the cottage owners and the camping tourists will be favored by reserving these state lands for a public camp site.

County parks. — Four small areas have been assigned to county parks. The proposed 320-acre park in T. 46 N., R. 22 W., is designed to preserve the falls of the Laughing Whitefish River. This beautiful falls is the outstanding scenic attraction in the western part of the county and has often been mentioned as a site for a state park. It lies but a short distance north of M-28 in the wooded rocky gorge of the Laughing Whitefish River.

The three other proposed county parks have been selected to insure that the local residents shall have public privileges to water frontage for bathing and fishing in association with adjacent well-drained shady sites for picnic parties and camping.

The area just southwest of Munising is located on Perch Lake and will be used chiefly by the residents of this city and their summer visitors. It is their most convenient inland lake and is already reached directly by foot trail from the city or over a poor automobile road from the north. It can be made accessible for automobiles from M-28, which passes to the south of the lake, and could be the principal objective in a more extensive system of improved foot trails and bridle paths leading out from the city of Munising.

The area just south of the corner of T. 45 and 46 N., Rs. 20 and 21 W., would be used principally by the rural residents of the Chatham-Trenary communities. Highway M-28 borders its northern margin. It is an area of light sandy soil that is well wooded near the highway, but more sparsely forested in the southern part. The water-power development that is being installed on the Au Train River will provide a body of water for this park by its flowage area.

The small area in the extreme northwest corner of the county is located on the improved shore-line highway that extends from Munising to Marquette. It will be used by the local residents who live in both counties in the vicinity of this park. In addition, it will provide camping and water-front facilities for those who tour this way. The area outlined extends southward from the Lake Superior shore past Sand River to include Sand Lake, a small inland body of water with a sandy, shaded shore and a good bathing beach on its north side.

Township parks. — The single area, Au Train Township Park, is already established. It is a rolling and hilly wooded area bordering the beautiful winding drive that leads from M-28 to Au Train Lake. It has no lake frontage, but includes a mile and a half of Au Train River.

City parks. — An area of about 4,500 acres, covering the forested hills and valleys that give the city of Munising its unusual and picturesque background, has been designated as a combined city park and wild-life sanctuary. No other city in Michigan has a natural setting so strikingly beautiful. In the foreground the blue waters of Munising Bay lead to a vista over Lake Superior that is framed on the one hand by rugged verdant Grand Island and on the other by the Pictured Rocks shore line. The city itself nestles snugly at the foot of an imposing forest-clad slope that rises protectingly in the background and gives way only to let the crystal-clear Ann River reach the bay. This spring-fed stream and its tributaries come tumbling down from the still cool forest at the valley heads. Here trout and beaver find a congenial habitat, ruffed grouse drum in the autumn sunshine, and deer bound away into the sheltering forest when startled from their roadside grazing by passing automobiles.

This rugged green-clad landscape of hills and valleys and forest and lake has a cool and inviting aspect in summer. Fall paints it with colors that beggar description, and winter wraps it in a protecting mantle of sparkling white till spring brings an awakening to renew the parade of attractive and appealing seasonal changes. Forest and lake give the clean cool air a flavor that quickens health and ambition and makes of this locality an incomparable place to work and play.

Munising can well afford to preserve her unusual natural environs by providing them with park and sanctuary status and improving them for both summer and winter enjoyment by the many who are interested in nature, healthful recreation and sport. The crowded municipal tourist camp should be supplemented by developing a half-dozen or more smaller camping sites scattered in attractive and accessible locations within the area of the proposed city park. These might be connected with one another and with the city by a system of foot trails and bridle paths that would open the entire park to equestrians, hikers and nature lovers. Such development of her inherent natural advantages would give to Munising an attraction that could not be shared by any other lake state city.

AGRICULTURE

Reference to the map of intent in ownership (Map 36) reveals that agriculture is the intended use for considerable blocks of land in the northern and eastern parts of natural District A, where high-lime productive loam soils predominate. The bulk of the county's agriculture has established itself in the vicinity of Chatham, Traunik and Trenary on these land conditions. Note how definitely the location of the existing farm development and the intention to farm coincide with the northern border of District A, where it joins on District C, the rolling, stony, sandy loam, hardwood uplands in the vicinity of Onota. Evidently District C is not considered potential farm land by either its present owners or by prospective farmers, since farming is the declared intention on only a few scattered parcels in this district.

Farming is, however, the declared intention in ownership for small areas near Munising, north of Shingleton and

south of Grand Marais. The Munising area falls within Natural District D on rolling to hilly, light sandy loam uplands. This combination of natural characteristics covers a large part of the county, but it has been unable to attract farm development except to certain small areas that were sufficiently favored by location to offset their less suitable soil and topography. In this vicinity two small areas closely adjacent to Munising have been reserved for the garden-home type of agriculture, where the industrial employees of Munising may occupy two- to five-acre farms similar to those developed by the furniture-factory workers at Grand Rapids and the mine workers at Iron River. The more distant portion of the area tributary to Munising has been assigned to the prevailing dairy-hay-potato type of agriculture.

A considerable area north of Shingleton has natural conditions comparable to those of Natural District A. It has attracted a modest acreage of farm development, but ownership for that purpose has not extended much beyond the limits of the land now in farms because existing stands of mature forest growth, lack of roads and distance to a shipping and trading point restrict the availability of this area for agricultural use.

The area of farm development near Grand Marais is located almost entirely on the level, hardwood, loam lake benches that extend to the south and west of that village. Ownership with the intention of farming has spread somewhat beyond the limits of present farm development. It is, however, apparently an over-optimistic intention, since the Grand Marais community can consume but a very small amount of farm produce and the surplus production must be trucked over twenty miles to the railroad station at Seney for shipment to distant outside markets. A diversified type of agriculture that emphasizes dairy products, poultry products, potatoes and fruit may be able to use the present acreage of cleared land, but there is apparently no evident need for its further expansion under the community's present economic environment.

The four southwestern townships, 44 and 45 N., Rs. 21 and 22 W., constitute an interesting problem. Map 32 shows rather generous transportation facilities already installed. Map 33 records a concentration of rural habitations that is exceeded only by the Chatham community in the adjoining townships to the north. Map 34 reveals Natural District A covering all of these four townships except the eastern margin, which is occupied by the western extension of District E (level, hardwood, loamy sand plains) and an arm of District H (swamp). Map 35 shows mature forest, second-growth forest and scattered farm land in the two western townships; and second-growth forest, farm land and open wild land in the two eastern townships. Map 36 indicates the intent in, ownership to be timber, speculation, farming and public (state) ownership in the two western townships, whereas farming, speculation, timber and public (state) ownership, or the negative intention of farm abandonment, dominate the two eastern townships. Map 37 gives high values on the mature forest, moderately high on the farm land and low on the land owned for speculation. Map 38 proves that delinquency is common on farming abandoned lands owned for speculation, open wild land and certain tracts of second-growth forest. The delinquency pattern alone, without further inquiry or understanding, leads to the inference that these four townships are headed toward timber depletion, further farm abandonment and state ownership. The dismal picture that the delinquency pattern predicts for them may develop. The only hope that it will not do so is found in the fact that the economic environment is seemingly out of adjustment with the natural conditions and that it may possibly be brought into adjustment, so that these lands may profitably be devoted to timber growing and agriculture. This area of good land, suitable for farms or forests or a combination of farms and forests, is suffering from "idle land indigestion" induced by an annually increasing ration of idle land that has been fed into it by the trend of events and a too burdensome system of taxation. The owners of the mature forest on the western side of the area have been dumping their clean-cut lands into delinquency under the "cut-junk-jump" policy, and a land settlement company owning a large acreage of cut and burned wild land through the eastern part has been forced to discard its equities to delinquency by the shrinking market for raw farm land. Ground between these two millstones of delinquency, the farmers of the central section have added their bit to the annually growing list of delinquent lands. Meanwhile, the fire-cleared wild lands and the abandoned farms grow grass that is ungrazed and the cut-over lands restock themselves to second-growth forest in which no profit in ownership can now be seen. And probably none will be visible until the warmth of a more equitable system of taxation dissipates the cloud that is casting the growing shadow of delinquency over this area.

The Upper Peninsula Agriculture Experiment Station at Chatham is near at hand. The results of its experimentation in soil management, crop adaptation and animal husbandry are available and indicate that the well-drained upland loam soils that prevail in these townships are suitable for agricultural use. Under a favorable economic environment this type of use should be able to occupy permanently a considerably larger acreage than at present.

The central portion has natural characteristics that adapt it to the common dairy-potato-hay type of farming that now prevails on the existing farms. The fire-cleared lands on the eastern margin invite a grazing type of livestock farming with larger units of ownership, a minimum of plow land and correspondingly lower acreage values. This type of use could give the neighboring farms of the central portion an adjacent market for hay, grain, roots, etc., to winter-feed the range stock. The dairy type of farming has already shown an inclination to move into the western part of the area, as evidenced by the scattered farm development

now established on rather recently cut-over lands. Here farming and forestry might be combined to afford year-around employment on farm-forest units of ownership that included plowland, pasture and forest growth.

CITIES AND TOWNS

Munising and Grand Marais are the only locations whose future growth may need to be guided to insure the highest functional use of the areas available.

Industries. — In the case of both of these towns the low, sandy level bench bordering the bay should be divided so that industries may occupy the eastern and northeastern parts and that the western part may be given over to business and residence.

Health homes. — At Munising three areas on the crest of the high wooded bluffs that overlook the city and the bay have been reserved for health home sites. Here, rather large tree-covered lots and shaded winding drives would offer their appeal to those summer residents who are seeking healthful outdoor surroundings and easy access to neighboring lakes and streams, without losing the advantages that would be offered by the adjoining city.

At Grand Marais a single smaller area, which also overlooks the village and the harbor from the crest of the second lake bench has been reserved for a similar use.

Airports. — Munising already has located its airport in the southeastern part of T. 46 N, R. 19 W, at a distance of about lour miles from the city and about one mile south of the Duluth, south Shore and Atlantic Railroad station of Wetmore. The highway leading south from Wetmore runs along the east side of the landing field and the Lake Superior and Ispheming Railroad passes close to its south end.

The site chosen is excellent in many respects. It is located on the northern margin of an expansive plain where the landing field is easily found by approaching aircraft. Its sandy soil drains rapidly and thoroughly. Its distance from the city and its elevation above the lake place the landing field beyond the smoke zone and above the reach of low-hanging lake fogs. The airport should, however, be extended to include at least the half-section of land outlined, so that the standard number of runways could be added while this acreage may still be cheaply acquired.

WATER POWER

Flowage rights and plant sites. — There are three sites capable of developing a marketable amount of water power: Au Train Falls, Miner's Falls and a place on the Sucker River southeast of Grand Marais. The lands that would be required for flowage rights and plant sites for each of these power projects are reserved for that use.

The Au Train and Miner's Falls projects are conveniently located for consumption of their power at Munising and by the several farming communities and their associated villages, or their energy could be diverted into a trunk-line hook-up with other north shore projects.

The Sucker River project has not yet been fully appraised by the Land Economic Survey. When electric power is needed at Grand Marais this project may be capable of meeting the demand.

CONCLUSION

The foregoing assignment of particular uses to definite land areas has been rested on the major differences of character and environment that the several land areas possess. The assigned uses are, therefore, simply a guide to point out the type of use that will be in closest harmony with the dominant nature of the areas. Greater refinement can and probably should be made, or at at least allowed, in the application of the utilization plan to permit the adoption of some use other than the assigned one, for those local areas that possess a character or an environment different from that of the larger area for which the assigned use was selected.

Further still, it would probably be inadvisable to employ the utilization plan as a basis for enforcing the assigned uses, or for excluding other uses, as is customarily done with city plans when zoning ordinances are adopted to enforce adherence to the plan. The thought is rather that this, or any, utilization plan will derive its effective momentum from its obvious soundness. Sound and acceptable plans can be expected only if the inventory has been adequate and accurate, if the facts found by the inventory have been impartially appraised and intelligently used, and if the composers of the plan have been sufficiently qualified in experience and judgment.

Poorly conceived and unsound plans probably cannot, and certainly should not, be enforced. A well-conceived utilization plan ought to carry itself into effect with only such encouragement and support as public agencies and public officials may be able to accord it by adopting policies and providing facilities that will assist the establishment of the assigned uses. In order that the final plan may merit such encouragement and support, the preliminary draft should be reviewed and criticized by the public agencies and officials most directly interested or concerned in the application of the assigned uses. In particular, the State Agricultural College and Agricultural Experiment Station, the University of Michigan, the Department of Conservation and other state departments, the U. S. Forest Service and its Forest Experiment Station, the U. S. Department of Agriculture and the Institute for Research in Land Economics and Public Utilities should lend their facilities and the benefit of their council in shaping the plan into its final form. Among others, the county officers and the county board of supervisors can, no doubt, lend material strength and effect to the utilization plan out of their experience and intimate acquaintance with local land affairs.

STATE DEPARTMENT OF CONSERVATION
LANSING, MICHIGAN

[1] Lovejoy, P. S., "Theory and Practice in Land Classification," *The Journal of Land and Public Utility Economics*, 1 (1925): 160-175; Barnes, Carleton P., "Land Resource Inventory in Michigan," *Economic Geography*, 1 (1929): 22-35; *The Department of Conservation, State of Michigan, Biennial Reports,* 1923-24, 1925-26, 1927-28, 1929-30; Michigan Department of Conservation, Land Economic Survey Division. Forms and Instructions Used by Field Parties. 1928.

[2] Further intensive investigation is given to the lakes and streams, in the interests of fish and waterfowl propagation, by the cooperative field work that is carried on by the State Department of Conservation and the Institute of Fisheries Research of the University of Michigan Museums.

[3] The general tax laws of the State of Michigan provide that lands delinquent for taxes for any five years shall under certain conditions revert to state ownership.

[4] The concept of the natural district was developed by the staff of the Land Economic Survey to provide a basis for correlating the physical and economic characteristics of land areas. Its use for that purpose was described by DeVries in the issue of the *Journal of Land and Public Utility Economics* for August, 1928, in an article on correlation of "Physical and Economic Factors as Shown by Michigan Land Economic Survey Data."

[5] EDITOR'S NOTE — Since the preparation of this paper the bill here referred to has been given legislative and executive approval. It is known as the Rushton-Coates Act, State of Michigan, 56th Legislature, Regular Session of 1931, Senate Enrolled Act No. 75, An act to amend sections two, four, seven, eight, nine, ten, thirteen, and thirteen-a of act number ninety-four of the public acts of nineteen hundred twenty-five, entitled "An act to provide for the establishment of commercial forest reserves and the administration and taxation of the same. . . ."

GLACIAL GEOLOGY OF IRON COUNTY, MICHIGAN

STANARD G. BERGQUIST

THE field work in Iron County was conducted during the summer of 1930 in connection with the program of the Land Economic Survey. Iron County lies within the area of the Superior Highland in the western portion of the Northern Peninsula. The bedrock is associated with the pre-Cambrian complex and is quite generally buried under a mantle of glacial drift with varying thickness up to 300 feet. The general broad features of the county are preglacial in origin and, according to Smyth,[1] represent a surface which was reduced to the condition of an approximate peneplain before glacial times.

During the Pleistocene epoch this region was overridden with a vast sheet of ice which moved down through the Superior basin from the Labrador center in eastern Canada. As the ice melted in retreat, it laid down the deposits which now give expression to the surface. The glacial features, which make up the relief of the area, are the results of deposition from two distinct ice lobes which occupied the region at different intervals during the late Wisconsin stage. (See Map 40.)

THE TILL PLAIN OF THE CHIPPEWA LOBE

The topography associated with the earlier of these two lobes is centered in the rather extensive till plain which forms the southern portion of the county, extending from Crystal Falls westward and lying to the south of the Paint River. This plain is characterized by broad uplands that stand at an elevation ranging from 1,400 to 1,800 feet (Pl. XXIV, Fig. 1). The surface is fairly rough and irregular and, where the drift cover is thin, it is controlled to a large extent by the topography of the underlying rock (Pl. XXIV, Fig. 2). The highest elevation in the plain is Sheridan Hill, a till-veneered monadnock which rises to a height of 1,840 feet, or practically 240 feet above the general level of the surrounding plain (Pl. XXIV, Fig. 3). This is likewise the highest point in the county.

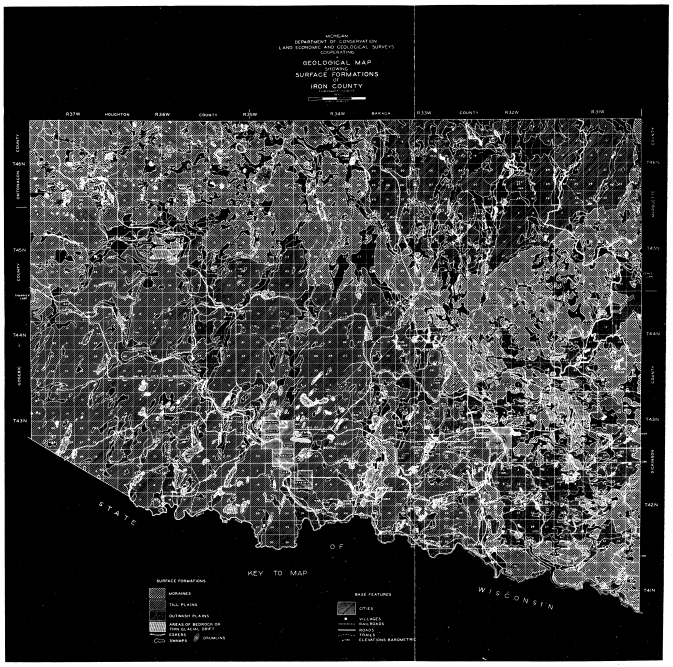
In the region extending from Crystal Falls and westward to beyond the limits of Iron River the topography is definitely ridged (Pl. XXV, Fig. 1). Drumlins and drumlinoid hills trending parallel and in a direction S. 20° W. feature the landscape (Pl. XXV, Fig. 2). The smoothly rounded ridges (Pl. XXV, Fig. 3) are separated by sags and basins which hold the numerous swamps, lakes and minor drainage ways.

The glacial drift which comprises the till plain is sandy to clayey in texture and contains a great number of erratics and large boulders which were drifted down from the north. Much local material from the iron formation is incorporated in the drift. The soil varies in color from light to reddish brown and shows but slight variation throughout the extent of the plain.

In the southwest corner of the county the relief is somewhat more subdued. Ridges give way to a topography which is more or less undulating. The drift in several of the townships in the vicinity of Elmwood in this district is composed of stratified material with heterogeneous associations of clayey till and numerous erratics as large as six feet. These boulders are not scattered over the surface alone, but are intermixed with the sandy, gravelly material, even at depth.

The drift of the till plain may be attributed to an ice movement which was much more extensive and definitely earlier than that of the Superior lobe. It is associated with the Chippewa-Keweenaw ice tongues which were directed in their movement largely by the Keweenaw Peninsula. The Chippewa lobe was induced by the broad embayment west of the peninsula, whereas the Keweenaw sheet found its way through the narrow bay to the east. The Chippewa was much the larger of the two lobes and in its maximum extension reached some distance south into Wisconsin, where it lay to the west of the Green Bay lobe. The Keweenaw ice-mass did not extend as a definite lobe very far beyond the limits of the present Lake Superior basin, but soon merged with the rapidly expanding Chippewa ice-sheet.

Russell[2] refers to this extensive plain as having a topography which is distinctly morainic. He also separates the drift into an older red till east of the Chicaugon—Trout Lake depression and a younger overlying gray till to the west of the slough.



MAP 40

Allen[3] likewise recognizes the presence of two drifts, the red and the gray, but emphasizes the fact that there is no great amount of distinction between the two types and that their separation would be extremely difficult.

Russell's interpretation of the topography in this plain was incorrect, for it is obvious that the ridgelike character of the surface and its drumlin associations would indicate deposition by moving ice rather than marginal deposition at definite stationary stages in ice retreat.

The general alignment of the ridges and valleys in the plain, together with the direction of the striae in the bedrock, would indicate that the ice in this lobe moved from the northeast and with a trend about S. 20° W.

A study of the soil in the till plain does not bring out any conclusive evidence that two different drifts are present. On the basis of color it is impossible to make any definite separation into red and gray drift. It is true that some local color variations do exist, but these are due mainly to the nature of the incorporated material rather than to a difference in age. In general, the till exhibits a fairly regular color throughout the plain and the soil has developed a profile which is consistently uniform.

GLACIAL FEATURES ASSOCIATED WITH THE SUPERIOR LOBE

Moraines

The moraine, which lies to the north of the till plain just referred to, is a terminal feature and was deposited at the margin of the Superior lobe. This moraine is the eastward continuation of a well-defined system which extends from the western end of the Lake Superior basin and follows a general easterly course into Iron County. In the northwest comer of the county it separates into two limbs, the outer one of which may be traced along the north edge of the county eastwardly to R. 34 W. Here it turns abruptly to the southeast and continues into the vicinity of Crystal Falls. To the east of this village the moraine is quite largely buried under glaciofluvial material and only the higher portions protrude.

The drift in the western portion of this moraine in Iron County contains considerable quantities of rock material which was drifted eastward from the Gogebic Range. There is a suggestion that the ice in this section moved slightly south of east. In the region of Perch Lake and southward glacial striae in the rock floor indicate that the movement of the ice-sheet was about S. 6° W.

The moraine stands as a rolling mass of till and is not clearly separable into distinct ridges. The relief is gently undulating to rugged, with elevations ranging from 1,400 to 1,700 feet (Pl. XXVI, Fig. 1). The drift is reddish to brownish, except in the region between Perch Lake and Net River, where it is quite distinctly of a grayish cast. The gray color of the soil in this area is due in large measure to the incorporation of material derived from the local rock, which consists principally of gray quartzitic slate and graywacke. In the vicinity of Perch Lake the moraine is made up of a series of more or less rounded knobs set in an otherwise fairly level plain (Pl. XXVI, Fig. 2).

The inner limb of the terminal moraine swings to the northeast across the south end of Houghton and Baraga counties, thence to the northeast corner of the county. A narrow strip of outwash situated in the southern portion of Houghton and Baraga counties separates the two limbs of the moraine for much of the distance. A small till plain lies between them in the northeast portion of the county. At this point the moraine turns south and follows along the east county line past Sagola in Dickinson County (Pl. XXVI, Fig. 3).

The drift in this portion of the moraine, especially along the line to the east of Crystal Falls, contains considerable quantities of dolomite, apparently of the Hermansville formation. The presence of this rock in the drift, together with the striae in the glacial pavement in the southeast portion of the county, would suggest an almost due westward movement of the Superior ice-sheet in this region.

Till plain

The small till plain which lies in the northeast portion of the county is characterized by a smooth to gently undulating surface. The drift is similar to that which is found in the adjoining moraine. It is brownish and is composed of intermixtures of sandy and clayey soils. Erratics and large boulders are strewn extensively over the surface and likewise generally incorporated with the drift.

Glacio-fluvial deposits

The glacio-fluvial deposits are confined principally to the major streams of the county. The valleys of the Paint, Iron, Deer, Fence and Michigamme rivers serve to illustrate the disposition of these features. They were formed, apparently, during the stage when the ice was receding northward by melting. Fast-flowing melt waters draining into the preglacial valleys served to scour out part of the glacial débris which had been left in the wake of the receding ice-sheet. The coarser materials, such as boulders, erratics and large cobbles, were not carried away by the water, but were concentrated by the removal of the finer till. These remnant boulders may now be observed along the older valley slopes and at the base of the gravel deposits where excavations have been made.

The gravel and sand which make up the bulk of the material in the deposits were no doubt carried in by rapidly flowing, sediment-choked waters issuing from the receding ice border. The preglacial valleys, which received these waters, were partly, but not completely, filled with coarse material, owing to the fact that the ice margin was receding quite rapidly. When the ice-sheet had retreated sufficiently far to the north to diminish the supply of sediments for the valleys, depositional activity was materially diminished and erosional work initiated. During postglacial times the rivers have continued to scour out the sediment and to sink their channels deeper into the deposits. Till the present, however, the streams have not cut through the material to encounter bedrock, except in very few places where the glacio-fluvial deposits were originally exceedingly thin (Pl. XXVII, Fig. 1).

In a deep cave near Caspian the stratified sand and gravel attain a thickness of 118 feet and rest directly on the bedrock of the iron formation. Large glacial boulders mark a somewhat definite contact between the rock ledge and the base of the deposit (Pl. XXVII, Fig. 2).

In many of the glacio-fluvial areas there is to be found on the surface of the gravel a layer of light brown, fine silt ranging in thickness from merely a few inches to six and more feet. It has developed a distinct profile and in the thicker portions is definitely weathered to depths of three to four feet below the surface. This fine material was carried down into the valleys by the slowly moving waters toward the close of the period when the glacier was contributing only the finer sediment. It represents the waning stages in glacial stream deposition. Much of the material is found some distance from the valleys of the present rivers and there is a slight suggestion that it may have been carried out from the valley ways by the wind. It would not be difficult to have loessial deposits developed under circumstances such as are found in these localities.

The general distribution of the gravel and sand in the main preglacial valleys of the county suggests the possibility that the term "valley train" might be correctly applied to cover the deposits. They are not typically of the outwash plain type and seem to bear little or no definite relationship to the moraines, as in the case of the true outwash (Pl. XXVII, Fig. 3).

In the region of Crystal Falls the gravel plain covers a quite extensive area. This material was undoubtedly carried down by the glacial waters which occupied the valley of the Paint River and was spread out over the older morainic surface when drainage to the south was cut off. Leverett[4] suggests that the outwash did not continue down the Menominee River because the ice of the Green Bay lobe was at the time covering up that valley nearly to the mouth of the Paint River.

DRAINAGE

The minor drainage lines of the county are largely controlled by the relief of the surface. In the till plain which lies to the south of the Paint River the smaller streams occupy the sags between the drumlins and the drumlinoid ridges and follow courses which parallel the trends of the hills. The majority of the lakes in this area lie in similar topographic positions and are elongated in a direction parallel to that of movement of the ice. Smoky, Pickerel, Stanley, Iron, Chicaugon, Trout and Fortune are among the larger ones which exhibit this relationship. (See drainage map, Map 41.)

The major drainage bears no relationship to the natural northeast-southwest topographic trends. Many of the larger streams, the Brule, Iron and Paint rivers, cut diagonally across the glacial ridges. In all probability many of the major rivers follow modified preglacial drainage courses for considerable portions of their distances (Pl. XXVIII, Fig. 1).

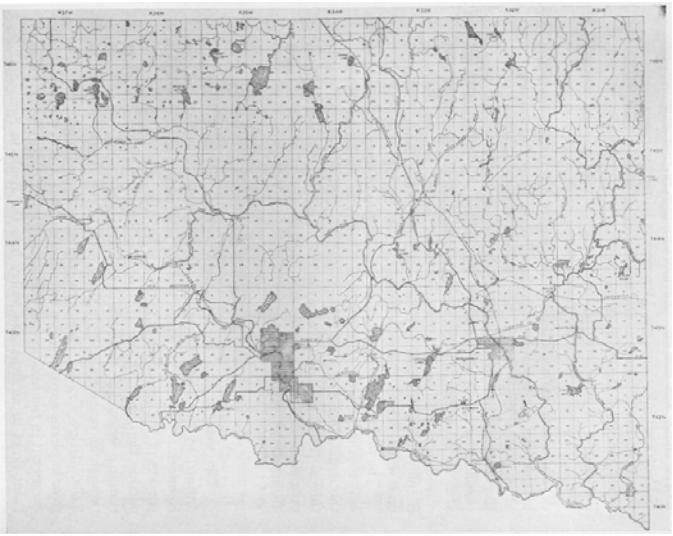
The Painted River

The western and northwestern portions of the county are drained by the Paint River and its tributaries, the Net and the Hemlock. The Paint River has its headwaters in the western portion of the county and follows a broadly curving course just outside the limits of the drift of the Superior lobe. The river rises in a series of glacial lakes at an altitude of 1,600 feet and flows through an area of relatively thick drift to the vicinity of Crystal Falls. Below Crystal Falls rock outcrops are prominent and the river in places narrows down considerably as it rushes through the gorges cut in the resistant rock masses (Pl. XXVIII, Fig. 2). The Paint flows in an expanded valley into the Brule in Section 12, T. 41 N., R. 31 W. at an elevation slightly below 1,200 feet (Pl. XXVIII, Fig. 3).

The Michigamme River

The Michigamme River, with its tributaries, the Deer and Fence, drains the eastern portion of the county. The drainage area of this system falls well within region of drift developed in the Superior lobe of the ice-sheet. The river heads in Lake Michigamme in Marquette County

just a few miles to the east of the northeast corner of Iron County. It enters Iron County in Section 25, T. 44 N., R. 31 W., and flows in a southerly course through a region in which the glacial drift is relatively thin and rock exposures are numerous (Pl. XXIX, Fig. 1). Near its mouth the rivers plunges over a resistant mass of quartzitic rock in a series of falls about twenty-five feet high (Pl. XXIX, Fig. 2). The Michigamme flows into the Brule in Section 16, T. 41 N., R. 31 W., to form the Menominee River.



MAP 41. Drainage lines of Iron County

The Brule River

The Brule River flows along the southern part of the county and forms the natural boundary between Michigan and Wisconsin. The entire drainage basin of the river in Iron County lies outside the limits of the Superior lobe. In much of its course the Brule River occupies a preglacial valley which has been modified by glacial deposition and it follows successively through areas of till, glacio-fluvial material and rock outcrops. In the southeast portion of the county the Brule and Michigamme rivers join to form the Menominee, which continues as the state boundary southward (Pl. XXIX, Fig. 3).

Iron River

Iron River has its headwaters in a fairly level gravel plain immediately south of Beechwood in T. 43 N., R. 36 W. It follows a course which is generally south and empties into the Brule in Section 28, T. 42 N., R. 34 W. Its valley carries considerable areas of glacio-fluvial sand and gravel, and in the vicinity of Iron River cuts through the iron formation to expose ledges of massive rock.

Lakes

Numerous lakes, most of them relatively small, are scattered through the county. They reflect a glacial origin and lie mostly within areas of moraines, till plains and glacio-fluvial plains. Those which have developed in the moraines are of the morainic or kettle type (Pl. XXX, Fig. 1). They occupy depressions and are set in between the knolls of the more rugged areas, where they are generally bordered by upland slopes (Pl. XXX, Fig. 2).

Lakes which occupy the glacio-fluvial plains are referred to as "pit lakes." They are generally bordered by level tracts of sandy material and are usually not so deeply depressed below the surface as are the basins in the moraines.

Many of the lakes are merely remnants of larger lakes which are gradually filling in with silt and organic remains (Pl. XXX, Fig. 3). These have developed swampy and marshy borders so characteristic of decadent types. The present lakes have been lowered appreciably in level since glacial times, as is evidenced by the position of their drainage outlets.

In general, it may be said that the drainage conditions in Iron County are quite youthful. The numerous lakes and swamps and the general haphazard drainage are evidences of this fact. The majority of the rivers have not yet cut through to bedrock; they are still excavating their channels in glacial drift. Further adjustments and changes will continue to take place as time progresses.

MICHIGAN STATE COLLEGE
EAST LANSING, MICHIGAN

[1] Smyth, H. L., *The Crystal Falls Iron Bearing District of Michigan, U. S. Geol. Surv., Monograph 36*, Part II, p. 331. 1899.

[2] Russell, I. C., *The Surface Geology of Portions of Menominee, Dickinson and Iron Counties, Michigan, Annual Report of the State Board of Geological Survey for the Year 1906*, pp. 40-52.

[3] Allen, R. C., *The Iron River Iron-Bearing District of Michigan, Mick. Geol and Biol Surv.*, Publ. 3, Ser. 2, pp. 15-22. 1910.

[4] Leverett, Frank, *Moraines and Shore Lines of the Lake Superior Region, U. S. Geol Surv., Prof. Paper 154-A*, p. 22. 1929.

PLATE XXIV

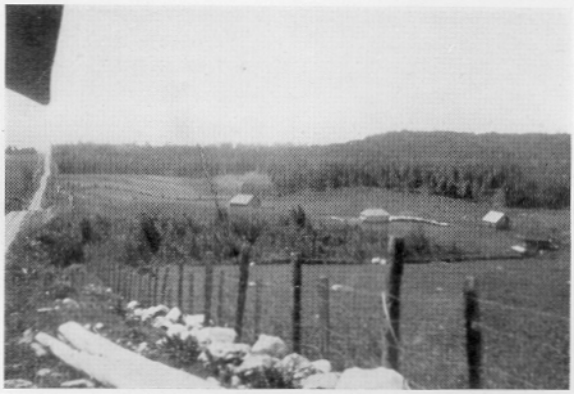


FIG. 1. Till plain two miles west of Crystal Falls

FIG. 2. Bouldery till plain, Section 2, T. 43 N., R. 33 W.

FIG. 3. Sheridan Hill, a till-veneered monadnock, Section 20, T. 42 N., R. 35 W.

PLATE XXV

FIG. 1. Till-plain topography, Iron River

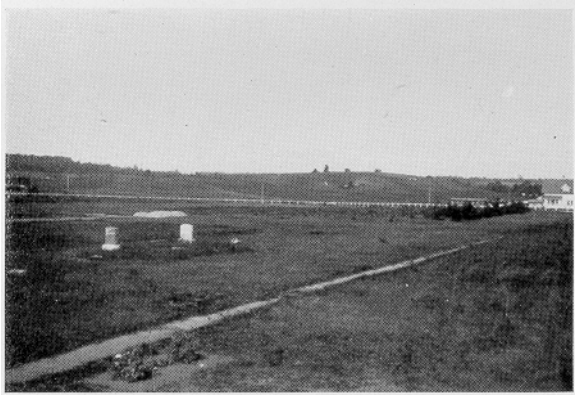


FIG. 2. Drumlin topography, one and one-half miles west of Iron River

FIG. 3. Characteristic drumlin near Iron River

PLATE XXVI

FIG. 1. Morainic topography near Amasa

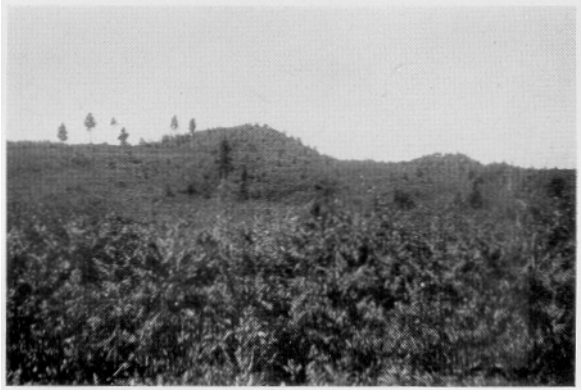


FIG. 2. Morainic hills, the Perch Lake area

FIG. 3. Morainic topography, east side of the county, Section 36, T. 43 N., R. 31 W.

PLATE XXVII

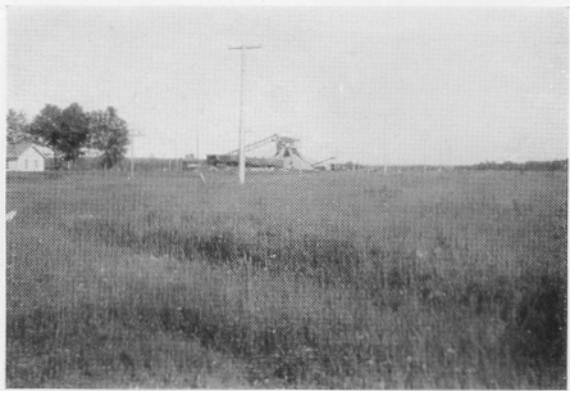


FIG. 1. Gravelly plain near Beechwood

FIG. 2. Cave showing gravel deposit resting on bedrock, near Caspian

FIG. 3. Glacio-fluvial plain in the valley of the Paint River, Section 25, T. 42 N., R. 32 W.

PLATE XXVIII

FIG. 1. Paint River above Horse Race Rapids

FIG. 2. Horse Race Rapids on the Paint River, Section 35, T. 42 N., R. 32 W.

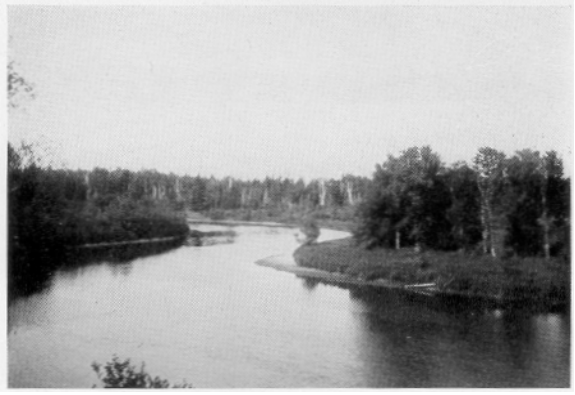


FIG. 3. Paint River near the junction with the Brule

PLATE XXIX

FIG. 1. Michigamme River near Mansfield

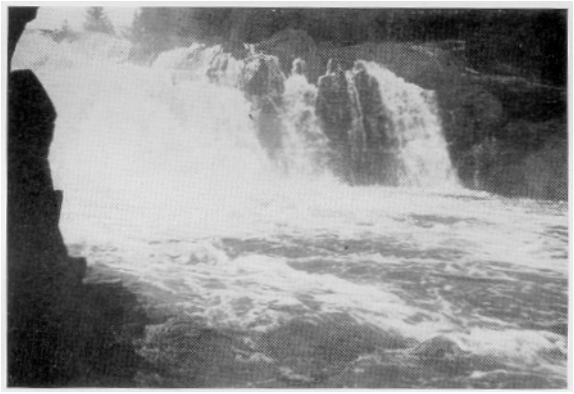


FIG. 2. Falls on the Michigamme River near the junction with the Menominee

FIG. 3. Brule River below the Brule Island Power Plant, Section 17, T. 41 N., R. 31 W.

PLATE XXX

FIG. 1. Perch Lake showing glacial pavement near shore

FIG. 2. Swan Lake, in till plain, Section 2, T. 43 N., R. 33 W.

FIG. 3. A pit lake, in glacio-fluvial plain, Section 27, T. 44 N., R. 32 W.

CONCERNING A GRANITE PEBBLE INCLUDED IN A VARVED PRE-CAMBRIAN SEDIMENT

EDWARD MORRIS BRIGHAM, SR.

THE specimen shown in Plate XXXI, with both sides represented, is a large pebble of solidified sediment which contains bedded in its substance a smaller pebble of granite. It was found in a stony field in Calhoun County, Michigan, three miles east of Battle Creek. The land surface there is known to be made of rock débris transported by the last sheet of ice which overspread the region during the latest period of glaciation affecting the continent. The specimen is hardly three inches in length. It is chiefly composed of a fine-grained matrix in which is set a conspicuous, rounded, crystalline pebble, whose longer diameter is about one inch. The banded appearance is due to successive layers of alternate seasonal deposits. Each contiguous pair of bands thus represents the product of a year of sedimentation. The record of such an annual cycle of deposition is called a "varve" by Swedish geologists, who have given particular attention to such structures.

Study of the relations of the component parts of the stone developed some interesting questions concerning its place of origin and its history. In the course of my investigations I sent it to Dr. Chester A. Reeds, geologist of the American Museum of Natural History, who determined its varved structure and its pre-Cambrian age. He also made suggestions concerning its origin and mode of deposition. In an effort to refer the larger pebble and its inclosed smaller one definitely to their parent formations, the specimen was submitted to several Canadian geologists, for it was believed to have come from within the range of their survey. Professor T. T. Quirke, of the University of Illinois, who had been working for the Canadian Geological Survey in the district north of Lake Huron, said he could duplicate the specimen in the Cobalt region of Canada. Director W. H. Collins, of the Canadian Survey, declared he could match the specimen in his collections and was of the opinion that it came from the Cobalt region. Professor A. P. Coleman, of the University of Toronto, thought the included granite pebble very closely resembled the Algoman red granite of Canada. Professor Coleman is the geologist who in 1908 found in the Cobalt district conclusive evidence of a Lower Huronian period of glaciation.

The specimen is composed of clastic material in sharply marked zones and contrasting colors. Red argillaceous sediments alternate with gray arenaceous ones. The red zones are quite homogeneous and uniform in texture and are entirely without megascopic inclusions. Their color suggests that they may have been derived from the source of the red granite pebble. The arenaceous zones are thicker and are composed of numerous thin laminae. They are much specked by minute, angular, unassorted

inclusions, most of which suggest by their color and form that they also may have been broken from the same parent red granite.

The form of the large included pebble indicates its glacial origin. In Figure 3, of Plate XXXI, there is shown the characteristic subangular form of glacial pebbles in contrast with the more rounded forms of water-worn pebbles. The coarse, angular inclusions scattered through the mud zones also indicate a glacial origin. Indeed there is no doubt among the authorities who have examined the specimen, that the whole structure is composed of glacial débris. Moreover, it is concluded that the thicker, gray, laminated zones represent the deposits of the summers, the seasons of special ablation, and that the red, argillaceous zones are the winter deposits. It is concluded, further, that the deposits were made in an inland fresh-water lake, since in salt waters flocculation would prevent such distinct laminations. Concerning the seasonal conditions of glaciers which induce variety and grading of rock waste, I quote Chamberlin and Salisbury:[1] "Stones in the base of a glacier may be held with great rigidity when the ice is cold and dry (as in winter), scoring the bottom with much force, while they may be rotated with relative ease when the ice is wet (as in summer). . . . a glacier should be more rigid in winter than in summer, and the whole thickness of the glacier should experience this rigidity chiefly at the ends and edges, where the relative thinness of the ice permits the low temperatures to reach its bottom." Hence, although the motions of the ice during the winter are slight, the rock grist of the glacier is developed chiefly during that season, with active corrasion confined largely to the heavy scoring on bedrock by stones held rigidly in the base of the glacier. The alternating zones of red and gray clastic material in this specimen are believed to represent this product, which was set free only during the summer, when the temperature was sufficiently high to loosen it and when the water of the subglacial streams under hydrostatic pressure carried it to the lake. The coarser materials of the gray summer layer were spread filmlike over the bottom of the lake as they were added from day to day. The finer, clay particles constituting the red winter layers were, however, kept in suspension during the summer season by the agitation of the lake water by the currents of the subglacial streams and by the slowness with which the clay particles settled. During the winter months, when the lake waters became relatively quiet, the clay particles settled gently to the bottom to form the winter layer, composed almost entirely of pure red clay derived by the ice from the red Algoman granite.

PLATE XXXI

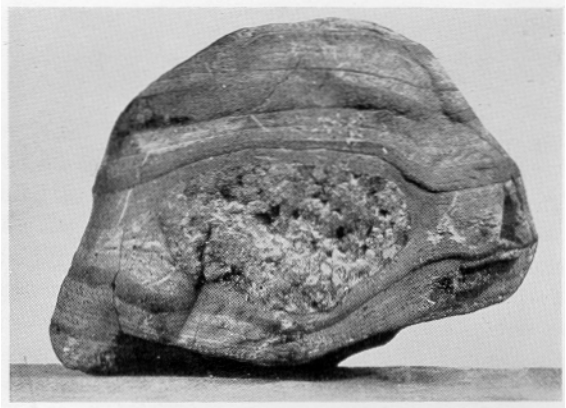


FIG. 1. A Pleistocene varved glacial pebble representing five years' deposits and composed of clastic sediments, which are of glacial origin in a lower Huronian period of glaciation. The laminae are distorted by the inclusion of a granite pebble. The alternating lighter and darker zones indicate summer and winter deposits

FIG. 2. The opposite side of Figure 1. Only nine seasonal zones shown, but remnant of tenth appears in upper view. The summer zone, including the pebble shown in the upper view, is indicated by the brace

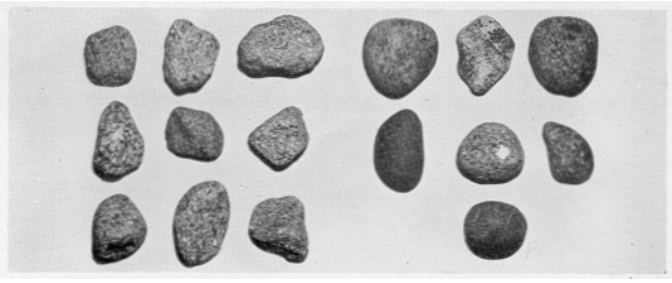


FIG. 3. The group of nine pebbles to the left illustrates the characteristic forms produced by glacial action; the group of six to the right, those produced by water action

One eminent geologist inclines to the opinion that the included pebble was rolled out on the muds by a subglacial stream, but there are some reasons for hesitancy in accepting this view. First, it is doubtful whether the pebble could have been rolled on a bed of such soft, depositing mud. The diagram in text Figure 7 shows a similar inclusion in the same sort of matrix, figured by Director Collins of the Canadian Survey, who believes that this pebble was dropped with such force as to punch through several of the laminae. Though the pebble we are discussing did not rupture the underlying laminae, several of the overlying laminae which were deposited later have settled over and about it. To be sure, if it is assumed that it was physically possible for the pebble to be rolled into that position, it is quite conceivable that its resistance to currents would cause a rocking or vibratory action, under the impact of the waters, that would cause it to settle deeper into the underlying deposits. Another consideration favoring the idea of dropping is that, according to the experiments of Sorby[2] and Forbes,[3] a current that would roll the granite pebble would have a degrading velocity not only on the mud but upon the megascopic inclusions common in the mud. Sorby found the current velocity required to start movement of a pebble the size of a pigeon's egg to be 1.45 meters per second. Forbes determined the velocity for movement of fine particles of fresh-water sand to be only 0.213 meter per second. From these demonstrations it is clear that a velocity of current that would move the pebble would energetically elevate and carry on the finer waste on which it was lying. Furthermore, on the same plane of deposits on which the large pebble rests there are numerous angular fragments of granite, none of which much exceeds a millimeter in diameter. A current that could roll the large pebble would certainly have moved these finer fragments forward before they would come to rest.

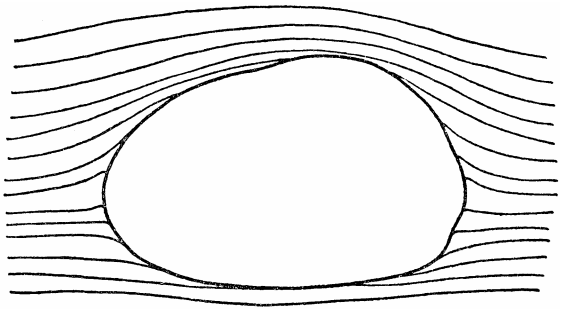


FIG. 7. Diagram showing how the weight of a glacial pebble dropped from floating ice into fine sediments enabled it to cut through several laminae (after W. H. Collins, Canada: Geol. Surv., Memoir 143, No. 124, Geological Series, p. 66.

The remarkably sharp lines of separation between the seasonal deposits appear to indicate an abrupt change of temperature, at least in the glacial ice, from season to season, and a consequent change in mode of deposition of the material. There appears no transitional mingling of the two kinds of sediments. This abruptness may be due to a sudden checking of ablation by winter temperatures which stopped the influx of the summer débris, and perhaps to an equally quick release in the warmer season. As suggested by the statement of Chamberlain and Salisbury already quoted, the general surface, the borders and the end of the glacier would be rendered rigid by extremely low winter temperatures and hence for the season would not be contributory to the discharge of débris. Accordingly, during winters subglacial scourings by ice rigidly holding stones would not be delivered to the lake. The winter deposits constitute but about 20 per cent of the volume of the specimen under discussion. They represent the settlement during the winter of the fine clay particles held in suspension in the preceding summer's influx.

We may assume, of course, that ablation is controlled by weather and that the thickness and varying physical aspects of the laminae from year to year are chiefly caused by fluctuations in ablation. Accordingly, the variation in quantity of the megascopic particles in the summer series appears to reflect special weather phases that condition excessive ablation, calving and flotation. The pebble was dropped nearly in the middle of the summer series of laminate deposits during the height of the season, when there was perhaps a maximum of calving and detachment of floating bodies of ice. It is noticeable that there was little of the coarser fragmental débris scattered over the lake bottom during the remainder of the summer. Thereafter, to the end of that summer, ablation appears to have waned, and we find no signs of the drizzle of the sharp bits of granite prevalent during the earlier half of the season.

During this Lower Huronian period of glaciation in the North American region under consideration the climate appears to have been marked by strongly contrasting seasons in respect to temperatures, possibly much more than in the same latitude today. There are suggestions also of a somewhat more abrupt beginning and ending of the seasons. The large numbers of distinct summer laminae must be interpreted as showing constantly variable weather conditions during the summer, if we assume that their thickness and texture indicate fluctuations in volume of ablation.

An occasional lamina of unusual thickness, bearing signs in its megascopic inclusions of having its substance drawn from an exceptionally wide area, suggests a period of abnormal surface melting due to unusual warmth.

The pebble shows ten zones, alternating red and gray. Hence there are five pairs, or "varves," representing the summer and winter deposits of five years,

Varved pebbles, and even boulders of large size, which are essentially like this pebble in both their general composition and megascopic inclusions, abound in the vicinity of Battle Creek. Their number appears to indicate that vast volumes of such rocks were destroyed by glaciation in Canada, especially when it is considered that such sediments are easily wasted by attrition.

Accordingly, it would seem that in Huronian times, in the higher latitudes of North America, extensive lakes received the finer rock waste from widespread glaciers.

From the varved sediments laid on those old lake bottoms the Pleistocene ice sheets lifted immense masses, piecemeal, as indurated rock. Among the fragments was the one from which the specimen in hand is a remainder. The little stone thus bears record of two periods of glaciation on our continent, the earliest one known and the latest. It is tributary from the former to the latter through an interval of time estimated, on bases of radioactivity and geological data, at one billion two hundred million years.

MUSEUM OF NATURAL HISTORY
BATTLE CREEK PUBLIC SCHOOLS
BATTLE CREEK, MICHIGAN

[1] Chamberlin, Thos. C., and Salisbury, Rollin D., *Geology* (*American Science Series*), 1:320-321. 1906.

[2] Sorby, H. C. "On the Application of Quantitative Methods to the Study of the Structure and History of Rocks," *Quart. Journ. Geol. Soc. of London*, 64 : 171-233. 1908.

[3] *Proc. Royal Soc. of Edinburgh*, 3 : 474-476. 1856-57.

NOTES ON *HYPOLAGUS BROWNI* AND *LEPUS BENJAMINI*, FOSSIL HARES FROM THE PLEISTOCENE OF ARIZONA

LEE R. DICE

IN 1921 a collection of mammals from Anita, on the Coconino Plateau, Arizona, was described by Hay.[1] Among the new forms were two fossil hares from the early Pleistocene. Although Hay published photographs of these specimens, he did not give figures of the enamel patterns of the teeth. Such figures are of great importance and are presented in this paper. Through the courtesy of Dr. J. W. Gidley I have been allowed the use of this fossil material, which is in the United States National Museum. The figures were drawn by Dora S. Dice.

It is interesting to find that hares belonging to two different subfamilies, Archaeolaginae and Leporinae, lived together in Arizona in the early Pleistocene . At the present time the hares of the subfamily Archaeolaginae are wholly extinct.

Hypolagus browni (Hay)

One species was described by Hay as *Brachylagus browni*, but an examination of the teeth shows that the animal belongs to the genus *Hypolagus*.[2]

Hypolagus browni is notable because most of the upper and lower teeth are present in the specimens and there is thus afforded an opportunity for describing the upper teeth of *Hypolagus*. The upper teeth of other species of *Hypolagus* are not well known. An upper molariform tooth, presumed to be of *Hypolagus vetus* (Kellogg), has been figured, and P^3 and P^4 of *Hypolagus giganteus* (Brown) have been described but not figured.

The upper molariform teeth of *Hypolagus browni* have quite simple enamel patterns, as is shown by Figure 8. The most anterior premolar, P^2, is unfortunately missing, and so is the last molar, but P^3, P^4, M^1 and M^2 are present. All these agree in having the anterior borders of the interior reentrant angles somewhat crenulated and the posterior borders of these angles only slightly wavy. The reentrant angles extend considerably more than halfway across the teeth. There is only a slight development of cement. In all these characters the teeth differ from the molariform tooth[3] believed to belong to *Hypolagus vetus* from the Thousand Creek beds of Nevada, which has only a short reentrant angle, with the enamel rather strongly crenulated, and which has a considerable amount of cement on the inner face of the tooth.

FIG. 8

FIG. 9

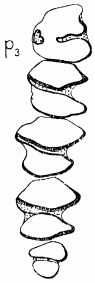


FIG. 10

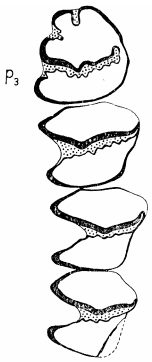


FIG. 11

FIG. 8. *Hypolagus browni*. Enamel patterns of left upper molariform teeth. U.S.N.M. (type) No. 10196. X 4.

FIG. 9. *Hypolagus browni*. Enamel pattern of right P^3. U.S.N.M. No. 10201b. X 4.

FIG. 10. *Hypolagus browni*. Enamel patterns of right lower molariform teeth. U.S.N.M. No. 10201a. X 4.

FIG. 11. *Lepus benjamini*. Enamel patterns of left lower molariform teeth. U.S.N.M. No. 10183. X 4.

Brown[4] states that the upper molariform teeth of *Hypolagus giganteus* from the Conard fissure of Arkansas have the reentrant angles extending only slightly more than halfway across the teeth, and that the enamel in the reëntrant angles is crenulated.

As shown by Figure 10, the enamel patterns of the lower molariform teeth of *Hypolagus browni* are quite simple. On the most anterior lower premolar (P_3) the external reentrant angle extends only about halfway across the tooth and is not crenulated. There is a shallow groove on the external side of the tooth anterior to the main external reentrant angle, but there is no reentrant angle on the anterior face of the tooth, such as is found in most modern hares and rabbits. The shape of this tooth is different from that of the corresponding tooth of any

other known *Hypolagus*, and the species *browni*, therefore, is distinct.

Near the internal border of P_3 (Fig. 10), opposite the external reentrant angle, there is on this specimen a small enamel island. Presumably at a younger stage of wear this would be connected with the internal border of the tooth, forming at that time an internal reentrant angle. If this occurred, the enamel would at that time have had the pattern characteristic of Palaeolagus and other genera of the subfamily Palaeolaginae. This may indicate that the genera *Hypolagus* and *Archaeolagus*, which I have placed in a separate subfamily Archaeolaginae, originated from the Palaeolaginae. However, no other of the three anterior lower premolars of *Hypolagus browni* in this collection show similar islands of enamel, and these, perhaps, were present only in the early stages of wear.

Hypolagus browni, as noted by Hay, was larger than *Brachylagus idahoensis*. The lower jaw is very similar in size to that of the brush rabbit of California, *Sylvilagus* (*Microlagus*) *bachmani*. Several humeri and femurs are shorter and more slender than those of the brush rabbit, but these may have belonged to individuals not quite mature. An innominate bone, No. 10205, is very similar in size to that of an adult *bachmani* from Corralitos, California, but the ischium of the fossil is longer and more slender. The general indication is that the fossil hare was about the size of the brush rabbit or perhaps slightly smaller.

The posterior nares of the fossil are very narrow, being decidedly more constricted than those of *Sylvilagus bachmani.* This indicates that the fossil animal could have had little endurance in running.

Lepus benjamini Hay

Hay[5] states that the posterior borders of the reëntrant angles of the lower molariform teeth in *Lepus benjamini* are crenulated, differing in this respect from *Lepus townsendii campanius*. An examination of the specimens of white-tailed jackrabbits in the University of Michigan Museum of Zoology proves this statement to be correct. In none of the specimens of *Lepus townsendii* or *Lepus t. campanius* is the enamel on the posterior borders of these reentrant angles crenulated, as it is in *Lepus benjamini* (Fig. 11).

The jaw of the type of *Lepus benjamini* is in size and shape almost identical with that of a jaw of *L. townsendii campanius* from North Dakota. Compared with *L. californicus vigilax* from Calaveras County, California, the fossil jaw is distinctly heavier and the diastema is shorter. The indications are that the fossil animal was of about the same size as *Lepus townsendii*, the white-tailed jackrabbit.

Three femurs of large hares are represented in the fossil material. The largest of these, No. 10192a, is shorter and lighter than the femur of an adult female *campanius* from North Dakota, but similar in length to that of an adult *L. californicus vigilax* from Ball's Ferry, California. The shaft has a smaller diameter than either *vigilax* or *campanius*, of similar length, and it is more nearly round in cross-section. The other two femurs, Nos. 10191 and 10192b, are nearly alike in size and shape, but they are much shorter than No. 10192a. In size and shape they agree closely with *L. townsendii campanius* and *L. californicus vigilax*, but they are smaller. No. 10191 seems to be from a mature animal, since its processes are well ossified. This apparently indicates, as Hay supposed, that two species of hares are represented by the femurs. To judge from the size of the jaw the large femur, No. 10192a, should belong to *Lepus benjamini*.

UNIVERSITY OF MICHIGAN

[1] Hay, O. P., *Proc. U. S. Nat. Mus*., 59: 617-639.

[2] Dice, L. R., *Journ. Mammal*, 10: 343. 1929. 379

[3] Dice, L. R., *Univ. Calif. Publ. Geol*., 10:181, Fig. 5. 1917.

[4] Brown, Barnum, *Am. Mus. Nat. Hist., Mem*. 9: 199. 1908.

[5] Hay, O. P., *op. cit*., 59: 629. 1921.

THE GEMS OF ISLE ROYALE, MICHIGAN

FRED DUSTIN

IT WAS my good fortune to be employed several weeks in the summers of 1929 and 1930 in a survey of the archaeology of Isle Royale for the University of Michigan. The work took me almost completely around its shores and into much of the interior. Part of nearly every Sunday was devoted to a search for gems, and when I was near some of the more noted localities any spare time was employed in traversing the beaches or studying the rocks from which these gems are derived.

Isle Royale extends northeast and southwest for forty-five miles; its surface presents a series of rocky ridges that follow the trend of the island, precipitous on their northern exposures but sloping more gently toward the south. Most of these ridges are formed from lava flows of a very ancient time. For some miles along the north side of Siskowit Bay and at Conglomerate Bay a peculiar conglomerate outcrop is found, whereas from Senter Point in the former to the vicinity of the mouth of Grace Creek at Grace Harbor and south to the shore a red sandstone is predominant, which gives a quite different character to the scenery. This sandstone seems to be barren of gems; the lava and conglomerate form their matrices.

It appears that there were several flows of the once molten material which so largely characterizes the Isle, and in these different formations certain predominating minerals are found. Thus the amygdaloid on the north shore is rich in thomsonites and similar stones; the "Greenstone Range," of which Blake Point is the northeast terminus, carries agates, prehnite and crystal quartz; the range of islands, Smithwick, Mott and

Caribou, and the corresponding ridge running southwest, gives chlorastrolites accompanied by prehnite, epidote, datolite and some of the zeolites; the conglomerate furnishes fine carnelians as well as good agates and some common opal. No carnelians were observed except from the conglomerate, but a few chlorastrolites were obtained from the amygdaloid, the "Greenstone Range" and the conglomerate; in fact, wherever prehnite occurs, one may look for these unique gems; a fine one came to my collection from Hart Cove on the north side of Tobin Harbor, where a seam of prehnite can be seen near the shore.

The several gem stones will be discussed separately.

A map of Isle Royale is to be found on page 2 of this volume.

CHLORASTROLITE

The first reference I have been able to find concerning these stones is in the report of Dr. Charles T. Jackson,[1] geologist, in which he gives the best synopsis of the prehistoric mining, geology, minerals and history of the Isle yet published. On page 418 he says: "Under the copper-bearing bed there is another bed of epidote. . . . This bed contains stellated masses of a mineral which I named chlorastrolite."

In the report of Foster and Whitney[2] the following statement is made: "Chlorastrolite. — This mineral was first observed by Dr. Locke, on the shores of Isle Royale, and afterwards obtained by Mr. J. H. Blake. It was analyzed and described as a new mineral by Mr. Whitney. . . . The name chlorastrolite was given to it by Dr. C. T. Jackson. . . . It occurs in finely radiated, stellated masses . . . hardness 5.5 to 6."

Since Dr. Locke was an assistant to Dr. Jackson, in the absence of any previous reports by Dr. Locke or Mr. Blake, it may be safely inferred that Jackson was the first to note its discovery. Whitney's analysis was somewhat faulty, since he gave the hardness too low and the specific gravity too high. So far as known, Isle Royale is the only place from which chlorastrolites of gem quality have been obtained, although imperfect nodules have been reported from the trap rock of Keweenaw Peninsula.

I had no opportunity of observing them in the epidote mentioned by Dr. Jackson, but saw them in place in the brown lava of the islands and on the ridge noted. I collected good specimens both free and in the matrix from the beaches on Smithwick and Mott islands, some from near the Old Light and from the south shore of Siskowit Lake, a few from Scovill Point and Todd Harbor, with occasional ones from Tobin Harbor. Some of the fishermen chisel them out of the rock along the trail from the head of Rock Harbor to Lake Richie and near Chippewa Harbor.

Near the outlet of Siskowit Lake they may be seen in several stages of alteration, both in the matrix and free. Where the alteration is advanced, they have a soapy feel and are easily scratched by the thumb nail. On one of the dumps at Minong Mine I found a small mass of crumbling rock of very different character from that of the breccia-like conglomerate which forms the rock-mass at the mine, filled with soft dark green nodules having the stellate formation of chlorastrolite and presumably altered forms of that mineral. They were easily extracted, and an analysis might be of interest.

There does not appear to be entire agreement among mineralogists as to the place chlorastrolite occupies among minerals, but from various analyses it would seem to be quite closely related to prehnite. On Isle Royale native copper is always associated with prehnite and often disseminated through it in small specks or larger pieces, but in no case have I observed copper in the same relation to chlorastrolite. There seems, however, to be a transitional form, which cannot be described as either of these two minerals. It appears to be an effort of nature to combine two similar minerals with poor success, for it is unlike either, being a mixture of light and dark green, showing no pattern of crystallization but containing specks of native copper.

In chlorastrolite there is quite a range of color and figure. Occasionally one will be found of a pale green shade and very small pattern, a good example of which may be seen on color Plate 3 of Dr. George F. Kunz's *Gems and Precious Stones of North America*, or in *National Museum Bulletin 118*, Plate 7. In my own collection there are stones that appear to be almost black, but under the pocket lens they reveal the same fine stellations as do the paler stones. Some show a mosaic pattern, others a radiate, resembling prehnite except in color. Some chlorastrolites have patches of pink or flesh color. Under the lens these are seen to be little starlike forms of singular beauty, or else they look like tiny roses. These were shown to a mineralogist who suggested that the pink mineral was thomsonite, but if so, it has been greatly altered, since it has the same hardness, 6.5, as the chlorastrolite. The resorters and fishermen do not seem to appreciate these beautiful little gems, and apparently pass them by, perhaps classing them with "zeolites," as the pink and white thomsonites are locally called.

Fine chlorastrolites have become very scarce, for during the resort season regular trips are made from Minong Lodge and Rock Harbor Lodge to collect them, and in the early spring the fishermen, three of whom have small lapidary machines and do very creditable work, visit the beaches where they are found. They have the first pick after the winter and spring storms, which release the stones from the rock and wash them up on the beaches. Some, especially very small ones, are worn and polished by wave action and show the pattern plainly, whereas others, recently freed from the matrix, require careful examination with the lens to determine whether they are worth cutting; even then one of fine appearance may be worthless, a mere shell of chlorastrolite filled with

crystallized calcite or other material which breaks to pieces when placed on the cutter's wheel. Others are hollow, having lined but not filled an amygdule in the lava, and show on the inside a small botryoidal surface. In my collection there is an irregular piece two and one-half inches long, one and one-quarter inches wide and one-half inch thick. It is attached to a piece of brown rock of similar form and dimensions. The two can be separated only by the diamond saw or the slower process of grinding off the rock matrix. How fine a stone this would be is a question; it is light in color, but if well stellated it would be a very unusual gem.

Several of the people who visit Isle Royale year after year have become the possessors of fine chlorastrolites, set in brooches, necklaces, rings and stick-pins. In former years it was not difficult to find a gem of fair size; now, one three fourths of an inch long is a rarity. I saw one of this size collected in 1929, but it was of only fair quality. A good "greenstone," as they are called in the Lake Superior region, is highly prized by those who love the place of its origin; it has a greater local value and interest on this account.

Professor N. H. Winchell[3] discusses chlorastrolite and gives reasons for considering it to be a distinct mineral. It has a marked pleochroism and a strong individuality in both structure and color. Winchell says: "Its chemical characteristics will be found as distinct as its physical." The collector will notice many green stones on the small beaches where chlorastrolites are found, some of which have the appearance of those gems so far as form and color are concerned, but are structureless. Winchell thinks that these often grade into mesolite on one side and into chlorastrolite on the other and says: ". . . these two minerals are closely allied in origin, structure, and composition, differing principally in the content of iron."

Whether it is a distinct mineral or not, it is certain that the mosaic, stellate and radiate appearance of this gem is unlike that of any other. Its rich light and dark shades of green place it in a class by itself. Its capacity for taking a very high polish and its slightly chatoyant reflections increase its beauty, and the fact that it is a distinctively American gem adds to its interest and to that of the beautiful Isle which gives it to us.

LINTONITE, THOMSONITE AND MESOLITE

In attempting to describe these minerals we are confronted by conflicting and confusing definitions. "When the doctors disagree, who shall decide?" is a true saying, so that if the terms used interlock more or less it will be due to a layman's confusion over the doctors' diagnosis.

In general, the local lapidaries of Isle Royale refer to the gems named above as "zeolites," for all three are collected on the Isle, but most of those obtained are the pretty pink and white stones, often showing green spots, which I shall describe as thomsonites. They are to be found on nearly every gravelly beach, although the amygdaloid of the north shore is the source of the finest gems of this class. They weather out of the rock in the form of rounded pebbles from the size of a pea to over an inch in diameter, and are collected on the shore by wave action, often receiving considerable polish thereby.

When further polished by the lapidary they show the pretty pink "eyes" or tufts of slender crystals with a silky or pearly luster; occasionally these "eyes" are green or there will be patches of green not showing crystallization. Rarely they contain distinct little masses of apple-green prehnite. In some stones the pink may predominate, and in others green will be the most striking color. They are subtranslucent and the hardness is 5.5. Owing to this comparative softness, they are more desirable as settings for stick-pins, cuff links and brooches than for rings or watch charms.

On Coast Chart 8 (Isle Roy ale and vicinity), issued by the War Department, Stockly Bay will be noted near the northeastern end. The several bays of which Stockly is the largest are called in general "Five Finger Bay" by the islanders. On the south side of this bay opposite the long island in the upper part of Duncan Bay there is a small beach known locally as "Thomsonite Beach," where some good thomsonites are found as well as a few lintonites; farther southwest in Todd Cove, two miles northeast of where the eighty-ninth meridian touches the shore, a place marked "Thomsonite Beach" will be noted. There are some of these gems at this point, but the true Thomsonite Beach is two and one-half miles southwest, a little beyond the meridian named.

Since this place is seldom visited, some fine specimens may be collected; a few are of the Grand Marais, Minnesota, type, designated by Winchell as rnesolite. Opposite Hawk Island near McCargo Cove many thomsonites can be seen in the amygdaloid along shore, but do not seem to weather out to any great extent, probably owing to an unusual hardness of the rock. On the outer beach of the small island southwest of Smithwick Island a pocketful may be collected, but all will be very small.

Lintonite, first described by Peckham and Hall,[4] appears to be the uncrystallized green mineral occasionally associated with thomsonite. I collected in Stockly Bay a very fine gem in which this mineral seems prominent. The cut stone is almond-shaped, one and one-half inches long, three quarters of an inch wide and one-quarter inch thick. The lintonite is two shades of green and is filled with finely radiated tufts of mineral about one-quarter inch in diameter. The outer ends of the needles become delicately pink; the center of the tufts is green. The stone is finely translucent, but it is not a perfect specimen, since there are two or three spots of the brown matrix rock which could not be ground away entirely. Another gem, cut and polished, seems to be wholly of this mineral; its color is dark green; it does not take a good polish and in itself is of little interest as a gem, since the color is too deep and it is only subtranslucent.

Professor N. H. Winchell[5] says of thomsonite: "That reported for several years from Minnesota [near Grand Marais] is mesolite, though thomsonite also occurs. Lintonite is worthy of being classed with the gems. It is allied to the jacksonite of Whitney." Dr. George F. Kunz[6] makes this statement: "From this account [Winchell's] these closely similar minerals would belong strictly as follows: thomsonite, so called, under mesolite, lintonite under thomsonite proper, and jacksonite under prehnite."

The lintonite described by Peckham and Hall would seem to be distinctively unlike the pink and white gems of Isle Royale, and even more dissimilar to the characteristic creamy and brown-spotted stones from Grand Marais called mesolites by Winchell. The last named are scarce on the Isle. The few gems of my own of this type seem to take a more brilliant polish than do the thomsonites, which perhaps indicates a slightly higher degree of hardness. Two small ones are masses of radiate, reddish brown tufts, that appear to the naked eye to have a background of pinkish cream, but under the lens it is seen that the needle-like crystals simply become lighter toward their extremities and produce the odd effect. One fine little stone has a patch of lintonite which adds to its attractiveness, but which is duller on its polished surface than is the harder mesolite.

The largest cut stone of this kind was made from a section sawed by the lapidary from the matrix, in which it formed a mass sufficiently large to furnish a gem one and one-quarter inches long and three quarters of an inch wide. The ground mass is milky white, containing many brown and white tufts of radiating crystals about one eighth of an inch in diameter. There are specks of copper scattered through it, but so small as to be imperceptible unless the lens is used. It is somewhat flawed, and is not a fine gem although unusual for size and markings.

CARNELIAN

At the head of Siskowit Bay there is a beach that forms an almost perfect arc of a circle, beginning at the site of the old county seat and extending south to Senter Point. It is about three quarters of a mile along the shore line; its gravel and boulders are the results of the disintegrating of the conglomerate rock, which is seen in place at the beginning of the old road to the Island Mine. I have named this Carnelian Beach, for here can be collected as fine stones of that name as one could wish for. They do not run large, but for purity and depth of color they can hardly be excelled. On two occasions my camp was made at this place overnight, which afforded opportunity for a slight study of the rock and the gravel from it.

It is a question whether all the gem stones found there (mostly agates and carnelians) were formed in the rock after it had become consolidated or whether some of them were in the gravel when the cementing process occurred. I would incline to the latter idea. There may still be seen in place agates, some of them large, showing plainly how they have filled irregular cavities in the conglomerate. The northerly half of the beach produces most of the gems, for the southern half is largely sand.

The shore is piled high with gravel lying in two or three terraces, and the pretty red pebbles from the size of a small pea to an inch or more in diameter will attract the attention of the mineral lover very quickly, and he will note other fine stones, predominantly red outside, showing the formation of an agate or jasper shell filled with a solid mass of pure white quartz crystals. The largest carnelian found was a beautiful specimen about two inches in length, of fine color and texture. Unlike most of the quartz gems of Isle Royale, it did not appear to be flawed.

Another interesting feature of these gems is that a large portion of them are finely translucent, unlike so many carnelians from other localities which are somewhat clouded. Often they are blood-red; others show delicate agate-like formation, and one a deep red little "eye" surrounded by a whitish zone, which in turn is circled by a narrow red line, all on a ground-mass of light carnelian. The prevailing shade is a deep red; a few, however, show pale orange tints.

AGATES

The agates of Isle Royale are not large; the largest noted was about eight inches in diameter. The rock in which they have formed influences their color and markings. The Greenstone Range, from Blake Point to its southwestern extremity near Washington Harbor, is the principal agate-bearing rock, although agates occur sparingly in other places, particularly at Carnelian Beach. On the north side of Tobin Harbor, far down toward Blake Point and along the shores of the islands thereabout, they can be seen in place in the greenstone, and may be collected from the little beaches along shore or in the shallow water contiguous. From time to time a few are freed from the rock and are collected by the resorter who possesses the secret of their locality. Most of them are flawed, some so greatly that they break into pieces. Occasionally one is found fine enough for polishing, usually a fragment. They are generally light in color; the banding is white and pale sard, but, rarely, a deep mottled red. Some are of the "fortification" type, with fine lines of delicate color; others are banded in curves that produce beautiful patterns.

At the southwest end of the Isle near McGinty Cove "Agate Beach" may be noted on the chart. Some fine agates have been collected here, from which it has received its name. While exploring southwest of Minong Mine near McCargo Cove, I collected from an old lake beach, perhaps two hundred feet above the present lake level, a much-weathered agate in its matrix. From its

appearance it had lain there for centuries, with its colors fading and its luster diminished.

The finest small agates are those found on Carnelian Beach, where many are unique in color or formation. Deep red color and curious markings give a special character, for we find them in true sardonyx, parallel layers of nearly white and brown; others have outward bands of red in different shades, with a solid center of quartz crystals that look like ice; one has bands of amethyst color, pale brown and white, breaking off into odd figures at right angles. Another shows not a trace of color, but has fine white bandings against clear translucent chalcedony. The most remarkable one of all displays an outside agate formation that incloses a dozen distinct parallel layers of at least ten shades, and another odd specimen looks like a slice of fine-grained beef.

Occasionally a stone will be found which from its beauty can be ranked as a gem, but which almost defies classification. It may have the hardness of quartz and the appearance of a zeolite, or it may have the banded marking of an agate, but display true opal reflections. One pretty gem has the fracture and opacity of jasper, but has fine agate markings, being a true jasp-agate.

Some of the agates from the Greenstone Range have a dark outer coating of green, a mere film of color which has been reported to be chrome; others are similarly coated with red, probably iron.

PREHNITE

Prehnite is one of the most prominent minerals of Isle Royale; there is not a single beach where other gems occur on which it may not be found. It ranges in color from white through pale shades of green to a fine apple-green, and some specimens show that malachite has added its deeper tones in small patches disseminated through the prehnite. Another striking fact is that no prehnite was seen that did not contain more or less native copper, and I have one treasured specimen that bears native silver. I have wondered whether the copper was not the sole coloring agency of this mineral. Another matter of interest is its close association with calcite, crystal quartz, datolite and some of the zeolites.

In most of such combinations the prehnite seems to have formed in the lava fissures and cavities first; the others were deposited later. Some fine masses collected from Hart Cove in Tobin Harbor show copper, calcite, crystal quartz with prehnite, and, at Todd Harbor and Todd Cove, prehnite with datolite. On Mott Island fine specimens in which were embedded shining masses of copper were collected.

Prehnite distinctly showing crystals is not often found, for the deposits are mammillary and consist of fine little radiate bodies of about one quarter of an inch in diameter, in close contact with each other and forming the mammillated groups that often cover several square inches of surface; the finest example seen was on the mantel at Minong Lodge.

It is not easy to secure a piece of prehnite of gem quality, for if it is sufficiently massive, it is likely to be too pale, or may contain substances which make it useless; also the finest pieces are often flawed. My own collection has one cut gem over an inch long by nearly seven eighths of an inch wide. The color is good, but it is flawed and has specks of copper showing on the polished surface.

At Duluth and vicinity prehnite is called "Minnesota jade," and for color and general appearance is quite appropriately thus named, but these local and fancy names for gems are confusing and altogether too numerous.

AMETHYST

So far as known, no amethyst of good gem quality has been found, but at Singer's Hotel at Washington Harbor the fireplace is formed of fine native mineral specimens, among which masses of this stone are prominent; they were secured in the vicinity, but no opportunity was afforded to learn the particular locality.

On the shore of a long island near the entrance to Tobin Harbor I collected a water-worn pebble of crystal quartz which showed in much of its mass beautiful violet tints; in the rock forming the island I saw other pale amethyst crystals in fissures or seams; also farther up the harbor, opposite Minong Lodge on the north shore, I secured a small mass of pale amethyst crystals. This gem has also been observed near the outlet of Siskowit Lake; a good specimen was obtained there in 1930. It was mottled with purple, not being of a solid color, but might furnish a fair gem if cut by a skilful lapidary. Good specimens of amethystine chalcedony were collected at Carnelian Beach, some of which are deep purple.

Another interesting form of quartz is sometimes picked up on the beaches of Mott and Caribou islands, fairly clear crystals coated with what has been called an ore of copper. It may be presumed that this is the "smoky quartz" referred to by Foster and Whitney.[7] It is not a true smoky quartz, the coloring being superficial.

At the Minong mine a geode lying on the dump was found to contain transparent quartz crystals, some of them faintly violet. Rarely, rock crystals are found sufficiently limpid to cut good gems, but usually they are only translucent or outwardly coated; few over an inch in diameter were seen.

ROSE QUARTZ

Crystallized rose quartz seems to be a rarity, but on Mott Island two or three specimens were collected that consisted of small masses of pale pink translucent crystals of fair quality. The color is not deep enough for a fine gem, but the stones are of interest to the gem

lover on account of their crystal form, and a beautiful specimen that has been cut for me adds an unreported gem to the list of those from Isle Royale.

CHALCEDONY

Under "chalcedony" the United States National Museum classes a dozen gems from agate to jasper, including the crypto-crystalline with the amorphous, but we may, for convenience, confine the term to those highly translucent forms that display little color or pattern and have a waxy luster.

A tiny little gem of this substance from Carnelian Beach is so brilliant that it reminds one of the "gouttes d'eau," peculiarly limpid topaz pebbles. Another mass, when fresh from the matrix, resembled clear beeswax of a delicate shade.

Solid masses of milk-white quartz crystals are found inclosed in thin shells of chalcedony; they make fine cabinet specimens. Some nodules of this mineral are bluish gray and would be suitable for watch charms.

JASPER

So far as known, jasper is one of the rarer minerals of Isle Royale. Dr. Charles T. Jackson[8] lists "Jasper formed from sandstone, Conglomerate Bay," probably from the outcrop of sandstone at that place. The conglomerate is the same as that observed at Carnelian Beach, and carries some agates, but it has not been broken up to any great extent.

At Carnelian Beach a very few jasper pebbles were collected, but many lumps of quartz mineral were found that lie on the border-line between a true chalcedony and a true jasper, having the uneven fracture of jasper and the luster and subtranslucency of the former. In some specimens the markings of an agate may be observed, and one of this description was cut into two cabochon gems, which for polish and beauty are unsurpassed. Some deep red jasper pebbles were obtained, but none of the blood-red stones characteristic of the jasper conglomerate of Canada were found.

OPAL

Foster and Whitney[9] report that "The agates occasionally pass into cacholong and carnelian." I collected a pebble at Carnelian Beach which shows true opal reflections, but it approaches quartz in hardness. When cut, it made an attractive gem. It is doubtless one of those "border-land" stones which seem plentiful on the Isle. Some mineralogists think that chalcedony is a form of microcrystalline silica, which carries a percentage of opal. If this be true, there is no line between the two forms; only the extremes give typical analyses.

DATOLITE

Datolite was reported by Foster and Whitney[10] as being plentiful at a mining locality in the fractional southwest quarter of Section 10, T. 65, R. 34. I had no opportunity to visit this place which is adjacent to "Epidote," another mining claim named for the prevalence of the mineral of that name, but collected good specimens of the massive form on the north shore at the true Thomsonite Beach. One piece as large as the hand is porcelain-white, with a faint tinge of pink near an edge. It shows thin layers and lenses of prehnite at one end.

None of the beautiful pink and flesh-colored datolite like that from the Upper Peninsula was seen, nor did I observe any crystals such as were reported at Datolite by Foster and Whitney.

The cut gems are pleasing; they take a good polish when not weathered, are slightly subtranslucent and would be suitable for beads.

EPIDOTE

Epidote, sometimes called pistachio stone from its peculiar shade of green, is found both massive and crystallized at Epidote near Epidote Lake about a mile and a half east of Chippewa Harbor. The epidote rock which takes its name from that mineral is conspicuous along the shore in a pale green band, but the mineral is a much deeper green, sometimes becoming brown or brown-green. I found no crystals of a size suitable for gems, but did secure a fine lump of the massive variety that weighs half a pound or more and also a smaller piece from which a good gem was cut. The intense color, in both the massive and crystalline forms, causes it to be held in slight esteem, although it is of considerable interest as a mineralogical gem.

WOLLASTONITE

Wollastonite is mentioned by Foster and Whitney:[11] "This mineral, or table-spar . . . occurs ... on Isle Royale, near Scovill's Point. Specimens . . . differ much from the same mineral, as it occurs elsewhere; so much so, indeed, that their real nature could only be learned by chemical analysis. The mineral, as it here occurs, is compact, of a light, flesh-red color, and remarkable for its exceeding toughness, surpassing in that quality any mineral, or rock known."

In the catalog of minerals by Dr. Jackson, already cited,[12] mention is made on pages 362-363 of nine specimens of "Jacksonite and compact table spar" and on page 366 of one specimen. Again we find the doctors disagreeing, for the following statement is made by William F. Foshag and Esper S. Larsen:[13] "A specimen labeled 'Wollastonite, Isle Royale, Mich.' in the United States National Museum was recently noticed to have the general appearance of the eakleite from the original locality at St. Inez, California, and further study

has confirmed the suspicion that the mineral actually is eakleite. . . . Microscopic examination showed that it is made up mostly of eakleite. . . . The Isle Royale mineral is finer fibered and is less pure."

In view of these dissenting opinions in which both parties have proved their cases by chemical analysis, it seems safe to call wollastonite two specimens of tough, compact mineral of a slightly pinkish shade and another small sample showing the crystallization of table spar. These were collected on Mott Island; the smaller massive piece was afterward cut as a cabochon gem. Its peculiar appearance, unlike that of any other stone, makes it of some interest, but it is not showy enough for wear, although a good cabinet specimen.

MISCELLANEOUS

In addition to the zeolites mentioned, some fine specimens of stilbite, pectolite and perhaps other minerals may be collected. At Washington Harbor I heard of apophylite, but saw none, although it has been reported from that vicinity.

Two porphyry pebbles of such compactness and fine, inclosed crystals as would warrant their cutting for gems were collected at Todd Harbor, and also a piece of what appears to be satin spar.

Some pitchstone was collected arid arrow-points of this mineral were seen; others called obsidian are probably of this material, which has been reported as forming a large mass in the lava, although record of the locality seems to be lost.

Good calcite crystals were obtained, one or two of greenish shade, others pink; also a few clear and colorless ones. Though too soft for gems, some are well worthy of a place in the cabinet.

Barite is found in good specimens at Washington Harbor, and a fair piece was secured at Todd Cove.

SUMMARY

In conclusion it may be said that, though Isle Royale will not be a source of wealth through its gems, its supplies of chlorastrolites, thomsonites and carnelians will not be exhausted for years, and the pleasure derived from seeking and collecting will be experienced by visitors who love these beautiful "flowers of the rocks."

Minerals like wollastonite, long ago reported exhausted, will in all probability be discovered from time to time, and perhaps amethysts of gem quality may be found. Crystals of datolite, apophylite and epidote might be gathered, but some of the zeolites that have been briefly mentioned are also worth looking for.

Although the old mine dumps are of more interest to the mineralogist than to the gem collector, a good crystal or nodule of gem quality may sometimes reward the seeker, and the small beaches will continue to be the popular resorts for the tourist or sojourner.

SAGINAW, MICHIGAN

[1] Published in 1849 as *Executive Document No. 5, 31st Congress, 1st Session, House of Representives*.

[2] Foster, J. W., and Whitney, J. D., *Report of the Geology and Topography of a Portion of the Lake Superior Land District*, Part II, p. 97.

[3] *American Geologist*, 23 (1899): 116-117.

[4] *American Journal of Science*, Third Series, 19 (1880): 122-130.

[5] *Ibid*., p. 123.

[6] *Mineral Resources of the United States*, pp. 591-592. 1899.

[7] Page 107 of work cited in note 2.

[8] *Catalogue of Rocks, Minerals, Ores, Collected during the Years 1847 and 1848, Ninth Annual Report of the Smithsonian Institution*, p. 365.

[9] Page 107 of work cited in note 2.

[10] Page 101 of work cited in note 2.

[11] Page 108 of work cited in note 2.

[12] See note 8.

[13] *American Mineralogist*, 7 (1922): 23.

A LIMESTONE CHIEFLY OF ALGAL ORIGIN IN THE WASATCH CONGLOMERATE, SOUTHERN WASATCH MOUNTAINS, UTAH

ARMAND J. EARDLEY

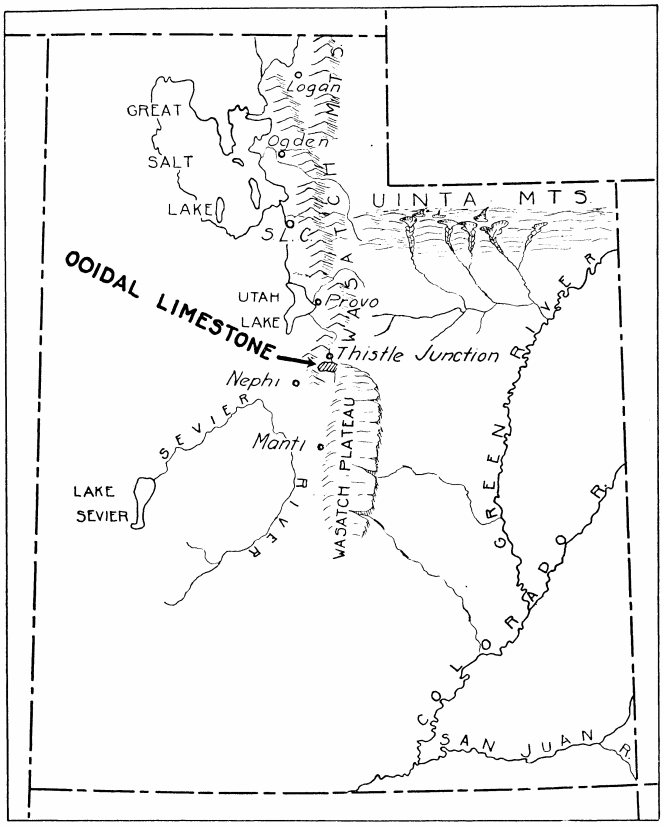
OCCURRENCE AND DISTRIBUTION

FLANKING the eastern slopes of the Wasatch Mountains both north and south of the junction with the Uinta Mountains there is a very coarse, red or gray, roughly bedded deposit known as the "Wasatch Conglomerate." It originated from rapid erosion of high mountainous areas thrown up during the Laramide revolution. It was deposited over the truncated Paleozoic and Mesozoic strata which were folded and thrust in this same revolution. Since the deposition of the conglomerate it has been eroded intermittently to the present time, so that in places it has been entirely removed. Its maximum thickness is over 1,000 feet.[1]

A limestone bed with maximum thickness of 300 feet occurs in the Wasatch conglomerate of the southern Wasatch Mountains in T. 10 S., R. 2 E., and T. 11 S., R. 2 E., and also to an unknown extent eastward. It is this limestone which the writer wishes to discuss in the present paper.

The map of the state of Utah (Map 42) shows the geographic position of this limestone (denoted as ooidal) and also other features which will be referred to.

The best exposures of the limestone are at Tinnie Flat, Santaquin Canyon, and on the east side of Frank Young Canyon, a tributary to Payson Canyon. At Tinnie Flat it is exposed as a cliff 300 feet high, rests directly upon the truncated Carboniferous strata, and is overlain by the conglomerate. In Frank Young Canyon it is both underlain and overlain by the conglomerate. These exposures indicate that the limestone is an interbedded member near the local base of the formation, since the underlying part of the conglomerate had thinned out and disappeared before the Tinnie Flat section was reached, leaving the limestone as the basal member. The diagram (Fig. 12) represents these relationships.



MAP 42. Map of Utah, showing area of ooidal limestone and other points referred to in this paper

CORRELATION AND NAME

The type locality of the "Wasatch Group," which is in Echo Canyon, was first described by Hayden.[2]

He noted variegated sands and clays at the summit, deep yellow sandstones in the upper part of Echo Canyon, and a conglomerate about 1,500 to 2,000 feet thick sculptured into very fantastic forms and standing in almost vertical cliffs in the lower part of Echo Canyon and in Weber Canyon. He correlated the lower Wasatch conglomerates in Echo Canyon with the basal conglomerate beds at Almy, not far distant in southwestern Wyoming. Veatch thought this correlation correct.[3] This series, which has been called the Almy formation by Veatch, constitutes the lowest of three formations, all of which he includes in the Wasatch Group. A part of the stratigraphic section that concerns us here is compiled from Veatch's report as follows (Fig. 13).

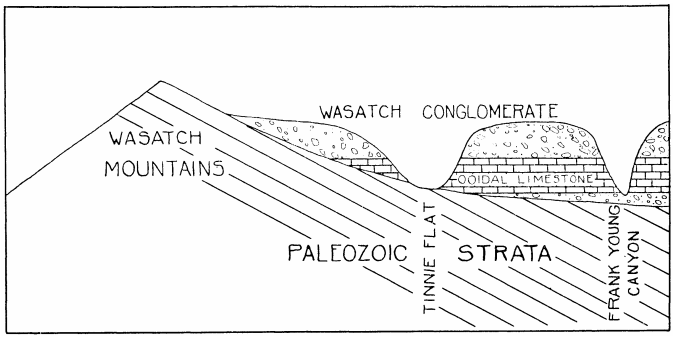


FIG. 12. Section showing stratigraphic and structural position of ooidal limestone

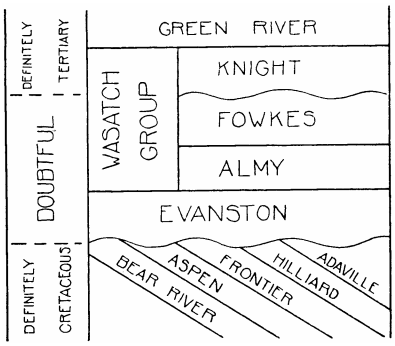


FIG. 13. Stratigraphic section of Cretaceous and Tertiary formations in southwestern Wyoming (after Veatch)

The term "group" appears to have been used by Hay den interchangeably with "formation," and now, owing to the fact that the Wasatch is so often spoken of and written of as a formation with divisions also called formations, the nomenclature is somewhat confusing. No attempt can be made here to clarify the situation. The coarse conglomerate immediately overlying the truncated Mesozoic and Paleozoic rocks east of the Wasatch Mountains is generally known as the Wasatch conglomerate, which name will be retained in reference to the coarse conglomerate of the southern Wasatch Mountains. The geologic map of Utah shows that the conglomerate east and northeast of Salt Lake City is separated from the great Tertiary basin to the south by the Uinta Mountains. This prevents the possibility of tracing the conglomerate formations from Echo Canyon to the southern Wasatch Mountains. Nevertheless, the similar character of the conglomerate and the same stratigraphic position seem to indicate that they are essentially of the same age.

Mr. L. S. Russell of the Canadian Geological Survey has identified shells from the limestone lens within the conglomerate as *Goniobasis simpsoni* or *Goniobasis tenera*.

They constitute a fresh-water fauna, and as such are not of much use in close correlation. Mr. Russell ventures a

probable correlation with the Knight formation of southwestern Wyoming. They may be definitely regarded as lower Eocene, but nothing more can be accomplished with such meager information.

Spieker and Reeside[4] have described a fresh-water limestone which occurs between upper and lower Wasatch beds in the Wasatch Plateau. It is possible that the fresh-water limestone herein described is equivalent to all or part of this "Flagstaff" limestone member of Spieker and Reeside. They represent the Flagstaff as thinning out and disappearing to the north, but it is possible that it can be traced laterally into the southern Wasatch fresh-water limestone. Fresh-water gastropods are common fossils, but these are of little value for close correlation. The limestones are of different lithologic types, but this has little bearing on their contemporaneity.

No name will be given to the fresh-water limestone described in this paper. It may prove to be continuous with the Flagstaff formation and in this event would require no different appellation.

DESCRIPTION OF LIMESTONE

Loughlin[5] described the limestone in the following terms:

> It consists for the most part of a dense matrix full of large and small grey to brown concretions of such shapes as to suggest that they were mostly formed by accretions of calcium carbonate around nuclei of shells.

The proportions of the two dominant constituents of the limestone, matrix and "concretions," vary widely. In one place, or at one horizon, the limestone may consist almost wholly of matrix and at another the rock may be made up chiefly of "concretions" with only a very small portion of matrix. (See Pls. XXXII-XXXIII.) Specimens with a predominance of matrix were observed, generally at a considerable distance from the ancient shore.

The matrix is creamy white to creamy brown, dense and solid. In thin sections it is very finely crystalline and appears to have been derived from a compacted, flocculent precipitate. (See Pl. XXXIV.) In places patches of clear calcite crystals were noticed. (See Pl. XXXIII.) Chemical tests show that the matrix is almost pure calcium carbonate. It contains less than 0.03 per cent of insoluble material, including iron, magnesium and aluminum. The insoluble residue from both matrix and the concentric aggregates was observed under the microscope and found to consist chiefly of small, fairly well-rounded quartz grains probably of wind-blown origin, and a few dark-red hematite grains. The matrix is, therefore, an accumulation of virtually pure calcium carbonate.

The nodules with concentric structure which Loughlin calls "concretions" will be referred to in this paper as "ooids." The term "concretion," according to Grabau[6] and Twenhofel,[7] should be limited as a name to various aggregates of mineral matter which are of inorganic origin. The writer believes that the nodules of the fresh-water limestone of the southern Wasatch Mountains are of organic origin and, therefore, finds the term "concretion" not suitable for use in describing them. Kindle[8] has used the name "marlyte balls" for spheroidal masses of $CaCO_3$ forming at the present time in certain fresh-water lakes as the result of the activity of algae and associated plants. Although the writer believes that the nodular masses here under consideration are similar in origin to marlyte balls, he does not feel warranted in applying this term, which implies a specific manner of origin, to objects formed in past geologic ages by an imperfectly known process.

The term "ooid," which is here proposed, is derived from Greek *oon*, meaning "egg," and *eidos*, meaning "shape." The definition will not be more precise than "a roughly egg-shaped aggregate of mineral matter probably of organic origin." In order to make the definition as general as possible neither the texture, structure, size, kind of material, nor time of formation relative to the inclosing rocks will be included.

The ooids of the fresh-water limestone of the southern Wasatch conglomerate range in size from submicroscopic to six inches in diameter. They are darker than the matrix, but differ in color from it. If the matrix is creamy white, the ooids are light tan and gray. If the matrix is creamy brown, the ooids are somewhat deeper brown. Nearly all ooids have nuclei which consist of snail shells, pebbles or fragmentary pieces of other ooids. The nucleus is usually eccentric in position, with enveloping layers of calcium carbonate, sometimes in considerable number, depending on the size of the ooid. About 50 per cent of the ooids are rather porous, having many irregular cavities distributed radially through the concentric layers. The rest are quite solid. The ooids are composed of pure calcium carbonate with only a very few inclusions of possibly wind-blown sand. In certain places the nuclei are usually pebbles, either of limestone, quartzite, or sandstone, and range in size from one quarter of an inch to two inches in diameter. In such places the limestone, if analyzed as a whole, is very impure and may even grade into the conglomerate.[9]

ORIGIN OF THE LIMESTONE

Evidence from general relationships

The rather extensive bed of ooidal limestone most probably represents the deposits of a local lake whose western and northern shores lay at the base of an imposing mountain range (now the southern Wasatch Mountains), where clastic fluviatile sediments were accumulating. These fluviatile sediments consist of coarse, poorly sorted, heterogeneous material and show in places high initial dips. Such characteristics indicate that the clastic sediments were probably deposited as alluvial fans. If the outer margins of two alluvial fans coalesce, a basin is often formed, surrounded by the

fans and the escarpment at the foot of which the fans are built. It appears that the lake of the ooidal limestone may have existed between two such alluvial fans. The postulated topography surrounding the lake is illustrated in Figure 14.

There is also a possibility that the lake was an arm or protected embayment of a much larger lake in which the Flagstaff limestone[10] of the Wasatch Plateau was deposited. If the ooidal limestone can be traced into the Flagstaff, then the lake in which the ooidal limestone was deposited must have been confluent with this larger lake to the east and not completely inclosed by alluvial fans. In either case the writer believes that the small lake was intimately associated with alluvial fans which were in the process of construction.

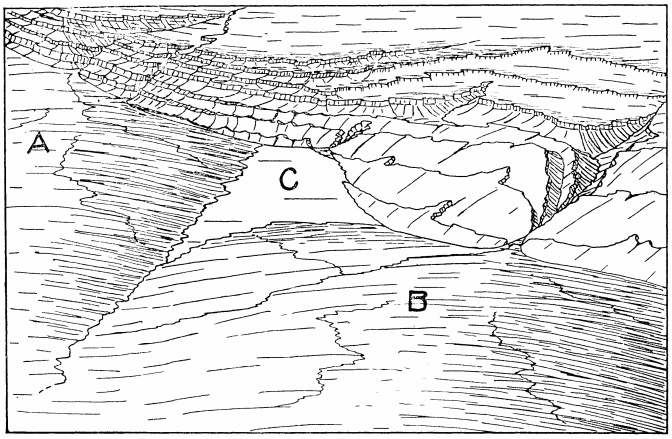


FIG. 14. Postulated setting of the lake in which the ooidal limestone was formed. *A* and *B* are large alluvial fans built at the base of a high mountain range. They coalesce at their outer margins to form a basin which is occupied by a lake, *C*, in which the ooidal limestone is supposed to have formed. The range, as depicted, is roughly reconstructed from the present strikes and dips of the beds of the southern Wasatch Mountains, and attempts to represent the writer's conception of its appearance shortly after the major orogeny of the Laramide revolution. The canyon into whose mouth alluvial fan *A* extends marks the approximate site of the present Salt Creek Canyon. The canyon from which alluvial fan *B* has formed marks the approximate site of Spanish Fork Canyon. The nature of the mountains of this early period and the position of the large fans are to a considerable extent hypothetical

The fact that the limestone is almost pure $CaCO_3$ indicates that it was precipitated in a lake of clear water free from any clastic material. Influxes of sediment-laden waters, however, entered the lake from time to time and spread considerable clastic material over the accumulating limey deposit. The water was turbid only in the vicinity and at the time of the ingress because the clastic material was soon incorporated in the clean calcium carbonate sediments, chiefly as nuclei of the growing ooids.

Intermittent currents of considerable velocity in the lake are also indicated by the pebble nuclei, many of which are large and could have been transported into the area of lime deposition only by streams and currents of considerable velocity. The ooids, as Bradley[11] has pointed out, for a different formation, show signs of having been rolled over from time to time. This rolling is recorded by the variations in direction of growth of the concentric layers.

The presence of fresh-water gastropods, types now found in streams, shows that the waters of the lake were fresh. (See section on "Correlation.") The limestone closely resembles certain freshwater marls and thus tends to confirm the evidence of the fossils.

Evidence from ooids

The precipitation of the $CaCO_3$ of the matrix or the ooids may be the result of either inorganic reactions or of organic metabolism, or a combination of these two. If the origin is assigned to life processes, then all those plants or animals that secret silica are immediately ruled out, because of the complete absence of silica except in the form of a few wind-blown sand grains. Diatoms, the usual contributors of the silica content of "marls" and fresh-water limestones, were looked for in the insoluble residues and in thin sections, but none were found. Only those life forms that cause the precipitation of calcium carbonate need be considered.

The origin of the ooids can be fairly well established from a study of present-day ooids, which they so closely resemble. H. Justin Roddy[12] makes a valuable contribution to this subject in his study of the "lake balls" or "water biscuits" of Lancaster County, Pennsylvania. He concludes that the agents which cause the formation of the ooids in the Little Conestoga River are blue-green algae and associated plants. His evidence that the ooids are a result of the life processes of these plants is as follows:

(1) The color of all growing specimens in the stream is the characteristic bluish green color of the Cyanophyceae, while those exposed to rain and sunshine are greyish white. Careful microscopic examination of such growing specimens also reveals a varied thallophytic flora, mainly of the Cyanophyceae. Species of the genera *Gleocapsa*, *Gleotheca*, *Aphanocapsa*, *Nostoc*, *Oscillatoria*, and *Rivularea* have been identified. Associated with these are several of the green algae (Chlorophyceae). Many species of *Diatomaceae* and *Desmidiaceae*, which generally live in close association with the blue-green algae, have also been identified and have, no doubt, contributed the siliceous matter which is so disseminated through the calcareous matrix. The charas are also occasionally present, contributing a small percentage of so-called marly material. Some bacteria have also been found in association with the other plants, but the bacteria have probably had little to do with the calcareous deposition, but may contribute the iron which is found in every "concretion."

(2) The arrangement and structure of the laminae also favors the view that these concentric accumulations are due to life processes. That periodic accretion alternates with a period of quiescence is shown plainly by the concentric laminations of nearly uniform thickness. The open porous texture of each lamina within, and the more solid character without, like the concentric arrangement is due, without doubt, to the seasonal

conditions of the region. Since algae are essentially thermophilic plants, each winter destroys many of them, and stops the growth of most of the rest; and thus, at the beginning of the plant year (spring), few and widely scattered algae at first produce slow and scattered accretion of the limy matter; later the plants become more and more abundant, and by summer they are crowded over the surface of each mass. This distribution of the algae seasonally would naturally have its effects upon the structure and arrangement of the limy matter, giving a decided, though rough, coralline appearance to the inside portion, and a more compact texture to the outer part. The theory just given has been confirmed by a study of the distribution of the algae on the concretions through the seasons.

(3) The observation that the lamellar accretion seems to progress more rapidly on the under side of a concretion proves that the formations are not due to mechanical precipitation of calcium carbonate through evaporation or changes of temperature. It does, however, suggest that the secretion or precipitation is chemical and dependent on a life process that produces conditions for chemical reaction where plants or animals are most abundant.

A comparison of the ooids of the southern Wasatch Mountains with those whose growth has been studied by Mr. Roddy shows such a close similarity that the arguments used for the origin of the latter might well apply to the origin of the former. It is immediately suggested, therefore, that the activity of algae was chiefly responsible for the origin of the ooids of the Tertiary limestone of the southern Wasatch Mountains. This conclusion is substantiated by other investigations.

W. H. Bradley[13] has studied algal reefs and ooids forming at present in Green Lake, New York, with the particular object in mind of investigating similar deposits of the geologic past, and finds that such study assists greatly in the interpretation of the spongy structure in many fossil reefs. Although it is only rarely that the complex assemblages of algae leave molds of the individual filaments or unicells from which generic determination can be made, he finds the deposit to be highly distinctive and not readily confused with limestone of any other kind.

Regarding the ooids he says: "If the pores of these pebbles [found on the shore near Squaw Island, at the north end of Canandaigua Lake, New York] were filled with secondary calcite they would be strikingly like many of those from the Green River formation."[14]

Bradley found that the dense felt obtained from the material at Green Lake, New York, consisted of an assemblage of blue-green algae and a few green ones. The genera *Microcoleus* and *Palmella* predominate.

He believes that many of the reefs of the Green River formation have been formed by unicellular algae almost identical with *Chlorellopsis coloniata* Reis. He has not found indisputable calcite molds of filamentous algae in the Green River formation, but certain parts of the "Manti beds" have provisionally been referred to the indefinite filamentous form genus *Confervites* Brogniart.[15]

Material from the southern Wasatch ooidal limestone was submitted to Mr. Bradley, who kindly examined it and communicated the following information:

A thin section of a porous concretion shows "no trace of Chlorellopsis, but does have very nicely preserved spongy structure such as is now forming in the algal deposits of Green Lake, New York. The spaces between the masses of spongy stuff in the thin section are filled with more coarsely grained carbonates apparently deposited later. The recurrent thin bands of dense and more darkly colored algal deposits spaced one to several millimeters apart in these nodules may have formed in winter, when the activity of the algae was reduced." (See Pl. XXXIV.)

Another thin section of a smaller non-porous concretion with “dense layers around a shell fragment does not have any decisive characteristics by means of which I could be sure whether it is algal or an inorganic incrustation." (See Pl. XXXV.)

It appears, therefore, that at least the porous ooids of the limestone here discussed are of algal origin. Others, especially the smaller dense ones which have a maximum diameter of one inch, with the alternating light and dark layers closely spaced, are possibly of algal origin. However, the fact that the porous ooids have in part also dense texture and closely spaced layers suggests that the entire growth resulted from algal action; the porous layers represent periods of abundant growth and possibly a diminished supply of calcium carbonate.

A typical ooid, three inches in the long diameter and two and one-half inches across, contained about forty-five concentric dark layers. This may indicate that the ooid required about forty-five years to grow to its present size. Growth finally ceased, probably because of burial.

The conclusions regarding the ooids of the fresh-water limestone of the southern Wasatch Mountains, in light of the evidence above, may be summarized as follows:

(1) The porous ooids, which constitute a good part of the limestone, were formed by blue-green and possibly also green algae.

(2) The genera of the algae are indeterminate.

(3) It is likely that more than one genus, even an assemblage of genera, of algae were present.

(4) The smaller, non-porous ooids may have been formed by physicochemical incrustation, but the evidence is suggestive of algal origin for them also.

(5) Part of the porous ooids is of physicochemical origin, namely, the secondary calcite filling.

(6) The alternate dense and porous layers suggest seasonal changes.

Evidence from matrix

The origin of the solid, dense matrix of the limestone presents a more difficult problem, which cannot be settled at present with any great assurance. Its insoluble content is only 0.01 to 0.02 of one per cent and, like that of the ooids, is negligible. The chemical analyses indicate the same source of origin for the $CaCO_3$ as for the concretion; at least, a different source is not suggested, but still it is not disproved.

The megascopic and microscopic appearance suggest it to be a marl,[16] now hard and massive.

The origin of marls is ably discussed by Kindle,[17] whose studies lead to the following general conclusions:

(1) Marl is limited to relatively small areas, in protected bays, the shores of islands free from strong wave action, wide shallow areas protected by bars or islands, and to shallow narrow straits protected from wave action.

(2) Deposits of marl occur in the warm epilimnion zone and above the cold hypolimnion zone. Waters in the cold deep zones are rich in CO_2 and dissolve any settling $CaCO_3$ that may have been formed near the surface.

(3) A hydrogen ion concentration at the surface of 7.8 to 8.2 is necessary.

(4) Calcium carbonate is precipitated in the summer during the period of thermal stratification.

(5) The precipitation is most rapid during the warmest part of the season.

(6) The calcium carbonate in the epilimnion zone must reach saturation before precipitation occurs.

(7) Saturation of $CaCO_3$ is produced by reduction of CO_2 by evaporation, photosynthesis in plants which extract the CO_2 from the water, and to a lesser extent by rising temperature, which lessens the solubility.

(8) Shallow protected areas of lakes in which mixture with cold deep waters rich in CO_2 is unlikely afford the best opportunity for the water to become saturated with respect to $CaCO_3$. Conditions are also favorable for the deposition of $CaCO_3$ where altitude and latitude do not keep the temperature of the epilimnion zone too low for the development of Chara, Potamogeton, and other plants that extract CO_2.

In 1927 Kindle wrote as follows:[18]

> It appears from the preceding discussion that plant life of widely different types is directly responsible for the separation from the water of much of the $CaCO_3$ of marl deposits. This is accomplished through the abstraction of CO_2 from a saturated or nearly saturated solution of $CaCO_3$. Loss of CO_2, whether it results from the photosynthesis of plants or rising temperature, is directly connected with thermal stratification of water.

The conditions necessary for the deposition of marl are, as Kindle suggests, very similar to those under which the ooids of the ooidal limestone of the southern Wasatch Mountains are believed to have formed. Therefore, an environment suitable for marl deposition probably prevailed in the Eocene lake in which the ooidal limestone was deposited. This fact, together with the similarity in color, composition and occurrence of the matrix of the ooidal limestone and the marl of present fresh-water lakes, leads the writer to believe that the matrix of the ooidal limestone is a lithified marl. The ooids probably represent concentric deposition around nuclei of layers of calcium carbonate formed by blue-green algae and possibly by associated plants. The matrix probably represents a fine flocculent precipitate of calcium carbonate caused by the extraction of CO_2 from a saturated solution of $CaCO_3$ by the entire assemblage of plants and by the physical agents of evaporation and rising temperature.

One definite difference between the marls and marlyte balls that are forming today and the limestones discussed here is that in almost all of the former numerous diatoms are found. The absence of these silica-producing diatoms is conspicuous in the latter.

The area covered by the fresh-water ooidal limestone of the southern Wasatch Mountains is, perhaps, much larger than the portions of the small lakes that Kindle has studied. Also, the thickness of the ooidal limestone is considerably greater than would accumulate in such shallow lakes as he describes. Nevertheless, the size of the lake as defined by the extent of the ooidal limestone is within the limits of small fresh-water bodies suitable for marl deposition. The only condition that must have existed in order that lime precipitation over the entire bottom may have taken place is that the lake be shallow enough throughout to eliminate zoning of temperatures within the lake waters. In order to account for a thickness of 300 feet of limestone, either subsidence of the lake floor equal in rate to the rate of accumulation or increase in height of the rim of the lake by the growth of the alluvial fans must be postulated.

COMMERCIAL VALUE

This ooidal limestone is being quarried and used for interior decoration in Salt Lake City and other cities in the United States. Museum specimens are sold by Ward's Natural Science Establishment. The polished stone has a pleasing, buffish cream color and an attractive texture. When dark brown varieties are used as trim and the lighter shades as panel an excellent combination is effected and for many purposes should be as usable as imported "marble." It takes a polish easily and lends itself well to cutting. Some difficulty was experienced in getting large blocks when the quarry was first opened, but now good-sized pieces are obtained. The rock is particularly free from small fractures and therefore proves to be quite strong and durable.

The quarry is situated on the east side of Thistle Canyon. It has a loading platform at the railroad tracks

and is operated by the Nebo Marble Co., of Salt Lake City.

SUMMARY

A limestone flanking the eastern slopes of the southern Wasatch Mountains and existing as a lens within a coarse conglomerate of Wasatch age is found to consist of two parts, namely, matrix and ooids. The ooids are believed to be chiefly of algal origin. The matrix represents a precipitate of pure $CaCO_3$, the deposition of which is believed to have been caused by its concentration to the saturation point by a varied plant assemblage, of which blue-green algae probably predominated, and also by the physical processes of evaporation and temperature changes.

The body of water in which the limestone was deposited occupied a basin formed between two large alluvial fans whose outer margins coalesced. The line of contact of the fans was the lowest place in the rim of the basin and, perhaps, allowed the inclosed lake to overflow and become confluent with a much larger lake to the east. The ooidal limestone lake was probably so shallow throughout the area of limestone deposition that the water was not thermally stratified. The lake was clear and free from clastic sediments except at irregular intervals when torrential streams from the high mountains to the west flowed into it and spread a considerable quantity of sand and pebbles upon the limey mud. Many of these pebbles served as nuclei about which algae attached themselves and deposited concentric layers of calcium carbonate. The alternating porous and dense layers in the ooids may possibly indicate seasonal changes.

ACKNOWLEDGMENTS

The author wishes to acknowledge the helpful criticism of Mr. W. H. Bradley of the U. S. Geological Survey and also of Professor G. M. Ehlers of the Department of Geology of the University of Michigan.

UNIVERSITY OF MICHIGAN

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[10] Spieker and Reeside, *loc. cit*.

[11] Bradley, W. H., *Algae Reefs and Oolites of the Green River Formation, U. S. Geol. Surv., Prof. Paper 154-G*, p. 219. 1929.

[12] Roddy, H. Justin, "Concretions in Streams Formed by the Agency of Blue-green Algae and Related Plants," *Proc. Am. Philos. Soc*., Vol. 54. 1915.

[13] Bradley, W. H., *op. cit*.

[14] *Ibid*., p. 219.

[15] *Ibid*., pp. 207-208.

[16] The name "marl" is often applied somewhat vaguely by geologists, especially in America, to a number of fine-textured sediments. For instance, according to the U. S. Geological Survey, the term "marl" is used for any earthy, generally incoherent material that is appreciably calcareous or glauconitic. Qualifying adjectives are used to distinguish the different kinds of marl, such as "green-sand," "shell," etc. In this paper the term "marl" is used to mean only those types of lake sediments of which E. M. Kindle speaks in the following citations. Kindle's marl is characterized by being almost pure $CaCO_3$.

[17] Kindle, E. M., "Role of Thermal Stratification in Lacustrine Sedimentation," *Trans. Roy. Soc. of Canada*, Sect. IV, Ser. III,21:1-35.1927. *Idem*, "A Comparative Study of Different Types of Thermal Stratification in Lakes and Their Influence on the Formation of Marl," *Journ. Geol*., 37: 150-157. 1929.

[18] On page 35 of the first article cited in note 17.

PLATE XXXII

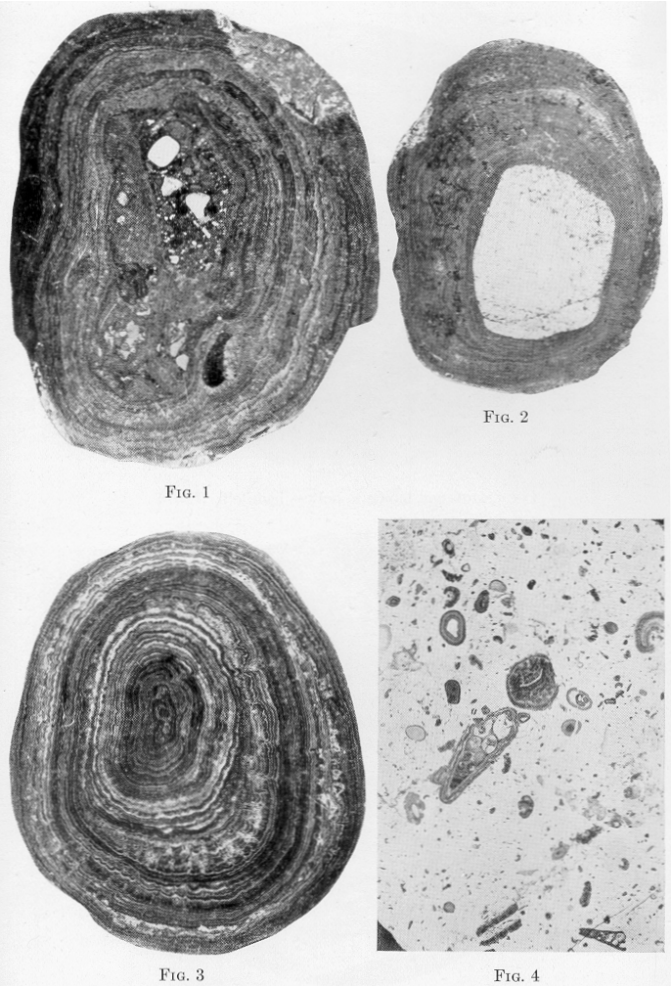


FIG. 1. Ooid with nucleus formed of coarse sand grains and limestone matrix. X 1

FIG. 2. Ooid with quartzite pebble nucleus. X 1

FIG. 3. Ooid showing radiating cavities and cuspate structure of concentric layers. X 1

FIG. 4. Polished slab of ooidal limestone which is composed chiefly of creamy white matrix. Ooids are light brown. X ½

PLATE XXXIII

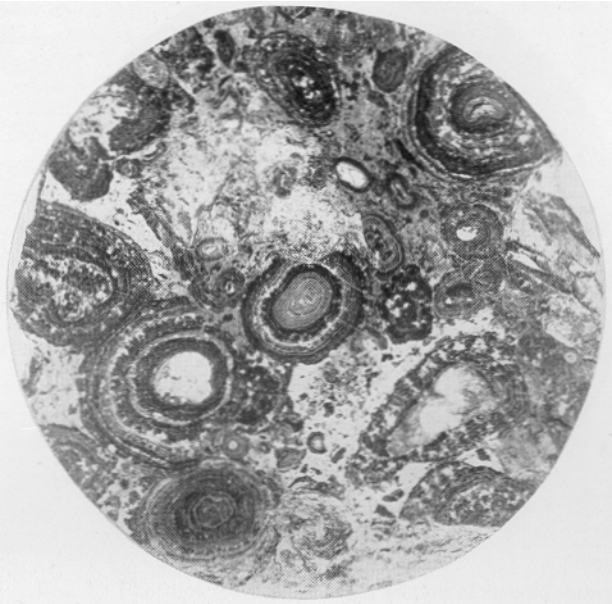


FIG. 1. Polished section of ooidal limestone. X 1

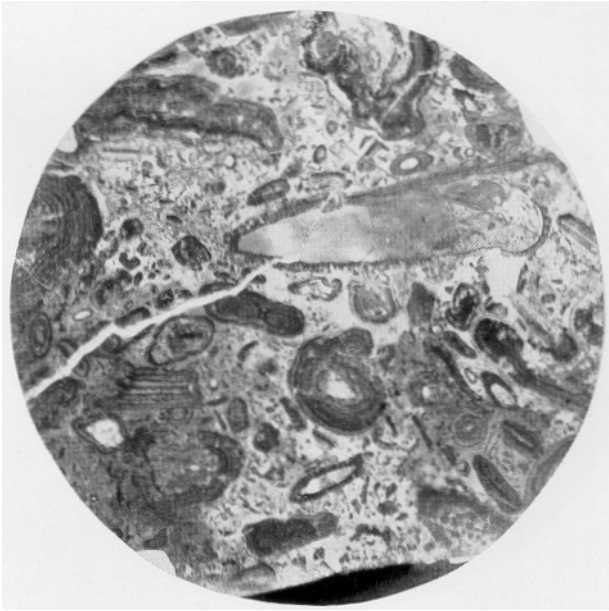


FIG. 2. Polished section of ooidal limestone. X 1

PLATE XXXIV

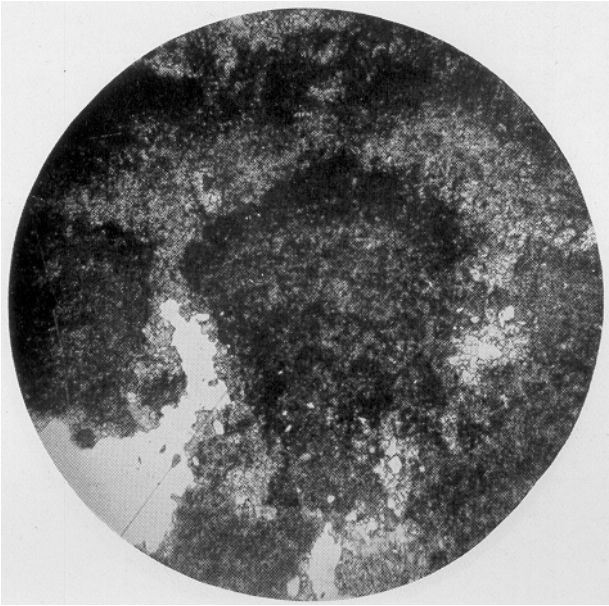


FIG. 1. Photomicrograph of a thin section of an ooid showing crystalline texture of calcite and cuspate structure of the concentric layers. X about 30

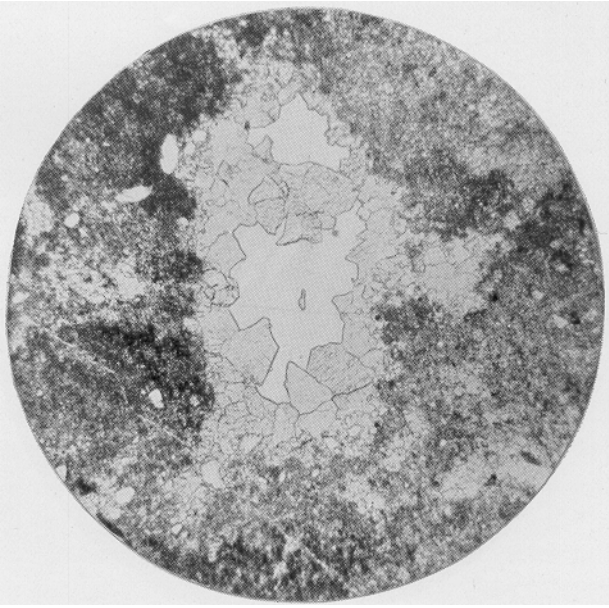


FIG. 2. Photomicrograph of a thin section of an ooid showing a radiating cavity partly filled with secondary calcite. X about 30

PLATE XXXV

FIG. 1. Photomicrograph of a section of an ooid showing creamy white matrix. At this magnification (X 30) the crystalline texture of the matrix is not resolved

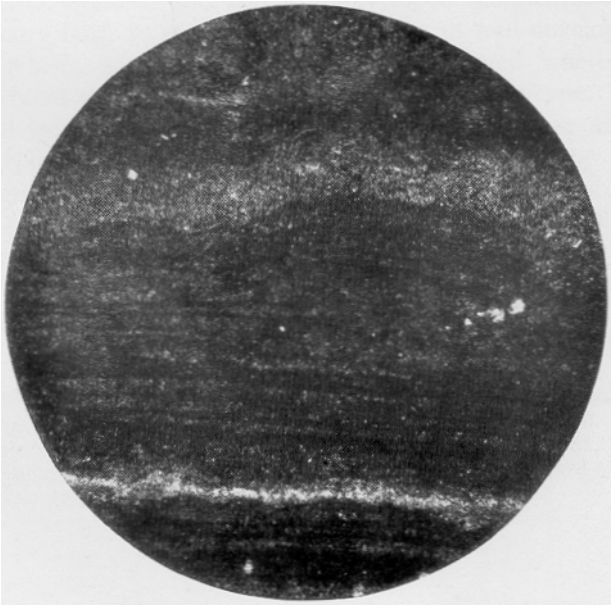


FIG. 2. Photomicrograph of a thin section of an ooid showing dense, compact layers which are, doubtfully, of algal origin

THE OCCURRENCE OF FLUORITE IN THE MONROE FORMATION OF THE MT. PLEASANT OIL POOL

PAUL E. FITZGERALD AND WILLIAM A. THOMAS

FLUORITE is unique in that it is formed under a wide range of geological conditions and occurs in all types of mineral deposits, from those whose relationships indicate that they developed at exceedingly high temperatures to those in which it is doubtful whether igneous action played any part at all in their development.

In chemical nomenclature fluorite is calcium fluoride (CaF_2), consisting of 51.1 per cent Ca and 48.9 per cent F.[1] The mineral, which is not particularly hard, falls into fourth place in Mohs' scale of hardness. It has a specific gravity of 3.1, crystallizes in the cubic system, and has well-developed octahedral cleavage. It occurs both in massive form and also in well-developed crystals, which, according to Wilson,[2] are formed where cavities are present and hence are of the low-temperature type. Its color ranges from white through yellow, green, blue, rose and violet to purple. Wilson[3] further observes that most of the fluorspar in pegmatites and other high-temperature deposits are violet or purple, whereas the more delicate hues prevail in deposits of the low-temperature type.

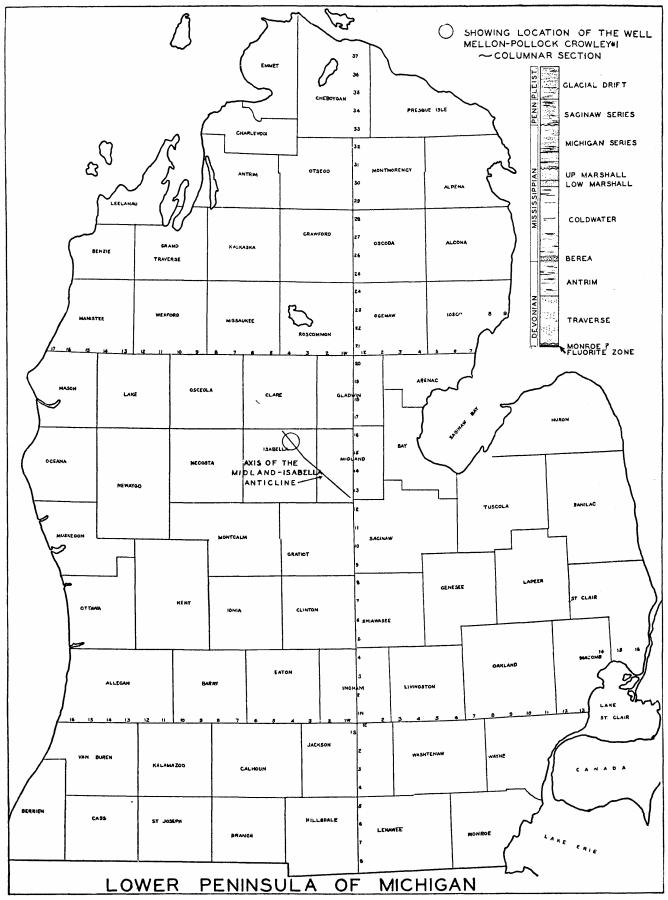
Fluorite is not particularly common in Michigan; it is mentioned by Rominger[4] as occurring in the Hudson River Series near the mouth of the Sturgeon River and also by Lane[5] as occurring in the Ordovician of the Upper Peninsula. Ehlers[6] found it in the Schoolcraft member of the Manistique Series. Carman[7] gives several localities for it in the northern part of the State of Ohio, notably in the Niagaran, Greenfield and Columbus formations. Here it is intermixed with celestite, which occurs in greater abundance.

The writers' observation of the mineral is confined to two places, namely, wells drilled for oil in Isabella County approximately ten miles north of Mt. Pleasant, T. 16 N., R. 4 W. (see Map 43). Here it occurred in Mellon-Pollock Crowley No. 1 at a depth of 3,743-53 feet and in the Mellon-Pollock Durnin No. 1 at a depth of 3,766-68½ feet. In the latter well only a few fragments were identifiable.

The mineral undoubtedly occurs in some member of the Detroit River Series (Upper Monroe). It will be difficult to determine in just what part of the Upper Monroe it is found, since fossil evidence is lacking. Correlation is made more complex in this area by an erosional unconformity along which practically all of the Dundee and, in some places, a considerable part of the Upper Monroe have been removed.

The first evidence of a major unconformity on the eastern side of the state seems to appear near the Midland-Isabella structure and this structure continues westward to Muskegon, where over 450 feet of Dundee and Upper Monroe sediments have been eroded.

The deposit under discussion occurs along this well-developed unconformity and the wells from which the mineral was collected are near the axis of the Vernon Township structure, which is a continuation of the Midland-Isabella fold and is traceable for over thirty miles. Its alignment suggests that the Paleozoic sediments have been laid down upon a highly faulted pre-Cambrian floor. The present evidence for faulting is from well records in Ontario, together with the presence of large faults in the Upper Peninsula, where displacements of from 5,000 to 10,000 feet are common. These faults, whose trend indicates that they continue into the Lower Peninsula, lose their identity either in the Great Lakes or under a mantle of glacial drift. Following this line of reasoning, we must bear in mind the rather extensive deposits of fluorspar in eastern Kentucky and western Illinois, which are associated with a more or less complex system of faulting of the Paleozoic sediments; however, the meager evidence available to date precludes the postulation of faulting with reference to these deposits.



MAP 43

The general conception regarding the origin of the major deposits of fluorite has been that they are intimately related to intrusive masses of igneous rocks. The smaller deposits, such as those mentioned by Wilson[8]

as occurring at Amherstburg and Niagara Falls, Ontario, have no apparent relation to major disturbances, nor are they derived from magmatic waters with fluorite in solution. The latter deposits were undoubtedly an original constituent of the dolomite and belong to the sedimentary type.

Regardless of the disturbances that pass near the location in the Vernon Township area, where the mineral was observed, there must be at least 4,000 feet of sediments between the basic formation and the horizon in which the deposit was found. Within this interval we have approximately 1,500 feet of salt in the Salina and Monroe formations, which would tend to seal off any upward migration of magmatic waters carrying fluorine into the Detroit River Series. One author[9] expresses the view that less than 1,000 feet of sediments is needed to constitute a barrier to the upward migration of magmatic waters.

Lack of evidence supporting the theory of igneous intrusion in the Lower Peninsula and the presence of salt in the Salina and Monroe formations precludes any direct connection between major igneous activity and the fluorspar deposits of the Lower Peninsula of Michigan.

The action of Paleozoic seas on old pre-Cambrian land masses carrying such minerals as cryolite, lepidolite and fluor-apatite may account, in part, for the fluorine in the Monroe seas. The reworking of Paleozoic sediments that contain mineral deposits such as exist in Ontario may constitute an additional source.

With subsequent emergence and erosion, large cavities or vugs of considerable size were formed. In the Crowley No. 1 the drillers report the dropping of their tools two or three feet, thus substantiating the evidence of sizable cavities in this area.

The majority of the specimens taken from these wells were well-developed cubic crystals, which partially or totally filled the cavities. The rest consisted of a granular mass; on close examination, however, most of these were found to be crystal aggregates (see Pl. XXXVI).

The mineral has a vitreous luster, is translucent and, when granular, white. The individual grains and crystals are generally colorless, although some of them are brown and one specimen is almost black. On heating, the mineral decrepitates vigorously; no fluorescence is noted. The specimens did not effervesce when treated with dilute hydrocholoric acid. The crystals vary in size from one quarter of an inch to two inches square.

The source of color of fluorite has not been conclusively determined, although some writers[10] express the view that it may be due to contained hydrocarbons. The color of the deposit in Vernon Township may be explained in this way, since oil is found near and in the fluorite zone. To substantiate further this origin of the color, water containing hydrocarbon compounds is found contiguous to the unconformity. The color may also be due to inclusions of minute particles of dolomite within the crystals themselves. These inclusions, where observed, appear in dark-colored bands parallel to the octahedron.

In this area secondary deposits of this type are likely to be a controlling factor in the accumulation and recovery of oil, for wells drilled in it are very erratic in both production and life. Many wells on structure, offsetting commercial producers, are short-lived or dry, owing undoubtedly to the cavities being filled with secondary deposits, leaving little or no porosity for the accumulation of oil.

In conclusion, the writers do not believe that there is any relation between this deposit and igneous activity of any type, first, because of lack of evidence of igneous intrusions, and, secondly, because it is not likely that magmatic waters could migrate upward, on account of the several hundred feet of salt in the Salina and Monroe formations.

This deposit, which is of secondary origin, was caused by reworking of old land masses and the subsequent deposition of the mineral within cavities formed by erosion along an unconformity.

The color may be due to contained hydrocarbons and inclusions of small particles of dolomite within the crystals themselves.

PURE OIL COMPANY
SAGINAW, MICHIGAN

[1] Wilson, M. E., *Fluorspar Deposits of Canada, Economic Geology Series*, No. 6, p. 2, 1929.

[2] *Ibid*.

[3] *Ibid*.

[4] Rominger, C., Vol. 1, Part III, *Geol Surv. Mich*., pp. 50-51, 1869-73.

[5] Lane, A. C., *Geol. Surv. Mich., Report of the State Board of Geological Survey for 1891 and 1892*, p. 176.

[6] G. M. Ehlers, personal communication.

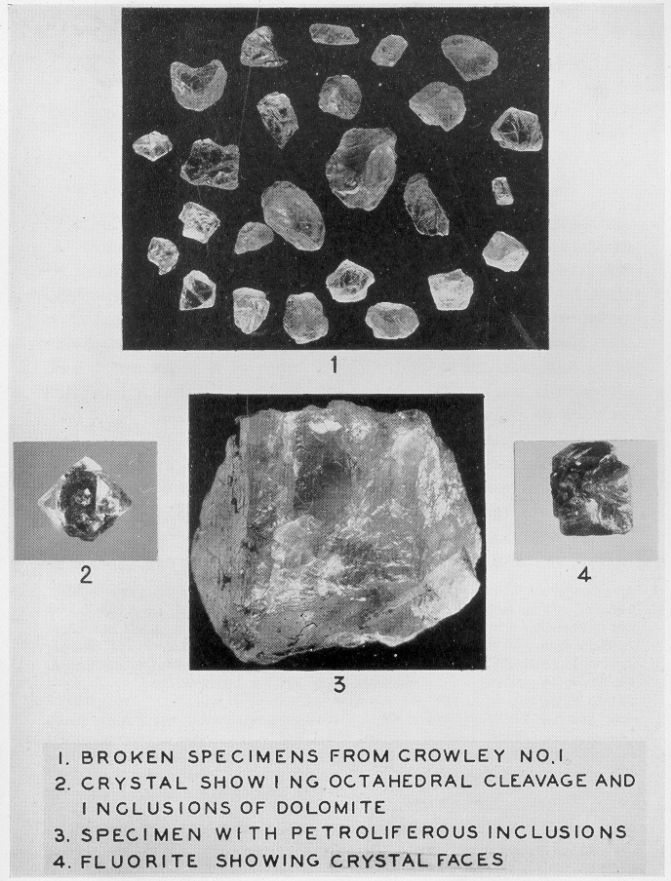
[7] J. Ernest Carman, personal communication.

[8] Wilson, M. E., *op. cit*., p. 12. 1929.

[9] Bagg, R. M., *Bull. Geol. Soc. Am*., 22 : 396. 1918.

[10] Ulrich, E. O., and Smith, W. S. Tangier, *U. S. Geol. Surv., U. S. Prof. Paper 36*, p. 125. 1905.

PLATE XXXVI



THE THICKNESS OF THE NEWARK SERIES IN PENNSYLVANIA AND THE AGE OF THE BORDER CONGLOMERATE

DEAN B. McLAUGHLIN

THE Newark Series (Triassic) consists of three principal formations: the Stockton, a basal quartz conglomerate overlain by arkosic red and gray sandstones; the Lockatong, a rather heavy-bedded, hard black shale; and the Brunswick, a red shale with fine sandstone members. The Border Conglomerate occurs extensively along the northwestern boundary of the Triassic belt. The entire series is intruded by fine diabase in dikes and great sills, and a few extrusive sheets occur in the upper Brunswick. The total thickness of the series is generally stated as approximately 20,000 feet.

In Bulletin No. 29 of the Virginia Geological Survey, Professor J. K. Roberts treats the Virginia Triassic and proposes views of the-thickness of the Newark series and of the stratigraphic position of the Border Conglomerate which differ radically from those previously accepted, as shown by the following quotation:[1]

Various geologists in the past have argued that the Border Conglomerate at Leesburg on the western side of the basin is the youngest of the Triassic areas and the quartz phase of this conglomerate on the western margin is the oldest. Sections have been measured across the Triassic . . . and without taking into consideration the matter of faulting and the duplication of strata, there have been derived enormous thicknesses . . . reaching as much as 35,000 feet. . . . The two conglomerates on the west and east sides of the basin are not the oldest and youngest Triassic sediments at all, but are contemporaneous in age . . . . A shallow basin was filled along the sides and bottom by coarse materials close at hand and as the basin was filled up the finer materials worked toward the center. In all probability the basin did not exceed 1,000 feet in depth.

Elsewhere[2] in the same paper he allows a thickness of 2,000 feet. He considers the same conclusions valid for other Newark localities. With special reference to the Pennsylvania Triassic Roberts states:[3] "The Stockton is very probably the same conglomerate which occurs on both sides of the Pennsylvania basins."

The writer has studied the Triassic at numerous localities in eastern Pennsylvania and adjacent portions of New Jersey. The field evidence there appears decidedly unfavorable to Roberts' views. In the following discussion the writer has drawn freely from the literature, but practically all the localities cited have been personally observed by him.

THICKNESS OF THE NEWARK SERIES

Except where they are cut out or displaced by the recognized major faults, the Stockton and Lockatong formations exhibit very uniform width of outcrop, with uniform dip to the northwest over distances of many miles. The same thing is true of the portion of the Brunswick beneath the great Haycock diabase sill. Such uniformity is difficult to explain if the region is so extensively faulted as to cause important repetition of beds, especially since the traces of the two major faults (which cause recognized complete repetition of the series) are not parallel to the strike, but are strongly concave to the northwest and cut out the formations at both ends. These relations will be evident from an inspection of the map shown in Figure 15. If one allows a thickness of 500 feet for the Lockatong formation, at least seven faults with displacement of approximately 500 feet, or a greater number of faults of smaller displacement, would be required to explain the observed width of outcrop. These faults would have to be spaced half a mile apart and extend for twenty miles or more along the strike without deviating sufficiently from uniform displacement to bring the underlying Stockton up or the overlying Brunswick down to the present erosion surface. Such a structure is obviously absurd.

Even if the hypothetical structure discussed above were entertained as a remote possibility in the case of those belts where the dip and strike are uniform, it fails entirely in regions where recognized folding occurs. The Haycock diabase sheet begins near the Delaware River

and extends southwestward in a sinuous course for about forty miles, measured along the strike (see Figure 15). At a few places it migrates upward in the series, but for stretches of many miles the trace of its contact with the underlying Brunswick shale is strictly parallel to the strike of that shale, even at a distance of three or four miles from the contact. The sinuous trace of the contact is clearly due to a succession of pitching folds, for everywhere the shale dips uniformly under the diabase from the south and east. It is inconceivable that a succession of dip-slip strike faults could follow closely the strongly curved strike of the beds involved in these pitching folds.

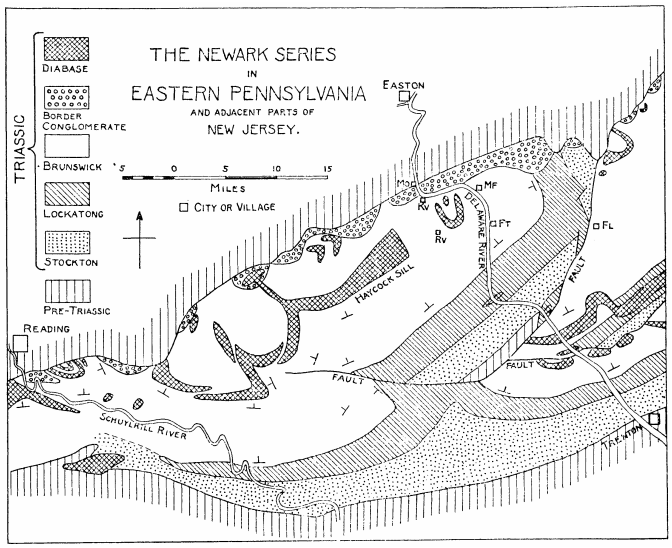


FIG. 15. Areal geology of the Newark Series in eastern Pennsylvania and adjacent part of New Jersey. Compiled from maps by the Pennsylvania Geological Survey, the New Jersey Geological Survey, the United States Geological Survey, B. S. Lyman, E. T. Wherry, and from field work by the author Abbreviations: Fl, Flemington; Ft, Frenchtown; Kv, Kintnersville; Mf, Milford; Mo, Monroe; Rv, Revere

A few miles east of Reading (extreme left of Figure 15) the upper Brunswick has been folded into a sharp pitching syncline, producing a V-shaped outcrop of two diabase sheets. Any fault of importance would be detected here (there is some evidence of a cross-fault, but it can cause no repetition). In this syncline there is conclusive evidence of from 5,000 to 6,000 feet of red shales.

Along the Delaware River south of Frenchtown, New Jersey (Ft in Figure 15), alternation of red and black shale suggests repetition by faulting of the contact of the Lockatong and Brunswick. Though the writer has not yet positively demonstrated that the alternation at this locality is due to interbedding, he has observed extensive interbedding of red and black shales at numerous localities near the contact of the Lockatong and Brunswick, and in some places such interbedding occurs high in the Brunswick formation. The alternation of the rock types cannot, therefore, be admitted as evidence of faulting.

A well drilled at Revere, Pennsylvania[4] (Rv in Figure 15), gives clear evidence of such interbedding, as well as definite information on the lower limit of thickness of the Brunswick formation. At a depth of 2,000 feet the Lockatong formation had not yet been reached, as is shown by the fact that the lowest rocks were still red shales and sandstones with smaller thicknesses of black shale.

It is observed, in sections certainly unaffected by faulting, that the diabase intrusives have altered the shales for thicknesses of hundreds of feet. If such sheets were intruded between the beds of a series of strata only 2,000 feet thick, a large percentage of the entire surface outcrop would show alteration. The observed small areal extent of the altered rocks is, therefore, clearly in favor of the large thickness of the Newark Series.

It must be concluded that the field evidence in Pennsylvania gives no support to Roberts' view that the Newark series is only about 2,000 feet thick. The indicated thicknesses in the Delaware River section are approximately:

Brunswick (below diabase)	6,000 feet
Lockatong	3,500
Stockton	3,000+

Farther west a thickness of over 10,000 feet is indicated above the diabase, which makes the total thickness of the series over 20,000 feet. Lyman[5] considered the thickness to be about 27,000 feet; Stose,[6] in the Fairfield-Gettysburg area, finds 20,000 feet; and similar figures are given by Kümmel[7] for New Jersey. It appears to the writer very improbable that faults now unrecognized will account for as much as 20 per cent of this apparent thickness.

AGE OF THE BORDER CONGLOMERATE

At some localities the Border Conglomerate appears to be basal; it is found in direct contact with pre-Triassic rocks. Southeast of Reading the conglomerate fills open joints in the Cambrian limestone. Several miles east of Reading the conglomerate and overlying shales, which form part of the syncline already referred to above, dip directly away from the pre-Triassic. These observations by themselves would appear to favor Roberts' view that the conglomerate is of Stockton age.

That the conglomerate near Reading is actually high up in the Newark series is shown by its relation to the Brunswick red shale. On both limbs of the syncline, just below the lower diabase sheet, conglomerate occurs inclosed by red shale which dips under the diabase. On the south limb the transition from conglomerate to shale *along the strike* is clearly observed. The change is rather abrupt, and in the absence of good exposures it might be considered evidence of faulting. Antietam Creek furnishes an excellent section of the transition phase of interbedded shale and conglomerate. There

can be no doubt whatever that this body of conglomerate is of Brunswick age.[8]

In the Delaware River section the conglomerate is well exposed at Monroe, Pennsylvania (Mo in Figure 15), where it is interbedded with red shale and sandstone which undoubtedly belongs to the Brunswick formation. Two miles east of Kintnersville (Kv in Figure 15) a few thin beds of conglomerate were found by the writer in Brunswick shale beneath an outlier of the Haycock intrusive sheet. The relations are clear also on the New Jersey side of the river. A mile and a half west of Milford, New Jersey (Mf in Figure 15), an abrupt transition from red shale and sandstone to interbedded conglomerate and sandstone occurs at a deep ravine. The writer found here evidence of several faults, but in every case conglomerate occurred on both sides of the fault, so that this is not a case of downfaulting of Brunswick shale against Stock-ton conglomerate. The age of the conglomerate at this locality is unquestionably Brunswick.

North of Milford, New Jersey, the rock types are quite varied. Red and black shales, arkosic sandstone and quartz conglomerate are found within an area of a few acres. Fortunately, the exposures are good and the writer was able to establish the fact that these diverse rocks constitute a conformable series having the following approximate thicknesses:

Interbedded quartz conglomerate, arkosic sandstone and red shale	120+ feet
Black shale, inclosing a thick red shale member	150
Brunswick red shale	indefinite, great thickness

The same series was identified at two localities approximately three fourths of a mile apart along the strike. This group is very evidently of Brunswick age.

The writer concludes that the Border Conglomerate is for the most part of Brunswick age, and is, therefore, among the youngest of the Triassic formations. On the other hand, it lies directly upon the pre-Triassic in places, showing that the Newark series has overlapped the older rocks from southeast to northwest. The same general conclusions were reached by Wherry[9] as a result of studies near Reading and elsewhere. Stose[10] finds the Border Conglomerate the youngest. Triassic formation in the Fairfield-Gettysburg area. Kümmel[11] finds that, in the Raritan area (north of Flemington, New Jersey, Fl in Figure 15), not only the Brunswick, but the Stockton and Lockatong as well, pass along the strike into Border Conglomerate. Thus, though the conglomerate is, in the main, of Brunswick age, local bodies of it may be of any age within the Newark series.

The writer is indebted to Mr. G. W. Stose and to Professors W. H. Hobbs and E. C. Case for helpful criticisms and suggestions.

UNIVERSITY OF MICHIGAN

[1] *Bull. Va. Geol. Surv*., 29: 76. 1928.

[2] *Op. cit*., p. 91.

[3] *Op. cit*., p. 170.

[4] Lesley, J. P., *Proc. Am. Phil Soc*., 29: 21. 1891.

[5] *Penna. Geol Surv., Final Rep*., 3, Part 2, 2589. 1895.

[6] *U. S. Geol. Surv*., Folio 225. 1929.

[7] *Ibid*., Folio 191. 1914.

[8] This locality was studied earlier by E. T. Wherry, *Trans. Wagner Free Inst. of Sci*. (Phila.), 7:5. 1910.

[9] *Proc. Acad. Nat. Sci. Phila*.. 65 : 114. 1913.

[10] *Op. cit*.

[11] *Op. cit*.

A PETROGRAPHIC STUDY OF THE MARSHALL FORMATION AND ITS RELATION TO THE SAND OF THE MICHIGAN SERIES FORMATION

MARGARET D. STEARNS AND CHARLES W. COOK*

DURING the month of July, 1930, a well drilled in Section 6, Grant Township, Clare County, encountered three million cubic feet of gas at a depth of 1,408 feet. Naturally this event aroused a great deal of interest in the area, especially since the pay sand indicated an abnormally high structure. The pay sand at that time was correlated as Marshall on the basis of lithological similarity. It was not long, however, before an offset well was drilled and, since it was dry, drilling was continued to the Dundee formation. This second well encountered about forty to fifty feet of shale and gypsum directly beneath the gas pay sand, clearly indicating that the sand was part of the Michigan Series formation. Similar sand conditions were encountered in Broomfield, Vernon and Isabella townships in Isabella County.

It therefore became a question of decided correlative value to discover a means of distinguishing between the sands of the Michigan Series and the Marshall formations without drilling through the whole section, since when gas was encountered the wells were shut down in the pay sand. With this idea in mind the petrographic study of the Marshall and Michigan Series was attempted.

When the work was begun only a very few data were at hand on which such a study could be based and for that reason analyses were made first on a vertical section reaching from the base of the drift to the top of the Coldwater formation. For this purpose well cuttings from one of the core tests of the Pure Oil Company in Tuscola County were used, and an analysis was made of samples for every five feet of core, sometimes for less.

The method of analysis consisted of separating the samples on the basis of size and specific gravity, and then examining the separates with the polarizing microscope.

The process of separation followed was, in general, that which Milner recommends in his latest edition of *Sedimentary Petrography*. A few changes, however, were made. Acetylene tetrabromide was used as the heavy medium instead of bromoform, since it gave a more constant 2.9 liquid. For the first series of separations a 2.6 liquid was also employed, but the results obtained from these separations did not pay for the work involved.

Of the dry sieved sand the separate caught in the 0.25 mm. to the 0.50 mm. screen was used. At first all the sand below 0.50 mm. was examined, but this was found to be unsatisfactory because the smaller silt particles resulted in a large separate, most of the constituents of which were undeterminable by petrographic methods. The separate from between 0.25 mm. and 0.50 mm. was then compared with the separate found between 0.10 mm. and 0.25 mm. This procedure eliminated the difficulty arising from the finer-grained particles, but there proved to be a possibility of loosing some of the heavy mineral grains which were too large to pass through the 0.25 mm. screen. From comparisons made with the sample of the same depth we found that the separates from the 0.25 mm. to 0.50 mm. size gave the best mineral assemblage. This separate occasionally had the disadvantage of containing grains too thick to permit of their identification by means of polarized light, and in such cases it was necessary to break up the grains.

This complete vertical section, when separated and determined microscopically, was used as a basis for comparison with samples from widely separated areas. Well cuttings of the Marshall and Michigan Series sands from various parts of the state were secured and compared with the complete section. This comparison showed that the formations as found in the Tuscola well are typical of all the localities studied for the whole state.

Figure 16 shows the result of the determinations made on the vertical section. Several things are worthy of note in the upper sandstone section. These sands (no attempt has been made to distinguish between the Parma and Saginaw formations) showed that the most varied assemblage of minerals, and also the least weathered surfaces of the whole section, occur in the Pennsylvanian formations. The quartz was angular to subangular and generally rutilated in parallel hairlike lines, which, according to Holmes,[1] is indicative of a granitic or related type of parent rock.

Some relationship seems to exist between the amount of rounding and the degree of turbidity in the quartz grains; that is, the more turbid the grains the more rounded they appear to be. However, since the upper sand formations were studied only from the one well, and in that case attention was directed to the heavy mineral assemblage, this relationship has been left for later investigation.

The Michigan Series was quickly recognizable, as might be expected, in the change from the sandstone of the Pennsylvanian to the shale and limestone of the Mississippian. The relatively large assemblage of heavy minerals ceases abruptly. Zircon is not found in any of the lower formations. Muscovite, having a relatively high specific gravity, also disappears. Tourmaline and hornblende occurred in only a very few slides, and in those not more than one or two grains were observed.

Above a depth of 225 feet, as shown in Figure 16, zircon is rather abundant and fairly persistent, pyrite is rare and such minerals as tourmaline, cyanite and rutile, characteristic of the Pennsylvanian sands, are present. Below a depth of 225 feet these heavy minerals are scarce and pyrite is very characteristic. Megascopically the determination at this point characterizes the formations above a depth of 225 feet as a sandy shale, those below as a coarse gray limestone and shale.

In passing downward from the Michigan Series to the Marshall formation it develops, unfortunately, that the heavy mineral assemblage of the latter is no richer than that of the Michigan Series. The change, which may be observed in the study of the vertical section, is, in general, an increase in the amount of magnetite and a decrease in the amount of calcite. It would be impossible to state definitely that the quantitative relationship of magnetite and pyrite could be used as a basis for differentiation at the present time. Quantitative data might possibly reveal something in this respect, but from the qualitative data on heavy minerals alone the sections are too similar for definite differentiation.

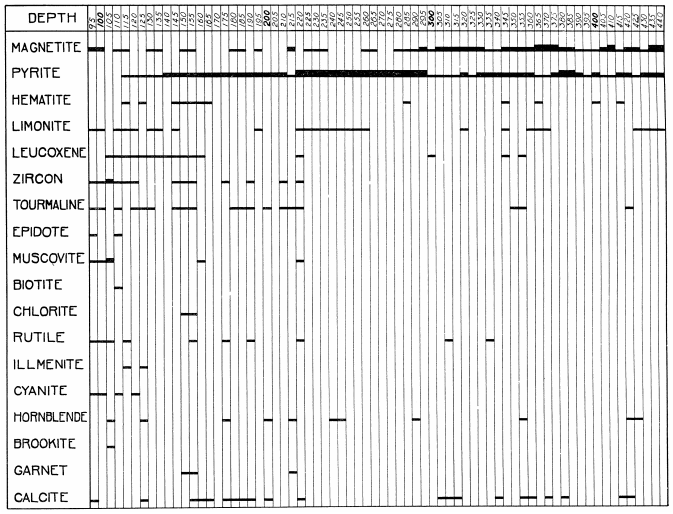


FIG. 16. Persistence chart for the Tuscola well section

It is evident that if one were given a sand from an unknown depth it would be impossible to distinguish between the Michigan Series sand and the Marshall sand by means of the heavy minerals. If the complete vertical section is examined one becomes accustomed to the variations from slide to slide and can detect differences such as the amount of weathering and an increase of magnetite, which are almost impossible to describe. This, however, is not of much assistance in the problem of correlation, for if the whole section is available megascopic correlation is simpler and just as

certain as a microscopic examination in this particular problem.

It follows, therefore, that the principal value of petrographic observations made on cuttings from the Marshall sandstone arises from the conclusions which may be drawn concerning the processes and conditions of deposition.

In order to ascertain definitely the relative diagnostic value of well cuttings and thin sections made from diamond drill cores, thin sections of cores from several localities were made and studied. The cores which were used for this purpose were obtained through the kindness of Mr. John Bruun of the Grayling Development Company and Mr. W. A. Thomas of the Pure Oil Company. The examination of these thin sections confirmed the conclusions which previously resulted from the study of the detrital material, and indicated clearly that the absence of heavy minerals in the separates was due to the nature of the sands and not to the methods of separation. Further, it showed that for the determination of heavy mineral content of a sand the use of thin sections has no advantage over the use of well cuttings.

The thin sections did, however, disclose some interesting facts not shown by the examination of the cuttings. In the first place, plagioclase was recognizable in the Marshall sandstone, but was not noted in the Michigan Series formation. Since the plagioclase rocks are very difficult to determine in detrital material, owing to the resulting products of decomposition, this was indeed an addition to our knowledge. Furthermore, the presence of plagioclase furnished very good evidence that the lack of heavy minerals was due to the absence of such minerals in the parent rock, for the plagioclase rocks alter much more rapidly than do zircon, garnet and such minerals. We may conclude, therefore, that, if the latter minerals had been present with the plagioclase in the original rock, they would certainly be present in the sand.

Further, the absence of heavy minerals cannot be explained on the basis of selective deposition, since the plagioclase was found in areas as widely separated as Sanilac and Roscommon counties. It does not seem plausible that both areas would have been receiving only material of light specific gravity indicative of the deeper part of the basin at the same period.

The plagioclase was determined to be of the more acid type — oligoclase to albite — and it occurs in both the Upper and Lower Marshall formations. It is, however, much more prominent in the former than in the latter.

Sericitization was prominent in the interstitial material of the core from Roscommon County and was present in the Lower Marshall core from Sanilac County. This indicates not that the deposition of the sand took place under conditions which were favorable to decomposition, but rather that later cementation by waters carrying carbon dioxide occurred. Much of the interstitial material is also calcite.

Both the quartz and plagioclase are angular to slightly sub-angular, with rather large grains, indicating that the haul had been of comparatively short duration and had not been allowed sufficient time for decomposition and rounding.

The question of the source of the pyrite and magnetite of the Michigan Series and Marshall formations previously mentioned and the conditions of deposition which gave rise to their association in the Marshall formation require consideration. From Figure 16 it seems evident that pyrite is characteristic of the Michigan Series, whereas both pyrite and magnetite occur in relatively equal abundance in the Marshall. A study of the pyrite and magnetite of the Marshall formation reveals the fact that the two are often intergrown. Some grains of magnetite show perfect pyrite crystals superimposed on the surface of the former mineral. The following hypothesis is an attempt to account for the conditions which have resulted in this type of deposition.

If the iron had been carried into the basin of the Michigan Series sea in the form of a sulphide, precipitation could have taken place simply by evaporation, loss of pressure or reduction of temperature. Since Michigan Series time was a period in which gypsum was being deposited, evaporite conditions are indicated and would be the easiest explanation for the deposition of the iron sulphide. The presence of hydrogen sulphide would also induce precipitation of the pyrite. There is plausible evidence that organic matter existed in the presence of the limestone of the formation. The organic matter might have acted as a source of hydrogen sulphide, or as a direct reducing agent to precipitate the sulphide from the sulphate form.

According to Lane,[2] the brines of the Michigan Series formation are strongly sulphate and carry large amounts of calcium and magnesium. Since the waters are sulphate in nature and since the pyrite crystals are small, fresh and widely disseminated, often showing close association with the quartz crystals, it seems more plausible that deposition took place from the ground waters subsequently to the deposition of the Michigan Series formation, and that the reducing agent which caused the precipitation of the sulphide from the sulphate solution was probably hydrogen sulphide.

To account for the precipitation of both pyrite and magnetite in the Marshall formation, consideration must be given to the fact that conditions of deposition of the iron minerals must have been different in this case. Two important factors may have accounted for the change. The waters of the Marshall formation are strongly chloride and carry large amounts of sodium and calcium. The lack of organic matter would suggest that reducing conditions were also absent. Thus it follows that the Michigan Series formation usually contains a sulphate

brine and the Marshall formation contains a chloride brine. The mingling of these two contrasting solutions is sufficient cause for the simultaneous precipitation of the iron sulphide and the iron oxide. Van Hise[3] gives the following equations to account for the close association of pyrite and magnetite:

$$22\ FeSO_4 + 20\ H_2O = FeS_2 + 7\ Fe_3O_4 + 20\ H_2SO_4$$

$$\text{or } 3\ FeS_2 + 4\ H_2O + 4O = Fe_3O_4 + 4H_2S + 2SO_2$$

Regarding the first equation, he says that, though it has not been proved in the chemical laboratory, there is much geological evidence in its favor. It appears to be the best explanation for the conditions found in the Marshall sandstone.

The possibility that pyrite is a replacement product from the magnetite was considered. Van Hise, however, gives no evidence for such a reaction. Clark[4] records Deolter's experiment in which pyrite was formed in the laboratory by heating magnetite with hydrogen sulphide and water to temperatures of 80 to 90 degrees Centigrade for 72 hours. These temperatures are too high for near-surface conditions, and in addition the magnetite does not appear to be more greatly altered than the pyrite. When the slide shows that alteration has taken place, both minerals are affected. If the pyrite were a replacement deposit, the magnetite should show much more alteration than the pyrite.

Van Hise does state that pyrite may be derived from hematite, but the quantity of hematite in it is very minor as compared with the amount of magnetite, and the pyrite does not show any definite relationship to the former mineral.

It thus seems that the best explanation of the association of magnetite and pyrite in the Marshall formation is that it is due to reactions which took place as a result of the mingling of the sulphate waters from the Michigan Series, and the chloride waters from the Marshall formation.

In conclusion the following points may be summarized:

1. The heavy minerals of the Marshall and Michigan Series formations do not furnish a means of distinguishing between the two sands.

2. No marked variation of the mineral assemblage is shown in samples from widely separated areas. Both formations appear to be typically barren of heavy minerals throughout their geographical extensions.

3. The presence of plagioclase feldspar indicates that heavy minerals are lacking, owing to their absence in the parent rock.

4. The magnetite and pyrite of the Marshall and Michigan Series formations are secondary in origin. In the former the two minerals are related and their deposition is the result of the same reaction. In the latter the abundant pyrite is the result of the action of reducing conditions on sulphate waters.

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