Wisconsin
Monroe & LaCrosse counties

Sparta and Tomah quadrangles

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13908.

Geography, geology and mineral resources of the Sparta and Tomah quadrangles, Wisconsin.

(Illustrations in map case in Room 4244)

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To be prepared by Martin or by U. S. G. S.

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Qfp, floodplain; Qlt, Lower terrace; Qht, High terrace of valley filling; Qot, Old terrace; Oo, Oneota dolomite; Cj, Jordan sandstone; Csl, St. Lawrence formation; Cf, Franconia formation; Cd, Dresbach sandstone; Cec, Eau Claire formation; Cms. Mount Simon sandstone; PC, Pre-Cambrian.

GENERALIZED SECTION FOR THE SPARTA AND TOMAH

SYSTEM	SYSTEM After Ulrich	SERIES AND GROUP	FORMATION	SYMBOL	COLUMNAR SECTION
			dune sand	Qds	
		Wisconsin	loess		
			UNCONFORMITY		
QUATERNARY	QUATERNARY	PLEISTOCENE	Valley filling	Qht Qlt Qfp	
			UNCONFORMITY		
		Pre-Wisconsin	Old terraces	Qot	
			UNCONFORMITY		
CRETACEOUS?	CRETACEOUS?		Windrow	Kw	
			UNCONFORMITY		
	ORDOVICIAN	Chazy (basal)	St. Peter	Osp	
ORDOVICIAN			UNCONFORMITY		
	OZARKIAN	Beekmantown (basal)	Oneota	Oo	
			DISCONFORMITY		
			Jordan and Madison?	Cj	
			St. Lawrence	Csl	
			DISCONFORMITY		
			Franconia	Cf	
			DISCONFORMITY		
CAMBRIAN	CAMBRIAN	St. Croix	Dresbach	Cd	
			Eau Claire	Cec	
			Mount Simon	Cms	
			UNCONFORMITY		
PRE-CAMBRIAN	PRE*CAMBRIAN			P C	

QUADRANGLES

THICKNESS IN FEET	CHARACTER OF ROCKS	CHARACTER OF TOPOGRAPHY
20	Sand	Hummocks and ridges.
10	Yellowish -brown silt	Covers gentle slopes.
150	Sand, gravel, clay	Valley bottoms and low terraces.
10	Chert gravel and sand	Rock terraces up to 140 feet above streams.
10	Ferruginous conglomerate and coarse sandstone.	Small areas on highest uplands.
50	Sandstone, fine to medium grained, yellow to brown, massive; at base red and green shale on unstratified dolomite residium.	Small irregular knolls and ridges.
170	Dolomite, gray, medium bedded, cherty; base sandy, oolitic.	Rolling uplands heavily covered by residium.
40	Sandstone, yellow and white, cross laminated, quartzitic at top.	Steep slopes, cliffs, and crags.
100	Sandstone, gray and yellow, fine grained, calcareous at base.	Steep slopes with local bench near base
150	Sandstone, fine grained, gray and green, thin bedded, glauconitic, micaceous sandy shale at base.	Rolling bench tops with local terraces.
250	Sandstone, medium grained, white and yellow, heavily bedded.	Steep slopes, castellated cliffs, tepee-shaped buttes, low benches.
200	Sandstone, medium to fine grained, gray; shale beds, blue, green, and red.	Mainly concealed.
150	Sandstone, medium to coarse-grained, gray and red; shale beds, blue, red, and green.	Concealed.
	Granite and gneiss.	Concealed.

SYSTEM	FORMATION	SECTION	THICKNESS	CHARACTER OF ROCKS
	Residium and loess.		60	Clay and chart bowlders.
Ordovician	Onéota dolomite		(95)	Dolomite, yelłowish gray, cherty.
			140 (15)	Sandstone, fine grained, gray, calcareous; green shale.
			(50)	Dolomite, sandy, yellowish gray.
	Jordan sandstone		25	Sandstone, coarse to fine grained, yellow.
	St. Lawrence formation.		(30)	Sandstone, very fine grained, light yellow, calcareous.
			50 (10)	Dolomite, sandy, gray.
			(10)	Conglomerate, green and yellow sandstone pebbles in sandstone.
Cambrian	Franconia formation		(45)	Upper greensand; sandstone, fine, greenish gray, glauconitic, calcareous.
			(25)	"Yellow" sandstone, fine grained, light yellowish gray.
			170 (75)	Lower greensand; sandstone, fine grained, yellowish and pinkish gray, glauconitic calcareous.
			(15)	Micaceous shale, yellow; some gray calcareous clay shale.
			(10)	Basal layer; sandstone, coarse grained, gray, very firm, calcareous glauconitic.
	Dresbach sandstone.		80	Sandstone, coarse to medium grained, light gray to yellowish gray.

Fig. 21. Section of Sorge well, Cashton, Wisconsin. From samples in geological museum, University of Wisconsin, interpreted by F. T. Thwaites, Scale 1 in. = feet. (Note: scale of tracing furnished is 1 inch equals 50 feet.)

Fig. 8. Geological map of vicinity of Sparta and Tomah quadrangles. Based on map of Wisconsin by Wisconsin Geol. and Nat. Hist. Survey, 1911; unpublished surveys for Wisconsin Geol. and Nat. Hist. Survey by E. F. Bean and F. T. Thwaites; Minnesota Geol. Survey, vol. 1. Sparta and Tomah quadrangles indicated by rectangle.

Fig. 9. Mechanical analyses of Dresbach sandstone.

a. Tunnel City, 65 feet below top.

1.168 - .833 mm.	0.036, spherical grains of transparent quartz.
.833- .589 mm.	0.755, well rounded grains of transparent quartz.
.589 - .417 mm.	12.080, transparent quartz, most grains well rounded, a few subangular.
.417 - .295 mm.	32.120, transparent quartz, grains well rounded to subangular.
.295 - .208 mm.	28.270, Transparent quartz, grains well rounded to subangular, a few grains angular.
.208 - .147 mm.	20.460, transparent quartz, estimated 10 per cent angular, 25 per cent well rounded.
.147 - .104 mm.	5.600, transparent quartz, a few grains well rounded, most subangular to angular.
.104 - .074 mm.	0.312, transparent quartz, nearly all grains sharply angular.

Smaller than .074 mm., 0.367, transparent quartz, grains angular.

b. Melvina, 30 feet below top.

1.168 - .833 mm.	0.05, Quartz, all spheres or egg-shaped, frosted surface.
.833 - .589 mm.	0.40, " " " " " " " "
.589-.417 mm.	1.64, " " " " " " " "
.417 - .295 mm.	6.00, " " " " " " " "
.295 - .208 mm.	16.88, " " " " " " " "
.208 - .147 mm.	44.76, " " " " " " " "
.147 - .104 mm.	14.78, Quartz, contains a large percentage of subangular grains, little frosting.
.104 - .074 mm.	14.10, Quartz, grains poorly rounded, many angular, a few yellow particles which are probably limonite.

Smaller than .074 mm., 1.29, Quartz, with a few dark particles, hematite ? all grains angular.

Fig. 10. Mechanical analyses of Franconia sandstone.

a. Boscobel, lower greensand.

1.168 - .833 mm.	0.00
.833 - .589 mm.	0.00
.589 - .417 mm.	0.00
.417 - .295 mm.	0.00
.295 - .208 mm.	6.83, transparent quartz, grains subangular to angular.
.208 - .147 mm.	28.80, essentially no rounding.
.147 - .104 mm.	19.27, no rounding, a little dolomite.
.104 - .074 mm.	15.71, as No. 7.
- .074 mm.	3.47, as No. 7, with about 10 per cent dolomite.
	25.84, this rectangle represents the glauconite present in the sample.

This sand was deposited some distance from the belt of constant wave-wash as shown by its fineness and little rounding.

b. Lower greensand from 21.7 to 22 above base of section.

1.168 -.833 mm.	0.00
.833 - .589 mm.	0.00
.589 - .417 mm.	0.00
.417 - .295 mm.	1.39
.295 - .208 mm.	4.23
.208 - .147 mm.	14.19
.147 - .104 mm.	17.17
.104 - .074 mm.	44.21
- .074 mm.	14.61
	4.30, glauconite.

Fig. 10 (cont.)

c. Lower Greensand, sample taken from 21.5 to 21.6 feet above base of section in road cut about one half mile west of Tunnel City.

1.168 - .833 mm.	0.00
.833 - .589 mm.	0.00
.589 - .417 mm.	0.00
.417 - .295 mm.	0.00
.295 - .208 mm.	7.06
.208 - .147 mm.	13.78
.147 - .104 mm.	2.41
.104 - .074 mm.	7.27
- .074 mm.	2.47
	67.01, glauconite.

Fig. 11. Mechanical analysis of St. Lawrence sandstone from two miles southeast of Norwalk 50 feet below base of Oneota.

1.168 - .833 mm.	0.00
.833 - .589 mm.	0.00
.589 - .417 mm.	0.00
.417 - .295 mm.	0.40, transparent quartz, grains rounded.
.295 - .208 mm.	0.36, transparent quartz, rounded and subangular grains, estimated 10 per cent muscovite flakes.
.208 - .147 mm.	0.60, as No. 5.
.147 - .104 mm.	12.00, transparent quartz, angular grains, occasional muscovite flakes and limonite grains, a little dolomite.
.104 - .074 mm.	17.92, transparent quartz, nearly all grains angular.
Smaller than .074 mm.	68.72, transparent quartz, 75 per cent aggregates, no rounding whatever.

This sand was deposited beyond the zone of constant wave wash.

Fig. 12. Mechanical analysis of Jordan sandstone, from Jeff Davis Rock.

1.168 - .833 mm.	0.00
.833 - .589 mm.	1.78, transparent quartz, grains highly spherical and pitted.
.589 - .417 mm.	10.00, transparent quartz. high sphericity, grains pitted
.417 - .295 mm.	6.45, transparent quartz. high sphericity, grains pitted estimated 5 per cent subangular.
.295 - .208 mm.	18.52, transparent quartz, with a few grains of limonite, grains well rounded and pitted, 5 per cent subangular.
.208 - .145 mm.	50.50, as No. 5.
.147 - .104 mm.	11.29, transparent quartz, well rounded with a few angular grains.
.104 - .074 mm.	1.06, transparent quartz, 60 per cent subangular to angular.

Smaller than .074 mm., transparent quartz, with a little clay, and dolomite, about 5 per cent rounded, about 10 per cent aggregates of finely divided quartz.

The assortment, rounding, and cross-lamination of this sand suggest wind deposition.

Fig. 13. Mechanical analysis of St. Peter sandstone from Cashton.

1.168 - .833 mm.	0.00
.833 - .589 mm.	1.80, transparent quartz, high sphericity.
.589 - .417 mm.	6.28, as No. 2.
.417 - .295 mm.	19.21, as No. 3.
.295 - .208 mm.	21.42, transparent quartz with a few limonite grains and fragments of calcite, most well rounded, but numerous subangular grains.
.208 - .147 mm.	40.00, transparent quartz with a few grains of limonite, well rounded, estimated 25per cent subangular.
.147 - .104 mm.	9.81, as No. 6, 50-60 per cent subangular, 10 per cent angular with no rounding.
.104 - .074 mm.	1.13, transparent quartz, 75 per cent sharply angular, rest subangular.

Smaller than .074, 0.352, transparent quartz, with rare garnet grains, essentially all angular.

The assortment, rounding, and cross-lamination of this sand suggest wind deposition.

Fig. 14. Sections showing pre-Wisconsin terraces.

a. Near Tomah from center Sec. 32, T. 18 N., R. 1 W. southwesterly to Sec. 13, T. 17 N., R. 2 W.

b. Across Stevens Valley, Sec. 12, T. 17 N., R. 2 W.

c. Across La Crosse valley near mouth of Little La Crosse river. Qfp, flood plain; Qlt. lower terrace; Qds, dune sand; Qht, high terrace of valley fill; Qot, old terrace. Bed rock shown by cross lining.

Fig. 15. Soils map of part of Sparta quadrangle. Based on map by Wisconsin Geol. and Nat. Hist. Survey, Soils Division and U. S. Dept. Agr., Bureau of Soils.

Fig. 16. Mechanical analyses of dune sands from Military Reservation, Tomah quadrangle.

a.

1.168 - .833 mm. 0.00

.833 - .589 mm. 2.88, all quartz, nearly all grains sphericaland frosted.

.589 - .417 mm. 28.22, " " " " " " " "

.417 - .295 mm. 35.12, " " many grains spherical, but about 25 per cent are angular.

.295 - .208 mm. 18.35 all quartz, rounding as in No. 4.

.208 - .147 mm. 10.35, " " " " " " "

.147 - .104 mm. 1.97, " " grains rounded to same degree, but many angular grains.

.104 - .074 mm. 0.13,all quartz, grains all angular.

- .074 mm. Included in 8.

2.98, woody matter.

b.

1.168 - .833 mm. 0.00

.833 - .589 mm. 0.34, quartz, nearly all spheres with frosted surfaces.

.589 - .417 mm. 6.50, quartz, most grains well rounded, a few subangular, surfaces frosted.

.417 - .295 mm. 24.26, quartz, as 3.

.295 - .208 mm. 35.93, " " "

.208 - .147 mm. 26.20, " majority of grains well rounded, a considerable percentage angular.

.147 - .104 mm. 3.23, quartz, about 50 per cent subangular.

.104 - .074 mm. 0.06, " a few grains well rounded, most angular to

Fig. 16 (cont.)

subangular.

- .074 mm. Included in 8.

3.47, woody matter.

Fig. 17. Map showing structure of base of Franconia formation. Contour interval 20 feet.

Fig. 18. Map showing interval between base of Franconia formation and base of Oneota dolomite. Contour interval 20 feet.

Fig. 19. Section from pre-Cambrian near Wisconsin Rapids southwesterly through Tomah quadrangle into Iowa. Based on U. S. Geol. Survey topographic maps, Iowa Geol. Survey Reports and on field notes by G. H. Thwaites and F. T. Thwaites.

Q, Quaternary deposits; Sn. Niagara dolomite; Om, Maquoketa shale; Ogp, Galena and Platteville formations; Osp, St. Peter sandstone; Oso, Shakopee and Oneota dolomites; Cj, Jordan sandstone; Csl, St. Lawrence formation; Cf, Franconia formation; Cd, Dresbach sandstone; Cec, Eau Claire formation; Cms, Mount Simon sandstone; PC, Pre-Cambrian.

Fig. 20. Sections showing artesian conditions in Sparta and Tomah quadrangles.

a. Section from Cashton northward down valley of Little La Crosse river.

b. Section along center line of La Crosse valley.

c. Section from Oil City up Kickapoo river and across ridge to Tomah.

Co, Oneota dolomite; Cj, Jordan sandstone; Csl, St. Lawrence formation; Cf, Franconia formation; Cd, Dresbach sandstone; Cec, Eau Claire formation; Cms, Mount Simon sandstone; PC, Pre-Cambrian.

Sparta Tomah Folio

No. ______

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Department of Interior

Albert B. Fall, Secretary

United States Geological Survey

George Otis Smith, Director

GEOLOGIC ATLAS

of the

UNITED STATES

S P A R T A - T O M A H F O L I O

WISCONSIN

by

F. T. Thwaites, W. H. Twenhofel, and Lawrence Martin

Surveyed in cooperation with

the Wisconsin Geological and Natural History Survey

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1922

DESCRIPTION OF THE SPARTA AND TOMAH QUADRANGLES.

By F. T. Thwaites, W. H. Twenhofel, and Lawrence Martin. 1/

1/ Surveyed in cooperation with hhe Wisconsin Geological and Natural History Survey in 1916, 1917, 1920, and 1921. The authors were assisted in the field work at various times by several students from the University of Wisconsin. Field conferences were held with Dr. E. O. Ulrich of the U. S. Geological Survey, Mr. W. O. Hotchkiss, State Geologist of Wisconsin, and Mr. E. F. Bean, Assistant State Geologist, to each of whom the writers are greatly indebted for criticisms, suggestions, and assistance. The writers are also indebted to many of the residents of the district for information and assistance.

INTRODUCTION

GENERAL RELATIONS OF THE QUADRANGLES.

The Sparta and Tomah quadrangles are bounded by parallels 43° 45' and 44°, and by meridians 90° 30' and 91°, comprising part or all of townships 15 to 18 North, ranges 1 to 5 West, 4th principal meridian. Together the quadrangles include one eighth of a "square degree" of the earth's surface, an area, in that latitude, of about 431 square miles. They are in the west-central part of Wisconsin (see Fig. 1), in Monroe and La Crosse Counties, 12 miles east of the Mississippi River. The quadrangles take their names from the principal city in each.

In their physiographic and geologic relations the quadrangles form part of the Driftless Area of the Upper Mississippi Valley which lies in the region of nearly horizontal Paleozoic rocks of the North Central States, immediately south of the pre-Cambrian "shield" which extends from Canada into the northern parts of Wisconsin, Michigan, and Minnesota. The Driftless Area, which includes nearly 15,000 square miles, is devoid of glacial deposits but contains materials brought from the glaciated area by streams, by lake waters, by floating icebergs, and by the wind. It is a part of the Interios Plains (see Fig. 1), which lie between the Appalachian

Highlands on the east, the Interior Highlands and Atlantic Plain on the south, the Rocky Mountain System on the west, and the Laurentian Upland which extends northward beyond the boundary of the United States.

GENERAL GEOGRAPHY AND GEOLOGY OF THE REGION.

The major portion of the Driftless Area of the upper Mississippi valley, in which the quadrangles under discussion are situated, differs markedly from the surrounding glaciated portion of the Interior Plains, which, in most localities, have slight relief. This part of the Driftless Area is a maturely dissected plateau, with local relief of from 200 feet to more than 650 feet. The Sparta and Tomah quadrangles are situated in one of the most hilly portions of this plateau, which has been termed the "Western Upland"[2] of Wisconsin. The lower and flatter country to the northeast, including the northeastern portion of the Tomah quadrangle, is separated from the plateau by a marked escarpment 400 to 500 feet in height. The lower land is what has been described as the "Central Plain"[3] of Wisconsin. Although unglaciated, this area owes much of its level character to the lake, stream, and wind deposits consequent upon glaciation.

The Western Upland of Wisconsin consists of three cuestas, whose dissected back slopes descend imperceptibly toward the south and southwest,

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2/ Martin, Lawrence, The physical geography of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, pp. 29-72, 1916.

3/ Ibid., pp. 299-323.

and whose escarpments face northward and northeastward. The escarpment bordering the first of these cuestas is a conspicuous topographic feature of the Driftless Area between Kilbourn, Camp Douglas, and Merrillan. The second cuesta is capped by the Oneota dolomite and the third by the Galena dolomite and the "Trenton" or Platteville limestone ~~dolomite~~. Each cuesta may be thought of as a typical topographic land form, resulting from an exceedingly long period of weathering, wind work, and stream erosion, etching into relief the more resistent formations of the Paleozoic sedimentary rocks which dip gently to the southwest. The first two of these cuestas occupy most of the Sparta and Tomah quadrangles (See fig. 2).

The Western Upland of Wisconsin is a part of an important physiographic division of the Interior Plains of the United States. The remainder of this upland is in Iowa, Illinois, and Minnesota. It includes portions of the cuestas mentioned above, ~~and~~ also a part of the Niagara cuesta. This dissected plateau is bisected by the gorge of the Mississippi River. Most of it lies in the Driftless Area of the Upper Mississippi Valley. Such a name as "Mississippi Upland" or "Driftless Upland" might well be adopted.

Fig 2

The geologic formations exposed in the Sparta and Tomah quadrangles consist of: (a) the surficial, unconsolidated residual, colluvial, stream, and wind deposits of Quaternary age; (b) the gravel and conglomerate (Windrow Formation) of undetermined age, either Cretaceous or Tertiary; and (c) the Upper Cambrian and Ordovician sandstone and dolomite formations, known as the Eau Claire, Dresbach, Franconia, St. Lawrence, Jordan, Oneota, and St. Peter. Of these formations the Oneota is part of what was formerly designated the Lower Magnesian limestone, while the underlying sandstone formations were formerly called the Potsdam sandstone. The rocks not exposed include the basal strata of the Cambrian and pre-Cambrian igneous and metamorphic rocks.

PREVIOUS STUDIES.

Little geologic work directly relating to the two quadrangles has been published, although as part of the Driftless area they have received the attention of many of the students who have been concerned with its ~~peculiar~~ problems. A reconnaissance survey was made in 1874 and 1875 by Moses Strong.[4/] Four university theses which directly relate to the

4/ Strong, Moses, Geology of the Mississippi region north of the Wisconsin River, Geology of Wisconsin, Vol. 4, pp. 3-98, 1882.

whole or parts of the two quadrangles have been written, but none of these has been published.[5/] A paper by W. D. Shipton[6/] gives a description of

5/ Johns, R. B., The physiography and geology of the La Crosse river valley, Unpublished thesis, University of Wisconsin, 1900; Shipton, W. D., The geology of the Sparta quadrangle, Unpublished thesis, University of Iowa, 1916; Blanchard, W. O., The geography of the Tomah-Sparta quadrangles, Unpublished thesis, University of Wisconsin, 1917; Smith, G. H., The influence of rock structure and rock character on topography in the Driftless Area, Unpublished thesis, University of Wisconsin, 1921. (Manuscripts in libraries of respective universities)

6/ Shipton, W. D., A Note on Fulgurites from Sparta, Iowa Acad. Sci., Proc. Vol. 23, p. 141, 1916.

fulgurites found by him near Sparta, and the same author in a second short paper proposed a new formational term for the fine-grained and shaley sandstones which constitute the middle portion of the exposed Cambrian.[7] Other papers which in some degree bear on the geology of

7/ Shipton, J. D., A new stratigraphic horizon in the Cambrian system of Wisconsin, ibid., pp. 142-145.

the two quadrangles are Ulrich's[8] "Revision of the Paleozoic Systems",

8/ Ulrich, E. O., Geol. Soc. Amer., Bull., vol. 22, Pl. XXVII, 1911.

Bassler's[9] "Bibliographic Index of American Ordovician and Silurian

9/ Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils, United States National Museum, Bull. 92, vol. 2, Pl. II, 1915.

Fossils" in which is given a geologic section for Wisconsin, and one of Walcott's[10] papers, in which is defined the geologic section for western

10/ Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 57, No. 13, p. 354, 1914.

Wisconsin as worked out by Ulrich. ~~The latest~~ Recent published works relating to the Sparta and Tomah quadrangles are an abstract describing the rock terraces which are such conspicuous features of the surface,[11] a discussion

11/ Martin, Lawrence, Rock terraces of the driftless area of Wisconsin, Geol. Soc. Amer., Bull., vol. 28, pp. 148-149, 1917.

of the Paleozoic formations exposed in the Sparta and Tomah quadrangles,[12]

12/ Twenhofel, W. H., and Thwaites, F. T., The Paleozoic section of the Tomah and Sparta quadrangles, Wisconsin, Jour. of Geology, vol. 27, pp. 614-633, 1919.

and a paper on the Windrow formation.[13] The last published work is that

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13/ Thwaites, F. T. and Twenhofel, W. H., Windrow formation; an upland gravel formation of the driftless and adjacent areas of the Upper Mississippi Valley: Geol. Soc. America, Bull., vol. 32, pp. 293-314, 1921.

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of A. C. Trowbridge[14] on the erosional history of the region.

Trowbridge, A. C., The Erosional History of the Driftless Area, University of Iowa Studies, Vol. 9, 127 pp., 1921.

For general discussions of the geology and physiography of the region which embraces these two quadrangles, and studies of the history of the Driftless Area, reference can be made to the bibliographies prepared by Lawrence Martin[15] and W. D. Shipton[16].

15/ Martin, Lawrence, The physical geography of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, pp. 70-72, 89-92, 168-169, 194-195, 322-323, 345-346, 1916.

16/ Shipton, W. D., Bibliography of the Driftless Area: Iowa Acad. Sci. Proc., vol. 24, pp. 67-81, 1917.

GEOGRAPHY

TOPOGRAPHY

General features. The Sparta and Tomah quadrangles lie at the southwestern edge of the great sandy Central Plain of Wisconsin. Within this plain the landscape features are different from any elsewhere in the United States east of the Mississippi. The hills are buttes and mesas with great bare cliffs and crags of sandstone. They contrast sharply with the flowing contours and soft curves of the adjacent territory. It is a bit of far western topography surrounded by country of the eastern type.

The hills of the central plain are outliers of a great escarpment which stretches from Kilbourn northwest through Tomah thence on to the north through Black River Falls and into the glaciated area south of Eau Claire. Fig 2. Southwest of the escarpment is the dissected plateau whose uplands are four or five hundred feet higher than the plain; this is the Western Upland of Wisconsin. The contrast between the plain and the hilly plateau may easily be seen from the Chicago, Milwaukee, and St. Paul Railroad which parallels the escarpment from Kilbourn to Tomah and thence passes through it into a west flowing river valley by means of the tunnel at Tunnel City just north of the Tomah quadrangle. A much better impression of the country can be gained by the automobile tourist who traverses the district on either State Trunk Highway 21 or 12.

The Central Plain. A small portion of the Central plain is shown in the far northwestern corner of the Tomah quadrangle. For a better understanding of its relations to the Western Upland the reader should consult the Dells, Kendall, and Mauston quadrangles which adjoing the region under discussion on the east. The plain is nearly a deal level area of sand, with large marshes. The swamp which stretches northeastward from Tomah is two-fifths as large as the state of Rhode Island. The prevailing vegetation is scrub oak, jack pine, sweet-fern and other plants unlike those prevalent in the surrounding areas of better soil. Pines on the plain and clinging in precarious positions on the rocky buttes and mesas,and tamaracks in the swamps, are outlying stragglers from the northern coniferous forests. They furnish a notable contrast to the open prairies near the Great Lakes, and to the deciduous trees of the East and South. The swamps and oak trees show definitely, however, that the region is not arid. The sandy soil makes the precipitation ineffective because much of the rainfall sinks into the ground at once. Wind work is dominant not because the district is in the arid lands, but because the surface materials are sandy. The smaller plants on the hills at Tomah, Camp Doubles, and at other places in the Driftless Area, nevertheless, include dwarf cacti such as the prickly pear. The soil of the western Central Plain is so sandy that farms are poor and settlement sparse. The crops grown are potatoes, buckwheat, oats, rye, barley, and cranberries.

The monotony of the plain is broken by occasional buttes, mesas, and rocky towers, which rise like islands from a sea of forest and swamp. Some of these reach an elevation of two to three hundred feet with precipitous sides and wierd irregular crags which may impress many as grotesque rather than beautiful. Below these high hills are low mounds of wind blown sand and rare knolls of old stream gravels. The whole region has an aspect much like portions of the far west.

The Western Upland. From the edge of Limekiln Hill in the Tomah quadrangle at an altitude of 1400 feet above sea level, or nearly 450 feet above the plain at the city of Tomah, one may see a sharp contrast between the topography to the west and south and that to the east (fig. 3). In the former direction is a rolling country with clay soil, nearly all cultivated, whose nearly level ridge tops, capped by the Oneota dolomite, blend in the distance into the semblance of a plain. Closer inspection shows, however, that no part of the dolomite upland is truly a plain, but that all is well drained. The entire upland is thoroughly cut up by branching, steep-sided valleys from 300 to 500 feet in depth, the largest of which are several miles in width. Turning to the east, one can see the irregular escarpment already referred to, dropping down 500 feet or more to the monotonously level surface of the Central Plain. The descent is in two steps, the first from the ridge tops of Oneota dolomite over the Jordan and St. Lawrence sandstones to a narrow, rolling shoulder or bench underlain by Franconia sandstones and greensands; the second over steep slopes and locally over precipitous cliffs of Dresbach sandstone to the level surface of the Central Plain. The Franconia bench, or cuesta as it may be called, is here 4 to 5 miles wide and is cut by valleys 100 to 200 feet in depth. The escarpment which separates it from the Central Plain is steeper than the slope or cliff which separates it from the ridge tops of Oneota dolomite, but they are much alike in plan. Looking farther eastward one sees the isolated castellated sandstone outliers, left behind in the retreat of the escarpment, and the vast flats of stream and lake deposits stretching away for more than forty miles to the terminal moraine of the Wisconsin stage of glaciation on the eastern horizon (fig. 2).

Rock Terraces. Turning back again to the west, one will see that this same rock terrace, or bench, is repeated in the wider valleys of the cuesta, so that the valleys may be described as double (Figs. 3 and 4).

A St. Lawrence rock terrace and a Franconia rock terrace are the two persistent topographic features within the valleys of the region. There are in places 4 or 5 minor steps in the Franconia terrace. The Kickapoo valley in the Tomah quadrangle is double or benched, the Franconia terraces making broad upper shelves, as if a narrower valley had been intrenched below the level of a broader one (see p.). The rock terraces and the cliffs in the Sparta and Tomah quadrangles are features due to weathering of unequally resistant rocks. The cliff-making sandstones are coarse-grained and thick bedded, the Jordan being quartzite at the top. The cliffs owe their existence, however, to firm layers above the soft sandstone: these firm layers are in the different places quartzite, dolomite, and calcareous sandstone. The terrace making sandstones are fine-grained shaly or calcareous. The St. Lawrence formation is very calcareous near the base and the Franconia ~~is~~ glauconitic ~~with~~ has a micaceous sandy shale bed at the bottom. Each forms a relatively impervious capping for the underlying soft rock. The steep slopes of the escarpment and valleys are nearly all wooded.

Elevations. The area of the Sparta and Tomah quadrangles ranges in altitude from 710 feet above sea level where the La Crosse River leaves the Sparta quadrangle to 1452 feet on the Oneota upland one half mile west of

Mitchell School south of Tomah. The Oneota ridge tops descend from this maximum to an average of 1340 feet in the southwestern part of the area. The La Crosse valley slopes from 820 feet at the east to 710 feet at the western border of the area. The Kickapoo valley descends from 1200 feet north of Norwalk to less than 900 feet at Oil City. Lemonweir Creek, near Tomah in the Central Plain, has an elevation of 950 feet above sea level.

Relief. The Franconia terraces average 100 to 200 feet in height above the Central Plain, and the tops of the Oneota ridges are 250 to 300 feet higher. The average difference in elevation from hill tops to the adjacent valley bottoms is over 400 feet. Many slopes exceed 25 degrees. In many places bold crags and precipitous cliffs, 30 to 50 feet in height, give a picturesque variety to the landscape. Castle, Chimney, Cave, and Chicken Rocks are among the better known of these.

Drainage. The Sparta dnd Tomah quadrangles lie at the headwaters of three of the principal streams of western Wisconsin. The La Crosse River flows nearly due west to the Mississippi and drains most of the area (277 square miles). South of the La Crosse basin 21 square miles are drained by Coon Creek which runs southwesterly to the Mississippi River. East of these basins the Kickapoo River drains about 94 square miles in the Tomah quadrangle. This stream is a tributary of the Wisconsin River, flowing into it at Wauzeka, not far above Prairie du Chien. Approximately 37 square miles of territory near Tomah drain into the Lemonweir River, another tributary of the Wisconsin, which it joins above Kilbourn. The small remaining portion of the area is drained in part directly to the Mississippi by Mormon Creek and in part to Black River through Fleming Creek (1.2 square miles each).

La Crosse River in few places is as much as 100 feet in width.

The discharge, measured a few miles west of the Sparta quadrangle, varies from a minimum of about 150 cubic feet per second to something like twenty times that amount during exceptional floods. (fig. 5) The flow of the

Fig 5

streams has not been measured. The streams rising upon the limestone uplands are most subject to floods. The streams which rise in the sandy areas are largely fed by springs.

CLIMATE.[1]

1/ Whitson, A. R., Geib, W. J. ~~and~~ Dunnewald, T. J., and Lounsbury, Clarence, Soil Survey of La Crosse County, Wisconsin, Wisconsin Geol. and Nat. Hist. Survey, Bull. 40, pp. 67-72, 1914.

The quadrangles have a continental climate with hot summers, cold winters, variable weather, and rainfall adequate for agriculture. The prevailing winds are from the south. The mean annual temperature is about 46°; for January the mean is about 15°; for July it is a little more than 70° Fahrenheit. The maximum range of temperature is 147°, ranging from 104 above to 43 below zero, Fahrenheit. The snowfall generally covers the ground from December to March, its total amount averaging 40 inches; the total annual precipitation (average annual rainfall) is a little more than 30 inches, ranging from 21 inches in the dryest to 37 inches in the wettest recorded year. The heaviest rainfall is in June, and nearly 70 per cent of the annual rainfall comes between April and September, inclusive, falling just before and during the period of plant growth. The period free from killing frosts is 142 to 175 days, and this constitutes the growing season. In winter the soil freezes to a depth of 10 inches to 2 feet. Thunder storms are frequent in summer, often with hail storms and high winds, but destructive storms are rare.

The climate varies considerably with altitude, the last killing frost in spring at Viroqua, on the upland, being several days later than in the valleys at West Salem and La Crosse. This is shown in the accompanying table, which gives temperature and rainfall at all regular U. S. Weather Bureau Stations and stations occupied by voluntary observers

Fig 6 and Table Fig 6 and Table To be furnished by Martin

adjacent to the Sparta and Tomah quadrangles, including those (a) at La Crosse, in the Mississippi Valley, and West Salem in the valley of the La Crosse River to the west, (b) at Viroqua, on the upland, a few miles to the south, and (c) at Valley Junction, Mauston, and Mather in the Central Plain to the east.

VEGETATION.

The native vegetation is closely related to the soil and topography. On the better soils and low slopes deciduous trees predominate. The principal varieties are black, red, white, and burr oak, maple, elm, hickory, and butternut. On rough and poor land jack pine, scrub and burr oaks predominate together with some poplar, Norway and white pine. On wet lands water birch and willow are the commonest trees. The country was originally forested much more heavily than now. The woods which remain are nearly all on steep slopes or areas of very poor soil, as near the Target Range east of Sparta. The merchantable timber has been nearly all cut but small saw mills still operate and supply much of the local demand for lumber of low grade. Among the smaller growth hazel brush is the most prominent shrub. In sandy districts the sweet-fern and blueberry are common.

CULTURE.

Population. The population of the Sparta and Tomah quadrangles is about 19,700, according to the census of 1920. Of this number about one-fourth live in cities or villages. Sparta has 4,466 and Tomah 3,257 inhabitants. The village of Bangor has 654 inhabitants, Norwalk ~~has~~ 531, Wilton 519, and the other villages are still smaller.

The proportion of foreign-born, as stated by the U. S. Census, varies from 13 per cent to over 30 per cent in different townships.(1) It is evident to any observer, however, that a very large proportion of the rural population is of foreign extraction. In the townships of Burns, Portland, Washington, and Leon the Norwegians are numerous. Elsewhere Americans of German descent predominate. Near Tomah there is a Winnebago Indian school which in 1914 housed 1274 American Indians.

Industries. Farming is the leading industry in the area. Eighty per cent of the private lands are used for farms; fifty per cent of the farm area is improved land. The principal crops, arranged in order of acreage, are oats, wheat, hay, corn, barley, rye, potatoes, and apples.

(1) Blanchard, W.O., The geography of the ~~Sparta~~ Tomah - Sparta quadrangles, unpublished thesis, University of Wisconsin, 1917

The hilly topography is better suited to small grain than to corn because of the excessive soil erosion resulting from cultivation of the latter. Near Sparta there is considerable truck gardening and growing of small fruits; but this is being overshadowed by dairying. There are now 12 creameries and cheese factories in the area. There are condensaries at Sparta and at Cashton, the latter just south of the Sparta quadrangle.

Manufacturing is not very important. The bridge works of the Chicago, Milwaukee, and St. Paul Railway at Tomah is the largest manufacturing establishment. Well drilling machinery and condensed milk are made at Sparta, where tobacco packing is also important. A former brewery at Bangor has been converted into a cannery. Waterpower is developed at Sparta, Angelo, and Wilton. A total of about 450 horse power is developed, most of which is used for electric light. Small mills are run by water power at Burns, Sparta, Leon and in Big Creek Valley.

Transportation. Situated at the narrowest part of the Western Upland, where the divide between La Crosse valley and the Central Plain of Wisconsin is easy to pass, this area is better supplied with railways than most of the adjoining region.

The main line of the Chicago, Milwaukee, and St. Paul Railway passes through Tomah and Sparta, crossing the divide at Tunnel City just north of the Tomah quadrangle. The maximum grade on this line is 0.66 per cent. Branches extend northeastward from Tomah and southward from Sparta. The latter, the Viroqua Branch, ascends to the dolomite upland through Pine Hollow in the southeastern corner of the Sparta quadrangle with a maximum grade of 2.51 per cent.

The Chicago and North Western Railway has two lines. The southern or old line passes through the headwaters of the Kickapoo basin. Two divides within the area are crossed by tunnels. The maximum grade is 1.25 per cent. A new line, designed mainly for freight service, parallels the Chicago, Milwaukee and St. Paul Railway from Tunnel City to Sparta. It has a maximum grade of 0.5 per cent eastbound and 0.7 per cent westbound.

The steep hills and the large areas of sand within the quadrangles result in poor highways. In addition, many of the roads were laid out with the idea of avoiding division of fields and not with a view of securing the best grades. This is now being remedied in ~~part~~ many places. Except in the vicinity of Sparta, only a small percentage of the roads were surfaced at the time of the survey of the area. The highways along the ridge south of Tomah to Sparta via Coles valley (Route 21), south of Tomah via Wilton to Oil City (Route 107), west of Sparta on the north side of the La Crosse River (Route 21), north of Sparta and up Leon valley to Cashton (Route 27), along the ridge through Portland and Middle Ridge (Route 33), and north and south through Tomah (Route 12) have been included in the State Trunk Highway system.

Federal Military Reservation. The Sparta Target Range, a federal military reservation northeast of Sparta, covers 14,127 acres. It was acquired by the U. S. Army in 1908 at a cost of about $150,000. Approximately $40,000 were spent for temporary buildings, roads, and water supply up to 1911. In 1917 additional wooden building for a large number of artillerymen were built. Water for 10,000 men can be supplied from artesian wells at Camp Robinson and at two other camp sites.

The reservation has 170 different tested artillery ranges from 1 to 5 miles in length; its rifle range has 180 butts, pits, and targets. There are 14 miles of railway sidetrack, capable of loading or unloading 22,000 men and their equipment in 24 hours. With extensions of the side-tracks 90,000 men could be handled in 24 hours.

During 1917-18 the Sparta Target Range was used extensively for the training of field artillery units for the American Expeditionary Forces. Subsequently the reservation has been used for the storage of explosives.

Educational Institutions. In addition to the rural and city schools, the Sparta and Tomah quadrangles have a State School for Dependent Children at Sparta, the county seat of Monroe County. There is an Indian School a quarter of a mile northeast of the Tomah quadrangle.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

The exposed rocks of the Sparta and Tomah quadrangles are wholly of sedimentary origin. They include an older group of early Paleozoic age, consisting of poorly cemented sandstones and compact and firm dolomites, and a younger unindurated group of Quaternary age, embracing valley alluvium with its bordering colluvium, dune sands, loess, and residual soils. Included in the latter group are local occurrences of conglomerates of probable Cretaceous age Near the northeastern corner of the Tomah quadrangle are deposits which were probably laid down in Glacial Lake Wisconsin.

The exposed thickness of the older group aggregates between 700 and 800 feet. The thickness of the younger group varies on the uplands from a few inches to about 75 feet. It has a maximum thickness of about 150 feet in the valleys. Deep wells prove that the sedimentary rocks extend about 350 feet below the lowest exposed strata.

Four definitely recognizable systems are represented in the unexposed and exposed strata of the two quadrangles--pre-Cambrian, Cambrian, Ordovician, and Quaternary. A fifth system is represented by gravels and conglomerates whose stratigraphic position lies somewhere between the Silurian and the Quaternary. Deep wells which penetrate the Paleozoic sediments have shown that the unexposed pre-Cambrian is represented by igneous and metamorphic rocks. The Cambrian strata are referred to the St. Croixan, the uppermost series of that system, while the Ordovician strata were deposited during the early portion of that period.

GENERAL SECTION

The sequence, general character, and approximate thickness of the exposed and unexposed formations in the Sparta and Tomah quadrangles are shown graphically in the accompanying columnar section. (fig. 7)

ROCKS NOT EXPOSED

PRE-CAMBRIAN GROUP

The exposures of pre-Cambrian rocks nearest to the Sparta and Tomah quadrangles are in the vicinity of Black River Falls, City Point, and Babcock, 20 to 25 miles to the north, and at Necedah, 20 miles to the east. (Fig. 8) Within the quadrangles the rocks of this system have been reached in deep wells at Tomah[1], Sparta, Oil City,[2] McCoy, and Bangor. Cuttings from the Tomah well alone have been available for examination. These indicate a granite or gneiss of medium texture with the mineral components consisting of clear and milky quartz, pink feldspar, and white mica. The top portion is of a greenish shade which is possibly due to chloritization. Other wells of which no record could be obtained are deep enough to strike the pre-Cambrian. Along the Black River at Black River Falls the pre-Cambrian rocks consist of light and dark colored acidic gneiss, coarse-grained gray diorite, fine-grained mica schist, and iron formation.[3]

1/ Strong, Moses, Geology of the Mississippi region north of the Wisconsin River, Geology of Wisconsin, vol. 4, p. 60, 1882.

2/ Ibid., pp. 59-60.

3/ Irving, R. D., Geology of Wisconsin, vol. 2, p. 499, 1877. See also vol. 4, pp. 59-60, 1882.

The pre-Cambrian rocks lie from 800 to 1,000 feet below the summit levels of the upland of the two quadrangles. They were reached in the Tomah well at 453 feet below the surface (527 feet above sea level), in the Oil City well at 490 feet below the surface (410 feet above sea level), in the Sparta well at 365 feet (425 feet above sea level), in the Bangor well at 375 feet (365 feet above sea level), and possibly at 300 feet in the McCoy well (585 feet above sea level).

Such data as are available indicate that the surface of the pre-Cambrian is essentially that of an irregular plain sloping to the south and west at the rate of about eight feet per mile. So far as the two quadrangles are concerned the facts are not sufficient to warrant this conclusion, but data derived from wells in many other parts of Wisconsin together with the surface of the pre-Cambrian from which the sediments have been removed but a relatively short time render the conclusion reasonably certain. This surface was developed by deep erosion. This is proven by the texture of the deep-seated igneous and metamorphic rocks which underlie it. The erosion of a great thickness of rock is implied and it is suggested that in pre-Cambrian time a mountainous region once existed over the Sparta-Tomah region, an inferrence supported by the occurrence elsewhere in the state of residuals on the pre-Cambrian plain, of which some project through the sedimentary rocks, while others are known from wells.

PALEOZOIC GROUP.

CAMBRIAN SYSTEM.

General Statement. The rocks which overlie the buried pre-Cambrian peneplain are known from exposures to the north of this district to be of Upper Cambrian or St. Croixan age. The unexposed Cambrian strata are sandstones with relatively thin strata of red, green, and blue shale. On the outcrop to the north they have been divided by Ulrich 1/ into the Mt. Simon sandstone and the Eau Claire shaley sandstone. The meager information available from well records within the quadrangle does not permit the exact discrimination of these formations.

1/ Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 57, No. 13, p. 354, 1914. Ulrich, E. O., personal communications.

Relations of the Cambrian formations to the pre-Cambrian. The sandstones and other Cambrian strata of which the Dresbach forms the upper unit rest unconformably on the eroded surface of the pre-Cambrian. This contact is not exposed in the Sparta and Tomah quadrangles, but the sharp change in the wells from poorly consolidated sands to compact crystallines clearly proves the unconformity. Exposures outside the quadrangles show that in many places the Cambrian rests either on residual material derived from the pre-Cambrian or directly on the crystallines. There is some disagreement as to the time of development of this residual material, Irving 1/ considering it to have been developed since the Cambrian was

1/ Irving, R. D., Kaolin in Wisconsin, Wisconsin Acad. Sci., Trans., vol. 3, pp. 13-17, 1876. Geology of Central Wisconsin, Geology of Wisconsin, vol. 2, p. 468, 1877.

deposited, while Weidman 2/ thought it to have been formed antecedent to

2/ Weidman, S., Geology of north central Wisconsin, Wisconsin Geol. and Nat. Hist. Survey, Bull. 16, p. 389, 1907.

the overlying Cambrian.

Thickness. The thickness of the unexposed Cambrian is about 350 feet as determined from well records only one of which, that at Tomah (see p.) has been verified from samples of the cuttings. On the geological sections the base of the Eau Claire, and therefore the top of Mt. Simon has been assumed to lie at the bottom of the shales which occur from 50 to 150 feet above the pre-Cambrian. A thickness of 200 feet has been tentatively assigned to the Eau Claire shaley sandstones, their upper limit being fixed at the shale zone which outcrops at Neshonoc on La Crosse River, five miles west of Bangor. 3/ Dr. Ulrich stated:" I

3/ Ulrich, E. O., personal communication, Sept. 29, 1921.

had some of the material ... prepared and find three zones of the formation represented in the collections. The top one . . . proves to have distinctly Upper Eau Claire fauna, so that we must assume that the beds there exposed are pretty near the top of the Eau Claire."

Character of the unexposed Cambrian. The unexposed Cambrian strata consis dominantly of quartz sands of fine to medium grain, and white, gray, and yellow colors. The record of the city test well at Sparta, drilled in 1921 is the best available, but shows only the strata above the lower Eau Claire shales. The rock down to 41 feet depth is probably Dresbach.

Record of city test well, Sparta, Wis. 4/

4/ Record from samples presented by Charles Erickson, Supt. of Waterworks, examined by F. T. Thwaites.

N.W. $\frac{1}{4}$. N. E. $\frac{1}{4}$, Sec. 13, T. 17 N., R. 4 W. Elevation about 855.

	Thickness	Depth
Surface soil	6	6
Sandstone, fine to medium, soft, white	35	41
Sandstone, fine to medium, light yellow	14	55
Sandstone, fine to medium, light yellow	5	60
Sandstone, fine to medium, light yellowish gray	14	74
Sandstone, fine to medium, white	13	87
Sandstone, fine to medium, light yellowish gray	22	109
Sandstone, medium, light yellow	5	114
Sandstone, fine to medium, light yellowish gray	25	139
Sandstone, fine, light yellowish gray, calcareous	3	142
Sandstone, fine to medium, light yellowish gray	17	159
Sandstone, fine to medium, white with streaks of blue shale	4	163
Sandstone, very fine to medium, yellowish gray and white	2	165
Sandstone, fine, gray	4	169
Sandstone, very fine to coarse, white, slightly calcareous	32	201
Sandstone, exceedingly fine to medium, light gray, slightly calcareous with some blue shale	13	214
Sandstone, very fine to coarse, light gray with some blue shale.	6	220

A few samples are available from the abandoned well at the Tomah city park and by combining the examination of those with the log published by Strong 5/ the following section has been made.

5/ Strong, Moses, Geology of the Mississippi region north of the Wisconsin River, Geology of Wisconsin, vol. 4, p. 60, 1882.

Log of Tomah City Park Well.

(Well 492 feet deep, curb at elevation of 982 feet above sea level.)

	Thickness	Depth
5. Soil and clay, probably terrace gravel and sand.	25	25
4. Sandstone, gray to yellowish, fine to coarse. Samples incomplete, but no shale reported, coarsest layers 220 to 520 feet	392	417
3. Sandstone, brick-red, medium to coarse grain.	36	453
2. Rock decomposed red and greenish, possibly residium from crystallines, but the material may be arkose.	17	470
1. Granite, pinkish, or granite gneiss.	22	492

The upper shaley zone of the Eau Claire which is exposed at Neshonoc is found in wells throughout the western and southern parts of the quadrangles but seems to be represented by fine grained sandstones in the vicinity of Sparta. Statements of well drillers with regard to the lower shales are contradictory. The fullest information was gathered by R. B. Johns 6/ in 1899. He found that there are two layers of shale at

6/ Johns, R. B., Physiography and geology of the La Crosse River valley, Unpublished thesis, University of Wisconsin, 1900.

Sparta. Of these the upper lies at a depth of about 250 feet below the surface at the city and the lower at 305 to 310 feet. The upper is red and blue and the lower is black. There are some shale layers between the two main beds, both of which vary much in thickness. Information collected by the writers, however, indicated that there are shales at lesser depths, a fact confirmed by the samples from the test well cited above.

The character of the rock below the 300 foot level at Sparta is not definitely known. From the statement of drillers that the water from that horizon is very ferruginous it appears probable that the strata consist of red sandstone and shale such as is exposed near Black River Falls north of the quadrangles.

ROCKS EXPOSED

Paleozoic Group

Cambrian System

St. Croixan Series.

General Description. The exposed Cambrian strata are dominantly sandy, but thin, usually sandy shales and dolomitic bands and lenses are present. The lower portion of the exposed strata consists largely of clean quartz sands while the strata of the upper half contain a great deal of greensand in two members and layers of sandy dolomite and shaly sandstone are present in others. The Cambrian strata are readily differentiated from those of the Ordovician, since in some places near the top of the former and at other places near the base of the latter there are quite commonly one or more beds of case-hardened, quartzitic gray sandstone which are overlain by the somewhat massive compact Oneota dolomites of the Ordovician.

Five Cambrian formations are exposed in the Tomah and Sparta quadrangles. In ascending order these are the Eau Claire shaly sandstone, the Dresbach sandstone, the Franconia glauconitic and shaly sandstones, the St. Lawrence sandstone, and the Jordan sandstone. It is possible that a fifth Cambrian formation is present since at the top of the strata which certainly belong to the Jordan formation there are a few feet of sandstone which resemble the Madison sandstone of southern Wisconsin. Farther to the northwest in the vicinity of Eau Claire Ulrich 1/ has differentiated two other formations

1/ Ulrich, E. O., in Walcott, C. D., Cambrian geology and paleontology, Smithsonian Misc. Coll. 57, p. 354, 1914.

beneath the Dresbach of which the basal has been called the Mt. Simon sandstone and the upper the Eau Claire shale. Each of these probably underlies the Sparta and Tomah quadrangles, as more than 40 feet of the latter are exposed in the banks of the La Crosse River at West Salem only a few miles to the west.

Both wave and current ripples and an abundance of cross-lamination with foresets up to 50 feet in length are present in many horizons. Mud cracks are present in the Dresbach, Franconia and St. Lawrence formations.

Except for local occurrences the sandstones of the Cambrian formations are poorly cemented. Many beds crumble on slight exposure and in numerous places the exposed rock has little more resistance than does a heap of sand, to which it may be readily reduced with slight pressure. In quite a number of places certain portions are quarried for sand. No satisfactory explanation of the absence of consolidation has yet been advanced. Consolidation may be produced by pressure, recrystallization of the constituents, or a cementation through material deposited by water. These strata have not been subjected to pressures other than those arising from the weight of the overlying strata and these pressures probably have never been great enough to be effective and the mineral constituents of the sandstones do not readily recrystallize in the absence of heat. In these respects there is nothing strange in the absence of consolidation, but it is somewhat more difficult to understand why cementation has not occurred generally, as it is known to have done locally. These sandstones are at present filled with water which carried a great deal of calcium and magnesium carbonates in solution and it is probable that such has quite generally been the case since their deposition. That a carbonate cement is widely present below the zone of weathering is shown by samples from deep drill holes, but the Dresbach formation is quite generally and other formations locally devoid of carbonate even far below the belt of weathering.

The thickness of the individual Cambrian formations, the Dresbach excepted, has been determined in many places. The thickness of the Dresbach and the formations which underlie it to the pre-Cambrian floor has been determined only in those places where deep wells have reached that floor. These wells show a variation from 615 feet at Sparta to 590 feet at Oil City. The interval from the base of the Franconia to the summit of the Cambrian varies from 230 feet near Norwalk to 330 feet near Melvina and is less than 275 feet over most of the northwestern quarter of the area(Fig. 18). It is least thick along a line extending northeast and southwest in the vicinity of Norwalk and rises to a little above 275 feet along the east border of the Tomah quadrangle. The variation in thickness of this interval is largely due to the St. Lawrence and Jordan formations which, taken together, average 120 to 150 feet in thickness.over most of the district, but rise to 200 feet near Melvina and fall to 89 feet near Norwalk. The places of greatest thickness may represent places of maximum accumulation or places of less erosion in the pre-Oneota erosion interval. The total thickness of the Cambrian strata is about 900 feet.

Eau Claire Formation.

General Statement. Only one exposure of strata which may be referred to the Eau Claire formation as defined by Dr. Ulrich is known within the area covered by the Sparta and Tomah quadrangles. This is in the bed of La Crosse River at Angelo where are exposeda few feet of heavy-bedded, white and yellow, medium grained, ripple marked and mud cracked sandstone with partings of greenish gray shale. This exposure is approximately 300 feet below the top of the

Dresbach Sandstone.

General Statement. The strata of the Dresbach formation underlie the lower land of the two quadrangles and along many of the valleys its upper strata form coalescing tower-like cliffs. Exposures of these upper strata are numerous.

Thickness. The formation has an exposed thickness of about 250 feet, but at no place is this thickness shown in a single section, although near Bangor a number of overlapping sections expose about 230 feet. The exposure showing the largest continuous section is that at Tunnel City on the Chicago and Northwestern Railroad (just off the northern edge of the Tomah quadrangle) where 70 feet of white and yellow friable sandstone may be seen.

Character of the Dresbach Formation. The Dresbach formation is almost wholly composed of clean quartz sandstones. The grains are well rounded in some layers while in others they are quite angular. Some of the rounding in respect to dimension of grains and perfection compares well with that which one finds in modern sands of eolian origin. The average large grain varies from one-fifth to three-fifths of a millimeter. In most beds the assortment is excellent, but inmany of the beds there is considerable mixing, diameters varying from one-fortieth to one-fourth millemeter with a few grains reaching even larger dimensions (see Fig. 9). Interbedded more or less throughout the exposed sandstones are thin lenticular laminae of green sandy shale, the maximum thickness of which is about a centimeter.

The colors of the Dresbach sandstones vary from white to yellow and locally some layers are brown to red. Some exposures are characterized by "iron rocks", or sands cemented by brown iron oxide. These do not appear to be characteristic of any horizon and apparently are the result of weathering.

The cementation of the sandstones is very poor and in many places the rock is quarried for sand. Case hardening is locally developed. The cliffs built on this formation are generally not due to resistance of strata within the formation, but to the protection given by the basal layers of the overlying formation.

The stratification is generally lenticular with the beds varying in thickness from about two inches to more than five feet. With one exception it has not been possible to recognize beds beyond the limits of an exposure. The exception is the group of beds at the top which are perforated by the vertical and horizontal tubes supposed to have been made by worms. The sandstones are generally cross-laminated with the directions of inclination widely variant, but there appears to be a predominance in a southerly direction. The foresets are for the most part short, 5 to 6 feet being the average maximum; but in an outlier on the south edge of the village of Rockland there are foresets with lengths of 50 feet and some of the inclined beds are themselves cross-laminated. The long foresets are inclined to the east at angles of 15 to 20 degrees. In the same outlier is other cross-lamination with inclination in other directions. Cross-lamination with the characteristics developed by wind deposition occurs at several localities.

Mud cracks occur just east of Rockland in a horizon about 100 feet below the top of the Dresbach. Farther northwest, in the exposures of the Eau Claire shales, mud cracks are extremely common and they probably would be equally so in the Dresbach did not the character of the sands quite generally preclude their development.

The sections which follow show in detail the character of the Dresbach formation. The Melvina section is thought to show strata which are a little higher than the upper bed of the Tunnel City section. (Plate I, Illustration sheet)

Section at Tunnel City (in C. & N. W. Ry. cut east of tunnel.)

9. Franconia formation,

8. Sandstone, medium to coarse grain, vertical worm holes abundant. The grains are mixed, varying from about one-twentieth to one half millemeter indiameter. 1 foot.

7. Sandstone, greenish yellow, weathers into sand nodules up to one-half inch in diameter, grains well sorted, angular, about one-tenth millemeter in diameter for maximum, worm perforated, contains fragments of Atremate brachiopods. 1.2 feet

6. Sandstone, similar to that of zone 8. 1 foot

5. Sandstone, similar to that of zone 7. 1 foot

4. Sandstone, white and yellow, in 4 to 6 inch beds, rock poorly cemented, this lenticular laminae of green sandy shale are sparsely present, generally less than a centimeter thick. The assortment is generally good, sands of medium grain. Wormholes are present, but are not conspicuous. 26.9 feet.

3. "Iron stone", medium to coarse sands cemented by brown iron oxide. The resistance of this layer determines a small shelf which is conspicuous as it supports considerable vegetation. 1 to 2 feet.

2. Sandstone, white to gray, medium grain, locally stained by iron

oxide, poorly and obscurely bedded. The sand grains are well rounded and polished, one-fifth to one-half millemeter in diameter. Some layers have short foreset cross-lamination with northwesterly inclination. Thin lenticular laminae of green sandy shale occur throughout. 30 feet.

1. Sandstone, yellow, medium to coarse grain, locally iron stained, generally friable. Two beds, the upper 3 feet thick, the lower with the base concealed. Lenticular laminae of green sandy shale present throughout. Base at elevation of 1053 feet. 8 feet exposed.

<u>Section at Melvina (about 2 miles N. E. of Melvina near school house, Sec. 3, T. 16 N., R. 3 W.</u>

14. Franconia formation.

13. Sandstone, yellow, medium to coarse grain, rounded grains, cross-laminated, perforated by <u>Scolithes</u> tubes. 4.5 feet

12. Sandstone, gray with yellow patches, fine to medium grain, grains angular. 1.5 feet

11. Sandstone, like that of zone 13. 1.2 feet

10. Sandstone, like that of zone 12. 0.2 feet

9. Sandstone, like that of zone 13. 0.8 feet

8. Sandstone, like that of zone 12. 0.2 feet

7. Sandstone, like that of zone 13. 0.6 feet

6. Sandstone, gray with yellow patches, medium grain, grains more or less rounded. 0.3 feet

5. Sandstone, like that of zone 13. 1 foot

4. Sandstone, like that of zone 12. 0.5 feet

3. Sandstone, like that of zone 13, cross-laminated with northerly inclination, foresets short. 0.8 feet

2. Sandstone, gray, medium to coarse grain, cross-

laminated. 1.3 feet

1. Sandstone, gray, medium to coarse grain, horizontally laminated. Appears as one bed, but is divided into 4 to 18 inch units by 1 to 2 inch bands of yellow and brownish sandstone. 11 feet.

Fossils. The uppermost beds of the Dresbach formation are characterized by vertical tubes which vary in diameter from 3 to 5 millemeters. These are generally known as Scolithaes and they are thought to have been made by marine worms. In the field the beds containing these tubes were generally known as the "wormstones". Locally associated with the highest bed of the "wormstones" are fragments of Atremate brachiopods. It is possible this bed should be referred to the Franconia. No fossils have been seen in the lower exposed strata. Fossils have been collected in the Dresbach at New Lisbon where they consist of tracks. The track horizon is about 200 feet below the top of the formation. The tracks are of two varieties; one small, the other large. Both consist of straplike impressions bounded by each side by a ridge and crossed by wavy ridges and impressions, the relief in the smaller averaging about 5 millemeters with the transverse ridges about 25 millemeters from each other. This track is from 5 to 7.5 centimeters wide. The larger form has a width of from 10 to 12.5 centimeters wide and its details are correspondingly larger. Professor Chamberlin has described the former under the name of Climatichnites youngi and to the latter he gave the name of C. Fosteri.[1]

1/ Chamberlin, T. C., Geology of Wisconsin, Vol. 1, p. 132, 1883. Todd, J. E., Description of some fossic tracks from the Potsdam sandstone; Wis. Acad. Sci. Arts and Letters, Trans., vol. 5, pp. 276-281, 1882.

It has been conjectured that these markings were made by a crustacean or a worm. If this be correct, there must have been quite large animals at that time, but no organisms have been discovered in the Cambrian strata of Wisconsin or adjacent states which could have made these markings. It is possible that they may be impressions of the ~~Halli~~ Thalli of algae.

Conditions of Origin of the Dresbach Formation. The Dresbach sandstones show by the cross-laminations, ripple marks and the mud cracks that they were mechanically deposited in extremely shallow water. The cleanness of the sands and the roundness of the grains show prolonged washing, long transportation, and maturity of decay. They were mostly deposited by water and it is possible that all of them were so deposited. Deposition by wind may have played a part. The general absence of fossils does not lead to the general conclusion thatthe waters were not marine as it is known that drifting sands offer little inducement for colonization by marine organisms while any shells which might have been introduced into the sands would have been in an environment most favorable for their being ground to powder and for their solution after burial if they escaped such grinding. The various characteristics would appear to be best explained on the assumption that the sediments were deposited on broad tidal flats.

Franconia Formation.

General Statement. Over considerable areas of the northern halves of the two quadrangles the rocks of the Franconia formation form most of the divides. Throughout the southern halves the Franconia strata are exposed only on the slopes, the tops of the hills being crowned with higher strata. Exposures are not common because of the weakness of the rock.

It is possible to divide the Franconia formation into five members which in ascending sequence are as follows: (a) basal sandstone and overlying calcareous layer, (b) micaceous shale, (c) lower greensand, (d) yellow sandstone and (e) upper greensand.

Relations to the Dresbach Formation. The strata of the Franconia and the Dresbach appear to be parallel, but the presence on the top of the latter of what may be small erosion channels and the fact that in some places the basal layer of the Franconia rests on a "wormstone" and at others on one of the finer grained, yellow spotted sandstones, coupled with the further fact that in some exposures there are many "Wormstones" and in others few, suggests that the contact may be one of disconformity and that between the times of deposition of the Dresbach and the Franconia there may have been erosion of the former.

Thickness. The Franconia formation varies in thickness from 120 feet near the head of Fish Creek Valley to 160 feet at Tunnel City. The variation in thickness appears to be referable to three causes. The upper surface of the Dresbach may have had a littlerelief which would have led to a greater thickness over the hollows. There were quite likely inequalities in deposition such as appear to be characteristic of shallow water 1/ and the upper surface of the Franconia was eroded before the

1/ Kindle, E. M., Inequalities of Sedimentation, Jour. Geology, vol. 27, pp. 339-366, 1919.

deposition of the overlying St. Lawrence strata and this erosion is quite likely to have been differential.

Character of the Franconia Formation. The sedimenta composing the Franconia Fromation show great lateral variation and as a whole are of finer grain than are those of the Dresbach (fig. 10). Some beds contain considerable proportions of calcite and dolomite and two members have a high glauconitic content. Very little argillaceous material is present, although some of the fine grained sandstones generally go by the name of shale.

The bedding of the fine-grained sandstones is quite regular, but that of the greensand members is extremely lenticular. Ripple mark of both the wave and current type occurs throughout. Cross-lamination is extremely prominent in the greensand members, the foresets are rarely greater than two feet in length and most of them are a foot or less. The coarse sandstone at the base has cross-lamination with steep foresets, some of which are as long as 6 feet. The foresets throughout the formation appear to vary in direction of inclination through all points of the compass.

About 26 feet above the base of the lower greensand member there is at least one and there may be several mud cracked layers. These have been found throughout the northern half of each quadrangle, an area of from 150 to 200 square miles. Since the cracks have been observed in the lower greensand only in artificial exposures, mostly quarries and railroad cuts, which, so far as the lower greensand is concerned, are confined to the northern halves of the two quadrangles, it is probable that the mud cracks extend over a greater area than that given above.

The detail of each member is as follows:

(a) Basal sandstone and overlying calcareous layer. The basal sandstone has irregular bedding and is invariably cross-laminated. The foresets vary greatly in inclination and direction and not uncommonly reach lengths as great as 6 feet. The color of the rock is commonly some shade of brown, but varies to gray and locally it is green due to the presence of glauconite. The grains vary in diameter from about one-tenth to three-fourths millemeters with the greater number appearing to fall around one-fourth millimeter. Most of the grains appear to be subangular. The glauconite grains which are locally present have smooth botryoidal surfaces which could hardly have been developed by rolling. They are generally slightly larger for the average than are the quartz grains. Goldman's [1/]

1/ Goldman, M. T., Lithologic subsurface correlation in the "Bend series" of north central Texas, U. S. Geol. Survey, Prof. Paper 129, p. 4, 1921.

observation relating to the character of glauconite above an unconformity appears to apply to this occurrence in that the grains of glauconite in this lower member appear to show more detail of surface than do those in the higher members. The differences, however, are not marked. The thickness of this basal sandstone varies from 1 to 6 feet, but is commonly about 3 feet.

This sandstone locally contains many fossils. Fragments of trilobites are those most common and with them are generally associated fragments of linguloid and oboloid brachiopods. Most of the material is difficultly indentifiable and all of it underwent considerable transportation before final deposition. In the vicinity of Coles Peak and about the mouth of Farmer's Valley this layer is simply crowded with trilobite impressions.

The calcareous layer is composed of clear quartz sands in a matrix of gray, pinkish, or yellowish calcite, the latter varying from very finely divided up to crystals of three-fourths millimeters diameter. Locally calcite makes the whole of the bed.

Glauconite is invariably present to a maximum of about 10 per cent.

The diameters of the glauconite grains are generally one-fourth millimeter or less, but a few grains have diameters up to one-half of a millimeter and rare grains of ellipsoidal shape have the longest diameters as great as three-fourths of a millimeter. The glauconite grains have smooth, shining botryoidal surfaces except in such of them as have concave depressions arising from the pressure of grains of quartz. Nothing which could be related to the shape of a foraminiferal shell has been recognized. The calcareous layer is quite commonly short foreset laminated. Its thickness varies from total absence to a maximum of about 6 feet.

The resistance of the calcareous layer leads to its occurrence as a covering of the Dresbach cliffs (Plate VII, Illustration sheet). It is a fact of interest that blueberries appear to thrive over rocks of this zone and, if generally wanting in a locality, they may commonly be found just above the top of the Dresbach.

The calcareous layer usually carries fossils which are mostly brachiopods. A form common locally is a small oboloid-like brachiopod. Billingsella coloradoensis, Lingulella acuminata and Dicellomus politus occur rarely. Trilobites are not common.

The descending section which follows Sec. 2, T 17 N., R 5 W is an average one.

Section in Town of Burns, SW¼, SE¼, Sec. 2, T. 17N, R. 5 W.

3. Sandstone, brownish yellow, quartz sand grains in a matrix of yellowish and brownish pink calcite and glauconite--the calcareous layer. Contains small oboloid-like brachiopods and fragments of trilobites. 1.5 feet.

2. Sandstone, irregularly bedded, light brown to caramel colored--the basal sandstone of the Franconia. Contains fragments of trilobites. 3 feet.

1. Sandstone, yellow, friable (Dresbach). 0.5 feet.

(b) Micaceous shale. This member, commonly called shale, consists of fine grained micaceous sandstones. Clayey material occurs in occasional thin partings. Colors vary from gray to yellow. The beds are horizontal laminated, cross-lamination is not common and small asymmetrical ripple mark is abundant in some beds. Fucoidal markings are abundant.

Fossils are common in this member. These are chiefly fragments of trilobites and small oboloid brachiopods. Toward the top is a bed containing many segments of the stems of either a cystid or a crinid. With the possible exception of some of the brachiopods, all of the fossils appear to have undergone considerable transportation before their final deposition.

Due to the rather general concealment of the upper portion of this member, its thickness has not been determined in many places. The best exposure is at Tunnel City where there are 14 feet. In section 12 of the town of Burns (T. 17 N., R 5 W) the thicknees is 16.5 feet. These figures appear to be representative for the two quadrangles.

(c) Lower Greensand. This member is well exposed in quarries and road cuttings for parts of its thickness, but fairly complete exposures of the entire thickness occur only at Tunnel City and Norwalk. At one time it ~~is~~ was extensively quarried for road material and building stone, the largest quarries being short distances west, south, and southeast of Sparta.

The strata are thin laminated and consist of fine to medium grained yellow and gray sand and glauconite. The laminations are extremely thin in some beds, one portion of a bed of three-fourths of an inch thickness showing thirty-six. Many beds are wholly cross-laminated; the foresets are generally short, the maximum being about a foot with most of them from 4 to 8 inches. Near the middle is the mud cracked layer or layers to which reference has been made. The spacing of the cracks varies from 2 to 5 inches. Current ripple mark is locally common. Numerous layers are covered with fucoidal markings and these layers quite commonly contain many fossils.

The quartz sand grains are clean and glassy and in most laminae they are not well rounded. The diameters vary around one-fourth millimeter for both the quartz and glauconite.

The percentage of glauconite varies with every layer, the smallest percentage determined being 4 and the largest 67, while a 2 to 3 inch bed in this member exposed in a road cutting near La Crosse gave a percentage in glauconite of 95. A 28 foot section of the lower greensand exposed about a half mile west of Tunnel City (SE¼, NE¼, Sec. 26, T 18, R 2W, north of Tomah quadrangle) shows a variation in the percentage of glauconite from its approximate absence in some layers to 67.1 per cent in the layer with highest percentage. Analyses made by E. G. Thompson[1/] of samples taken from eleven places in the section, show percentages of glauconite as follows:

[1/] Thompson, E. G., The greensands of Wisconsin, unpublished thesis, University of Wisconsin, 1920.

Lower 8 feet	glauconite	13.3 %
12 to 16 feet from base	"	5.4
16 to 16.5 " " "	"	21.4
16.5 to 18.5 " " "	"	9.98
18.9 to 19.5 " " "	"	24.67
19.5 to 21.2 " " "	"	9.98
21.5 to 21.6 " " "	"	67.1
21.7 to 22 " " "	"	4.3
22 to 22.8 " " "	"	5.7
22.8 to 23.5 " " "	"	21.4
23.5 to 25 " " "	"	10.4

The glauconite of the lower greensand member is similar to that in the upper greensand and in the basal strata although the grains in the last appear to have more detail of surface and to be a trifle larger. The differences, however, are not decidedly marked. All of them are quite similar to the glauconite from the Cretaceous of New Jersey. Analysis of glauconite from the Franconia or Minnesota[1/] gave results as follows.

1/ Hall, C. W., and Sardeson, F. W., The magnesian series of the northwestern states, Geol. Soc. America Bull., vol. 6, p. 185, 1895. Analysis made by S. F. Peckham and originally published in Ann. Rept. Geol. and Nat. Hist. Survey of Minnesota, p. 61, 1876, and again in 1879, p. 152.

SiO_2	48.18
FeO	27.08
Al_2O_3	6.97
K_2O	7.40
Na_2O	1.25
H_2O	8.75
	99.63

Analyses of the glauconite from the exposures on the hill near Norwalk gave potassium in percentages varying from 3.546 to 4.86.[1]

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[1] Brant, H. J., Glauconite as a potash fertilizer, unpublished thesis, University of Wisconsin, p. 10, 1920.

These percentages approximate those of modern glauconites of which Clarke[2]

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[2] Clarke, F. W., Data of Geochemistry, U. S. Geol. Survey, Bull. 695, p. 514, 1920. Murray, John and Renard, A. F., Rept. of the scientific results of the voyage of H. M. S. "Challenger" during the years 1873-76, etc., deep sea deposits, p. 387, 1891.

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gives the average of four analyses as 3.49% expressed as K_2O.

Fossils are quite common in the lower greensand and all appear to have undergone transportation before final deposition. A loosely coiled, flat spired gastropod is rather characteristic.

The member is 32.5 feet thick at Tunnel City with the top not positively exposed while 46 feet are known in the hill near Norwalk. The descending section (Norwalk Hill) which follows shows the character of this member in detail.

Section on Road North of Norwalk.

10. Sandstone, gray quartz sands and glauconite, grains fine to medium. glauconite subordinate.	5.5 feet
9. Greensand, rich in glauconite, really a lens, highly cross-laminated.	1.5 feet
8. Greensand, mostly quartz with glauconite along laminations, thin laminated with beds around a foot thick.	3.5 feet
7. Greensand, rich in glauconite.	1 feet
6. Sandstone, gray, flecked with glauconite.	1.5 feet

5. Greensand, contains much glauconite, highly cross-laminated. 0.3 feet

4. Greensand, rich in glauconite, cross-laminated with short foresets in many directions and with gentle inclinations 0.7 feet

3. Greensand, a mud cracked layer near the top. Beds up to five feet, cross-laminated. Foresets short and inclined in many directions, many fossils. 11 feet

2. Sandstone, mostly quartz, very little glauconite, flakes of white mica along the bedding and lamination planes, beds 2 to 6 inches. 19 feet

1. Micaceous shale. 1 foot

(d) Yellow sandstone member. There is no complete exposure of this member in either of the two quadrangles and exposures of any part of it are rare. The most extensive are in the first cutting on the Chicago andNorthwestern Railroad to the southeast of Norwalk, at Norwalk itself, and on the west side ofCannon Valley (SW$\frac{1}{4}$ Sec. 10, T. 15N, R 4W). The thickness of this member is about 30 feet.

The strata of the yellow sandstone member consist of thin bedded and thin laminated, fine grained yellow sandstone. The sands are quartz, and small angular fragments of glauconite, the former predominating, the latter rare. The sorting is excellent. Most of the grains are angular and they average about one tenth millimeter in diameter. The bedding is regular and the laminations approximate parallelism to the bedding. The only traces of organisms which have been observed in the exposures of these two quadrangles are transverse tubes for which worms may have been responsible.

(e) Upper Greensand. Natural exposures of this member are rare, but artificial ones are common. The best exposures are at Summit, Norwalk, Tunnel City, Spring Valley, and Middle Ridge.

The rock consists of quartz and glauconite, the latter being extremely abundant in some beds, the average for a sixteen foot exposure of the member at Boscobel on the Wisconsin River being 22%.1/

1/ Thompson, E. C., The greensands of Wisconsin, unpublished thesis, University of Wisconsin, 1920.

Both types of sand are similar to those of the lower greensand member. A little pyrite is present in an exposure at the west end of Tunnel No. 3 on the Chicago and Northwestern Railroad. Many of the beds are perforated by worm tubes which have been filled with sands of a yellow color. Ripple mark of both wave and current type is common and cross-lamination occurs throughout. The foresets vary in direction and are generally short.

Most of the beds appear to be without fossils, or have them so poorly preserved as to be difficultly recognizable. A few beds locally have them in considerable abundance. All appear to have experienced considerable transportation before final deposition.

Due to the absence of complete exposures the thickness has not been determined in many places. At Bean's quarry near Tunnel City north of the Tomah quadrangle, there is a thickness of 54 feet. //

<u>Fossils</u>. Fossils which have been identified from the Franconia formation are given in the list which follows.2/ It is not known that all

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2/ Walcott, C. D., Cambrian geology and paleontology, Smithsonian Misc. Coll.,

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of them occur in these two quadrangles.

1. Obolus matinalis (Hall).
2. O. mickwitzi Walcott.
3. Lingulella (lingulepis) acuminata (Conrad)
4. Eorthis (?) diablo Walcott.
5. E. remnichi (N. H. Winchell)
6. Dicellomus politus (Hall)
7. Billingsella coloradoensis (Shumard)
8. Finkelnburgia finkelnburgi (Walcott)
9. F. osceola (Walcott)
10. Syntrophia primordialis (Whitfield)
11. Eccyliomphalus n. sp.
12. Agnostus josepha Hall
13. A. parilla Hall
14. Saratogia hamulus (Owen)
15. S. wisconsinensis (Owen)
16. Ptychaspis miniscaensis (Owen)
17. P. striata Whitfield
18. Chariocephalus whitfieldi Hall
19. Conaspis anatina (Hall)
20. C. bipunctata (Shumard)
21. C. eryon (Hall)
22. C. ownei (Hall) ?
23. C. nasuta (Hall)
24. C. patersoni (Hall)

25. *C. perseus* (Hall)

26. *C. shumardi* (Hall)

27. *Ptychoparia diademata* (Hall)

28. *Elliptocephalis ? curtus* Whitfield

29. *Konocephalina misa* (Hall)

Origin of the Franconia Sediments. The general abundance of marine fossils in the Franconia formation prove the marine origin, while the general fineness of the sands and the angularity of the grains suggest distance from the shore. Shallowness of waters is shown by the cross-lamination, ripple mark and the mud cracks. The cleanness of the quartz sandstones shows long washing. A shallow sea, little more than awash, appears to best fulfill the conditions necessary.

The origin of the glauconite can only be given by inference. In modern seas glauconite is said to be deposited in depths of 91 meters along the northern Atlantic coast to 3152 meters in the Indian Ocean. 1/

1/ Goldman, M. I., Maryland Geol. Survey, Upper Cretaceous, p. 176, 1916.

The limitation to these depths in existing seas cannot be taken as a criterion of the depth of the Franconia seas as all the other evidence is adverse to even the minimum of these depths. The glauconite grains are not products of corrasion, although some appear to have been transported short distances, and the interlamination with the quartz sands prove mechanical deposition. Nearly every one shows a botroyidal surface to some degree. The conditions are such as to suggest that the glauconite grains fell into the quartz sands while they were depositing, coming to rest after no, or short transportation. The dominance of the glauconite in laminations which alternate with others which are mostly composed of quartz suggests a rhythmical precipitation of the glauconite. As alternative hypothesis suggests that the glauconite was deposited in grains which were the products of corrasion and that the botryoidal surfaces developed through subsequent growth. It is not thought that this hypothesis can be sustained.

The method or origin of glauconite does not appear to be yet fully understood and it is probable that it may develop in several different ways. In modern seas it occurs in greatest quantity near the mud line of deposition in the presence of a certain quantity of organic matter, both the proportion of mud and organic matter appearing to be essential to the formation. A superfluity of mud is thought to lead to the development of green mud while too much organic matter is believed to give rise to pyrite or marcasite instead of glauconite. According to Collet, 1/

1/ Collet, L. W., Les Depots Marins, Paris, p. 189, 1908.

the decaying organic matter acts on the calcium sulphate in the sea water forming calcium sulphide. The latter unites with carbon dioxide and water to form calcium carbonate and hydrogen sulphide. The hydrogen sulphide unites with any ferric oxide present in the sediments forming ferrous sulphide and sulphur. The former is thought to combine with colloidal matter in clay, the iron taking the place of the aluminum while potassium and water are taken from the sea water. Intermediate stages with grains having the shape of glauconite have been observed by both

Collet and Goldman. In this explanation foraminifera have no essential place in the development of the substance.

Murray and Renard have a slightly different explanation. According to them organic matter enclosed in shells and in mud which enters the shells changes any iron which may be in the mud to the sulphide. If this be oxidized to the hydrate, sulphur will be set free which becomes oxidized to sulphuric acid resulting in the production of colloidal silica from the clay. This and the hydroxide of iron, absorb potassium salts from the sea water forming glauconite. 1/ Foraminiferal shells are considered those which are mainly responsible for the development of glauconite. As no foraminiferal shells or molds are known to have even been observed in any of the upper Mississippi Valley glauconites, they can hardly be appealed to as factors concerned in its development.

1/ Murray, John, and Renard, A. F., Rept. of the scientific results of the voyage of H. M. S. "Challenger" during the years 1873-76, etc., Deep sea deposits, p. 389, 1891.

St. Lawrence formation.

Genera**l** Statement. Steep slopes or butte like hills are characteristic of the areas of St. Lawrence exposures, depending on whether the formation is overlain by higher strata or forms the surface rock. The formation is possible of subdivision into two members of which the lower has parts of shaly aspect and others which are dolomitic, while the upper member consists of fine grained sandstone which locally is sufficiently firm to be quarried for construction stone.

Relations to the Franconia Formation. So far as may be determined from individual exposures the strata of the St. Lawrence formation are parallel to those of the Franconia. However, at all places where the basal strata of the St. Lawrence have been seen there is a conglomerate of rounded pebbles of disk shape. The contact is hence considered one of disconformity.

Thickness. The determination of the thickness of the St. Lawrence formation is difficult as there are few exposures where both the base and the summit may be seen. The thickness varies from a minimum of 77.5 feet on South Ridge road (Sections 17 and 18, T. 15N., R. 1W) to 108 feet at Norwalk. It is 85 feet at Bean's quarry, 103 feet at Castle Rock, and 107 feet at Middle Ridge. The thickness varies within comparatively short distances, as for instance, the maximum and minimum thickness are within about three miles of each other. These variations in thickness are thought to be due to the irregular surface of deposition, inequality of deposition, and possible erosion of the St. Lawrence strata before those of the overlying Jordan were deposited.

Character of the St. Lawrence Fromation. The St. Lawrence strata consist of shaly, dolomitic and fine grained sandstones in the lower half and fine grained sandstone in the upper half. Fig. 11. Locally the lower half contains one or more layers of nearly pure dolo mite. Traced southward to the Wisconsin Valley the percentage of dolo mite increases to form a member at Muscoda, Black Earth, and elsewhere which is about 15 feet thick. The conglomerate at the base is poorly sorted, the pebbles are composed of yellow sandstone and greensand, the former predominating. Diameters vary up to 4 inches and they are about an inch thick for the largest. The pebbles are oriented in essentially every direction. The matrix is everywhere a mixture of glauconite and gray and yellow quartz sand. The fine grained sandstones which compose the greater portion of the formation consist of angular to only slightly rounded grains of quartz. The diameters vary for most of them from one fortieth to one-tenth of a millimeter. Thin beds of conglomerate are present at several levels. These consist of thin yellow sandstone pebbles in a yellow sandstone matrix. Generally the pebbles are in horizontal position, but in one layer of wide distribution they are edgewise. The strata of the formation are generally soft and weak, but locally nearly every part has been quarried for building stone. Some layers are almost flour-like.

The color of the rock varies from light gray to light brown. Green shades occur near the base. Many beds contain small dark particles (iron oxide) giving the rock a "pepper and salt" appearance.

The bedding is generally well defined and the laminations are parallel to, or at a low angle with the bedding. The foresets are around 4 to 5 feet. A shaly sandstone exposed in Bean's Quarry at an elevation of 27 feet above the base contains mud cracks and such have also been seen at Muscoda on the Wisconsin River.

The thickness of individual beds varies up to about 5 feet. Nearly every one is horizontal or low angle cross-laminated with the laminations up to one-half inch in thickness.

The sections which follow show the detail of the sequence.

(Section on South Ridge Road, (Sections 17 and 18, T. 15 N., R. 1W)

12. Sandstone, fine grained, yellowish gray, thin laminated. Contains worm tubes and fragments of trilobites. 10.5 feet

11. Conglomerate consisting of small, light colored, fine grained sandstone pebbles in a matrix of medium grained yellow sands. 0.5 feet

10. Sandstone, soft, fine grained, yellowish gray. 1 foot.

9. Conglomerate like that of zone 11. This zone truncates the laminae of zone 8 throughout almost the whole of the exposure of the latter. 1.5 feet

8. Sandstone like that of zone 10, cross-laminated with foresets up to 4 feet long. Trilobite fragments are sparingly present. 3.5 feet

7. Conglomerate, small pebbles of fine grained brown sandstone in a matrix of medium grained yellow sand. 1 foot

6. Sandstone, fine grained, pale to brownish yellow. Generally low angle and horizontal thin laminated. Contains dolomite layers in the lower portion and fragments of trilobites are present near the base. locally this zone is extensively quarried. 22 feet

5. Conglomerate. Lower 6 inches an edgewise conglomerate; upper 2.5 feet with the pebbles in horizontal position. The pebbles are of fine grained yellow sandstone, the matrix is slightly coarser in grain, but of the same color. The edgewise pebbles are inclined

at high angles. 3 feet

4. Sandstone, shaly and flaggy, fine grained, yellow. Some layers may be dolomitic. 7 feet

3. Dolomite, sandy and brownish yellow. Contains considerable glauconite. This zone is filled with many Billingsella coloradoensis and rare Owenella (?) and Hyolithus. 1.5 feet

2. Sandstone, fine grained, yellow. 6 feet

1. Conglomerate, interstratified with yellow dolomitic sandstone and thin laminae of greensand. The pebbles are either greensand or yellow sandstone while the matrix consists of glauconite and yellow quartz sand. The pebbles are of disk shape and up to three inches for the longest diameter. Rare fragments of trilobites are present. Base of the St. Lawrence. 4 feet

Section at Middle Ridge, (SW$\frac{1}{4}$ sec. 2, T. 15N., R. 5W).

10. Sandstone, massive bedded, low angle and horizontal laminated, fine to medium grain, yellow and brown. Some layers are perforated with transverse worm tubes. No other fossils observed. 33 feet.

9. Sandstone, brownish yellow, fine to medium grain, thin laminated. Thick bedded above, thin bedded below. 6 feet

8. Sandstone, yellow, fine tomedium grain. 6 feet

7. Sandstone, yellow, very friable, medium to fine grain, beds 4 to 6 inches thick. Contains many worm tubes and fragments oftrilobites. 10 feet

6. Edgewise conglomerate. Thin, fine grained sandstone pebbles in a matrix of coarser sands. This bed is compact and resistant. 1 foot

5. Sandstone, yellow, fine grain, thin bedded. Stained to brownish color along the horizontal and low angle laminations. Worm tubes and trilobite fragments are abundant throughout. 10 feet

4. Shale, dolomitic, gray to yellow. Contains rare oboloid brachiopods and trilobite fragments. 7 feet

3. Concealed. 11 feet

2. Shale as in zone 4, but the lower 5 feet of mottled yellow, gray and brown dolomite. 11 feet

1. Concealed. The base of the St. Lawrence is in this interval as the zone below belongs to the Franconia. 6 feet

Fossils. Fossils are quite abundant in many horizons, but they are mostly fragments and evidently underwent considerable transportation before their final deposition. Transverse worm tubes are more or less present from the base to the summit. The following listedspecies have been identified.1/ It is not known that all of them occur in the

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1/ Walcott, C. D., Cambrian geology and paleontology, Smithsonian Misc., vol. 57, No. 13, p. 356, 1914.

St. Lawrence strata of the Sparta and Tomah quadrangles.

1. Obolus (Westonia) aurora (Hall)
2. O. (Westonia) stoneanus (Whitfield)
3. Finckelnburgia finckelnburgi (Walcott)
4. F. osceola (Walcott)
5. Lingulella mosia (Hall)
6. L. Oweni (Walcott)
7. L. winona (Hall)
8. Syntrophia primordialis (Whitfield)

9. *Serpulites murchisoni* Hall

10. *Owenella antiquata* (Whitfield)

11. *O. vaticina* (Hall)

12. *Hyolithes corrugatus* Walcott

13. *Spirodentalium osceola* Walcott

14. *Agnostus disparilis* Hall

~~14. Spirodentalium osceola Walcott~~

15. *Calvinella spiniger* (Hall)

16. *Dikelocephalus limbatus* (Hall)

17. *D. minnesotensis* (Owen)

18. *Saukia leucosia* Walcott

19. *S. crassimarginata* (Whitfield)

20. *S. pyrene* Walcott

21. *S. lodensis* (Whitfield)

22. *S. pepinensis* (Owen)

23. *Osceola osceola* (Hall)

24. *Ptychoparia? binodosa* (Hall)

25. *Illaenurus quadratus* Hall

26. *Triarthrella auroralis* (Hall)

27. *Aglaspis eatoni* Whitfield

28. *A. barrandei* Hall

Conditions of Origin. The St. Lawrence strata were deposited in shallow marine waters which were far enough removed from the shore so as not to be strongly modified by its influences. Organisms flourished in the waters, but did not obtain burial immediately following death as is evidenced by their worn character. The mud cracks in the shaly layer at Bean's quarry and at Muscoda indicate the temporary exposure of a mud flat. The pebble conglomerates may possibly be the effects of occasional violent storms, while those with the pebbles in edgewise position may be the result of slumping or rapid deposition. The dolomitic beds in the lower half probably resulted from replacement of calcareous sediments.

Jordan Formation.

General Statement. The areas underlain by the strata of the Jordan formation are commonly characterized by steep slopes and cliffs, nearly every one of the upper tier of cliffs having its basal portion formed of strata of this formation. Except for its presence in a rare outlier like Castle Rock the formation is generally wanting over the northern halves of the two quadrangles.

Relations to the St. Lawrence Fromations. Locally the Jordan formation begins with the long foreset cross-laminated stratum which in comparison with the low angle or horizontally laminated St. Lawrence strata renders the contact very marked, but in others it is difficult to locate a boundary and one might be justified in considering the Jordan formation as an emergent phase of the St. Lawrence. There is no paleontologic evidence on which to base a separation since it is not known that fossils occur in the Jordan.

<u>Thickness.</u> The thickness of the Jordan formation varies from a few feet up to about 40 feet. There are 27 feet at Norwalk, 39 feet on the South Ridge Road, 37 feet at Tunnel No. 3 on the Chicago and Northwestern Railroad, 31 feet at Castle Rock and 17 feet on the creek flowing north from Middle Ridge (It may be a little thicker at Middle Ridge as there is a 10 foot concealed interval to the exposed Oneota - not the base). These variations are considered to be largely due to inequalities of deposition.

<u>Character of the Jordan Formation.</u> The Jordan sandstones are commonly friable and locally they are quarried for sand. The grains vary from very fine to small pebbles which locally form thin conglomerates. (Fig. 12) All degrees of sorting occur within the limits of the dimensions which are known to be present. The sand grains vary from extremely well rounded to decidedly angular, but the latter is not commonly true. The colors vary from gray to yellow with portions locally stained with brown oxide.

The bedding is generally very irregular and ripple mark of current origin is common. No symmetrical ripple mark has been observed. Cross-lamination is present from top to bottom with the foresets varying from a few inches to 30 feet and from very low angles to 25 degrees. The inclinations are in essentially every direction, but there appears to be a predominance of these to the south. Some beds are characterized by cross-lamination which suggests wind deposition. The formation locally contains many spherical concretions varying in dimensions to as great as two inches in ~~character~~ diameter, but most commonly are a half inch or less. These have developed through the local segregation of lime carbonate thus cementing the sand around the centers of segregation.

<u>Fossils.</u> No fossils other than fucoidal markings have been found in the Jordan sandstones.

<u>Conditions of Origin.</u> Some of the Jordan sandstones were deposited in water which no evidence known to the writer suggests was marine; and it is probable that considerable portions were laid down above water level. The absence of fossils is not proof that the deposition did not take place in marine waters, but it is in harmony with the other facts leading to that conclusion. The great cross-lamination between parallel planes proves the presence of strong water currents and the thin conglomerates at several levels add to the evidence. The cross-lamination and the bedding of eolian aspect with the sand grains of high sphericity suggest wind deposition for those portions. The facts lead to the conception of a wide sand flat over which water moved at times while other parts were above water level and traversed by wind blown sands.

<u>Madison (?) Formation.</u>

<u>General Statement.</u> Overlying the typical Jordan sandstones are others which in some respects resemble those of the Madison. No fossil evidence has been found to support the suggestion, so that it rests entirely on lithic resemblance and hence contains all the weakness that such a correlation includes. It is equally as probable that these strata constitute upper portions of the Jordan.

Relations to the Jordan Formation. The strata of the two divisions are parallel to each other and as fossils are not known to have been found in these areas in either one of the divisions, it has not been possible to prove a hiatus.

Thickness. The thickness of these strata varies from almost nothing to 18 feet which is the thickness near the mouth of Dutch Creek. There are 6.5 feet on the South Ridge Road (Secs. 17 and 18, T. 15N., R 7W).

Character of the Madison Formation. The Madison strata are better stratified than are those of the Jordan although the differences are not conspicuous. There is considerable variation in the character of different beds. A case-hardened layer locally occurs near the top of these strata and it appears to have attained that characteristic antecedent to the deposition of the overlying Oneota as pebbles which might have come from this layer are locally present in the latter. Asymmetrical ripple mark and cross-lamination are present throughout. The section which follows shows in detail the character of this sandstone.

Section on Coon Creek (N. E. 1/4 sec. 23, T. 15N, R 5W).

7. Sandstone, white, firm, medium grain.	1.5 feet
6. Sandstone, brown and yellow, dolomitic, firm.	5 feet
5. Sandstone, yellow, case-hardened.	3 feet
4. Sandstone, white, friable, medium grain.	2 feet
3. Sandstone, dolomitic, yellow, medium grain. Contains small pebbles of sandstone.	0.7 feet
2. Sandstone, gray, dolomitic, medium grain. Small sandstone concretions are present.	1 foot

1. Sandstone, dolomitic, yellowy medium grain, compact. 2 feet

<u>Conditions of Origin.</u> These strata were deposited under conditions quite similar to those which gave rise to the Jordan sandstone with the conditions of deposition somewhat more stable so that greater regularity of bedding was developed.

Ordovician System.

<u>General Statement.</u> The Ordovician system is represented within the two quadrangles by the Oneota dolomite and the St. Peter sandstone. That the Shakopee and Platteville dolomites once extended over the region is quite probable as the latter occurs only 18 miles to the south. The Maquoketa shales may also have been present as they are exposed along the southern border of Wisconsin and also exist in the Blue Mound outlier about 60 miles to the southeast. It is also possible that the Niagara limestone once overlay this region as it also is exposed at Blue Mound and to the southwest in Iowa.

The two Ordovician formations which are present are very different in character, origin, and distribution. The former covers the summits of all the higher uplands, while the latter occurs in erosion depressions in the Oneota and is confined to the southern halves of the two quadrangles.

Oneota Formation.

General Statement. The lithology of the Oneota formation is in striking contrast to that of the sandstones which lie beneath, the former being firm and sub-crystalline, the latter friable and crumbling. Over the northern halves of the two quadrangles the Oneota forms a capping over the highest ridges; over the southern halves a greater thickness is preserved beneath the broad uplands which are characteristic of that portion of the two quadrangles.

Relations to the Cambrian. The Oneota is disconformable on the underlying sandstones. The conglomerate at the base of the Oneota, the mud cracks locally developed in the basal strata and the erosion at the top of the underlying sandstones lead to this conclusion.

Thickness. The entire thickness of the Oneota exceeds 200 feet a little to the south, but that thickness is not present in either of the two quadrangles, the thickest section showing not more than 120 feet and it is improbable that much more than an additional 50 feet are concealed beneath the higher uplands.

Character of the Oneota Formation. The Oneota exhibits a variety of phases. The basal beds are sandy and locally conglomeratic with pebbles of sandstone of which some are case-hardened. Some beds are pure quartz sandstone and these also are locally case-hardened. Oolitic beds make their appearance a short distance above the base and such beds recur up to about 20 feet. The higher beds are compact and hard and have a light gray to buff gray or cream color. The surfaces of the beds are generally pitted in consequence of small cavities present in the fresh rock becoming enlarged through weathering. The dolomite also contains many cavities lined with white, yellow, and amethystine quartz, the last color being extremely common. Chert is abundantly present and numerous fields which are underlain by the formation are cloaked with residual chert. Many beds have a crumpled appearance due to the algal growths to which these beds are due. Several beds have a brecciated appearance. Five chemical analyses from La Crosse, west of the area, give the following variation between different beds.

Insoluble	4.96 per cent	to	11.48 per cent
Al_2O_3 (acid sol.)	0.00	to	0.49
Fe_2O_3	0.43	to	0.76
$CaCO_3$	49.45	to	53.30
$MgCO_3$	37.50	to	40.73
P_2O_5	0.02	to	0.24
Total carbonates	87.10	to	94.03
Dolomite	82.10	to	89.10
Calcite	2.55	to	5.00

The rock is shown to be a true dolomite for the calcite is known to be wholly in veins and openings.[1/]

1/ Analyses made by W. G. Crawford, furnished by courtesy of Edward Steidtmann.

The sections which follow show in detail the character of the formation.

Section at Castle Rock (S. E. 1/4 of S. W. 1/4, sec. 33, T. 18N, R. 4W.)

8. Dolomite, yellowish gray, thick-bedded, hard 13 feet

7. Dolomite, oolitic, gray basal portion not oolitic. 0.5 feet

6. Dolomite, yellowish gray, thick beds. 4.7 feet

5. Sandstone, while, fine to medium grain, case-hardened, contains dolomitic patches. 2.8 feet

4. Dolomite, yellow, sandy, contains thin laminae and pebbles of greenish shale. 1.3 feet

3. Dolomite, gray, sandy, oolitic. Contains grains of sand covered with films of dolomite. 1 foot

2. Dolomite, yellow, sandy. 0.3 foot

1. Sandstone, white, contains laminae of green shale. 0.5 feet

Section on Coon Creek (N. E. 1/4 of N. E. 1/4 Sec. 23, T. 15N, R. 5W.)

8. Dolomite, gray. Quite generally concealed but blocks are scattered over the surface and at the top there is exposed a 4 foot bed of compact, light yellow dolomite. 45 feet

7. Dolomite, gray, one bed. 1.5 feet

6. A bed consisting of a reef of algae (Cryptozoa). The algal growths form domes up to about 18 inches in circumference and 10 inches high. They are almost wholly silicified, but dolomite surrounds the domes. 0.8 feet

5. Dolomite, yellow, weathers gray and becomes pitted.

The beds are 1 to 4 feet thick, but separate on weathering into 3 to 4 inch units. Much chert is present in some of the beds. 21 feet

4. Dolomite, yellowish gray, oolitic. Contains much sand coated with a film of dolomite. Five beds. 3.5 feet

3. Dolomite, brownish yellow, compact, no sand. One bed. 4 feet

2. Dolomite, yellow, thin laminated. Weathers light gray, yellow, and brown along the laminae. 2.8 feet

1. Dolomite, yellowish gray, compact. Two beds. Each of the beds has about the same thickness and each has an irregular band of case hardened sandstone about 7 inches from the top. These bands locally disappear and locally increase, 4 inches being the maximum thickness observed. 4.7 feet(?)

Fossils. The most common fossils are the domes of *Cryptozoa*. These occur as isolated individuals; or are grouped together to form reef-like masses, one such commonly occurring about 30 feet above the base. The domes vary in dimensions up to 18 inches high and 3 feet wide. They are most commonly silicified. Other fossils are extremely rare in the dolomite itself, but locally are quite common in the cherts, silification appearing to be more favorable to their preservation than dolomitization. The fossils commonly so preserved are gastropods and cephalopods. Species which have been identified are as follows.

1. Ophilita sp.

2. Murchisonia sp.

3. Raphistoma minnesotense (Owen)

4. Raphistoma sp.

5. Sinuopea obesa (Whitfield)

6. S. strongi (Whitfield)

7. Endoceras (siphuncle)

8. Cyrtoceras sp.

Conditions of Origin. The basal deposits of the Oneota are those of the littoral and adjacent neritic zones; the regularity of the bedding and the absence of marks of extreme shallow water are evidence that the succeeding deposits were laid down in quieter waters. There is no evidence suggesting that the waters were of great depth.

The existing dolomites were quite probably originally ~~lime~~ calcitic sediments. The dolomitization and the development of the chert ~~being~~ were subsequent to initial deposition but both ~~thrxxxxxx~~ processes are thought to have destroyed the fossils and to have developed the brecciated appearance which is locally conspicuous in the dolomite although the latter may have been produced by the breaking up of algal crusts. How extensive was the destruction of the fossils is ~~mere~~ conjecture, but their abundance in some of the cherts suggests that originally there were a great many. The dolomitization was not subsequent to solidification.

This is thought to be proven by the fact that it is complete, that very few fossils are in the dolomite while many are in the chert, that casts of fossils are wanting or rare in the dolomite and Cryptozoa which are dolomitized usually have not as well preserved structure as do the silicified specimens. Had the sediments been solid before dolomitization it is thought that many fossils would be present as molds and casts and that many parts of the rock would have escaped the change. How the ~~lime~~ calcium carbonate was originally deposited is not known for all of it. A large portion was contributed by the Cryptozoa which at different times locally covered the sea bottom. A part was probably derived from the shells of gastropods and cephalopods, but the proportion is not known. It appears quite probable that these agencies were not responsible for the whole of ~~it~~ the carbonate and the remainder may have been contributed by bacteria or precipitated directly from the water.

The conditions leading to dolomitization do not yet appear to be clearly understood. The great development of algae in the dolomite and the fact that modern calcareous algae precipitate both calcium and magnesium carbonate to form their stony growths [1/] suggests

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1/ Clarke, F. W., and Wheeler, W. C., Inorganic constituents of marine invertebrates, U. S. Geol. Survey, Prof. Paper 102, p. 44, 1917.

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that the dolomite may have developed through the recrystallization of substances already in the deposits. This could not have been accomplished, however, except by the introduction of magnesium carbonate from without unless the algae of the past carried a greater percentage of magnesium than do those of the present. The change to dolomite appears to have been brought about bed by bed while the sediments were still soft or only slightly solidified, this change destroying the fossils in such parts as became dolomite, but preserving them in those parts which were changed to chert. The development of most of the chert appears to have been antecedent to or contemporaneous with dolomitization.

St. Peter Formation.

General Statement. The stratigraphic position of the St. Peter sandstone, so far as the upper Mississippi Valley is concerned, is above the Shakopee dolomite, but if that formation were ever present over any parts of the Tomah and Sparta quadrangles it has been wholly removed. The St. Peter sandstone in the two quadrangles occurs as small patches filling depressions in the Oneota. The most extensive of those exposed in that on the south margin near the head of Pine Hollow. Other large patches are those of Middle Ridge, Portland, about the head of Spring Valley, and on a western tributary of Heiser Creek. Numerous occurrences whose exposures are altogether too small to be shown on the map may be of considerable size and there may be many occurrences of large area for which there are no surface indications. Float from the St. Peter has considerable distribution over the southern third of the Sparta quadrangle and the southwestern sixth of the Tomah quadrangle.

Relations to the Oneota Formation. The St. Peter is disconformable on the Oneota. Some of the patches may represent filled pre-St. Peter sinkholes, but on that point data are wanting. The occurrence at Middle Ridge appears to be situated in a valley in the Oneota which on the south side of the occurrence was cut to the Jordan sandstone.

At all places where the base of the St. Peter is exposed it rests on, or is flanked by, a red clay and chert residium from the Oneota. This is of variable thickness up to 5 or more feet. Its age is that of the erosion interval between the Oneota and the St. Peter.

Thickness. Little data relating to the thickness of the St. Peter in the two quadrangles was obtained. The only measurement of thickness was made at Middle Ridge where the base is at 1191 feet elevation and the top at 1260 feet, giving a thickness of 69 feet. It is quite probable that a greater thickness obtains in the large area about the head of Pine Hollow, but it was not possible to make any estimate from the exposures.

Character of the St. Peter Sandstone. The St. Peter formation consists of friable, yellow to gray, medium to coarse grained sandstones with the basal strata consisting of yellow, greenish, reddish and black shales and fine grained sandstone or red residual clay with chert boulders. Except for these basal strata, clay is not known to be present. Most of the sandstones are well sorted and the grains are well rounded (Fig. 13). The diameters vary from about one-tenth to one-third millimeter with most of them falling between one-sixth and one-fourth millimeter.

In some occurrences the sandstones are not friable, but are really quartzites. Blocks of this type are abundant in the chert piles over the southwestern fourth of the Sparta quadrangle.

So far as observed, the lower beds of the St. Peter are regularly and horizontally laminated. These were deposited by water. Some of the upper portions show no bedding planes through considerable thickness.

<u>Fossils</u>. The St. Peter sandstones have yielded no fossils in either of the two quadrangles, nor are fossils known to have been found in positively determined St. Peter in any part of Wisconsin. Sardeson reports an occurrence in strata transitional to the overlying Platteville limestones near Dodgeville.[1/]

1/ Sardeson, F. W. The St. Peter sandstone: Minnesota Acad. Sci., Bull., vol. 4, pp. 71-72, 1910.

<u>Conditions of Origin of the St. Peter Formation</u>. Most, if not all of the St. Peter formation as exposed in the Tomah and Sparta quadrangles was deposited by water, although the high degree of rounding of the grains suggests that the wind may have been concerned in providing the water with its load. The deposition appears to have been done in a region of little relief as the sands are well sorted and no water deposited conglomerate is present. Oceanic deposition is precluded because of the thoroughly unsorted character and irregular upper surface of the underlying Oneota residium which under marine conditions would most

certainly have been planed down to a uniform level and to some degree have been sorted. In other parts of the Mississippi Valley some of the St. Peter sandstones have been considered the eolian deposits of an arid climate.[1/] but evidence of this type of deposition is not present

1/ Grabau, A. W. Principles of stratigraphy, pp. 569, 571, 1913.

in either of the two quadrangles. However, in a sand pit on the extreme head of Pine Hollow just south of the boundary line of the Sparta quadrangle are clean, well rounded and well sorted St. Peter sands which are not stratified and whose grains have the frosted appearance which is characteristic of wind drifted sands. Other students have assigned a marine origin to some occurrences of the St. Peter,[2/] but this interpretation does not appear possible for the occurrences in the Tomah and Sparta quadrangles.

2/ Trowbridge, A. C., Origin of the St. Peter Sandstone, Iowa Acad. Sci., proc., vol. 24, pp. 171-175, 1917.
Dake, C. L., The problem of the St. Peter sandstone: Missouri School of Mines and Metallurgy, Bull., vol. 6, No. 1, 1921.

CORRELATION WITHIN THE PALEOZOIC GROUP.

In the correlation of the different formations of the Sparta and Tomah quadrangles the published reports and unpublished views of Dr. E. O. Ulrich[3/] have been largely followed. His long and extensive

3/ Ulrich, E. O., Revision of the Paleozoic Systems, Geol. Soc. America, Bull., vol. 22, pl. XXVII, 1911;
Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils, U. S. Nat. Mus. Bull. 92, pl. 1, 1915, 1915, Am. Bull., vol. 22.

studies of these formations make his conclusions of more value than would be those of the writers. In respect to systematic grouping, Drs. E. O. Ulrich and R. S. Bassler have made certain proposals which have not yet gained general acceptance, nor has all the evidence fundamental to those proposals been completely developed. In place of the Cambrian and the Ordovician there have been proposed four systems--Cambrian, Ozarkian, Canadian, and Ordovician. Were this systemic classification applied to the formations of the Sparta and Tomah quadrangles they would be grouped as follows:

Ordovician (lower) St. Peter formation.

Canadian (upper) Shakopee formation.

Ozarkian

(upper), Oneota formation.

(middle), Wanting in upper Mississippi Valley.

(lower), Madison formation.

Cambrian

St. Croixan

Jordan formation

St. Lawrence Formation

Franconia formation

Dresbach formation

Eau Claire formation

Mount Simon formation.

The sandstones and associated sediments from the base of the Mount Simon to the top of the Madison constitute the group formerly known as the Potsdam sandstone. These are correlated by Ulrich (Madison excepted) with the Nolichucky shale and Mayville limestone of the southern Appalachians; the Elvins formation, Bonne Terre dolomite and Lamotte sandstone of Missouri, and the Basal Arbuckle limestone and Reagan sandstone of Oklahoma. The Madison sandstone is correlated with the lower Knox dolomite of the southern Appalachians and the Theresa and Hoyt limestones of New York and the Champlain Valley. It is possible that the Jordan sandstone and overlying Madison (?) are the equivalent of the Madison of southeastern Wisconsin.

The Oneota constitutes one member of the division once generally known as the Lower Magnesian Series to which in later times the name of Prairie du Chien formation was applied. The Oneota formation has its immediate correlative in the formation of the same name occurring in Iowa and Minnesota. Ulrich correlates it with the Gasconade limestone and Gunter sandstone of Missouri, the Chepultepec limestone of Alabama and the Little Falls dolomite of New York.

The St. Peter sandstones are a part of the widespread formation of the same name which extends over a great part of the Mississippi Valley.

MESOZOIC GROUP

CRETACEOUS (?) SYSTEM

WINDROW FORMATION

General Statement. At a number of points on the uplands of the Sparta and Tomah quadrangles, as well as in parts of Wisconsin, Iowa, Minnesota, and other states, occur conglomerates and gravels with associated limonite, clay, and sandstone. These deposits are pre-Pleistocene and post-Paleozoic and probably date from either the Cretaceous or the Tertiary. They have been described in detail as the Windrow formation by two of the authors of this folio[1] ~~in greater detail~~. Shipton[2] previously studied certain of the deposits and published photographs of the pebbles in these gravels.

Relation to Underlying Formations. The Windrow formation rests unconformably upon the Madison (?) sandstone at Windrow Bluff and upon the Oneota dolomite at all other points except near Pine Hollow church, in the southeast corner of the Sparta quadrangle, where the underlying rock appears to be the St. Peter sandstone. The exact plane of contact is nowhere exposed in the area under discussion. It seems clear that it is an irregular one, although the extent to which

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1/ Thwaites, F. T., and Twenhofel, W. H., Windrow formation; an upland gravel formation of the Driftless and adjacent areas of the upper Mississippi Valley: Geol. Soc. America, Bull., Vol. 32, pp. 293-314, 1921.

2/ Shipton, W. D., Geology of the Sparta quadrangle, Wisconsin, unpublished thesis, University of Iowa, 1916. Trowbridge, A. C., The erosional history of the Driftless Area; University of Iowa Studies, Vol. IX.

some of the gravels may have slumped is indeterminate.

Thickness. The Windrow formation occurs in small patches, none of which has a thickness of more than 20 feet.

Character of the Windrow Formation. The pebbles of the Windrow formation are mainly quartz and chert. All the quartz pebbles are well polished and rounded to spherical and elliptical shapes. The chert pebbles are also well polished, but are mainly of sub-angular shapes. Most of the pebbles (see plate II) are small; specimens of greater than an inch in diameter are rare, although a few chert boulders up to a foot in diameterhave been observed. The last named are not rounded or polished. The relative abundance of chert and quartz varies widely. At the Tunnel No. 3, southeast of Sparta, a count gave 50 per cent chert, 45 per cent yellow and milky quartz and 5 per cent pink quartz. At a locality nearby it was found that 75 per cent consists of yellow and milky quartz, 24 per cent of black, gray, and brown chert, and 1 per cent of pink quartz, with an occasional pebble of dolomite. The quartz pebbles vary considerably in shades of color and are utterly unlike any material found in the Paleozoic rocks of the region of their occurrence.

At a number of localities the pebbles are cemented into a conglomerate by manganiferous limonite. The sands which constitute a part of the deposit are mainly coarse grained, poorly assorted, and imperfectly rounded. Wherever bedding has been observed, it is rude and imperfect. Current ripple marks were seen at Tunnel No. 3.

The type locality of the formation here discussed is on

Windrow Bluff, an outlier of the Oneota escarpment between Tomah and Sparta, on the divide between Lemonweir and La Crosse rivers (NE $\frac{1}{4}$, Sec. 10, T. 17N., R 2W). A small ledge exposes limonite-cemented conglomerate and ferruginous sandstone which rest on the Madison (?) and Jordan sandstones of the uppermost Cambrian. The pebbles are the same as elsewhere, but a few subangular boulders of Oneota chert are present, one of them a foot in diameter. Bedding is very poorly indicated. The elevation is 1400 feet.

Two of the most accessible of the other occurrences are on the highway just above Tunnel No. 3 on the Chicago and Northwestern Railway between Sparta and Norwalk (NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 18, T. 16N, R. 2W) and on the hill nearby just south of the station of Summit at the eastern portal of the tunnel (SW $\frac{1}{4}$, Sw $\frac{1}{4}$, Sec. 17, T. 16N, R. 2W). At these places the formation consists of much weathered and broken down conglomerate with a sandstone matrix, yellow and red stratified sandstone, and powdery and botryoidal limonite. The thickness appears to be from 10 to 20 feet. The bedding is not well defined. The elevation of these localities is between 1360 and 1380 feet.

Loose pebbles, possibly lowered by creep, are extremely abundant near Pine Hollow church, about a mile north of Cashton (NE $\frac{1}{4}$, Sec. 29, T. 15N., R. 3W). The elevation is about 1310 feet. The material rests on the Oneota dolomite and possibly also in part on the St. Peter sandstone.

Other places in the Sparta and Tomah quadrangles where pebbles or rock of the Windrow formation are definitely known are listed below. In the preparation of this list all doubtful occurrences of one or two pebbles have been omitted, since such pebbles may represent material transported by human agency--either attached to mud on the wheels of vehicles or transported in road material or fertilizer, or carried as curiosities or "lucky stones". At all these places the underlying rock is the Oneota dolomite.

Locality		Elevation
T. 17 N, R. 3W		
N. Half	Sec. 27	1400 feet
T. 16 N, R. 2W		
S ½, post "	12	1440 "
SW ¼, NW ¼ "	19	1400 "
NE ¼, SW ¼ "	20,	1300 "
T. 16 N, R. 3W		
NW ¼, "	23	1400 "
S ½, post "	24	1380 "
S ½ "	36	1400 "
T. 15 N, R. 3W		
S ½ post "	20	1360 "
S ½ " "	22	1360 "
T. 15 N, R. 4W		
N ½ post "	22,	1334 "
Center "	23	1360 "

Fossils. Fossils are rather common in the chert pebbles of the Windrow formation. Not uncommonly they are well preserved and in a few instances a fossil makes an entire pebble. The specimens for the most part are considerably worn, but a few have been collected which show scarcely any wear. No fossils have been discovered in the formation which appear to be of the same age as the deposit. The fossils in the pebbles are of Ordovician and Silurian age and it is possible that one or two may have been derived from Devonian strata. The writers have found fossils at Tunnel No. 3, at Summit, and at Windrow Bluff.

Conditions of Origin of the Windrow Formation. Strong considered the gravels near Seneca[1] to have been deposited by ocean currents. He

1/ Strong, Moses, Geology of the Mississippi region north of the Wisconsin River, Geology of Wisconsin, vol. 4, p. 88 , 1882.

thought they had been cemented by iron oxide coming either from ferruginous springs or from some other source, operating to precipitate iron from water.

Chamberlain[2] observed the gravels on the East Bluff at Devils

2/ Chamberlain, T. C., Fluctuation of level of the quartzite of Sauk and Columbia County, Wisconsin, Wis. Acad. Sci., Trans., vol. 2, pp. 123-138, 1874.

Lake, but did not express any view as to their origin, except that they are not glacial. Irving[3] considered that the gravels and potholes at

3/ Irving, R. D., Geology of Central Wisconsin, Geology of Wisconsin, vol. 2, p. 508, 1877.

Devils Lake record a higher level of the pre-glacial Wisconsin River. Chamberlain and Salisbury ascribed the conglomerate at Seneca either to the marine Cretaceous or to the older drift.[4] Salisbury first recog-

4/ Chamberlain, T. C. and Salisbury, R. D., Preliminary paper on the Driftless Area of the upper Mississippi, (U. S. Geol. Survey), pp. 275-276, 1885. See 6th Ann Rept nized the wide extent of the upland gravels and correlated them with the high level gravels to the south, but did not make clear his views as to their origin.[1] Howell[2] ascribed the deposits at Waukon, Iowa, to

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[1] Salisbury, R. D., On the northward and eastward extension of the pre-Pleistocene gravels of the Mississippi Basin. Geol. Soc. America, Bull., vol. 3, pp. 183-186, 1903.

Salisbury, R. D., Pre-Glacial gravels on the quartzite range near Baraboo, Wisconsin, Jour. Geology, vol. 3, pp. 655-657, 1895.

[2] Howell, J. V., The iron ore deposit near Waukon, Iowa; Iowa Geol. Survey, vol. 25, pp. 37-92, 1916.

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accumulation in a bog on a peneplain, a view earlier stated by Calvin[3]

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[3] Calvin, S., Geology of Allamakee County; Iowa Geol. Survey, vol. 4, pp. 97-103, 1895.

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for the same deposit. Trowbridge,[4] Shipton,[5] and Hughes[6] considered

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[4] Trowbridge, A. C., Preliminary Report on Geological Work in the Driftless Area; Geol. Soc. America, Bull., vol. 26, p. 76, 1915;

Preliminary report on geological work in northeastern Iowa, Iowa Acad. Science, Proc., vol. 21, pp. 205-209, 1914.

History of Devils Lake, Wisconsin; Jour. Geology, vol. 25, pp. 352-353, 1917.

Erosional history of the Driftless Area; University of Iowa Studies, Studies in Natural History, vol. IX, No. 3, 1921.

[5] Shipton, W. D., The Geology of the Sparta quadrangle, Wisconsin; Unpublished Theses, University of Iowa, pp. 39-45, 1916.

[6] Hughes, U. B., A correlation of the peneplains in the Driftless Area; Iowa Acad. Science, Proc., vol. 21, pp. 125-132.

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that the gravels originated as stream deposits on a Tertiary peneplain.

Criteria relating to the origin of the Windrow formation may be divided into four groups, as follows: Composition and assortment of materials, sedimentary structure, distribution of deposits and nature of the underlying surface.

The materials of the Windrow formation fall into two general groups (1) the pebbles and associated sands and clays and (2) the iron oxides. The chert pebbles are shown by their fossils to have been derived from Paleozoic limestones, none of which was younger than the Devonian. Most of them came from the Niagara dolomite. They are generally highly polished and well rounded specimens are ~~extremely~~ rare. These facts prove that the transportation of the cherts has varied greatly and as so few of them are well rounded, it follows that they have not been subjected to much washing and are probably of stream rather than of beach origin. The quartz pebbles do not appear to have been derived from any of the Paleozoic formations now exposed in the upper Mississippi Valley and it is quite probable that their mother rock is in the pre-Cambrian. All are well polished and rounded, but not one of lenticular shape has been found. It is concluded that they have been brought a great distance by streams and were not washed along a beach.

The assortment of the gravels and associated sands is very poor, Chert and quartz pebbles are intimately intermixed. In a small hand specimen variations in size from a tenth of a millimeter to two or three centimeters is common. The sand grains show similar imperfect assortment. These characters, while they do not preclude marine deposition, strongly suggest river origin.

It has also been suggested that the pebbles owe their smoothness to desert polish, but the poor assortment of the associated sands would appear to preclude this possibility.

The iron oxides are present as concretionary masses which range up to several tons in weight and as a cement for the pebbles and the sands. They are characterized by a variable state of hydration and by the presence of a variable percentage of manganese, phosphorus, and clay. The intimate association of the different kinds strongly suggests, if it does not prove, that their deposition took place simultaneously. The iron oxides are of the bog ore type.

Such bedding as has been observed, is poorly defined. Cross-lamination was observed in a few places. The iron-bearing portions show essentially nothing in the way of bedding, but this is possibly due to the development of concretionary structure subsequent to deposition which would have brought about the elimination of bedding. A few current ripple marks were observed at Tunnel No. 3. None of the structures suggests marine origin and all are in harmony with the view of stream deposition. The Cretaceous sea lay to the south and west. The pebbles are believed to be of stream deposition in a region of considerable relief and to have been deposited by streams flowing to the south and southwest. The absence of cherts containing Mississippian and Pennsylvanian fossils is in harmony with this conclusion since such cherts would certainly have been among the pebbles had the streams flowed in the opposite direction.

<u>Age of the Windrow Formation.</u> With slight reservations

Winchell[1] and Upham[2] ascribed the upland gravels and associated deposits

1/ Winchell, N. H., Geology of Fillmore County, Geol. of Minnesota, vol. 1, pp. 309-310, 1884.

Winchell, N. H., Geology of Goodhue County, Geol. of Minnesota, vol. 2, pp. 20-61, 1888.

Winchell, N. H., Geology of Mower County, Geol. of Minnesota, vol. 1, pp. 355-356, 1884.

2/ Upham, Warren, Geology of Wright County, Geol. of Minnesota, vol. 2, 1888, p. 292.

of southeastern Minnesota to the Cretaceous. Salisbury[3] considered

3/ Salisbury, R. D., On the northward and eastward extension of the pre-Pleistocene gravels of the Mississippi Basin; Geol. Soc. America, Bull., vol. 3, pp. 183 186, 1892.

that "it is not beyond the possibility that some of the beds are Cretaceous, while others are Tertiary"; but that "the balance of evidence seems to favor" reference to the latter. Howell concluded that the plain on which he conceived the gravels to occur "may be assumed with considerable confidence to be of Pleiocene age since it bears gravels which belong to the Pliocene Lafayette formation." Chamberlain and Salisbury[4]

4/ Chamberlain, T. C. and Salisbury, R. D., Geology, vol. 3, pp. 300 301, 1907.

discussed these gravels under the Pliocene, but suggested that they may be older. Trowbridge and his associates[1] hold that they are of

1/ Trowbridge, A. C., Preliminary report on geological work in the Driftless Area: Geol. Soc. America, Bull., vol. 26, p. 76, 1915; Preliminary report on geological work in northeastern Iowa: Iowa Acad. Sci., Proc., vol. 21, pp. 205-209, 1914; The erosional history of the Driftless Area: Univ. of Iowa Studies, Studies in Natural History, vol. 9, No. 3, pp. 78-79, 111-113, 121-123, 1921;
Hughes, U. B., A correlation of the peneplains in the Driftless Area: Iowa Acad. Sci~~ence~~, Proc., vol. 21, pp. 125-132, 1916.
Shaw, E. W. and Trowbridge, A. C., Geologic atlas of the United States Galena-Elizabeth, folio, U. S. Geol. Survey, Folio No. 200, pp. 9-10, 1916.
Shipton, W. D., The Geology of the Sparta quadrangle, Wisconsin; Unpublished thesis, University of Iowa, pp. 39-45, 1916.

Tertiary age. McGee,[2] describing the Rockville conglomerate of Iowa,

2/ McGee, W. J., Notes on the Geology of a part of the Mississippi Valley; Geol. Mag., 2d sec., vol. 6, pp. 353-361, 412, 420, 1879; The Pleistocene history of northeastern Iowa, U. S. Geol. Survey, 11th Ann. Rept., pt. 1, pp. 304-308, 1891.

referred it to the Cretaceous. Alden[3] reviewed all the known occurrences

3/ Alden, W. C., The Quaternary geology of southeastern Wisconsin; U. S. Geol. Survey, Prof. Paper 106, pp. 99-102, 1918.

of these gravels, but reached no conclusion as to whether they are Cretaceous or Tertiary, suggesting that both may be represented.

There are two problems involved, the correlation of the occurrences with each other and their correlation with deposits of known age. In the discussion which follows the two problems are not separated. Criteria which bear on the age of the gravels of the Windrow formation may be divided into six groups: (1) lithological similarity, (2) topographical position, (3) fossils, (4) age of underlying formations, (5) relation to overlying formation, and (6) history since the advent of glaciation.

The correlation of the different occurrences of the Windrow formation with one another is in large part based on their lithological similarity. Such differences as exist are quantitative, not qualitative. This fact taken in connection with other evidence leads the writers to the conclusion that the gravel and limonite deposits as far west as Mitchell County, Iowa, are of the same age.[1] The gap of 150 miles from Mitchell

[1] In this connection it should be stated that the writers do not assume the gravels were necessarily deposited within a duration of time represented by any terrestrial or marine formation. An entire period may have been involved and some portions of the gravels may well be somewhat older than others, but they are believed to have been deposited within a space of time during which the same general conditions of deposition were maintained throughout the area of distribution.

County ti Guthrie County, Iowa, is more difficult to bridge. There seems little doubt that the Guthrie County beds are Cretaceous and could a correlation with the gravels of the Windrow formation be definitely established, the age of the latter would be determined.

One of the strongest lines of evidence tending to show the great age of the Windrow formation is its topographical position. Most of the known occurrences are on the summits of the highest hills in the vicinity. The Windrow Bluff occurrence is over 800 feet above the rock bottoms of the adjacent valleys. Eastof the last named point the strata on which the

Windrow deposits rest have been entirely removed over thousands of square miles leaving the great Central Plain of Wisconsin. The production of these topographic features took a long time and the topography seems to have had essentially its present form at the beginning of the Glacial Period. The general harmony of the elevations above sea level is an additional argument that the different patches of gravel were deposited at essentially the same time.

It has been suggested in the consideration of the origin of the Windrow formation that it was deposited by streams under conditions of considerable relief. ~~Such being~~ If such were the case, it follows that at the time of the deposition of the gravels the present location of the formation were the lowest parts of the surface instead of the highest as they are today. The divides have migrated, so that what once was a valley bottom is now the top of a ridge. Such migration of divides and shifting of stream courses has, doubtless, been brought about, in part, by the resistance to erosion of the iron oxide deposits; but an intervening period of peneplanation and a subsequent uplift are not necessary events in the sequence. The nature of the gravels suggests moderately wide valley bottoms with fairly high divides. Hills doubtless rose to considerable heights along the stream courses and from their erosion, the chert pebbles were derived. We must picture the country as it appeared when the deposits were laid down; we must realize that not only have rivers migrated through the complete elimination of the former divides, but streams have eroded their bottoms 800 to 900 feet below the former floors of their valleys; we must appreciate that, over thousands of square miles, wind, streams, and the weather have totally removed rock layers 800 feet or more in thickness, forming the great Central

Plain of Wisconsin; only then do we obtain an adequate conception of the great age of the Windrow formation.

Although no contemporaneous fossils have been collected in any of the deposits, the cherts have yielded fossils which range in age from the Ordovician to the Silurian and possibly the Devonian. This gives positive assurance that the gravels are of post-Silurian age.

The youngest rocks known to certainly underlie the Windrow formation are of Devonian age. If the Guthrie County, Iowa, conglomerates are part of this formation, then the Windrow formation is post-Carboniferous.

The materials known to overlie the Windrow formation are the loess. This relation proves that the formation is older than the Pleistocene.

The earliest ice sheets in Wisconsin found the topography of the Driftless Area not greatly different from what it is today.1/ Apparently

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1/ Leverett, Frank, Outline of Pleistocene history of the Mississippi Valley: Jour. Geol., vol. 29, pp. 620-621, 1921.
Trowbridge has expressed the view that the valleys are of post-Nebraskan age (See p.____). The earliest ice in Wisconsin may be of Nebraskan age. Weidman, Samuel, The Pleistocene succession in Wisconsin (abstract): Science, New Series, vol. 37, pp. 456-457, 1913; Geol. Soc. America, Bull., vol. 24, pp. 697-698, 1913. Dr. Weidman later reversed the views expressed in these papers. The writers of this folio have never been satisfied that there is any drift in Wisconsin older than the Kansan.

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the ice entered the Central Plain of Wisconsin in Wood and Jackson Counties, thus showing that this plain is of preglacial age and that the Windrow formation long antedates the time of these glaciers. The time occupied in weathering and erosion which has taken place since the retreat of the earliest ice sheet from Wisconsin is a mere nothing compared to that which has elapsed since the formation of the upland gravels and bog iron ore.

Unless the time necessary for deepening of the valleys of the Sparta and Tomah quadrangles is much less than is generally thought, the entire Tertiary period does not seem too long, in the opinion of the writers, to have brought about theexisting distribution and altitude of the gravels of the Windrow formation in relation to present topography. It is true that in the mountains and plateaus of western United States huge canyons have been carved since middle Tertiary time, but the conditions of climate and slope there are vastly different from any which could ever have existed in Wisconsin.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES

General Statement. The deposits of Pleistocene and Recent age within the Sparta and Tomah quadrangles comprise:

Alluvial fans and *Alluvium of flood plains	(Recent)
*Peat and muck	(Recent)
*Sand dunes	(Wisconsin and Recent)
Loess	(Wisconsin)
*Wisconsin valley filling	(Wisconsin)
*Older terrace gravels	(Pre-Wisconsin)
Deposits due to creep and hillside wash	(Pre-Pleistocene to Recent)
Residual soil	(Pre-Pleistocene to Recent)

The deposits listed above were formed after the region had nearly or quite reached its present topographic form. They contain materials derived from all the older formations, from which they are seperated by great unconformities. Excepting for parts of the residual soil, the pre-Wisconsin terrace gravels are the oldest of these deposits. Only the deposits marked with an asterisk are shown on the areal geologic map.

Residual Soil.

General Statement. The residual soils of the Sparta and

Tomah quadrangles are composed of the debris derived from the weathering of dolomites, sandstones, and sandy shales. They grade downward into the parent rock but exposures showing this are not common.

Character. The soil developed by the weathering of the Oneota dolomite is a brownish red clay filled with chert. In the lower portion of the soil fragments of rotted dolomite are common. The sandstones weather into sand but no considerable amount of residual soil can be ascribed to the shaly zones.

Thickness. The thickness of the residual deposits is not known exactly. It is greatest on broad uplands where exposures are uncommon. It is believed that well records which show as much as 75 feet of loose material on the ridges include a considerable amount of broken dolomite below the true residual soil.

Age. The residual deposits are far older than the Wisconsin epoch of glaciation, since within the area covered by drift of that age such deposits have not had time to form in post-Glacial time. Their relative age with respect to the older drifts is more difficult to estimate.1/

1/ McGee, W. J., Pleistocene history of northeastern Iowa: U. S. Geol. Survey, 11th Ann. Rept., pt. 1, pp. 548-566, 1891.
Chamberlin, T. C. and Salisbury R. D., Preliminary paper on the Driftless Area of the Upper Mississippi Valley: U. S. Geol. Survey, 6th Ann. Rept., pp. 221-258, 1885.

Within adjacent areas covered by older drift there is much residual soil. To what extent this has developed in the time since glaciation and to what extent it is pre-Glacial has never been satisfactorily determined. In the opinion of the writers a not inconsiderable portion of the residual soil of this area is older than the Pleistocene. Residual soil is still in process of formation.

Deposits Due to Creep.

<u>General Statement</u>. Under the heading of deposits due to creep are included accumulations of weathered rock debris which have moved to a greater or less extent from the position where the material was severed from the ledge. The residual soils are also involved in this movement and have crept to an extent not generally realized. Talus accumulations comprise the bulk of these deposits.

<u>Thickness</u>. On the uplands wherever there is any considerable slope the residuum has moved to some extent. In most cases this cannot be demonstrated but at localities where patches of St. Peter sandstone have survived in hollows of the Oneota dolomite the phenomenon is striking. In a road cut at Pine Hollow Church, the residual clays of the Oneota overlie St. Peter sandstone so that the soil of an older formation has crept over a younger rock. The talus and creep deposits of the hillsides are a heterogenious mixture of residual clay and sand mixed with blocks of chert, dolomite, and the harder sandstones. In many places the material resembles a glacial till in its physical character.

<u>Age</u>. The deposits due to creep occur in valleys which apparently, in large part at least, antedate the oldest known drift [1/] so that

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1/ Leverett, Frank, Outline of Pleistocene history of Mississippi valley: Jour. Geology, vol. 29, pp. 620,621, 1921.
Trowbridge favors the post-Nebraskan age of the valleys of the Driftless

Area (See p.).
Trowbridge, A. C., Preliminary report on geological work in northeastern Iowa: Iowa Acad. Science, Proc., vol. 21, pp. 208, 209, 1915: Erosional history of the Driftless Area: University of Iowa Studies, Studies in Natural History, vol. 9, No. 5, pp. 123-127, 1921.

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they are probably in considerable part of pre-Glacial age. Their formation is still going on.

Pre-Wisconsin Terrace Gravels.

General Statement. Throughout the area are gravel-covered rock terraces from a few feet to 140 feet above the adjacent stream bottoms. Most of the pebbles are chert, with a subordinate amount of sandstone and quartz pebbles. There are no dolomite pebbles. Little sand or clay is found. The deposits are in many places covered by loess or dune sand. The thickness of gravel is in few places much over 10 feet.

Relation to Underlying Formations. Terrace gravels are found lying upon rock benches at several horizons in the Franconia and Dresbach sandstones. Some of the gravel capped terraces are hard to distinguish from the rock terraces.

Thickness. The older terrace gravels in few locations exceed 10 feet in thickness. The maximum is probably not over 40 feet.

Character. The older terrace gravels consist of rather coarse, ill assorted, rudely bedded, poorly rounded stones with much sand. (Plate IV.) In all but one locality the pebbles are from 80 per cent to virtually 100 per cent cherts derived from the Oneota dolomite. They are more or less water-worn. In size they range from a fraction of an inch in diameter to boulders more than 15 inches thick. The pebbles other than chert are nearly all hard sandstones, in which fragments from the quartzitic and ferruginous layers are most abundant. At one locality (Sec. 2, Sparta (T 17N, R. 4W) the general rule is reversed and pebbles of sandstones predominate. The sandstone pebbles are smaller and better rounded than the cherts. They decrease in percentage in descending a stream. For instance, in Stevens Valley, west of Tomah, sandstone makes up about 20 per cent of the pebbles, while at Tomah, three miles to the northeast scarcely any sandstone pebbles are found. The size of all the pebbles also decreases down stream. Quartz pebbles from the Windrow formation are locally conspicuous, but form an insignificant part of the whole mass. The deposits are roughly stratified, with occasional cross bedding. Layers of clean sand are found in places (Plate IV). The percentage of stones is greatest near the surface of the ground.

Distribution. Along the headwaters of Lemonweir River near Tomah the older terrace gravels are seen to best advantage (Fig. 14). They cap isolated hills and rock terraces. The largest single deposit is at Tomah, where the city is built on a terrace more than a mile long, half a mile wide, which is almost completely mantled by gravel and sand. The highest occurrences northwest of the city are about 40 feet above the stream. Those in the vicinity of Jacksonville School are 60 feet, and near the northwest corner of section 36 (T. 17N, R. 2W) small patches of gravel are 80 feet above the creek. This represents a grade of about 20 feet per mile, compared with the slope of 13 feet per mile in the present stream.

In the southwest quarter of Sec. 18 and the northwest quarter of Sec. 19, Tomah (T. 17 N, R. 1W), Terrace gravels cap three distinct levels, respectively about 60, 80, and 100 feet above the stream. The upper limit of the deposits is very hard to determine since they are deeply eroded and heavily covered by loess and have no topographic expression. The much eroded terraces west of Lemonweir River, and at the cemetery south of Tomah, contrast sharply with the low, little dissected, gravel terrace along the southeast side of the stream in Secs. 16, 17, and 18, Tomah.

In the narrow valleys of Kickapoo River and its tributaries are numerous small remnants of older terrace gravels. The elevations reach a maximum of 140 feet above the river Northeast of Wilton. The gravels rest upon several horizons of the Franconia and Dresbach formations. Doubtless much gravel is concealed beneath the loess, which in places reaches 10 to 15 feet in thickness.

In La Crosse valley and its branches exposures of the gravels are somewhat less common, a fact due in large part to the covering of loess and windblown sand. In the main valley they occur as high as 90 feet above the alluvial floor of the valley or 110 feet above the river (~~See D. S. Burns~~ Sec. 36, Burns) (T. 17 N, R. 5W.).

A number of deposits are known in Leon Valley, among them a gravel pit in SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 29, Wells (T.16 N., R. 3 W.). A thickness of 6 to 8 feet of sandy, ill assorted chert gravel is worked on a face of about 250 feet. (Plate IV) It lies upon heavily bedded white sandstone of the Dresbach formation. The deposit extends only a few rods back from the present face. In Sec. 24, Leon (T.16 N, R.4 W.), coarse gravels are found on much eroded loess-covered terraces at elevations of approximately 20, 40, 80, and 120 feet above the stream. The gravel is everywhere very thin. Only a few scattered remnants of gravel were found in the northern tributaries.

Age. The origin and age of the older terrace gravels is more fully discussed under the head of Geological History. The age of the formation is indicated by the erosion it has suffered. This has resulted in the formation of valleys over 200 feet deep since the gravel was deposited and in the almost complete removal of the entire deposit over large areas. The older terrace gravels are interpreted as alluvial fans and valley filling of early Pleistocene age, when the rock floor of the valley may have been higher than at present.

Valley Filling of Wisconsin Age.

General Statement. The bottoms of the larger valleys of the Sparta and Tomah quadrangles are flat with alluvial filling. These deposits consist mainly of sand, with subordinate amounts of gravel and clay. In places they are overlain by loess.

Relation to Underlying Formations. The younger valley fill has evidently been formed since the erosion of the pre-Wisconsin terrace gravels, for it occupies valleys cut through that formation, and is of a different composition.

Thickness. At Sparta the greatest known depth to rock is reported to be 140 feet. Further down La Crosse Valley it is 80 to 100 feet. At Tomah it is 70 to 104 feet. In the smaller valleys the thickness of the valley fill in few places exceeds 25 feet. It is safe to conclude, therefore, that the maximum thickness of these deposits is probably not over 150 feet.

Character. In the valleys of the larger streams the valley fill is mainly sand with a few sandstone pebbles; in the narrower valleys, especially near their headwaters, gravel and rubble predominate. Where relatively free from admixture from the pre-Wisconsin terrace gravels the limestone and sandstone pebbles make up more than 50 per cent of the deposit, contrasting sharply with the older gravel formation. Black, blue, and brown clays are seen, in places interbedded with the sand, and in other localities forming the soil over the gravels. The dark colors are due to the presence of organic matter. In many places there are gravel lenses in the clay and sand. Ravines along La Crosse River show cross-bedded sands and clayey sands with abundant current marks. Deposits of typical brownish yellow loess occur in places near Tomah and in La Crosse Valley and its tributaries (Fig. 15). Occasional peat beds are found interbedded with the sands of the valleys. The buried soils are a natural consequence of the process of alluvial deposition.

Record of Well at Sparta,
2 Blocks East of Court House on Oak Street. 1/

	Thickness	Depth
Loam, black sandy	5	5
Sand, yellow	75	80
Loam, black sandy, with twigs, shells, and grass	2	82
Clay, yellow	3	85
Gravel, chert pebbles	2	87
Loam like that above	2	89
Gravel, chert pebbles and sand, white	28	117
Sandstone with shale beds	168	285

1/ Reported by Con~~tracter~~ Crowley, Driller.

Well records reported by A. E. Hollister of Tomah show tamarack logs buried in sand and clay from 30 to 40 feet below the present valley bottoms.

Distribution. The valley fill is in many places separated from the adjoining hillsides by a fairly definite break in the slope. For long distances, however, the division is not well marked and the two merge into one another, the valley floor sloping towards the stream.

This condition is further complicated where sand dunes are found. There is every gradation from hillsides covered by talus and by residual deposits to alluvial fillings, so that the boundaries shown on the map are necessarily more or less arbitrary. In other words, the valley fill is in part alluvial and in part colluvial.

In some of the smaller streams the relatively flat valley floor heads upon the uplands, where it has a width of only a few yards, too narrow to show on the map. These narrow flats are not strictly valley fill but represent the freshet deposits which can not be carried by the normal stream. The ravines on hill sides are now being eroded more actively and all streams are subject to greater floods than before settlement and partial deforestation of the country. This subject is considered at greater length under Geological History.

Age. The alluvial valley fill is separated by a pronounced unconformity from the pre-Wisconsin terrace gravels. It also differs in the greater percentage of limestone and sandstone pebbles and sand. It seems possible that the valleys were eroded in this interval from the level of the pre-Wisconsin terrace floors to the present rock floor. The upper terrace has been traced into the highest terrace of the Mississippi Valley which consists of glacial outwash of Wisconsin age. Whether or not all the valley fill is of this age is not clear, for the lower parts may well be older. Many of the small streams are aggrading their beds at the present time.

Loess.

General Statement. Deposits of buff or yellowish-brown loess are widely distributed throughout the Sparta and Tomah quadrangles. The 1 loess is of eolian origin and overlies the rocks, residual deposits, older terrace gravels, and upper alluvial terraces of the valley fill. It supplies excellent soil.

Relation to Underlying Formations. The loess mantles the erosion forms of the present surface, resting unconformably upon all formations, including parts of the Wisconsin valley filling. It is probable, however, that a part of the loess found on the valley filling may have been worked over by streams and rain wash.

Thickness. The loess is absent over large portions of the quadrangles and where found varies from a few inches thick to 20 feet or possibly more. The thickest deposits of loess are found on the rock terraces within the valleys and in ravines. They are best developed in valleys and on the eastern sides of ridges.

Character. The loess consists of mineral particles of the grade of fineness known as silt and clay, as shown in the accompanying table of mechanical analyses. It is of a light porous texture, free from stones and of a buff or yellowish brown color, thus differing sharply from the sticky, red, residual limestone soils and the stony residual sands. It is unstratified. Where resting upon sand or sandstone the wind-transported origin of the loess is made evident since it rarely contains particles as coarse as the grains of the underlying formation. The clays of the valleys are in large part deoxidized loess worked over by water, and mixed with sand. The chemical composition of the loess of the quadrangles has ~~only~~ been determined only at Tomah.

The accompanying analysis is presumed to be of the clay in the old brick yard on a terrace of Lemonweir Creek in NE 1/4, NW 1/4 Sec. 8, T. 17, R 1 W. It closely resembles analyses of typical loess in adjoining counties.

Analysis of loess, Tomah, Wisconsin. 1/

1/ Buckley, E. R., Clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 7, p. 274, 1901. (Analyst unknown. A search of Buckley's notes showed nothing on this deposit.)

SiO_2	76.37
Al_2O_3	11.61
Fe_2O_3	5.22
CaO	0.94
MgO	0.54
Na_2O	0.69
K_2O	1.07
H_2O + C	2.59
	99.83

The high percentage of silica, above 76 per cent, is in contrast with the residual limestone clays whose silica content in few cases much exceeds 50 per cent. The content of iron and aluminum oxides is also proportionally lower. The loess of this area is not calcareous, as are the thicker deposits farther to the south and west. The microscopic examination shows a great variety of minerals, but about 50 per cent is quartz. Feldspar, hornblende, and pyroxene, biotite and magnetite have been discovered in the loess.1/

1/ Chamberlin, T. C., and Salisbury, R. D., Preliminary report on the Driftless Area of the Upper Mississippi Valley: U. S. Geol. Survey, 6th Ann. Rept., pp. 239-288, 278-307, 1885.

Mechanical analyses of loess.

	U.S. Bureau of Soils, Composite Analysis. (a)	Average of analyses in area to North. U.S. Bureau of Soils (b)	La Crosse County Average. (c)	Average of Residual Limestone Clay. Soils Division, Wis. Survey. (d)
Fine gravel 1-2 mm	0.1	.0	.0	0.4
Coarse sand .5-1.0 mm	0.1	.0	.4	1.4
Medium sand .25-.5 mm	0.1	.0	.3	1.8
Fine sand .10-.25 mm.	1.7	.7	.9	4.2
Very fine sand .05-.10 mm	18.2	19.6	5.4	7.1
Silt .005-.05 mm	63.1	64.8	76.5	57.7
Clay -.005 mm	16.4	14.7	16.5	27.4
	100.0	100.0	100.0	100.0

(a) Alden, W. C., Quaternary Geology of southeastern Wisconsin: U.S. Geol. Survey, Prof. Paper 106, p. 322, 1918.
(b) Weidman, Samuel, Hall, E. B., and Musbach, F. L., Reconnaissance soil survey of south part of northwestern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 23, 1914.
(c) Whitson, A. R., Geib, W. J., Dunnewald, T. J., and Lounsberry, Clarence, Soil survey of La Crosse County, Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 40, p. 20, 1914.
(d) Whitson, A. R., et. al., Soil Survey of Juneau County, Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 38, p. 26, 1918: Soil

Survey of Iowa County, Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 30, p. 24, 1914.

The most marked difference between loess and residual clay are in the larger percentages of silt in the former and in color (see p. -)

Distribution. The portion of the Sparta quadrangle in La Crosse County has been mapped by the Wisconsin Geological and Natural History Survey in cooperation with the U. S. Bureau of Soils.[1] A

1/ Whitson, A. R., Geib, W. J., Dunnewald, T. J., and Lounsberry, Clarence, Soil Survey of La Crosse County, Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 40, 1914.

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copy of this map, altered to show the origin of the soils, is reproduced as Fig. 15. Especially worthy of attention is the distribution of loess in Big Creek Valley on the eastern side of a ridge. This relation is common. It is better shown farther to the east, but no attempt was made to map the areas. An excellent place to observe the effect of loess on the fertility of the soil is at Windrow Bluff, west of Tomah. Here one sees to the west barren wastes of low scrub growth upon residual and wind-blown sands. To the east, scarcely a stone's throw away, is a rich farming country. The difference is due to the presence of the loess upon the eastern slope and its absence on the western. The significance of these facts is discussed under the head of Geological History.

Age. The loess now preserved in the district is younger than the terrace gravels since apparently undisturbed loess is found on the highest of the younger alluvial vallgy deposits as well as upon some of the terraces eroded in that formation. It is possible, however, that formation of the loess covered a great lapse of time, or reoccurred at different periods, although no definite evidence of this have been discovered in this area. Some, at least, of the loess of this area is of post-Wisconsin age.

Dune Sand.

General Statement. Sand dunes, nearly all quiescent, occupy large areas in La Crosse Valley and its tributaries. They occur mainly upon the alluvial valley fill, but are also found on the rock hills.

Relation to Underlying Formations. The sand dunes are largely confined to the upper terrace of the valley filling although some are found at lower levels near Angelo. They rest upon the rock hills with pronounced unconformity, in places blocking small valleys.

Thickness. Sand dunes upon the plains rarely exceed 20 to 30 feet in height. On hillsides the thickness is more difficult to estimate. Two excavations near Camp Robinson show rock at a depth of a few feet, and one set of long trenches at a depth of only 4 feet.

Character. The sand dunes are composed of sand grains which are considerably better rounded than those in the Paleozoic rocks or the alluvial deposits. The diagram shown in Fig. 16 shows mechanical analyses of these sands. They should be compared with those of the sands from which they were derived (Figs. 9-13).

Distribution. The largest area of dunes is on the Sparta Target Range. Dunes also occur along the base of the ridge which separates Farmers and Coles valleys, and in small patches through La Crosse valley and the lower part of Leon valley. Since there is every gradation between dunes and alluvial sand plains on the one hand, and the slope wash of the hillsides on the other, the mapping is necessarily confined to areas of well-marked character. In form, few dunes are of crescentic shape but most are low swells or mounds which in many places enclose depressions. In one instance, northeast of Coles Peak, a small pond has been dammed up by dunes. The best developed dune topography is in the vicinity of James Dugway on the Sparta Target Range, where the knob-and-kettle topography occurs, with local relief of 12 to 15 feet. Some dunes are known which have no surface expression but are the filling of old valleys. The bedding of these deposits shows that they are not stream laid, as can be observed in Burns valley (Secitons 14 and 23, Burns (T.17N, R5W)) and in SE $\frac{1}{4}$ NE $\frac{1}{4}$, sec. 15, Adrian (T.17N, R2W).

Age. The sand dunes are the coarse phase of the aeolian deposits, as explained under the head of Geological History. They were formed during, and in large part after, the period of valley filling. Locally sand dunes are still forming where fed from fields and river flood-plains, but for the most part the dunes of this area are quiescent.

Other Deposits.

General Statement. In addition to dunes of Recent age, deposits of peat and muck occur. The modern alluvium of the flood plains and the swamp deposits along the stream courses are still in process of formation. Small alluvial fans and some alluvial valley filling are being deposited at the present time.

Floodplain and Terraces. The top of the valley filling is the present floodplain in all valleys except that of the La Crosse and a few of its larger tributaries. The floodplains are marshy in places. They are furroughed by abandoned oxbows, some of which cut laterally into the adjacent hills. The streams at normal stage flow in narrow more or less meandering channels several feet deep.

In the larger valleys the streams have intrenched themselves in the valley filling, forming terraces. La Crosse River flows in a broad shallow trench from one-half to one mile in width and 20 to 30 feet deep, eroded in the alluvial deposit. The sides of this trench show well-defined terraces. A level varying from 4 to 15 feet below the high terrace has been mapped as the "low" terrace (Fig.20). Lower terraces, not over 10 feet above the water level, are included upon the map with the floodplain. Slightly-developed terraces are found also in the valleys of Little La Crosse River, Burns Creek, Big Creek, and the Lemonweir River near Tomah. The subject of the origin of the terraces is considered under the head of Geologic History ~~(See Fig.)~~.

GEOLOGIC STRUCTURE.

General Statement. The Paleozoic sediments of the Sparta and Tomah quadrangles dip to the southwest, descending 300 feet in 25 miles. This is a dip of about 12 feet per mile or about 8 minutes of arc. The general southwesterly descent is broken by slight folds, both parallel to and normal to the direction of dip. The maximum dip of the irregularities does not exceed one and a half degrees. The structure is shown in Fig. by means of contours drawn on the base of the Franconia formation. The base of the Oneota is not parallel, but shows much the same features.

Description. The structure contours show that the strata dip in a series of slight monoclines, separated by broader areas of nearly flat-lying rocks. A notable example of a monocline is that between Farmers and Leon valleys. In the steepest place the inclination does not exceed 60 feet to the mile.

Of the slight folds parallel to the dip, that running from northwest of Tomah to near Melvina is best marked. On the northwest side the strata rise slightly to an anticline and then descend to a syncline on the southeast with a maximum dip of 60 to 70 feet in half a mile. That there is no faulting is demonstrated by the abundance of exposures in which the observer can readily see the gradual descent of the strata. A similar, but lower, anticlinal roll runs northeast from Bangor along the ridge between Burns and Big Valleys.

Origin of Folds. The relation of the Melvina folds to the thickness of the Franconia, St. Lawrence, and Jordan formations may be seen by comparing Figs. 17 and 18. The decrease in thickness of these formations along a northeast-southwest line coincident with the west side of the folds shows that initial dip was probably the cause of the location of disturbance. It is also possible, however, that the change in thickness was accentuated by the formation of the fold. The larger part, if not all, of the departures from a regular slope displayed by the strata of this area are best explained by a combination of initial irregularities of deposition and subsequent inequalities of settling after the region was uplifted. The height of the rock terraces above the present valley floors is, naturally, affected by the altitude of the strata which control them. Thus the terraces rise or fall with local folds in certain valleys.

Joints. No special investigation was made of the jointing of the rocks in this area, since the lack of large quarries or other excavations renders any conclusion based on small exposures of doubtful value. Such joints as can be observed are irregular in both vertical and horizontal extent and run in a great variety of directions. It appears improbable that they owe their origin to great earth movements but simply to shrinkage and ~~settling~~ adjustment following the uplifting of the region from the sea. No relation can be made out between the larger features of the topography and either the folds or joints in the rocks, although locally the courses of small streams may be affected by joints.

GEOLOGIC HISTORY

PRE-CAMBRIAN TIME

The granites and metamorphic rocks underlying the Sparta and Tomah quadrangles were evidently once involved in intense mountain-making movements. The results of deep well drilling in the area suggest that at present the pre-Cambrian rocks form a surface of low relief. That the existing buried surface is nearly flat or rather gently undulating is suggested also by the topography of the pre-Cambrian nearby to the northeast where the underlying Cambrian sandstone is thin, or has recently been removed by erosion. This buried surface of the pre-Cambrian in the Sparta and Tomah quadrangles is a peneplain, developed in pre-Cambrian time.[1/] The occurrence of coarse granites and highly folded, crystalline, metamorphic rocks, which must have originated at a great depth below the surface of ancient lofty mountains, gives an idea of the vast amount of erosion which the area underwent during the formation of the pre-Cambrian peneplain. The long and complicated history of what occurred in the Sparta-Tomah region during the eons preceding the Cambrian included many events concerning which we can only conjecture. The region ~~was~~ may have been covered by the sea many times and as many times left dry. The

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1/ Weidman, Samuel, The pre-Potsdam peneplain of the pre-Cambrian of north central Wisconsin: Jour. Geology, vol. 2, pp. 289-131, 1903. Geology of northcentral Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 16, pp. 592-600, 1907.

Van Hise, C.R., A central Wisconsin base level: Science, N. S., vol. 4, pp. 57-59, 1896.

structure of thepre-Cambrian rocks proves that they were involved in movements of tremondous magnitude which resulted in the formation of mountains, not once, but many times. The vast unconformities within the Archean and Algonkian represent enormous lapses of unrecorded time. At the end of pre-Cambrian time the Sparta-Tomah region was a peneplain. Subsequently it was warped so that, at present, this buried peneplain slopes southwestward at the rate of 10 or 12 feet to the mile ~~(See Fig. 8)~~.

PALEOZOIC ERA

CAMBRIAN PERIOD.

The advance of the late Cambrian or St. Croixan sea from the south and southwest over the nearly flat pre-Cambrian land inaugurated Cambrian deposition in the region. Over the Tomah and Sparta quadrangles the sea must have deepened gently so that shallow waters extended outward for many miles. This sea appears to have been bordered by extremely low and flat lands over which at the times of the spring tides and storms the waters advanced far inland making broad sandflats of which some parts were permanently under water, other parts were bared when the waters retreated, while extensive areas were above water level. These elevated portions no doubt shifted from time to time with the changes of the currents and the strength of the waves. With such extensive shallow waters and wide flats the sands would become thoroughly cleaned from muds resulting in the general absence of that material, but its local occurrence in occasional depressions; the sands would be likely to become well sorted and the grains well rounded, there would be mud cracking where the sediments permitted such; there would be an abundance of ripple marking and a great development of cross-lamination of which some would be likely to be of eolian aspect. No such extensive sand flats exist today. The Rann of Cutch, near the mouth of the Indus comes near to meeting the requirements. The reason is probably to be found in the in the present high altitudes of the lands so that in no place can the sea transgress over an extensive plain of erosion. On the contrary, the existing conditions are such that the low plains ~~are~~ tend to build~~ing~~ out against the sea.

The constant moving of the sands and the ephemeral character of the water bodies made it difficult for organisms to obtain a foothold so that there was probably scant life where the sands were depositing. A zoologist in those days would probably have found dredging in these Dresbach waters a very discouraging task.

At the close of Dresbach time the area might have been above the sea for a short time, but it was mostly beneath marine water during the time of Franconia deposition. The earlier deposits of the Franconia indicate waters of considerable stability, but the later deposits show an oscillation of the sea bottom so that at times parts of it were long enough above water for the muds to become broken over extensive areas by shrinkage cracks.

The sediments which reached the sea during the earlier part of Franconia time contained an abundance of small flakes of mica indicating the erosion of a terrane rich in that substance although it is possible that the mica is of secondary development. Precipitation of glauconite occurred for long periods twice during Franconia times and the distribution of the glauconite suggests that the precipitation occurred in cycles. Nothing is known which is suggestive of the duration of a cycle.

Franconia deposition was brought to a close by uplift and the upper green sands were subjected to erosion. How long this erosion endured is conjecture, but it was long enough for erosion to reach sediments sufficiently indurated to form pebbles.

The sediments of the lower St. Lawrence were deposited in a sea which at times swarmed with trilobites and brachiopods. Conditions were oscillating so that times existed when the sediments were calcareous and at other times muds and sands. Locally parts of the sea bottom were brought above the water for periods of time long enough for the muds to crack.

Stability of sedimentation obtained during the upper St. Lawrence although the waters appear to have been shallow so that streams could bring small pebbles into the sequence of fine sands which were generally being deposited.

The Jordan sandstones appear to record a retreat of the sea and the long foreset beds of local distribution at the base may be the advancing deposits of streams. Nearly everything in the Jordan sandstone bespeaks violence of deposition and it appears quite certain that parts of them were deposited by the wind. If life existed over the area of deposition, no positive evidence of its occurrence has been found. The Madison (?) sandstones appear to have been deposited under essentially the same conditions as those which prevailed during the Jordan.

If imagination pictures a vast plain bordering a shallow sea with sandy bottom, with the tidal waters flooding widely over the plain and with sand islands appearing from time to time in the shallow water and with ephemeral peninsulas of sand extending from the shore into the waters of the sea, a conception of the conditions of deposition as they are thought to have existed will be attained.

ORDOVICIAN PERIOD.

It is thought that an interval of subaerial erosion existed between the deposition of the Madison ? and the Oneota during which some thickness of the Cambrian sands were eroded, but, whatever the case, the beginning of the Oneota time found the area beneath the sea and in somewhat deeper waters than had prevailed during any part of the Cambrian. The sea bottom was covered with dense mats of algae which plastered the surfaces on which they lived with crusts of ~~lime~~ calcium carbonate. Animal life in many groups of invertebrate was probably abundant in this sea, but only the gastropods and cephalopods have left much of a record. The abundant chert nodules which are present suggest that some organisms which made their tests of silica may have lived in considerable numbers, but no direct evidence of their presence has been found.

Between the close of the deposition of the Oneota and beginning of St. Peter deposition there was uplift and erosion of

Oneota strata. A residual clay with chert boulders developed during this interval. Whether this erosion totally removed the Shakopee formation can not be stated, but it is not unlikely that such was the case. At any rate valleys were carved and a surface with at least 60 to 70 feet relief was developed. A change which appears to have been climatic caused the rivers to become aggrading and the valleys to become filled with fluvial sands. The region during the deposition of the sands exposed in the Sparta and Tomah quadrangles might then have had a climate similar to that of the semi-arid Great Plains. The sand is not known to have been produced in the region of deposition, but it is suggested that it came from the north.

SILURIAN, DEVONIAN AND LATER PALEOZOIC PERIODS.

The St. Peter sandstone is the latest Paleozoic deposit which has been preserved in either of the two quadrangles, but the northward and northeastward facing escarpments of the Platteville and Galena limestones and dolomites, the Maquoketa shale, and Niagara dolomites, some miles to the west and the south mutely attest to other submergencies, separated by intervening times of emergence and erosion. Indeed, it seems probable that all formations up to and including the Niagara dolomite (Silurian) were once present in the Sparta and Tomah quadrangles, as debris from these formations is found in the Windrow formation. Again, in the Devonian period there may have been submergence of the region, as strata of that age occur at Milwaukee and in southeastern and central Iowa, and, if not sea bottom, the site of the Sparta and Tomah quadrangles was probably a relatively low area bordering the Devonian sea. There may also have been a Mississippian submergence as strata of that system once existed and may still exist near Chicago 1/ and the great Mississippian area of southeastern Iowa is not far distant.

The area was probably land through the Pennsylvanian and Permian Periods.

1/ Davis, W. W., Evidence bearing on a possible northeast extension of Mississippian sea in Illinois: Jour. Geology, vol. 25, pp. 576-585, 1917.

MESOZOIC AND CENOZOIC ERAS.

Continental conditions probably continued throughout the Triassic and Jurassic periods as no strata of these systems are known within the quadrangles; or for that matter, anywhere in the upper Mississippi valley.

CRETACEOUS (?) PERIOD

During the Cretaceous 1/ the area under discussion was probably a region of rolling topography bordering the Cretaceous sea to the west.

1/ Used in the sense of including both upper and lower Cretaceous.

The only sedimentary record within the quadrangles bearing upon events during the vast lapse of time between the Silurian and the Quaternary is in the Windrow formation. This deposit is interpreted as a river gravel. There is no reason for believing that the streams were flowing in broad valleys, or possibly on a peneplain, at the level of the present hilltops. The coarseness of the pebbles in the Windrow formation suggests streams with rather steep gradients rather than those of a peneplain. These streams may well have flowed in valleys as narrow and as steep-sided as the present streams of the Sparta and Tomah quadrangles. The range of altitudes at which the Windrow gravels occur show that at the time of deposition of these gravels, there was at least 100 feet of local relief in short distances, and perhaps much more. Subsequently bog iron ore appears to have been deposited in flood plains, swamps, and ox-bows, much as in the present valleys of the La Crosse and Kickapoo Rivers, cementing parts of the gravel deposits into conglomerate.

TERTIARY TIME.

The long period of Tertiary weathering and erosion resulted in producing topographic features in the Sparta and Tomah quadrangles very similar to those in existence today. Indeed, at the close of the Pliocene Epoch, all of Wisconsin must have looked very much as the Driftless Area does today.

The normal processes of Tertiary time continued throughout the Quaternary with interruptions occasioned only by the aggrading of the Mississippi Valley by glacial outwash. In the glaciated areas, however, the restoration of normal physiographic processes, following glaciation, has not yet, except in some of the older drift regions, produced topographic forms remotely resembling those in the Sparta and Tomah quadrangles. This, of itself, is a striking proof of the vast length of Tertiary time.

The time since the deposition of the Windrow formation, in the Cretaceous (?) has been sufficient for the lateral shifting of streams from their former courses, and for the entire removal of the Windrow gravels throughout many of the former valleys. The amount of subsequent deepening of valleys is demonstrated at Windrow Bluff. Here the Windrow formation occurs at an elevation of about 1400 feet. The stream which brought the pebbles in this conglomerate is thought to have come from the northeast. The present rock surface to the west near the city of Sparta lies at an elevation of about 650 feet. Therefore, erosion has reduced the valley bottoms at least 750 feet since the Windrow gravels were deposited. At that time a large part if not all of the pre-Cambrian of Wisconsin must have been still buried beneath the Paleozoic rocks. There is no lack of evidence that the region has been changed greatly since the period of its geologic history when the Windrow formation was being laid down, but there is no evidence that the type of topography has changed except in so far as formations of different character now form the surface. The slowness with which erosion is taking place is shown by the fact that the area of the Sparta and Tomah quadrangles had reached essentially the present form by the time of deposition of the early Pleistocene drift of north central Wisconsin.

POSSIBLE INTERRUPTIONS IN THE EROSION CYCLE.

The Problem. The time since the Sparta and Tomah quadrangles were last uplifted from the sea is so long that it seems probable that the process of erosion might well have been subject to interruptions due to climatic changes and to elevations or depressions of either the land or the sea surface. Changes of either kind could not be expected to have left any definite traces unless at one or more times the area had been reduced to a peneplain, remnants of which have not yet been reached by the valleys of the present cycle of erosion. We could hardly expect to find any surviving portions of a very ancient peneplain in such relatively non-resistant rocks as those of this area. The heart of the problem lies in the discovery of criteria by which can be separated the effects of rock character and rock structure from the effects of uplifts following peneplanation. In the nearly horizontal rocks of these quadrangles, which have varying degrees of resistance to weathering and erosion, this problem is infinitely more difficult than in a region of folded strata.

Previous Investigations. Many geologists who have examined the Driftless Area previous to the studies of the writers have described one or more dissected peneplains but their interpretations have varied widely. They regarded the rolling uplands as more or less undissected remnants of an erosion surface or surfaces formed with a higher base level than that which now prevails. Emmol based his conclusions on the meandering course of certain rivers farther to the south 1/. Hershey 2/ first described the uplands to the south and west as

1/ Kümmel, H. B., Some meandering rivers of Wisconsin: Science, new series, vol. 1, pp. 714-716, 1895.
2/ Hershey, O. H., Pre-Glacial erosion cycles in northwestern Illinois: Am. Geologist, vol. 18, pp. 72-100, 1896: The physiographic development of the upper Mississippi Valley: Ibid., vol. 20, pp. 246-268, 1897.

dissected peneplains. Van Hise 3/ first described the peneplain to

3/ Van Hise, C. R., A central Wisconsin base level; Science, New Series, vol. 4, pp. 57-59, 1896.
4/ Weidman, Samuel, The pre-Potsdam peneplain of the pre-Cambrian of north central Wisconsin: Jour. Geology, vol. 11, pp. 289-313, 1903.

the north of the area and suggested that it might be younger than the Paleozoic rocks, a view shown later by Weidman 4/ to be erroneous. Salisbury and Atwood 5/ interpreted the alluvial and lacustrine plain

5/ Salisbury, R. D. and Atwood, W. W., The geography of the region about Devils Lake and the Dalles of the Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 5, p. 51, plates XVII, XVIII, 1900.

of central Wisconsin as a peneplain. Grant described a peneplain in southwestern Wisconsin in reports on the lead and zinc deposits and in a paper written with Bain asserted that this plain bevels across the strata to the north, passing through the area here discussed. 6/ The same view was again stated by Bain, and by Grant and Burchard. 7/

6/ Grant, U. S., Lead and zinc deposits of southwestern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 9, p. 11, 1903; Bull. 14, p. 11, 1906.
Grant, U. S. and Bain, H. F., A pre-Glacial peneplain in the Driftless Area: Science, new series, vol. 19, p. 528, 1904.
7/ Bain, H. F., Zinc and lead deposits of the upper Mississippi valley; U. S. Geol. Survey, Bull. 294, pp. 11-16, 1906; Wisconsin Geol. and Nat. Hist. Survey, Bull. 19, pp. 11-16, 1907.
Grant, U. S. and Burchard, E. F., Geologic atlas of the U. S., Lancaster Mineral Point folio No. 145, p. 2, 1907.

The first phase of the study was closed by the work of Martin 1/ who interpreted the uplands as a series of cuestas caused

1/ Martin, Lawrence, The physical geography of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, pp. 65-70, 1916.

by the alternating resistant and weak rock formations. He demonstrated that the upland of southwestern Wisconsin does not bevel across the strata to the north but if projected in that direction would lie high above the uplands north of Wisconsin River. The difficulty of separating the effects of rock character from those of change of elevation was shown for the first time. Since Martin's work was published the old conception has been abandoned. Trowbridge and his associates 2/ postulate two peneplains, one of which has been dissected

2/ Trowbridge, A. C., Preliminary report on geological work in the Driftless Area: Geol. Soc. America, Bull., vol. 26, p. 75, 1915; History of Devils Lake, Wisconsin: Jour. Geology, vol. 25, pp. 352-354, 1917; The erosional history of the Driftless Area: University of Iowa Studies, Studies in Natural History, vol. 9, No. 3, 1921.
Hughes, U. B., A correlation of the peneplains in the Driftless Area: Iowa Acad. Science, Proc., Vol. 21, pp. 125-132, 1916.
Shipton, W. D., The geology of the Sparta quadrangle, Wisconsin, Unpublished thesis, University of Iowa, 1916.

into a series of cuestas, but which explains the subequality of elevation of their crests; the other an incomplete one present only in the bottoms of the vales between the cuestas. The work of these later students has been far more critical and detailed than the previous work. The problem centers not upon the facts but upon the relative importance to be placed on different phenomena in reaching a conclusion.

The upland surfaces. The upland surfaces of the Sparta and Tomah quadrangles in common with those of all the Driftless Area consist of rolling ridge tops no portion of which is mathematically flat. All the ridges are well drained either by means of broad valleys or, where the underlying rock is dolomite, by sink holes. An observer who looks at one of these uplands from a distance gets the impression that he sees the dissected edge of a plain, but on close approach no level upland can be found. Instead the "plain" constantly recedes like a will-o'-the-wisp until he realizes that what he sees on the horizon is nothing more than the blending in the distance of fairly level topped ridges of sub-equal elevation. In the opinion of the writers the levelness of the ridge tops has been greatly exaggerated in descriptions; they regard the phenomenon as a mere optical illusion caused by the universal relative inconsequence of vertical relief as compared to horizontal distances.

The Oneota Upland. The topography of the areas underlain by Oneota dolomite, is one of relatively gentle slopes (Plate VI), which lead from the ridges into the heads of the steep-sided valleys which have cut through into the less resistent Jordan sandstone beneath. Locally the drainage is into sink holes, some of which have a diameter of over 60 feet. The depth to the base of the dolomite beneath the ridges varies from a few feet on narrow spurs or isolated hills to over 200 feet on broad ridges. A not inconsiderable part of this thickness is made of loess, residual clay, and decomposed dolomite; in places these deposits exceed 50 feet in depth. The change in slope from the gentle angles of the upland to the steep valley sides lies at different geological horizons in different parts of the area. Where the ridges are narrow and a quartzite layer is present at the top of the underlying sandstones, the change in slope is either at or near that stratum; where no such resistant bed is present, especially where the ridge is broad, the break occurs quite well up in the Oneota dolomite. The latter condition prevails along Coon Valley in the southwestern part of the Sparta quadrangle.

<u>The Franconia Upland</u>. An observer standing upon Castle Rock in the northern part of the Sparta quadrangle sees south and northwest of him the Oneota upland previously described (see fig. 4). Two hundred to two hundred and fifty feet below is a similar series of relatively even crested ridges, capped by the Franconiasandstone. There are rather broad ridges with rolling tops, level enough for farming, where the soil is good, but for the most part the "surface" is merely the blending in the distance of narrow ridges and isolated hills of about the same elevation. These ridges slope abruptly down to the valleys with the break in slope on either the micaceous sandy shale layer or the hard calcareous sandstone bed at the base of the Franconia formation, or locally a hard layernear the top of the Dresbach. At their outer ends, the ridges break down to the alluvial plains in successively lower and lower, smaller and smaller conical hills or tepee-shaped buttes.

The Franconia bench is present at all points where erosion has cut through to the underlying Dresbach sandstone. Near Tomah the ridge tops are broader than in the La Crosse Valley. The bench extends up all tributaries and is least developed where erosion has recently cut through the formation. In Kickapoo valley, for instance, it becomes wider as one goes down stream and, if followed south of the area under discussion, disappears where the top of the Dresbach passes beneath the valley bottom. Looked at in detail, the Franconia bench or terrace consists of a number of subordinate terraces which are irregular in occurrence and distribution. Most persistent is one upon the relatively firm and heavily bedded "yellow sandstone" member of the formation. Others occur both above and below this horizon but are for the most part merely slight benches on spurs (Plate V). Where present they are found on both sides of small valleys, thus showing that they are not due to stream action but simply to differences in hardness or thickness of bedding of the underlying sandstone. While older (or pre-Wisconsin) terrace gravels occur on the Franconia at some places, nevertheless it is clear that the bench as a whole is due solely to differential weathering and erosion. The thin bedded Franconia sandstones weather into rounded slopes somewhat resembling those developed on dolomite formations.

<u>Relations of the uplands to rock structure.</u> The interpretation of the uplands as remnants of dissected peneplains or as due solely to the effect of differences in the resistance of the strata must

rest largely upon the presence of portions of the uplands not yet affected by the streams of the present erosion cycle, and upon the parallelism or lack of parallelism of the ridge tops and the base of the resistant formation. The first criterion has been tested by the writers, not only within the area of the quadrangles but over almost the whole of the Driftless Area, without finding a single square rod of surface whose present topography is not in strict relation to rock character or that cannot be explained as a result of the present erosion cycle. In the case of the Oneota upland there is an apparent beveling of the Oneota dolomite so that as one goes south or southwest the upland lies higher and higher in the formation. The question then arises as to what degree this fact is due to first peneplaination, second, the relative recency of the removal of the overlying formations, and third ~~an~~ original variation in thickness of the Oneota dolomite (See p.). The second and third are factors not considered by previous students of the area. The areas longest uncovered by the retreat of the next or Galena-Platteville cuesta are naturally now worn down more than the recently exposed strata ~~in the vale~~ at the foot of the escarpment. This is shown in Fig. 19. ~~a section between Kickapoo and Mississippi rivers southwest from the area to Prairie du Chien and thence southwest into Iowa.~~ It has been stated that this ridge shows an undissected portion of a high level peneplain which actually bevels across from the Oneota dolomite into the Galena dolomite.[1] The writers have traveled this ridge along State Trunk Highway

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1/ Trowbridge, A. C., The erosional history of the Driftless Area: University of Iowa Studies, Studies in Natural History, vol. 9, No. 3, pp. 71-73, Fig. 17, 1921.

27 and find that a confusing factor is the irregular thickness of the Oneota and Shakopee dolomites. Locally the St. Peter sandstone is very thin and where such is the case no marked escarpment exists at the base of the Platteville limestone. Wherever the St. Peter is thick a sharp slope is found and the Oneota-Shakopee upland extends to the southwest on the ends of the spurs. In the case of the Franconia upland the effect of lowering of the ridge tops by solution is not present and the parallelism of the rock layers and the ridge tops is much more marked. 1/ The relation of this upland to the Oneota uplands to the south and to the Franconia benches in valleys within that upland is such as to remove all doubt that it is due solely to the character of the underlying strata. It bears no relation whatever to the uplands at the same elevation above sea level on the bluffs along Mississippi River to the west. Instead these are the continuation down the dip of the Oneota upland as my readily be seen along State Trunk Highway 22. It has been shown in the discussion of the Windrow formation that the gravels on the uplands are not necessarily an evidence of a former peneplain (p.   ).

1/ Trowbridge, A. C., Op. cit., p. 20.

Conclusion. The writers of this folio have been more impressed by the influence of rock character upon the position and form of the uplands than by any other phenomena. They therefore favor the simpler explanation of the facts: that the present topography is explainable on the basis of one erosion cycle. This does not mean that peneplanation has not occurred, but that the available evidence is now insufficient, in their judgment, to prove that such has been the case.

<u>Topography of the Jordan and St. Lawrence Sandstone Areas.</u> The outcrop area of the Jordan sandstone is in most places a narrow band around the edge of the areas of Oneota dolomite, but it runs out along spurs from which the capping of dolomite has been removed in geologically recent time. The narrow width of the band is due to the softness of the sandstone and its comparatively slight thickness, (40 to 50 feet). There are cliffs up to 50 feet in height; crags and towers of most fantastic form are common on spurs. Wind erosion, the influence of protecting hard strata at the top, the tendency of the sandstone to case-harden on exposure to the weather and of fallen blocks to roll down the slope away from the foot of the cliff preserve the cliffs in this friable formation. The topography of the upper part of the St. Lawrence formation is similar to that of the Jordan. Owing to its finer grain and greater friability, cliffs and crags are less abundant. The lower calcareous portion of the St. Lawrence caps hills and ridges. Because the difference in hardness between these beds and the underlying Franconia is not great, the break in slope is not so prominent (Plate X) as that at the contact of the Jordan and Oneota. The St. Lawrence bench is, therefore, not as conspicuous as those above and below it. The fact that it is at all points closely associated with the same calcareous beds, and occurs on both sides of the valleys in which it is developed,

shows plainly that its origin is the result of erosion of beds of different resistance.

<u>Topography of the Dresbach Sandstone Areas.</u> The Dresbach sandstone differs markedly from the Franconia in its heavier bedding. The firm layers at the top of the Dresbach and at the base of the Franconia are protected from percolating waters by the nearly impervious micaceous shale bed. Where erosion has reached the Dresbach a steep slope or cliff is formed beneath the protecting hard beds near the top. Where the protecting beds have been removed, erosion is relatively rapid. At the ends of spurs isolated buttes develop. The form of these buttes depends upon the hardness of the underlying sandstone. The Dresbach is, for the most part, quite soft, except at the very top; hence smooth cones are more common than crags. Rock forms like that at Rockland (center of Sparta quadrangle) are rare. A poorly developed terrace is found in a few scattering places about 80 to 90 feet below the top of the Dresbach. It is known that in some places it is capped by an iron cemented layer. As iron cemented layers are very irregular, both in ~~elevation~~ stratigraphic horizon and in horizontal extent, structural terraces are not as widespread or prominent as in the higher formations. Most of the gravel capped terraces bear no distinct relation to the distance from the top of the formation; they are due to stream action and are not found on both sides of a valley as are the structural benches. A good example of such a stream terrace is found in Stevens Valley, west of Tomah. That the level central plain of Wisconsin near

Tomah is due to alluvial and lacustine deposits has been demonstrated by the results of well drilling. The rock surface is irregular and is covered by a maximum thickness of over two hundred feet of sand and clay.[1] Portions of the plain outside the quadrangles are flat

1/ Martin, Lawrence, The physical geography of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, pp. 305, 306, 318-322, 1916.
Weidman, Samuel, Geology of north central Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 16, pp. 518-520, 1907.

because of the effect of shale beds in the Eau Claire.[2]

2/ Smith, G. H., The influence of rock structure and rock character on topography in the Driftless Area: Unpublished thesis, University of Wisconsin, 1921.

<u>Significance of the Rock Terraces</u>. In the discussion of Topography it was explained that the larger valleys within the Western Upland are double or benched, and that two of the benches or rock terraces are more persistent and conspicuous than any others. These are an upper, or St. Lawrence, terrace and a lower, or Franconia, terrace, the cliffs at their borders being, respectively, the Jordan sandstone and the Dresbach sandstone, with details as described in the pages immediately preceding. It was also stated under <u>Topography</u> that the existance of these rock terraces in no way implied periods of base leveling within the valleys, followed by uplifts of the land.[3]

3/ Martin, Lawrence, Rock terraces in the Driftless Area of Wisconsin: Geol. Soc. America, Bull., vol. 28, pp. 148-149, 1917.
Smith, G. H., The influence of rock structure and rock character on topography in the Driftless Area; Unpublished thesis, University of Wisconsin, 1921.

Had there been such halts during uplift of the land, the pattern of the terraces would be decidedly different. There would be in many places terraces on one side of a valley but not on the other. There would probably be entrenched meanders. Instead, the terraces are in nearly all locations present on both sides of the valleys and are of nearly equal width on each side of the present stream courses.

That the minor features of topography in the Sparta and Tomah quadrangles are controlled by rock texture and structure. is another argument, not independently decisive to be sure, which must be added to those which lead to the simple interpretation of the upland near the Mississippi River in Wisconsin and adjacent states as a cuesta rather than a dissected peneplain or peneplains. A reconnaissance of a considerable number of valleys in the Driftless Area outside the Sparta and Tomah quadrangles reveals the same rock terraces. The lower ones are covered in places with chert gravels, but neither these gravels nor the rock terraces themselves seem to necessitate the postulation of earlier cycles of erosion followed by uplifts of the land (See p.).

Summary of Results of Mesozoic and Cenozoic Denudation.

The topography of the Sparta and Tomah quadrangles is the result of the forces of weathering and erosion acting upon gently inclined strata of varying resistance. Steep slopes are found where weak formations are being worn back, thus undermining resistant layers. Gentle slopes occur near the level of the streams where erosion is not active, either on soluble formations like the Oneota dolomite which becomes mantled with a thick layer of residuum, or weak formations like the Franconia, which are protected by resistant underlying layers. We may think of the landscape as having been etched out by the forces of the atmosphere, the process being retarded wherever hard layers were met, and accelerated in the softer beds. No evidence of important halts in the process of degradation can be distinguished between the time of the latest emergence of the area, probably during the Silurian, and the present time. The first definitely proven uplift following a halt is a tiny one. It is demonstrated by the elevation and tilting of the benches of the Glacial Great Lakes and of Lake Agassiz in the latter stages of the Pleistocene. The terraces of the Mississippi River were probably tilted at the same time.1/ There were larger uplifts to the east and to

1/ Martin, Lawrence, The physical geography of Wisconsin, Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, pp. 153, 154, 1916.

the north in the late Devonian and in the Cretaceous, but the Sparta and Tomah quadrangles present no evidence bearing upon this possibility of the extension of these uplifts to the area under discussion. A modification of stream volume and load, due to glaciation and change of climate, probably accounts for the deposition and subsequent erosion of the older terrace gravels in the early Pleistocene.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

FACTORS AFFECTING PHYSIOGRAPHIC PROCESSES.

During the Glacial Period, in the Pleistocene Epoch of the Quaternary, the Sparta and Tomah quadrangles were never invaded by the ice itself. The area was affected indirectly, however, in important ways. The physiographic processes and the factors involved with them include glacial climate, vegetation, animals, streams, the wind, and uplift of the region.

<u>Climate.</u> There were oscillations of climate. The genial climate of the Tertiary Period was replaced by a cooler and wetter climate. This eventually gave way to a normal climate, probably similar to that of the Tertiary and to the weather and climate of the present epoch of the Recent Period. With each readvance of the ice sheets the cooler and wetter climates again recurred. Such oscillations of climate were repeated several times during the Nebraskan, Kansan, Illinoian, Wisconsin, and other stages of glaciation culminating, in severity, during those glacial epochs when the Driftless Area may have been completely surrounded by the continental glaciers.

The Tertiary and Quaternary Periods, combined have been estimated by some students to have had a duration of one to five million years. The whole Glacial Period in the Pleistocene Epoch of the Quaternary may have lasted for ~~1,000,000 years~~ a fifth of this time. The latest ice sheet in the Western Upland of Wisconsin began to melt away 80,000 years ago, perhaps only 35,000 years ago.[1] During

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1/ Martin, Lawrence, The physical geography of Wisconsin, Wisconsin Geol. and Nat. Hist. Survey, Bull. 36, pp. 109-128, 1916.

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a period that may be as much as a million years, there were marked oscillations of climate within the Sparta and Tomah quadrangles. With such oscillations of climate naturally occurred variations in the nature and amount of weathering, or creep, of wind work, and of stream erosion and stream deposition. The last-named were probably greatly affected by increased rain and snow-fall.

Vegetation. Second, the vegetation of the Sparta and Tomah quadrangles doubtless suffered great changes with the variations of climate. At present the soil freezes in winter to a depth of 10 inches to 2 feet. (See p.). When the continental glacier adjoined the Driftless Area and terminated only 22 miles west, 28 miles notth, 39 miles east, and 49 miles northwest of the Sparta and Tomah quadrangles, the climate was necessarily much more severe. Instead of having ~~afxx~~ a period of 142 to 175 days without killing frosts, as at present, the region probably had killing frosts nearly every night in the year. Permanent frost may have remained in the ground all summer to depths of 175 feet or more, as is the case today at Fairbanks, Alaska, where the summer climate is as mild as in western Wisconsin. Accordingly, the theory may be entertained that an important part, and perhaps all of the vegetation of the Sparta and Tomah quadrangles adapted to climatic conditions like the present was killed during the several glacial maxima. If such were the case, the physiographic processes in this portion of the Driftless Area varied tremendously, in kind and in degree, with the modifications of Pleistocene climates.

<u>Fauna</u>. Third, animal life was also modified during the Glacial Period. Burrowing animals could not have lived in permanently-frozen soil and sub-soil. Herbivorous animals would have starved to death, if the uplands of the Driftless Area were without plants and trees. It is even possible that the mastodon and the hairy mammoth, and various other extinct Quaternary vertebrates, including the bison, the wolf, and the peccary, all of whose bones we find in the Driftless Area, were killed off in this region by the climatic results of glaciation outside. If so they died of starvation, not of cold. It is improbable, however, that all plant life was destroyed.

<u>Streams</u>. Finally, the normal physiographic processes of the part of the Driftless Area within these quadrangles were affected directly during the Pleistocene Epoch. The Glacial Mississippi

River had a much greater volume than during the Tertiary or today. It deposited gravel, sand, and clay, and built up a great valley trains of outwash deposits during each glacial invasion. This necessitated aggradation by the La Crosse River and its tributaries, at times in a lake at the mouth of this stream near La Crosse. Glacial Wisconsin River, east of the quadrangles, shifted its course westward and aggraded its bed, thus necessitating aggradation in the Lemonweir River near Tomah. Eventually Glacial Lake Wisconsin was formed, extending into the northeastern corner of the Tomah quadrangle where lacustrine deposits were probably laid down.

Wind. Æolian processes were doubtless also directly accentuated by glaciation. Wind velocity may have been increased by the presence of the ice sheets to the east and north.

The deposits of loess are the best evidences of increased wind transportation and deposition together with diminished vegetable cover. To the obvious primary source of the loess in the valley train of the Mississippi and its western glacial tributaries, should be added a certain amount ~~far west~~, of dust and other particles finer than sand, which originated on the uplands of the Sparta and Tomah Quadrangles and even far to the west. If vegetation disappeared entirely for long periods during the Pleistocene, the amount of loess derived from the preglacial and interglacial residual soil of the sandstones and dolomites was greatly increased. As soil and vegetation have nowhere been found between the loess and bed rock it appears likely that no plants were growing on the ridges of the Western Upland during the periods of accumulation of loess.

Uplift. The physiographic processes within the Sparta and Tomah quadrangles were modified slightly, during the late stages of the Pleistocene, by uplift and tilting of the land. The Whittlesey Hinge Line probably crosses the Sparta and Tomah quadrangles. North of this line the streams were much more rejuvenated by uplift than to the south.

DEPOSITION OF OLDER TERRACE GRAVELS.

The conditions during the epoch of Quaternary history when the Pleistocene deposits of the Sparta and Tomah quadrangles were being formed are described below. They are divided into the ages when the older terrace gravels were being deposited. When those deposits were being eroded, when the valley filling of Wisconsin age was being laid down and subsequently terraced, and when the loess, the sand dunes, and the deposits of Glacial Lake Wisconsin were accumulating.

It seems probable, as explained below, that the older terrace gravels were deposited before the rock bottoms of the valleys were cut as low as they are today. The valleys must then have had nearly the same widths as now, with broad, relatively flat, rock floors. The deposition of the gravels is ascribed partly to climatic changes due to early Pleistocene glaciation (Illinoian, Kansan, or Nebraskan) and partly to aggradation of the adjacent valleys leading from the ice. Such external outwash deposits induced deposition by streams heading in the Sparta and Tomah quadrangles in order to keep the latter graded up to the new and higher base-level. This process was probably accelerated by an increase in the rate of erosion due to lack of vegetation and to increased precipitation near the glaciers. The pre-Wisconsin terrace gravels are remnants of alluvial fans and flood plains, which were extensively dissected in interglacial time. They are apparently to be correlated with the much dissected, high level, glacial outwash terraces near Prairie du Chien.1/

1/ Alden, W. C., The Quaternary geology of southeastern Wisconsin: U. S. Geol. Survey Prof. Paper 106, pp. 170-172, 1918.
McClintock, Paul, The Wisconsin valley below Prairie du Sac: Unpublished thesis, University of Chicago, 1920.

~~Most~~ Most of the older terrace gravels lie upon rock terraces. In only a few instances can these gravel-mantled terraces be explained as due to differences in resistance of the underlying rocks. The extent of the gravels near Tomah seems too great to be explained as remnants of old floodplains, left behind by lateral shifting of the streams during erosion, although certain of the deposits in Kickapoo valley may be of that origin. The plain deposits must have once formed large alluvial fans. It seems probable that some of the lower, less eroded gravels represent reworked material incorporated into terraces ~~dating from~~ during the period of erosion of the of the original deposit.

INTER-TERRACE EROSION.

After the deposition of the pre-Wisconsin terrace gravels was completed, erosion recommenced. Before the Wisconsin stage of glaciation the main valleys were eroded, or reexcavated, about 200 feet deeper. Had the rock floor been much below the level of the terraces when built, many stream diversions would have occurred when erosion recommenced. No such diversions have been recognized. In Stevens valley, west of Tomah, there appears to be good evidence that the rock bottom of the valley was higher than at present when the terraces were formed. Only small remnants of the older gravels are now preserved on the ends of spurs and along the flanks of valleys. The rare patches found far out in the plains demonstrate the former wide distribution of these deposits. The survival of many of these remnants is probably due to the resistant character of the chert gravel; it may be presumed that the gravel was not deposited evenly and that the localities where there was little or none were more readily worn down than those where the gravel beds were thick. It is probable that some loess was deposited during this erosion interval.

VALLEY FILLING DURING WISCONSIN STAGE

Following the inter-glacial erosion deposition, northern, eastern, and northwestern Wisconsin were invaded by the continental ice sheet of the Wisconsin stage of glaciation. The valleys leading away from the glaciers were again filled by outwash; non-glacial aggradation then ensued once more in the Driftless Area. During this period of valley filling were formed the deposits from which the main terraces of the valleys of the Sparta and Tomah quadrangles were subsequently eroded. During the latter stages of the alluvial filling the streams meandered and beds of peat and other vegetal material were formed in ox-bows and elsewhere upon the floodplain, where they were subsequently buried.

<u>Erosion of Wisconsin Terraces</u>. Following the melting back of the Wisconsin ice sheet, the Mississippi River was never again heavily laden with gravel, sand, and mud; at times it was the outlet of Glacial Lakes Agassiz and Duluth. The relatively clear water from these lakes eroded the outwash deposits. Changes in grade due to the uplift of the land to the north may have made the water flow more swiftly. This initiated the formation of terraces in the Mississippi valley, for it caused the cutting of the Wisconsin valley filling to begin. La Crosse River then began to cut down into its valley filling in order to meet the changing base-level. The meandering course con-

tinued, in certain places, however, for this non-glacial stream was still overloaded with sand, especially at low water. In this way the ox-bow furrowed surfaces of the intermediate and low terraces and the present floodplain were formed. A rock ledge at Neshonoc, north of West Salem, controlled the terraces above that point. Another rock ledge at Angelo had the same result on the terraces at the north.

In the upper Kickapoo valley, there has been relatively little erosion in the valley filling, for ~~the stream has a flat gradient and~~ the Sparta and Tomah quadrangles are far from the mouth of the stream. Lemonweir Creek near Tomah has lowered its bed about 10 feet to meet the lowering of the mouth of the river, and now flows over a broad, marshy floodplain.

In the process of downcutting the streams have, in places, found themselves superimposed on rock ledges. At Angelo, the La Crosse River is cutting into sandstone. A few miles north of Angelo the La Crosse River crosses the end of a concealed spur, forming Trout Falls. A short distance north of the Tomah quadrangle Tarr Creek crosses a sandstone ledge, forming Tarr Falls.

FORMATION OF DUNES AND LOESS

During and following the period of valley filling, which has been correlated with the Wisconsin stage of glaciation, occurred an important period of dune and loess formation. The dunes and loess now preserved in the region are, naturally, almost entirely confined to the upper terrace and to the uplands. The distribution of dunes and loess on opposite sides of the divide between the La Crosse and Lemonweir valleys plainly indicates that westerly winds were the agency of transportation. The sand and silt largely originated on the glacial outwash plain of the Mississippi River and the floodplains of its aggrading, glacial and non-glacial tributaries. The materials were sorted by the winds, the loess accumulating in the lee of ridges. The fact that the upland loess thickens toward the west is taken to show that a large part of its material came from the Mississippi outwash plain and from glacial streams farther to the west. Probably not much of the loess came from the arid regions still farther west, for they supply little loess today. That the dunes are now almost entirely quiescent and covered by vegetation strongly suggests that there was less plant covering at the time of loess and dune sand deposition than at present.

BRIEF DURATION OF GLACIAL LAKE WISCONSIN.

There seems to be no serious doubt that Glacial Lake Wisconsin, which covered an area about 1100 square miles, extended into the northeastern corner of the Tomah quadrangle. Bowlders and pebbles of crystalline rock have been found in the city of Tomah, but not in such numbers or positions as to remove all suspicion of possible transportation there by man in railway ballast or in fertilizer, rather than by ice bergs floating in Glacial Lake Wisconsin. The high terrace at Tomah was undoubtedly graded up to the surface of Glacial Lake Wisconsin, which had an elevation of about 980 feet above sea level, but the duration of the lake seems to have been too brief for the development of marked deltas or beaches.

RECENT EPOCH

<u>Present Conditions.</u> When the Sparta and Tomah quadrangles were first entered by settlers, between 1851 and 1861, the area had long been almost entirely forested. One of the natural prairies occupied the southwestern corner of the Sparta quadrangle, extending westward to La Crosse and southward beyond Viroqua.

The timber on clay areas was mainly red and black oak; on rocky ledges, white and Norway pine; on the sand, scrub oak and jack pine; and in the swamps, tamarack, water birch, and willows. On account of the hilliness of the country only half to three quarters of the timber has been cut, most woods being left on hillsides, and in sinkholes on the upland ridges. The present distribution of forest and scrub timber is shown on one of the edition of the topographic map of the Tomah quadrangle. The forests of the Sparta quadrangle have not been mapped.

The effect of the removal of the timber, of plowing and harrowing, and of over-pasturing has been to leave bare ground or hard turf instead of the more porous surface of dead leaves and mould, such as is found in natural woodlands. Soil erosion and runoff have, therefore, increased. Small streams, which formerly flowed on sod bottoms, are now cutting actively. Large gullies have developed on the hillsides. The coarse debris carried out of these gullies is being deposited in alluvial fans. There is no clear evidence that the water table has been permanently lowered, since the decrease in percolation is offset, to some extent at least, by the lesser amount of water consumed by trees. The extent to which soil erosion has proceeded on the steep hillside fields during the 60 years of settlement by white men, is alarming. The loess has been removed entirely from some slopes, leaving only poor residual sandstone soil. Many of the smaller streams are now aggrading their lower courses.

ECONOMIC GEOLOGY

GENERAL STATEMENT

The geologic resources of the Sparta and Tomah quadrangles include building stone, crushed rock, shale, lime, gravel, clay, glauconite, sand, surface and underground water, soil, and iron ore. Geologic conditions affecting engineering operations are also discussed.

BUILDING STONE.

The Oneota dolomite is locally quarried for foundation stones. Some stone of good quality is found and doubtless much better material could be obtained were it not for the residual soil and broken rock which covers the larger part of the formation.

The upper sandstone beds of the St. Lawrence formation are extensively quarried near Tunnel City, less than a mile north of the Tomah quadrangle, and to a less extent within the area. The stone is a soft, yellowish or gray, fine-grained sandstone which hardens somewhat on exposure. It ~~also~~ is used as foundation stone. The lower thin bedded calcareous layers of this formation were formerly more used than at present.

Near [illegible] the lower greensand member of the Franconia formation is quarried. It furnishes slabs of soft greenish-gray sandstone, up to 8 inches in thickness. The increasing use of concrete and cement blocks has greatly decreased the use of building stone in this area and it is clear that in the future the use of local stone for building material will decline.

CRUSHED ROCK.

The only source of crushed rock for concrete is the Oneota dolomite. At present quarries are operated near Burns, north of Castle Rock, and at the head of Pine Hollow near Cashton.[1/]

1/ Hotchkiss, W. O., and Steidtmann, Edward, Limestone road materials of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 34, pp. 118-120, 1914.

None of these has a permanent plant or facilities for rail shipment, and most of the local demand has been supplied in the past from the large quarries at La Crosse. In the future the construction of the State Trunk Highways will cause a demand for stone at points remote from railway stations, so that more quarries will be necessary.

In locating a quarry in the Oneota the fact should be considered that the ends of spurs need the least stripping. Occasionally spots can be found on the upland where the cover is not too thick. However, it will undoubtedly be found that, at any point far removed from the side of a valley, disintegration extends to such depths as to render the expense of quarrying prohibitive. Each locality must be considered on its own merits, for considerations of accessibility, ownership, etc., are usually more important than any others. If care is taken to send only sound unweathered rock to the crusher, the Oneota will furnish crushed rock of good quality at nearly all points. The lower 10 to 15 feet of the formation should be avoided, as they contain a great deal of sand.

SHALE.

Throughout the sandy districts of central Wisconsin shale is frequently used to surface roads. Within the Sparta and Tomah quadrangles the best shale for this purpose comes from the micaceous sandy beds at the base of the Franconia. Shale pits are shown on the geological map. Some of the calcareous sandy shale at the base of the St. Lawrence could also be used but is for the most part of inferior quality.

LIME

There is no calcite limestone within the area. The Oneota is wholly dolomite, or magnesian limestone. It can be used either for lime or ground for fertilizer. Formerly, before the competition of purer lime made from the Niagara dolomite of eastern Wisconsin, the Oneota was burned for lime at a number of points within the area. It is still used for that purpose in some of the more remote districts.

The production of ground rock for use as a fertilizer on sandy and marshy soils is worthy of attention, but, here again, purer material is readily imported.

GRAVEL

The terrace gravels of Pleistocene age are the principal source of usable gravel in this area. They consist of chert and sandstone pebbles with more or less sand. The chief difficulties in exploitation are (1) the irregular size of stone, ranging up to boulders a foot or more in diameter, (2) the large percentage of sandstone pebbles at some localities, (3) the heavy covering of loess, and (4) the limited extent and thickness of many of the deposits. In considering the development of this resource each deposit should be explored by test pits. If the amount of gravel is proved to be sufficient, as it undoubtedly is in many localities, proper crushing and screening will overcome the first two difficulties mentioned. The best locations for development are near Tomah and in Leon valley near Melvina. ~~including~~ Some areas not now exposed at the surface on account of coverings of loess or sand, are worthy of development for road metal or for use in concrete culverts, bridges, etc. Some gravel can be dug from bars in the present streams. The chert gravels are not suitable for concrete roads.

CLAY

In the past the loess deposits and alluvial clays have been developed to supply small brick yards at Sparta, Tomah, and Bangor. The bricks were red and were at one time extensively used. The exhaustion of local fuel supplies, cheap lumber, and imported brick led to the abandonment of all the brick yards in this area. Clay is locally used to improve sandy roads.

GLAUCONITE

The upper and lower greensand members of the Franconia sandstone contain considerable glauconite. This mineral is variable in abundance, ranging from scattered grains to 93 per cent of the rock.[1]

1/ Thompson, E. G., The greensands of Wisconsin, Unpublished thesis, University of Wisconsin, 1920.

Layers of such richness are, however, thin and rare. The average of any considerable thickness of strata is in few places as great as 15 per cent. No use has thus far been made of the glauconitic sandstone of this area, except that a little has been used for road surfacing. Their value as fertilizer is demonstrated by the former use of similar material in New Jersey and by experiments by H. J. Brant at the College of Agriculture of the University of Wisconsin. Although not as effective as concentrated soluble potash, glauconite could doubtless be used to advantage on some of the sandy soils of central Wisconsin. Magnetic concentration would probably be necessary. The percentage of potassium oxide in pure glauconite as determined by Brant 1/ varies from 3.547 per cent to 5.575 per cent.

1/ Brant, H. J., Glauconite as a potash fertilizer, Unpublished thesis, University of Wisconsin, 1920.

SAND

Sand for building purposes is obtained from a wide variety of sources. At Sparta, Bangor, and Tomah alluvial sands are used. At a large number of points on the uplands the friable Jordan, St. Lawrence, or St. Peter sandstones are quarried for this purpose. On lower ground the Dresbach is used in like manner. The principal sand pits are shown on the areal maps. Figs. 9, 13, and 16 show mechanical analyses of sands.

WATER RESOURCES.

General Statement. Underground water of excellent quality is found abundantly throughout the Sparta and Tomah quadrangles at depths which vary from a few feet to over 500 feet, depending upon the elevation of the surface. Artesian water can be obtained in the principal valleys, and springs are very abundant.

Springs. Springs are found in nearly all the deeper valleys of the area wherever a relatively impervious stratum of the Paleozoic rocks brings the ground water to the surface. Less commonly, springs occur where streams have cut into the water table in the alluvial plains. The heads of Silver and Stillwell Creeks are the best examples of the latter class. These creeks are fed by springs in the rock hills. The flow is lost in the sand of the valley floor and reappears lower down in the stream courses.

Relation to Geologic Formations. The micaceous shale at the base of the Franconia formation is the source of the great majority of the larger springs of the area. Such springs occur wherever there is sufficient catchment area above. In many places the springs are on hillsides far above the valley bottoms. Water also issues at higher levels in the Franconia where the valley is not deep enough to reach the shale. Somewhat less common are springs consequent upon iron cemented or relatively impervious layers in the Dresbach, such being found mainly in the northern part of the Sparta quadrangle. Other springs are caused by the shaly calcareous beds at the base of the St. Lawrence, especially near Wilton. Smaller springs are found in places at or near the base of the Oneota. Fig. 20 shows the relation of springs to the geologic section.

Relation to Human Occupation. The abundance and large flow of the springs of this region have had a considerable influence on settlement. The older farm houses are practically all located at springs, although in recent years many such sites have been abandoned in favor of more accessible ones. Many farmers have led spring water to their houses, by gravity where the source is high enough, and otherwise with the aid of hydraulic rams. The springs are, however, subject to fluctuations in volume and many are reported to have failed during the dry years of the '90's.

Non-flowing Wells. Throughout the wider alluvial plains water can be found at a depth of only a few feet. Shallow, inexpensive, driven wells are used, furnishing a satisfactory supply on farms. In cities and villages like Sparta, Rockland, and Norwalk such wells are likely to be contaminated, since the water is so near the surface that seepage from above is not purified.

On the uplands the question of a water supply is a serious one. Until drilled wells were introduced about 1870, there were few settlers outside the valleys, and they either hauled water from the valleys or used rain water. As may be seen from Fig. 20 there are several horizons which are charged with water. The shallower wells on the limestone uplands get their water from the St. Lawrence, but this supply is not everywhere dependable. Somewhat deeper wells penetrate the saturated zone in the Franconia, while still others reach the Dresbach not far from the level of the adjacent valley bottoms. In many cases a well has been drilled not to, but through one of the water-bearing zones, thus losing the water and making it necessary to continue the drilling to the next level. This phenomenon was well shown in the condensery well at Cashton just south of the area (Fig. 21). The droughts of the '90's also led some persons to deepen their wells to the never-failing main water table of the Dresbach sandstone, though this entailed wells 500 feet or more in depth. As pumping water by hand from such depths is hardly practicable, wind mills and gasoline engines are almost universal, water being stored in cisterns to tide over calms or other interruptions.

Artesian of Flowing Wells. There are about 180 artesian wells in the La Crosse Valley and about 25 along the portion of the Kickapoo valley within the area. The water from these wells rises in places as much as 40 feet above the adjacent streams, but in few localities over 10 feet above the ground. In depth the wells vary from 75 feet to over 500 feet. All these wells, whether starting on the valley fill on on rock ledges, obtain the water from the Dresbach, Eau Claire, or Mt. Simon sandstone formations. The confining stratum, beneath which water is found under pressure, varies widely in geological horizon. In the La Crosse valley it is a series of shale beds interbedded with sandstones, the highest of which are about 450 feet blow the top of the Dresbach sandstone. These are apparently near the base of the Eau Claire formation. In the valleys of the Little La Crosse above Leon and in Kickapoo valley a shale layer is reported about 250 feet below the top of the Dresbach, or at the top of the Eau

Claire, while a few wells get flows from strata 150 feet higher than that in the Dresbach. In the last case it seems probable that local shale lenses or iron cemented layers are present, but exact records are lacking.

Origin of Flows. An artesian basin may be likened to a city supply system, in which the outcrop of the water bearing rock is the reservoir, the rock with its overlying, retaining stratum of relatively impervious material corresponds to the distributing pipes, and the well to the tap. The water will never rise as high as the source for two reasons: Leakage upward to the surface and loss of head through frictional resistance to flow. The height to which water rises in wells, therefore, declines away from the source of supply, the slope being known as the artesian gradient (Fig. 20). In the Sparta district it is difficult to determine this gradient on account of leaky and clogged wells. An attempt has been made to fix it from the most reliable data obtainable. Contours in blue on the areal sheets indiccate the height to which it is believed water will rise in properly constructed wells. This artesian gradient declines down the valley at the rate of about 9 feet per mile. Since the slope of the river is less than this, the absence of artesian wells on the upper terrace below Rockland is explained. The approximate area within which wells will flow is shown on the map. The artesian pressure is reported to be less below than above the lower shale bed which lies at a depth of about 300 feet inthe city of Sparta.

In Kickapoo valley the artesian gradient measured in an air line is about 16 feet per mile, or nearly the same as that of the river below Wilton. Flows should not be expected in any of the smaller tributaries, for their steep grades only pass beneath the artesian gradient near the main valley.

If we project the artesian gradient from Wilton to the north we find that its elevation would be much higher than that of the city of Tomah (Fig. 20), near which the upper shales should outcrop. The lower shales of the La Crosse valley do not outcrop south of the plains near Black River Falls and Mather, and come to the surface at a lower elevation than the highest flows. It is, therefore, clear that the artesian gradient does not extend very far to the north or northeast at the same rate, and that the source of pressure must be in large part the water under the high ridges at the heads of the valleys. This leads the writers to conclude that the retaining strata are either not entirely impervious or that they give out to the northeast. Under the first hypothesis, the water penetrates the shale layers beneath the hills, where the water table is high and joins that trapped beneath them at their outcrop farther north. If the shales are not continuous to the northeast, and they are not reported at either Tomah or Mather, the condition is somewhat simplified. Furthermore, this hypothesis explains the low pressure in the basal sandstone beds. It is evident that, without a relatively impervious layer dipping away from a ridge, flows are impossible. This explains their absence near Tomah.

<u>Causes of Local Failure.</u> Failures to obtain flows are occasionally reported within areas which are apparently favorable. In some cases this may be due to local leaks in the retaining stratum, or to leaks above, due to fissures or to improper casing of wells. In addition, many drillers have been disappointed through failure to recognize that the elevation was too great for a flow. Leaks into crevices, or simply into the porous sandstone above the shale bed, are very common, since the casing is usually carried only to the rock into which it may not fit tightly. Leaks in the casing are also probable. Such defects are sometimes remedied by placing a smaller pipe inside the well, packed with a "seed bag" at or near the shale. This method makes it difficult to clean or repair the well. Fig. 22 shows the best way to construct

an artesian well, and one which will undoubtedly prove the cheapest in the long run. A fair sized casing is carried to the rock, and the hole is drilled to the shale. A smaller casing is then inserted, and driven down firmly. The well is then deepened into the water bearing rock. This prevents all loss of water and will permit or repairs at any time. The outer casing may sometimes be removed.

<u>Loss of Flow</u>. Diminution or loss of flow may be due to the development of leaks through corrosion of the casing, clogging with iron deposit, or interference from other wells. In the city of Sparta it is stated by well drillers that the wells have only half the head which they had 20 years ago; it is said to have decreased from an average of 14 feet to 7 or 8 feet on account of interference and clogging. This does not agree with the account of Strong [1] who stated that in 1875 the wells at Sparta had a head of 6 to 10 feet. Few wells are now allowed to flow to their full capacity; most are capped, and only enough water is drawn to supply the normal consumption. [2]

1/ Strong, Moses, Geology of the Mississippi region north of the Wisconsin River: Geology of Wisconsin, vol. 4, pp. 57-58, 1882.

2/ Weidman, Samuel and Schultz, A. R., The underground and surface water supplies of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 35, pp. 475-476, 1915.

<u>Quality of Water</u>. According to recorded analyses the underground waters of the Sparta and Tomah quadrangles vary from 54 to 256 parts per million of dissolved matter. The principal substances included are the carbonates of calcium and magnesium.

The waters may be divided into two general groups, first, those from shallow wells and springs and second, those from artesian wells. The former average only 58 parts per million of total solids while the latter contain a mean amount of 165 parts and are therefore moderately "hard". Most of the artesian waters deposit iron oxide, but this is not true of all. A few artesian well waters appear to be low in iron. Unfortunately the analyses do not show the reason for this difference, since the iron and aluminum are usually grouped together. Analyses made under the direction of W. G. Kirchoffer show from 1.5 to 5 parts per million of iron. The iron deposit is probably due to bacteria which feed upon ferrous iron and convert it to the ferric form. Its presence is not harmful to health, but gives trouble by clogging pipes and causing unsightly coloring wherever water escapes. Large amounts of hydrous iron oxide, or limonite, can usually be seen around artesian wells where water escapes.

Public Water Supplies. The city of Sparta is supplied from a shallow well on the bank of the mill pond and an artesian well with an air lift. The public drinking fountains in Sparta are supplied by direct pressure from artesian wells.

Bangor has a water supply from the flowing well at the cannery which is 162 feet deep. Wilton is supplied from an artesian well about 300 feet deep.

On the Federal Military Reservation, east of Sparta, there are 5 wells, some of 6 and some of 8 inches diameter, from from 240 to 300 feet in depth. Three of these wells are at Camp Robinson. Each supplies 75,000 to 100,000 gallons a day. They flow into a tank, but can also be directly connected to the pumps.

Cashton, just south of the area, is supplied from a well whose water comes from the Franconia formation. (See Fig. 21.) The city of Tomah has three wells, averaging about 200 feet in depth, in the Dresbach sandstone. The old well reaching the pre-Cambrian is not in use. The remaining villages have no public supply.

<u>Yield of Wells.</u> The yield of few of the deep wells has been measured. Tests by Capt. F. L. Buck at Camp Robinson in 1917 showed a natural flow of about 115 gallons per minute from two wells with the tank half full. This is more than 165,000 gallons per day. If the tank had been lower, the amount would evidently have been greater. Captain Buck stated that at times the 30,000-gallon tank overflowed while a pump was drawing 300 gallons per minute. When a third well was completed a 300-gallon pump could be supplied without direct suction. It is estimated that the total water supply of the North Target Range is 400,000 gallons per day, and that additional wells could be located 600 feet apart without affecting each other.

The first large condensery well at Cashton, 10 inches in diameter is stated by the driller to have supplied 90 gallons per minute during a 10-hour test, but failed entirely after a short time, probably on account of the inner casing which was carried too deep. A second well is said to have yielded only 60 gallons per minute since the hole was too crooked to permit of a large pump. The village well, 8 inches in diameter to 172 feet and 6 inches to 254, feet is stated to have supplied 90 gallons per minute. The pump was double acting, of $4\frac{3}{4}$ inch diameter, and was placed at a depth of 230 feet.

The Interstate Milk Products Company at Sparta obtains 400 gallons per minute by direct suction from their five inch wells from 281 to 287 feet deep. The wells are all within a distance of 400 feet in a north-south direction..

The natural flow of the artesian wells varies inversely with the height of the barometer, but no exact tests have been made in this area. In some wells of low head the change in flow with changes of weather is quite marked.

<u>Surface Water Supplies</u>. The area of the Sparta and Tomah quadrangles, as indicated under <u>Springs</u>, is rich in perennial spring-fed streams. Some fair sized creeks are supplied by a single spring. The clear cold water of these springs is of great value to farmers for watering cattle and cooling milk.

The Sparta Target Range has two running streams of spring water, each estimated to be capable of supplying 750,000 gallons of water per day. There are three additional streams whose flow has not been estimated.

The discharge of La Crosse River is shown in Fig. 5. Its minimum flow rarely falls below 200 cubic feet per second, although, as stated under Drainage, a flow of only 130 feet (~~See Fig.~~) was measured during one winter. This figure represents the spring water contribution, the underflow in the valley fill is probably not over 15 cubic feet per second. The highest floods, which attain a recorded maximum of 2480 cubic feet per second, are due to melting snow. The difference in water level between the highest and lowest recorded, is 6 feet. Summer floods are mainly of much less amount. Above Sparta the river is almost wholly supplied in summer by springs. It probably has a more even rate of flow than at the gauging station a few miles west of Bangor. The yearly run-off is between 11 and 12 inches, or a little over one third of the average rainfall at La Crosse (30.9 in.).

Water Power. The surface supplies are utilized only for water power. The following table gives data on the power plants.

WATER POWER IN SPARTA AND TOMAH QUADRANGLES 1/

Location	Stream	Head	Horse Power	Use
Angelo	La Crosse	11	500	Electricity
Sparta	La Crosse	6	100	Electricity
Sparta	La Crosse	6	61	Feed mill
Big Creek	Big Creek	15	25	Grist mill
Burns	Burns Creek	10	10	Grist Mill
Leon	Little La Crosse	9	48	Grist Mill
Wilton	Kickapoo	10	35	Electricity

1/ Data in part from Smith, L. S., The Water powers of Wisconsin, Wisconsin Geol. and Nat. Hist. Survey, Bull. 20, p. 322, 1908.

General Statement. The soils of the Sparta and Tomah quadrangles may be divided into those of residual and those of transported origin. The first group comprises the residum of dolomites and sandstones; the second group, materials deposited by streams and by the wind. The portion of the Sparta quadrangle in La Crosse County has been mapped by the Soil Survey of the Wisconsin Geological and Natural History Survey in cooperation with the U. S. Bureau of Soils. 2/

2/ Whitson, A. R., Geib, W. J., Dunnewald, T. J., and Lounsberry, Clarence, Soil survey of La Crosse County, Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 40, 1914.

The soils of Monroe County are virtually the same, but have not been mapped in detail. Fig. 15 shows the soil map, altered to express more clearly the origin of the soils. A much more generalized map, covering the Viroqua Area, was prepared in 1903 by the U. S. Bureau of Soils. It covers Ranges 3 and 4 west. 1/

1/ Smith, W. G., Soil survey of the Viroqua area, Wisconsin: U. S. Dept. Agr., Bur. Soils, Field operations, 1903, 1904.

<u>Residual Soil</u>. The residual dolomite soil is a sticky red clay, filled with chert. Over large areas, where undisturbed by the plow, a few inches of wind blown loess cover this soil. This type has been mapped by the Soil Survey with the Knox Silt Loam, which is defined as loess; in other parts of Wisconsin the names "Baxter" and "Dodgeville" silt loam have been applied to the same material. The chert has been to a large extent picked up from the fields and left in large heaps.

The residual soils from the sandstones are the Boone fine sandy loam and Boone fine sand. Although the Boone soils series is defined as of residual origin, sands transported by both water and wind have been grouped under this classification by the Soil Survey.

As a whole the residual sands are very poor soils. There is no evidence that those formed from either the glauconitic sandstone or the sandy shales are any better than those soils from which such materials are absent. Nevertheless, the concentrated glauconite may be useful for fertilizer (p.).

<u>Transported soil</u>. The most important member of the group

of transported soils is the loess, or Knox silt loam, which covers uplands, rock terraces and slopes. The lowlying phase of the loess, which in places overlies alluvial deposits and may have been in part redistributed by water, is called the Waukesha silt loam by the Soils Survey. The soils of wind-blown silt are the best within the quadrangles. Their upper 8 inches contain from 900 to 1500 pounds of phosphorus per acre, in contrast to 700 to 800 pounds in the sandy residual and alluvial soils. The potassium content is 35,000 pounds, as against 4,000 pounds in the sandy alluvial soils and 1,600 pounds in the residual sandstone soils. The loess is more pervious than the residual dolomite soil.

The alluvial soils comprise the Wabash loam, Waukesha fine sandy loam, and the Waukesha sandy loam. The first is confined to the smaller valleys and is, in part, loess which has been washed from the hills and deposited on the floodplains of the streams. It is a dark colored more or less marshy soil. The Waukesha sandy soils are found in the La Crosse valley and have been in part redistributed by wind. The Soil Survey does not distinguish quiescent dunes.

IRON ORE

The only known occurrence of iron ore within the Sparta and Tomah quadrangles is in the Windrow formation on the top of Windrow Bluff, west of Tomah. Here an outcrop of manganiferous limonite, mixed with and cementing conglomerate, occupies the space of less than an acre. This ore is similar to that mined at Waukon, Iowa,[1] but the

1/ Thwaites, F. T., and Twenhofel, W. H., Windrow formation; an upland gravel formation of the Driftless and adjacent areas of the upper Mississippi valley: Geol. Soc. America, Bull., vol. 32, pp. 293-314, 1921.

quantity at this locality, as well as its thinness, and the presence of so much conglomerate, render the deposit of no economic value. From the absence of float it appears unlikely that other deposits of any considerable size occur in this area.

GEOLOGIC CONDITIONS AFFECTING ENGINEERING OPERATIONS.

The character of the geologic formations has a marked effect on engineering operations, such as excavation, tunneling, well drilling, and the improvement of unsurfaced roads.

Excavation. From the standpoint of excavations the rock formations of the Sparta and Tomah quadrangles may be divided with those which will stand in vertical walls and those which require a slope of 45 degrees or less.

The Oneota dolomite is hardest, requiring the most blasting. It will stand well in vertical faces, as shown in the railway cuts on the Viroqua branch of the Chicago, Milwaukee, and St. Paul Railroad. The Cambrian sandstones are all quite soft and can in most places be excavated with pick and shovel although blasting is needed before they can be handled economically. The Jordan and Dresbach sandstones stand well in vertical faces as does also the upper part of the St. Lawrence. The shaly, thin bedded parts of the St. Lawrence and Franconia formations cannot be trusted to form vertical walls on account of the danger of landslides. In the deep railway cut at Tunnel City (Plate I), just north of the Tomah quadrangle, the Franconia was terraced back to a low slope, while the firm layers at the top of the underlying Dresbach sandstone enable that formation to stand in a vertical wall. The tendency of most of the sandstone to harden on exposure to weather renders the walls of cuts less and less liable to falls as time goes on.

The unconsolidated formations important in this connection comprise residual dolomite deposits, loess, gravel, and sand. The depth of residual dolomite deposits ranges from a few inches to about 75 feet. They contain many chert fragments which vary from a fraction of an inch to several feet in diameter. Excavations in such material will stand for a short time with vertical faces; if permanent they must be graded back to at least 45°. Excavating machinery can only be used with difficulty. In loess, which over large areas caps the residual deposits, excavating machinery can be readily used. Cuts stand well for a long time, but it is wise to grade them back to a slope. Cuts in gravel hold vertical faces fairly well, but these deposits are not numerous. Excavation in sand is easy, but all cuts must be graded to a slope of about 1 in 2 if expected to be permanent. Freshly exposed sand surfaces suffer much from wind action in dry weather.

<u>Tunneling</u>. Tunnels have been driven in or near this area only in the St. Lawrence and Dresbach sandstones. No especial difficulty has been reported, although the formations are very soft and weak and require careful timbering during the work. All the tunnels are lined either with brick or concrete. One tunnel at Tunnel City, just north of the Tomah quadrangle, which was not so lined, was abandoned. Later the attempt was made to drive another level below this old tunnel. This operation failed after a disastrous cave-in. The cause was, in part, a faulty system of timbering and, in part, the loosening of the

rock by vibration due to trains in the old tunnel and in the new one along side. Tunneling would probably be successful in all the rock formations of the area.

Well Drilling. None of the formations in the Sparta and Tomah quadrangles cause excessive difficulty in well drilling. Wells have been drilled to depths of over 500 feet with light portable machines. The depth to solid rock varies widely. On the uplands it is in few places less than 20 feet and may reach 75 feet. Chert bowlders are encountered in the clay overlying the Oneota dolomite. In the valleys a maximum of 150 feet of sand and clay is found. The rock formations have a considerable number of troublesome joints and crevices, and inclined beds (cross-bedding) cause a deflection of the hole. Layers soft enough to cave are found in places. Aside from chert layers in the Oneota there is little rock which is extremely hard. Some of the fine grained sandstones are hard to cut because the sand will not stay in suspension but packs in front of the drill. This trouble can be remedied by placing clay in the hole.

Improvement of Unsurfaced Roads. The materials found in constructing the unsurfaced roads include residium from dolomite, loess, and sand. A large number of the upland roads, and, to some extent, those on the slopes leading down to the valleys are on dolomite residuum. This material is a red or brown clay, filled with cherts, which are broken by the wheels of vehicles into sharp edged fragments. When dry, the clay is hard and forms a good surface. When wet, it is very sticky, slippery, and slow drying. The sharp jagged flints are very bad for automobile tires, a set of which can be ruined in a few hours of driving in wet weather. These roads are virtually impassable for motor trucks after a heavy rain. Drainage conditions on this soil are poor. As loess is a brownish-yellow silty clay, free from stones, it dries more quickly than the residual clays, but is quite slippery after a rain. The sands of the area make roads of variable quality. Wherever the sand contains humus and is in an undisturbed condition, the roads will stand light traffic fairly well. Wherever the natural surface has been cut away, or the sand much disturbed by wind, water, or wheels, theroads are very poor. In dry weather the presence of such poor spots makes most of the sand roads impassable for automobiles or motor trucks. A light rain packs the sand and improves the roads, but a heavy rain makes a disagreeable, slimy mud, and causes washing of the roads on slopes. While the mud dries quickly, the dry, washed sand is very hard to travel through. Hay, straw, potato vines, peat, etc., are used on bad sand holes for temporary improvement. The subject of materials for highways is treated above.