in many cases are filled with crystals of calcite and dolomite and the faces of many exposed cliffs are thickly coated with tufa.

*New Richmond Sandstone.*—Good outcrops of the New Richmond sandstone are rare in northeastern Iowa and none were seen within the area. However, the presence of the above mentioned blocks in the stream alluvium indicates that outcrops of this horizon may be found. The rock commonly is a light-colored, crystalline, sparkling, almost quartzitic sandstone. Calvin has shown<sup>1</sup> that the hardness and crystalline character are due to a secondary enlargement of the quartz grains in such manner as to produce optical continuity between the nucleus and the envelope. The entire thickness of the member never exceeds twenty feet and is usually less where seen in adjoining regions.

*The Shakopee Dolomite.*—Above the New Richmond sandstone lies a considerable body of dolomite which is somewhat variable in occurrence, having been eroded, for the most part, before the deposition of the St. Peter formation. The Shakopee is similar to the Oneota and cannot be distinguished from that member on lithologic grounds alone. It is practically unfossiliferous except for the presence of a peculiar form known as *Cryptozoon minnesotense*, concerning the organic origin of which there is some question.

*Fossils of the Prairie du Chien.*—No recognizable fossils were found in the Prairie du Chien of Makee township or in the contiguous territory, but a few casts of cephalopods and gastropods were collected from the Oneota four miles northeast of Waukon.

<sup>1</sup>American Geologist, XIII, 1894, 225-227.



Calvin has described<sup>2</sup> the following forms from the chert beds of the upper Oneota of southeastern Allamakee county:

Murchisonia sp.  
Tryblidium sp.  
Metoptoma alta.  
Straparollus claytonensis  
Straparollus pristiniiformis  
Raphistoma pepinense  
Raphistoma multivolvatum  
Raphistoma paucivolvatum  
Holoepa turgida  
Orthoceras primigenium  
Cyrtoceras luthel

*Stratigraphic Relations of the Prairie du Chien.*—The Prairie du Chien is conformable with the Jordan sandstone below, the change from the one to the other taking place through many feet of transition beds. At many places where the thickness of the Prairie du Chien and St. Peter formations may be ascertained, although the total thickness of the two formations is always the same their individual thicknesses may vary greatly. The fact that where one is thin the other is always thick, can mean but one thing, namely, that there is an erosional unconformity between the two strata. This unconformity would explain also the absence of New Richmond and Shakopee at many places, as they probably were eroded away before the deposition of the St. Peter. This unconformity has been strikingly demonstrated at many places.

#### THE ST. PETER FORMATION.

Lying above the Prairie du Chien, and unconformable upon it, is the St. Peter sandstone. It has a wide distribution within Makee township, forming prominent and typical outcrops in all of the stream valleys. It has its widest distribution, however, in the valley of Village creek. On account of its soft and incoherent nature it does not form towers and steep bluffs such as are characteristic of the dolomites. Weathering goes on very rapidly and it is only in fresh exposures that satisfactory study can be carried on.

The topographic expression of the St. Peter sandstone is very characteristic. The friable sandstone weathers to gentle slopes

<sup>2</sup>Bull. Lab. Nat. Hist. S. U. I., Vol. II, No. 2, 189-193.

and broad, U-shaped valleys, and forms a rolling upland, easily cultivated and well drained. The soil is sandy and is of no great value for agricultural purposes.

The presence of a resistant iron band at the top of the formation results in the production of peculiar erosional forms. Flat-topped, mesalike remnants occur where the overlying formations have been entirely removed, while a more or less prominent ledge is usually noted where the Platteville-St. Peter contact appears on a hillside.

The St. Peter formation is a soft, fine-grained, incoherent, variously colored quartz sandstone. It is, in general, so loosely cemented that at many places it resembles a deposit of sand.

The rock usually is somewhat laminated, although in many places massive layers, several feet in thickness, occur. A striking illustration of this laminated phase is found 4.5 miles northeast of Waukon, where a small stream cuts through a considerable thickness of it.

The St. Peter is highly variable in color and its hues range from pure white through the shades of buff, yellow, brown, red and purplish, the colors being most pronounced in fresh and unweathered exposures. These colors are due to the iron oxide of the cement and the variation results from varying degrees of oxidation. Alternate laminae may be differently colored and impart a strikingly variegated appearance to the rock. Such an occurrence may be seen along the south side of the road some three miles east of Waukon.

The top of the formation is marked by a resistant iron band from one to four inches in thickness, below which the sandstone is more or less impregnated with ferric salts. This iron band forms a very convenient horizon marker as it lies immediately beneath the basal shales of the Platteville formation, and differential weathering at the contact usually leaves the iron band exposed.

Although in general the St. Peter sandstone is very soft and unconsolidated, there are exceptional phases where it is exceedingly hard. Just west of the main road three miles north of Waukon, in the southeast quarter of section 12, township 98 north, range 6 west, a small quarry has been opened in such a phase. The stone exposed is regularly bedded, very hard, and

almost quartzitic in texture. Four miles northeast of Waukon in the northeast quarter of section 22, township 98 north, range 5 west, well-drillers were hampered by the rapid dulling of drills while passing through the St. Peter. Examination of the fragments brought up in the slush bucket showed that they came from a very hard, quartzitic sandstone.

No fossils have been found in the St. Peter of Iowa, although some have been found in Minnesota and Wisconsin. The porous and sandy character of the rock, and the conditions which must have prevailed during sandstone deposition seem sufficient to account for the absence of an extensive fauna.

#### THE PLATTEVILLE FORMATION.

The Platteville formation, within the present meaning of the term, embraces the lower part of the Galena-Trenton formation of the earlier reports of the Iowa Survey and follows the usage proposed by Bain.<sup>3</sup> That is, the Platteville is understood as including all the rocks which lie between the top of the St. Peter sandstone and the top of the Decorah shale.

The Platteville has been subdivided on lithologic grounds into the following divisions:

- |                                |                          |
|--------------------------------|--------------------------|
| 3. Decorah shales .....        | 25-30 feet (Near Waukon) |
| 2. Platteville limestone ..... | 50 feet                  |
| 1. Basal shale .....           | 3-5 feet                 |

*The Basal Shale.*—The Basal shale member of the Platteville is present very generally in northeastern Iowa and appears to be developed typically in the region under consideration. It is a rather thin band lying immediately upon the iron band which caps the St. Peter formation. The shale is arenaceous, fissile, and weathers easily to form a dark and sticky mud. Fossils are rare in this member and but two recognizable forms were collected, both of these being species of *Lingula*. In addition the shale is found to contain many nodules of worn and comminuted shells, apparently of linguloid character.

The following section illustrates the general character of the shale:

<sup>3</sup>Bull. U. S. Geol. Survey, No. 246, 1905, p. 19.



## SECTION IN "SAND CUT," SOUTH OF IRON HILL.

	FEET.	INS.
7. Dolomite, thin-bedded, buff, arenaceous.....	2	
6. Shale, gray-green, fissile .....	3	4
5. Sandstone, soft, friable, ferruginous .....		2
4. Shale, gray-green, arenaceous, fissile.....		3
3. Sandstone, hard, brown, ferruginous .....		1
2. Sandstone, broken, calcareous, some iron.....	2	
1. Sandstone, massive, soft, friable.....	8+	

Numbers 1, 2 and 3 belong to the St. Peter sandstone; numbers 4, 5 and 6 to the basal shale; number 7 is lower Platteville limestone.

*The Platteville Limestone.*—Immediately above the Basal shale is a succession of limestone beds which constitute the Platteville limestone. As they occur in the Waukon district these calcareous beds reach a thickness of fifty to sixty feet, and may be divided on lithologic grounds into the following beds:

3. Upper Thin Beds.
2. Blue Beds.
1. Lower Buff Beds.

The Lower Buff Beds are made up of a relatively unfossiliferous, buff-colored dolomite. The stone is compact, hard; the beds are two to three feet in thickness and cleave readily into slabs. The stone is light buff in color when fresh, but weathers to a somewhat darker hue, though without important crumbling or scaling. The fracture is irregular and the jointing is much less perfect than in the upper beds.

Lying conformably on the Buff Beds and separated from them by a few inches of marly limestone, are the Blue Beds. The rock of which they are composed is a thin-bedded, hard, compact, somewhat broken or nodular, undolomitized limestone, of a light gray color on fresh surfaces, but weathering to a distinct light blue. Thin marly partings appear between layers. The limestone is exceedingly fossiliferous, being made up almost entirely of the shells of brachiopods.

The Upper Thin-bedded member is made up of rather heavy lower layers, sometimes a foot or more in thickness, but with the thickness gradually diminishing toward the top of the member. The general average is but a few inches. The rock is but slightly dolomitized, is gray-buff in color, much broken, and has shaly

partings. The jointing is in two directions at approximately right angles and usually is noticeable in the outcrops. Fossils are very abundant, and on account of the ease with which the rock weathers it is not difficult to obtain good specimens.

*The Decorah Shale.*—In the Waukon district the Decorah shale maintains a thickness greater than at any point to the east, ranging from fifteen to twenty-eight feet in thickness. It is a light gray-green, calcareous, soft, fissile shale, with interbedded limestone layers and with frequent bands of calcareous nodules and lenses of shaly limestone. The limestone is usually rather impure but appears never to be dolomitic.

Immediately below the Galena the calcareous material usually predominates and often forms a massive phase, with layers six to eight inches in thickness.

The calcareous layers are highly fossiliferous, while the shaly portions are somewhat less so. The following section is characteristic of the shale as it occurs in the vicinity of Waukon:

SECTION OF DECORAH SHALE THREE AND ONE-HALF MILES NORTH OF WAUKON.

	FEET. INS.	
10. Shale, light green, nodular, fossiliferous, calcareous .....		6
9. Limestone, hard, nodular, impure .....	2	
8. Shale, impure, fissile, green, soft, fossiliferous. ....	1	6
7. Limestone, nodular, impure, broken; with many fossils. One 2 foot <i>Orthoceras</i> .....	1	8
6. Shale, thin-bedded, fissile, light green.....	1	
5. Concealed .....	4	6
4. Limestone, compact, impure, nodular .....	1	
3. Shale, thin-bedded, fossiliferous, gray-green, fissile .....	1	
2. Shale, impure, nodular, calcareous; and interbedded limestone .....	10	
1. Concealed .....	12	

*Fossils of the Platteville Formation.*—The Platteville undoubtedly is the most highly fossiliferous formation of the Ordovician system, and the gradual increase in the numbers and varieties seems to have culminated in the upper part. In many species there is also an increase in size in the upper part. The following species were collected\* from the Platteville limestone, chiefly in the neighborhood of McGregor, Iowa:

\*Identified by Professor A. O. Thomas.

*Streptelasma corniculum*.  
 Crinoid stems.  
*Monticulipora* (several sp.).  
*Orthis subaequata*.  
*Orthis tricenaria*.  
*Orthis testudinaria*.  
*Rafinesquina alternata*.  
*Strophomena minnesotensis*.  
*Strophomena rugosa*.  
*Strophomena* sp.  
*Leptaena rhomboidalis*.  
*Leptaena unicastata*.  
*Rhynchotrema dentata*.  
*Plectambonites sericea*.  
*Ambonychia radiata*.  
*Avicula* sp.  
*Liospira vitruvia*.  
*Trochonema umbilicatum*.  
*Trochonema* sp.  
*Murchisonia gracilis*.  
*Bellerophon* sp. One with indistinct keel, one with a distinct ridge,  
 and a third with a spine.  
*Hyalithes* sp.  
*Orthoceras* sp.  
*Oncoceras pandion*.  
*Cyrtoceras* sp.  
*Ceraurus pleurexanthemus*.  
*Isotelus iowensis* (?).  
*Isotelus gigas*.  
*Calymene* sp.  
*Bumastus* sp.  
*Ascidaspis* sp.  
*Beyrichia* sp.

As was noted above, the number of species and individuals shows a gradual increase toward the upper part of the Platteville formation. This tendency culminates in the uppermost member, the Decorah shales. Most of the fossils are contained in the calcareous nodules which make up a considerable part of the rock, and from these nodules they weather readily, so that excellent specimens may be secured. The following forms were collected in the Decorah shales of Makee and Ludlow townships:

*Streptelasma corniculum*.  
 Crinoid stems.  
 Massive bryozoa (2 sp.).  
*Monticulipora pulchella*.  
*Rhinidictya* sp.  
 Branching bryozoa (2 sp.).



*Prasopora simulatrix*.  
*Lingula iowensis*.  
*Crania* sp.  
*Orthis tricenaria*.  
*Orthis* (*Platystrophia*) *lynx*.  
*Orthis* (*Platystrophia*) *lynx* var. *acutilirata*.  
*Orthis* (*Dalmanella*) *testudinaria*.  
*Orthis* (*Dalmanella*) *subaequata*.  
*Orthis* (*Dinorthis*) *pectinella*.  
*Orthis* (*Dinorthis*) *subquadrata*.  
*Orthis* (*Hebertella*) *insculpta*.  
*Orthis* (*Hebertella*) *bellirugosa*.  
*Orthis* sp.  
*Rhynchotrema capax*.  
*Rhynchotrema inequivalvis*.  
*Rhynchotrema perlamellosa*.  
*Rhynchotrema anticostiensis*.  
*Plectambonites sericea*.  
*Strophomena filitexta*.  
*Strophomena nutans*.  
*Strophomena* sp.  
*Strophomena planumbona*.  
*Rafinesquina alternata*.  
*Rafinesquina minnesotensis*.  
*Leptaena rhomboidalis*.  
*Fusispira nobilis*.  
*Fusispira intermedia*.  
*Fusispira* sp.  
*Liospira vitruvia*.  
*Bellerophon* sp.  
*Ceraurus pleurexanthemus*.

Of all the above species *Prasopora simulatrix* is the most common, and within the Waukon area at least, serves as a convenient indicator of the horizon. The most abundant brachiopods are *Orthis testudinaria*, *Plectambonites sericea* and *Platystrophia lynx*.

#### THE GALENA FORMATION.

The Galena formation, as the term is used here, includes everything between the top of the Decorah shales and the bottom of the Maquoketa shale. In many of the older reports of the Iowa Geological Survey, notably the Allamakee county report, the Mid-Ordovician was considered to be represented in Iowa only by a single great formation, the Galena-Trenton. Of this the upper phase, or Galena, was dolomitized, while the lower phase was pure limestone. More recently, however, the work of Bain<sup>5</sup>

<sup>5</sup>Geology of Dubuque County: Iowa Geol. Survey, X, pp. 402-412.

in Dubuque county and of Calvin<sup>6</sup> in Winneshiek county, has shown that the most satisfactory division is made at the shale horizons, as stated above.

The Galena covers the hills in the southern and western parts of the area. Waukon is located on a plain which is underlain by the Galena and a long tongue of the rock extends northeastward through Iron Hill. As there are no overlying rocks, with the exception of unconsolidated material, the formation does not reach its normal thickness, but its maximum here is less than 100 feet. Where the overlying Maquoketa formation is present, as in the Dubuque region, the Galena reaches a rather uniform thickness of 240 feet.

Good outcrops are rare near Waukon, owing chiefly to the slight thickness of rock remaining. The hillside and quarry north of the pumping station at Waukon furnish a section of the lower, non-dolomitic phase which also is highly fossiliferous. A fair exposure of the non-dolomitic lower beds is seen also in an old quarry two miles south of Waukon.

The plain underlain by the Galena is characterized by the presence of many sinkholes. Near the crossroad in the center of section 9, township 97 north, range 5 west, the sinkholes are especially well developed. By the caving in of a number of them a stream bed several hundred yards in length has been developed, with several apparent natural bridges remaining to indicate the origin.

*Lithologic Character.*—In general the Galena is a heavy-bedded, crystalline, vesicular, buff-colored dolomite. In the Waukon region, however, dolomitization has not taken place and the rock is a limestone. The thickness of the beds varies according to their positions within the formation, the thick beds being in the middle. On a strictly lithologic basis the Galena is divisible into five members:

	FEET.
5. Upper Thin Beds .....	30
4. Upper Massive Non-cherty Beds.....	60
3. Lower Massive Cherty Beds .....	90
2. Lower Massive Non-cherty Beds .....	50
1. Lower Thin Beds .....	0-10

<sup>6</sup>Geology of Winneshiek County: Iowa Geol. Survey, XVI, pp. 80-82.

The two upper members, and most of the third, have been removed by erosion.

The Lower Thin Beds lie conformably on the Decorah shale and frequently grade into that member. For example, it is not possible to draw a sharp line of demarcation between the two members in the exposure just north of the Waukon pumping station as the change takes place through many feet of transition beds. Throughout most of the Waukon district this lowermost member of the Galena is undolomitized.

The Lower Massive Non-cherty member is a more or less dolomitic, crystalline, thick-bedded, buff-colored limestone. It usually contains many fossils, as is the case in the water-works section at Waukon. Here may be seen a number of fossils that have ranged upward from the Platteville.

*Fossils of the Galena Formation.*—Fossils are not common in the Galena of this region, except in the undolomitized lower portion. The most common form present outside of the Lower Thin Beds is *Receptaculites oweni*, which is found to lie in very definite zones, one of which is located forty feet from the base and the other seventy feet from the top of the formation. These zones are definite over wide areas and are used commonly as horizon markers in mapping. About midway between these two zones *Ischadites iowensis* is present, in places in large numbers, but it is much less persistent than *Receptaculites*.

The "Gastropod Zone" of the Dubuque<sup>7</sup> and Winneshiek<sup>8</sup> county reports lies about ten feet below the upper *Receptaculites* zone, or eighty feet below the bottom of the Maquoketa shale. In Winneshiek county<sup>9</sup> this zone has been found to contain *Maclurea bigsbyi*, *Hormotoma major*, and *Trochonema umbilicatum*. In Allamakee county, according to Calvin<sup>10</sup>, the zone contains not only these forms but also *Maclurina cuneata*, *Murchisonia bellicincta*, *Fusispira elongata* and *Fusispira inflata*.

Near Bluffton, in Winneshiek county, according to Calvin (op. cit. <sup>11</sup>), there is a narrow zone about seventy feet above the base of the Galena which is particularly rich in fossils of *Plectambonites sericea*. This form, as well as *Rafinesquina*

<sup>7</sup>Iowa Geol. Survey, X, 409.

<sup>8</sup>Iowa Geol. Survey, XVI, 90-95.

<sup>9</sup>Iowa Geol. Survey, XVI, p. 90.

<sup>10</sup>Iowa Geol. Survey, X, p. 409.



*alternata* and a number of other Ordovician species continues to range up into the Maquoketa, although *Plectambonites* is not known to be abundant in the Galena, except locally. Calvin says<sup>11</sup>, "Of the two persistent brachiopods mentioned (*P. sericea* and *R. alternata*) the evidence at hand would indicate that they were not uniformly distributed at any particular time over the old sea bottom, but seem to have been grouped more or less in local colonies."

From the Lower Thin Beds near Waukon the following forms were collected.

*Streptelasma corniculum*.  
Crinoid stems.  
Bryozoa (2 sp.).  
*Orthis* (*Dalmanella*) *testudinaria*.  
*Orthis* (*Platystrophia*) *lynx*.  
*Lingula iowensis*.  
*Strophomena* sp.  
*Hormotoma gracilis*.  
*Illaenus* sp.

#### Structural Geology.

While the indurated rocks of northeastern Iowa are considered in general to be practically horizontal, or to slope to the southwest with a gentle monoclinal dip, there are important exceptions in many localities. McGee<sup>12</sup> noted the presence of a number of local disturbances and mapped them approximately. Calvin, in the reports on Allamakee and Dubuque counties, and Leonard, in the report on Clayton county, mention the presence of many abrupt pitches in the strata and note some minor folding.

Allamakee county is traversed in a northwest-southeast direction by the rather conspicuous fold that McGee has called the Sny Magill anticline. As was pointed out by Calvin, the flanks of this fold have rather variable dips and bear many minor folds.

Such a lateral fold is found to extend into Makee township from the north, occurring as a well defined anticline whose crest dips toward the southwest. The crest of this fold passes through Iron Hill (figure 4).

<sup>11</sup>Iowa Geol. Survey. XVI. p. 94.

<sup>12</sup>Pleistocene History of Northeastern Iowa: 11th Ann. Rept. U. S. Geol. Survey, pt. 1, pp. 338-347.

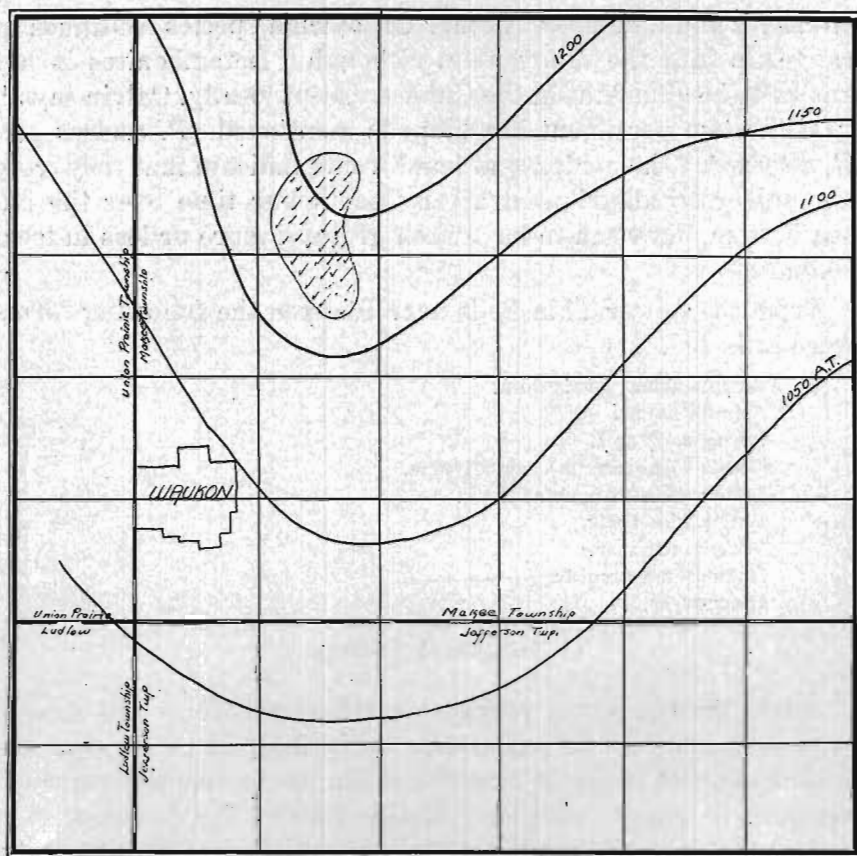


FIG. 4—Contour map of top of St. Peter sandstone, Makee Twp. Ore body shown by checks.

#### Physiographic Geology.

*General Statement.*—One of the most striking features of the topography of northeastern Iowa, as well as of the entire Driftless Area, is the singularly even skyline. This skyline maintains its symmetry throughout a wide extent of territory, being broken only by the gaps formed by deep stream valleys and by the presence of a few mounds that rise to a somewhat higher level. If the valleys which dissect the region could be filled to the level of the tops of the ridges the resulting surface would form a plain extending over much of the Driftless Area. Further filling to the level of the tops of the mounds, which include Sherrill and Sinsinawa mounds, would result in the production of a higher plain.

It would seem, therefore, that there are two very definite and well developed plains, the lower of which is the more widespread, and the more marked in the neighborhood of the streams. Farther back from the rivers the higher plain becomes well developed, and in many places, as in Allamakee and Clayton counties, both plains may be seen.

The upper of these two plains was studied by Calvin<sup>13</sup> in Allamakee county and by him believed to be a peneplain of Cretaceous age. Leonard<sup>14</sup> speaks of the presence of an old peneplain in Clayton county but ventures no opinion as to its age. Grant and Burchard<sup>15</sup> have described a peneplain in the Lancaster-Mineral Point area, whose lowest point is at 900 feet above sea level at Asbury, near Dubuque. They consider it to be of Tertiary age. They also note the presence of a higher plain, of which Sherrill and Sinsinawa mounds are remnants, and suggest that it may be a structural plain developed on the Niagaran. This upper plain is probably to be correlated with "Peneplain No. 1" described by Hershey<sup>16</sup> and by him considered to be a true peneplain of Cretaceous age. Bain<sup>17</sup> mentions the peneplain and agrees with Hershey regarding the explanation. Hershey<sup>18</sup> also recognizes a lower peneplain on which Sherrill, Sinsinawa and the other mounds form monadnocks, but to this lower plain he assigns no definite age.

Trowbridge<sup>19</sup> has described two plains in Jo Daviess county, Ill., the upper, or Niagara, being equivalent probably to the Allamakee Peneplain of Calvin. The lower, or Galena plain, is to be correlated with Hershey's "Peneplain No. 2" and with the Lancaster Peneplain described by Grant and Burchard. The same writer<sup>20</sup> correlates the higher of the Northeastern Iowa plains with the high plain at Baraboo, Wisconsin, described by Salisbury,<sup>21</sup> and the lower one with the Galena Peneplain in Jo Daviess county, Illinois. The latter is held to be early Pleistocene in age.

<sup>13</sup>Iowa Geol. Survey, IV, 1894, p. 43.

<sup>14</sup>Iowa Geol. Survey, XVI, p. 229.

<sup>15</sup>U. S. Geol. Survey, Lancaster-Mineral Point Folio, 1907, p. 2.

<sup>16</sup>American Geologist, XVIII, 1896, pp. 75-78.

<sup>17</sup>Bull. U. S. Geol. Survey No. 234, 1907, p. 15; Bull. Wis. Geol. Survey No. XIX, 1907, p. 15.

<sup>18</sup>Amer. Geologist, XVIII, 1896, pp. 78-80.

<sup>19</sup>Jour. Geology, XXI, 1913, pp. 731-742.

<sup>20</sup>Bull. Geol. Soc. America, XXVI, 1915, p. 76.

<sup>21</sup>Jour. Geology, III, 1895, pp. 655-667.



The work of the various authors is correlated in the accompanying table:

CORRELATION OF THE PENEPLAINS.

AUTHOR	UPPER PLAIN	LOWER PLAIN	REFERENCE
Bain		Lancaster Peneplain (Tertiary)	Wis. Geol. Surv. Bull. XIX, p. 15 U. S. Geol. Surv. Bull. 294, p. 15 1907
Calvin	Allamakee Peneplain (Cretaceous)		Ia. Geol. Surv. IV, p. 43 1894
Grant and Burchard	Noted, but no name given (Cretaceous)	Lancaster Peneplain (Tertiary)	Lancaster—Mineral Point Folio, p. 2 1907
Grant		Noted, but no name given (probably Tertiary)	Wis. Geol. Surv. Bull. XIV, p. 11 1906
Hershey	Peneplain No. 1 (Cretaceous)	Peneplain No. 2 (Tertiary)	Am. Geologist XVIII, pp. 78-80 1896
Hershey	Trenton Plain Cretaceous Plain	Lower Magnesian Plain Tertiary Plain	Am. Geologist XX, pp. 246-268 1897
Kümmel		Noted, but no name given	Science, N. S., Vol. I, pp. 714-716 1895
Leonard		Noted, but no name given (Late Cretaceous or Tertiary)	Ia. Geol. Surv. XVI, p. 229 1906

CORRELATION OF THE PENEPLAINS—CONTINUED.

AUTHOR	UPPER PLAIN	LOWER PLAIN	REFERENCE
Norton	Noted, but no name given	Noted, but no name given	U. S. G. S. Water Supply Paper 293, p. 239 1912
Salisbury	No name applied (Pliocene)		Jour. Geol. III, pp. 655-667 1895
Salisbury and Atwood	The 1400 foot plain (Pliocene)		Wis. Geol. & Nat. Hist. Surv. Bull. 5 pp. 62-64. 1900
Trowbridge	Niagara Plain (Structural)	Galena Plain (Tertiary)	Jour. Geol. XXI, pp. 731-742 1913
Trowbridge	The higher plain	The lower plain (Late Tertiary or early Pleistocene)	Ia. Acad. Sci. Proc. XXI, pp. 205-209 1914
Trowbridge	Upper Plain (Late Tertiary)	Lower Plain (Early Pleistocene)	Bull. Geol. Soc. Am. XXVI, p. 76 1915

THE PENEPLAINS

*The Upper Plain.*—The upper of the two plains is well developed at Waukon, where it is at an altitude of about 1,300 feet above sea level. Iron Hill rises to a height of forty to fifty feet above the plain. Roads follow the plain wherever possible and the chief highways of the region are the "Ridge Roads," which lie on the divides at the level of the Upper Plain.

The Upper Plain was studied with some care by the members of the field class from the Universities of Iowa and Chicago during the summer of 1914. It was found to be well developed at the following places:

#### UPPER PLAIN.

Lansing .....	altitude 1200.....	lies on Platteville.
Church .....	altitude 1280.....	lies on Galena.
Waukon .....	altitude 1300.....	lies on Galena.
Eldergrove .....	altitude 1180.....	lies on Galena.
Turkey River .....	altitude 1200.....	lies on Niagaran.
Osterdock .....	altitude 1180.....	lies on Niagaran.
Sherrill .....	altitude 1200.....	lies on Niagaran.

The above table seems to indicate that the plain is not structural, for it cuts across beds in an unmistakable manner. This would indicate that it is an erosional plain. The possibility that it is a plain of marine erosion may be immediately discarded since there are no evidences of cliffs, bars or shore lines in the vicinity. It must be, therefore, a peneplain.

The presence of the high ridge near Waukon, which seems to rise above the general level of the plain may be explained in two ways. The first, and most obvious explanation, is that it is the result of warping during the uplift of the region. It may be, however, the remnant of a low divide which existed on the old peneplain, for it must not be assumed that the peneplained surface was perfectly flat. The fact that Iron Hill, which is the highest point on the ridge, lies on the crest of a local anticline, seems to favor the first view, but the fact that the anticline is beveled by the plain renders the latter explanation more probable.

At many places on the Upper Plain, and especially on Iron Hill and in the upper part of the iron ore, there are to be found many well-rounded and water worn quartz pebbles, which bear evidence of long continued rolling in stream beds. Their size is



fairly uniform, from one-fourth inch to one-half inch in diameter, and there is a liberal admixture of smaller quartz pebbles and pure quartz sand. Most of the pebbles are white or yellow in color. Many are opaque, some are clear and many are translucent.

Many hundred of these pebbles were broken and examined by the writer, both in the ore pits and elsewhere, but not a single piece of igneous material was found among them. Apparently all the pebbles are quartzose and must have been deposited during a time of complete weathering. Not only are the pebbles smoothed and practically all angularity removed, but many of them are polished, a fact which bears witness to their hardness.

*The Lower Plain.*—The appearance and general character of the Lower Plain is very similar to that of the Upper. The divides of which it is composed are of comparatively uniform height, and the tops are gently rolling, while the stream valleys between them are steep-sided and gorgelike. Proximity to the main drainage lines has resulted in a greater degree of dissection than has occurred in the case of the more remote Upper Plain.

Study of the Lower Plain in an area considerably wider than that properly considered in this report shows that it also bevels the edges of the beds in unmistakable manner. This is illustrated in the following table:

#### LOWER PLAIN.

New Albin .....	altitude 1120.....	lies on	Prairie du Chien.
Lansing .....	altitude 1100.....	lies on	Prairie du Chien.
Waukon .....	altitude 1100.....	lies on	Galena.
McGregor .....	altitude 1040.....	lies on	Platteville.
Clayton .....	altitude 1065.....	lies on	Galena.
Turkey River .....	altitude 920.....	lies on	Maquoketa.
Osterdock .....	altitude 940.....	lies on	Maquoketa.
Asbury .....	altitude 900.....	lies on	Maquoketa.

Although careful search was made no igneous material was found within a considerable distance of the top of Iron Hill. Abundant glacial or fluvio-glacial material was found, however, considerably below the top, and it is common at the level of the Lower Plain. This drift is very persistent in all directions from Iron Hill, and occurs either at or below the surface of the lower

plain. The deposits lie usually on the rough and weathered surface of bedrock and in most instances are found beneath an overburden of several feet of fine loesslike material.

The close association of the old glacial drift with this plain is very marked. The fact that the drift is found in the valleys below the lower plain, as well as on its surface, seems to indicate, as pointed out by Trowbridge<sup>22</sup>, that the plain had been not only developed but also partly dissected before the first invasion of the ice. In no other way can the presence of true drift in the valleys be explained.

The drift material is very generally characterized by the advanced state of decay of the igneous pebbles, as the basalts in many cases are so far advanced in decomposition that they can be crushed between the fingers. An average of many pebble counts shows the igneous pebbles to be about 90 per cent decayed. This fact, together with the high topographic position of the material, seems to point to a very early origin for these drift deposits. The Illinoian and Wisconsin ice sheets approach the area at no point and the material is clearly too highly weathered for the Iowan. It must therefore be either Kansan or pre-Kansan. The question as to whether the deposits are of glacial or fluvio-glacial origin cannot be settled from the exposures within this small region, and in any event is not pertinent to this discussion.

*Ages of the Peneplains.*—It is obvious that the Upper Plain is post-Niagaran in age, since it lies partly on the eroded surface of that formation. Drift is present both upon and below the Lower Plain so it seems safe to consider that the Upper Plain had been baseleveled, uplifted, and partly dissected before the advent of the ice which gave rise to the glacial deposits on the lower plain. Had the ice sheet advanced over the region before the uplift a much greater amount of drift would have been deposited on the Upper Plain, and none would be found on the Lower Plain or beneath it.

Assuming that the Upper Plain had been partly dissected and the Lower Plain formed before the advent of the ice sheet, it must be concluded that most of the drift would be deposited in the low places; that is, on the Lower Plain.

<sup>22</sup>Trowbridge, A. C., Bull. Geol. Soc. America, XXVI, 1915, p. 76.

Study of the well rounded quartz pebbles which are found so abundantly in the ore and to a lesser extent on other portions of the Upper Plain seems to shed some light on the question of its age. Gravels apparently identical with these have been found in the Baraboo region of Wisconsin, and were there studied by Salisbury,<sup>23</sup> who assigned to them a Tertiary age. He remarked on the similarity between the Baraboo gravels and those which had been shown to belong to the Lafayette formation and suggested that they should be correlated. He held that the high topographic position in which they occur at Baraboo (along the crest of a high bluff at an elevation of 1,560 to 1,580 feet above sea level), taken in conjunction with the lithologic character, served to fix them as a northward extension of the high-level gravels which occur at many places in the Mississippi Valley south of the limit of Pleistocene ice. Gravels apparently to be correlated with those on the crest of Crowley's Ridge, in Arkansas, were traced through Pike, Adams and Calhoun counties in Illinois, and also in Crawford county, Wisconsin. His conclusions (loc. cit.) are as follows:

(1) that the pre-Pleistocene gravel exists in the form of widely separated erosion remnants south of the drift covered country;

(2) that isolated remnants of it are known to exist at many points beneath the drift, as many as 125 miles north of the southern limit of glaciation (Adams and Hancock counties);

(3) that the glacial drift here and there at many points for 90 miles north (Rock Island County) contains gravel which might well have come from remnants of the northern extension of the same formation;

(4) that remnants of similar gravel occur in the driftless area where there has been no chance of destruction or burial by the ice; and

(5) that the gravel in all these situations has the same topographical habit, all point to the conclusion that they are parts of a once widespread and continuous gravel formation.

Chamberlin and Salisbury<sup>24</sup> have more recently expressed the same view and have discussed the gravels under the chapter on the Pliocene:

<sup>23</sup>Jour. Geology, III, 1895, p. 662.

<sup>24</sup>Chamberlin and Salisbury, Geology, Vol. III, 1907, pp. 300-301.



.....they are the older part of the complex series of river deposits, shifted repeatedly to lower levels, and nearer the sea, until the main part of the series is near the coast, while only meager remnants remain in the sites of original deposition. The farther these remnants are from the low coast-plain the smaller they are and the greater their altitude, and if the above interpretation be correct, the greater their age.

Other writers, notably Calvin<sup>25</sup> and Hershey<sup>26</sup> have considered this Upper Plain to be Cretaceous, correlating the High Level Gravels found thereon with certain supposedly Cretaceous gravels in southeastern Minnesota described by Winchell<sup>27</sup>. The age of the Minnesota gravels, however, seems not to have been definitely proved, hence the former view seems preferable.

The entire discussion may then be summed up as follows:

(a) The Upper Plain is certainly post-Niagaran, since it rests partly on the eroded surface of that formation.

(b) It is pre-Pleistocene, apparently, for little igneous material is found on its surface, although it is abundant on the lower plain.

(c) It may be assumed with considerable confidence to be of Pliocene age since it bears gravels similar to those which belong to the Pliocene Lafayette formation which extends from the coastal plain near the Gulf of Mexico, northward through Arkansas, Missouri, Illinois and Wisconsin, occurring always on high ridges, as in the present instance.

(d) The Lower Plain must be younger than the Upper Plain since it lies below it.

(e) This Lower Plain certainly had been formed before the earliest ice invasion, since glacial material is found on it, and below it.

(f) The Lower Plain seems to have been developed in early Pleistocene time, before the first ice invasion, since the presence of drift deposits in the valleys beneath the plain indicates that it had been partly dissected before these deposits were formed.

<sup>25</sup>Iowa Geol. Survey, IV, 1894, p. 43.

<sup>26</sup>Amer. Geologist, XVIII, 1896, pp. 78-80. Amer. Geologist, XX, 1897, 246-268.

<sup>27</sup>Final Rept. Minnesota Geol. & Nat. Hist. Survey, Vol. I. pp. 305-309. 355-356.

**Economic Geology.****THE IRON ORE.****GENERAL CHARACTER OF THE ORE.**

The ore deposits here described form a cap on the top of the eminence known as Iron Hill. The deposit is unsymmetrical with respect to the hill, as it extends much farther down the southern than the northern slope. The greatest thickness of ore occurs on the northern side of the hillcrest, and the deposit becomes thinner in each direction from this place.

The ore body is directly in contact with the bedrock and lies unconformably on the Galena and Platteville formations and probably slumps to some extent onto the St. Peter. At the highest point of bedrock beneath the ore the deposit is underlain by forty to fifty feet of thin-bedded, undolomitized lower Galena. The fact of the presence of the Galena is shown by the fossils in



FIG. 5—Large limestone boulders in the iron ore. South end of new pit.

the limestone fragments from those pits which were continued to bedrock. The estimate of the thickness was obtained by measurement from the Platteville-St. Peter contact on the hill just above the concentrating plant.

Overlying the ore is a thickness of five feet or less of a fine, grayish, loesslike material. Probably it is not true loess, how-

ever, for it exhibits a jointed or starchy fracture on drying. The contact of the overburden with the ore is unconformable (fig. 6) and many somewhat rounded fragments of ore are found imbedded in the overburden several inches above the contact.



FIG. 6.—Unconformable contact between ore-body and overburden.  
East wall of south pit.

*Physical Character of the Ore.*—The Waukon ore is, in the main, a brown, coarsely cellular limonite. The cavities which produce the cellular character are very irregular in size and shape, and range from a fraction of an inch to a foot or more in greatest dimension. The usual size, however, is but a few inches.

These cavities contain, in a considerable number of cases, masses of clay, usually in the form of small concretions or oölites. Mingled with the clay there are in places sand and fragments of chert and fossils of Ordovician age. These fossils will be considered more fully later.

The ore body is much jointed and fractured and this fact has resulted in the development of a boulder character, in which the ore breaks up into large or small masses of very irregular form (figure 10). Many of these boulders weigh hundreds of pounds or even several tons, and are so resistant to further division that it is necessary to resort to blasting to reduce the larger ones to sizes that can be handled readily. The walls of the crevices are usually somewhat weathered and the crevices



are filled with clay, which varies in color from a light cream to a deep red. The different colors in many cases form alternating bands in the crevices.

Large numbers of chert nodules are found throughout the deposit, usually surrounded by a greater or less thickness of dense limonite which in some cases grades into and partly replaces the outer portion of the chert. The pieces of chert are broken and angular, but never give any indication of having been rolled or stream worn.

Many of the chert nodules are found to have been fractured and subsequently cemented by limonite. Others exhibit a core of fresh chert surrounded by roughly concentric layers of decayed chert, ferruginous chert, and limonite. (Plate I.) In the latter cases it appears that weathering must have taken place in the chert before it was imbedded in the limonite.

In the new pit of the company, as well as in many of the nu-

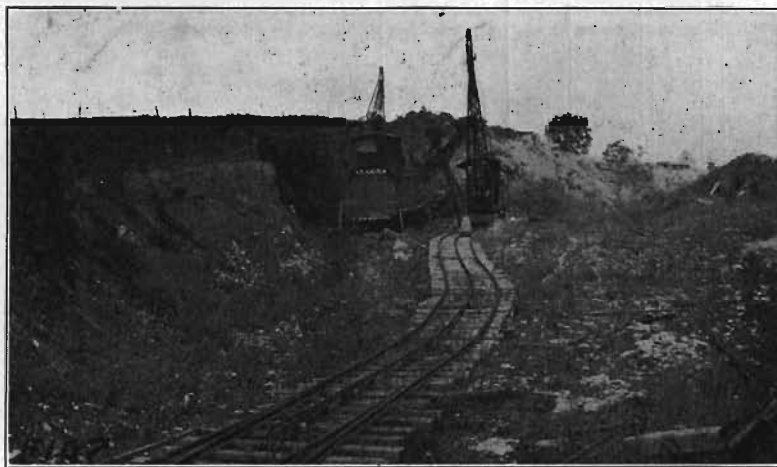


FIG. 7.—View of new pit near south end. Sept. 1, 1914.

merous test pits scattered over the property, there are exposed limestone boulders, or "lime horses," some of which are of large size. The largest one seen in the pit was about ten feet in length by five feet in height, and extended for an unknown distance back from the pit wall (see figure 5). Many of these masses of rock have been removed entire and hauled outside of

the pit, where they may be examined readily. Some are well rounded (figure 8) and exhibit no angular surfaces, while others are more or less angular. In those which have not been long



FIG. 8—Large limestone boulder from new pit, showing rounded form and pitted surface.

subject to weathering outside of the ore body the surface presents a deeply pitted appearance resembling that produced by the subaerial weathering of a dolomite, or in like measure the



FIG. 9—View showing boulder character of the ore.

pitting produced by the solvent action of underground water. At no place in the ore body, so far as known, is there any gradation from the ore into the limestone.

The bowlders, wherever they can be observed in position, lie with their bedding planes in close approximation to the horizontal. One boulder in the new pit has a departure from horizontality of 8°, another of 5°, and a third of less than 1°. According to Mr. Erwin the bowlders met with in sinking the test pits in various parts of the deposit show the same approximate horizontality.

Most of the limestone bowlders are fossiliferous and many recognizable forms were obtained from them. From a large, flat boulder in the bottom of the pit and near the south end (106 feet above top of St. Peter) the following forms were collected:

*Receptaculites oweni.*  
*Rafinesquina alternata.*  
*Streptelasma* sp.  
*Liospira vitruvia.*  
*Murchisonia gracilis.*  
*Bellerophon* sp.  
*Ischadites* sp.  
*Lingula iowensis.*  
*Platystrophia lynx.*  
*Dalmanella testudinaria.*  
*Leptaena unicastata.*  
*Plectambonites sericea.*

This association of life, especially the presence of the index fossil *Receptaculites oweni*, indicates that the rock is of Galena age, while the brachiopods are found in the same association in the undolomitized beds of the lower Galena throughout the vicinity.

A second boulder not far from the first one furnished the following list:

*Receptaculites oweni.*  
*Rhynchotrema capax.*  
*Dalmanella testudinaria.*  
*Streptelasma* sp.

This one also appears to belong to the lower Galena.



From a large, horizontally bedded block of limestone in the west wall of the pit the fossils obtained were:

Plectambonites sericea.  
Streptelasma sp.  
Dinorthis subquadrata.  
Murchisonia sp.

This boulder appears also to belong to the lower undolomitized Galena.

On faunal grounds then, the limestone boulders seem to have belonged to the lower part of the Galena formation, which in this vicinity is undolomitized and grades imperceptibly downward into the calcareous upper portion of the Decorah shale. In many localities it is impossible to determine the exact contact between the upper part of one and the lower part of the other.

*Fossils in the Ore.*—In the first published account of the Waukon iron ores Mr. Ellison Orr<sup>28</sup> mentions the fact that he had picked up “. . . . several pieces of ore in which were imbedded well preserved specimens of Trenton fossils.” Later writers make no mention of these fossils, probably because their investigations were confined to the old pit, now abandoned, where fossils are of exceedingly rare occurrence.

If the concretions from many parts of the new pit, as well as concretions taken from various test pits, are broken open, numerous well preserved fossils can be found. Some of these occur imbedded in the sides of the cavities or in the denser ore of the walls, but most of them are only slightly attached to the interior or are found loose with the core of clayey concretions. Where the shells are yet attached to the walls they are, in many cases, found to be coated with a hard, black variety of iron oxide, or even partly replaced by that substance. The coating may be so even over the surface of the shell that identification can be made without removing it.

In the material taken from test pits in the highest part of the deposit, a very highly fossiliferous ore is found (Plate IV, figures 2, 3). In this material the body of the limonite is packed full of small, somewhat comminuted shells. Many complete shells also occur in this material, and both they and the frag-

<sup>28</sup>American Geologist, I, 1888, p. 130.

ments are completely silicified and show no evidence of ferruginous replacement. In the material thrown out from the test pits there are also many loose shells, completely silicified and well preserved, but showing no replacement by iron.

The following forms have been found in the ore:

*Prasopora simulatrix*. Plate III, figure 13.

Several specimens, more or less replaced.

*Streptelasma corniculum*. Plate III, figures 7, 9-12, 14.

Very common and most of them well preserved. Silicified.

Many with apices intact. No indication that they were ever rolled in stream.

Crinoid stems.

Many fragments of stems, most of them with annular ribs.

Some imbedded in limonite. Silicified.

*Plectambonites sericea*. Plate II, figures 1-16, 31.

Represented by many small, perfectly preserved, siliceous specimens, both entire shells and single valves. Maximum size 16 mm. by 9 mm. Fine surface striae very distinct.

No beekite rings. 40 complete specimens.

*Dalmanella testudinaria*. Plate II, figures 17-30.

Many small, well preserved specimens. Many entire and several separate valves. Breadth from 4 mm. to 13 mm. Silicified. Striae perfect. No beekite. 35 complete shells.

*Platystrophia lynx*. Plate III, figures 1-3.

Four well preserved specimens. Silicified and showing few beekite rings. Maximum width 18 mm. Hinge lines somewhat extended and eared.

*Rafinesquina minnesotensis*. Plate III, figure 5.

A single well preserved, silicified specimen. Striae lost in silicification or by weathering. Found on dump from test pits. Width at hinge line, complete, 36 mm. Shows some beekite rings.

*Hebertella bellirugosa*. Plate III, figure 4.

A single specimen, silicified, striae partly removed in silicification. Shows beekite rings.

*Streptelasma profundum*. Plate III, figure 8.

A single medium sized specimen. Silicified but shows very few beekite rings. Well preserved. Part of calyx broken away.

*Rhynchotrema capax* (?). Plate III, figure 6.

Posterior half only. Silicified and striae well preserved. Interior hollow and lined with quartz crystals. Bears heavy imbricating lines, even on umboes, but in other respects agrees well with *R. capax*. Single specimen in dump from test pit No. 291.

The fact should be emphasized, that all the fossils found in the iron ore are silicified, whereas, so far as can be determined,

none of the same forms as they are found in the Platteville and Galena have been so replaced. The silicification is supposed to have taken place during weathering and as one of the processes of weathering<sup>28a</sup>.

*Composition of the Ore.*—The principal ore mineral of the Waukon deposit is the hydrated sesquioxide of iron, or limonite. Associated with this mineral, however, are the lower hydrate turgite, and the anhydrous oxide hematite, although neither occurs in any considerable quantity. Mr. Erwin states that göthite also has been found, but none was seen by the writer. The relation between these minerals may be shown as follows:

NAME	COMPOSITION	PER CENT $\text{Fe}_2\text{O}_3$	PER CENT $\text{H}_2\text{O}$
Limonite.....	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	85.5	14.5
Göthite.....	$2\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$	89.9	10.1
Turgite.....	$2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$	94.7	5.3
Hematite.....	$\text{Fe}_2\text{O}_3$	100	0

The limonite is largely of the massive variety and varies widely in both hardness and color. On fresh surfaces it is dark brown, or even black in color, with an irregular fracture, and has a hardness of about 5 in the Moh scale. On surfaces that have been exposed to weathering the color approaches a light brown and the hardness may fall as low as 1.5. The harder phase has a submetallic luster and shows no definite structure on a polished surface.

A third phase of the limonite is found to line the interiors of some of the cavities. Here the mineral has definite radial structure (Plate IV, figure 1) which results in the production of a botryoidal or renniform internal surface, which is coated with a velvety black film of the same material. This phase resembles göthite in form but may be distinguished from it by opaqueness and streak.

<sup>28a</sup>Bassler, R. S., Proc. U. S. Nat. Mus., Vol. XXXV, 1908, p. 135.



The limonite also forms stalactites and stalagmites in many of the cavities, and these have in many instances united and practically filled the entire space.

Hematite occurs massive in the walls of the cavities and in some cases may be determined readily by its red color and streak. In other cases its presence may be detected only by the fact that analyses of the ore show an iron content much in excess of what would be expected were it composed entirely of limonite, which contains but 59.8 per cent of iron, while hematite carries 70.0 per cent. On the whole it may be said that hematite is a rare mineral in the Waukon deposit.

Turgite is found sparingly in the interiors of some ore nodules, in which it appears as a reddish powder resembling hematite. It is rather rare and has no especial importance.

Manganese seems to be present constantly, as is shown by analyses, but the amount is not large. Mr. Erwin reports that on the east end of the property wad was found in two pits. It occurs there as a layer about eight inches thick at a depth of twenty feet.

The limonite is rather siliceous and carries a large percentage of alumina, which, in the form of clay, is disseminated through the massive ore and also is concentrated in the cavities, in most cases as concretions. Much of the silica is in the form of the chert nodules which are imbedded in the ore, while in certain portions of the deposit there is a large amount of siliceous conglomerate made up of well worn and rounded quartz pebbles cemented by limonite. In such places the ore is not of sufficient richness to repay the expense of working it.

Microscopic examinations of the clay found in the cavities in the ore and of that found in the crevices show that there are many fine, angular pieces of quartz, as well as hematite, limonite, kaolin and other unidentified minerals. The residue remaining after solution of the massive ore in concentrated acid also contains similar angular quartz fragments, as well as a few small fragments of silicified fossils.

Lining the interiors of many cavities and deposited on the surface of the fibrous limonite, there occurs a small amount of the hydrous, amorphous form of silica known as hyalite. It is

found in clear, colorless, botryoidal masses, never of any great thickness or extent. See Plate IV, figure 1.

*Analyses of the Ore.*—The management consider the following analyses to be representative of the raw ore.

- I. From test pit No. 155.
- II. From test pit No. 122.
- III. From test pit No. 34.
- IV. From test pit No. 256.

#### ANALYSES OF WAUKON IRON ORE.

##### ANALYSIS BY MISSOURI IRON COMPANY.

	I	II	III	IV
Fe.....	30.99	31.49	32.32	32.30
P.....	.1011	.099	.17	1.87
Mn.....	.122	1.02	1.06	.88
SiO <sub>2</sub> .....	36.08	42.40	....	35.06
Al <sub>2</sub> O <sub>3</sub> .....	11.26	3.57	7.30	9.33
Loss on ignition..	5.30	7.33	11.36	6.88

##### ANALYSIS OF ORE FROM RICHEST TEST PIT. SAMPLE TAKEN FROM 29 TO 34 FEET FROM SURFACE. ANALYSIS FROM MISSOURI IRON COMPANY.

	PER CENT.
Fe .....	52.41
P .....	.072
Mn .....	.41
SiO <sub>2</sub> .....	3.924
Al <sub>2</sub> O <sub>3</sub> .....	8.44
CaO .....	.56
Loss on ignition .....	7.50

##### ANALYSIS SHOWING LOWEST IRON CONTENT CONSIDERED AS ORE. ANALYSIS BY MISSOURI IRON COMPANY.

	PER CENT.
Fe .....	6.77
P .....	.103
Mn .....	.33
SiO <sub>2</sub> .....	60.25
Al <sub>2</sub> O <sub>3</sub> .....	18.07

## THE ORIGIN OF THE ORE.

*General Features.* The only effort that has been made to explain the origin of the Waukon ore is that by Calvin in his report on the geology of Allamakee County.<sup>20</sup> He pointed out the impossibility of the deposit having been formed by secular decay of the overlying material, and considered it to be a bog deposit.

According to this view a depression first formed somewhat above the present site of the deposit, and into this the iron oxide drained from a wide area. Here it was precipitated through organic action. After the waters of the marsh had been drained the ore hardened, and becoming more resistant than the surrounding rock, it was eroded less rapidly. As a result it now stands out in relief.

This statement of the origin of the ore has been widely copied and has been generally accepted. But certain facts which have come to light recently seem to indicate that the above explanation is inadequate. While in a general way it seems to account for the deposit, it nevertheless fails when applied to many specific features. Since a bog deposit is due to precipitation from solution it could not be expected to contain fossils of older formations, neither should it contain great boulders of limestone. Most bog iron ore is high in phosphorus, while the Waukon ore contains but little of this element. Bog deposits also should show some evidence of bedding planes.

The theory of replacement of the limestone by iron-bearing solutions appears untenable on account of the lack of bedding planes, which should follow those of the original rock. There should be also a gradation from the fresh rock to the ore, with some evidence of siderite, which generally is an intermediate product. Such a gradation is found in no part of the deposit, but the change from ore to limestone is abrupt or through a slight thickness of residual clay.

A second feature which is antagonistic to the replacement theory is the high content of alumina in the ore. Analyses of the bedrock beneath the deposit show only small amounts of  $\text{Al}_2\text{O}_3$ .

<sup>20</sup>Iowa Geol. Survey, IV, 1894, pp. 97-103.



## IRON ORE DEPOSITS NEAR WAUKON

## ANALYSIS OF BEDROCK IN PIT NO. 240.

	PER CENT.
CaO .....	51.72
MgO .....	.35
Al <sub>2</sub> O <sub>3</sub> .....	.45
SiO <sub>2</sub> .....	4.80
Mn .....	.03
P <sub>2</sub> O <sub>5</sub> .....	.056
Fe .....	1.09
Loss on ignition .....	40.95
	<hr/>
	99.446

The amount of alumina here is small and some other means must be found to explain the marked concentration of this material in the ore. Simple replacement of limestone is not sufficient.

The apparently close relation between the ore deposit and the Upper Plain strongly suggests an origin in a bog which may have existed there. This would be much the same as the mode advanced by Calvin and the objections which were stated in connection with that theory would apply here also.

A fourth possible mode of origin is that by secular decay. Such a process might account very well for the presence of the unworn fossils, the pieces of chert, the bowlders, the absence of bedding planes and the large amount of alumina. But it seems to offer no adequate explanation for the richness of the ore nor for its physical character. True residual ores occur as concretions or nodules of limonite imbedded in a matrix of clay.

As a starting point in the discussion of the origin of the ore it seems best to consider the geologic and physiographic conditions which must have existed during the period of its formation. It has been shown (on page 61) that northeastern Iowa must have been a land area since the end of the Niagaran epoch. The process of base-leveling begun at that time continued through the Triassic, Jurassic and Cretaceous periods, and for a considerable part of the Tertiary, an enormous interval of time. Within this period the Appalachian mountains were uplifted, reduced to complete base-level (Kittatinny peneplain), uplifted a second time and again reduced to partial base-level (Shenandoah peneplain). Yet during this entire time, so far as has been determined, northeastern Iowa suffered uninterrupted

subaerial erosion, and by Pliocene time had been reduced to a condition of approximate flatness, traversed by sluggish, meandering streams, which, because of low velocity, could carry only very slight loads of very fine material.

*The Residuum.*—It is probable that during the early part of the old age of the region the process of weathering began to forge ahead of that of transportation and the accumulated residual matter continued not only to grow somewhat deeper but to become more completely weathered.

According to Russell:<sup>30</sup>

Throughout the valley of the Shenandoah and in the region drained by the James, New River, etc., in Virginia, the surface of the country is covered to a depth sometimes exceeding 50 feet with a red clay which has resulted almost entirely from the decay of limestone.

Chamberlin and Salisbury in their report on the Driftless Area<sup>31</sup> state that the amount of residual material varies according to the topographic position, the greatest thicknesses being on the broad ridges and in the valleys. In the Driftless Area of Wisconsin they state that the thickness of the residuum, as averaged from some 1,800 measurements, is 7.08 feet, the maximum being 70 feet.

The Shenandoah Valley, mentioned above, has been developed since the uplift of the Kittatinny Plateau, in Cretaceous time, and hence has developed its residuum in a comparatively short period. The Driftless Area has suffered erosion for a much greater length of time and might be expected to show greater thicknesses of residuum were it not for its proximity to the Mississippi and its height (400-700 feet) above the stream, which has permitted much of the rock debris to be removed.

Yet in spite of the excellent opportunities for the removal of the residuum, the ridges of Allamakee county still show considerable thicknesses of clayey material, as shown by the following well records:<sup>32</sup>

<sup>30</sup>Bull. U. S. Geol. Survey No. 52, p. 24, 1889.

<sup>31</sup>Sixth Ann. Rept. U. S. Geol. Survey, p. 254.

<sup>32</sup>Water-Supply Paper U. S. Geol. Survey No. 293, pp. 251-252.

## IRON ORE DEPOSITS NEAR WAUKON

## THICKNESS OF CLAYEY RESIDUUM ON RIDGES. NEAR WAUKON, IOWA.

LOCALITY	ELEVATION Feet	THICKNESS Feet
County Farm. NE. of Waukon.....	1250	30
NE. $\frac{1}{4}$ , sec. 26, T. 100 N., R. 5 W.....	1040	40
Sec. 2, T. 99 N., R. 4 W.....	1040	75
SW. $\frac{1}{4}$ , sec. 21, T. 96 N., R. 5 W.....	1100	40
SE. $\frac{1}{4}$ , sec. 32, T. 96 N., R. 5 W.....	1120	20
Waukon pumping station.....	1280	40

It seems safe, then, to assume that during the later stages in the development of the upper plain considerable thicknesses of residuum had been formed, which completely mantled the surface, but no doubt reached a maximum depth on the ridges and in the valleys as at present. The amount of this residuum certainly was not less than that now present and probably was much greater.

*Nature of the Residuum.*—According to Merrill,<sup>33</sup> the sub-aerial decay of limestone results in the removal of  $\text{CaCO}_3$  and the concentration of  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$  and  $\text{Fe}_2\text{O}_3$ . The analyses quoted in the following tables are typical of this process.

TRENTON LIMESTONE FROM LEXINGTON, VA., AND RESIDUE LEFT  
BY ITS DECAY. R. B. RIGGS. (BULL. U. S. GEOL.  
SURVEY NO. 52, 1889, P. 24.)

CONSTITUENT	UNALTERED LIMESTONE	RESIDUUM
$\text{SiO}_2$ .....	.44	43.07
$\text{Al}_2\text{O}_3$ .....	.42	25.07
$\text{Fe}_2\text{O}_3$ .....	....	15.16
$\text{CaO}$ .....	54.77	.63
$\text{MgO}$ .....	Tr.	.03
$\text{K}_2\text{O}$ .....	Und.	2.50
$\text{Na}_2\text{O}$ .....	Und.	1.20
$\text{CO}_2$ .....	42.72	.00
$\text{H}_2\text{O}$ .....	1.08	12.98

<sup>33</sup>Rocks, Rock-weathering and Soils, p. 232.



KNOX DOLOMITE AND RESIDUUM LEFT BY ITS DECAY. MORRISVILLE  
 ALA. ANALYSIS BY W. F. HILLEBRAND. (BULL. U. S.  
 GEOL. SURVEY NO. 52, 1889, P. 25.)

CONSTITUENT	UNALTERED LIMESTONE	RESIDUUM
SiO <sub>2</sub> .....	3.24	55.42
Al <sub>2</sub> O <sub>3</sub> (+TiO <sub>2</sub> +P <sub>2</sub> O <sub>5</sub> ).....	.17	22.17
Fe <sub>2</sub> O <sub>3</sub> .....	.17	8.30
FeO.....	.06	Tr.
CaO.....	29.58	.15
MgO.....	20.84	1.45
K <sub>2</sub> O.....	....	2.32
Na <sub>2</sub> O.....	....	.17
CO <sub>2</sub> .....	45.54	....
H <sub>2</sub> O (2.10 at 100°C.).....	.30	9.86

Such residual clays then have resulted from the leaching out of the calcium carbonate from the limestone and its removal in solution, while the less soluble silica, alumina, and iron oxide remain. Other insoluble materials are found in clay, but rarely make up over five to ten per cent of the whole. Much of the alumina and silica occurs in the colloidal condition; some of the iron also may be in the form of colloidal ferric hydroxide. Van Bemmeln<sup>34</sup> has shown that the hydrogels of alumina and ferric hydroxide have a strong absorptive (adsorptive) power for salts of the alkaline earths and alkalies, and this property may explain the rather high content of these usually soluble materials which is often found in the clays.

While the major portion of a residual clay is made up of fine amorphous or colloidal matter, there is to be found a considerable percentage of angular quartz fragments. This feature was discussed by Chamberlin and Salisbury<sup>35</sup> in their description of the residual materials of the Driftless Area. The same characteristics were noted in residual clay from the Niagaran dolomite near Dubuque.

According to Ries,<sup>36</sup> the process by which limestone weathers into clay consists in the dissolving out of the carbonates of lime and magnesia while the clayey impurities are left behind. The change from clay to rock is therefore abrupt, and no gradual transition is noted as in the case of granites. The surface of

<sup>34</sup>Zeitschr. Anorg. Chemie, 23, 1900, pp. 321, 358, 364.

<sup>35</sup>Op. cit., p. 244.

<sup>36</sup>Clays, Occurrence, Properties and Uses, pp. 7, 8.

the rock is commonly pitted and roughened, and may be more or less spongy for a short distance from the surface, but the change from clay to unweathered rock is, nevertheless, a sharp one.

Practically all limestones are much jointed and show very distinct bedding planes. The circulating waters flow through these ready prepared channels and attack the rock from all sides of the opening (see figure 10). As a result of this process it is not uncommon to find large, rounded boulders resting undisturbed well up in the layer of residuum. Alternating bands of thick-bedded and thin-bedded rock are especially favorable for the development of such boulders.

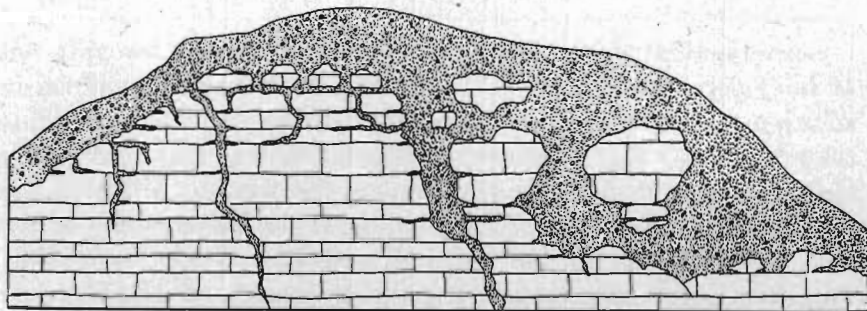


FIG. 10—Ideal section showing development of boulders by decay of limestone. Weathering occurs most rapidly along crevices and bedding planes.

*Source of the Iron.*—The limestone and shale formations which once overlay northeastern Iowa were low in iron, as shown by analyses of samples from the same horizons near. Consequently the secular decay of even the somewhat excessive thickness of 800 feet assumed by Calvin cannot have produced a very highly ferruginous residuum. If, however, it be considered that a very large area was similarly covered with such a lean residuum, it must be admitted that considerable iron was available, requiring only some means of concentration.

The deposits on Iron Hill may be assumed to contain about twelve million tons of ore,<sup>37</sup> which averages 28 per cent metallic iron. Assume a drainage basin on the peneplain on which the ore is located, to have been of the same size as that of the Upper Iowa river; and assume also that the residuum over the entire basin had an average thickness of ten feet, a figure which is

<sup>37</sup>Beyer, Iowa Geol. Survey, XII, p. 61.

only slightly greater than that which holds for the Driftless Area of today, and which certainly is far too low. Then if the residue contained the very low proportion of 5 per cent  $\text{Fe}_2\text{O}_3$  there would be available on the plain within that drainage basin 8,712,000 tons of iron oxide. The amount of  $\text{Fe}_2\text{O}_3$  in the twelve million tons of ore is 4,800,000 tons, so that these conditions would be adequate, provided the *means of concentration* were sufficiently perfect.

As shown above, however, the thickness of residuum present must have been nearer that found in the Shenandoah Valley of today, or about forty feet in valleys and on divides. And the average of four analyses of residual clays from southern Wisconsin<sup>28</sup> shows a content of  $\text{Fe}_2\text{O}_3$  of 10.57 per cent. If we assume, then, a thickness of forty feet of residual material containing 10 per cent  $\text{Fe}_2\text{O}_3$ , 71,696,000 tons of available iron oxide are indicated.

On peneplains, however, large rather than small rivers are the rule, and the greatest change in the figures would undoubtedly arise through assumption of an increased drainage basin. Unfortunately nothing can be determined concerning the drainage of this period.

Plant growth on the plain was abundant, for climatic conditions were very favorable. The vegetation which died was not removed rapidly, and its decay produced a deep layer of humus, which in its turn tended greatly to increase plant growth. These plants too, by their products of growth and by decay, produced great quantities of the so-called humus acids,<sup>29</sup> which are thought to be very important agents in rock decay and weathering. These colloid organic substances have been shown to have a marked solvent action on iron compounds, probably through reduction of the ferric salts, and they must have aided greatly in the solution of the iron of the residuum.

*Concentration of the Iron.*—The conditions which have been described above as existing on the peneplain during the Tertiary undoubtedly were favorable for the abundant growth of vegetation. Drainage, both surficial and deep, was sluggish, and the top of the water table probably was at no great distance

<sup>28</sup>Sixth Ann. Rept. U. S. Geol. Survey, p. 250.

<sup>29</sup>Julien, A. A., Geol. Action of Humus Acids: Proc. Am. Assn. Adv. Sci., Vol. 28, p. 311.

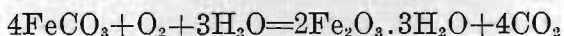


from the surface. Such stagnant waters are found to contain large amounts of organic matter in solution, resulting from the life processes and from the decay of plant tissues. Such organic matter, assisted by the  $\text{CO}_2$  released from the decaying material, is highly effective in the solution of ferrous compounds.<sup>40</sup> This also must have added to the iron content of the sluggish waters which flowed across the northeastern Iowa peneplain.

In this region of slight relief and poor drainage swamps and bogs must have formed. The bogs occupied the depressions in the surface and probably followed the drainage lines, so that the streams had their courses through a chain of marshes. No doubt there were also ox-bow loops, which eventually would become marshes.

The residuum, especially in the plastic state induced by saturation with water, tends to slump down into depressions. Hence it seems probable that there were thick layers of clayey material beneath the marshes, and this layer was increased slightly by the action of the acids of the water which came in contact with the underlying limestone.

*Precipitation of the Iron.*—The processes involved in the precipitation, as limonite, of the ferrous salts contained in swamp waters, are somewhat complicated. Oxidation by atmospheric oxygen which is adsorbed at the surface of the water forms, perhaps, the simplest possibility. The following reaction, according to Van Hise,<sup>41</sup> illustrates such a process:



Evaporation also may be a factor, especially along the shores. Ascham<sup>42</sup> recently has suggested that under certain conditions bacterial action may assist in the precipitation. It has been well known for some time that certain low forms of life, notably *Crenothrix*, have the power of extracting iron from water and depositing it as the hydroxide.

No doubt all of these factors were in operation and they slowly formed a considerable body of bog iron ore, probably much more extensive than the present deposits. The clay be-

<sup>40</sup>Clarke, F. W., Data of Geochemistry: Bull. U. S. Geol. Survey No. 491, p. 505.

<sup>41</sup>Treatise on Metamorphism: Mon. U. S. Geol. Survey, Vol. 47, p. 826.

<sup>42</sup>Zeitschr. für prakt. Geol., 1907, pp. 56-62.

neath the bog also contained some ferric oxide which had accumulated during the weathering process, and which had not been removed by the subsequent leaching.

At the close of the Pliocene the crustal movements which affected all of the Mississippi Valley caused the peneplain to be uplifted. This uplift, as shown above, was not less than 600 feet in all, but there is some evidence that it took place in two stages, the first including a movement of about 200 feet. At this time the drainage of the Mississippi probably was in much the same direction as now, namely, toward the Gulf of Mexico. Since the Lafayette gravels, which are terrestrial in origin and of Pliocene age, extend down to the present shore line of the Gulf, it may be safely assumed that this line has not changed materially since the Pliocene.

Northeastern Iowa, then, was uplifted a maximum of 600 feet above sea level, for as a peneplain it must have reached an approximate base-level, and according to accepted theories its streams were rejuvenated. But rejuvenation begins in that portion of a stream which is nearest the sea. Since the Driftless Area is some 800 miles from the nearest point on the Gulf coast, it is evident that the fall produced by the uplift was less than nine inches per mile and during the first stage may have been less than three inches per mile. With such a low gradient the effects of rejuvenation in Allamakee county must have been very slow in appearing, and the drainage of the swamps, when it did occur, was very gradual.

It was in this period between the first uplift and the renewal of downward cutting produced by the second uplift, that the present ore deposits were formed. Much of the drainage of the bogs was downward, and even after they themselves were drained the meteoric waters continued to flow through the same channels. Thus the bog deposits were leached by descending waters, the iron carried down into the residuum, and there deposited, partly by precipitation and partly by replacement<sup>43</sup> of the residual material. The precise conditions of this replacement are not now apparent. Much of the residuum, as well as the material in solution in the circulating waters, was of colloid

<sup>43</sup>Lindgren, Mineral Deposits, p. 803.

nature, and the explanation of the replacement probably involves colloid chemistry. Recently it has been shown<sup>42a</sup> that colloidal ferric hydroxide carries a positive electrostatic charge, whereas colloidal kaolin and clays carry negative charges. Colloidal particles of opposite sign may combine through the process of mutual adsorption and form larger particles whose sizes prevent them from remaining in suspension. The intimate relation between the iron oxide and the clay in the ore suggests strongly that these processes were the most important factors in the precipitation.

#### SUMMARY.

The theory of origin of the ore as brought out in the present investigation may be summed up as follows:

(1) Northeastern Iowa became a land area at the close of the Niagaran epoch and was subjected to continuous erosion until late in the Tertiary, at which time it had been reduced practically to base-level.

(2) Drainage on this peneplain was sluggish, weathering exceeded transportation, and a thick mantle of clayey residuum accumulated.

(3) The iron oxide occurring in the residuum was dissolved through the agency of organic acids, carbon dioxide, and other means. This iron was then deposited in a large bog through the agency of other organic acids, atmospheric oxygen and the action of organisms.

(4) At the close of the Tertiary the region was uplifted a total of about 600 feet, causing the rejuvenation of the streams. The marshes were drained slowly owing to their distance from the sea, and for a long time the waters, both of the normal drainage and those which fell as rain on the surface of the old bog, passed through the ore deposit, leached out the iron oxide, and deposited it by precipitation and replacement in the residuum beneath. As the streams cut downward the action became slower, but appears to have been carried to approximate completion, since but little totally unchanged clay remains. The continued downward cutting of the streams left the more resistant ore to

<sup>42a</sup>Ostwald, Wo., *Grundriss der Kolloide Chemie*, p. 233.



form a cap over the hill. The unsymmetrical position on the hill is probably due, as suggested by Calvin, to more rapid weathering on the southern slope.

This explanation seems to account for the topographic position of the ore and for its stratigraphic unconformity. The presence of chert, limestone boulders and unworn fossils is common in all accumulations of residuum or geest. Lower Galena fossils, rather than those of younger beds, are to be expected, for the younger beds have suffered erosion for a much longer time and their fossils may have become disintegrated. Furthermore, the fossils of the upper part of the Galena are casts and would not persist in a geest. It is worthy of note that silicified fossils are common in geest in many places, even though no silicified forms occur in the rock from which the geest was formed. Silicification of the fossils seems to occur during the weathering process.

Angular pieces of quartz occur in the massive ore and within the unbroken nodules, an association that can be explained in no other way than by replacement of a residuum. The high alumina content, the presence of unchanged clay in the cores of the nodules (which clay is shown by microscopic examination to be residual in origin), as well as the layer of clay between the base of the ore body and the bedrock, appear convincing bits of evidence in favor of this view.

The crevices in the ore are believed to be due largely to settling as solution continued beneath the protecting cap of ore. The sand pockets and beds of gravel were deposited over the surface of the original bog ore before, or immediately after the uplift, and have been cemented by secondary processes within the ore. It is noticeable that the sand ore is very lean, and that the highest phosphorus content noted in the entire deposit is in the neighborhood of a gravel bed. Hence it is possible to conceive that this really is part of the original bog, later covered by the gravels, which it cemented together.

Crane<sup>44</sup> regards analagous limonite deposits in southeastern Missouri as having had a similar origin, except that he assumes the replacement of a cherty, rather than a clayey residuum. The Missouri ores also are overlain by Tertiary gravels and occur on the ridges, hence their age may be considered to be approxi-

<sup>44</sup>Missouri Bur. Geol. & Min., 2d Series, X, pp. 78-79.

mately that of the Waukon ores. No fossils have been found there and the field evidence appears much less conclusive than at Iron Hill.

#### TREATMENT OF THE ORE.

Attempts to exploit the Iron Hill ore have been made at intervals for several years, but the first really serious effort seems to have been made in 1899 when the Waukon Iron Company was organized among residents of the town and work actually was begun. In 1901 a complete ore washing plant<sup>45</sup> of the McClanahan-Stone type was installed and an effort made to concentrate the ore by the washing process. Crude methods of handling were used and the fact that the physical nature of the ore made the washing treatment unsuccessful assisted in rendering the entire venture a failure.

The property of the Waukon Iron Company was taken over in 1907 by the present operators, the Missouri Iron Company, of St. Louis, Missouri. They have accomplished much additional exploratory and experimental work; the deposit has been carefully studied by means of a great number of drill holes and test pits, and new methods of treatment and handling have been developed to fit the needs of the situation. At the present time they state that they have reduced the process to a point at which the ore can be marketed in competition with the northern ore and can be produced at a profit.

The pit and plant in which present operations are carried on was opened in 1913, but the property has been operated only a short time in the period which has since elapsed.

*Present Development.*—Development is at present being carried on through a single open pit located near the crest of Iron Hill and on its southern exposure. This opening has a length of about 400 feet and a width about one-third as great (figure 7). A thickness of only twenty-two feet is now being taken off as it is the intention eventually to work a lower level for the remainder.

It is the intention of the management to work through the ore body at about the present level, forming what is known as a "thorough cut," and following the contour of the bedrock. Oth-

<sup>45</sup>Beyer, Iowa Geol. Survey, XIII, p. 59.

er benches can be run parallel to this cut and having access to it for the convenient handling of ore to the plant without the necessity of constructing other track.

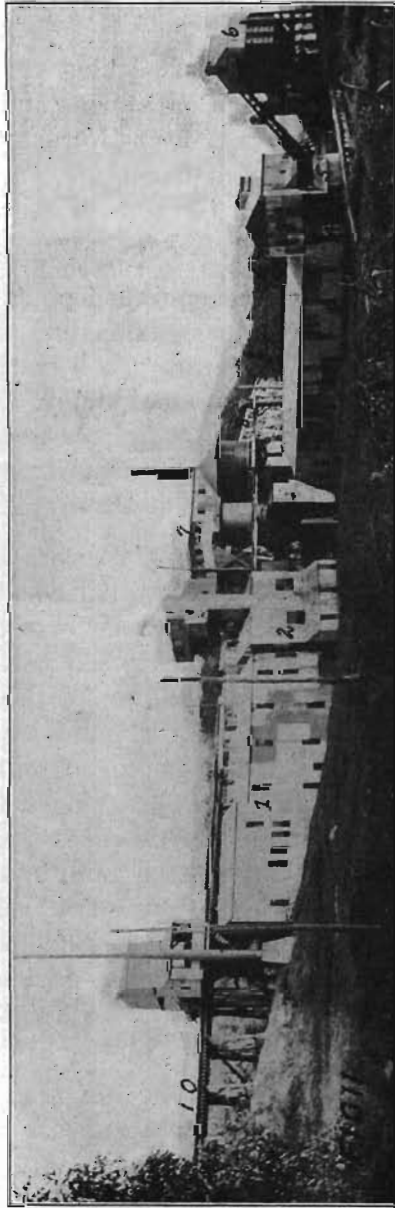


Fig. 11—General view of concentrating plant. 1, Dryer; 2, Roaster; 3, Air Washer; 4, Reducer; 5, Magnetic separator; 6, Loading bins; 7, Screens; 8, Bridge giving access to main tracks; 10, Bridge leading to pit.



The power plant and other buildings of the concentrating plant are located at a distance of about 550 yards south of the pit and a 7 per cent grade of the tracks favors the loaded cars on their way to the bridge. The following are the chief buildings composing the plant (figure 11):

Drying and Crushing house.	Refuse bins.
Roaster.	Coal storing and drying house.
Air Washer.	Power House and Machine
Reducer.	Shop.
Magnetic Separator.	Office and Laboratory.
Loading bins.	

Power is furnished by a well equipped plant developing 440 horsepower by means of producer gas engines, direct connected to 220 volt Direct Current generators. All machinery is motor driven and each unit has an individual motor. There is also an emergency power plant consisting of a 200 horsepower motor-generator set, current for which is secured from the hydroelectric plant on the Upper Iowa river at Decorah.

*Mining.*—The boulder character of the ore makes it rather difficult to mine and handle. A churn drill located on the brow of the pit is used in sinking holes to the level of the pit floor and in these holes are placed rather heavy charges of 60 per cent dynamite. The holes are set at distances of twelve inches from center to center and the charges are fired simultaneously by means of batteries. This blasting has the effect of loosening the ore for a considerable distance and breaking it up into fine material and into boulders, some of which are of large size. That portion of the ore which is sufficiently small in size is loaded by steam shovel and hauled immediately to the crusher and dryer. Those boulders that are too large to be handled by the shovel are broken by light charges of dynamite. Jackhammers operated by means of compressed air are used in drilling the "plugholes" for this work.

The overburden is nowhere of great thickness, and on account of this fact and of the appreciable amount of intermingled pebbles of ore, it has been found economical to omit stripping and to send the entire body through the plant.

Loading in the pit is accomplished by a seventy-five ton Vulcan steam shovel.

*Haulage.*—The ore is loaded by the steam shovel onto twelve ton, standard gauge, electrically propelled dump cars, the motors of which are mounted on the axles. The haulage system is double tracked, with power transmission through central third rails. The system is divided into sections, by which the movements of the cars may be readily controlled. Central control of the cars while they are outside of the pit is obtained from a tower which is located above the bridge at the north end of the plant, and from which a view of the entire tracks may be had. On entering the pit the cars leave the control of the operator on the bridge and pass, by their own momentum, on to a section which is controlled from the steam shovel, and from which they may be obtained as desired for loading. Automatic brakes are provided which will prevent runaways from crashing through the plant.

The ore from the bridge and from many of the bins is handled by gravity, and in fact this method is used whenever it is possible. Where it is necessary to lift the ore, however, bucket conveyers are used.

A switch some three miles in length has been constructed from the mine property to the Chicago, Milwaukee and St. Paul railroad, connecting with the latter in the southeastern part of Waukon. The loading bins are located over a spur of the switch and this is connected also with the trackage in the pit, so that ballast or additional machinery may be taken to the scene of operations without unloading. All track about the plant and in the pit is of standard gauge. A small switch engine, coal burning, is used for switching, and for conveying the employees to and from Waukon.

*Concentration.*—In the early efforts to market the Waukon ore the operators sought to obtain a separation of the ore from the gangue by washing to remove the clay, and subsequently by getting rid of the chert and other larger impurities by hand picking as the material passed along a belt. By this method, however, the ore could not be brought to a sufficient degree of

concentration, nor was the process economical. Furthermore the necessary addition of water to the porous ore materially increased freight charges.

After a few years of trial this treatment was abandoned, and when the Missouri Iron Company took possession they instituted a series of experiments to develop a process which should produce a marketable and profitable product. The first experimental plant was located at Waukon Junction, but the method of treatment used there (washing and jigging) was not successful, and it was realized also that whatever the treatment used, it would be economy to apply it at the mine, in order to avoid the expense of shipping the gangue.

As a result of several years of experiment the present plant has been constructed and the management state that the process in use will produce a satisfactory concentrate at a cost which will permit a good profit. The treatment used is known as the "Goltra beneficiation process."

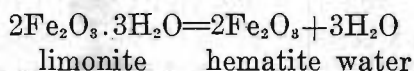
Following is a brief sketch of the Goltra process:

1. The ore is hauled from the mine to a bridge or tippie where, after weighing, it is dumped on to fourteen inch grids, the larger lumps being broken with sledges, and the sized material passes to the dryer, which is located immediately beneath.
2. The dryer is of the horizontal tubular type, 10 by 125 feet, and is driven by a motor at the rate of one revolution per minute. The fuel used is powdered coal, which is blown in at the lower end by an Aero pulverizer. At the upper end of the dryer is a large fan with a capacity of 35,000 cubic feet of air per minute, and this draws the heated air through the cylinder and discharges it, together with the fine sand and dust, into a dust catcher. A temperature of about 300° F. is maintained and here about 99 per cent of the free or mechanically held water is driven off.
3. The dried ore then passes to a movable grid set to 2½ inches, the oversize going to a No. 8 gyratory crusher which reduces it to 2½ inches. The crushed material meets the undersize at a common point from which it is hoisted by a pivoted bucket conveyer to a triple concentric trommel from which the succeeding flow is by belt conveyer to the bins. The fines below 1-16 inch pass to the waste pile, the middlings go to the storage



bin, while the lumps pass over the cobbing belts, where the chert and other float is removed, after which the lump ore goes to the storage bin. From here the ore is fed to the roaster.

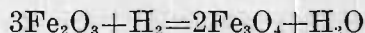
4. The roaster is similar to the dryer except that it is of slightly smaller size, measuring 8 by 125 feet. In it also powdered coal is used as fuel and the roaster is operated at a temperature of 1600° to 1800° F. At this temperature limonite loses combined water according to the formula



leaving all of the ore in the form of the anhydrous hematite.

5. The dehydrated ore, still at a temperature not less than 1100° F., leaves the lower end of the roaster and is conveyed to a double jacketed trommel. All material above 1/2 inch goes to the shipping bins, while that which is below 1/2 inch goes into a closed reducer, 6 feet in diameter by 70 feet in length, and turning at a rate of three revolutions per minute. Here it is sprayed with crude oil under 125 pounds pressure.

On striking the heated ore the oil is broken up into its component gases, chiefly hydrogen and the lighter paraffins. These gases have a very high reducing power and remove one-half an atom of oxygen from the hematite:



The above reaction is much simpler than the one which actually occurs in the process, but it serves to illustrate the principle involved. Because of the large number of compounds entering into the reduction the exact formula cannot be given.

6. After passing through the reducer the ore is raised by an elevator to a rotary cooler, from which it passes to a trommel (42 inches by 18 feet) whose jackets are 1/16 inch, 1/8 inch and 1/4 inch mesh. The sized ore drops directly into bins.

7. From the bins the sized ore goes directly to magnetic separators of the Ball-Norton type. The 1/4 inch to 1/2 inch material is not concentrated but goes directly to the loading bin where it meets the larger size ore from the roaster. The tailings are thrown on the dump.

*Results of the Treatment.*—The recovery by the above treatment is from 37 per cent to 62 per cent, depending on the grade of ore worked, and the average is approximately 50 per cent. From this it will be seen that from  $\frac{1}{3}$  to  $\frac{1}{2}$  of the deposit may be classed as gangue. The average, so far as concentration tests have been made, is 55 per cent ore.

In American metallurgical practice it is considered that iron ore should contain not less than 35 to 50 per cent metallic iron at the furnace, and the process in use at Waukon is designed to produce such a concentration. The product is not allowed to fall below a content of 55 per cent metallic iron and manganese. The following analyses will illustrate the character of the concentrate:

AVERAGE OF 8,000 TONS CONCENTRATES. ANALYSIS BY MISSOURI IRON COMPANY.

	PER CENT.
Fe .....	55.52
SiO <sub>2</sub> .....	12.02
*Insoluble .....	15.34
Phosphorus .....	.1044
Loss on ignition .....	.201
CaO .....	.69
MgO .....	.504
Sulphur .....	.024
Mn .....	.88

\*Insoluble chiefly Al<sub>2</sub>O<sub>3</sub>, with some Si and Fe.

AVERAGE OF 200 CARS CONCENTRATES.

	MINE ASSAY. UMPIRE.	
	PER CENT.	PER CENT.
Fe .....	55.38	55.18
Mn .....	1.04	1.02
SiO <sub>2</sub> .....	14.03	13.15

The highest analysis of a daily sample of the concentrate has shown a metallic content of 62.3 per cent. When very rich ore is being worked the monthly average has been as high as 61.9 per cent.

DISPOSITION OF THE ORE.

The low sulphur and phosphorus content of the ore make it very suitable for the manufacture of all classes of pig iron except Bessemer, and a ready market has been found for it in ordinary times. It has been used chiefly in furnace mixtures.

The results of a test of the Waukon ore by the Sligo Furnace Company, of Sligo, Missouri, are of interest. During an eight day run on Waukon ore alone the furnace was found to handle easily on various grades of iron, ranging from .09 per cent to 3.25 per cent silicon, most of the metal produced being 1.25 per cent. The addition of manganese to the burden was found to be unnecessary, as sufficient of this element was present in the ore.

In comparison with a ten months previous run on Missouri ores carrying 54.5 per cent Fe., the Waukon ore was found to give a 25 per cent increase in production, with a decrease in fuel consumption of 22 per cent. Charcoal was used as fuel in these tests.

Phillips<sup>46</sup> states that "The finished product obtained by this process (the Goltra process) is excellently adapted for use in the blast furnace. The free and combined water are completely, and the clay, sand, etc., almost completely, removed. The sulphur, except in the case of some magnetic concentrates, is eliminated. The physical nature of the ore is greatly improved, particularly in respect to its porosity and easy reducibility in the blast furnace."

The article from which the above extract is taken contains a very complete discussion and analysis of the process, and should be consulted for further details.

The concentrates have been shipped to Milwaukee, Chicago and St. Louis, at all of which places it competes with the northern non-Bessemer ores. Freight rates to Chicago and Milwaukee are \$1.00 per ton gross, and to St. Louis \$1.50.

Profitable operation of a deposit of this kind must depend very largely on the condition of the markets. With the price of pig-iron at or above normal the Waukon property may be expected to remain a profitable producer. The plant was operated for a short time after its completion in 1913, but the depression in the iron industry made it necessary to shut down until prices should be more favorable. Operations were resumed in November, 1915, at which time shipments to South Chicago furnaces were reported. Production at present is 350 tons per day.

<sup>46</sup>Iron Age, Nov. 12, 1914, p. 1150.



The present development was begun in 1913 and the total production, up to the time of the recent resumption, has been 27,000 long tons. The capacity of the plant on full time is 450 tons per day.

The available tonnage in the deposit amounts probably to ten million tons at least. The property, which is held in fee simple, by the Missouri Iron Company, consists of approximately 258 acres.

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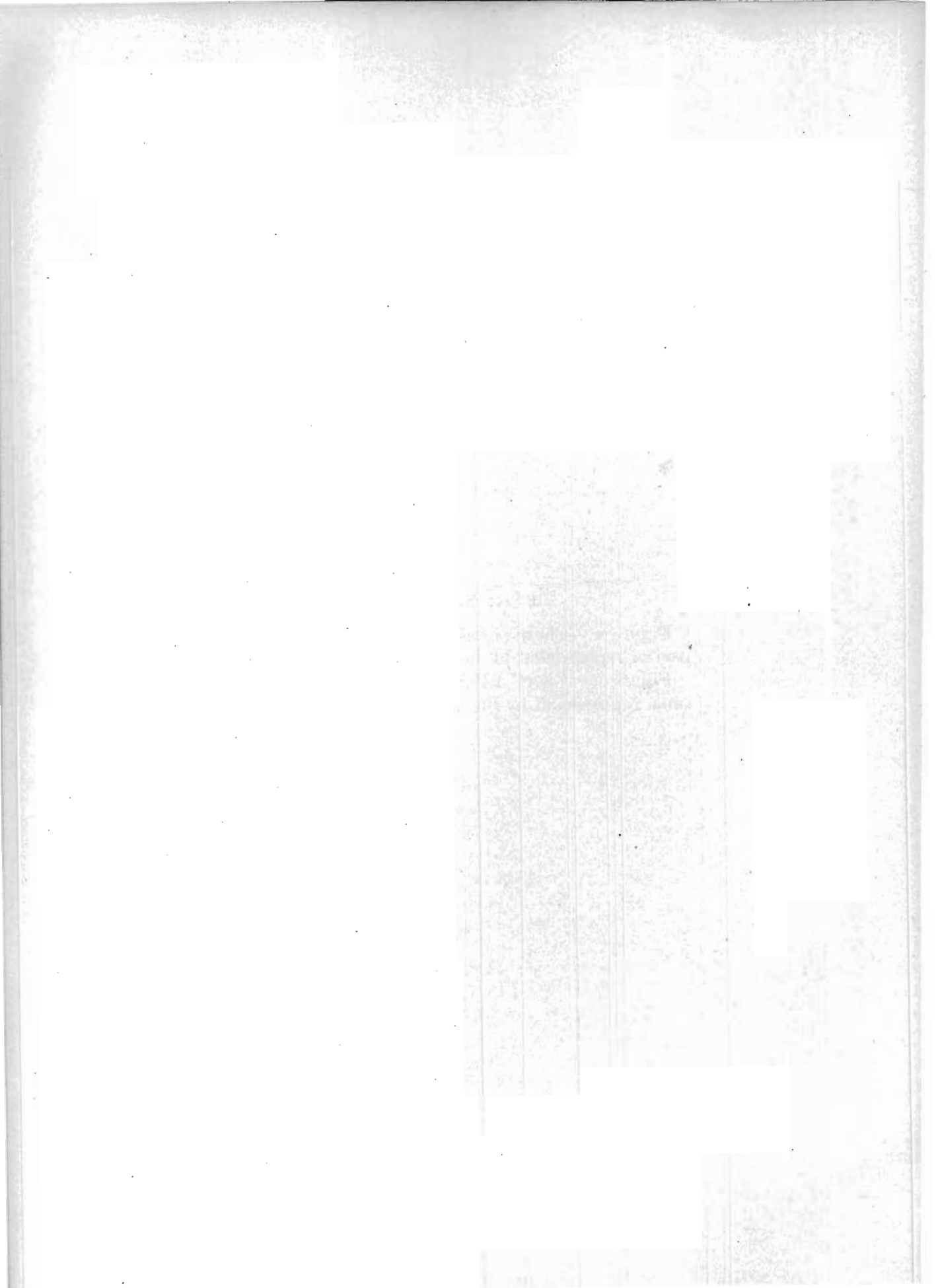


PLATE I.

Chert Nodules from the Ore.

Figure 1.—Chert nodule showing concentric weathering and partial replacement by limonite.

Figure 2.—Chert nodule showing advanced weathering and some replacement by limonite..

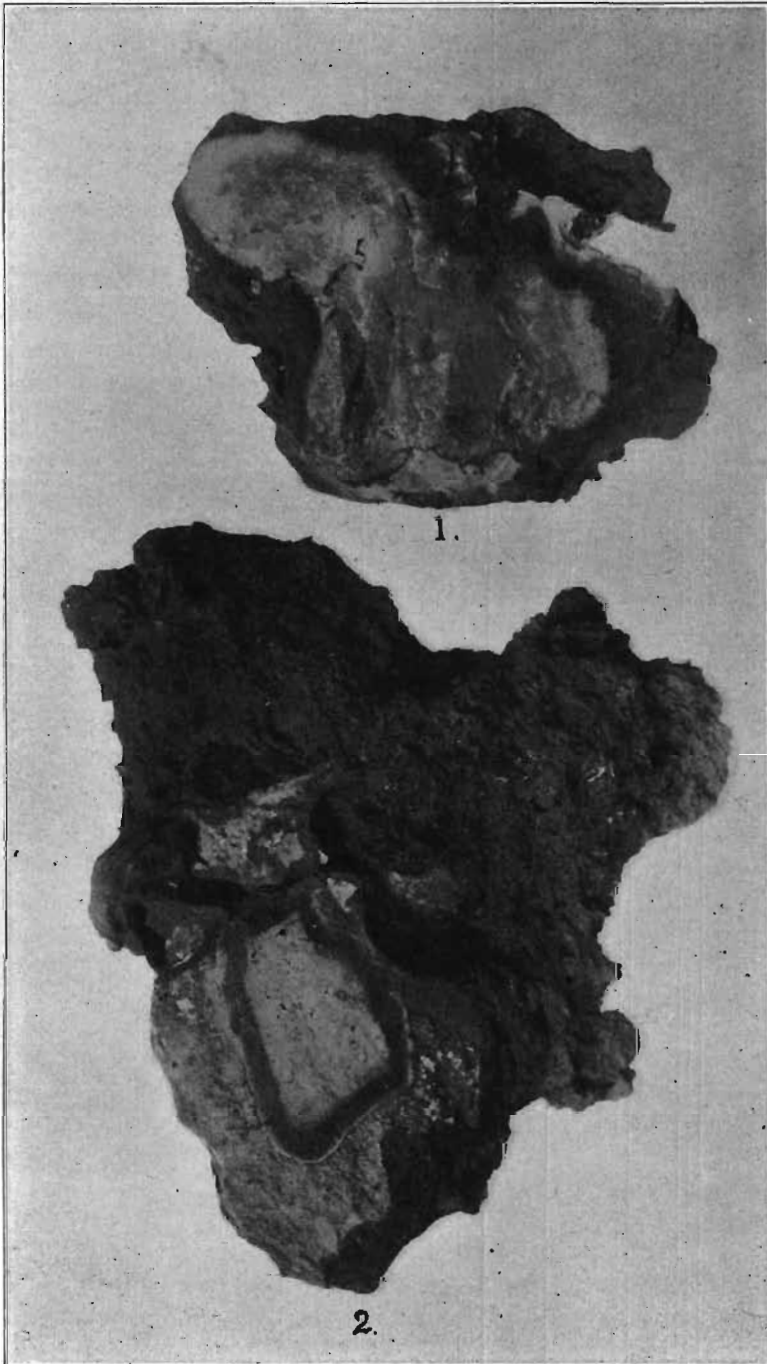




PLATE II.

Fossils from the Iron Ore.

1-16, 31. *Plectambonites sericea*.

17-30. *Dalmanella testudinaria*.

Fossils from Decorah Shale.

32-39. *Plectambonites sericea*.

40-53. *Dalmanella testudinaria*.

Note perfect preservation of specimens from the ore. Also note that size and general appearance of the Decorah individuals are almost identical with those of the fossils in the ore. The Decorah specimens are not silicified.

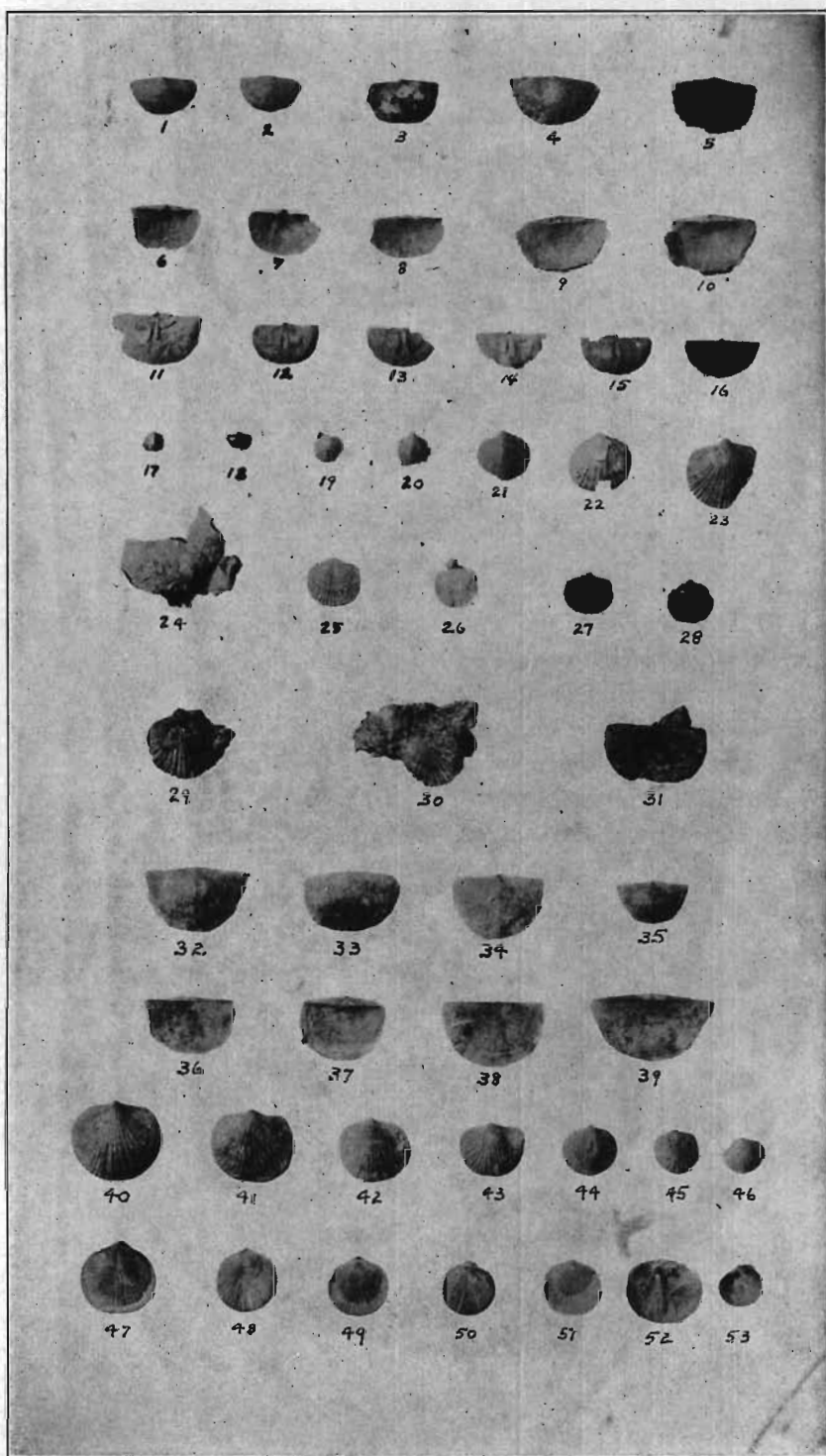


PLATE III.

- 1-3. *Platystrophia lynx*.
4. *Orthis bellirugosa*.
5. *Rafinesquina minnesotensis*.
6. *Rhynchotrema capax*.
8. *Streptelasma profundum*.
- 7, 9-12, 14. *Streptelasma corniculum*.
13. *Prasopora simulatrix*.

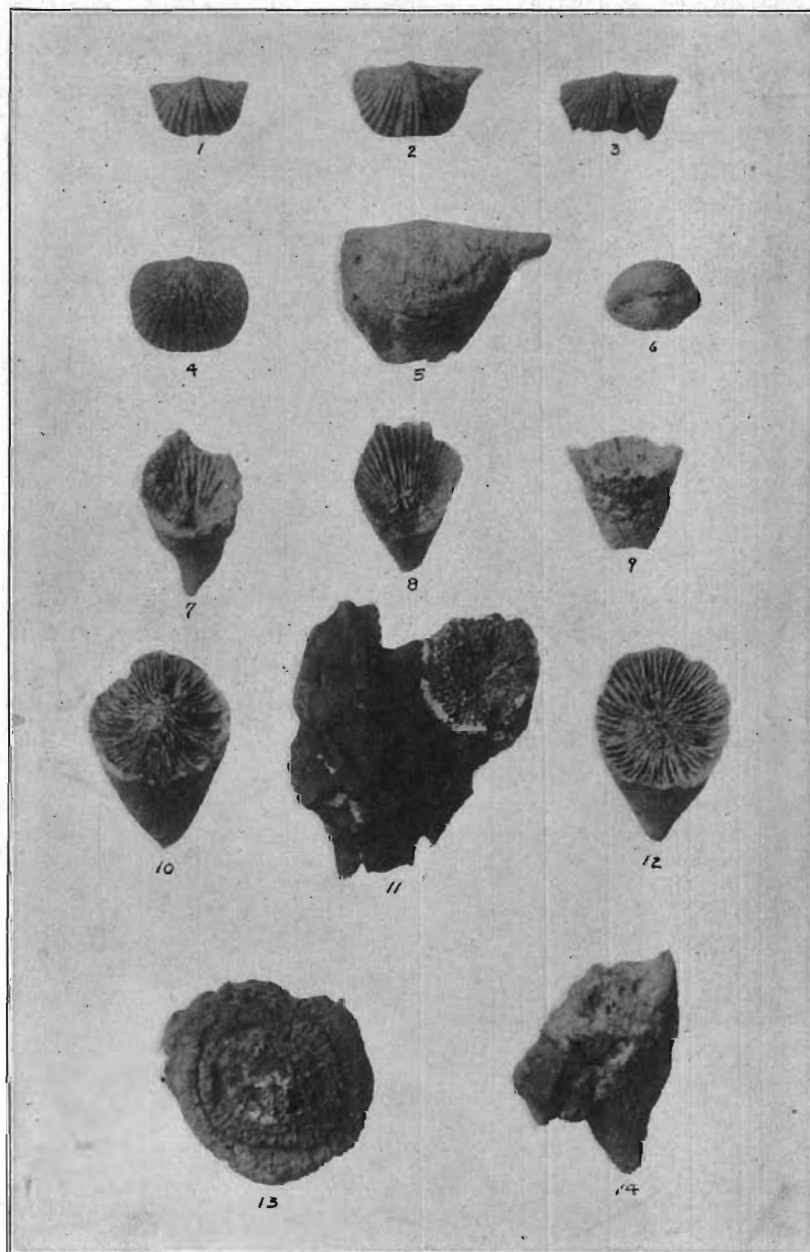




PLATE IV.

1. Interior of cavity in ore showing dense limonite surrounding band of fibrous, radiating limonite. Interior surface botryoidal. Also (in circle) small mass of hyalite.

2, 3. Pieces of very fossiliferous ore, showing silicified and un-replaced shells. Complete *Dalmanella testudinaria* at "a."

