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CHARLES C. ADAMS, *Director*

THE GEOLOGY AND ORIGIN OF THE SILURIAN SALT OF NEW YORK STATE

BY
HAROLD L. ALLING

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INTRODUCTION

It is now many years since Merrill (1893) published his bulletin on the Salt and Gypsum Deposits of the State. During his time the salt industry was experiencing an unusually brisk development that proved to have been over-extended. Many of the salt brine plants that flourished at the time of Merrill's investigations have long since disappeared and nothing remains of these plants except records of their salt wells and the remembered experiences on the part of the citizens of the towns in which these plants were located. Now that the industry has become more stabilized and the brine plants and mining companies are operating under more normal conditions it has been considered desirable to put into available form a report covering the geology of the New York State salt deposits.

At one time it was planned that an extensive report should be prepared giving the history of the industry. The technology of its manufacture and its many uses were to be dealt with in a rather detailed manner. It has not been possible to carry out this plan, however. The present bulletin will deal with the geological aspects and not the commercial phases of the subject. It is believed that the salt well records alone furnish a key to many interesting features that have not as yet been appreciated.

ACKNOWLEDGMENTS

In the preparation of this report extensive use has been made of the early reports by Bishop, James Hall, D. D. Luther, F. E. Englehardt, Doctor Goessmann and Dr John M. Clarke, as well as the report by Merrill. Subsequent reports from which information has been gathered include Salt Resources of the United States by W. C. Phalen; Bulletin 669 of the United States Geological Survey; Brine and Salt Deposits of Michigan by Charles W. Cook (1914), together with reports of the Ohio and Canadian Geological Surveys. The most valuable sources of information are Grabau's Geology of the Non-Metallic Mineral Deposits, Principles of Salt Deposition, volume 1, 1920, and Swartz *et al*, Maryland Geological Survey, Silurian Volume. The writer is indebted to D. H. Newland, Dr Rudolf Ruedemann, W. C. Phalen, C. A. Hartnagel, G. H. Chadwick, J. E. Carman and H. B. Kümmel, who have rendered valuable assistance during the preparation of the manuscript. To the superintendents and managers of the salt companies the writer takes pleasure in acknowledging service and courtesy extended to him while visiting the various plants. Among these he wishes to express his indebtedness to E. R. Moynes of the Retsof Mining Company and to J. T. Fetherston of the Sterling Salt Company.

Many others have been of real assistance in discussing the subject of origin. Among those who have shown interest in the petrographic method of investigation I wish to thank Dr David White, Dr M. I. Goldman and Dr J. E. Hoffmeister.

THE DISTRIBUTION OF THE SALT DEPOSITS

The Salina beds which carry the salt extend as a belt running east and west across the State. It is 12 miles wide at the Niagara river and extends eastward across the central group of counties south of Oneida lake from which point it gradually tapers to an end not far from Schoharie. At the foot of Cayuga and Seneca lakes this belt is about 20 miles wide. The Salina beds dip to the south at an average of 45 feet to the mile. The salt mining and salt brine plants are located south of this outcropping belt. As the salt is very soluble it is not itself exposed on the surface and is reached only through wells and shafts. The district under which salt is known to exist comprises the eastern portion of Genesee and Wyoming counties and probably the whole of Livingston county and the southern portion of Ontario county. It is in these above-mentioned counties that the bulk of the salt is produced. There are a few wells located in Yates, Schuylcr, Cayuga, Tompkins and Onondaga counties, that penetrate to the salt. The most eastern well that reports salt is at Morrisville, Madison county. It is believed, however, that the salt continues south of this district and passes into Pennsylvania. But the dip of the rocks carries the salt many hundreds of feet below sea level. This, and the fact that the land is higher in the southern portion of the State, makes it unprofitable to reach the salt either by wells or by shafts.

The western limit of the field is difficult to define. The early reports stated that rock salt was not encountered in the East Aurora well where strong brine was obtained. The same condition is reported from Eden Valley and Gowanda. Later reports, however, state that rock salt was found at Eden Valley and Gowanda (Newland, 1914, p. 57).

The salt is known to cross the Wyoming-Erie county border, but it probably terminates somewhere in the interval between that and the eastern end of Lake Erie. Many of the gas wells in the Buffalo region and along the south shore of Lake Erie to Dunkirk indicate that salt is absent in that area. This is also true of Chautauqua county (Bishop, 1895, p. 391). The western limits of the salt field can be roughly indicated by a line drawn from East Aurora to Patchen and to Boston Corners and then south to a point on Cattaraugus creek on the Cattaraugus county border line about three miles north of Springville. This line may be extended from East

Aurora northward to Batavia, probably indicating the limits of the salt in this direction. In southeastern Ohio there is an area under which salt is known to occur and it may be that the western limit of the salt field in New York swings southwestwardly to include this area in Ohio. The absence of the salt in northwestern New York does not, however, imply the absence of the Salina beds, for these beds are known to extend to the Niagara river where gypsum is reported from wells at Buffalo. It is not known whether salt was deposited in this area and subsequently removed by solution, or whether it was never deposited. I am of the opinion, however, that the latter interpretation is more likely to be correct. The northern limits of the New York field appear to be indicated by a line connecting the wells at Le Roy with those of Caledonia. East of Caledonia the boundary swings southward so as to include only a part of the town of Avon and probably very little of the town of Lima. In fact, no salt has so far been reported from any of the gas wells drilled in Lima township. This indicates that the solution of the salt has occurred at greater depths than is usual or that the salt never existed in that neighborhood.

In any case the hope of securing usable salt from Erie county is decidedly unfavorable. An interpretation that seems very reasonable is that *salt shales* and not *rock salt* have been reached at these localities. On the basis of all the available information we can consider that the salt wells are upon the northern margin of the basin located in New York and in northern Pennsylvania. We probably shall never know the full extent of this basin as our information is confined to the northern rim.

In Ohio the salt wells are located in the neighborhood of Cleveland. The salt deposits are not limited, however, to this small area in Ohio, for the beds are found farther east near Cortland, Trumbull county, Ohio, where 148 aggregate feet of salt are reported. This would indicate that the salt strata reached the eastern limit of Ohio.

In view of the doubtful nature of the records reporting salt in Erie county, New York, it is impossible to state with any certainty whether or not the salt deposits of Ohio are connected physically with those of New York. Yet it is well established that the salt in the two states is probably of the same geological age. The writer is inclined to the belief that we are dealing with a single basin (see figure 1).

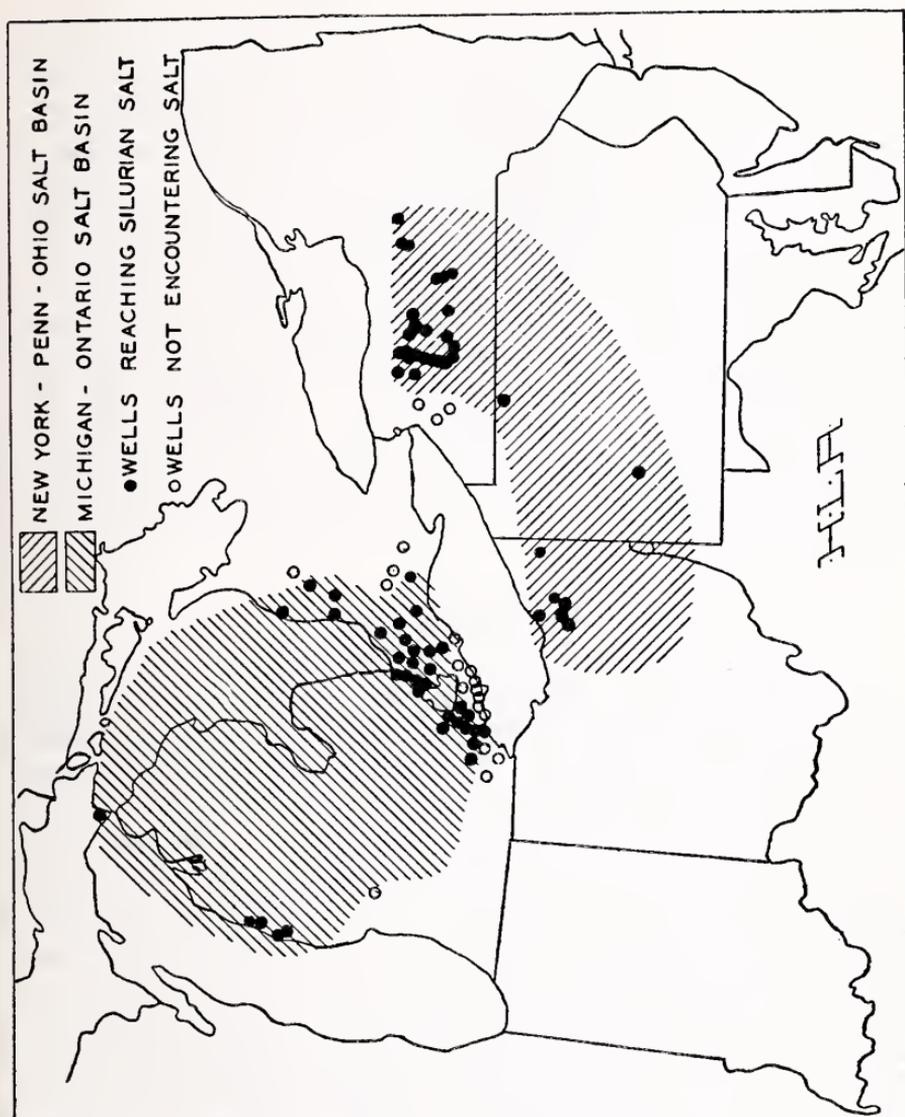


Fig. 1 Map showing the conception of two salt basins; the New York-Pennsylvania-Ohio basin and the Ontario-Michigan basin. This applies only to the Silurian deposits. While there is probably salt in the center of the Michigan basin, the great depth below the surface renders it too expensive to be utilized. The northern edge or rim of the New York basin has been removed by erosion. Data for this map have been secured from Cole, L. H., *The Salt Deposits of Canada*, Can. Dep't Mines. Mines Br. 1915, no. 325, map facing page 20, and Phalen, W. C., *Salt Resources of the United States*. Bul. U. S. Geol. Surv. 669, 1919, plate 1 and text.

In Michigan salt and brines are secured from several horizons. The lower one, the Salina, carries salt and anhydrite, while the upper formations, the Marshall sandstone of Mississippian age and the Parma sandstone of early Pennsylvania age, carry brines. We are here interested chiefly in the Salina of Michigan and its relation to the equivalent beds in Ohio, Ontario and New York. From the records of the salt producing area in Michigan we can gather that the district in Michigan continues into Ontario, Canada. It is known that the thickness of the Salina increases to the north, while to the south and southeastward the salt thins to disappearance. Salt wells drilled at Trenton, Wayne county, Michigan, indicate the exact southeast limit of the salt as only one of a number of wells encountered it. There is no conclusive ground for believing that the Michigan salt continues into New York and hence our present information would incline us to believe that these two areas are separate basins (see figure 1).

Amount of Salt

The tonnage of the salt now known to exist in New York State is very great. I. P. Bishop (1885, p. 34) estimated the area underlain by salt to be eleven hundred square miles in extent. Since that time the known area has been greatly extended; hence Bishop's estimate is far too low. Among the numerous difficulties in computing the tonnage of salt is the variability of the thickness and number of the salt beds themselves. From the cross sections that accompany this report we can appreciate the fact that the number of salt beds as well as the thickness of individual beds increases from north to south. The wells at Watkins and Ithaca report seven distinct beds which give an aggregate of four hundred to five hundred feet of salt. The Ithaca works of the International Salt Company, as well as the Cayuga works of the same company at Ludlowville, Tompkins county, apparently utilize the uppermost salt bed and have not penetrated to the beds that are inferred to lie below. In view of the fact that there is an excessive tonnage of salt within the limits of the State and that there is an almost inexhaustible supply of the material, such estimates as might be given are of no great importance, in that they would be at the best mere guesses based upon inadequate data.

CORRELATIVE STRATIGRAPHY

The presence of natural saline springs early led to the belief that a deposit of salt lay beneath the surface rocks of western and west central New York. East of the Genesee river these springs follow the belt of the red Vernon shales, whereas to the west of that river they follow the red Medina-Queenston formations. Therefore, these two different rocks were correlated by Eaton (1824) under the name "Saliferous" rock, which he believed to be of the age of the salt-bearing Triassic "New Red Sandstone" of Europe. Eaton and later Conrad (1837, p. 183) recognized the presence of gypsum in the gray shales next above the red beds. To both of these formations Vanuxem (1839, p. 249) and Hall (1839, p. 290) by mutual consent applied the locality name "Saliferous group of Onondaga." This was afterward shortened to "Onondaga Salt Group."

The name "Onondaga" being already in use, however, for a limestone series, Dana in his *Manual of Geology*, First Edition, (1863, p. 246) introduced the now current term "Salina" for the salt-bearing formations and the inclosing beds. Clarke and Schuchert (1899-1900) proposed the term "Cayugan period or group" to include the Salina beds, Rondout waterlime and the Manlius limestone. Nine years later Grabau (1908, p. 622; 1909, p. 209-52) and Chadwick (1908, p. 346; 1909, p. 77) independently suggested elevating the Salina to group rank, Chadwick restricting the term "Cayugan" to the higher beds which Grabau referred to his new group, the Monroan.

The fact that the Salina could be subdivided was recognized by the geologists of the early New York Survey, who described its structure in some detail, and in 1903 Clarke proposed formational names within the series, namely Pittsford, Vernon, Syracuse, Camillus and Bertie, the last being a term first used by Chapman in 1864 in Ontario and revised by Schuchert in 1903.

Schuchert (1908, p. 538-39) uses the term "Cayugan Series" to include the Salina group embracing all formations between the Guelph-Niagara group and the top of the Manlius limestone of eastern New York. Williams (1919, p. 82) likewise uses the term "Cayugan group" to include all the Silurian sediments in Ontario above the top of the Guelph dolomite. Thus in the Buffalo region, the formations included are, as recognized by Bassler (1915, pl. 3) the Salina (represented by the Camillus shale) the Bertie waterlime and the Akron dolomite, the latter correlated with the Cobleskill of

eastern New York. In the Detroit river region the Salina and the Bass Island series are included in the Cayugan group. The Camillus shale division of the Salina is well marked in this western region and it is probable, as will be seen below, that the Bertie and Akron dolomites of the east are to be correlated with the Raisin River and the Put-in-Bay dolomites of the Bass Island series, and consequently, contrary to former usage, this series belongs in the Cayugan group.

Meanwhile the term "Monroe" has been proposed for the dolomites and limestones of the Michigan district that lie above the Salina, which would thus include the now recognized Bass Island series, the Sylvania sandstone and the Detroit River series. Unfortunately, however, Lane formerly applied the term "Monroe" to all of the Silurian rocks above the Niagara, that is, to the beds between the Niagara and the Dundee limestone. He found it very difficult, however, to draw the line between the Salina and the overlying dolomitic limestones. Lane recognizes, however, the following subdivisions in ascending order: the Salina, the Bass Island series, the Sylvania sandstone and the Detroit River series. Later he restricted the term "Monroe" to the beds above the Salina but the difficulty of separating the Salina from the above rocks still remained. Although the top of the Salina is thus difficult to determine, it is made the base of a division of the Monroan, which comprises all of the Silurian above the Salina and which in distinction to that formation exhibits marine or semimarine conditions of accumulation.

The name "Monroe Beds" first appeared in a geological column prepared by Lane in a report by Wadsworth in 1893. In that publication these beds were not defined, but two years later Lane proposed that the term should include all rocks between the Niagara and the Dundee limestones of Michigan.

Darton (1894) described the "Monroe shales" of southeastern New York to which he ascribed a Devonian age. Thus there has arisen uncertainty whether the term "Monroe" as used in Michigan should be employed in discussing equivalent beds in Ohio and in New York. The question was submitted to Bailey Willis, chairman of the committee on geological names of the United State Geological Survey. It was decided that the Monroe of southern Michigan should be retained on the ground that it was established through usage.

Lane, in proposing the term "Monroe," to cover all the formations between the Niagara and the Dundee, made it synonymous with the Cayugan of Clarke and Schuchert. This nomenclature seemed to imply that the division between the Salina and the overlying waterlimes was an indefinite one and not at a fixed horizon. But, on the

contrary, the line of demarcation is a very distinct one and hence Grabau and Sherzer (1910, p. 226) do not include the Salina in the Monroe.

The age of the lower Monroe or Bass Island series of Ontario, Michigan and Ohio is without much question Upper Silurian and will be considered here as Cayugan. A controversy centers around the age of the upper Monroe or Detroit River series. Apparently the paleontologic and stratigraphic evidence are in conflict. Williams (1919, p. 19) lists the fossils of the Detroit River series and shows that they possess a Devonian aspect. To this Grabau (1910, p. 217) agrees. But this Devonian fauna is situated beneath the Lucas which Grabau says carries a Silurian fauna and hence concludes that the whole group must be assigned to the Silurian. Williams discusses the fossil content and shows that there is a decided Devonian aspect even to the Lucas fauna. He says, "In view of the presence of unquestioned Devonian elements in the Lucas fauna, and of the decidedly Middle Devonian character of the faunas of the other upper Monroe divisions which underlie the Lucas, it seems decidedly inadvisable to place this whole formation in the Silurian. . . It would seem much more logical to consider the Detroit River series or upper Monroe as of Devonian age, the Silurian species present being regarded as holdovers from Silurian time" (Grabau, 1910, p. 20).

Williams feels that, in as much as the Monroe spans the Silurian-Devonian boundary line, "the terms upper Monroe and lower Monroe are obviously no longer appropriate, since the so-called Monroe is now seen to belong to different geological systems. Grabau's alternative names 'Detroit River' and 'Bass Island' will hence be used." I am inclined, nevertheless, to retain the term "lower Monroe" in the correlation tables, not because I am fully in agreement, but for the express purpose of indicating the present status of the problem of correlation.

Ulrich and Bassler (1923, p. 267) have realized that the Monroe is not an exclusively Silurian formation, but that the original term embraced Devonian rocks as well. They conclude that the Bass Island series alone is Silurian while the Detroit River series is Devonian. Their table places the Silurian-Devonian boundary line at the base of the Sylvania sandstone. This conclusion seems to have been established by Carman (1924, p. 250; 1927, p. 481-506) in his studies of the Monroe in Ohio.

This discussion shows that the Monroe as employed by Grabau and Sherzer spans the division between the Devonian and the Silurian.

Thus our attention is focused solely upon the lower Monroe, as the middle and upper Monroe formations are in all probability Devonian.

In attempting to correlate the Upper Silurian or Cayugan of New York, Ohio, Ontario, Pennsylvania and Maryland there is a great deal of difficulty because of the wide difference of opinion expressed by various authors. I do not entertain the hope that the correlation table which I have compiled (table 6) will prove entirely satisfactory. I believe that a completely satisfactory correlation is impossible at the present time. There are too many unknown factors.

The New York Survey employs at the present time the nomenclature as set forth in table 1 drawn up by Hartnagel.

TABLE I

		<i>Hartnagel 1912</i>				
		Western New York	West Central New York	Central New York	East Central New York	Eastern New York
Devonian				Coeymans	Coeymans	Coeymans
SILURIAN	CAYUGAN	***** ***** Cobleskill Bertie Camillus <i>Salina</i> Syracuse Vernon Pittsford	Manlius Rondout Cobleskill Bertie Camillus <i>Salina</i> Syracuse Vernon Pittsford	Manlius Rondout Cobleskill Bertie Camillus <i>Salina</i> Syracuse Vernon Pittsford	Manlius Rondout Cobleskill Bertie Camillus- Brayman Syracuse Vernon Pittsford	Manlius Rondout Cobleskill Bertie Rosendale <i>Salina</i> Wilbur Binnewater High Falls Shawangunk
	NIAGARAN	Guelph Lockport	Guelph Lockport	***** Lockport	***** Lockport	***** *****

It will be seen that Hartnagel places the Pittsford shale at the base of the Salina continuously from western to East-Central New York. I am inclined to question whether the Pittsford as such is present in the Buffalo region. Pittsford, near Rochester, is the most western locality for the eurypterid fauna. In commenting upon the fact that the horizon of the Pittsford which can be designated "as the horizon of *Hughmilleria socialis*, and that of . . . [the] higher shale as that of *Ceratiocaris salina*," Ruedemann (1921, p. 4-5) adds a footnote: "As pointed out to me by Mr Hartnagel, it is of interest to note that the occurrence of this fauna is near the western terminus of the red Salina shales. This may explain the fact that the development of the Vernon at Pittsford is not quite typical and also accounts for the presence of a higher intercalation of dark fossiliferous shale."

This would seem to indicate that Hartnagel entertains similar suspicions about the presence of the Pittsford west of Rochester.

Hartnagel suggests that the Shawangunk grit in eastern New York, may be of Pittsford age. At the time he made this correlation, eurypterid remains had been found only in Silurian rocks and not in older formations. The discovery of Ordovician eurypterid faunas (Clarke and Ruedemann, 1914) does not strengthen the force of the argument for age equivalency. Ruedemann says: "The Hughmillerias of the Pittsford shale and Shawangunk grit, not being specifically identical, can therefore no longer be considered as demonstrating the taxonomic equivalency of these beds. The Hughmillerias [of these formations] are clearly the last stragglers of a . . . race and, as such, of less stratigraphic significance than they would be otherwise" (Ruedemann, 1921, p. 5). There are other suggestions offered by various geologists regarding the age of the Shawangunk. The fact seems to be that the exact age is not known; there is certainly no agreement on this matter.

Hartnagel assumed the presence of the Vernon at Buffalo. The well at Buffalo, whose record Grabau has interpreted, while not as significant as is desired, would cause us to exercise some caution in advocating the presence of the Vernon in western New York. The apparent absence of red shale in this region would suggest that the Vernon is not present. Williams (1919) states that the interval between the Niagaran and the Bertie series is occupied by the Camillus alone. As is pointed out in another section, however, the criterion of the red color of the Vernon is probably not a reliable one. In Ohio the salt beds are close to the bottom of the Salina, and while they may have been deposited in a separate basin, yet it is quite possible that the Vernon was never deposited in the Ohio and Michigan areas. My present feeling is that the Vernon does come to an end in Ohio; but whether it is actually absent in the Buffalo region is unknown. It may be present but not recognized, because it lacks the red color.

It will be observed from table 1 that Hartnagel regards the Akron and the Cobleskill as identical. It is quite possible that this is correct. But in view of the disagreement expressed by Bassler (1915), Ulrich (1913, p. 115-17), Swartz (1923, p. 213) and Chadwick (1919,

TABLE 2

Grabau and Sherzer. *Michigan Geol. & Bio. Surv. Pub. 2, Ser. 1, 1910 p. 234*

UPPER SILURIC OR MONROAN	Dev.	Dundee	Michigan & Ohio	Western New York	Eastern New York	Appalachians
			Dundee	Dundee	Onondaga	Onondaga to Coeymans	Coeymans
Detroit River Series		Hiatus and disconformity	Hiatus and disconformity	Hiatus and disconformity	Continuity of deposition	Continuity of deposition
		Lucas dolomite	Wanting	Wanting	Manlius limestone Rondout waterlime	Corrigan formation of Maryland with perhaps part of Upper "Salina" of Schuchert's section, Lewiston formation of Pennsylvania.
		Amherstburg dolomite Anderdon limestone.	Akron dolomite Bertie waterlime	Akron dolomite Bertie waterlime	Cobleskill limestone Rosendale waterlime	
		Flat Rock dolomite Hiatus	Hiatus and Disconformity	Hiatus and Disconformity	Hiatus and Disconformity	
		Sylvania sandstone Hiatus				
Bass Island Series		Raisin River beds Put-in-Bay limestone Tymochtee shale Greenfield dolomite Hiatus and disconformity			Continuity of deposition	
		Salina formation	Salina series	Longwood High Falls Shawangunk conglomerate	"Salina" of Md. wanting (?) in Pennsylvania	Hiatus and disconformity

p. 93) I have indicated in table 6 the possibility (or perhaps the probability) that the Cobleskill and the Akron are distinct. If one is stratigraphically higher I am inclined to follow Bassler, Swartz and Chadwick in placing the Cobleskill above the Akron, yet recent investigations by the New York Survey may place it equivalent to the Bertie.

Table 2 gives the correlation table proposed in 1910 by Grabau. It will be noticed that it differs considerably from the other tables here introduced. The striking thing about the table is that both the Detroit River and the Sylvania sandstone of Michigan and Ohio are regarded as Silurian and that there is a hiatus between the Salina and the Bertie in Western New York. This places the Amherstburg, Akron and Cobleskill as equivalents. He says: "From a comparison of the Cobleskill and Akron faunas it becomes evident that the two faunas are very closely related. In fact, all the most important species of the Akron fauna are typical also of the Cobleskill. . . . If we correlate the Cobleskill with the Amherstburg and accept the correlation of the Cobleskill and Bullhead [Akron] of Buffalo, we are forced to the conclusion that a great hiatus exists between the Bertie and the Salina of Western New York" (Grabau, 1910, p. 228-29).

But if we question the Silurian age of the Amherstburg, as Williams, Ulrich, Bassler, Swartz and Carman do, and make it Devonian, then the hiatus proposed by Grabau must be reduced from "a great hiatus" to a smaller stratigraphic break.

Grabau made the beds in Maryland, usually called "Salina," synchronous with a stratigraphic break at the base of the lower Monroe or Bass Island series. He says: "In Maryland, the lower Monroe is represented by shales and limestones commonly called 'Salina'; the true Salina being absent" (1910, p. 624). In view of the more recent work of Ulrich, Bassler and Swartz who reached the conclusion that the McKenzie, Bloomsburg and Wills Creek of Maryland and Pennsylvania are of Cayugan age, I dissent from Grabau's correlation table on a number of points.

Grabau proposed that the Greenfield limestone and the so-called "Bullhead" waterlime of the Buffalo region, that is the Akron, were identical (1898, p. 800). But two years later (1900 p. 350) the Greenfield was correlated with the Manlius (Cobleskill) of eastern New York. The latter is stated to be 7 to 8 feet thick and to rest upon some fifty feet of waterlime. This is interpreted to mean the Bertie. Hartnagel believes that the Akron and the Cobleskill are identical. Bassler, however, would suggest that the Cobleskill was equivalent only to the upper portion of the Akron and equivalent to the Tonoloway limestone of Pennsylvania, Maryland and Virginia. The Cobleskill, Rondout and Manlius of central and west central New York are regarded by Ulrich (1913, p. 115-17) as distinct from the formations of the same names in eastern New York. Ulrich would place the Cobleskill, the Rondout and the Manlius of central New York in the Cayugan and the formations of eastern New York as Helderbergian (of Decker Ferry age). Hartnagel (1903) on the other hand maintains that all these formations are Cayugan, while the Cobleskill (of eastern New York) is of Decker Ferry age. A proper correlation depends upon additional field work on the relation between the Akron, Cobleskill and Manlius of eastern and central New York. Until that is done satisfactory agreements are impossible.

Bassler has offered a still different correlation table which is reproduced in table 3. The Salina of New York, the Pittsford, Vernon, Syracuse and Camillus are made equivalent to the McKenzie of Pennsylvania and Maryland, and that in turn to the High Falls and Longwood shales of Eastern New York. The Bloomsburg of Pennsylvania is placed in the hiatus between the Camillus and the Bertie, while Swartz places it lower down. The Wills Creek of Maryland is assigned to the Bertie-Akron interval. I am inclined to follow Ulrich and Bassler and place the Wills Creek with the

McKenzie and together pigeon-hole them with the Vernon-Camillus series.

TABLE 3

Bassler, R. S. U. S. Nat. Mus. Bul. 92. v. II, pl 3

		Western New York and Ontario	Central and Eastern New York	Pennsylvania & Md. & Va.
DEVONIAN HILDEBERGIAN		*****	Becraft formation	*****
	Becraft (N. Y.)	*****	New Scotland formation	*****
	New Scotland (N. Y.)	*****	Coeymans limestone	*****
	Coeymans (N. Y.)	*****	Keyser-Decker Ferry	*****
	Keyser (W. Va.)	*****	Manlius (Tentaculite limestone)	Bossardville limestone
CAYUGAN	UPPER	*****	Cobleskill	Tonoloway limestone
		Akron dolomite Bertie waterlime	*****	Wills Creek
		*****	*****	Bloomsburg
	LOWER	Salina (N. Y.)— McKenzie (Md.)	High Falls-Longwood **** ***** ***** *****	McKenzie
NIAGARAN	LOCKPORT	Louisville (Ky.)	*****	*****
		Guelph (Can.)	Shelby dolomite	*****

We turn now to a consideration of the classification offered by the Maryland Geological Survey (Ulrich and Bassler, 1923). Here we find the Salina of Maryland recognized as such, with the Pitts-

TABLE 4

Ulrich and Bassler, 1923. Maryland Geological Survey

		Western New York	Eastern New York	Pennsylvania and Maryland	Michigan and S. W. Ontario
DEV.		Upper Manlius	Upper Manlius	Keyser	Sylvania sandstone
	CAYUGAN	UPPER CAYUGAN	Lower Manlius Cobleskill *****	Lower Manlius Cobleskill *****	(Bossardville) Tonoloway	Raisin River Put-in-Bay dolomite Tymochtee dolomite
LOWER CAYUGAN		(?) Bertie Camillus Syracuse Vernon Pittsford	***** Binnewater High Falls	Wills Creek (Bloomsburg) McKenzie	Greenfield dolomite Salina
NIAGARAN	LOCKPORT	***** Lockport including Guelph	***** ***** *****	***** ***** Rochester	***** Lockport with Guelph

ford, Vernon and Camillus correlated with the McKenzie, Bloomsburg and Wills Creek, a correlation which I prefer and which will be here employed.

The Cobleskill is placed above the Bertie and correlated with the Tonoloway of Maryland. Recent work of the New York Survey would suggest that the Cobleskill is below the Akron and thus perhaps assigned to the Bertie series. Nothing can be done further with this problem until the investigations now under way at Albany are completed. Discussion of the correlation of the High Falls shale in eastern New York is deferred until the correlations proposed by the New Jersey Survey are discussed.

The Maryland correlation of the upper Cayugan of Michigan with that of southwestern Ontario is essentially the same as that suggested by Williams. The Maryland Survey is cautious when it places the Greenfield dolomite on the dividing line between the upper and lower Cayugan. In Ohio gypsum occurs above the Greenfield and may be in the Tymochtee formation. We can question, with Hartnagel, whether the Pittsford and Vernon are present in the Buffalo region.

Williams gives us a very reasonable correlation between the Detroit river and the Niagara river. The third column in table 5 is for Western New York as proposed by Williams assisted by Chadwick, and shows the individual members of the Bertie series correlated with the members of the Bass Island series.

TABLE 5

Williams, M. Y. Canadian Geological Survey, 1919

DEV.		Detroit River	Niagara River	Western New York
		Sylvania sandstone		
SILURIAN	CAYUGAN	Akron	Akron	Akron
		Bertie	Bertie	Bertie Series Williamsville Scajaquada Falkirk Oatka
	Salina	Camillus including salt and gypsum	Camillus including gypsum	Camillus Vernon (?)
	Guelph	Guelph	Guelph	Guelph

The Salina is represented by the Camillus; the salt and gypsum being assigned to it. I am much inclined to follow this procedure. Whether the Greenfield is a true member of the Bass Island series is a matter of some doubt.

The Ohio classification is being revised. It is exceedingly difficult to obtain reliable information about the Salina of that State. The Salina does not outcrop; it is believed that all our knowledge has to be secured through wells. The finding of gypsum above the Greenfield adds to the complexity of correlation. It is obvious that much work is necessary before satisfactory comparisons are possible.

The New Jersey Survey, I have learned through the kindness of Dr H. B. Kümmel, would regard the Shawangunk conglomerate and the Green Pond conglomerate as remnants of the same formation and the earliest Silurian representatives in New Jersey; possibly of Medina age. The High Falls as such is held to be not a single formation but one of several ages. It is only the upper part together with the Longwood that should be correlated with the High Falls-Longwood of New York and that with the Salina. It is possible that the Poxino Island shale and the Bossardville limestone is also Salina. The Bossardville, however, may well be of Akron-Cobleskill-Bertie age and included with the Decker Ferry as equivalent to the Rosendale, Wilbur and Rondout series.

If we entertain the views offered by Ulrich, Bassler and Swartz and the New Jersey Survey as at all reasonable, as I do, then there is a considerable area occupied by rocks of Salina age in the east. That is, there are rocks to be correlated with the Salina of New York, Michigan, Southwest Ontario and Ohio which carry salt and gypsum in adjacent districts, that are not salt and gypsum-bearing. This is important in the discussion of the origin of the rock salt and gypsum.

In table 6 I have attempted to compile the correlation as I see it at the present time. Here I have made use of ideas secured from many sources. With all frankness I admit that it is tentative and subject to revision. I believe that it enables us to approach the subject of the geology of the salt deposits of New York with a hope of success otherwise impossible.

TABLE 6

		Alling, 1924					
		Western New York	Central New York	East Central New York	Ontario, Mich. and Ohio	Maryland	
SILURIAN	LOWER MONROAN	UPPER CAYUGAN	***** ***** Akron Williams-ville Bertie Series Scajaquada Falkirk Oatka	Tentaculites limestone ***** Akron Williams-ville Bertie Series Scajaquada Falkirk Oatka	Manlius Rondout ? Cobleskill? Bertie?	? Raisin R Put-in-Bay Tymochtee Greenfield Bass Island Series	Tonoloway
	SALINIAN	LOWER CAYUGAN	Camillus, Inc. gypsum Vernon?	Camillus, Inc. salt and gypsum Vernon (Pittsford)	Camillus=Brayman *****	Camillus, Inc. salt and gypsum *****	Wills Creek (Bloomsburg) McKenzie
		NIAGARAN	Guelph Lockport	Guelph Lockport	***** Lockport	Guelph Lockport	

It will be noted that I am recognizing the "Pittsford" shale only as a local faunal phase of the Vernon. I have omitted the term "Syracuse" as applied to the salt beds as stratigraphically awkward, making the gypsum and salt directly associated and genetically connected with the Camillus type of rock. Furthermore, I am not drawing the distinction any too sharply between the Vernon and the Camillus. The actual conditions prevailing at the line of contact are very uncertain. I have suggested elsewhere that the plane of change in color from the red Vernon to the gray mud rocks of the Camillus may not be a stratigraphic horizon, but that it migrates diagonally across the series. I would in a similar manner regard the Bloomsburg of Pennsylvania only as a member of the McKenzie-Wills Creek group.

Correlation of the upper Cayugan, which is equivalent to the term "lower Monroan," is patterned after Williams and Chadwick. The position of the Cobleskill is still, as far as this paper is concerned, a matter of doubt. In reviewing these correlation tables I am impressed with the value of each and at the same time conscious of

the lack of agreement. Such tables are, it seems to me, unfortunate in one sense in that they convey a sense of finality and permanency not really intended by the authors themselves. We realize that geologic history is too complicated to be classified into neat and simple pigeon holes under the present prevailing conditions. One of the chief difficulties is the discordance of the units, particularly the "formation"; due to personal training, experience and individual interpretations. One geologist recognizes extreme details and names every bed that can be distinguished by lithologic and faunal peculiarities. Another is not meticulous and may give a new formational name to rocks which would be referred to under the name of a group, series or system.

This great diversity of methods is a serious obstacle for coordination. One may place a rock unit in the geologic scale upon the supposedly characteristic fauna which it contains; another considers the migration of faunas and may reach a very different conclusion regarding its age; a third may attempt to combine these two methods; a fourth may base his correlation on strictly lithologic grounds with but little emphasis upon the fossils; still others employ the more comprehensive diastrophic method. If one area is described and the rocks there classified and ages assigned to them by purely faunal distinctions, while in another the lithology is emphasized, attempts to effect a satisfactory correlation is well nigh impossible. But the classification proposed for each of the two areas may be supported in a very logical manner, which does not help us to establish a systematic classification and correlation of geological formations. That desirable end can only be attained by an agreement upon the method. The surprising thing is that geologists manage to agree as well as they do.

STRATIGRAPHIC LITHOLOGY

The Vernon

Throughout the west central portion of the State extends the monotonous red shaly Vernon. Its eastern limit is between the meridian of Herkimer and Saltspringville. It thickens rapidly, as it progresses westward, to its great thickness of about 600 feet at Syracuse, and then thins as it leaves that locality, coming to an apparent end between Batavia and Buffalo.

At Vernon, its type locality, it is a purplish-red crumbly shale with occasional grayish-green layers and spots. The layers are very narrow, rarely over an inch wide; the spots are from 10 to 20 millimeters in diameter. Its base is decidedly greener, alternating layers of bright emerald green, purplish-red and mottled green and red shales. The transitional zone is some 20 to 30 feet in thickness. At certain and apparently limited localities black carbonaceous argillaceous dolomites appear which carry the interesting and at the same time perplexing eurypterid fauna of which more is said later on.

The demarcation of the summit of the Vernon is a matter of uncertainty. The New York Survey places the rock salt on top of the Vernon. But as will be shown beyond, the rock salt occurs in several distinct layers or beds and is interbedded with and more closely associated with the Camillus type of sediment. So characteristic is the red colorization of the Vernon that its utilization as a criterion has become established. As a real criterion, however, it may be well to entertain some doubt. The wells sunk along the northern margin of the salt area report, directly beneath the salt, "red shale," which is interpreted to mean the Vernon. This information is in conformity with the usage of the New York State Survey. The records of the wells in the central strip of the field, however, reveal salt shale, brown shale, black shale, green shale and even limestone beneath the salt beds before they report red shale. The wells of Watkins and Ithaca report brown shale, limestone and green shale and only a little red shale. The bulk of these beds may be assigned to the Vernon even though they lack the red color. Because of the lack of detailed study at these great depths below the surface we reach the none too satisfactory conclusion that, when the sediments become anhydritic magnesian lime mud rocks or marlites of brownish to grayish color with veinlets of saline minerals, we pass from the Vernon into the Camillus phase of sediments. This is a lithologic stratigraphic correlation, forced upon us by a lack of paleontological material.

The Salt and Salt Shales

The crude rock salt, as mined, is grayish white in color, composed of 96 to 98 per cent sodium chloride in coarse well-crystallized grains. The remainder of the rock is composed of "shale" and "waterlime" substances: grains of anhydrite (not gypsum), sylvanite (potassium chloride), polyhalite ($\text{H}_2\text{Mg}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$), carnallite ($\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$), pyrite, carbonaceous matter with traces of quartz, feldspar, hornblende, leucoxene, etc. The shale and waterlime masses are composed of magnesian bearing calcite, dolomite, quartz, weathered feldspar, colloidal iron and aluminum hydroxides, sericite, paragonite, chlorite, leucoxene, pyrite, hornblende, pyroxene and indefinite flaky minerals.

Shale and waterlime masses included in halite frequently appear corroded, giving rise to concave surfaces and "dreikanter" shapes. These masses vary in size from 10 mm to .004 mm. No rock salt, no matter how pure, except the recrystallized veins cutting the minable salt, are entirely free from such matters. These particles are frequently connected by rods and branching needles of carbonaceous matter. Above and below the mine horizon the rock contains more shale, waterlime and anhydrite, passing into anhydritic, magnesian lime-mud rocks with irregular masses and veins of halite. It is in these beds, associated with and interbedded with the rock salt, that the rarer saline minerals such as sylvanite, carnallite, polyhalite, calcium chloride etc. are especially situated. These beds vary in color from blue gray, through buff, to a yellow brown. Some are massive like ordinary limestones, while others are fragile shales. Our nomenclature of sediments utterly fails in attempts to describe them. They possess in an indistinct manner a shaly structure, but in composition they are magnesian-lime-rich substances. Their fine grain and colloidal iron and aluminum hydroxides apparently are responsible for their shaly structure. Sericite, chlorite, epidote and other flaky and micaceous minerals materially contribute to their make-up. Quartz and weathered feldspars rarely fail.

The Camillus

The New York State Survey refers to the bed situated between the rock salt and the base of the Bertie series as the "Camillus shale." In a general stratigraphic sense the term "shale" is satisfactory. But in dealing with it in detail, a necessity in this investigation, we find that it is not a "shale" in the sense that we apply the term to the Hamilton series. At the type locality, Camillus, it is a fine-

grained, massive, ashen gray magnesian-lime mud rock with "salt-hopper crystals," with occasional secondary mineralization in zinc-blende, galena, pyrite, marcasite etc. All through it calcium sulphate occurs in veins as secondary enlargements and plumose masses. If the specimen was secured from beneath the surface, as from shaft walls, the calcium sulphate is in the form of anhydrite. If, however, it was obtained from an outcrop the substance is always gypsum. There are a number of distinct horizons which are richer in calcium sulphate. The minable gypsum zone varies from 50 to 150 or more feet below the base of the Bertie series. There is evidence that the gypsum occurs as lenses and not as distinct beds. These lenses may be a mile in length along the strike, but even then pinch and swell. There are other zones, layers and lentils of more argillaceous substances interbedded in these magnesian-lime mud rocks which apparently do not extend any great distance along the strike. It is with great difficulty that a sufficiently extensive outcrop can be found to ascertain the exact behavior of individual masses. Comparisons of the modernized records of the Lehigh, Livonia and Retsof shafts reveal that satisfactory correlations with the Devonian formations can be made, but identification and correlations of the rocks below the Bertie are very uncertain.

It ought to be obvious that our knowledge of the beds situated directly beneath the uppermost salt bed of commercial thickness is very scanty. The majority of salt wells stopped either in or just below it. What information is available has been secured through the courtesy of the mine managers of the Retsof and the Sterling companies (Mr Moynes of the Retsof Mining Company and Mr Fetherston of the Sterling Salt Company). The specimens placed at my disposal show that the salt is directly associated with and is part of the Camillus type of rock. So indefinite is the actual information about the Camillus that two distinct and opposite views are held; one that the term is satisfactory in view of the scarcity of knowledge; and the other that it is a mistake to affix a single label to 350 feet of rock of such character. An acquaintance of mine, a capable geologist, expressed his feelings in a humorous mood, "There is no such thing as the Camillus." I agree with him in spirit but am not inclined to carry the implication into actual practice.

As the Camillus is not a rock type listed among the usual sediments, it may be that in forcing a name upon it we are stretching too far our habit of assigning definite geographical names to stratigraphic units.

In giving the term "Syracuse" to the rock salt, the New York Survey sought, very commendably, to honor the "late" Salt City, and to furnish a convenient term by means of which correlation tables could be prepared with an appearance of finality otherwise impossible. On the other hand, the multiplicity of the salt beds, their lithological and probable genetic associations with the Camillus type of rock, render the name of doubtful value in any detailed stratigraphic discussion. In the proposed, and admittedly provisional, correlation given in table 6, I have used the "Camillus" to include the "Syracuse."

Great difficulty is experienced in establishing the base of the Camillus in view of the accumulated facts. The nomenclature of the state survey calls the contact of the bed of rock salt and the overlying "shales" the base of the Camillus. This can hardly be satisfactory. As is indicated above, the salt frequently occurs in more than one bed; the intervening rocks are of the Camillus type. The recently acquired information from the Retsof and Sterling shafts shows that a succession of salt, salt and anhydritic magnesian-lime mud rocks lie beneath the mine horizon. Other and less reliable well records, more particularly in central and southern portions of the State, show that the Camillus type of rock continues below the commercial salt horizon for 20 to 50 feet or more. The passage into the Vernon may be abrupt or gradual. I do not know which it is. This matter is discussed again when we deal with the sedimentation and the distribution of the Salina series.

The Bertie Series

Above the Camillus in central and western New York lie the Bertie and Akron waterlimes. Early attention was directed to the Bertie because one of its prominent members furnished suitable material for the manufacture of hydraulic cement, an industry long since replaced by the production of Portland cement.

Chadwick has made a preliminary study of the Bertie in Western New York (1917, p. 173). He recognized that the Bertie is not a lithologic unit, and that it was possible to subdivide it into:

Williamsville shale
Scajaquada shale
Falkirk waterlime
Oatka waterlime

The rock quarried and mined for the manufacture of hydraulic cement is a grayish buff fine-grained argillaceous dolomitic limestone. Grabau would call it an argillaceous calcilutite.

A chemical analysis of an average specimen (Clarke & Ruedemann, 1912, p. 101) is given below:

TABLE 7

Analysis of Bertie Waterlime at Buffalo (?)

Si ₂ O.....	11.48
Al ₂ O ₃	17.50
FeO & Fe ₂ O ₃	0.90
CaCO ₃	42.75
MgCO ₃	20.35
K ₂ O.....	1.00
NaCl.....	0.80
H ₂ O and loss.....	5.22
Total.....	100.00

An inspection of this shows that the rock is an impure limestone, high in magnesia, silica and alumina.

O'Connell says that at Buffalo the Bertie "follows upon the Camillus shales and gypsum, a part of which may belong to the undoubted Salina . . . but the upper part of which certainly belong with the Bertie to the upper Monroe [recent studies would suggest lower Monroe as correct] since it contains *Leperditia scalaris* (1916, p. 107). This conveys the impression that no stratigraphic break occurs at the top of the Camillus and that the passage of that into the Bertie is continuous although the conditions of sedimentation of the two were somewhat different. This conclusion is based upon paleontological evidence. On the other hand, Chadwick suspected that the Bertie waterlimes "rest with an irregular, apparently disconformable contact, upon the ashen pitted shales of the Camillus" (1917, p. 173). This suggestion has been substantiated at one locality; north of North Le Roy, at Fort Hill. There the lowest beds of the Bertie rest upon the Camillus, the contact being well exposed. By careful measurements it was shown that the pitted gypseous shales are diagonally truncated by the lowest member of the Bertie series. How widespread or important this unconformity will prove to be it is impossible to state at the present time. The paleontological evidence would suggest that the time break was of short duration. Stratigraphically, however, there is a break.

An examination of the relative position of the gypsum beds and the Bertie shows that sometimes the former are situated directly beneath the Bertie, while in other localities they lie a hundred feet or more below. Even though it is realized that the gypsum is probably situated in layers, lentils or lenses which are not continuous over great distances, yet this indicates that an unconformity is situated at the summit of the Camillus. Mr Newland has already observed this peculiarity, but the full significance does not seem to have been appreciated.

Above the Bertie is the Akron dolomite or waterline. There is a difference of opinion whether the Akron, which is five to seven feet in thickness, is or ought to be included in the Bertie series. All examinations of the contact show no unconformity at all. This question does not need to be settled here as it is really of small moment to this investigation. In the correlation chart, table 6, the Akron is not included in the series.

The upper beds of the Camillus are quite similar to the Bertie in that they consist of heavily bedded waterlimes and platten dolomites, and calcareous shales. They are very similar in general appearance and under the petrographic microscope, even though they contain the wrong ratio of silica, alumina, lime and magnesia for hydraulic cement contain more gypsum than is permissible. This similarity between the two formational series has made it practically impossible for the driller to distinguish between them. This is the cause of many peculiarities in the well records which sometimes report "waterlimes" for many feet below the top of the Camillus.

Chadwick (1917, p. 173) in an abstract shows that there is marked unconformity between the Bertie-Akron series and the Oriskany-Onondaga formations. The Oriskany-Onondaga is found resting upon the Akron in some localities, and at others the Akron, Williamsville and Scajaquada are missing, so that the contact is between the Oriskany-Onondaga and the Falkirk member of the Bertie. The variation of the thickness of the rocks, as penetrated by the drill, due to this unconformity is not greater than 30 to 50 feet.

The Oriskany Sandstone

This Devonian sandstone is a coarse-grained rock composed almost entirely of semirounded quartz grains cemented by silica that has enlarged the grains. A few rhombs and irregular masses of dolomitic calcite are present. Small amounts of various feldspars, pyroxene, amphibole, garnet, magnetite etc. complete the list. On

the outcrop it varies in thickness from a maximum of nearly a foot to total absence. In dipping to the south it thickens, as is indicated by the fact that the salt wells in the Ithaca region report from 13 to 32 feet of Oriskany.

It is possible that the Oriskany is situated between two hiatuses or stratigraphic breaks. The lower unconformity marks the horizon of the Manlius and lower Helderberg series, a group absent along the strike in Western New York but present in Eastern New York, and in partial degree encountered in the wells and shafts in the southern portion of the salt field. The study of the Livonia Shaft diagram, as given by Luther and interpreted by Clarke (Luther and Clarke, 1893) in the light of our present knowledge, shows that the Manlius and the Rondout formations are present even though they do not outcrop. The uncertainties attached to the well records located in the southern portion of the salt field fail to indicate just what members of the Manlius and lower Helderberg group are present. It would appear, however, that they wedge in from the south.

The "Springville" Sandstone

At Oak Corners, in the Phelps quadrangle, a peculiar black pebbly conglomerate has been obtained (Chadwick, 1917, p. 42). It contains fragments of waterlimes and the cement is chloritic and serpentinous. These waterlimes are more like the subjacent Akron of the Bertie-Akron series than they are like the normal Onondaga. It may be that this rock is a lateritic deposit indicating an erosional interval. Further information about this probable break is necessary before its significance can be obtained.

The Unconformities

Above the Oriskany sandstone is still another unconformity. In eastern New York the Esopus and Schoharie formations are present above the Oriskany and below the Onondaga. The Oriskany is erratic in that it often presents merely a narrow streak of sandstone, frequently absent and only occasionally reaching its maximum thickness of a foot. Consequently, any unconformity that cuts out the Oriskany can only be of minor significance when the Manlius, lower Helderberg (Alling, 1923), Esopus and Schoharie strata are absent. When the Manlius and Rondout appear, as they do in the southern area, the unconformities associated with the Oriskany are important, since they render uncertain any calculation of the depth of the salt below the surface based upon the thickness of the rocks.

The various unconformities recognized as actually existing between the Onondaga and the rock salt beds are as follows :

Onondaga
Unconformity
Oriskany
Unconformity
Lower Helderberg
Unconformity
Manlius
Unconformity
Akron
Bertie Series
Unconformity
Camillus
Rock Salt ("Syracuse")
Vernon
(Pittsford)

The full significance of these unconformities has not been fully appreciated. To the salt manufacturers these have a bearing upon the depth of the salt below the surface, or below a definite datum plane. A convenient datum plane is the Onondaga limestone, for the cherty nodules within this formation are easily recognized by the driller. Merrill has published a chart (1893) showing the position of the salt beds with reference to the top of the Onondaga limestone. The salt lies from 375 to 975 feet below this plane. These figures mark the extremes; the wells at Dansville and at Dundee supplying these limits. In the Oatka-Genesee district the salt is usually found to lie at levels from 550 to 750 feet below the top of the Onondaga. Merrill experienced the same difficulty in constructing a contour map of the salt beds that I have. He felt, in view of the many uncertainties associated with the well records, that he was not justified in drawing conclusions directly from them. He employed the more conservative plan of obtaining the *average* depth of the salt beds below the top of the Onondaga. He found that if the figure of 610 feet was taken, it intersected the majority of the beds and upon this based his contour map, a map that is very suggestive, but possibly misleading unless fully understood. It is really a contour map of the Onondaga limestone with the figure 610 feet too low. Merrill's method thus ignores the unconformities above noted (see page 80 and figure 14)

STRATIGRAPHIC PALEONTOLOGY

The Salina of New York is not rich in fossils; hundreds of feet are absolutely barren of organisms. Hence, in a general way the paleontologist has not been attracted to the Salina as a fruitful field. What paleontological specimens have been secured are very significant, and, at the same time, perplexing.

The Guelph Fauna

We commence our paleontological review with a study of the Lockport, which lies beneath the Salina.

Clarke and Ruedemann (1905, p. 114-18) have thoroughly studied the Guelph fauna and conclude that "the species on the whole are either large and heavy shelled or diminutive and thin shelled. . . . More than one consideration suggests that increasing salinity assisted the development of the thick shelled mollusks. We must look upon the Guelph as a distinct phase in the development of the vast Niagaran coral sea into the desiccating, inclosed sea of the Salina stage, when the salinity of the water finally destroyed all life. . . . It is therefore legitimate to conclude that the enclosure and desiccation of the continental Niagaran sea had already begun to manifest its influence."

"The dolomite series from top of the Rochester shale into the Salina beds shows an irregular increasing magnesian content and increasing salinity. . . . Dall (1894, p. 113) [says] that in the salt lagoons or salt pans of the Bahamas the effect of [increase in salinity] . . . is shown in the diminished size and thin shells of the mollusks and among the gastropods in a tendency to irregularity of coil effacement of sculpture. Such extreme conditions may be conceived to have led to the depauperation and actual extinction of the fauna of the Salina stage."

Clarke and Ruedemann (1905) have shown that in a number of localities the passage between the Lockport and the Vernon (Pittsford) is an "interlocking boundary." At Farmer's Mills, a few miles south of Clinton, I found that the so-called Lockport consists of four or five thin beds of dolomite (which assume an arched form) separated from each other by a bed of blue black shale. The upper beds of the black shale pass gradually from dark green, green, mottled green and purple into red shales. The boundary is more than interlocking at this locality; it is gradational with no evidence of erosion prior to the deposition of the Vernon. In one of the

dolomitic shaly layers the huge eurypterid, *Eusarcus vaningeni*, has been found, suggesting the Pittsford phase. The gradational character of the beds, their lithological and paleontological aspects show that the marine conditions of the Guelph-Lockport, with increasing salinity, continued up to and into the Vernon.

The Guelph-Lockport group pinches out from west to east in the State, and is entirely wanting before Herkimer county is reached. "Moreover, rocks of Lockport age are wanting entirely in the Appalachian region to the south of Maryland. . . . But the absence of the Lockport in eastern New York is not due to erosion prior to its overlap by the Salina, nor is there any evidence to show that the Lockport was deposited in the Appalachian region between eastern New York and Tennessee and then removed by erosion before Cayugan [Salina] sediments were laid down in the same region." (Swartz, 1923, p. 245-46).

The Pittsford Fauna

The discovery of eurypterids by Sarle (1901-03) from the Pittsford horizon of the Vernon, and their detailed study by Clarke and Ruedemann (1914), Ruedemann (1918, p. 3, 4), Grabau (1913, p. 498) and O'Connell (1916, p. 1-278) has shed a great deal of light upon the conditions under which the base of the Vernon was deposited. At the same time it has given rise to wide difference of opinion regarding the habitat of these interesting organisms.

At a number of localities eurypterids have been found in thin black carbonaceous, argillaceous dolomites, which are imbedded with green, purplish and mottled shales of the basal Vernon. The finding of these organisms lead the state survey to propose the term "Pittsford shale." Stratigraphically, however, I am inclined to regard this fossiliferous zone too erratic to justify formational rank. To name merely transitional beds, which occasionally supply eurypterids, the "Pittsford" unquestionably emphasized this assemblage.

Clarke and Ruedemann (1914) believe that the eurypterids were able to live in very salty and brackish waters and therefore indicate such conditions during Vernon times. The finding of lingulas, pterineas, cephalopods and salt hopper crystals in the same slabs with the eurypterid remains would seem to exclude the possibility that fresh water conditions prevailed at this period.

On the other hand, Grabau and O'Connell, following Chamberlin, regard them as indicative of fresh water conditions. O'Connell, in

an elaborate paper, reached the conclusion that the Eurypterida lived in the rivers and were swept into marine waters on entering the epicontinental seas or salt lagoons.

Ruedemann says: "It is clearly a dangerous begging of the question to make . . . [the eurypterids] either fresh water animals that were drifted into the marine assemblage, or have the latter, with its countless specimens, conveniently drift into fresh water with the waiting eurypterids" (1916, p. 115).

Additional light has recently been thrown upon the problem of the habitat of the Eurypterida by the studies of Versluys, Demoll and Pompeckj (Versluys, 1919; Versluys and Demoll, 1922; Versluys, 1923), as shown by Ruedemann (1924, p. 227-32). Versluys and Demoll conclude that the ancestors of the eurypterids were evolved from land animals. These derived organisms went directly into the sea. Pompeckj holds that the ancestors of the eurypterids "spread from the land into fresh water and thence intermittently into the sea" (Ruedemann, 1924, p. 227-32). Ruedemann (1923) has stated that he believed that the study of the Vernon and Pittsford faunas indicated conditions of more or less abnormal salinity, mostly higher than normal, and suggestive of shore lagoons along flat coasts of desert lands.

Chadwick (1919, p. 152) noted in the more recently discovered horizon of the recurrent Pittsford fauna, *Leperditiae*, *Emelezoe decora* and *Ceratiocaris salina*, occurring on the same slab with eurypterid remains. He says: "The indications are not favorable to a fresh water habitat for [the eurypterids]."

Swartz (1923, p. 209) says: "It is manifest that the [lower] Cayugan of New York was ushered in by the formation of extensive deposits of salt associated with arid climatic conditions. While we can not correlate the beds of this period in New York with those of Maryland by fossils, since there are none [note beyond] above the Pittsford in the former state, it is highly probable that salt was deposited in Maryland and New York at essentially the same time, since they are parts of one province. It is, moreover, probable that the conditions which produced aridity would affect the climate of both areas at the same time. As a matter of fact we find imprints of salt crystals in the strata of Maryland, indicating arid conditions here. It is also significant that these salt crystals are underlain by red deposits in Maryland as in New York but with this difference: The red deposits occupy the entire interval between the Pittsford and the salt beds in New York, while they appear only at the base of the Wills Creek in Maryland where salt crystals appear at the top of the formation."

Sarle says: "It is thus seen that preparatory, as it were, to the coming of the Salina fauna, there was a change in physical conditions. The shallowing of the sea, with a probable increase of salinity and turbidity of waters, probably had more than anything to do with the displacement of the Niagara fauna" (1902, p. 1085). Whichever view we are inclined to accept regarding the habitat of the eurypterids, the evidence furnished by these organisms points to saline conditions during the deposition of the basal beds of the Vernon. There may have been fresh water rivers flowing into this desiccating sea. The salinity of the Vernon was, without much question, greater than that which prevailed during Guelph-Lockport times.

The following is a list of the forms found in the Pittsford and basal Vernon (Ruedemann, 1919, p. 205-6).

Upper Zone

- Lingula semina* Ruedemann c (also in lower zone)
Lingula sp. rr
Rhipidomella sp. rr
Atrypa reticularis (Linnaeus) (characteristic Silurian and Devonian throughout world)
Trochoceras aff. *costatum* Hall rr
Hexameroceras chadwicki Ruedemann rr
Worm borings cc
Leperditia scalaris Jones cc (also in Falkirk of Bertie series)
Leperditia sp. r
Emmelzoe decora Clarke r
Ceratiocaris salina Ruedemann cc
Ceratiocaris cf. *praecedens* Clarke rr
Eurypterus pittsfordensis Sarle cc
Mixopterus multispinosus (Clarke and Ruedemann)
Hughmilleria phelpsae Ruedemann rr
Pterygotus vernonensis Ruedemann rr

Lower ("Pittsford") Zone

- Lingula semina* Ruedemann cc (also in upper zone)
Pterinea postriata Ruedemann cc
Hexameroceras cf. *chadwicki* Ruedemann rr
Orthoceras sp. rr
Leperditia scalaris Jones cc (also in upper zone and Falkirk of Bertie series)
Emmelzoe decora Clarke r (also in upper zone)
Pseudoniscus roosevelti Clarke rr
Ceratiocaris praecedens Clarke rr
Eurypterus pittsfordensis Sarle c (also in upper zone)
Mixopterus multispinosus (Clarke and Ruedemann) rr (also in upper zone)
Hughmilleria socialis Sarle c
Hughmilleria socialis var. *robusta* Sarle rr
Pterygotus monroeensis Sarle rr

Vernon Fauna

Chadwick (1919, p. 205) has noted ostracods in the red Vernon. Eaton (1924, p. III, 112) lists the following species:

- | | |
|---|--|
| <i>Leperditia scalaris</i> (Jones) | <i>Poleumita scamnata</i> Clarke and Ruedemann |
| <i>Calymene? niagarensis</i> Hall | <i>Streptomytilus?</i> cf. <i>eduliformis</i> (Clarke and Ruedemann) |
| <i>Phragmoceras</i> sp. | |
| <i>Diaphorostoma? niagarensis</i> (Hall)? | |

Cuneamya cf. *alveata* Whitfield and Hovey
Ctenodonta cf. *salinensis* Ruedemann
C. ruedemanni nov.
Pterinea cf. *poststriata* Ruedemann
P. rotunda nov.
P. jordani nov.
P? sp.

Orthodesma? sp.
Camarotoecchia litchfieldensis
 (Shuchert)
Lingula veroni nov.
Cornulites hopkinsi nov.
Kloedenia normalis U. and B.
Dizygopleura acuminata U. and B.

The last two . . . "species are particularly characteristic of the lower part of the Wills Creek and the upper part of the McKenzie formation in Maryland, hence of the position to which [Ulrich] has assigned the Vernon shale" (See Maryland Rep't, 1923, p. 267).

"The fauna is marine, and flourished apparently in a solution concentrated enough to allow of the occasional crystallization of halite. This interesting fact may aid in the determination of the origin of the Vernon formation."

Camillus Fauna

The lamellibranch *Ctenodonta salinensis* Ruedemann has been found at various horizons in the Camillus: Bull's quarry, Lenox, Madison county, Bellisle, Onondaga county, and at Garbutt, Livingston county. Ruedemann (1916, p. 75-76) comments about the specimens from Lenox as follows: "The sole interest in this insignificant little pelecypod consists in its occurrence in the Salina beds close to the gypsum beds. . . It is a true Salina species. It must have been quite common locally, for we have before us, on a slab measuring 3 by 4 inches, some 18 specimens. Mr Hartnagel states that he has also observed a *Leperditia* in the Salina beds, and wormtubes and tracks are seen on the other side of the slab with [*Ctenodonta*] *salinensis* and these are the only signs of organic life in the Salina beds of which I am aware, even this little life seems out of place considering the conditions indicated by the repetition of salt and gypsum beds, hopper-crystals etc."

I found, in company with Mr Hartnagel, similar specimens of a pelecypod at Garbutt six feet below a layer of gypsum nine inches thick. Doctor Ruedemann (1923) says that it is "undoubtedly identical with the *Ctenodonta salinensis* Ruedemann which I described from the Salina beds [Camillus shale] at Bull's quarry, town of Lenox, Madison county. I have since found also a slab in the old collection of typical rocks in the [New York State] Museum, that is covered with poor specimens of the same form. It is from . . . [the Salina] near Bellisle, Onondaga county, N. Y."

At Saltspringville, Schoharie county, I found a graptolite in the Brayman shale of Grabau (1906), which is without much question the eastern extension of the Camillus. This was submitted to Doctor

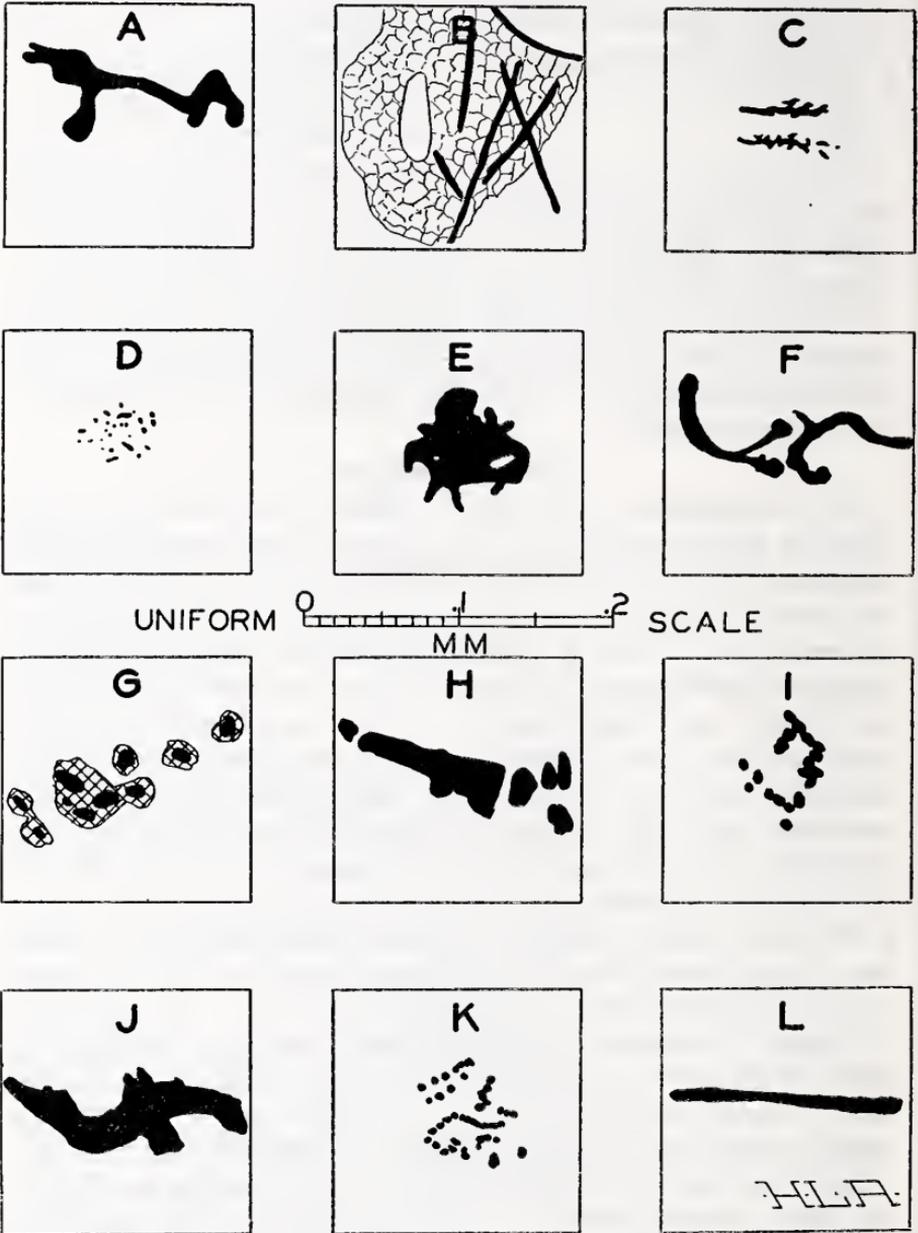


Fig. 2 Camera lucida drawings of carbonaceous matter in calcareous sediments to illustrate the organic remains found in the Vernon and Camillus beds. All are drawn to a uniform scale, magnification about 180 diameters.

Ruedemann for identification. He reports as follows: "The graptolite is a form of *Palaeodictyota*, near *Palaeodictyota clintonensis* Ruedemann, but judging from the imperfect specimen, having smaller and relatively narrower meshes . . . [it is] probably a new form" (1923, personally communicated).

Explanation of figure 2

- A Carbonaceous matter in Camillus lime-mud rock directly associated with red salt, bottom of Greigsville shaft. (1903)
- B Carbonaceous (?) matter found on dissolving red salt from Greigsville shaft. (1903A-dt)
- C Carbonaceous matter in Camillus "shale" 12 feet above main salt bed of the Sterling Salt Company, Halite, N. Y. (1722)
- D Carbonaceous matter in Camillus lime-mud rock veined with white, red and brown salt, three feet above main salt bed, Sterling shaft. (1725)
- E Carbonaceous matter in Camillus lime-mud rock, dark colored, impregnated with salt forming the footwall of the Sterling mine.
- F Carbonaceous matter in Rochester (shaley limestone) "shale," Barge canal, South Greece, near Rochester. (1419)
- G Carbonaceous matter coated with (organic?) pyrite in recurrent (upper) eurypterid bearing Vernon shale, Pittsford, N. Y. Sometimes the relations of the carbonaceous matter and pyrite are reversed; the carbonaceous matter coating pyrite. (957)
- H Carbonaceous matter in "Reynales limestone," Clinton group, Genesee Gorge, Rochester. 58 inches below *Pentamerus oblongus* zone. (1700)
- I Carbonaceous matter in nodule in salt being mined, Sterling Salt Company. (1727A)
- J Carbonaceous matter in Coeymans limestone, west of Catskill. (5-C-13-282)
- K Carbonaceous matter in green spot in red Vernon from Vernon, N. Y. Carbonaceous matter occurs in the red rock as well but the iron oxide obscures it to the extent that a camera lucida drawing is difficult to make. (954)
- L Carbonaceous matter in red Vernon shale, Spring House locality, Pittsford, N. Y. (1002g)

Petrographic studies of the Camillus rocks under the microscope in thin-sections reveal carbonaceous matter. This takes various forms, some of which are shown in figure 2. The common forms or shapes are long narrow ribbons reminding me of small thin flakes of graphite viewed in longitudinal sections. Usually they are 0.1 to 0.15 mm in length and 0.01 to 0.02 wide. The other form consists of round pellets about .002 mm in diameter, frequently arranged in rows like beads strung on a string. These "strings" of carbonaceous pellets are twisted into loops which take on the appearance of letters and figures such as F, L, 7, 0 and 9. Carbonaceous matter of this kind is distributed throughout the Camillus. Of the 30 slides examined only four failed to show carbonaceous matter. It occurs in salt shales, above and below the mine horizons of the Retsof, Sterling, Greigsville, and Livonia shafts; in the lime-mud rocks directly associated with the anhydrite taken from the mine shafts and in the gypsum bearing layers now worked for gypsum.

For comparison similar examination of thin sections of calcareous rocks deposited under more normal marine conditions show them in exactly the same way, perhaps more abundantly. The Rochester, Depew, Lockport, Trenton, Chazy, Coeymans and other limestones and shaly limestones present carbonaceous matter in the identical forms found in the Camillus.

Dr David White, on seeing the carbonaceous matter in these salt and anhydritic rocks, expressed the view that it was organic carbon, and suggested that it may have been derived from algae. In Great Salt Lake, where the salinity is 22 per cent to 25 per cent or seven times the salinity of sea water, the fauna and flora are scanty; "there are a few algae, the larvae of an *Ephydra* and of a *Tipula* fly . . . [and] the brine shrimp, *Artemia salina*" (Enc. Brit. 1910, p. 422). Many calcareous and siliceous sediments as deposited contain iron as limonite, hematite or chloritic minerals. During the metamorphism subsequent to deposition this iron may combine with the sulphur that is frequently present in muds as hydrogen sulphide, derived from decaying organic matter, to form pyrite. In the graphitic schists pyrite has acted as a center about which the graphite has aggregated. A similar process has evidently taken place in the Camillus lime-mud rock but to a lesser degree because the rocks have suffered less metamorphism (or "epimorphism") (Alling, 1925).

Pyrite, as well as the carbon, is regarded as indicative of organic matter in the Camillus.

Complete correlations of the Salina formations of New York with those in Maryland, on the basis of fossils, are impossible. The New York rocks are too scantily supplied with paleontological remains to be of any correlative value. Such organisms as we are accustomed to regard as excellent index fossils in New York have been found to have an extensive vertical range in Maryland. For example, the Wills Creek is certainly of Salina age, and probably equivalent to the Camillus in a general way, and perhaps to the Bertie as well; yet the Wills Creek contains *Spirifer vanuxemi*, which we find as a typical fossil of the Manlius limestone of this State. The same fossil occurs in the Tonoloway formation of Maryland. The striking fact about the presence of *Spirifer vanuxemi* in the Wills Creek is that it occurs *below* the beds with imprints of salt crystals. The conclusion therefore reached is that correlation upon paleontological evidence alone is impossible; similarly correlation upon lithology may be misleading. The McKenzie, Bloomsburg and Wills Creek taken as a unit are probably synchronous with the Vernon (with its eurypterid zones), the salt and the Camillus. This is more fully discussed in the chapter on sedimentation. Since it is impossible to compare the faunas of the lower Cayugan (Salina) of New York and Maryland it is necessary to examine the faunal content of the upper Cayugan.

There are four species of the Wills Creek that are common to the Cayugan of New York: *Spirifer vanuxemi*, *Camarotoechia litchfieldensis*, *Calymene camerata*, and *Schuchertella interstriata*. They are found in the Cobleskill and Rondout of New York, Raisin River of Michigan and Ontario, the Lucas, Amherstburg and the Greenfield of Ohio and the Wills Creek and the Tonoloway of Maryland.

Camarotoechia litchfieldensis and *Calymene camerata* are found in the Wilbur and Cobleskill of New York, in the Wills Creek of Maryland, the Tonoloway and Keyser formations, and also in the Decker Ferry of New Jersey. *Spirifer vanuxemi* is restricted to the Manlius in New York, but it ranges from the Wills Creek through the Tonoloway into the Keyser in Maryland.

The top of the Wills Creek carries eurypterids which suggest the Bertie series of New York.

The Bertie Fauna

The fauna of the Bertie series has for some time been of interest. Specimens of eurypterids from Buffalo are to be found in many museums.

The Akron and Bertie can be tabulated, following Grabau, Chadwick (1917, p. 173) and Williams (1919, p. 85), as follows:

Akron dolomite with <i>Cyathophyllum hydraulicum</i>	12 feet or less
Williamsville cement bed carrying eurypterids.....	6
Scajaquada dark shales and blocky waterlimes and at base, the Bridgeburg horizon with eurypterids.....	8
Falkirk dolomite, with marine fauna, but eurypterids at base	30
Oatka beds, dark grey and shaly with a blocky waterlime at base carrying eurypterids.....	20 or less

The fauna and flora of the Akron and Bertie series in the Erie district is as follows:

Akron:

- Nematophycus crassus* (Penhallow) horizon doubtful
Cyathophyllum hydraulicum Simpson
Schuchertella interstriata (Hall) (also in Raisin River of Michigan and Ontario, Lucas and Greenfield of Ohio, Cobleskill of New York, Wills Creek and Tonoloway of Maryland)
Spirifer eriensis (Grabau)?

Williamsville:

- Inocaulis lesquereuxi* (Grote and Pitt)
Lingula testatrix Ruedemann
Diaphorostoma sp.
Hercynella patelliformis O'Connell
Hercynella buffaloensis O'Connell
Hormotoma gregaria Ruedemann
Orthoceras vicinus Ruedemann
Phragmoceras accola Ruedemann

Bertie (Eurypterids)

- Dolichopterus macrocheirus* Hall
Dolichopterus siluriceps Clarke and Ruedemann
Eurypterus dekayi Hall
Eurypterus lacustris Hall (Harlan)
Eurypterus lacustris var. *pachychirus* Hall
Eurypterus pustulosus Hall
Eurypterus robustus Hall
Eusarcus scorpionis Grote and Pitt
Pterygotus buffaloensis Pohlman
Pterygotus cobbi Hall var. *juvenis* Clarke and Ruedemann
Pterygotus grandis (Pohlman) Grote and Pitt

Falkirk (Chadwick)

- Whitfieldella sulcata* (Vanuxem) (*W. subsulcata* Grabau in Greenfield of Ontario)
Gomphoceras osculum Ruedemann
Leperditia cf. *scalaris* (Jones) (also in "Pittsford"-Vernon zones)
Orthoceras undulatum
Trochoceras gebhardi
Leperditia alia
Goniophora sp.
Proscorpius osborni

Bertie:

- Brachiopod — *Lingula* sp.
Pulmonate Gastropods — *Hercynella buffaloensis*

H. patelliformis

- Graptolites — "*Buthotrephis lesquereuxi*" (formerly considered seaweed, now identified by Ruedemann as graptolites)
Ceratiocarid — *Ceratiocaris acuminata*

Plant — *Chondrites graminiformis* (may be a graptolite)

(b) Bertie fauna of Herkimer district:

Eurypterids

Dolichopterus macrochirus

D. testudineus

Eurypterus remipes

Pterygotus macrophthalmus

P. cobbi

Associated forms — Scorpion

Proscorpius osborni

This list has been materially changed in its aspect by the more recent collections of Mr Reinhard and others. It reads now (new forms marked by asterisk):

(a) Bertie fauna and flora of Erie district:

Eurypterids, same as above in O'Connell's list

Associated forms

Plants

Algae

**Calithamnopsis silurica* Rued.

**Morania* (?) *bertiensis* Rued.

**Sphenophycus* (?) spec.

Corals

**Stromatopora* sp.

**Ceratopora* (?) sp.

Graptolites

Inocaulis lesquereuxi (Grote and Pitt)

**Palaeodictyota buffaloensis* Rued.

Medusaegraptus graminiformis (Pohlman)

**Orthograptus* (?) sp.

Pyrgocystis batheri Rued.

Cystids

**Pyrgocystis batheri* Rued.

Bryozoans

**Stigmatella* sp.

Brachiopods

**Lingula media* Rued.

**Orbiculoidea bertiensis* Rued.

Camarotocchia cf. *andrewsi* Prouty

Spirifer (*Delthyris*) *criensis* (Grabau)

Vermes

**Bertiella obesa* Rued.

**Serpulites* sp.

Mollusca

Lamellibranchs

**Rhytimya buffaloensis* Rued.

Goniophora sp.

Gastropods

Hercynella buffaloensis O'Connell

H. patelliformis O'Connell

**Loxonema bertiensis* Rued.

**Hormotoma gregaria* Rued.

Conularidae

**Conularia perglabra* Rued.

Cephalopods

**Orthoceras* sp.

Dawsonoceras oconnellae Rued.

Trochoceras cf. *anderdonense* Grabau

**Pristeroceras timidum* Rued.

Crustaceans

- Ceratiocaris acuminata* Hall
C. maccoyana Hall
 **Lepidocoleus reinhardi* Rued.
 **Emmelezoe minuta* Rued.
Leperditia alta (Conrad)
L. scalaris (Jones)

Merostomes

- **Bunaia woodwardi* Clarke
 **Hemiaspis* (?) *eriensis* Clarke

(b) Bertie fauna of middle and eastern districts:

Eurypterids

- Dolichopterus macrochirus* Hall
D. testudineus Clarke and Ruedemann
Eurypterus remipes Dekay
Pterygotus macrophthalmus Hall
P. cobbi Hall
 **Eusarcus trigonus* Rued.

Associated forms

- **Lingula subtrigona* Rued.
 **L. testatrix* Rued.
Orthoceras vicinus Rued.
 **Phragmoceras accola* Rued.
 **Pseudoniscus clarkei* Rued.
Proscorpius osborni Whitfield

A comparison of the two lists shows that the additions are all in the associated forms, that they consist of seaweeds, corals, graptolites, cystids, bryozoans, brachiopods, lamellibranchs, gastropods, cephalopods and crustaceans, or, in other words, of marine fossils.

The significance of the eurypterid fauna of the Bertie has been interpreted in two widely different ways: O'Connell (1916, p. 1-278), after her exhaustive study of Eurypterida with the purpose of establishing the habitat of these organisms, has reached the conclusion that the eurypterids lived in rivers. Her conception is that the Bertie at Buffalo represents the flood-plain or delta deposit from one or more rivers, perhaps built in playa lakes. Where the Bertie is eurypterid-bearing, the rock, she contends, was deposited above sea level, as a subaerial deposit. O'Connell states that in the Bertie plant remains have been found. "The plant remains are important, for many of the specimens of *Eurypterus* are found embedded in *Buthotrephis lasquereuxi* (1916, p. 87), and in one case there is a large mass of *Buthotrephis* at the side and on top of a *Eurypterus* . . . (Some of these specimens of *Buthotrephis* are now regarded as graptolites)." Hence O'Connell maintains that the eurypterids drifted into their present position and so became mixed with a marine or euryhaline fauna.

Ruedemann (1916), p. 113-15) attempts to refute O'Connell's belief that these organisms have drifted into a saline-marine assemblage by saying: "The *Buthotrephis* has been proved in this paper

to be a good sessile graptolite of the genus *Inocaulis*. It occurs in the waterlime in splendidly preserved colonial stocks, which can not have drifted any great distance. The lingulas and hormotomas [*Lingula testatrix* Ruedemann and *Hormotoma gregaria* Ruedemann] occur in certain layers in such immense quantities that they are certainly in their proper surroundings where found. . . . There is not in the whole assemblage of the Bertie waterlime a single genus that could be considered as indicative of a fresh water fauna, and all these marine forms are found on the same slabs with the eurypterids, so that an alternation of marine and fresh water conditions can not be assumed either."

Ruedemann "has for some time been engaged in the study of a new collection from the Bertie waterlime containing various graptolites, cephalopods and other marine forms, and it is his intention to take up again in . . . [a future] paper the problem of the habitat of the eurypterids, at least as far as the Bertie waterlime is concerned. It may be stated here that his conclusion of 1916, that the eurypterids of the Bertie waterlime are associated with a truly marine fauna, is greatly strengthened by the new material; furthermore, that the occurrence of the eurypterids there is such that they undoubtedly inhabited the sea at the localities where they are now found. . . . In regard to those of the Bertie waterlime, the assumption that they flourished as euryhaline forms in shore-lagoons . . . still accounts best for the peculiarities both of their distribution and of the strata in which they are found" (1924, p. 230-31).

In this promised paper (1925, p. 12-13) Ruedemann says that there is a "gradual graduation of the Bertie waterlime into the overlying . . . Akron dolomite" . . . and that is believed to be the "western continuation of the Cobleskill limestone." "The close connection of the . . . [Cobleskill] limestone with the Bertie suggests the view that the Bertie is a lagoon deposit formed behind coral reefs. The coral reefs during Bertie time were farther south extending from east to west or rather southwest, the coast lying north and the pool running from east to west. This hypothesis would explain a host of facts much more readily than Doctor O'Connell's delta hypothesis; especially the wide horizontal extension and relative thinness of the Bertie waterlime; the presence of "hopper-crystals" (salt skeleton crystals) in the Bertie such as are also found in the Camillus and which indicate a highly saline condition of the water; the appearance of a number of strange fossils . . . which point to conditions not normally marine, but well reconcilable with those

existing in the broad lagoons behind the reefs. Considering that the Bertie is underlain by the barren Camillus shale, denoting salt pan conditions and overlain by the marine Akron dolomite, it follows that a sinking of the land with resulting gradual invasion of the sea from the south is to be inferred. It is significant in this connection that all the fossils of the Bertie, inclusive of the eurypterids, are found, according to Mr Reinhard, in the uppermost Bertie beds, where the purely marine conditions of the Cobleskill were approached. The presence of marine conditions indicating open sea at the same time in the south and southwest (Pennsylvania, Maryland and West Virginia) is brought out by the work of Swartz (1923, p. 40-50) in Maryland."

The Culmination and Decline of the Salina Sea

Hartnagel (1903, p. 1158-60) has made a very suggestive summary of the paleontologic significance of the Salina of New York. It will be understood that Hartnagel regards the Cobleskill and the Bertie, certainly the Akron, as stratigraphic equivalents. The occurrence of Guelph and Niagaran species in the Cobleskill at the close of the Salina is very suggestive. The limits of the Salina deposits as now known are marked by lower (Pittsford) and upper (Bertie) Eurypteridus beds, signifying that the period opened and closed under similar physical conditions. If however, we start at the close of the Niagaran period, we find the first indication of increasing salinity, and with this change came the Guelph fauna (Clarke & Ruedemann, 1903). "With the ever increasing salinity of the waters the Guelph fauna retreats, and next in the black Pittsford 'shale' at the base of the Salina there occur Eurypteridi, and with them constantly associated a species of *Lingula*. With the retreat of this fauna we find, as physical changes went on, deposits of gypseous shales (Hartnagel, 1903, p. 1159) and later the salt beds. The deposition of these great beds of rock salt marks the turning point in this cycle, at which time the Salina sea contained very little if any water at all. With the increasing depth of the sea, beds of gypsum were again deposited, but never again were the conditions favorable for the deposition of extensive beds of rock salt." This can be expressed in another way, that the cycle of events from the salt beds upward, to and including the Cobleskill, is the mirror image of what went before from the Guelph up to the salt horizons.

SEDIMENTATION

The Vernon

The typical red Vernon shale has been interpreted by Grabau (1913, p. 569) as a land deposit of wind-blown loess. He maintains that the color alone is a safe criterion for terrestrial formations. The color is unquestionably dependent upon the oxidation of the iron content present in the clastics. Ferrous compounds produce greens, while ferric compounds result in browns and reds. The color of such sediments is modified by the presence of carbon, which tends to retain the iron in the ferrous condition. The actual amount of carbonaceous matter present, however, is small, and little or no difference in content has been seen in the green and red shales. Under the arid climatic conditions that undoubtedly prevailed at this time the amount of organic material was exceedingly limited, and consequently the carbon content of erosional débris was low, permitting the oxidation of the iron to the ferric condition and resulting in red colors.

W. J. Miller (1910, p. 150-56) applied this principle to the Vernon shale from Clinton and reached the conclusion that the color is due to the presence of dehydrated ferric oxide in a finely divided condition which reached that state through the agencies of pressure and moderate temperature subsequent to deposition. Barrell (1908, p. 290-91) reached a similar conclusion in regard to the beds associated with the salt and gypsum deposits of Nova Scotia (which are of later age than those of New York). I have studied the Vernon red shales from a number of widely separated outcrops and have reached the same conclusion regarding the origin of the color, and feel confident that it is the product of processes subsequent to its deposition. I differ, however, from Grabau, who considers it to be a loess deposit. I believe that it is the delta silt deposit of a river flowing from a desert area into playa lakes or lagoons. This is inferred from field work and from petrographic and chemical studies. Field observations show that the material is distinctly bedded, especially in proximity to the interbedded green shales near the base and top of the formation. Examples of sun cracks were found in a number of localities, especially along Steele's creek in the Ilion gulf. Cross bedding was suspected in a few instances.

The petrographic studies show that the quartz grains which make up 20 to 30 per cent of the rock are less than 0.1 mm in diameter and are very angular. Walther, (1903) (Grabau, 1913, p. 97) and others

believe that waves and rivers are incapable of rounding sand grains of that size or smaller, regarding wind action alone efficacious in the process. While it is difficult to arrive at a clear conclusion, yet the inference is strong, even from their own criteria, that the grains have not been subjected to wind action, but that they were water laid.

Further light upon the nature of the Vernon shale is obtained from a consideration of chemical analyses and their comparison in terms of mineral constituents, obtained by the process of recasting. The method of calculating the percentages of the component minerals is a duplex one; based upon quantitative microscopic analyses, (Alling, 1918, p. 50) and upon the application of the principles of the quantitative classification of igneous rocks (Cross, Iddings, Pirsson, Washington, 1903).

TABLE 8
Analyses of Vernon shale

	RED SHALE			GREEN SHALE	
	1	2	2a	3	4
SiO ₂	52.30	56.90	56.90	57.79	33.14
Al ₂ O ₃	18.85	24.14	24.14	16.15	11.26
Fe ₂ O ₃	6.55	6.26	6.26	5.20	2.31
FeO.....	.....	1.26	1.26	.....	1.06
CaO.....	3.36	.94	.94	2.73	16.50
MgO.....	4.49	1.37	1.37	4.67	8.77
K ₂ O.....	4.65	5.06	3.69	4.11	2.56
Na ₂ O.....	1.35	2.36	1.00	1.22	1.21
CO ₂	3.04	1.08	1.08	3.42	20.48
H ₂ O.....	5.30	4.36	4.36	4.50	2.88
Total.....	99.89	103.73	100.00	99.79	100.17

1 and 3 Specimen from Warner's Onondaga county, N. Y. State Mus. 49th Ann. Rep't v. 2, p. 692

2 and 4 Specimens collected by H. L. Alling, analysis by H. F. Gardner, N. Y. State Museum laboratories

2 Original analysis. Gardner reports that the alkalis are undoubtedly too high

2a is 2 altered to total 100, by reducing per cent of the alkalis

2 is from Oneida Center; 4 is green marlite from Pittsford, Monroe county

TABLE 9
Analyses of Vernon shale recast in terms of minerals

MINERAL, FORMULA	1	2a	3	4
Quartz, SiO ₂	20.88	18.67	31.75	14.26
Sericite, KH ₂ Al ₂ (SiO ₄) ₃	32.16	27.07	37.30	17.53
Paragonite, NaH ₂ Al ₂ (SiO ₄) ₃	13.91	10.66	8.13	12.45
Chlorite, H ₂ Al ₂ (Mg,Fe) (SiO ₄) ₃ ·3H ₂ O.....	7.36	4.12	11.85	1.95
Epidote, Ca ₂ Al ₂ (AlOH) (SiO ₄) ₃	8.28	1.75	2.91	5.74
Dolomite, (Ca,Mg)CO ₃	6.18	2.58	7.32	43.10
Kaolinite, H ₂ Al ₂ (SiO ₃) ₂ ·H ₂ O.....	8.81	28.05	.....	.....
Hematite, Fe ₂ O ₃	2.00	5.75	.....	.....
Water, H ₂ O.....	.81	.35	.....	1.08
Salt, NaCl.....	.....	.....	.65	.....
Gypsum, CaSO ₄ ·2H ₂ O.....	Trace	Trace	Trace	Trace
Total.....	99.39	100.00	99.91	96.20

Now it has been suggested that the Vernon is a consolidated loess deposit and hence a comparison of analyses of loess with those of the shale will be illuminative.

TABLE 10
Analyses of Loess

	5	6	7
SiO ₂	60.69	71.20	67.10
Al ₂ O ₃	7.95	18.56	11.76
Fe ₂ O ₃	2.61	1.34	3.35
FeO.....	.67	.15	.56
CaO.....	8.96	.14	4.08
MgO.....	4.56	.52	2.06
K ₂ O.....	1.08	.32	2.03
Na ₂ O.....	1.17	1.26	1.39
CO ₂	9.62	.....	3.47
H ₂ O.....	1.14	6.30	3.79
Accessories.....	1.16	.88	.....
Total.....	99.61	100.67	99.68

5 Loess, Vicksburg, Miss. Chamberlain and Salisbury. 6th Ann. Rep't U. S. G. S. p. 282

6 Loess. Fuller and Clapp. Geol. Soc. Amer. Bul. v. 14, p. 159

7. Average of seven analyses, F. W. Clarke, U. S. G. S. Bul. 616, p. 510

The loess shows a higher silica content than the Vernon, a deficiency in alumina, ferric and ferrous oxides, and potash. The shale contains more potash than soda, while the loess contains the alkalis in the reverse order or in nearly equal amounts. It must be remembered, however, that the loess is comparatively unconsolidated and that the minerals are but little decomposed (katamorphosed) in contrast to the shale. This fact is strikingly demonstrated when analysis (7) is recast. The analysis itself forbids recasting on the basis that the component minerals are the hydrated, micaceous forms. They are probably therefore unaltered feldspars etc., as is shown in analysis (7').

TABLE II
Average analysis of seven Loesses recast

	7' ORIGINAL UNCON- SOLIDATED	7'' INDURATED INTO A SHALE
Quartz.....	45.25	49.00
Sericite.....	12.66	14.90
Orthoclase, $KAlSi_3O_8$	3.22	.....
Paragonite.....	.....	10.80
Albite, $NaAlSi_3O_8$	11.59	.....
Chlorite.....	.97	.99
Anorthite, $CaAl_2Si_2O_8$	12.59	.....
Epidote.....	.....	10.92
Dolomite.....	7.30	7.46
Hematite.....	3.35	3.41
Water.....	3.32	2.42
Total.....	99.69	99.90

If some soda is assumed to have been lost as carbonate, as well as some other changes in the process of shale formation, such as the hydration of secondary products, an analysis can be obtained that is much more available for comparison. Still in (7'') there is an excess of quartz and epidote, a deficiency of sericite, chlorite and kaolinite which shows that there is some marked difference between loess and the Vernon shale. While I do not wish to give the impression that unwarranted confidence has been placed in these comparisons, yet I do feel strongly inclined to view the Vernon as representing a deposit other than a consolidation of loess. It seems more probable that it is a rock derived from river silt.

TABLE 12
River silts

	8	9	10	11
SiO ₂	50.14	45.02	49.67	45.10
Al ₂ O ₃	4.77	7.83	11.98	15.95
Fe ₂ O ₃	2.69	9.16	11.73	13.25
FeO.....	.....	.....	.....	.....
CaO.....	.77	.32	.88	4.85
MgO.....	.34	.44	.27	2.64
K ₂ O.....	.55	?	1.29	1.95
Na ₂ O.....	.54	?	.69	.85
CaCO ₃	30.76	24.08	.....	.....
MgCO ₃	1.24	6.32	.....	.....
SO ₃.....	.....	.....	.....	.34
H ₂ O.....	.99	6.85	23.21	15.54
Loss.....	1.66	.....	.....	.....
MnO.....	.35	.....	.....	.....
FeCO ₃	5.20	.....	.....	.....
Total.....	100.00	100.00	99.72	100.47

8 Rhine silt, delta in Lake Constance. Analysis by Bischof

9 Danube silt at Vienna. Bischof

10 Vistula silt at Culm. Bischof

11 Nile Mud. C. V. John. All taken from F. W. Clarke. U. S. G. S. Bul. 616, p. 505, 1916

It will be evident that the silica content of the above river silts is of the same order of magnitude as that of the Vernon; the alumina and alkalis slightly less. Emphasis can quite properly be placed upon analysis (11) as representing that of a delta of a river similar to those which it is believed existed during Salina times; a river draining a desert area. It would have been desirable to have tabulated the analyses of river silts flowing from such areas into saline waters, but "analyses of river silt or mud are not very numerous, nor are they always comparable" (Clarke, 1916, p. 510). On recasting, the analysis of the Nile mud becomes very similar to that of the Vernon. The two sets of recast analyses are tabulated below.

TABLE 13

MINERAL	NILE MUD	RED VERNON SHALE	
	11'	1'	2a'
Quartz.....	21.30	20.88	18.67
Sericite.....	15.35	32.16	27.07
Paragonite.....	9.46	13.91	10.66
Chlorite.....	16.80	7.36	4.12
Epidote and Uralite.....	23.05	8.28	1.75
Kaolinite.....	.....	8.81	28.05
Hematite.....	3.42	2.00	5.75
Water.....	10.00	.81	.35
Gypsum.....	.77	Trace	Trace
Total.....	100.15	99.39	100.00

While the quartz, paragonite and hematite are of the proper order of magnitude, the silt is low in sericite and kaolinite, and excessive in the ferromagnesian minerals. Yet there is a better agreement between the silt and the shale than between the loess and the shale.

The geological reasons for believing that the Vernon is a river deposit are that the interbedded green shales, marlites and water-limes are without doubt marine formations which do not give the appearance of being deposited near the shore. Evidence is accumulating to the effect that the abrupt termination of the Vernon in eastern New York is caused by an overlap; the thinning of the formation is from the bottom up and not from the top down, and is due to overlap upon a previous land surface. Consequently there is but little data to be secured bearing upon the delta origin of the Vernon in the east. Our knowledge of the western margin is very incomplete. There are at least two interpretations of the change in the color of the Salina, from red to gray, in passing from the Genesee Valley to Buffalo: (1) That the Vernon is overlapped by the Camillus. (2) That the red shales interfinger the gray shales by a gradational change.

It is believed that the theory that the Vernon is a river silt deposit would be in harmony with the latter interpretation.

If the Vernon is a river deposit the question arises regarding its correlations. In the Shawangunk conglomerate we possess a formation that may well be correlated chronologically as well as genetically with the Vernon. Grabau has already suggested a fluvial origin of this formation. It seems to me that the geologic age of the Shawan-

gunk is still a matter of dispute. Schuchert (1916, p. 531-54) and Van Ingen (1911, p. 905) believe that it is of Medina age while Grabau (1906, p. 123) and Hartnagel (1907, p. 50) are inclined to assign a Salina age to it. The presence of eurypterids in the Shawangunk has been proposed as evidence of its Pittsford age. But the presence of the genus *Hughmilleria* in both the Shawangunk and Schenectady beds (the latter of Ordovician age) makes questionable the value of eurypterids as index fossils. Schuchert bases his contention for the Medina age upon the finding of *Arthropycus alleghaniense* in the Shawangunk at Otisville. The value of "worm" trails and burrows as horizon markers is questionable. The Shawangunk, lithologically, may be of Oneida, Clinton (Herkimer), Vernon, or Medina age as far as our present knowledge is concerned. If, however, it is of Vernon age the hypothesis here suggested would be in accordance with the facts. Thus the Vernon may represent the fine silts of the Shawangunk river, flowing northward into the area over which the later Camillus waterlimes and marlites were deposited.

Another possible correlation is, however, suggested: that the High Falls and the Longwood shales of southeastern New York and New Jersey are of Vernon age. These beds are red shales that may well be so related. Our present knowledge is too meager to permit a definite conclusion, yet there seems no adequate reason why the Vernon can not be a river silt deposit and perhaps correlated with either the Shawangunk or the High Falls—Longwood beds.

It has already been shown that a completely satisfactory correlation between the lower Cayugan of New York and Maryland, upon paleontological grounds, is impossible. The close lithologic resemblance between the two series is certainly highly suggestive, as has already been pointed out.

There remains the method of investigating the climatic, physical and diastrophic evidence. Swartz points out that we possess excellent information for a tentative solution of this problem. In New York the Salina consists of the thick red Vernon, practically barren of fossils, overlain by the argillaceous, lime-mud rocks carrying salt and anhydrite which of course indicates arid conditions of sedimentation. The McKenzie-Bloomsburg-Wills Creek beds in Maryland suggest the same thing. In New York the red beds occupy to a large extent, certainly on the outcrop, the interval between the Lockport and the commercial beds of rock salt. In Maryland, in contrast, red beds appear only at the base of the Wills Creek, where the salt hopper crystals occur. In going eastward in Maryland the red beds occupy a greater and greater thickness of the formation, until in

the North mountains they occupy a large part of the Wills Creek. East of this locality the rocks have been removed by erosion but judging from what is known, it is clear that it would not be necessary to go much farther before the entire formation was composed of red beds, overlying which the salt-bearing rocks would appear.

Swartz believes that "the open sea lay towards Maryland where marine strata would occupy the same horizon as the red beds of New York. Due to oscillations of the sea the red deposits of the northeast would intertongue with gray marine deposits in the southwest, with an increasing amount of marine formations towards the open sea. Marine fossils actually occur in ever increasing numbers to the southwest." More fossils are found in the beds of the same age in Maryland than in Pennsylvania, and more in the strata of Pennsylvania than is the case in New York. "Indeed, a change is manifest even in such narrow limits as are presented in the State of Maryland, marine forms appearing in ever increasing numbers toward the southeast, where arenaceous deposits give way to shale and then to limestone" (Swartz, 1923, p. 210).

The Camillus

It is concluded, therefore, that the salt-bearing strata of the two states are synchronous; that the gray-colored Wills Creek of Maryland is the esturine and marine phase, and that it, together with the McKenzie formation, corresponds to the Vernon and Camillus of New York. The boundary between the Vernon and the Camillus on the one hand, and the McKenzie and Wills Creek on the other, may be a migratory one not at a fixed horizon, but diagonally passing up and down through the series. Such a suggestion — for it is not more than a suggestion — is decidedly a departure from the customary conception entertained. An excellent illustration is that of the so-called marine Chemung and the red Catskill of Devonian age. Both of these cases show that the red Silurian beds and the Devonian red beds do not have an equal time value, but that Salina sedimentation began earlier in the east and that it continued longer there and consequently the beds are thicker in that direction.

The Bertie

O'Connell, realizing that an appreciation of the origin of the Bertie waterlime as a sediment had a direct bearing upon the problem of the habitat of the eurypterids, investigated the Bertie at Buffalo in this light. In discussing the subject of origin it is necessary to

understand the meaning of the term "origin." Doctor Galloway holds that "origin" should cover (1) derivation or source of material; (2) the transportational history of the material; and (3) the deposition of that mineral.

O'Connell says (1916, p. 108): "Such a fine-grained, stratified rock might have been deposited in one of the following four ways, and these appear to cover all possibilities: (a) by chemical precipitation; (b) by bacterial precipitation; (c) by the formation of an organic accumulation of calcareous shells or plants, or both; (d) by the accumulation of clastic or fragmental material."

Chemical origin: O'Connell does not believe that the Bertie was deposited by chemical precipitation because it is stratified. She holds that a massive rock is more likely the result of such formation. Her conception of chemical precipitation is a process during which no currents supply fresh material. The presence of silica and alumina caused her to seek another origin for the Bertie. O'Connell's reasoning is too simple. The argument that stratification prohibits chemical origin is not convincing. Experimental work shows that lamination of lime-muds is produced even when continuous precipitation and sedimentation take place. The rate of precipitation, and the temperature under which the experiments are conducted, all affect the amount of lamination (Kindle, 1924, p. 42). The alumina and silica as well as lime-muds may be formed by precipitation. O'Connell does not consider any other system than one of a few components. We know that the solutions of a euryhaline sea are complex and not simple. We can conclude that a chemical origin is not necessarily impossible.

Organic origin: "If the Bertie," continues O'Connell, "were an organic deposit, its fine texture would permit of only two types of organisms active in its formation, namely the protozoa or the algae." Would it? Probably not. "The microslide of the Bertie shows no trace of any of these organisms." From what division of the Bertie was the single microslide prepared? There are shales as well as blocky waterlimes in the Bertie series. A single slide can not possibly convey a true conception of the Bertie series. As to the lack of evidence for the presence of organisms in the Bertie, let me quote from her own paper: "There are also many fine black specks, probably of carbonaceous matter." She does not say what she believed this carbonaceous matter to signify. Furthermore, there has been some recrystallization which would have destroyed small structures. Bacteria in warm seas can precipitate lime-muds. This is probably true, but that the Bertie could not have been formed by

such process because it contains silica and alumina to the extent of 28.98 per cent is probably not true. "Since the chemical and microscopic study [one analysis and one slide] of the Bertie *proves* [my italics] the impossibility of either chemical or an organic origin, we must conclude that the rock is a clastic."

Clastic origin: To my mind O'Connell's arguments for a clastic origin are difficult to follow. She says: "There seems to be no escape from the conclusion that these lime-muds of the Bertie represent the flood-plain or delta deposits from one or more rivers, or else that they accumulated as playa lake deposits. Of course, the nature of the deposit demands a source of supply in which calcareous material plays a dominant role." O'Connell, following Grabau, holds that "the only available source of the lime in the Bertie is from the muds derived by the erosion of an older magnesian limestone, the Niagaran, or in some cases, perhaps, the Trenton" (O'Connell, 1916, p. 113).

I am inclined to agree with Williams (1919, p. 87) that the Bertie series "appears to be sediments derived from older rocks laid down in a shallow sea. The water was probably too salty and too muddy to favor the development of diversified life."

In seeking for a source of these lime-muds, O'Connell calls upon the Niagaran. It is quite possible that the disintegration of this limestone formation supplied the material for the Bertie. It is known that the upper portions of the Lockport-Guelph are more argillaceous than the middle and lower sections, which of course supports such a contention. But too hasty an acceptance of this ignores the fact that, along the strike in New York, the Salina overlaps the Niagaran. Much the same condition prevails in Pennsylvania and in Maryland. There was not much erosion if any of the Niagaran in these states. Of course it is possible to call upon the Niagaran of Canada north of New York State. Elsewhere it has been suggested that the salt deposits of New York are situated upon the northern rim of a depositional basin. It is apparent that the salt beds did not extend many miles farther north than they do now, but that does not give us any clue how far the Vernon and the Camillus extended northward even though salt may not have been deposited with them. Since the Salina, if formerly present, has been removed from Canada, north of New York State, there is no evidence that, during Bertie times, some portion of the Niagaran rocks situated there furnished these lime-muds. Nor is there any evidence to the contrary; a type of reasoning that leaves us in the dark. It is possible, of course, to suggest that material came from areas that are no longer exposed

to our view. We might postulate a continent to the east of the present Atlantic coast. Any of the suggestions here proposed may suffice, yet it is perhaps best to have a suspended judgment regarding the source of the Bertie lime-muds.

We still need to discuss the means of transportation of this material. O'Connell, as above stated, proposed that rivers were the means of transporting the muds. If we are inclined to accept this view it does not in any way involve the question of the habitat of the eurypterids; the two questions are independent. Such fine muds have been considered by many to imply deep water deposition, some distance from the shore. Such a condition is not necessarily applicable to the conditions here found. The velocity of such postulated rivers must have been low; the lack of coarse material in the Bertie as such suggests low, flat lying land areas surrounding the Bertie basin. The saline character of the sea would imply rapid precipitation of these muds on contact with the salts of the Bertie basin, which would destroy by electrolytic action the suspensionoids in the comparatively fresh river waters.

On the basis that the Bertie mud-rocks are clastic in origin, the presence of argillaceous minerals and quartz is easily accounted for, yet other modes of origin may well explain their presence. The matter sums up to this: Our actual knowledge of the deposition of lime-muds in a euryhaline sea, their source and mode of transportation is so limited that any further remarks would be highly speculative.

PALEOCLIMATOLOGY

It would seem necessary to postulate an arid climate, if not actual desert conditions, during Vernon and Camillus times. Desert climate of the Salina would not be unique in earth history. We find that the climate of mid-latitude zones fluctuated through alternate periods of warmth and cold. In many cases warm periods were closed by mountain building, which in turn was followed by cool to cold climate, frequently intense enough to produce glaciation. Geological students of diastrophism and orogenetic disturbances have frequently emphasized the periodic relationship between fluctuations in climate and mountain building. Such relationships apparently occur, but it may be questioned whether there is any genetic connection between the two phenomena. There is a sequence of events.

The profound orogenetic disturbance of the Proterozoic were followed by Huronian glaciation in Canada. The Caledonian orogeny preceded the Silurian ice age. The Appalachian revolution fore-

shadowed Carbonaceous-Permian glaciation, and so on. The climate of the intervening periods was correspondingly warm, peneplanation took place, coral reefs grew in the polar seas, and salt, with accompanying red beds was deposited.

Here we are seeking a cause of warm climates. A glaciologist attempts to explain cold climates and hence, paradoxically as it may seem, we have much in common. Explanations of desert conditions should be consistent with theories offered to account for glaciation. One group of paleoclimatologists claim a periodicity. They assemble and plot data as in figure 3. They point out the periodic cycles through which the climate of the earth has passed. "Two cycles seem to be shown in the . . . geological record. The minor cycle recurs every 200,000 years or thereabouts, and has determined the duration of the four Pleistocene ice ages. . . . The major cycle is about 100,000,000 years long, and we have a record of " at least four such major cycles since Proterozoic times. "The minor cycles are superimposed on the major cycles in such a fashion that in each major cycle, after long ages of fairly uniform climate throughout the world, there appears a zonal arrangement of climates. This culminates at the . . . great ice epochs, that is, Proterozoic, Cambrian-Ordovician, Silurian-Devonian, Carbonaceous-Permian, and Pleistocene" (Taylor, 1919, p. 289).

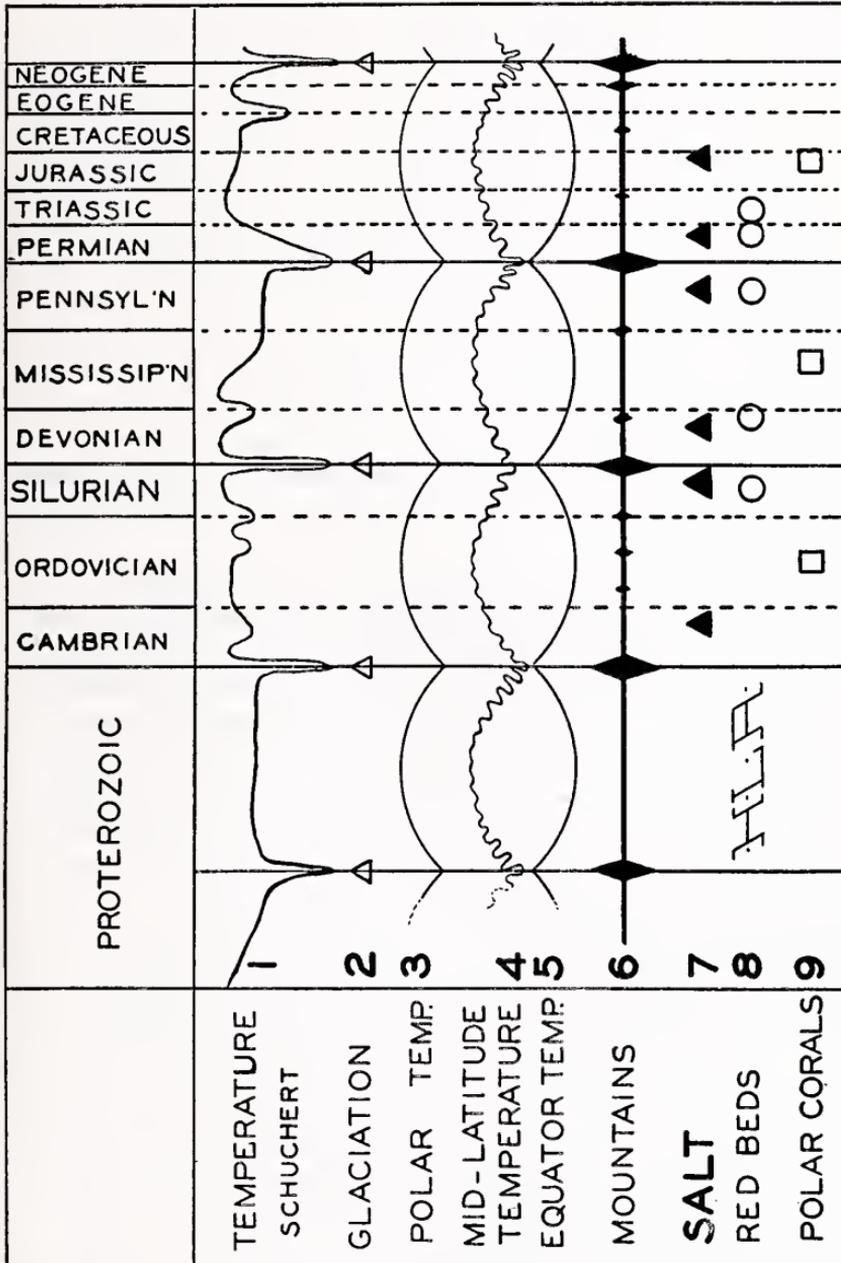


Fig. 3 Chart designed to show the variation in climatic conditions of the past. It has been drawn from data secured from Griffith Taylor, Schuchert, Geikie and others.

- 1 Temperature curve, modified from Schuchert.
- 2 Periods of glaciation, data taken from Geikie, Schuchert, Coleman and others.
- 3 Polar temperatures taken from Taylor.
- 4 Mid-latitude temperatures, minor cycles of 200,000 years superimposed upon the major or 100,000,000 year cycles. After Taylor.
- 5 Equatorial temperatures. After Taylor.
- 6 Periods of mountain building, modified from Schuchert.
- 7 Salt depositional periods, data from Geikie.
- 8 Red bed accumulation, after Schuchert.
- 9 Time of polar coral reefs, Schuchert and Taylor.

A study of the chart, figure 3, shows (1) the temperature curve as modified from Schuchert's diagram (Schuchert and Osborn, 1917); (Huntington, 1914, p. 256). Observe how the curve rises and falls; the pronounced drops correspond to the period of glaciation as is shown by the row of triangles in row 2. The next three rows, 3 to 5, are taken from Griffith Taylor's chart (1919, p. 316). Curve 3 is polar temperatures, ideally expressed by the smoothness of the curve. Curve 5 is that for the equatorial belt. The most interesting of the three is that of the mid-latitude zones, curve 4. Here the minor cycles of 200,000 years are superimposed upon the major, or 100,000,000 year, cycles. The minor variations seem to account for the interglacial periods.

The periods of mountain building, line 6, have been modified, after Schuchert. Note especially the coincidence of mountain building, low temperatures, similarity of polar and equatorial climate, and periods of glaciation.

We are especially interested in the periods of salt deposition. The information for these has been secured from Geikie (1882, p. 661, 692, 704, 757, 759, 765), Schuchert (1914, p. 265-98) and others. In order, from left to right, the salt beds are located as follows: Northern India, the deposits of New York and adjacent states; in Russia, unidentified, Zechstein in North Germany, and the Cheshire deposits of England. Note how they are distributed at the beginning and at the close of the major cycles. Associated with them are red beds, row 8, from data supplied by Schuchert. The last row shows periodic development of coral reefs in the polar regions. The significant point of this discussion is that desert conditions and salt deposition are apparently periodic occurrences and not unique.

On the other hand, another group maintain that "at *irregular* [my italics] intervals throughout [geologic] history, there have been relatively short periods of cold" (Coleman, 1926, p. 246) because evidence of glaciation, prior to the Pleistocene, rests upon finding tillites, striated stones and boulder clay in all parts of the world. The probabilities of finding additional tillites in unexpected positions in the geologic time scale are so likely that they feel that any periodicity based upon present data is misleading.

The various theories have been tabulated by Scott (1926, p. 269) as follows:

Terrestrial causes

The earth as a whole

Changes in the eccentricity of the orbit

Shifting of the earth's axis

Shifting of the earth's exterior on the interior

The internal heat of the earth

Atmospheric factors

Variation in the proportion of carbon dioxide

In the amount of suspended volcanic dust

Oceanic factors

Variations in salinity

Topographical factors

Changes in the area, altitude and disposition of the land-masses

Cosmical causes

Passage through cold regions in space

Variations of the sun's activity

To which may be added: Passage of solar system through gaseous nebulae
(Aiken, 1926, p. 137)

A thorough discussion of the cause of the fluctuations in climate is hardly within the province of this paper. A brief review of the various theories, however, may prove of interest.

Lord Kelvin suggested that variation in solar radiation may be the cause. Doctor Abbott of the Smithsonian Observatory states that such variations actually occur. In a paper read before the National Academy of Science Clayton (April, 1925) emphasized this factor. Scott is inclined to look to this phenomenon as a very likely factor. It is obvious that no short cycle of solar change will serve our purpose. Huntington and Visser (1922) have proposed a solar cyclonic hypothesis which they maintain "accounts not only for ice ages, but also for times of aridity" (Coleman, 1926, p. 278). They hold that cold climate occurs during sun spot periods and conversely aridity when sun spot activity is at a minimum.

Humphreys (1920; 1925, p. 449-59) has stated that variation in the output of solar energy is not the sole nor even the chief cause "of all of the numerous climatic changes indelibly recorded in the book of ages." The sun spot cycle is a little over 11 years in length. The change is of the order of 1 degree centigrade and the shortness of the cycle is regarded of so little moment that we can dismiss it from our consideration as a factor affecting climate.

The orbit of the earth about the sun does vary in shape and there is a rotation of the axis of the earth so that first one hemisphere and then the other, every 21,000 years, has its winters when we are farthest from the sun and therefore longest. This eccentricity of the earth's orbit does affect our climate somewhat.

Croll propounded his theory (1875; 1886) of changing eccentricity of the earth's orbit. His periods of fluctuation were too short (Keyes, 1926, p. 49-74; Richarz, 1926, p. 97-108; Koppen, W. & Wegener, A., 1925). "Had ice ages occurred with the rhythmical regularity which Croll postulated, the northern and southern hemispheres must each have had 40,000 of them, which does not seem likely" (Scott, 1926, p. 270).

Astronomical calculations, others believe, show that such changes are exceedingly small and may not account for desert conditions such as probably prevailed during Salina times.

We may be tempted to employ the theory that the obliquity of the ecliptic, through change, would cause variation in climatic conditions, but we find that celestial mechanics indicate that this inclination can never vary more than a degree or two on either side within a period of a million years or more.

Since the earth passes closest to and farthest from the sun, respectively, about two and a half minutes later from year to year, it follows that first one hemisphere and then the other has relatively long cold winters and short hot summers. But two winter extremes do not differ in absolute temperature more than 2.8 degrees centigrade. Because, however, of the storing up and giving out of heat, the oceans prevent any such contrasts.

Changes in earth heat is a factor too small to be considered here.

Latitude is argued as an important cause of changes in climate. If we can shift latitude by a shift in the poles of the earth, we might account for some changes. There is considerable difference of opinion whether such a shift is possible.

Grabau has postulated that the theory of polar migration as formulated by Reibisch (1901, p. 105-24), Simroth (1907) and Kreichgauer (1902) would explain the conditions here presented. Grabau fully realized that the mathematical analysis of G. H. Darwin (Cotton, 1923) places very severe limitations on possible migration of the polar axis, and yet is disposed to question whether Darwin has had "the last word" on the subject.

L. A. Cotton (1923, p. 453-503) in a very suggestive paper, shows that there are at least three schools of thought: (1) Those who deny polar wanderings, concluding that Darwin's analysis is sound. (2) Those, like Grabau, who would consider the theory plausible in spite of the mathematical denial. (3) Those who advocate the theory. Cotton has reexamined Darwin's paper and shows that the "whole question is, therefore, one which depends on the primary assumptions as to the nature and constitution of the earth's interior" (op. cit. p. 496). Many lines of evidence "converge towards the conclusion that the earth behaves like a highly viscous solid. . . . When these postulates are substituted in Darwin's analysis . . . the mathematical investigation actually supports the view that polar wanderings are not only possible but probable."

I believe that Cotton has made a very real contribution to this subject. If we postulate the continent of Appalachia to the east of the present coast and the poles of the earth somewhere in the vicinity of the present equator in the Pacific, easterly winds laden with moisture which is precipitated upon the high mountains of Appalachia, we could in this fashion account for the desert conditions.

I was sufficiently impressed with the possibilities of polar wanderings so that I have corresponded with Professor Cotton. On the basis of present geographical distribution of deserts in respect to the equator, Professor Cotton suggested (1924) that it would be interesting "if one could establish a distribution of desert conditions during any particular epoch, so arranged as to lie about a small circle of the earth, or better still on two small circles equidistant from a great circle; this would afford strong evidences as to the position of the earth's pole at that time."

A shifting of the poles of the earth would not "get rid of the necessity of admitting climatic change" (Scott, 1926, p. 270) at the same time. Hence this theory can not be called upon as an independent factor.

Lyell suggested changes in the size, distribution and altitude of land masses. Brooks (1922) and Jeffreys (1924) have recently elaborated this theory.

We know that the height of the land above the sea, especially the mountainous regions, has varied greatly through geologic time. The causes of these elevational changes are matters concerning which facts are fewer than hypotheses. If a high ridge lies for a great distance across the path of the prevailing winds, the bulk of the precipitation occurs on its windward slopes and consequently in the lee of this ridge the area is arid. If such a ridge supported snow fields, a vast amount of cooled air drains down its sides and affects the temperature of the plains. Land elevation is a control of very great importance.

The distribution of land and water is a powerful factor. Large bodies of water maintain a much more uniform temperature than land masses. That is so well appreciated that we can pass to other controlling factors.

The oceanic circulation in the production of currents, like the Gulf Stream, the Japanese Current, the Labrador Current and the Humboldt Current, profoundly affects the climate of the land masses washed by such currents, and is so well known as to need no emphasis. If we should shift these currents we could argue that great changes can occur.

The variation in the surface covering, excluding the oceanic expanses, is a control of no small moment. Rocky areas are poor emitters of earth radiation, while snow emits it twice as well. Snow will cool areas because of this ability.

Winds, easily appreciated as exceedingly important climatic controllers, tend to equalize the temperature of the globe. Evaporation, a cooling process, occurs in the warmer regions while a large portion of the condensation, a process that liberates much heat, occurs in cooler regions.

At the present time the salt district of New York lies in the belt of westerly winds that follow well established paths. The cyclones and anticyclones swing across the country from west to the east. They drop their moisture to the windward of the Pacific coast mountains and hence produce the deserts in the Great Basin. They then cross the plains. How is it that we have abundant rainfall at the present time? The cyclones, centers of low barometric pressure are "holes" towards which air is rushing from areas of high pressure. In their swirling they circle back from the Atlantic coast and thus bring moisture from the sea. Thus westerly winds bring rain from the east. If a mountain range of more pronounced nature existed to the east of the present salt field during Salina times and precipitated the rain, could we in this manner account for our desert? I wonder.

Or we could postulate trade winds instead of westerlies. By shifting the poles a little we could bring the district here concerned into the belt of these winds. This is also possible.

Humphreys regards volcanic dust clouds as effective in producing cooler temperatures. Mountain building and volcanic activity are coincident phenomena, and are thought to be a contributing cause to the production of periods of glaciation.

If we summarize this discussion, we reach the conclusion that warmer periods of the mid-latitude zones occurred when the seas transgressed upon the land areas and, conversely, glaciation when the land areas were extensive. The mountains, with their snow-covered slopes and volcanic dust in the air, would produce climatic conditions that would be in a critical state. Lower and lower becomes the temperature until internal forces of mountain building and volcanic activity can quiet down and allow a return to more favorable conditions for warmer climatic conditions.

The above appears to "explain" a good deal and yet it is not a completely satisfactory theory. In conjunction with the diastrophic hypothesis variation of altitude of the land and size and distribution

of land and oceanic areas may furnish a partial solution to our problem of fluctuations in geologic climate.

The reader may expect me to produce a clear statement to the effect that only one theory will answer our inquiry. This I do not feel willing to do. I am convinced that to do so would be unwise if not unscientific. It is my opinion that a "final" solution will be developed from a combination of astronomic, geologic and atmospheric theories.

GEOLOGICAL SECTIONS OF THE SALT FIELD

The sections that accompany this report are based upon published well records, supplemented by maps and field observations; they represent the present status of our knowledge in regard to the geology of the salt deposits. It is perhaps necessary that they should be considered as approximate, in part at least, for the records have been gathered from numerous sources, chiefly from the logs of the well drillers themselves who, humanly enough, reported the rock formations in terms best suited for securing the highest possible compensation for their services. In this light we may interpret the "fact" that the rock from the Onondaga limestone to the salt was reported to consist entirely of waterlime in the Junction Well, south of Le Roy, the Conesus Salt Co. and the Dansville wells. Some uncertainty must be entertained in regard to the elevation of the surface of wells. Most of the figures used were secured by the early field geologists who were not provided with the federal topographic maps. The elevations were secured by hand leveling from benchmarks furnished by the railroad companies. A number of elevations have been checked and found to be slightly in error. This fact alone modifies the amount of dip and position of minor folds in the sectional drawings in view of the fact that a great exaggeration of the vertical scale was necessary.

It is, of course, impossible to state with any degree of certainty what are the exact conditions *between* the wells. The sections have been drawn across these unknown regions; the change in the character of the salt beds, particularly, has been inferred from the available data. The necessarily restricted size of the sections forbids the indication of many details and thin formations. The subdivision of the Manlius limestone and Bertie waterlimes has not been possible although unconformities occur within this group of strata. Some well records give suggestive details which the neighboring well records

fail to note. Some of them have been extended into the unmapped area while others have been ignored.

One of the problems, as yet imperfectly solved, that is of interest to the salt industry, is the "splitting" of a salt bed; it becoming two seams in the course of a few miles. The difficulty is to determine whether the single bed splits into a double seam or whether the second bed is a lens and overlaps or underlaps the other, or perhaps was not reached by the drill. As the driller was usually only interested in reaching the first salt bed free of shale impurities, and cared little for what lay beneath, our knowledge is sadly deficient, and hence it is not known what are the actual conditions. In the cross sections the beds are often drawn as splitting, although this has not been demonstrated.

The Batavia-Bliss Section

Figure 4

The section is based upon three well records, the Batavia well after Prosser, the Attica well after Bishop and the Bliss well after R. D. White. It represents a north and south section near to the western margin of salt deposits of the State, especially the Batavia and Attica wells, where 15 inches of salt and 10 feet of salt shale were found respectively. The Bliss well is noted as showing 56 feet of salt at a much greater depth below the Onondaga limestone than the majority of the wells in the state.

The LeRoy-Castile Section

Figure 5

This is an important section as it involves the Oatka-Genesee field in which salt was first manufactured from rock salt. It is based upon 18 wells and one shaft and thus can be relied upon with greater confidence than the previous one. Of the 16 or 18 wells at Le Roy, the one chosen is the one published by Bishop with a surface elevation of 875 feet, one of the first wells sunk where the thickness of the salt was not indicated. In a well sunk some distance away the third salt bed found (the others were one or two feet thick) has a thickness of 21 feet. A bed of similar character is assumed for the entire bed. This procedure was necessary, due to a possible error in measuring the elevation of the latter well.

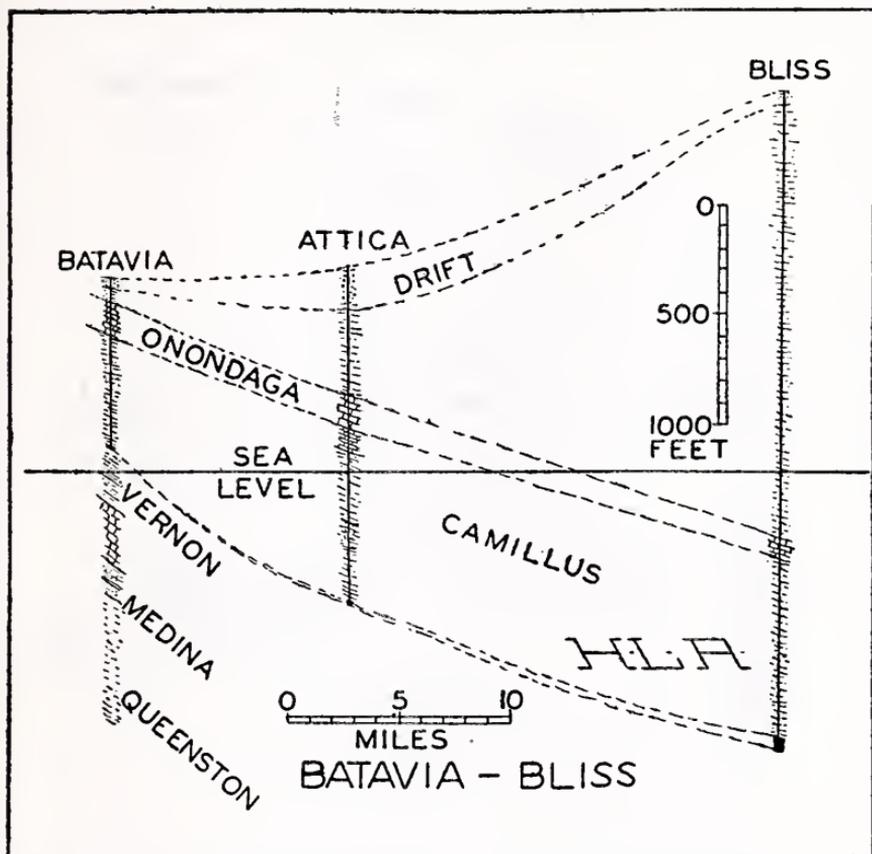


Fig. 4 Geologic cross section of the New York salt field. Section drawn from north to south from Batavia, through Attica to Bliss. The Batavia record is after Prosser, *Roch. Acad. Sci.*, 2, 1892, p. 90; the Attica well after Bishop; and the Bliss well after R. D. White. The great depth of the salt below the Onondaga limestone in the Bliss well, 800 feet, may be due to the southern extension of the Clarendon-Linden fault, noted by Chadwick in *Bul. Geol. Soc. Amer.*, 31.

In the Lehigh shaft, of course, we possess reliable information that can be used in assigning the boundaries of the formations. For a more complete section of the shaft, see figure 6.

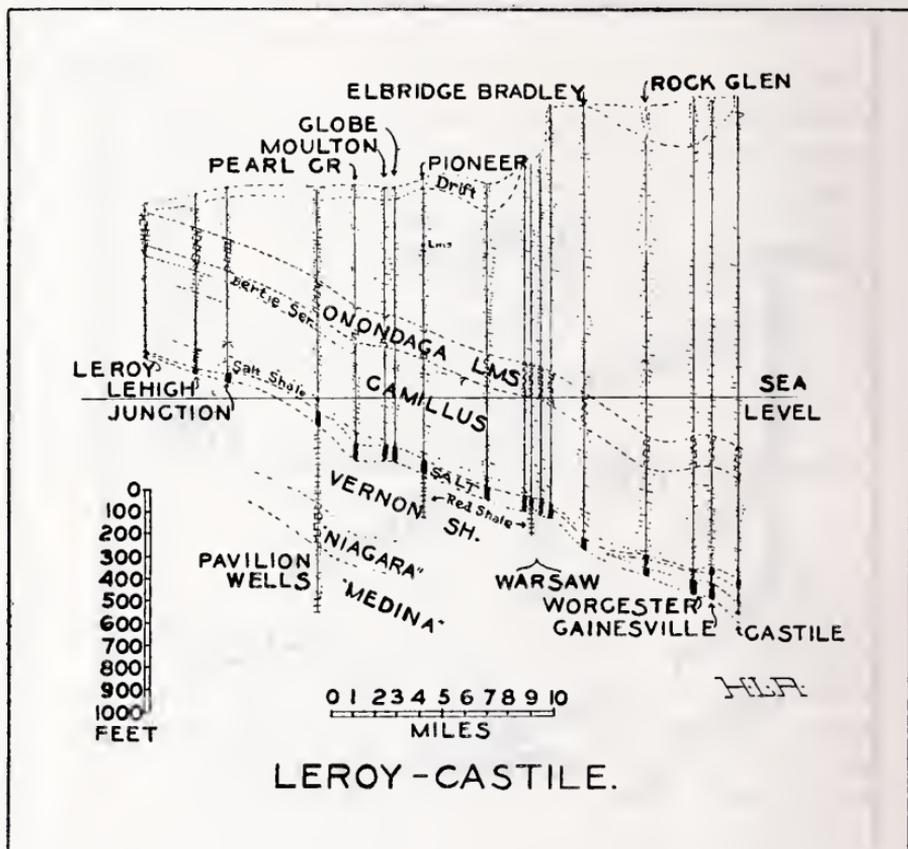


Fig. 5 Geologic cross section of the New York State salt field, from north to south, from Le Roy south to Castile. The Le Roy well record has been taken from Bishop, N. Y. State Geol. 5th Ann. Rep't 1885, p. 20. The Lehigh record is from Luther as interpreted by Clarke. The Junction well is after Bishop. The Pavilion well records supplied by R. D. White have been supplemented by D. W. Williams of the Dominion Gas Co. The record of the Pearl Creek well is after R. D. White and Bishop. The Moulton well record is taken from Th. Avery.

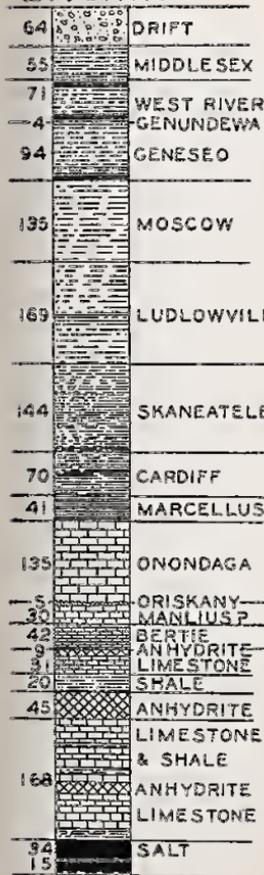
Information about the Globe well was obtained from Werner.

C. B. Mathews has given us the record of the Pioneer well. The Crystal well (name omitted from chart) at Saltville after Bishop.

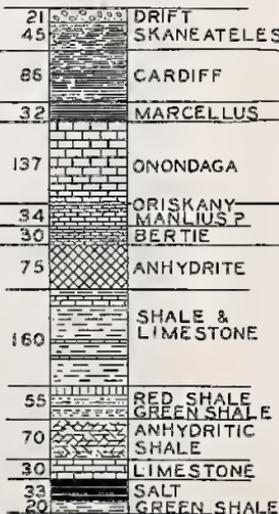
Bishop, Avery, Englehardt and Percy have furnished the records of the wells at Warsaw. Rock Glen, Worcester and Castile records are due to Bishop while the Gainesville data is after White.

Merrill, in his report (facing page 32) reproduces the above section. He failed, however, to suggest how the salt beds should be correlated. In drawing the Rock Glen section he made an error, placing the top of the Onondaga limestone 144 feet above sea level, while it should be 144 feet below.

LIVONIA



LEHIGH



RETSEF



H.L.A.

Fig. 6 Diagrammatic representation of the records of the Livonia, Lehigh and Retsof shafts. Data secured from D. Dana Luther and John M. Clarke as given in New York State Museum Report 47. Modified by Ruedemann, Hartungel, Chadwick and myself. The three sections have been arranged with the base of the Onondaga limestone at the same level. Note that correlation from the Oriskany sandstone upwards is wholly satisfactory while attempts in the Camillus are impracticable.

LIVONIA

DRIFT		0-10
MIDDLEBURY		10-15
WEST RIVER		15-20
CLINTONIA		20-25
DECEASED		25-30
MOSLOW		30-35
LEHIGH		35-40
LEHIGHVILLE		40-45
SHARPLESS		45-50
CARROLL		50-55
MARPLES		55-60
ONONDAGA		60-65
GREENBAY		65-70
MADISON		70-75
LESLIE		75-80
FRANKFURT		80-85
LIME STONE		85-90
SHALE		90-95
AMHYDRITE		95-100
LIME STONE		100-105
SALT		105-110

F

PLM

1. This is a preliminary report of the results of the geological survey of the Livonia region, New York, conducted by the U.S. Geological Survey, 1900-1901. The work was done under the direction of J. W. Foster, Chief Geologist, and the assistance of J. H. Johnson, J. C. Smith, and J. E. Smith. The report is based on a reconnaissance of the region, and is not intended to be a final report. It is published for the information of the public, and is not to be construed as an official statement of the U.S. Geological Survey.

A departure from the actual log is made in the Junction well (B. R. & P. and D. L. & W. railroads) which recorded "Lower Helderberg Limestones" from the Onondaga ("Corniferous") limestone to the salt. It seems highly probable that the driller made this record for his own benefit, as it costs more to drill through limestone than through shaly beds. South of this point the line of demarcation between the Manlius limestone and Bertie waterlimes and the lime-mud rocks of the Camillus becomes uncertain and is left uncompleted from the Pioneer well south.

The Pavilion wells and the Moulton well fit in without any adjustment. The Pioneer well is one of the wells that penetrates the salt, recording beneath it 190 feet of red shale which is probably the Vernon. The Atlantic Salt Company near Warsaw sank below the salt into 104 feet of red shale.

The wells at Warsaw — The Miller Salt Co., Atlantic Salt Co., Warsaw Salt Co., Gouinlock, Gouinlock and Humphrey — are close together on the section. Some projecting upon the plane of the section has been done which may account for the downward "bump" of the salt beds at this point. Otherwise it is difficult to account for this peculiar behavior of the salt.

The (Eldridge) Bradley well is after Th. Percy. As originally given, the "Corniferous" limestone (Onondaga) is recorded as 225 feet thick, which is obviously an error; and it is thought that the Manlius and Bertie formations are included in this measurement.

Next below is "Flint Rock" for which no adequate interpretation is forthcoming. Below comes "Lower Helderberg" which is Camillus mud-lime rocks and shales. These beds are grouped in the record in this bulletin, as Onondaga limestone, waterlimes, lime-mud rocks and shales. The proper divisions are inferred from neighboring wells. Below the salt is a "pocket."

This may illustrate the difficulties I had in rendering the well records of any real value in constructing the geologic cross sections.

The Rock Glen Salt Company's record shows two beds of salt, the upper one 25 feet, the lower 40 feet thick, separated by 31 feet of shale. The Worcester wells also encounter two beds, 10 and 75 feet thick with an intervening bed of shale 45 feet thick — showing irregularities and peculiarities. In the section the main salt bed is shown splitting, although definite information is not at hand. It is of course possible that the bed is a lens and that the idea of the bed splitting is not the correct interpretation. It is an interesting fact, nevertheless, that this second bed occurs at a point of flexion, the rocks assuming a slight undulation, a fact emphasized by the exagger-

ation of the vertical scale. This habit of the salt is better shown in the Caledonia-Nunda section.

The Castile well, the last in the section, shows 35 feet of salt shale, here assumed to represent the upper bed of the Rock Glen and Worcester wells, on top of the main bed 45 feet thick. Below is 40 feet of shale overlying more salt shale 65 feet thick. Beneath this is recorded five feet of salt. The red shale of the Pioneer and Atlantic wells evidently was not reached by the drill.

The Caledonia-Nunda Section

Figure 7

This section is in some respects the most interesting one of all. It illustrates the independence of the salt and the Onondaga, as well as the effect of folds upon its thickness. The Caledonia well is probably incorrectly located upon Merrill's map (1893), its true position being half a mile farther south. The log is striking in that immediately beneath the Onondaga are "gypseous [anhydritic] shales," which, if correctly determined by the driller, would lead to the supposition that the Onondaga-Bertie unconformity was so excessive that the former rested directly upon the Camillus waterlimes. These extend 151 feet below the anhydritic beds. In the York well a more "normal" succession is reported in respect to the Bertie waterlimes. The 10-foot bed of red shale at the base of the Camillus waterlimes should be noted. To find red beds within the Camillus is apparently a much more common phenomenon than was formerly believed. If the contact between the Camillus waterlimes and the shales of the Caledonia and York wells be joined, as has been done in the section, such a line assumes a parallel position with the Onondaga-Bertie line of contact. Although neither gypseous shales nor anhydrite were reported in the York well, such beds are recorded as occurring in the Retsof and Griegsville shafts, and thus they are tentatively carried across the gap. Whether or not there is any real foundation for a division between the Camillus waterlimes and shales as shown in the section can not at present be ascertained, but the available data certainly points to such a conclusion.

In the Retsof shaft we possess reliable data. (For a more detailed section see figure 6.) The absence of drift on top of the section is due to the fact that the shaft was sunk in the floor of an old quarry. Here beneath the Manlius-Bertie waterlimes is an anhydritic layer 47 feet thick, while in the Griegsville shaft only a short distance away the corresponding bed is 75 feet thick, a fact difficult of interpretation without considering that the sulphate salt is present as

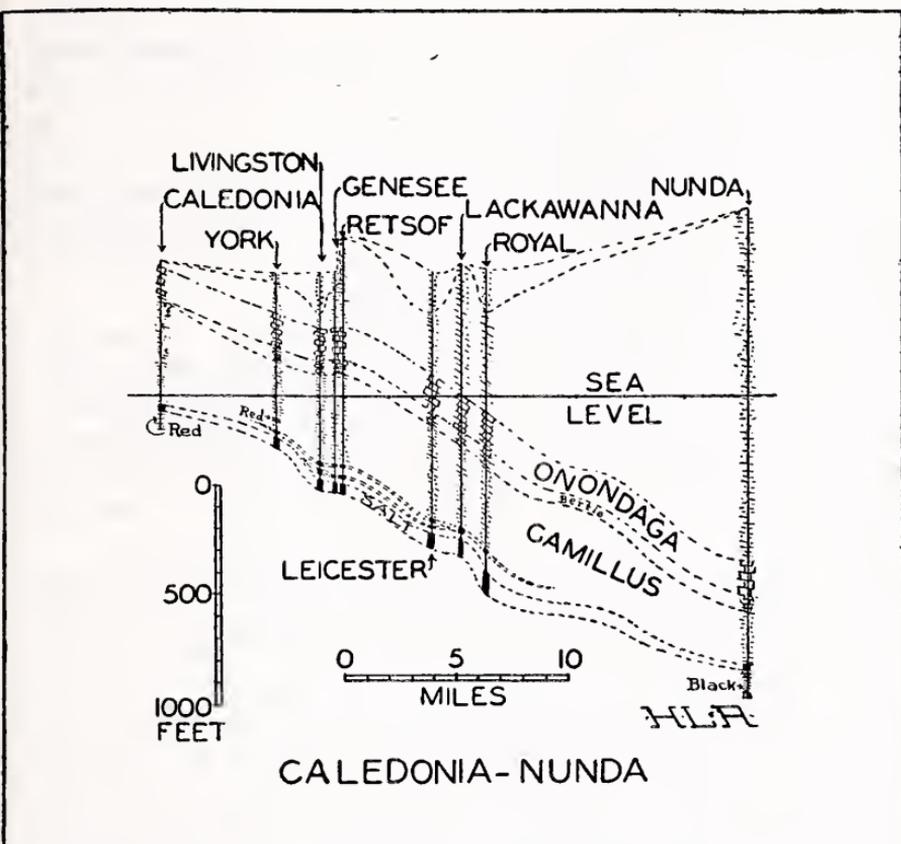


Fig. 7 Geologic cross section of the New York State salt field, south from Caledonia to Nunda. The Caledonia well record has been secured from C. L. Goodwin; the York well after M. B. Gilman; Englehardt has supplied data concerning the Livingston and Genesee wells. Luther and Clarke are the authorities for Retsof shaft. Rev. John Ripplly gives us the information about the Leicester Salt Company's well. For the Lackawanna well record we are indebted to Graham and for the Nunda well to Hambly. I am under the impression that I secured the record of the Royal well from Werner. Vertical exaggeration 52.8 times.

lenses. The single bed of salt in Caledonia well, 25 feet, has become two beds in the wells to the south. The 25-foot bed of the Caledonia well can be taken to be the main bed, the additional seam being an upper lens, or that the bed becomes two by splitting. The latter conception is the one indicated.

The shafts and wells at Retsof and Piffard furnish interesting data which the section emphasizes; the Onondaga limestone has a dip to the south, becoming anticlinal, while the salt beds experience a synclinal flexure, illustrating the geological independence of the two formations, due to the unconformities and the plasticity of the salt.

The detailed log of the Sterling Salt Company is not available for this report; the conditions are inferred from the neighboring wells, from the model of the shaft in the State Museum at Albany and from aneroid observations of the writer.

In the Leicester (Phoenix) Salt Company's abandoned well the two beds of salt are still shown, but are reduced in thickness to four feet and 28 feet, separated by three feet of shale. At this point the Onondaga limestone is seen to be approaching a slight anticlinal structure, the opposite to that assumed by the salt.

South from the synclinal flexure of the Leicester well the salt beds return to their former thickness, 23 feet and 75 feet with an intervening shaly bed 20 feet thick. A similar state of affairs obtains in the Royal Salt Company's abandoned well at Mount Morris; here 20 feet of salt comprises the upper bed; 35 feet the separating shale, and the lower greater than 75 feet, as the bottom of the lower seam was not reached.

Between the Royal well and Nunda, the relations underground change, rendering conclusions somewhat uncertain. Only one bed of salt is recorded, 35 feet thick. It is assumed that this is the upper bed, for its position below the Onondaga is less in distance than that held by all the other wells of the section. The 35 feet of salt shale beneath may represent the lower bed. Below the salt shale is black shale for 85 feet—a notable fact when the red Vernon shale was believed directly to underly the salt. In all wells situated in the southern portion of the salt fields which penetrate the salt beds, the rock found directly beneath is not red, but is reported as either black or brown. This fact may have a bearing upon the origin of the Vernon and the salt itself.

The Lakeville-Dansville Section

Figure 8

This is based upon four wells; the interval between the Livonia shaft and Dansville is a long unrecorded interval and irregularities in dip, position and thickness of the different beds may well be expected.

The first well is that of the abandoned Conesus Salt & Mining Company at Lakeville at the foot of Conesus lake. The "waterlimes" are 325 feet thick, which are, according to the present nomenclature, divisible into the Manlius limestone, the Bertie group, and the Camillus waterlimes. Only five feet of Camillus shale is recorded, either due to the massive character of the Camillus in this area or to the desire of the driller to secure the best return for his

services. Two beds of salt are shown. The upper bed is 25 feet thick, the lower 20 feet, with an intervening 30 foot layer of shale.

Next in order is the Livonia well. This records 32½ feet of salt, which undoubtedly represents the upper bed, the parting of shale between the two beds apparently not being penetrated by the drill. Here the bulk of the Camillus above the salt, all but five feet, is unfortunately recorded as "waterlime."

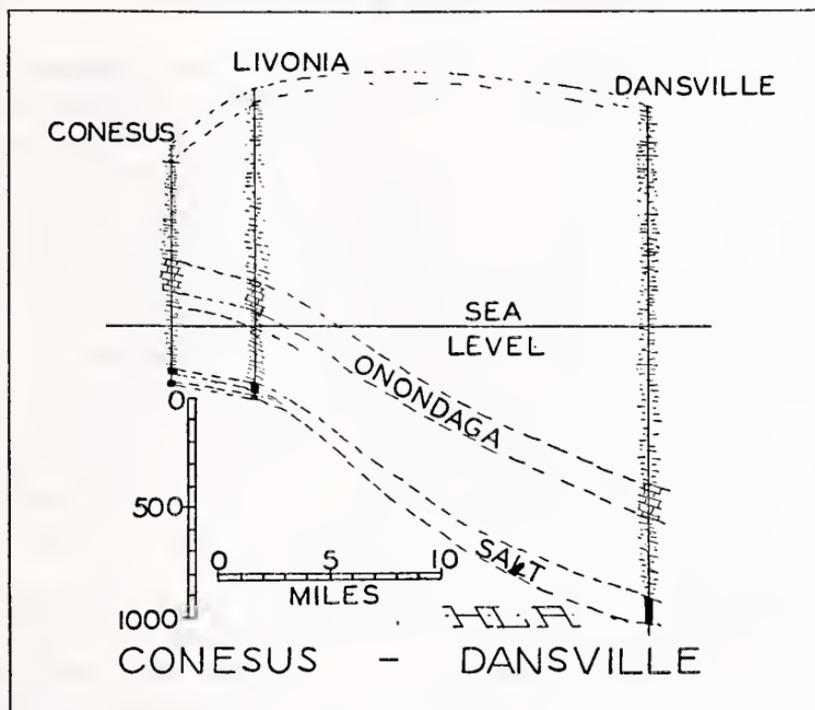


Fig. 8 Geologic cross section of New York State salt field, south from the head of Conesus lake to Dansville. To Bishop we owe the record for the Conesus Salt Company at Lakeville; to Luther and Clarke for the Livonia record and to Burgess for the Dansville well data. Exaggeration 52.8 times.

The Livonia shaft, the record of which we owe to Luther, and the faunal analysis to Doctor Clarke, is the most complete record available. Here then is 30 feet of Manlius, 42 feet of Bertie and 291 feet of gypseous shales (not "waterlimes" as in the two previous wells). The two salt seams are present; the upper is 34 feet thick, and the lower 15½ feet, separated by 7½ feet of shaly waterlime. This shows a thickening of the upper bed, a decrease in the lower and a pinching out of the dividing rock to the south.

In the Dansville well, the record of which is after Englehardt, there are 240 feet of "waterlime," divisible as before and interpreted in like manner. The salt appears to be a single seam 60 feet thick. On the section the parting is assumed to die out southwardly and the 60-foot bed is regarded as equivalent to both the seams reached by the Lakeville well, the Livonia well and the Livonia shaft.

The Clifton Springs-Watkins Section

Figure 9

The increase in the thickness and the amount of salt to the south is clearly shown in this section. The Clifton Springs well records salt shale 20 feet thick. At Himrod a distinct bed of rock salt, still with considerable "shales," 47 feet thick is shown. Below this lie salty beds 200 feet in thickness. The Watkins well, the record of which I owe to Hill and to Prosser, shows a succession of beds of rock salt, seven in number, aggregating 458 feet of salt! (See figure 10.) If we regard this latter record as reliable, it is clear that the Glen Works have not reached all the salt there is at this point. Four wells from which to draw a section is of limited application in reaching broad conclusions. Yet it is of interest to note that this section without the Himrod data was first drafted in 1919. In 1925 the record of the Himrod well became available and was found to fit into the section with only a thirty foot error. That is, the salt at Himrod as actually found was 30 feet lower than I had it drawn in 1919.

The undulations of the beds in this section are an attempt to represent the incipient Appalachian folds which undoubtedly exist. How successful I have been remains to be seen, but I am fully convinced that the dip is by no means uniform and any diagram with uniform dip for any portion of the salt field is at the best a simplification or indication that the facts have been disregarded.

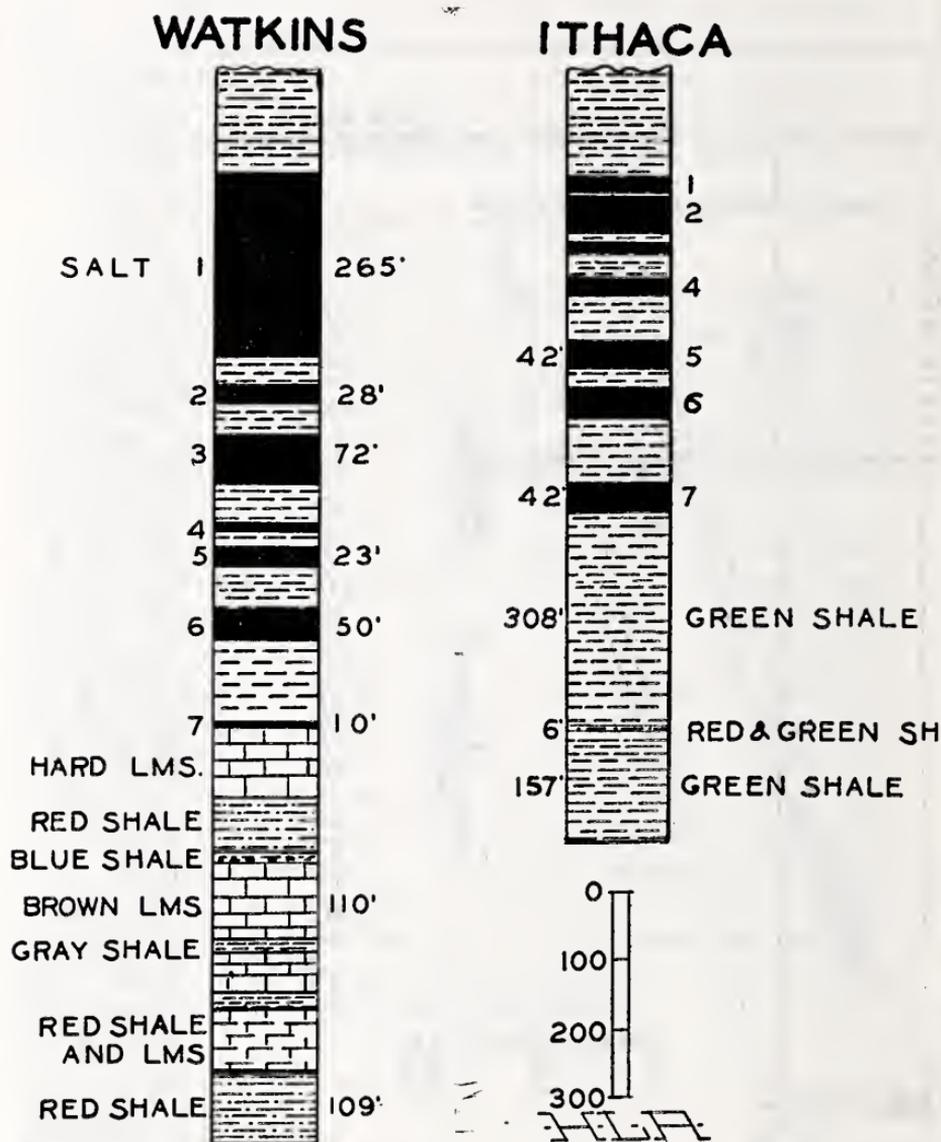


Fig. 10 Portions of the well records at Watkins and Ithaca arranged for comparison. The Watkins well is that of the Consumers Gas Company while the Ithaca well record is that supplied by Prosser. The significance of these records is the reported thickness of the salt beds and the fact that the demarcation of the summit of the Vernon, on the basis of lithology, is impossible.

The Aurora-Ithaca Section

Figure 11

The rocks of this area have been much more disturbed since their deposition than in the northwestern portion of the salt field. The anticlinal and synclinal folding, while relatively slight as compared with the Appalachian ridges in Pennsylvania, are clearly shown when the vertical scale is exaggerated, as has been done in the section. This folding has resulted in certain structural relations of importance to the salt manufacturers. This section has been difficult to construct for a number of reasons. With the exception of three wells, the deep Ithaca well, the well of the Remington Salt Company and that at Aurora, the available records are more or less defective. The data furnished by the Rock Salt Corporation, through the kindness of J. B. Calkins, are curiously ambiguous in finer details. Additional information has been obtained from Harris (1905); Cleland (1903), the Watkins Glen—Catatonk folio (Williams, Kindle & Tarr, 1909) and Luther (1910).

The position of the crests or axes of the swells has been checked by observations of the dip along the lake shore and in a few instances found not to agree with the folio.

The Aurora well is often quoted as one of the few that penetrated anhydrite *below* the salt. I doubt if this is such an unusual occurrence as has been maintained in the past. The majority of the salt wells, even when anhydrite is known to be present above the salt, fail to record it; probably the drillers have called it waterlime, "Lower Helderberg" limestone or shale. As only a comparatively few wells penetrate the salt, it is not surprising that anhydritic beds below the salt should be questioned. This has an important bearing upon the origin of the salt, a neglected factor in most articles on the subject. But the Ithaca well records no anhydrite at all. It may be present nevertheless.

The next well to the south is one of the International Salt Company, at Myers Point, near Ludlowville. At present the only available record is imperfect and has not been accurately followed in detail. The main salt bed (or beds?) totals 70 feet without anhydrite. In the section, therefore, the anhydrite of the Aurora well has been drawn as grading into salt, a procedure without positive proof. The shaft and wells at Portland Point should, theoretically at least, furnish reliable data. Unfortunately, however, this is not the case and little reliance can be placed upon them. The diamond drill, the churn drill wells, and the shaft fail to give concordant results. The

slight faulting and plasticity of the salt can account for some of the lack of agreement. A striking disagreement is seen in the records of

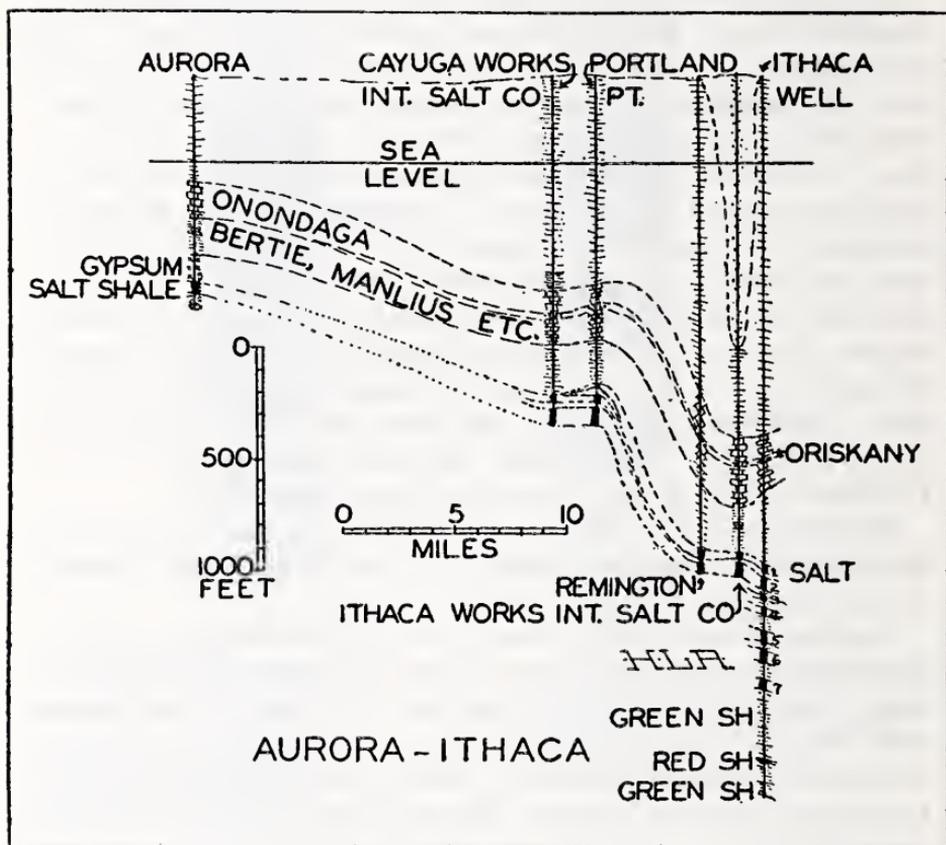


Fig. 11 Geologic cross section from Aurora to Ithaca based upon well records obtained from many sources. The anticlinal and synclinal structure of the district is clearly shown. Vertical exaggeration 52.8 times. Note that the salt is not a great distance below the base of the Onondaga limestone. The Oriskany sandstone is thick enough to be shown in this section.

the Remington well as furnished by the Remington Company and by J. B. Calkins. The former gives *two* seams of salt 42 and 44 feet thick separated by eight feet of limestone (waterlime, anhydrite?) while the latter gives *one* bed 70 feet thick. Furthermore, the company's own statement places the bottom of the salt at a depth of 2192 feet or at 1792 feet (about) below sea level, while Calkins states it occurs at a depth of about 2009 feet, or at 1609 feet altitude. It is possible, of course, that these are records of two different wells with different elevations. Such are the difficulties in attempting to utilize such data. As our information of geology below ground is largely

obtained from such well records, it behooves those in charge of such work to note with extreme care the character and position of each sample or core, making a full and permanent record. A better agreement between Calkins and the Company's records is that of the Ithaca works of the International Salt Company. Whiting gives two beds, which is probably correct, 20 and 60 feet with a 20-foot parting of shale. The bottom of the latter is placed at a depth of 2250 feet while Calkins reports but one bed of 70 feet at 2220 feet depth. It would appear that Calkins has ignored the undulations of the rocks and makes the salt beds assume a uniform dip to the south.

The record of Whiting for the Ithaca works and the Ithaca well, which is reasonably accurate, completes the section. By virtue of the exaggeration of the vertical scale a smooth flexure of the thick beds has been impossible in the section and is not true to nature. The axes of the folds are probably not vertical but perpendicular to the plane of average dip. All these uncertainties and difficulties render the construction of the Aurora-Ithaca section an unwelcome task. Nevertheless it is believed that it presents some significant facts relating to the geology of salt deposits.

One noticeable fact the well records show is the thickening of the Cardiff and Ludlowville shales, the unusual thickness of the Oriskany sandstone, and the decrease in the thickness of the Onondaga limestone southward.

The Tully Section; Solvay Process Company

Figure 12

This diagram of the Solvay Process Company's wells at Tully is after Merrill (1893, p. 20), but with modifications. This is on a different scale from the rest, the vertical being three and one-third times the horizontal, and is introduced to show how apparently irreconcilable facts can be correlated by a little allowable interpretation. As originally given, the great thickness of salt at well 1 and 3 of group B is not duplicated by the neighboring wells. Wells 1 and 3 of group D show two beds separated by shale. It is assumed that an error has occurred in recording the elevation or the depth of wells 2 and 4 of group B, as suggested on the basis of finding salt below the line connecting the tops of uppermost salt beds. If this is true, then the postulation of three beds makes a consistent section. The majority of the wells were sunk only to the base of the first or uppermost bed. The great depth of salt in wells 1 and 3 of group B can be accounted for on the basis that the shale partings were comparatively thin, or were ignored by the driller, or both.

The Retsof-Sterling Section

Figure 13

Through the kindness of mine managers of the Retsof Mining Company and the Sterling Salt Company I have been able to present this section showing portions of the shaft records of the two com-

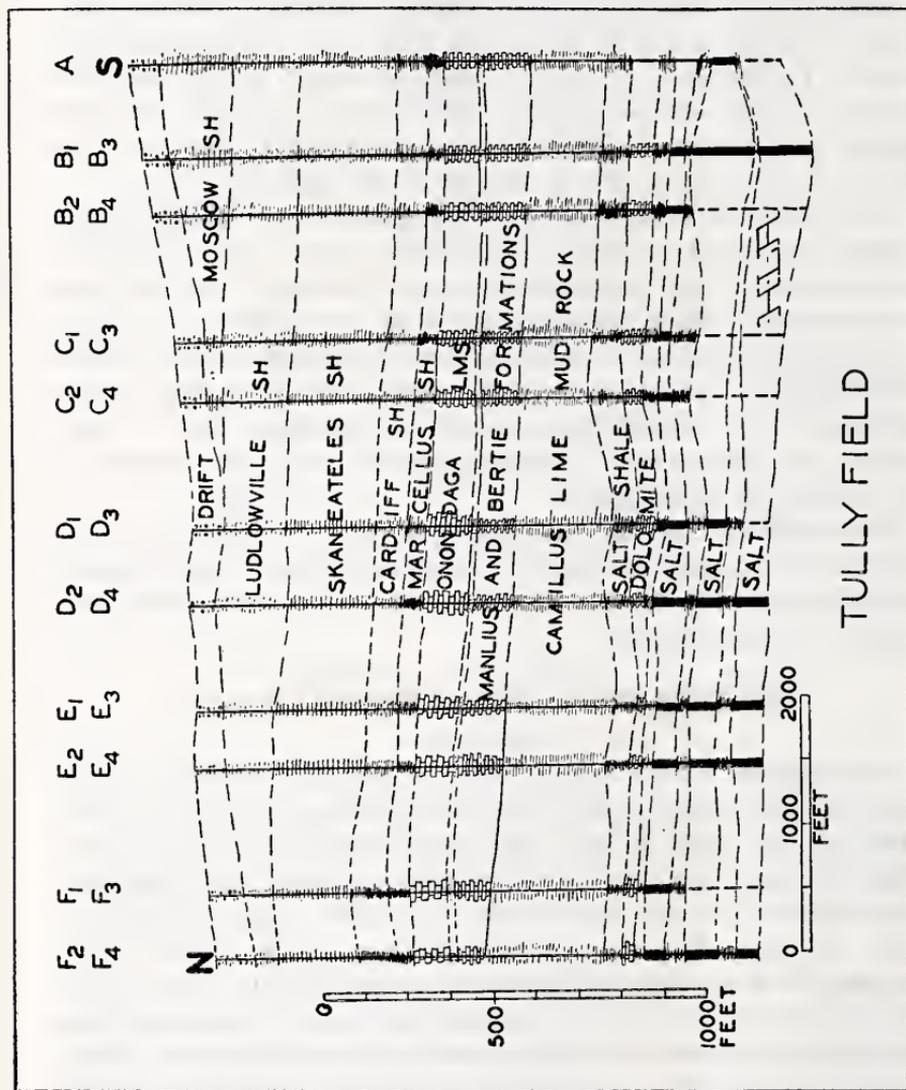


Fig. 12 Geologic cross section of the wells of the Solvay Process Company at Tully. Information secured from Merrill but modified by the writer. Exaggeration 3.5 times. The letters with figures are the numbers of the wells.

panies. The Retsof column is a composite one, having been secured from many sources, and may not be accurate. Detail correlations here are very uncertain in spite of the completeness of the information. Similar conditions, I understand, obtain between closely grouped wells in the vicinity of Himrod.

The portion of the main salt bed now being mined by these companies is indicated upon the sections.

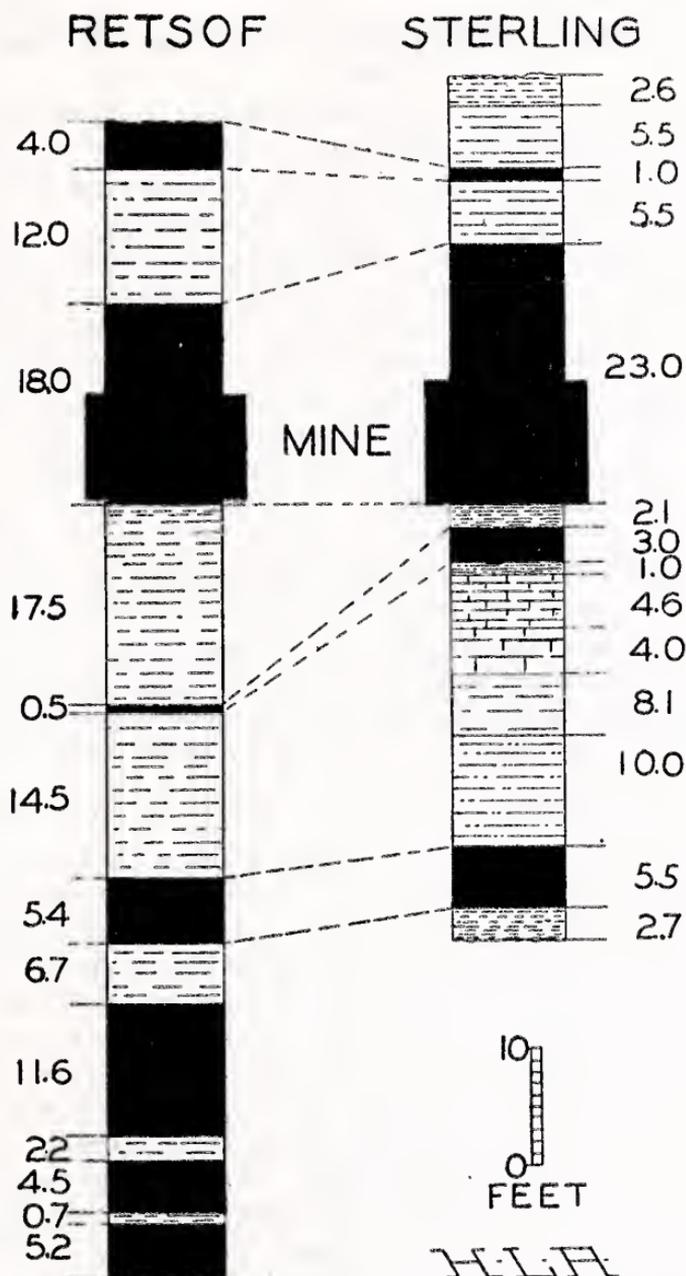


Fig. 13 Portions of the record of the Retsof and Sterling shafts showing the beds of rock salt arranged for comparison. The base of the thickest bed of salt in each section has been correlated and placed on the same level. Note that correlations are very uncertain. The Retsof column has been secured from many sources; it is a composite and may not be accurate. Assistance has been rendered by Mr. Moynes of the Retsof Mining Company. The Sterling record has been supplied by Mr Fetherston of the Sterling Salt Company.

Contour Map of the New York State Salt Field

Figure 14

In figure 14 I have attempted to construct a subsurface contour map, the foregoing cross sections being used. I was compelled, after much experimenting, to draw the contours on the basis of the top of the main salt bed in every case. This map differs from the map published by Merrill in 1893 in that he drew the contours on the basis that the salt was situated 610 feet below the summit of the Onondaga limestone. So many departures were made from this "average," due to unconformities and independent folds, that his map is open to criticism. The contours on the western margin of the map are shown interrupted by the Clarendon-Linden fault which has been extended farther south than Chadwick has investigated. It may be that it crosses the Batavia-Attica-Bliss section north of Bliss and thus accounts for the excessive depth of the salt below the Onondaga limestone. The map clearly indicates the presence of terraces and even reversals in dip. Here the contour interval is 100 feet; the datum plane, sea level. If a smaller contour interval had been employed, some closed contours would have been necessary. Insufficient data in the southern portion of the area here mapped prevent extending the anticlinal and synclinal structure of the Ithaca region westward.

THE CHEMISTRY OF SALT DEPOSITION

The problem of the conditions under which salt beds are deposited is more than a geological one. It is very evident that very little progress can be made by attempting to apply geological methods alone. The physical chemist is in a far better position to appreciate and to solve the events that have taken place to form deposits of salt. From the composition of the rock salt and associated rocks it is reasonable to suggest that they were derived from the evaporation of sea-water; "and hence it may at first appear perfectly simple to repeat the process in the laboratory by evaporating sea-water to dryness. This was carried out on a large scale by Usiglio (1849, p. 27, 92, 172); but the results obtained by him failed to correspond with the natural deposits in several important respects" (Stewart, 1922, p. 612). This is true of the Stassfurt deposits and of those in New York. Hence one is tempted to say, with Keyes (1923, p. 290), that we would make more progress if "van't Hoff, Hinrichen, Weigat, and Myerhoffer . . . [had] been permitted to leave their indoor theoretical environment and go into outdoor observational laboratories."

The difficulty is not with the physical chemists, nor with the geologists, but rather with a lack of cooperation between them. To

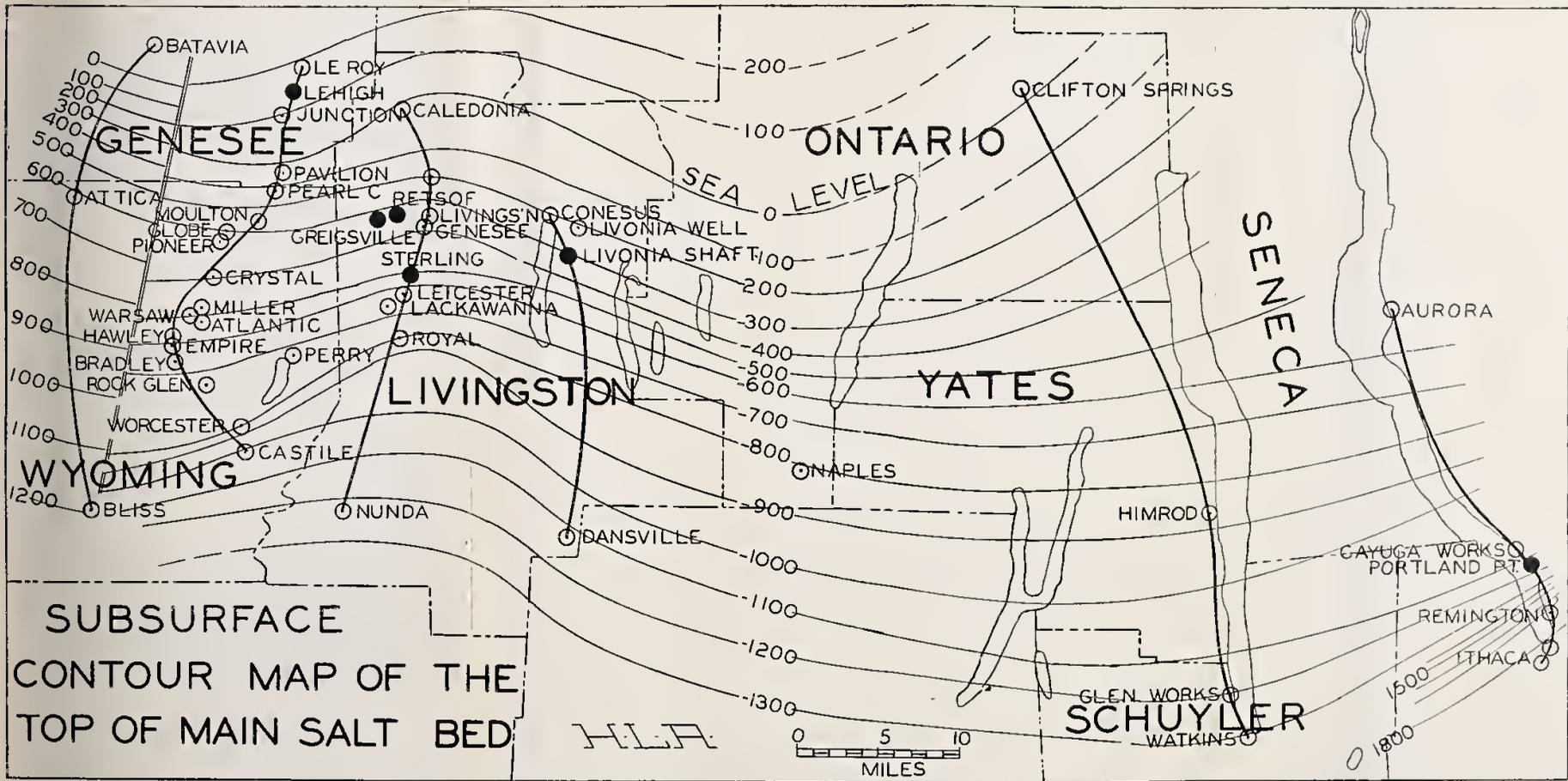


Fig. 14 Map of the New York State salt field showing tentative subsurface contouring of the top of the main salt bed. Constructed from the geologic cross sections which are indicated by the heavy lines passing through the wells. The shafts are shown by black circles, the wells by circles and dots. This map differs considerably from a similar one published by Merrill in 1893, as he drew his contours 610' below the top of the Onondaga limestone, as an "average" position for the salt. The many departures from this figure show that his method has many disadvantages. The present map used the position of the salt as found. Contour interval, 100 feet; reference plane, sea level. The Clarendon-Linden fault is shown interrupting the contours on western margin of the map.



SUBSURFACE
 CONTOUR MAP OF THE
 TOP OF MAIN SALT BED

effect this interrelationship upon this problem between these two divisions of science is my difficult task. It is not possible to do a great deal because of many unknown and uncertain factors involved in these problems. Perhaps all I can do is to indicate the complexity of the problems with which we are concerned.

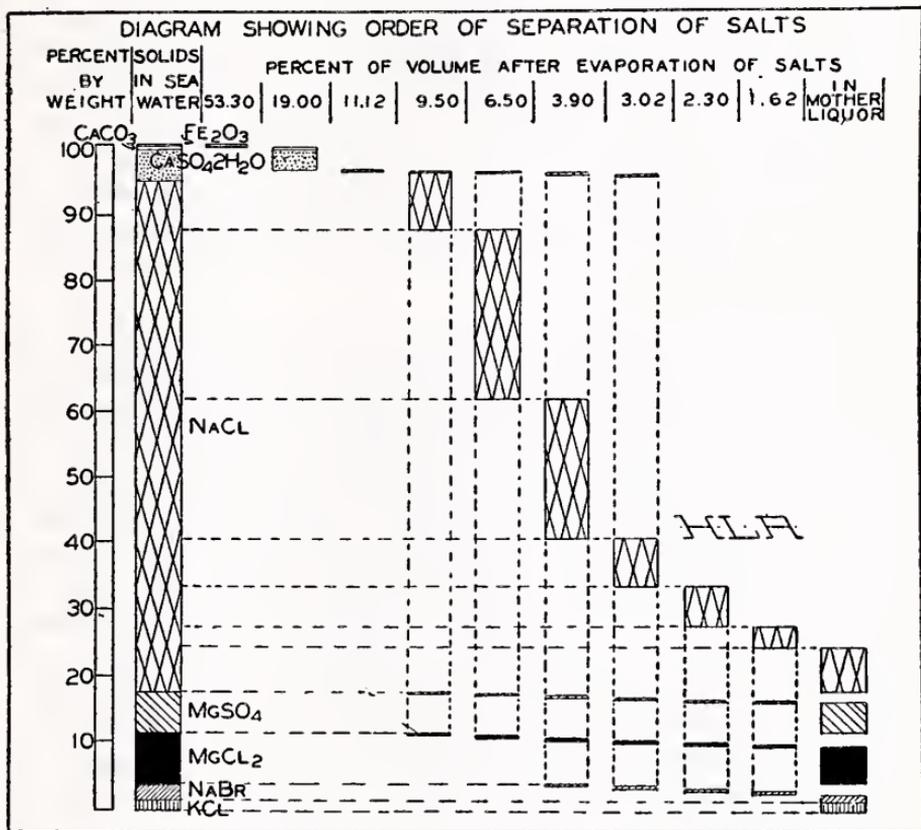


Fig. 15 Diagram showing order of the separation of salts on evaporation, under atmospheric pressure, of sea water. The dry salts, per cent by weight, calculated to be in sea water, are given at the left. The percentage of each salt which separates as the volume of the solution is reduced by evaporation is shown in the succeeding columns. That is, when the volume has been reduced to 53.30 per cent of the whole, a little ferric oxide and calcium carbonate has crystallized. At 19 per cent the rest of the calcium carbonate and some of the gypsum have separated, and so on. If all of the "blocks" of these columns should be shoved together they would reconstruct the first column. Note that at no time is pure sodium chloride precipitated without some other salt. Diagram based upon figures given by Grabau, Principles of Stratigraphy. 1913, p. 349.

Usiglio's results are presented graphically in figure 15. It shows that, as evaporation of sea water is carried on, various salts are precipitated, not in the reverse order of their solubility in pure water,

but as they reach the saturation point in the presence of the other salts. The order of deposition was as follows: ferric oxide, calcium carbonate, gypsum, gypsum and salt. Remaining in the mother liquor is some salt, magnesium sulphate, magnesium chloride, sodium bromide and potassium chloride. Usiglio (1849, 1849a) failed to obtain kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) polyhalite ($\text{K}_2\text{Mg}(\text{SO}_4) \cdot 6\text{H}_2\text{O}$), kainite, ($\text{MgSO}_4 \cdot \text{KCl} \cdot 3\text{H}_2\text{O}$) and anhydrite. "These experiments lacked those essential elements which are operative in the formation of salt deposits in nature, namely (1) long periods of time, (2) extensive changes of temperature during deposition, (3) pressure and accompanying development of heat . . . after burial under later deposits, . . . which furnish the condition for reactions between the original salts and the production of meta-salts." (Grabau, 1920, p. 61; Berkey 1924, p. 116).

"It is therefore evident that in order to obtain an insight into the conditions under which the Stassfurt strata or any other salt deposit were laid down, more refined methods must be employed than mere evaporation of seawater. The question remained practically at this stage until the year 1887, when van't Hoff (1887, et seq; 1905, 1909) and his collaborators (van't Hoff and Myerhoffer 1898-99; Janecke 1906) attacked the problem from a different point of view. "Instead of taking a solution like sea-water, which contains a very large series of solutes, van't Hoff in his researches worked always from simple to more complex cases" (Stewart, 1922, p. 62). The simplest case is that of one salt in solution; that is, a system composed of one solvent, water, and one solute, a salt. As evaporation proceeds a decreasing volume would result in the complete saturation of the remaining solution with the salt. Further evaporation would cause precipitation.

In dealing with two or more salts in solution in water, van't Hoff and his coworkers employed the method of measuring the contents of such solutions in terms of moles instead of percentage by weight. From a chemical point of view this has many advantages, but to many geologists, who have studied the crystallization of igneous rocks by means of thermo-equilibrium diagrams, this different nomenclature is a difficulty of no small moment. The solid models that are offered in explanation of the events that take place on evaporation of a solution of two, three and four salts are at best exceedingly difficult to understand. Most geologists, and I feel that they are quite justified, pass them by, claiming, in order to justify themselves, that they are geologists and not chemists. This, of course, does not improve matters. I shall therefore attempt to suggest some of the experimental details of a few of the systems that have been studied.

If to a saturated solution of sodium chloride some potassium chloride is added, potassium chloride will dissolve until the solution is saturated in respect to the potassium salt. It will also contain as much sodium chloride as it can. If the solution is evaporated, both salts will precipitate together. But if one salt only is present to its maximum at that temperature, it will precipitate on evaporation until the volume of the solution has decreased so the other salt fully saturates it, then both will separate together as before.

If sodium chloride and magnesium sulphate are dissolved in water, we find that double decomposition will take place. On evaporation four salts instead of two will be obtained: magnesium sulphate, magnesium chloride, sodium chloride, and sodium sulphate. This indicates an increasing complication.

A third experiment may be cited as an illustration of the problem of salt deposition. When solutions of magnesium chloride and potassium chloride are mixed, under certain conditions of temperature a double salt is formed: $MgCl_2 \cdot KCl \cdot 6H_2O$, carnallite. From a solution of two solutes three salts have been formed: potassium chloride, magnesium chloride and carnallite. The physical chemist is therefore called upon to determine the solubility relations of (1) Potassium chloride in water, (2) Magnesium chloride in water, (3) Carnallite in magnesium chloride solution, (4) Carnallite in potassium chloride solution and to construct diagrams and models to express the relationships at different temperatures and pressures.

If we investigate a solution of potassium chloride and magnesium sulphate we find that, besides the four salts produced by double decomposition of the two solutes, under conditions, controlled by temperature and pressure, a double salt $MgSO_4 \cdot K_2SO_4 \cdot 6H_2O$, schönite, will form. The chemist finds that he can first deal with these salts in pairs, then in threes, and then with four, five, six salts. Many of these salts form hydrates, some of which are stable through a considerable change of temperature and pressures, while others are very transitory. The list of the possible salts that can be expected to form by the evaporation of a solution similar to that of sea water is very great, provided temperature, pressure and time were variable. A reasonable list of such salts that are of interest in this study of the New York salt deposits may reach a figure of 40. It must be pointed out, however, that such a large number of salts could not exist in equilibrium with each other in the same basin. Reactions between them would ensue with the disappearance of some of them.

Suppose to this system of potassium chloride and magnesium sulphate, which produce additional salts by double decomposition, and the formation of double salts and hydrates, we add sodium chloride. Without going into detail, perhaps the reader can imagine what a complicated problem the physical chemist has. And this detailed study of saline substances is still going on. In the *Journal of the American Chemical Society* for August 1924 we find a paper on the system magnesium sulphate-sodium sulphate-water (Archibald and Gale, 1924, p. 1760-71).

All this detailed information at our disposal is at the same time both a help and a hindrance. We are tempted to apply these results in a universal manner to all salt deposits without realizing that they primarily apply to the Stassfurt deposits. There the conditions were comparatively simple, even though it took years for van't Hoff, Myerhoffer and others to work out the involved physical chemistry of these deposits.

The Stassfurt deposits in Prussia, of Upper Permian age, exhibit two or possibly four cycles of evaporation. The first and lowest series of evaporites begins with Zechstein limestone and dolomite, anhydrite and gypsum, which are in turn overlain by rock salt beds. Next a polyhalite zone and kieserite zone, ending in carnallite deposits.

The second cycle, not as complete as the lower, is separated from it by a bed of salt clay. It begins with anhydrite and ends with rock salt. A bed of red clay separates the second cycle from the possible third series, which begins with anhydrite and ends in salt, without the more soluble salts. The last cycle is less complete, in that it contains anhydrite without any deposition of salt; the only indication of the latter is salt cavities in the overlying red clay.

The Stassfurt deposits therefore indicate interruptions of evaporation by influx of clastic materials and a new supply of sea water. The rock salt in the lowest group contains 3000 layers, called annual rings which suggest that "they are due to seasonal fluctuations in the density of the water—a periodic slight reduction in the salinity during a moister period, putting a temporary end to salt deposition and permitting the formation of anhydrite" (Grabau, 1920, p. 236).

"In the hands of van't Hoff and his collaborator . . . the whole question has been . . . developed to such a point that even the temperature of the period at which any particular series of beds was deposited can be determined with moderate accuracy" (Stewart, 1922, p. 61).

Such interruptions, influx of clastic materials, deposition of lime-mud over a deposit of saline minerals seem to have taken place in

the development of the Salina salt of New York, Michigan, Ontario and Ohio.

Before it is possible to apply the principles of salt deposition to the Salina, we must investigate the assumptions upon which they are based.

If we assume that the salt has been derived from sea water by evaporation let us ask what was the composition of the sea water. The same as modern sea water? It is well known that the salinity of sea water varies from place to place; it differs in strength according to depth as well. What was the composition of sea water in the open oceans during Salina times? We do not know. There have been many attempts to arrive at the "age of the earth" by calculating the increased sodium content of the oceans on the basis of the influx of additional supplies by the rivers of the present. Such speculations assume a saltless sea which by gradual accumulation from the decomposition of land areas has reached its salinity in a uniform manner. If we concede this assumption, and I venture to voice the opinion that it is nothing more than an assumption, we are forced to conclude that Salina seas had a different composition. But we do not know what it was, nor do we know whether this different sea water on evaporation would deposit saline substances in the same order under similar circumstances as sea water now existing. Of course, I, as well as others, dislike to state that we are in the dark regarding a number of essential points with which we are greatly concerned in this investigation. The hope of real success is to know what we *do* know and what we do *not* know.

In case of the Stassfurt deposits it would seem that they "were formed by the drying up of a large body of sea water which had become separated from the main ocean by the formation of a land barrier" (Grabau, 1920, p. 61). Then we would hasten to suggest that in New York State a similar basin existed in which a number of cycles of evaporation took place. But a discussion of this matter is deferred to another section.

In the early days of the salt industry the interest taken in the natural brines of Syracuse and Montezuma was intense and a great many chemical analyses were made. The Syracuse brines varied considerably in their mineral content, but more particularly in their strength. The total salts in solution varied from 13 to 14 per cent. Later on with an increase in the depth of the wells the figures rose to 19 and 20 per cent, but during the decline of the Syracuse field the total salinity fell to the neighborhood of 16, which in part accounts for the decline of the Onondaga field.

In general, the purity of the natural brines does not equal that of the artificial solutions. The dry salts from the Syracuse field range from 93.7 to 95.6 per cent sodium chloride while the artificial brines average 97 per cent.

The number of analyses of artificial brines that have been published is surprisingly few. There is a remarkable similarity and uniformity among them. The amount of salt per hundred volumes varies from 21.5 to 26.3. There appears to be a lower calcium sulphate content in the brines of the Ithaca-Watkins district than in those of the Genesee-Wyoming field. The analyses here tabulated fail clearly to establish this point, but the fact that the grainer pipes in the plants in the Ithaca-Watkins district are scaled only every 10 days while in the other fields the scale is removed every three or four days points to such a conclusion.

If we do not know the composition of the Salina sea we do possess a group of analyses of artificial brines from the salt plants of the State as well as from Michigan, Ontario and Ohio. The term "artificial brine" means that fresh water is pumped down the wells and there in contact with the rock salt becomes saturated with saline materials. This brine is forced to the surface, usually by compressed air and there evaporated. I have calculated these analyses in parts per hundred of solution, as well as per cent of the dry salts. Of course, in the solution they are not combined as salts but exist as ions. The advantage of the method used is that it renders the analyses more readily comparable. It must not, however, be imagined that these salts are merely mixed in a mechanical manner with each other. We have seen that double salts and hydrates exist. The calculation of these salts as given below is sufficiently difficult without attempting to suggest any additional refinements.

In figure 16 the composition of 22 brines is given in a graphic manner. These vertical columns represent 100 per cent. In as much as the brines range from 95 to 98 per cent sodium chloride it was necessary in order to show the amounts of the other salts to break the column in the middle and to leave the per cent scale from 6 to 94 out of the diagram. Figure 16 is suggestive in that magnesium chloride, calcium chloride and calcium sulphate exist in all the brines. In a few ferric oxide has been determined, but there is every reason to believe that all brines contain iron. It would have been interesting to have a complete analyses of a brine where the rarer salts had been determined. But I am not sure whether such an analysis would be highly significant. If we are searching for the potash salts, which these analyses do not report, on not finding them we are not

BRINES

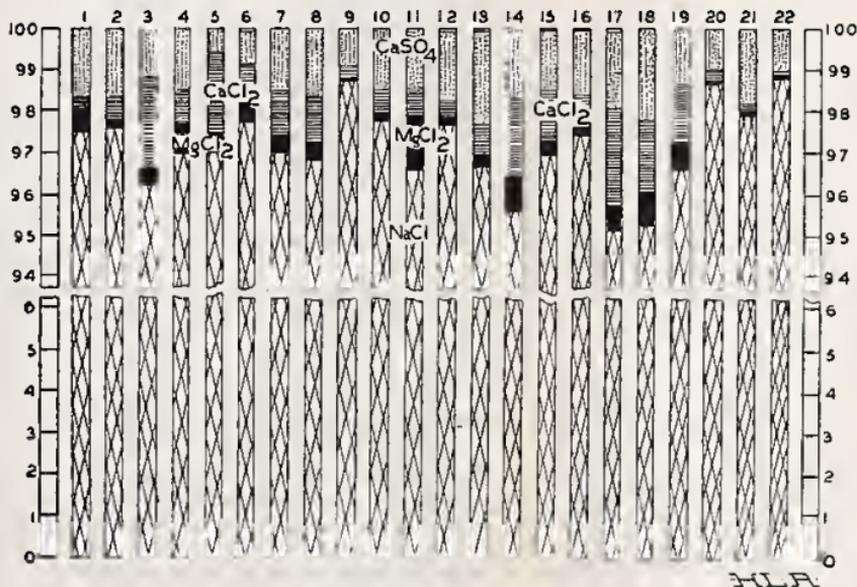


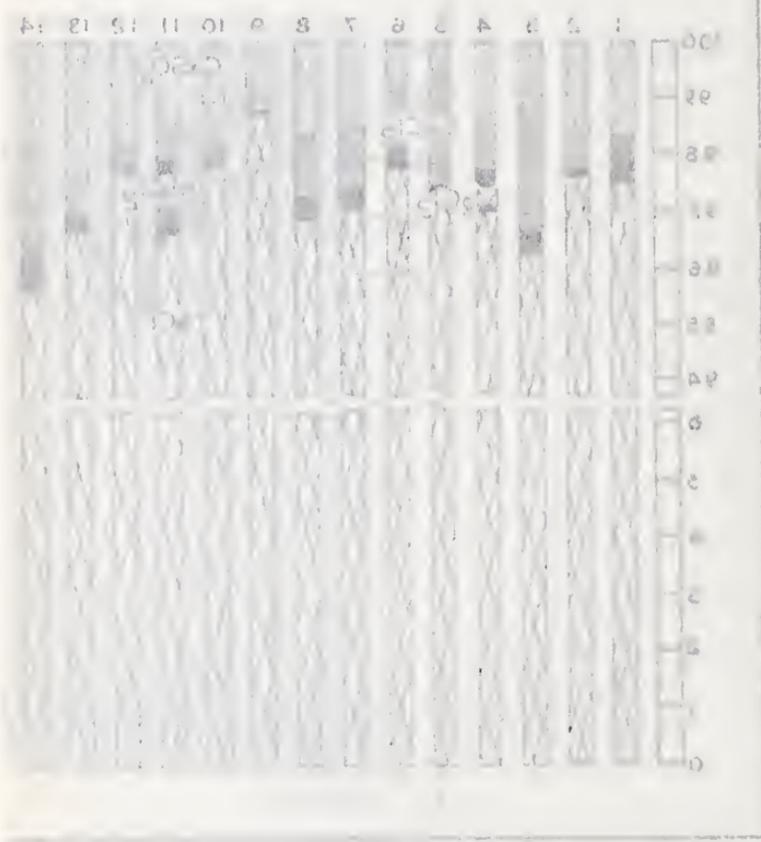
Fig. 16 Diagram to show the chemical composition of 22 artificial brines from New York State. These columns represent 100 per cent of the dry salts calculated in terms of the common compounds.

- 1 Pearl Creek Salt Co.
- 2 Warsaw Salt Co.
- 3 LeRoy Salt Co.

- 4 Livingston Salt Co.
- 5 No. 1 well, Le Roy Salt Co.
- 6 No. 1 well, York Salt Co.

7-13 inclusive, Wells in the Wyoming valley.
 14-19 inclusive, Wells in the Genesee valley.
 20-21 Warsaw district.
 22 Cayuga Works, International Salt Co., Ludlowville.

BRINES



1. 100% solution of sodium chloride in distilled water.
 2. 90% solution of sodium chloride in distilled water.
 3. 80% solution of sodium chloride in distilled water.
 4. 70% solution of sodium chloride in distilled water.
 5. 60% solution of sodium chloride in distilled water.
 6. 50% solution of sodium chloride in distilled water.
 7. 40% solution of sodium chloride in distilled water.
 8. 30% solution of sodium chloride in distilled water.
 9. 20% solution of sodium chloride in distilled water.
 10. 10% solution of sodium chloride in distilled water.
 11. 5% solution of sodium chloride in distilled water.
 12. 2.5% solution of sodium chloride in distilled water.
 13. 1.25% solution of sodium chloride in distilled water.
 14. 0.625% solution of sodium chloride in distilled water.

justified in stating that the Salina sea was lacking in potash or that potash was not deposited. For these analyses represent the soluble portions of the rock salt horizons and do not and can not give any true indication of the composition of beds any great distance above or below the salt layers penetrated by the wells.

The lack of definite satisfaction experienced over the analyses of the brines of the state is somewhat, though not completely compensated by the available analyses of bitterns. These strong and bitter solutions accumulate in every brine plant. It is the mother liquor remaining after the salt has been separated. That is, the manufacturers of salt do not evaporate the brine down to dryness for the resulting product would contain the hydrates of calcium and magnesium chloride that render a salt nonpouring in wet weather. Part of the value of shaker salt for table use lies in its comparative freedom from such salts. Makers of high grade salt usually add a little magnesium carbonate to the product. This added substance coats the cubical grains, furnishing a free flowing salt. The Norton Salt Company, with headquarters in Chicago, advertises its salt by saying: "When it rains it pours."

It was hoped that a comparison of these bitterns might give a clue to differences in composition of various salt layers or indicate a geographical difference. The analyses were recast as were the brine analyses, into parts per hundred of solution and per cent of dry salts. The latter figures were to be arranged in the form of vertical columns, which in turn were to be arranged geographically after a pattern of the salt well records. This proved, however, to be of no real significance in that the degree to which the bitterns had been evaporated differed materially from plant to plant. In a number of plants the only available samples of bittern were from the waste pipes, into which exhaust steam had been fed. The proposed method of tabulation had to be abandoned and consequently they have been arranged in order of their increasing content of salts other than sodium chloride (see figure 17). Attention is drawn to the presence of potassium chloride. After investigating the possibility of securing potash from these bitterns because of the extreme shortage during the World War, I reached the conclusion that it was not a commercial proposition even under those trying conditions.

It will be noticed that when the calcium sulphate content is low, the calcium chloride content rises along with a similar though a smaller increase in magnesium chloride.

This information seems to indicate that the so-called rarer salts are not entirely lacking in the New York salt deposits. Again let

us remember that analyses of the minable rock salt, brines and bitterns give the composition of only a part of a possible solution from which they may have been derived. If potash salts of any extent were deposited in New York they certainly are not to be found in the rock salt layers but would lie, if present, above some

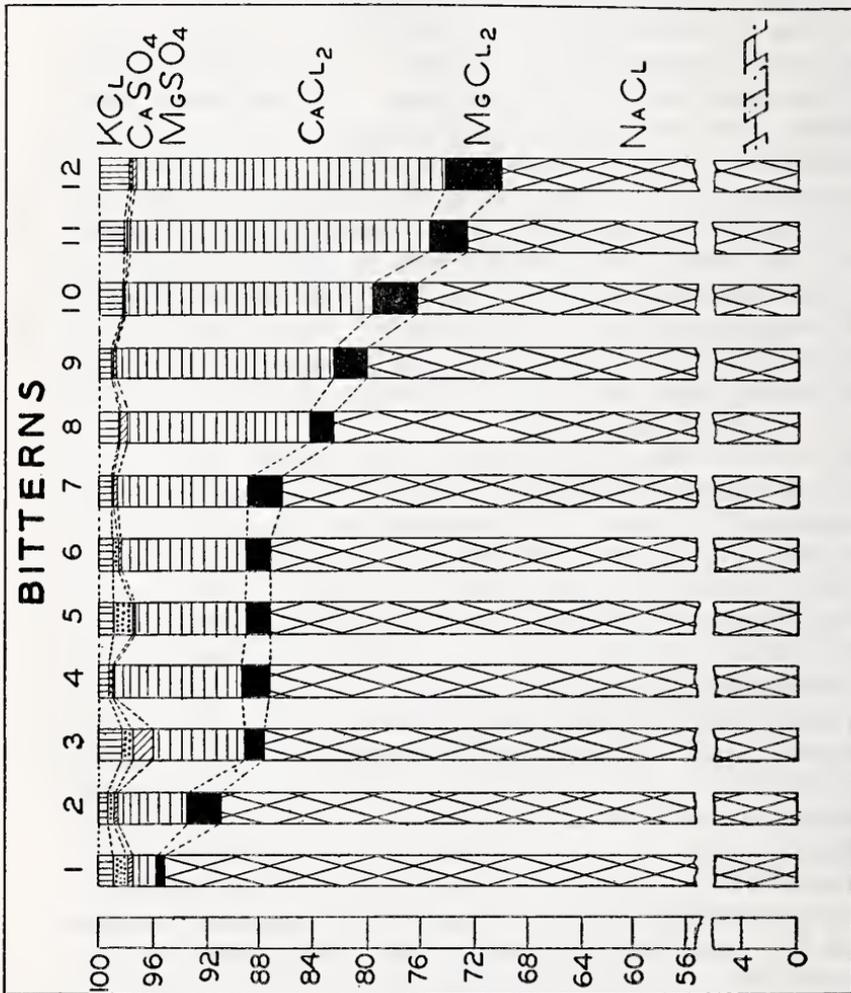


Fig. 17 Graphic representation of the chemical composition of the bitterns from the brine plants in New York State. Calculated on the basis of 100 per cent of dry salts. The analyses have been arranged according to increasing per cent of calcium chloride. The portion of the scale from 4 per cent to 56 per cent has been omitted.

- 1 Watkins Salt Co.
- 2 Genesee Salt Co.
- 3 Le Roy Salt Co., includes waste steam
- 4 Remington Salt Co., bittern from vacuum pan
- 5 Crystal Salt Co., bittern from open pan
- 6 Rock Glen Salt Co., bittern 10 days old
- 7 Cayuga Works, International Salt Co
- 8 Worcester Salt Co., bittern from grainer
- 9 Crystal Salt Co., bittern from grainer
- 10 Ithaca Works International Salt Co., bittern from grainer
- 11 Rock Glen Salt Co., bittern from grainer
- 12 Ithaca Works International Salt Co., bittern from grainer

of them at least. So far as our meager information goes we have not encountered them in drilling or in shaft sinking in beds by themselves. Petrographic studies of Camillus lime-mud rocks in microscopic thin sections indicate that there are some potash salts mixed and entangled in the rocks above the rock salt horizons. This matter is treated more at length in the section on petrography.

Associated with the problem of the deposition of the beds of rock salt is that of the formation of the gypsum, which is of great commercial importance. For many years a number of plants have been mining gypsum along the strike in New York, Michigan, Ontario and Ohio. In fact, the areal distribution of the gypsum deposits is far greater than that of salt. In New York the commercial deposits are situated above the salt horizon. This fact has given rise to the belief that there is little or no gypsum beneath the salt—a belief which I entertained until facts to the contrary were obtained.

The shaft on Portland Point supplies information concerning the nature of the calcium sulphate layers associated with the rock salt. In the past it has been the custom to refer to the calcium sulphate as gypsum. At the 1200-foot level a layer of banded rock taken by the engineer of the company to be gypsum proved to be anhydrite. This was ascertained by microscopic examination in thin section. There is a little gypsum present, however, which appears to be of secondary origin, due perhaps to the dynamic disturbance to which the rocks there had been subjected. The anhydrite is mixed with the shale in quite a similar way to that shown by the salt beds. Other specimens show a pearly and scaly material that contains more gypsum, but is still composed in large measure of anhydrite. Specimens of the shale associated with the salt at Retsof show anhydrite in distinct layers which have not been so much disturbed as in the Ithaca district. If the calcium sulphate was deposited from aqueous solutions as gypsum, it is quite possible that the subsequent load due to the accumulation of the overlying formations has caused the dehydration of the gypsum, to anhydrite. As erosion brought the surface down by removing the overlying rocks the underground circulations permit the reformation of gypsum. Thus at the outcrop we find gypsum, but at the depth to which the salt shafts penetrate the calcium sulphate exists as anhydrite.

These observations have been substantiated by the group of specimens furnished by Mr Fetherston of the Sterling Salt Company. This suite of rock specimens was taken from a horizon 25 feet above the mine roof and extending down through the minable zone to 40 feet below the mine floor. Many specimens have been thin-

sectioned without the use of water, so the soluble minerals are still retained. The calcium sulphate in all of these sections proved to be anhydrite. I feel very confident that gypsum now worked on the outcrop and in the mines along the strike is secondary; having been derived from anhydrite by hydration.

Mr Newland was so impressed with this observation in his work in the gypsum fields that he has emphasized the commercial importance of the limit below the surface that minable gypsum occurs (1922, p. 89-98; 1921, p. 393-404).

"Van't Hoff and his associates (van't Hoff and Weigert, 1901) in their experimental work . . . found that solutions of calcium sulphate, when evaporated in open containers, and therefore under atmospheric pressure, deposit gypsum or anhydrite according to the temperature reached at saturation. Up to 66°C. gypsum separates; above that limit anhydrite; however, if the solution contains other salts, the boundary temperature for gypsum-anhydrite will be lowered. In the presence of sodium chloride, anhydrite begins to form at 30°C. and the gypsum deposited below that temperature will, in contact with a solution saturated for sodium chloride, change into anhydrite. In the evaporation of sea water, the crystallizing point of anhydrite is 25°C." (Newland, 1922, p. 90; see Vater, 1900, p. 270 ff).

Thus it is possible that, if we assume that the calcium sulphate in the New York Salina is an evaporite from sea water or a natural brine in lagoons or playa lake basins, this salt was deposited either as gypsum or anhydrite. Petrographic studies indicate that even this anhydrite is secondary. If so, then the gypsum of the outcrop is tertiary.

Newland (1921, p. 397), from field experience in western New York and core-drill records, notes that "anhydrite begins to show in the rock at 100-125 feet depth and its proportions increase more or less steadily in ratio with increasing cover. The critical depth seems to be around 250-300 feet, below which the mineral, except as cavity and vein fillings, is in the form of anhydrite."

He notes that similar conditions obtain in southern Ontario, Michigan, Iowa and in the salt domes of the Gulf region (Grimsley, 1904, p. 84; Kay, 1920, p. 107-10).

If it is possible to utilize van't Hoff's results and apply them to New York, which I think it is best to regard as somewhat questionable, it is not an unreasonable suggestion that anhydrite rather than gypsum was deposited by evaporation of saline waters. Under arid conditions, which most assuredly prevailed, a temperature greater

than 25 degrees centigrade seems likely. This conclusion together with the petrographic evidence, which is submitted in another chapter, complicates our problem instead of solving it. But the secondary character of the gypsum does not throw any real light upon the *origin* of the New York gypsum.

An entirely different view has been advanced by Grabau (1912, p. 357) who states that the gypsum of New York occurs for the most part "in irregular masses, commonly with a flat base but rising through the inclosing limestones with layers of more clayey material or impure limestones passing through limestones and gypsum alike and marking the original stratification (see figure 106). Dana (1880, p. 234) has correctly interpreted [?] these gypsum masses as resulting from the limestones which make up a part of this formation, the alteration being affected by the acid sulphate waters which abound [?] in the formation and which have resulted from the oxidation of the iron pyrite in the rock."

It seems to me that Grabau has placed too much confidence in Dana's interpretation. The gypsum does not assume "masses commonly with flat bases" as numerous as the reader may gather from Grabau's statement. Its present position and partial penetration of the overlying beds does not constitute evidence of having been derived by interaction of sulphate waters and limestone. Hydration of anhydrite in forming gypsum involves an increase in volume which has in hundreds of localities arched and broken the overlying rocks. Complicated brecciation has taken place in many places; breccias that today are recemented by veinlets of fibrous gypsum. Grabau interprets these little synclines as due to the alteration of limestone to gypsum.

In attempting to explain the formation of thick beds of gypsum many authors have calculated that when about 37 per cent of the saline water is evaporated gypsum begins to be precipitated; and when 93 per cent of the water is similarly disposed of sodium chloride crystallizes. On this basis geologists postulate basins containing sea water miles in depth. In as much as this is obviously absurd they proceed to hunt for other theories. Difficulties are many and consequently the theories are numerous.

The simplicity of Usiglio's results is so attractive that many have been led to stray into unforeseen difficulties, many of their own fabrication. Van't Hoff clearly shows that the crystallization of saline solutions, such as are frequently found in desert basins, may deposit certain salts in a certain sequence, but if the temperature is raised 20° or 30° C. solutions of identical composition frequently give rise

during desiccation to some entirely different minerals. Usiglio used five liters of sea water to which he did not add any more during the evaporation. I would, in a less serious mood, suggest that in as much as Usiglio, the celebrated Italian chemist, did not add water to his vats, many have unconsciously concluded that nature does not add new supplies to a playa lake in a desert basin, hence they postulate waters miles in depth. Absurd as this may seem, many have concluded that certain deposits of salt and gypsum could not have been formed by the evaporation of sea water or even playa bitters because the basins in which they were deposited were not miles deep. Hence many overflow basins are postulated in which the brine having dropped its gypsum in one basin spills over into a convenient and awaiting basin in which salt is deposited. This, of course, helps to explain the absence of gypsum where there is salt and vice versa. The whole trouble with this is that these theories contain enough truth to be confusing.

Some deserts of today are forming nearly pure gypsum, thick enough to call for deep basins. Walther, Andrussow, Hobbs, Grabau and many others are turning our attention to desert phenomena. Playa basins with saline saturated soils are subjected to occasional rains, infrequent rivers, and wind. These agents can and do concentrate gypsum sands. Wind can even form dunes of saline substances which are subsequently leached of their more soluble minerals, including the chlorides of sodium and potassium by rain water. This rain water, containing the more soluble salts, drains away through the sands and dried mud and on evaporation leaves these salts in the interstices of these clastic materials or is absorbed (adsorbed) by them. In New York traces of potash salts have been identified in the salt shales and lime-mud rocks of the Camillus type. The playa lake muds when exposed to the drying action of the sun become mud-cracked, the edges of the polygonal sheets which curl up, become detached and are blown by the wind, ground into small fragments and transported to other places in the desert area. Such materials accumulate in masses, the stratification of which is ordered by mechanical and not by chemical processes. Salt and gypsum by such aeolian activity become patchy and irregular in distribution and exhibit many secondary characteristics. Playa lake waters differ in composition, far more so than sea water. It is not a mere matter of concentration, of halinity or of salinity, but the proportion and presence of various salts in solution. A glance at the composition of Great Salt lake water, which is a sodium chloride brine, and that

of the Dead sea, which is a magnesium chloride brine, indicates this difference. This variation is unquestionably due to many causes, some primary and some secondary. It is impossible to evaluate all of them. One of the factors that is undoubtedly contributory is the kind of rocks the streams encounter in their courses before entering the playa lake basins. Decomposed rocks situated in the drainage basin contributed their soluble salts. Acid igneous rocks, high in potash, may contribute that element. The kind of saline deposit derived from dolomitic limestones would, other things remaining the same, be more magnesian than if the streams drained areas of argillaceous sediments.

Grabau (1920, p. 165-67) has made some suggestive calculations on the amount of sodium chloride locked up in the pore space of marine sediments. On the assumption that limestones of Niagaran and Salina times have a pore space of 30 per cent and that the seas of that time had a salinity of $3\frac{1}{2}$ per cent the same as now, of which 77 per cent was sodium chloride, it follows that the sodium chloride content of marine limestones may reach .365 per cent. This is logical if we accept the assumption on which it is based. Grabau proceeds to calculate that if 50,000 square miles, or an area slightly larger than the State of New York, of such limestones are eroded to a depth of 100 feet and the salt so obtained could be deposited in a basin covering 100 square miles, it would be 182.5 feet thick. This is an attractive theory and may, perhaps, be applied to New York.

A study of the composition of river waters, streams that flow over rocks which may be similar to those rimming the Salina basin, reveals many additional problems. Where do many of the substances they contain go? We see visions of long and tedious investigations, dealing with precipitations and absorptions, of suspensionoids and complex solutions.

Clarke, (1916, p. 177) has pointed out that the water of Lake Lahontan which is fed by streams flowing over igneous rocks differs radically from lake waters situated in regions of sedimentary rocks. The latter are saline while the former are not.

But we do know that if the simple evaporation of a body of sea water isolated from the main ocean by a land barrier, deposits a bed of salt, so does a playa lake in a desert basin into which a few streams enter, flowing over marine limestones. Furthermore, these different modes of origin are *not* mutually exclusive, for there is the possibility, if not a probability, that a cut-off arm of the sea undergoing evaporation may experience replenishment in the form of sea water splashed over a bar, or saline substances may be con-

tributed by streams which have obtained such salts from the decomposed rocks situated in their drainage basins.

This review, even though not a thorough one, should indicate that the chemistry of salt deposition is very complex, that we are not justified in accepting any one theory of deposition, on the basis of the few facts which we possess about the salt deposits of New York, with expectation of success. And all this in the face of the inestimable service of the physical chemist.

It is quite possible that I have conveyed the impression that there is no advantage to be gained by discussing the problem of the origin of the New York salt in the light of the above observations. I would only direct attention to the fact that we do not *know* how they originated, and that, whatever may be the theories proposed, they must be highly speculative in nature.

PETROGRAPHY

The complexities of determining the geologic history of the salt deposits with their associated rocks causes us to seek all possible aid. It was hoped that detailed microscopic studies would reveal a great deal of valuable information. In all frankness, I have been disappointed. The study of sedimentary rocks with the petrographic microscope is both difficult and perplexing. Some of the difficulty lies in unexpected findings which are too frequently at variance with the more customary conceptions. Rocks, that are called "shales" in stratigraphy, prove to be highly calcareous under the microscope. The nomenclature of sediments, as commonly used, becomes an obstacle in this investigation. But this is not the place to advocate a new system, although the temptation is strong. Grabau has made suggestions that, in theory, mark an advance, but the mere complexity of his nomenclature prevents its adoption. Instead I am using descriptive terms which I hope will be self-explanatory.

Petrographic studies of sediments show that rocks of this kind have experienced considerable reorganization, recrystallization, even though they have not experienced folding, mountain making stresses, or metamorphism in the ordinary sense. These diagenetic changes are in reality a form of incipient metamorphism. In the broad meaning of the term "metamorphism" as used by Leith and Mead (1915), such rocks are "metamorphosed." This stretching of this old term to include changes not originally embraced is often criticized, and perhaps justly. Yet there is much to be said in its favor. The petrographic stratigrapher is placed in a peculiar position since most

of the sedimentaries are "metamorphosed," and yet many geologists object to the term! We might use diagenesis. I would, however, suggest the term "epimorphism," a modification of the term "epi-zone" of Greübenmann (1907, p. 21) to signify incipient metamorphism.

The Lockport-Guelph

In west-central New York the Lockport-Guelph rocks are siliceous dolomites. They are made up of rhomboidal grains of dolomitic calcite, frequently interlocking and inclosing grains of quartz. These mineral constituents range in size from .08 to .20 mm in diameter and hence are classed by Grabau as "fine sand." Smaller amounts of chlorite, sericite, epidote, pyrite and carbonaceous matter are easily identified. Smaller percentages of feldspar, members of the pyroxene and amphibole groups, various micas, garnet and zircon complete the list. Detrital material is unquestionably present mixed with the calcareous matters. The rock both paleontologically and petrographically is a marine sediment.

These formations become more siliceous and argillaceous to the east. At Clinton the rock referred to as Lockport or Rochester is an argillaceous sediment but still retains the same rhomboidal grains of dolomitic calcite. Because they are less abundant than in the west they appear as pseudo-phenocrysts in an argillaceous groundmass. The passage beds into the basal Vernon at Farmers Mills, a few miles south of Clinton, retain these characteristic pseudo-phenocrysts (see figure 18A).

The Vernon

The basal Vernon is not universally red. The mottled red and green beds are transitory to the typical red formation. These basal beds under the microscope consist of argillaceous matters, such as chlorite, epidote and sericite, with abundant quartz and the characteristic dolomitic rhombs (figure 18 *B, C, H* and *I*). The eurypterid-bearing zones are more calcareous than the rest, indicating, if I have interpreted them correctly, detritus of rivers deposited in bodies of standing water, perhaps lagoons or euryhaline lakes. The pseudo-phenocrysts ranged from .008 to .01 mm in diameter, and hence come under the classification of rock flour. The groundmass is chloritic and sericitic. Quartz grains, small angular grains from .004 to .008 mm, never fail. The groundmass shows an arrangement that is characteristic of the Vernon. Around each rhomb of dolomitic calcite and quartz, sericite flakes are arranged in long shreds which

give a much more angular appearance than the grains themselves. The chloritic matters are, as a rule, prevented from coming in contact with the pseudo-phenocrysts by these micaceous flakes. They give to the groundmass a "basket-weave pattern." The argillaceous materials in the Lockport are more irregular in arrangement, and are more dense and browner in color. This basket-weave pattern is not common. I have found something similar in certain layers of the Maplewood shale of the Clinton group at Rochester.

In the mottled red and green layers, the Vernon shows the same characteristic basket-weave pattern with fewer pseudo-phenocrysts of dolomitic calcite, but the quartz and occasionally feldspar and garnet grains are present. The red colorization is unquestionably secondary, probably derived from the chlorite. The iron content of the green and red phases of the rock is very likely the same; the difference so noticeable to the eye is due to the state of the iron. In the form of chlorite the iron is principally in the ferrous condition, while the red color is due to ferric iron. The red hematitic matter is apparently amorphous and suggestive of colloidal iron oxides. It obscures the other minerals when present as if a fine network of red matter had been interwoven into the basket weave fabric. In specially prepared slides, ground extra thin and with thin cover glasses, the oil-immersion lens picks out the basket-weave pattern even though masked by the iron oxide. Even in the reddest of the Vernon, this iron net-work is patchy; it is not uniformly distributed (figure 18 *E* and *F*). In certain localities, such as at Oneida and Clinton, the Vernon is spotted with gray green semispherical matters. These show very distinctly the basket-weave pattern and differ from the surrounding red rock in lacking the red colorization.

The cause of these green areas, which are about an inch or two in diameter, is not known. Carbonaceous matter and pyrite are often present in the centers, but do not seem to be universal in these areas, and hence their presence can not be called upon to explain them (figure 18 *H* and *I*).

Thin sections of the red Vernon, when washed by concentrated hydrochloric acid, lose to a large degree the red colorization, leaving the basket-weave pattern, although it is not so distinct as in the originally green rocks. An interpretation is that some of the chloritic minerals have suffered alteration to the iron oxide form. I entertain considerable doubt whether the red colorization is a reliable criterion for terrestrial deposition. My feeling in this matter is that much depends upon the subsequent history of the rock; perhaps more than upon the conditions under which it was first deposited.

The Camillus

The Camillus is a fine-grained lime-mud rock, a calcilutite. The grains of dolomitic calcite are from .01 to .025 mm, and thus range from clay size to rock flour. Argillaceous matter is exceedingly difficult to identify, but it is probably acting, in the majority of specimens examined by the oil-immersion objective, as the cement. Quartz does not fail, but many individual fields are made up exclusively of dolomitic calcite (figure 19 *C, D, E* and *F*). Long flakes of muscovite are frequently found. Horizons of the Camillus that possess a distinct shaly structure, and are more yellow in color, contain more grains of quartz, feldspar, hornblende, serpentine etc. The quartz grains are all below .04 mm in size, are very angular and splintery. Most of them possess a wavy extinction. I would offer the interpretation that they were derived from metamorphic rocks. Yet it may be that they were imbedded in other sedimentary rocks before being transferred to the Camillus. There are too many possibilities to justify a definite conclusion about the sources of these grains.

Carbonaceous matter, pyrite and many other minerals in small quantities are found in the Camillus (figure 19 *F*).

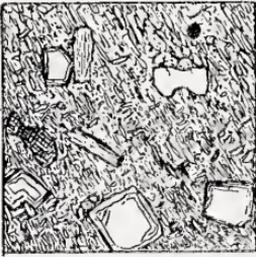
Other horizons are more argillaceous. Grains of sericite, paragonite, chlorite and epidote are interlocked with dolomitic calcite. The latter do not possess the characteristic rhomboidal outlines found in the basal Vernon. These argillaceous substances, together with less definite mineral substance, show considerable reorganization and crystallization. They were probably deposited as colloidal substances with much absorbed salts. Now they are to a large degree anisotropic.

In districts south of Rochester the upper Camillus and Onondaga limestone have been arched into long narrow ridges or buckles. Many suggestions have been made to explain them. One is that either the solution of gypsum in the beds below, or the hydration of the anhydrite, disturbed the overlying strata. Certainly brecciation and slumping is observable in the Camillus along the outcrop. Slides of such material exhibit microfaulting and the rehealing by secondary vein filling by gypsum and calcite.

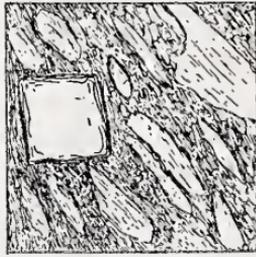
The Brayman

The Brayman shale of Schoharie county is here considered as the eastern extension of the Camillus. Microscopically it possesses much the same characters as the thicker formation to the west. It is distinctly coarser grained in certain horizons. Water-worn quartz

VERNON



A



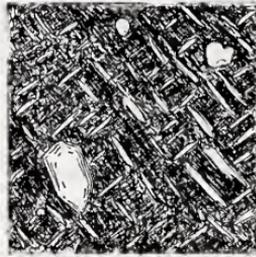
B



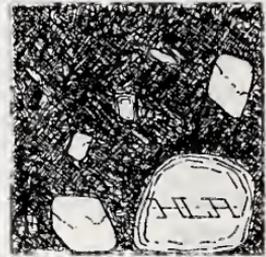
C



D



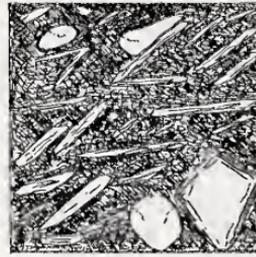
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H



I

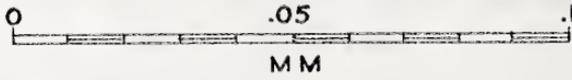


Fig. 18 Vernon Shale

Explanation of figure 18

- A* Black Vernon (Pittsford Horizon) Farmers Mills, two miles south of Clinton. Interlocking boundary between Lockport and Vernon. Rhombs of dolomitic calcite, shown with concentrically lined borders; clear grain with rows of gas bubbles, quartz; fragment of microcline with gridiron twinning; and shreds of sericite; all set in a groundmass of chlorite, epidote and sericite matters. (1028)
- B* Green Vernon on top of the "Lockport," College ravine, Clinton, N. Y. Rhomb of dolomitic calcite set in a shaly groundmass composed of sericitic minerals, light streaks and chloritic and epidotic substances, dark background. (1024)
- C* Green lime-mud rock, basal Vernon, from Barge canal, Pittsford, near Rochester. East avenue bridge crossing. Clear grain of quartz in a fine-grained background of dolomitic calcite cemented with green chlorite and epidote. (1022X)
- D* Black dolomitic shale, basal Vernon, higher eurypterid horizon, Pittsford, N. Y. Discolored and partially replaced grains of dolomitic calcite cemented by sericite and chlorite. Note the dark carbonaceous matter and the section of an eurypterid fragment. (957)
- E* "Typical" red Vernon shale, Vernon, N. Y. A grain of dolomitic calcite and quartz set in fine groundmass of sericite, epidote and chlorite, exhibiting "basket-weave" pattern, all but obscured by red fluculent iron oxides. (954)
- F* Red Vernon shale, College ravine, Clinton, N. Y. Pseudocrysts of dolomitic calcite and quartz in shaly matters impregnated with iron oxides. The hematitic matters all but obscure the "basket-weave" pattern of the groundmass. (1889A)
- G* Red streak, left side; of iron-stained shale in green Vernon, Oneida Castle, N. Y. Rhombs of dolomitic calcite occur in both the red and green portions, a few grains of quartz and shreds of sericite are shown. (919)
- H* Green mass in red Vernon, College ravine, Clinton, N. Y. Pseudocrysts of magnesian calcite and quartz, set in a fine grained groundmass of sericite, chlorite and epidote. Note "V-basket-weave" pattern as shown by the shreds of sericite. (1889B)
- I* Green Vernon below the green spotted red shale, College ravine, Clinton, N. Y. Notice the pseudocrysts of magnesian-bearing calcite, quartz grains and in center, the masses of pseudoisotropic chlorite. (1888)

CAMILLUS

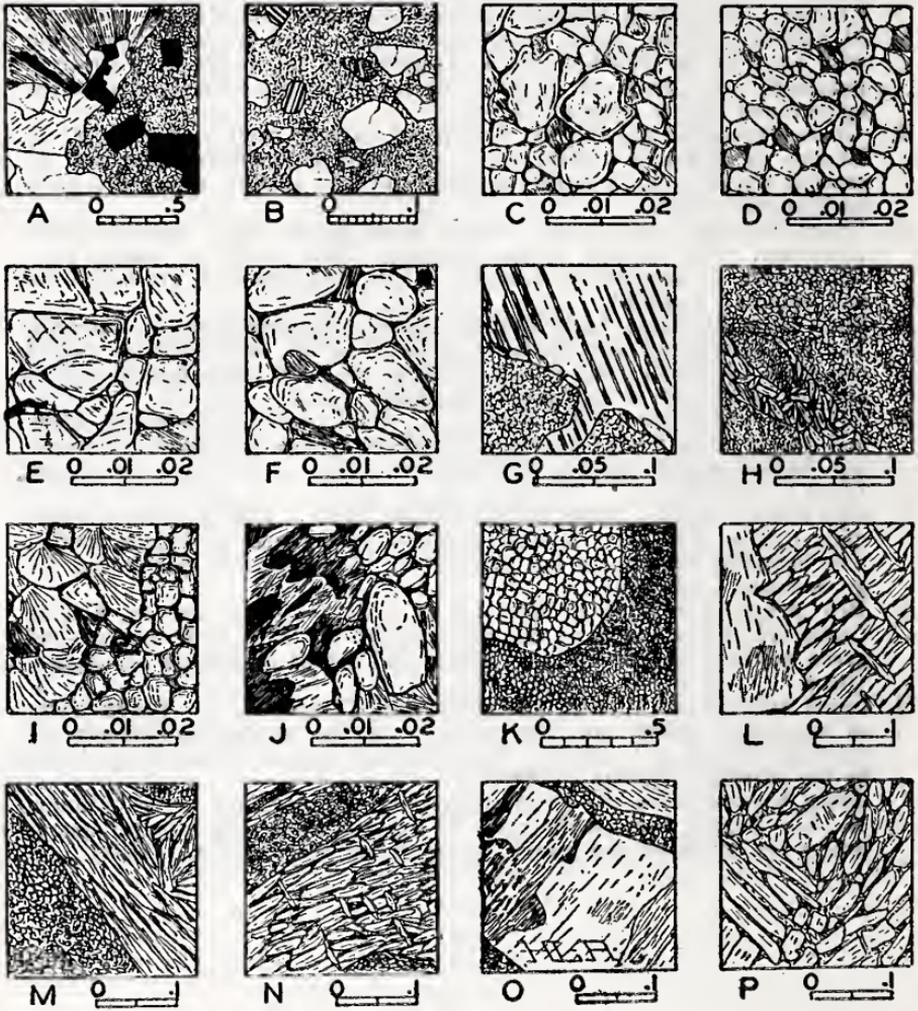


Fig. 19 Camera lucida drawings of Brayman and Camillus lime-mud rocks. All drawn under polarized light conditions.

Explanation of figure 19

- A* Mineralized Brayman-Camillus lime-mud rock, Schoharie, N. Y. Black, copper-bearing pyrite. Long bladlike grains, celestite. Clear grains with row of bubbles, quartz. Fine-grained groundmass on right side of drawing, dolomitic calcite cemented with argillaceous matters. Actual magnification: X19. (1005)
- B* Siliceous Brayman-Camillus lime-mud rock, Howes Cave, Schoharie, N. Y. Quarry of Helderberg Cement Company. Clear grains with row of bubbles, quartz. Striped grains, plagioclase. Grain with gridiron twinning, microcline, all set in a fine groundmass of dolomitic calcite with an argillaceous cement. Actual magnification: 108. (1006a)
- C* Camillus lime-mud rock from Camillus, N. Y. Showing dolomitic calcite with an argillaceous cement. The darker grains are in position of extinction. Actual magnification: X645. (1032)
- D* Camillus lime-mud rock from between Mumford and LeRoy. The rock exhibits well developed "salt hopper crystals." Very similar to C. Actual magnification: X645. (1045)
- E* Camillus lime-mud rock, four miles west of Auburn. Composed of grains of dolomitic calcite. Actual magnification: X645. (1033)
- F* Camillus lime-mud rock, Fort Hill, north of LeRoy. Very similar to last three but contains carbonaceous matter, black, and shreds of sericite. Actual magnification: X645. (1429)
- G* Secondary gypsum, variety selenite, veining Camillus lime-mud rock, Le Roy. Actual magnification: X142. (913-2)
- H* Secondary gypsum, fine flaky grains in veinlet in Camillus lime-mud rock, near Oneida. Magnification: X142. (914)
- I* Secondary gypsum, plumose grains, left side of drawing, in Camillus lime-mud rock, Empire Gypsum Company, Garbutt, N. Y. Specimen from working face of mine. Magnification: X645. (967B)
- J* Fibrous gypsum in Camillus lime-mud rock, Fayetteville, N. Y. Magnification: X645. (967A)
- K* Camillus lime-mud rock from Livonia shaft at a depth of 1403 feet. The upper left-hand corner shows the dolomitic calcite secondary filling of "salt hopper cavity." See text. Magnification: X27.5. (934)
- L* Anhydrite crystals composing grainer pipe scale, Remington Salt Co., north of Ithaca. Section cut perpendicular to pipe. The contact with the steam pipe to the left of the drawing. Magnification: X98. (929a)
- M* Elongated grains of anhydrite in Camillus lime-mud rock, shaft of the Rock Salt Corp., Portland Point, north of Ithaca. X98. (930)
- N* Elongated grains of anhydrite in veinlets in Camillus lime-mud rock, shaft of Rock Salt Corp., Portland Point. X98. (928)
- O* Large size plates of secondary gypsum in commercial gypsum rock, Empire Gypsum Co., Garbutt, N. Y. Selected from ore car as being high in gypsum. Magnification: X98. (1914)
- P* Anhydrite grains in Camillus, Livonia salt shaft, at a depth of 1463 feet. Magnification: X98. (1915)

grains, from 0.3 to 0.65 mm in size, ranging from medium to coarse sand, occur. These are cemented by argillaceous and dolomitic calcitic minerals. It possesses the Camillus appearance, which is sufficiently distinctive to be of correlative value, as proved by submitting unlabeled slides to my students at the University of Rochester (figure 19 B).

The Brayman is pyritic. Cubical grains of pyrite are scattered through the "Brayman," especially at Schoharie and at Howes Cave. It certainly has been introduced. Chalcopyrite and celestite occur with pyrite at certain horizons, more particularly near the top of the formation. This secondary mineralization is difficult to understand. Something very similar is reported in formations in Ohio, Michigan and Ontario. Consider the strontium ore in the Put-In-Bay dolomite of Ohio.

The celestite-pyrite zone (Sheppard, 1835; Newland, 1921, p. 282) is interesting. The microscope reveals beautiful cubical forms of copper bearing pyrite and long slender blades of celestite. Calcite completes the list of essential minerals (figure 19 A). All these minerals are clearly secondary and have been introduced. An occasional grain of glauconite is found in these beds. The strontium free beds are indicative of shallow water conditions, probably near the source of the material. Round pebbles of microcline, plagioclase and rock fragments are sufficiently abundant to indicate a short transportational history for these detrital grains.

The Anhydritic Lime Mud-Rocks

Specimens from horizons stratigraphically near the commercial beds of rock salt all show considerable anhydrite, if such specimens are secured from the mine shafts. If collected from the outcrop or gypsum quarries they contain gypsum instead of anhydrite. The difference has been discussed before.

The Camillus that contains but little anhydrite is characteristic of the whole formation, but carries this additional mineral in aggregates and bunches roughly parallel to the bedding planes. There appears to be some readjustment in the dolomitic calcite and argillaceous matters. The anhydrite has apparently compelled the rock minerals to make room for it. There is a little microfaulting to be seen and other modifications indicate that the anhydrite forced its way into its present positions. In specimens that contain more anhydrite this readjustment is more pronounced. The anhydrite occurs in plumes and in long aggregated stringers that twist and curve after the

manner of rock flowage in igneous extrusives. Pyrite and long winding rods of carbonaceous matter stream along parallel to the anhydrite. Why the anhydrite should take such a structure is difficult to say. Clearly we are not dealing with a simple matter here, for some form of subsequent changes has occurred in the rock (figures 19 *G* to *P* and 20).

Petrographic slides prepared dry, so that the soluble salts are retained, show, especially with the use of the oil-immersion objective, small grains of polyhalite; carnallite and other potash rich salts were determined with extreme difficulty and patience. Hours of labor were necessary. Grains of these substances were never larger than .005 mm in size, and yet interference figures were obtained. Extinction angles, birefringence and some idea of the index of refraction were necessary to reach this conclusion. It is impossible to give any estimate about the quantities present.

Layers that are composed to large extent of anhydrite present that mineral in many peculiar and beautiful forms, plumes, fanlike structures, irregular aggregates and thin veinlets. There has certainly been considerable reorganization of the material; rather extensive epimorphism. What the full significance of this observation may be, only future work can determine. It certainly raises the question whether the calcium sulphate was deposited as gypsum or as anhydrite. I do not know which it was. Petrographic evidence leaves the way open for either interpretation.

Layers closely associated with the rock salt show abundant anhydrite and veinlets of halite. The rocks are unquestionably of the Camillus type. The evidence all points to the conclusion that the salt and the Camillus are genetically related. The stratigraphic unit, the "Syracuse" salt, is not a feasible nomenclature.

The halite is never free from dolomitic calcite and argillaceous minerals. The grains of such minerals, imbedded in the salt appear to be corroded; they possess concave surfaces and remind me of the "driekanter" pebbles of desert areas. There is evidence that such masses are due to corrosion or partial solution, as grains not in the salt are not affected. Frequently these inclosed masses are attached to each other by rods and branching needles of carbonaceous matter.

Red salt is found in these lime-mud rocks both above and below the mine level. Such layers are relatively thin. The thickest I have seen is about a foot. Specimens of this red salt from the abandoned Greigsville shaft, when dissolved in water, leave a scum and a sediment of iron oxides. This material when examined under the

microscope reveals long narrow rods; I have been unable to suggest any reasonable explanation for them. Red salt in other areas is

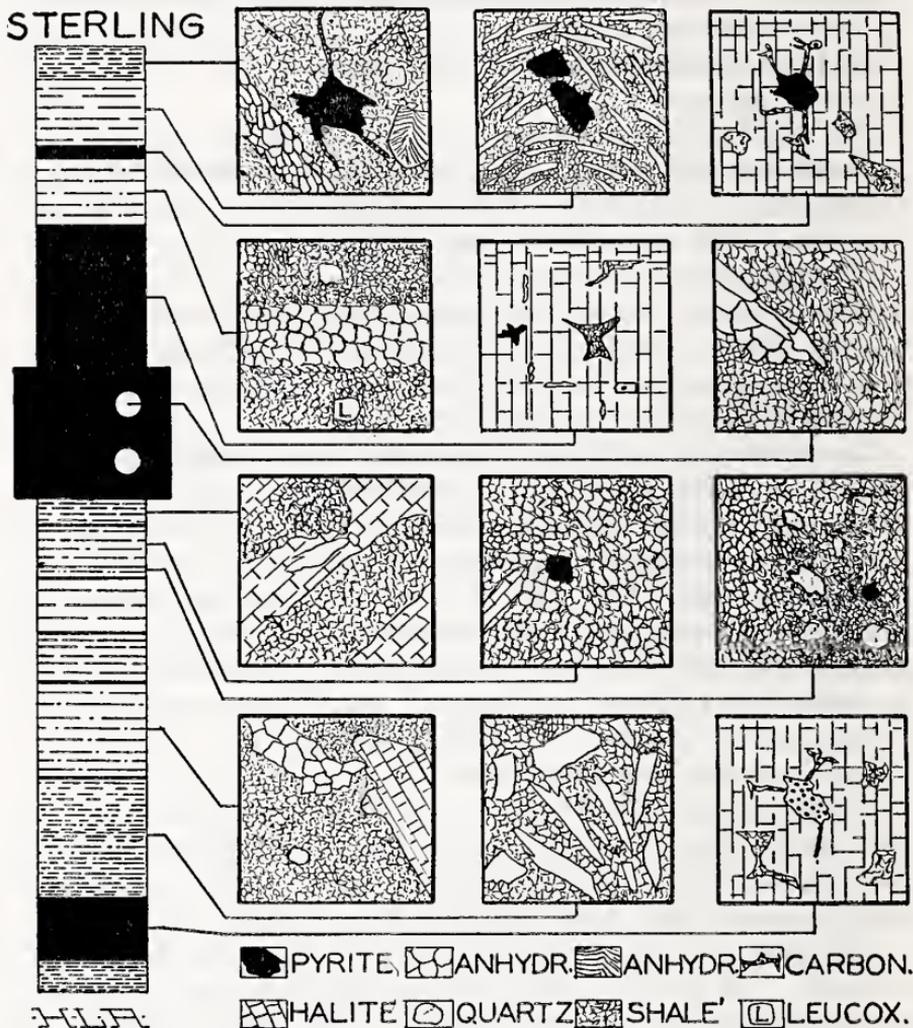


Fig. 20 The portion of the log of the Sterling shaft showing the beds of rock salt, solid black, and the intervening lime-mud rocks; together with camera lucida drawings of microscopic thin-sections cut from specimens as indicated. Both the record and specimens were supplied by Mr Fetherston of the Sterling Salt Company. Note the presence of carbonaceous matter in three of the drawings, and the abundance of anhydrite (not gypsum). The round "holes" in the section of the rock salt now being mined are nodules. Magnification about 100 diameters.

reported to contain red algae. There is certainly ample proof that organisms are not lacking in the anhydritic lime-mud rocks and even in the salty rocks directly associated with the main salt beds.

The veinlets of reddish or brownish salt transverse the anhydritic lime-mud rocks often diagonally to the bedding planes, and show very clearly that microfaulting has occurred. Solutions of saline matters filled these crevices. In the Retsof mine I have found a number of veins, several inches thick, of nearly pure recrystallized halite that cut the rock salt stratum in directions nearly at right angles to the bedding. I am confident that this investigation has demonstrated that considerable readjustment and resolution of much of the material now present has taken place. I would even go so far as to suggest that the beds of rock salt themselves may have been deposited where they are today by solution and reevaporation. How inadequate the usual theories of origin seem in the face of such possibilities. The truth seems to be that we do not know enough to understand what has happened.

Specimens taken from the abandoned Livonia shaft at a depth of 1403 feet, one and a half feet from the bottom of the reported 30-foot bed of rock salt, have been thin-sectioned. It is of the Camillus type of sediment, composed of dolomitic calcite 0.003 mm in size. There are semicircular cavities from 0.55 to 1.10 mm in diameter which have subsequently been filled with argillaceous minerals, dolomitic calcite, quartz and pyrite grains. My interpretation is that these cavities represent solution holes due to the removal of more soluble salts. Detrital matter now occupies the spaces (figure 19 K). Under the microscope, with ordinary light conditions, the material in these cavities is much lighter in color than the surrounding rock, while under cross nicols the color reactions are reversed.

The most illuminating suite of rock specimens, sent to me by Mr Fetherston of the Sterling Salt Company, shows the actual conditions prevailing both above and below the salt horizons. The suite commences 37 feet, 2 inches above the mine floor and extends 40 feet, 10 inches below. Some 25 slides, with many duplicates, have been prepared. Figure 20 is an attempt to reproduce by drawings the appearance of these rocks as viewed under the microscope.

The stratigraphic column at the left shows where the specimens were obtained. The round "holes" in the minable salt are nodules. These are about three inches in diameter and occur imbedded in the gray crystalline salt. Note particularly the forms assumed by the anhydrite, the presence of pyrite and carbonaceous matter, and that the rock salt is not pure, but contains various matters.

A less complete group of slides was secured from specimens picked from the rock dump of the Retsof Mining Company. These are less significant in that definite horizons are unknown. But they tell

the same story. Specimens from the Greigsville shaft are similar. The salt is in the Camillus type of sediment, not in the Vernon, and is saturated with anhydrite.

Gypsum Beds

Slides of the Camillus, rich in gypsum, secured from gypsum quarries on the line of outcrop, show the same type of rock; fine-grained argillaceous lime-mud rocks with secondary gypsum. The latter mineral occurs as aggregates of fine flaky gypsum occupying veinlets and irregular areas, clearly made by the growth of the mineral, presumably by the hydration of anhydrite. The beds now being worked for gypsum obviously contain a large percentage of the mineral, but in no case examined did the rock consist entirely of gypsum. Calcareous and argillaceous minerals are universally present. Carbonaceous matter, pyrite and a number of very small grains of quartz, feldspar, mica, pyroxenes, amphiboles, garnet, zircons etc. can be identified by careful examination with a high power objective.

Specimens taken from mine breasts, a half mile from the outcrop, show anhydrite, and with greater depths below the surface the anhydrite shows an ever increasing percentage. Newland has already noted this; my observations are in perfect agreement. It is difficult to prove that the gypsum has been derived by the hydration of anhydrite. The microscope shows that gypsum surrounds the grains of anhydrite, but the latter show that they have been enlarged. Specimens from the horizon of the commercial gypsum, but secured from the shaft of the Rock Salt Corporation at Portland Point, north of Ithaca, show abundant anhydrite grains in the form of narrow rods, averaging 0.10 mm long and .01 mm wide, which possess the same type of foliation and parallel to it as the normal minerals of the rock. But in the specimens secured from the working face of the mines of the Empire Gypsum Company at Garbutt, the anhydrite grains exhibit plates whose directions are more independent of the foliation than the above, averaging 0.14 mm long and 0.09 mm wide. Large beautiful plates of gypsum, in reality selenite, have been developed as secondary matters, pushing aside the lime-mud minerals. The plates of anhydrite are associated with the contacts of the gypsum and the lime-mud minerals. The evidence so far accumulated seems to point to the hydration of anhydrite as the source of the gypsum on the outcrop, but the process is not a simple one. Goldman and Wells (Goldman, 1925, p. 77) point out that "the transformation of

anhydrite into gypsum can take place at almost any temperature in the presence of pure water, but in the presence of sea water it could probably take place only at a temperature below 30° C. and in the presence of a saturated solution of NaCl only at somewhat lower temperatures. So far as observations go, it does not seem probable that the temperature of this transformation would be much influenced by pressure, but it obviously is much affected by the presence of dissolved salts."

We secure the impression that it is the presence of water rather than the release of pressure that is the determining cause (Rogers, 1915, p. 123-42; Gill, 1918, p. 89-98). Newland (1921, p. 91) would stress pressure as an important factor. Similar problems are presented by the Manitoba deposits (Wallace, 1914, p. 271) which indicate that the change is due to several causes. I would call attention to the hydration as due to surface waters reaching the anhydrite and this has a relation to the depth below the surface. In as much as pressure has a similar relation for moderate depths it is seen that both are functions of depth. I would therefore urge caution before accepting pressure alone as the important factor.

Specimens secured along the outcrop which show, in addition to gypsum, considerable slumping and brecciation, due in part, I believe, to hydration as well, frequently exhibit beautiful crystalline masses of selenite. These are often clear and transparent, though inclosing dolomitic calcite, pyrite and other mineral masses common to the Camillus. These selenite masses are not so large as those frequently found in the Lockport formation. Even in this selenite, stout crystals and plates of anhydrite occur. The anhydrite appears to be secondary. I can not but feel that much of the gypsum may have passed through the cycle of gypsum, anhydrite and gypsum several times, but of course am unable to prove it.

Grainer Pipe Scale

All of the brine plants of the State evaporate some of their brine at least in grainers. Throughout the length of these long rectangular shallow tanks substantial steam pipes of metal are placed. As the brine is evaporated for the purpose of precipitating the salt, calcium sulphate collects as a scale. This acts as a heat insulator and lowers the efficiency of the grainers. Periodically, every three to five days, the grainers are drained and the scale is knocked and chiseled off. Every plant therefore has a dump of grainer pipe scale. Specimens from several brine plants have been thin-sectioned.

Under the microscope the material is seen to be composed of anhydrite crystals almost exclusively. The scale from the Le Roy Salt Company's pipes showed that all of the calcium sulphate was anhydrite. This scale was taken from a grainer supplied with live steam and consequently the temperature of the pipes was high. Specimens from "dividend" grainers, using exhaust steam show some gypsum interlocking with the anhydrite. A little gypsum occurs in the scale from the Remington Salt Company, which uses exhaust steam from a neighboring electric generating station.

The scale found in the yard and considered by the foreman to be five years old showed considerably more gypsum, which clearly is secondary after anhydrite.

The slides cut perpendicular to the pipes show a variation in the size of the grain. The thickness of the scale averaged about one centimeter. At the contact with the hot pipe the grains average 0.04 by 0.015 mm. About 0.2 mm from the contact the grains become smaller, averaging 0.03 by 0.01 mm to a point about 1.0 mm from the pipe where the smallest grains are found, 0.02 by 0.007 mm. From that point they become larger again at a uniform rate until about 0.2 mm from the outer surface, where the crystals are about 0.05 by 0.02 mm in size. The grains at the surface are suddenly very large in comparison, 0.36 by 0.22 mm.

The Bertie

The microscopic studies of the Bertie series reveal striking similarities with the Camillus. The differences are slight. If the latter are to be emphasized, the Bertie is a little finer grained, ranging from 0.01 to 0.015 mm (rock flour to superfine sand) and is lower in quartz content. But the series is not homogeneous. The Scajaquada and the Oatka divisions contain more argillaceous minerals. The Falkirk is more dense and more massive. Petrographically the Camillus, including the anhydrite lime-mud rocks and rock salt, and the Bertie are similar. Have we sufficient basis for the interpretation that they have been derived from similar sources, have been formed by similar agents, have been deposited under similar conditions and have experienced a similar subsequent history? No, and yet we can ask ourselves: why not? If we choose to follow O'Connell, the Bertie is a flood-plain deposit of one or more rivers. But I can not accept this view because O'Connell has "proved" that the eurypterids lived in rivers during Bertie times. I do not know whether they did or not. The view I am inclined to accept at the present time is that the Camillus and the Bertie have much in common.

Conclusion

The microscope reveals much that we did not know about these sediments. We see that the nomenclature as commonly employed can not be used; epimorphism has affected the sediments, making interpretations more difficult. Reorganization, readjustment, microfaulting, resolution and reevaporation of saline matters render definite conclusions impossible. Such an examination demonstrates that correlation to a limited extent upon petrographic characters is possible, and yet it does not indicate the stratigraphic breaks which field work would suggest. We must appreciate the fact that the microscope can not solve all the problems. Life of some sort is indicated in all specimens examined; the Vernon, the Camillus, even the rock salt, contain carbonaceous matter. Organisms and potash salts are present. I would voice a word of caution: we can not theorize with any hope of attaining the truth until we get more facts. The petrographic microscope will furnish much information.

THE ORIGIN OF THE SALT

It is my hope that the reader has become convinced of the complexity of the problem of origin. It has not, however, been my purpose to perplex, but rather to share with the reader my attitude of mind. If I am not clear upon matters of scientific importance in this investigation it is because the scanty facts are conflicting; the theories are inadequate and the proposed explanations of origin are confusing because fact and theory are so inextricably interwoven. The desire of those who write upon this subject to reach a conclusion of apparent finality is so natural, so human, that I can not with justice voice any disapproval. But still I am convinced that scientific progress may be hampered by such attempts. We would all claim that our ideal is truth, but alas it does not always seem so. I have found a very real obstacle in the preconceived ideas of the average geologist. Our scarcity of actual information has given rise to the opinion that the problem is a simple one. I quite agree with Grabau in his belief that it is hopeless to arrive at the origin of a salt deposit without an exhaustive study of the formation in which it occurs. In as much as an exhaustive study has only just begun I am sure that definite conclusions would be premature.

Theories, however, have their place in geologic thought. They have a place here. The advocates of any theory, however, would set it upon a pedestal and isolate it from all the others in order to make sure that we distinguish it. This removes the opportunity of

comparing one theory with another. We lose the similarities and see only the contrasts. The truth may be that none of these, or even all of these furnish suggestions that aid us in our problem. The reader may well say that all of these theories can not be correct. This is my first contention: That it is customary to say that the salt originated according to *this* theory, and not by *that* theory. How do we know but that a union of the ideas contained in the contrasted and apparently conflicting theories will lead our thinking along the right path? We shall see how this may be possible as we now review the theories of origin.

The early geologists ascribed to volcanic activity the origin of many perplexing phenomena as the easiest way out of difficulties. Sodium chloride can be produced by such means. We may be compelled, in our ignorance, to call upon volcanoes as a source of chlorine. To undertake a discussion of this phase of the problem, however, is not the purpose of this paper. We are tending in the opposite direction today, and realize that volcanoes, in all probability, played no rôle in forming the salt of New York.

It has been stated that all deposits of salt have a primeval source in the sea. When sea water is evaporated, salt is precipitated. It makes little difference to us here whether the salt is derived from modern sea water, a Salina sea, or connate salt, that is, sea salt locked up in limestones. Examination of Russell's monograph on Lake Lahontan (1885), for example, shows that the lakes in that basin are supplied with water from areas of igneous rocks, which consist chiefly of rhyolites and andesites, and yet the lake waters, while more alkaline than Great Salt lake, contain sodium chloride. Surely this is primary salt and not sea salt. I am inclined to believe that this general statement is true *when applied* to commercial deposits of the extent of those here considered. Yet we ought to be cautious how we accept without qualification a statement of this kind.

Theory 1

Complete evaporation of an arm of the sea would deposit salt. If such sea water were like modern sea water and were evaporated to dryness without any replenishment during evaporation, we would expect a thin layer of salt associated with gypsum and mother liquor salts.

Objection (a) The actual beds are thicker than a single basin of reasonable depth filled with sea water would furnish.

Objection (b) The sequence of the deposits is other than that which may be inferred from laboratory experiments.

Objection (c) The mother liquor salts have not been found in any commercial amounts.

Discussion: What if Salina sea water were different from modern oceans? It is possible that it would deposit less or more salt and in a different sequence. Perhaps the variation from laboratory results would be so small as to be negligible. This is the usual implication in applying this theory to New York.

Potash salts have been detected in the Camillus. There is a little potash in the bitterns of the salt plants. There is a little variation in the amount of potash in bitterns from artificial brines taken from the different salt horizons. But no systematic search for potash has been made. No extensive diamond drilling has been done with the finding of potash as the object. We do not know whether potash is present in any amount or not. It certainly is not entirely lacking.

Theory 2

Partial evaporation of an arm of the sea, isolated by a barrier, the precipitated salt covered by the lime-muds derived from sediments of a sea which flooded the area and removed the mother liquor salt before their precipitation occurred.

Objection (a) The thickness of the beds of salt in New York is unexplained.

Objection (b) The sequence of the beds of gypsum and salt is not explained.

Objection (c) The nondiscovery of mother liquor salts is attributed to their nonexistence.

Discussion: The theory implies that there was no deposition of marine sediments within the inclosed basin of the age of the salt. If the sea flooded the basin, burying the previously precipitated salt, we ought to find marine sediments immediately on top of the salt beds, not only in New York but in adjacent territory. In New York we find the Camillus 200-400 feet thick, of lime-mud rocks which are certainly nonmarine. In Maryland, Swartz *et al* is of the opinion that the Wills Creek is the esturine and marine phase of the Camillus. This is only a partial agreement of the facts and the theory.

Theory 3

Partial evaporation of an arm of the sea, isolated by a barrier. The precipitated salt concentrated in the low places in the basin by river waters, rains, or winds and then buried by lime-muds derived from a flooding sea or rivers. This influx of the sea would remove the mother liquor.

In the Dansville well, the record of which is after Englehardt, there are 240 feet of "waterlime," divisible as before and interpreted in like manner. The salt appears to be a single seam 60 feet thick. On the section the parting is assumed to die out southwardly and the 60-foot bed is regarded as equivalent to both the seams reached by the Lakeville well, the Livonia well and the Livonia shaft.

The Clifton Springs-Watkins Section

Figure 9

The increase in the thickness and the amount of salt to the south is clearly shown in this section. The Clifton Springs well records salt shale 20 feet thick. At Himrod a distinct bed of rock salt, still with considerable "shales," 47 feet thick is shown. Below this lie salty beds 200 feet in thickness. The Watkins well, the record of which I owe to Hill and to Prosser, shows a succession of beds of rock salt, seven in number, aggregating 458 feet of salt! (See figure 10.) If we regard this latter record as reliable, it is clear that the Glen Works have not reached all the salt there is at this point. Four wells from which to draw a section is of limited application in reaching broad conclusions. Yet it is of interest to note that this section without the Himrod data was first drafted in 1919. In 1925 the record of the Himrod well became available and was found to fit into the section with only a thirty foot error. That is, the salt at Himrod as actually found was 30 feet lower than I had it drawn in 1919.

The undulations of the beds in this section are an attempt to represent the incipient Appalachian folds which undoubtedly exist. How successful I have been remains to be seen, but I am fully convinced that the dip is by no means uniform and any diagram with uniform dip for any portion of the salt field is at the best a simplification or indication that the facts have been disregarded.

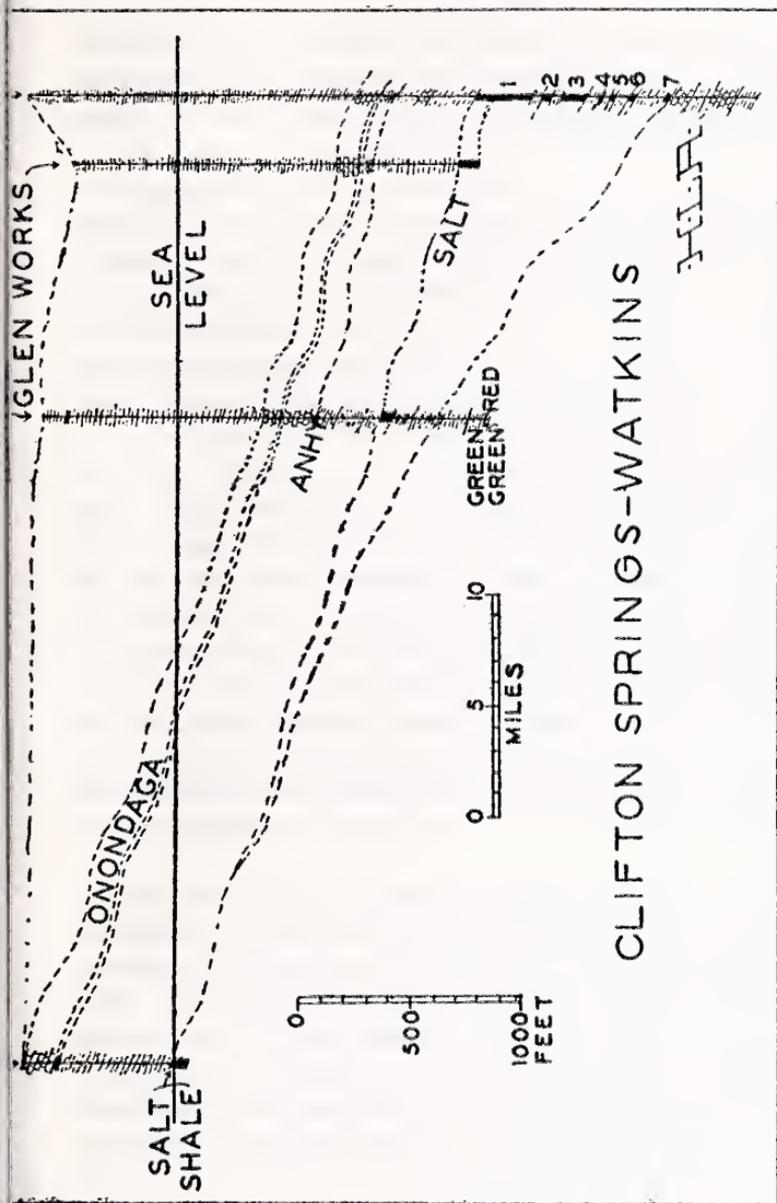


Fig. 9 Geologic cross section of the New York State salt field, south from Clifton Springs to Watkins. The Clifton Springs record is due to J. S. Hanna and I am indebted to F. C. Eckmann for the Himrod record. From Werner I secured the information for drawing the Glen Works column. There is an actual reverse dip of the surface rocks at this point. From George G. Hill and Prosser I obtained the data regarding the Watkins well. Vertical exaggeration 52.8 times.

distribution of the salines by rivers and by wind, which is implied by this theory.

Theory 5

Partial evaporation of an arm of the sea, isolated by a barrier over which, or through a narrow channel in this barrier or bar, occasional new supplies of sea water may enter. This, the reader will recognize as Carl Ochsenius' "Bar Theory" (1887-88).

Objection (a) To explain in a satisfactory manner the sequence of salines the influx of sea water must occur only at specified times.

Objection (b) The Karaboghaz (Karabugas) gulf, so frequently cited as an example of the process called for by the *Bar Theory*, is not a complete illustration. The salinity is not high enough to precipitate salt. Near its shores gypsum crystals are forming while in the center of the Gulf sodium sulphate is being precipitated (Kusnetsoff, 1898, p. 26) only during the winter months. It is essentially a sulpho-chloride bittern.

Objection (c) The bar theory states that evaporation "takes place only at the surface, and the upper layers, thus becoming denser, must sink;" so by producing a saline concentration at the bottom, the salinity of the bay will gradually increase "until saturation is reached and deposition of salt begins. So long as salt water can enter the bay the process will continue, and the depths of the basin will . . . become a solid mass of salts covered by a sheet of bittern" (Clarke, 1916, p. 221). It is possible to dispose of the bittern by allowing it to dry up and blow away or by flooding the area, draining away the brine and depositing it elsewhere in the district.

Yet the process is in delicate balance, and warping of the land or the destruction of the barrier would bring the deposition of salt to an end. The objection is that it is of too limited application, due to its special character, to be considered in any serious manner. The theory of Ochsenius seems to imply a comparatively level bottom to the inner basin into which sea water can enter. If this inner basin contained a deep depression, the accumulated salt would concentrate there. The proper thickness of salt could in this manner be provided.

Theory 6

A desert basin, isolated from the sea, into which rivers empty draining limestones which carry a low percentage of salt, giving rise to one or more playa lakes, which through evaporation deposit saline minerals.

Objection (a) Playa lake brines in many localities contain such a large number of salts, that the objection may be raised that the New York salt is too simple, too pure.

Objection (b) Would playa lakes account for the position of gypsum? It is possible, but it would imply many variations in volume of the river water sources of supply, and of temperature prevailing during deposition.

Objection (c) Would this desert theory explain the presence of the pelecypod *Ctenodonta salinensis*, Ruedemann, in the anhydritic Camillus beds? If it is a marine form this objection is a serious one. If, however, this organism is a fresh water form it could have inhabited the rivers.

Discussion: Applying this to New York, we find that there are many difficulties that still face us. The theory seems from one point of view too simple to be satisfactory, from another it entails many disturbing factors. How can we explain the dry climate during Salina times in New York, Pennsylvania, Maryland, Ontario, Ohio and Michigan? If we assume westerly winds, we are confronted with the problem of explaining away the moisture in the atmosphere. Consequently we may postulate easterly winds, the continent of Appalachia to the east, which would extract the rain from the clouds, and even shift the geographical poles of the earth to provide for a change in direction of the prevailing winds. As long as these speculations are acceptable to us, all well and good. But the moment we entertain a doubt regarding any one postulate we find the elaborate edifice in danger of collapse.

Grabau's Contentions

Grabau who follows Walther (1900; Grabau, 1909) has given considerable thought to the problem of the origin of salt, especially of the Silurian of North America. He does not favor the theories involving the complete evaporation of a body of sea water cut off from the ocean by a barrier, no matter how narrow or wide. His reasons are as follows:

1 "Complete evaporation of sea water furnishes a normal succession of deposits, beginning with gypsum, followed by sodium chloride and ending in potash salts" (Grabau, 1913).

Discussion: This is based on (a) modern sea water, (b) laboratory experiments, (c) where no new supplies are added. I feel confident that Grabau's first objection ignores the assumption upon which it is based.

2 "Later deposits should be separated from the first by layers of detrital sediment, for it is inconceivable that a flooding of a

ation of the vertical scale. This habit of the salt is better shown in the Caledonia-Nunda section.

The Castile well, the last in the section, shows 35 feet of salt shale, here assumed to represent the upper bed of the Rock Glen and Worcester wells, on top of the main bed 45 feet thick. Below is 40 feet of shale overlying more salt shale 65 feet thick. Beneath this is recorded five feet of salt. The red shale of the Pioneer and Atlantic wells evidently was not reached by the drill.

The Caledonia-Nunda Section

Figure 7

This section is in some respects the most interesting one of all. It illustrates the independence of the salt and the Onondaga, as well as the effect of folds upon its thickness. The Caledonia well is probably incorrectly located upon Merrill's map (1893), its true position being half a mile farther south. The log is striking in that immediately beneath the Onondaga are "gypseous [anhydritic] shales," which, if correctly determined by the driller, would lead to the supposition that the Onondaga-Bertie unconformity was so excessive that the former rested directly upon the Camillus waterlimes. These extend 151 feet below the anhydritic beds. In the York well a more "normal" succession is reported in respect to the Bertie waterlimes. The 10-foot bed of red shale at the base of the Camillus waterlimes should be noted. To find red beds within the Camillus is apparently a much more common phenomenon than was formerly believed. If the contact between the Camillus waterlimes and the shales of the Caledonia and York wells be joined, as has been done in the section, such a line assumes a parallel position with the Onondaga-Bertie line of contact. Although neither gypseous shales nor anhydrite were reported in the York well, such beds are recorded as occurring in the Retsof and Griegsville shafts, and thus they are tentatively carried across the gap. Whether or not there is any real foundation for a division between the Camillus waterlimes and shales as shown in the section can not at present be ascertained, but the available data certainly points to such a conclusion.

In the Retsof shaft we possess reliable data. (For a more detailed section see figure 6.) The absence of drift on top of the section is due to the fact that the shaft was sunk in the floor of an old quarry. Here beneath the Manlius-Bertie waterlimes is an anhydritic layer 47 feet thick, while in the Griegsville shaft only a short distance away the corresponding bed is 75 feet thick, a fact difficult of interpretation without considering that the sulphate salt is present as

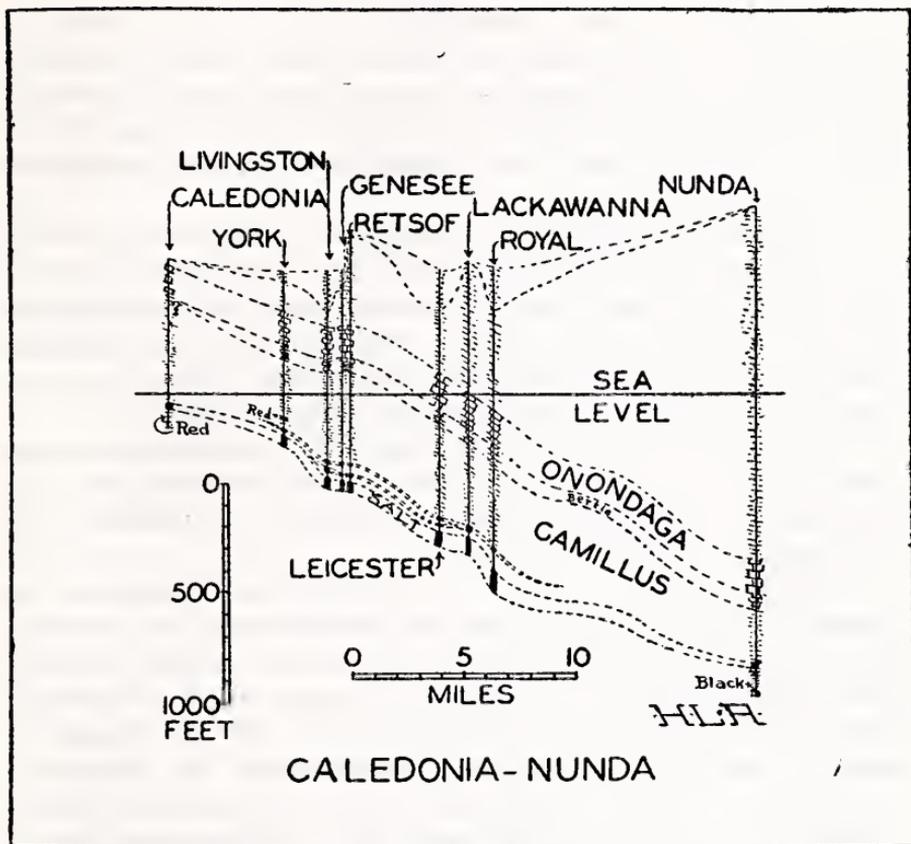


Fig. 7 Geologic cross section of the New York State salt field, south from Caledonia to Nunda. The Caledonia well record has been secured from C. L. Goodwin; the York well after M. B. Gilman; Englehardt has supplied data concerning the Livingston and Genesee wells. Luther and Clarke are the authorities for Retsof shaft. Rev. John Ripplly gives us the information about the Leicester Salt Company's well. For the Lackawanna well record we are indebted to Graham and for the Nunda well to Hambly. I am under the impression that I secured the record of the Royal well from Werner. Vertical exaggeration 52.8 times.

lenses. The single bed of salt in Caledonia well, 25 feet, has become two beds in the wells to the south. The 25-foot bed of the Caledonia well can be taken to be the main bed, the additional seam being an upper lens, or that the bed becomes two by splitting. The latter conception is the one indicated.

The shafts and wells at Retsof and Piffard furnish interesting data which the section emphasizes; the Onondaga limestone has a dip to the south, becoming anticlinal, while the salt beds experience a synclinal flexure, illustrating the geological independence of the two formations, due to the unconformities and the plasticity of the salt.

that a separation of the salt takes place from the surface downward to the bottom as evaporation proceeded (Credner, 1887, p. 317-20). By this theory Credner sought to "explain" the so-called "reverse" order of the saline substances, that is, gypsum overlying salt. F. G. H. Merrill (1893) applied this hypothesis to the salt deposits of New York.

Objection (a) As Turrentine (1913, p. 11-12) points out, "this theory of the concentration of saline waters really accounts only for the formation of concentrated brines and not for the actual crystallization. Obviously, crystallization does not occur from saturated brine unless it is chilled, or further evaporated. Chilling may take place in the bottom of a lake, but evaporation can not."

Objection (b) Under such conditions beds of salt would be formed overlying beds of gypsum. Any influx of sea or river water would interrupt the process giving rise to alternations of limestone, salt and gypsum.

Objection (c) The "reverse" order which Merrill attempted to explain, I take it, is that of the main salt beds and the overlying gypsum, now worked on the outcrop. There is a series of lime-mud rocks several hundred feet thick separating these two horizons. Hence, a large amount of introduced water would be necessary to cause an interruption of the process and to account for these intervening rocks. Then as evaporation continued, following this interruption, the concentrated brine would sink to the bottom, and, if Credner's theory continued to hold, salt and not gypsum would precipitate. But this is not what we find. If, however, Merrill had in mind the alternation of anhydritic lime-mud rocks and the commercial beds of rock salt, such a theory would work, but so would almost any other theory since the influx of sea or river water would bring about an alternation of beds. Thus if Credner's theory is used to explain the field facts found immediately above and below the salt mine horizons, it can not be employed to elucidate the overlying gypsum several hundred feet above. Furthermore, I question whether Merrill was acquainted with the nature of the rocks found in the salt mines. It is through the complete suite of specimens from the Sterling shaft studied in thin section that these observations are forthcoming.

If the lime-mud rocks above the rock salt and below the commercially important deposits of gypsum were formed by such a process, it would follow that these lime-mud rocks were chemical precipitates. This interpretation is not so attractive as that they are clastic sediments.

Theory 9

An arm of the sea cut off from the open ocean by warping of the land or by some other barrier, and subject to evaporation under desert conditions, into which flowed streams charged with lime-muds and salt derived from the decomposition of marine limestones situated in their drainage basins. Interruptions by fresh influx of river waters caused alternation beds of salt and gypsum. Upon drying, wind and river water would bring about a redistribution of saline substances by the blowing of gypsum sands over the desert area and subsequent leaching of more soluble substances by rain or river water. The deposits as we find them may be the product of many incomplete cycles of evaporation. The calcium sulphate in the upper portion of the Camillus may thus belong to a separate series of cycles distinct from those which are responsible for the lower horizons of anhydrite and rock salt. The process that separated these two groups of cycles may have been a fresh supply of sea water from the ocean.

Discussion: It can readily be seen that elements of many of the foregoing theories have been incorporated in theory 9. The bar theory with modifications, Grabau's so-called desert theory, and interruptions by influx of water from various sources, have all been introduced. We have discussed the elements before as separate matters but it remains now to be seen how this particular combination would explain the New York salt deposits.

The paleontological evidence in the Lockport indicates a growing salinity of the waters during Guelph times. The interpretation here accepted is that the eurypterids of the basal Vernon show an increase in salinity of the Vernon over that of the Guelph. This would indicate a continued restriction of the connection with the open ocean. We find, however, that instead of a general restriction of the Vernon and Camillus beds in the Lockport depositional basin, the Vernon overlaps the Lockport in east-central New York, not because the Lockport was eroded, but because that group of rocks was not deposited. In fact, the Camillus overlaps the Vernon in the East and probably does in the West. Consequently, it would seem to be a mistake to state that the Vernon basin is merely a restricted portion of the Lockport basin. It was a different basin. This conception, I believe, needs to be emphasized more than it usually is. Yet over a portion of the Lockport-Guelph formations lies the Salina. The contact is not abrupt but rather of the nature of an interlocking. A warping of the land surface seems necessary to

Contour Map of the New York State Salt Field

Figure 14

In figure 14 I have attempted to construct a subsurface contour map, the foregoing cross sections being used. I was compelled, after much experimenting, to draw the contours on the basis of the top of the main salt bed in every case. This map differs from the map published by Merrill in 1893 in that he drew the contours on the basis that the salt was situated 610 feet below the summit of the Onondaga limestone. So many departures were made from this "average," due to unconformities and independent folds, that his map is open to criticism. The contours on the western margin of the map are shown interrupted by the Clarendon-Linden fault which has been extended farther south than Chadwick has investigated. It may be that it crosses the Batavia-Attica-Bliss section north of Bliss and thus accounts for the excessive depth of the salt below the Onondaga limestone. The map clearly indicates the presence of terraces and even reversals in dip. Here the contour interval is 100 feet; the datum plane, sea level. If a smaller contour interval had been employed, some closed contours would have been necessary. Insufficient data in the southern portion of the area here mapped prevent extending the anticlinal and synclinal structure of the Ithaca region westward.

THE CHEMISTRY OF SALT DEPOSITION

The problem of the conditions under which salt beds are deposited is more than a geological one. It is very evident that very little progress can be made by attempting to apply geological methods alone. The physical chemist is in a far better position to appreciate and to solve the events that have taken place to form deposits of salt. From the composition of the rock salt and associated rocks it is reasonable to suggest that they were derived from the evaporation of sea-water; "and hence it may at first appear perfectly simple to repeat the process in the laboratory by evaporating sea-water to dryness. This was carried out on a large scale by Usiglio (1849, p. 27, 92, 172); but the results obtained by him failed to correspond with the natural deposits in several important respects" (Stewart, 1922, p. 612). This is true of the Stassfurt deposits and of those in New York. Hence one is tempted to say, with Keyes (1923, p. 290), that we would make more progress if "van't Hoff, Hinrichen, Weigat, and Myerhoffer . . . [had] been permitted to leave their indoor theoretical environment and go into outdoor observational laboratories."

The difficulty is not with the physical chemists, nor with the geologists, but rather with a lack of cooperation between them. To

effect this interrelationship upon this problem between these two divisions of science is my difficult task. It is not possible to do a great deal because of many unknown and uncertain factors involved in these problems. Perhaps all I can do is to indicate the complexity of the problems with which we are concerned.

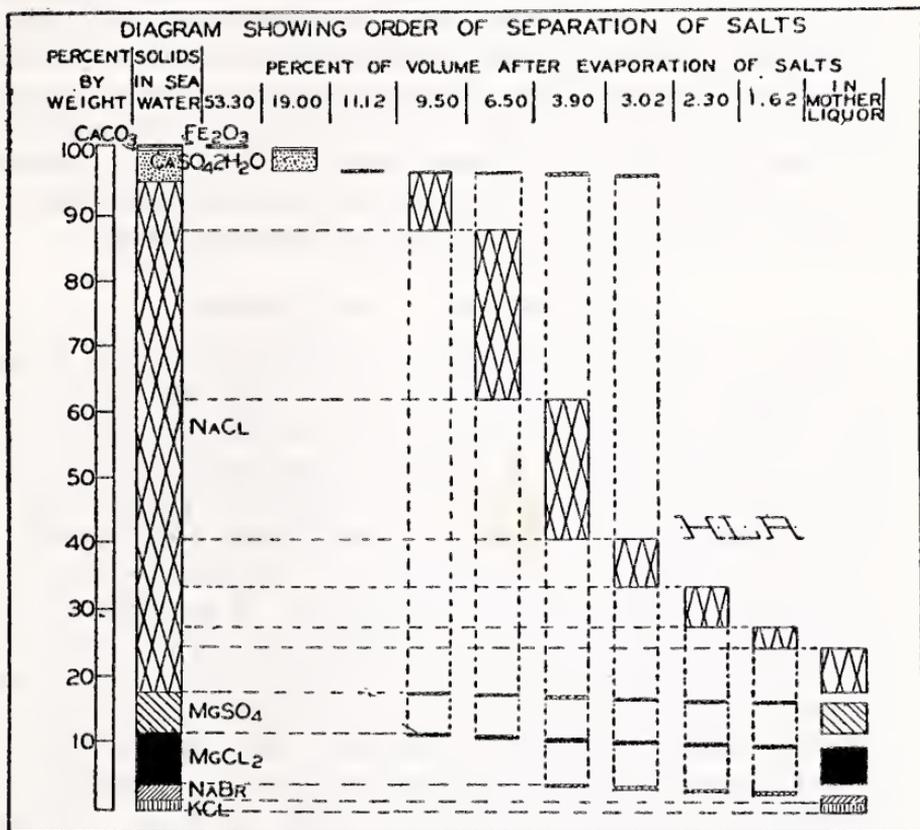


Fig. 15 Diagram showing order of the separation of salts on evaporation, under atmospheric pressure, of sea water. The dry salts, per cent by weight, calculated to be in sea water, are given at the left. The percentage of each salt which separates as the volume of the solution is reduced by evaporation is shown in the succeeding columns. That is, when the volume has been reduced to 53.30 per cent of the whole, a little ferric oxide and calcium carbonate has crystallized. At 19 per cent the rest of the calcium carbonate and some of the gypsum have separated, and so on. If all of the "blocks" of these columns should be shoved together they would reconstruct the first column. Note that at no time is pure sodium chloride precipitated without some other salt. Diagram based upon figures given by Grabau, Principles of Stratigraphy. 1913, p. 349.

Usiglio's results are presented graphically in figure 15. It shows that, as evaporation of sea water is carried on, various salts are precipitated, not in the reverse order of their solubility in pure water,

draw logical interpretations from them and reason about the processes which originated these deposits all indicate that the origin of the New York salt is exceedingly complex. But I do not maintain that, just because I believe the origin to be complex, I accept the first theory that possesses a good deal of complexity as the probable one. I would rather leave this matter where it is, even though others as well as I may be disappointed, than to set out to demonstrate the impossibility of all other theories and then propose a new one, for which claims could be made that this is the only one that satisfies the facts. The truth seems to be that we do not yet possess enough facts to be at all sure whether we are in a position to discuss, with any hope of success, the subject of origin.

SUMMARY AND CONCLUSION

When I approached the problem of the geology and origin of the salt deposits of New York State in 1917, I had some conception of the difficulties involved. As the work was continued, both in the field and in the laboratory, I became more and more convinced that the problem was very complicated. Of course, this growing appreciation of the difficulties, of the many uncertainties and the number of factors concerned, is experienced by all geologists working on any problem. But in this case the elements of uncertainty were present to an unusual degree. For example, the economic geologist has claimed this field for himself, not because his services were needed in finding more reserves for the salt companies, but because salt is a valuable commodity commercially. His value and skill in applied geology are fully appreciated, yet broad stratigraphic and paleontologic correlations are not, as a rule, his forte. He has accepted the classification of the Salina as proposed by the New York Survey, published in 1912, and has attempted no thorough revision. He has walked along the mine levels in beautiful crystalline rock salt and expressed doubts that any theory could account for so much salt.

Fossils were scarce and poorly preserved so that paleontologists were not attracted to the Salina. They had more attractive fields. The petrographer found no igneous rock to examine in thin section, and so left the Salina alone.

Grabau, the student of lithogenesis, applied Walther's observations of desert phenomena to salt deposition within the State. This point of view was indeed needed and yet he failed to distinguish clearly between fact and theory. Meanwhile the young and ambitious

science of sedimentary petrography promised fresh hope. Sedimentation was becoming better understood. The habitat of the eurypterids was hotly disputed. Geologists were swinging away from the conception that all sediments were marine deposits; deserts existed in the past as now. Theories were plentiful; facts were few. The salt deposits were considered continental in origin; the Vernon a loess deposit, and the accumulated salt a result of desert conditions.

Then a few facts from the field, fossils in the Vernon and in the Camillus and carbonaceous matter throughout the Salina, even in the salt itself, were found. The beds beneath the salt were not always red. Reluctantly I abandoned the current opinions; opinions which, in the minds of some, had been transformed from theories into accepted facts, and decided, with the students of the salt domes of the gulf states, to find the facts before theorizing. From the start I believed in the doctrine of multiple hypotheses as a guiding principle. I returned to it on finishing my examination in the field.

A study of the New York deposits necessitates a review of the conditions prevailing in adjacent states. Hence some sort of a correlation between the Salina of Ohio, Ontario, Michigan, Pennsylvania and Maryland with that of New York was attempted. So far as I can determine, the correlation of the Salina of New York with that of Ohio, Ontario and Michigan, together with that of the Wills Creek-Bloomsburg-McKenzie of Pennsylvania and Maryland, is a logical and reasonable one. Yet the Vernon and equivalent beds are probably peculiar to the New York-Pennsylvania-Maryland district. Under such a correlation two depositional basins are necessarily postulated. The Ontario-Michigan basin is probably the deeper of the two and lacks the argillaceous sediments known as the Vernon. The details of the evaporation and the deposition of the salts differ in the two cases. In both basins, however, the salt is stratigraphically, petrographically and genetically associated with and related to the Camillus sediments of lime-muds. In New York they are very fine-grained rocks with argillaceous cementing materials, while in Ontario and in Michigan the Salina consists of dolomitic rocks more akin to the usual run of magnesian limestones. This fact prevents satisfactory demarcation from the overlying Bass Island series of Lower Monroe age, correlated with the Bertie-Cobleskill-Akron group of New York and with the Tonoloway of Maryland.

The two basins are separated by the lack of continuity of the salt. The Camillus is a little thinner where it rests upon the Ontario barrier between the two basins. The absence of the Vernon in the Michigan basin is compensated for by the thickness of the Bass

slight faulting and plasticity of the salt can account for some of the lack of agreement. A striking disagreement is seen in the records of

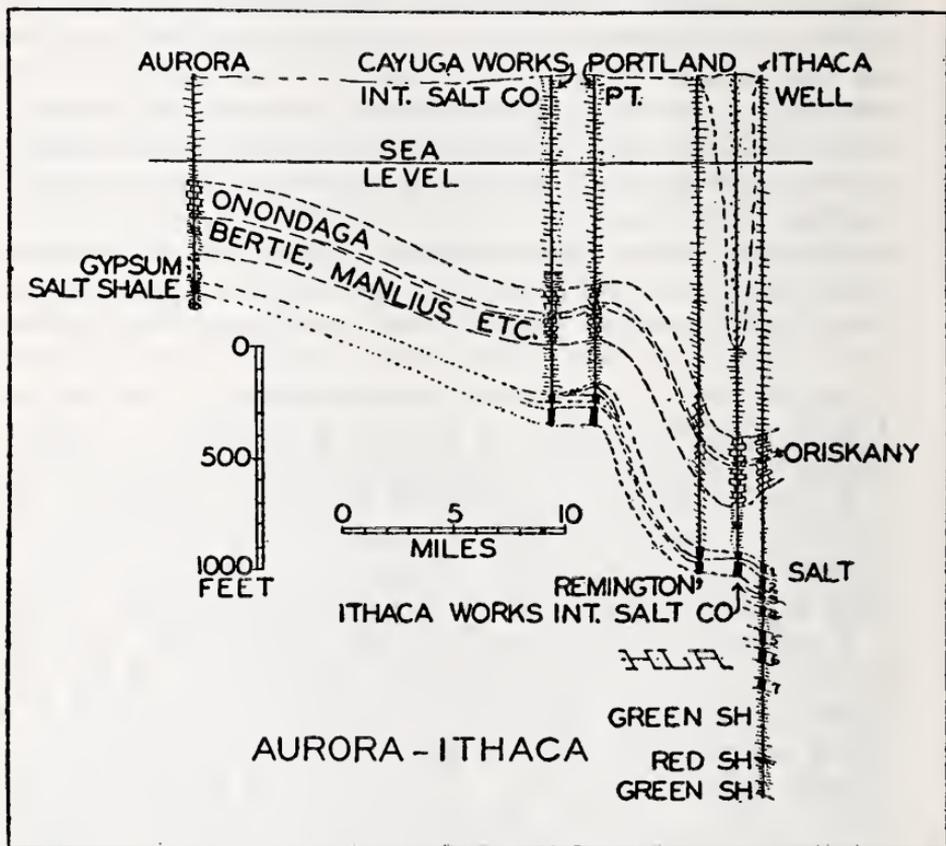


Fig. 11 Geologic cross section from Aurora to Ithaca based upon well records obtained from many sources. The anticlinal and synclinal structure of the district is clearly shown. Vertical exaggeration 52.8 times. Note that the salt is not a great distance below the base of the Onondaga limestone. The Oriskany sandstone is thick enough to be shown in this section.

the Remington well as furnished by the Remington Company and by J. B. Calkins. The former gives *two* seams of salt 42 and 44 feet thick separated by eight feet of limestone (waterlime, anhydrite?) while the latter gives *one* bed 70 feet thick. Furthermore, the company's own statement places the bottom of the salt at a depth of 2192 feet or at 1792 feet (about) below sea level, while Calkins states it occurs at a depth of about 2009 feet, or at 1609 feet altitude. It is possible, of course, that these are records of two different wells with different elevations. Such are the difficulties in attempting to utilize such data. As our information of geology below ground is largely

obtained from such well records, it behooves those in charge of such work to note with extreme care the character and position of each sample or core, making a full and permanent record. A better agreement between Calkins and the Company's records is that of the Ithaca works of the International Salt Company. Whiting gives two beds, which is probably correct, 20 and 60 feet with a 20-foot parting of shale. The bottom of the latter is placed at a depth of 2250 feet while Calkins reports but one bed of 70 feet at 2220 feet depth. It would appear that Calkins has ignored the undulations of the rocks and makes the salt beds assume a uniform dip to the south.

The record of Whiting for the Ithaca works and the Ithaca well, which is reasonably accurate, completes the section. By virtue of the exaggeration of the vertical scale a smooth flexure of the thick beds has been impossible in the section and is not true to nature. The axes of the folds are probably not vertical but perpendicular to the plane of average dip. All these uncertainties and difficulties render the construction of the Aurora-Ithaca section an unwelcome task. Nevertheless it is believed that it presents some significant facts relating to the geology of salt deposits.

One noticeable fact the well records show is the thickening of the Cardiff and Ludlowville shales, the unusual thickness of the Oriskany sandstone, and the decrease in the thickness of the Onondaga limestone southward.

The Tully Section; Solvay Process Company

Figure 12

This diagram of the Solvay Process Company's wells at Tully is after Merrill (1893, p. 20), but with modifications. This is on a different scale from the rest, the vertical being three and one-third times the horizontal, and is introduced to show how apparently irreconcilable facts can be correlated by a little allowable interpretation. As originally given, the great thickness of salt at well 1 and 3 of group B is not duplicated by the neighboring wells. Wells 1 and 3 of group D show two beds separated by shale. It is assumed that an error has occurred in recording the elevation or the depth of wells 2 and 4 of group B, as suggested on the basis of finding salt below the line connecting the tops of uppermost salt beds. If this is true, then the postulation of three beds makes a consistent section. The majority of the wells were sunk only to the base of the first or uppermost bed. The great depth of salt in wells 1 and 3 of group B can be accounted for on the basis that the shale partings were comparatively thin, or were ignored by the driller, or both.

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us remember that analyses of the minable rock salt, brines and bitterns give the composition of only a part of a possible solution from which they may have been derived. If potash salts of any extent were deposited in New York they certainly are not to be found in the rock salt layers but would lie, if present, above some

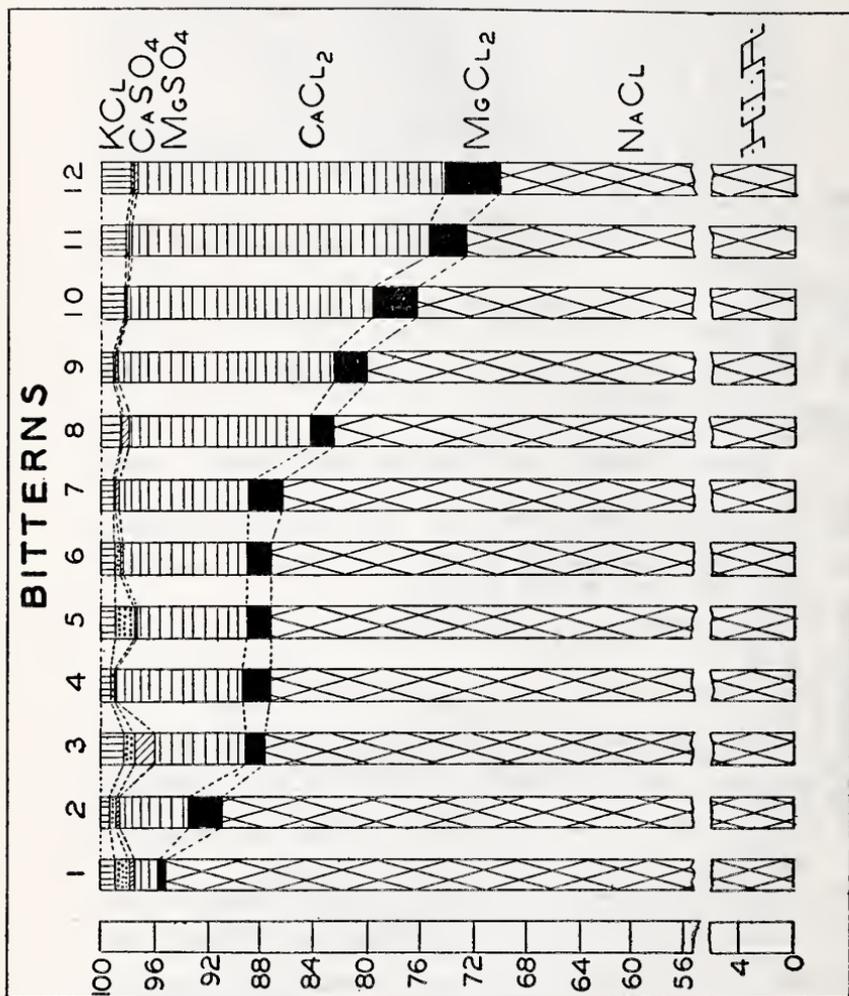


Fig. 17 Graphic representation of the chemical composition of the bitterns from the brine plants in New York State. Calculated on the basis of 100 per cent of dry salts. The analyses have been arranged according to increasing per cent of calcium chloride. The portion of the scale from 4 per cent to 56 per cent has been omitted.

- 1 Watkins Salt Co.
- 2 Genesee Salt Co.
- 3 Le Roy Salt Co., includes waste steam
- 4 Remington Salt Co., bittern from vacuum pan
- 5 Crystal Salt Co., bittern from open pan
- 6 Rock Glen Salt Co., bittern 10 days old
- 7 Cayuga Works, International Salt Co
- 8 Worcester Salt Co., bittern from grainer
- 9 Crystal Salt Co., bittern from grainer
- 10 Ithaca Works International Salt Co., bittern from grainer
- 11 Rock Glen Salt Co., bittern from grainer
- 12 Ithaca Works International Salt Co., bittern from grainer

of them at least. So far as our meager information goes we have not encountered them in drilling or in shaft sinking in beds by themselves. Petrographic studies of Camillus lime-mud rocks in microscopic thin sections indicate that there are some potash salts mixed and entangled in the rocks above the rock salt horizons. This matter is treated more at length in the section on petrography.

Associated with the problem of the deposition of the beds of rock salt is that of the formation of the gypsum, which is of great commercial importance. For many years a number of plants have been mining gypsum along the strike in New York, Michigan, Ontario and Ohio. In fact, the areal distribution of the gypsum deposits is far greater than that of salt. In New York the commercial deposits are situated above the salt horizon. This fact has given rise to the belief that there is little or no gypsum beneath the salt—a belief which I entertained until facts to the contrary were obtained.

The shaft on Portland Point supplies information concerning the nature of the calcium sulphate layers associated with the rock salt. In the past it has been the custom to refer to the calcium sulphate as gypsum. At the 1200-foot level a layer of banded rock taken by the engineer of the company to be gypsum proved to be anhydrite. This was ascertained by microscopic examination in thin section. There is a little gypsum present, however, which appears to be of secondary origin, due perhaps to the dynamic disturbance to which the rocks there had been subjected. The anhydrite is mixed with the shale in quite a similar way to that shown by the salt beds. Other specimens show a pearly and scaly material that contains more gypsum, but is still composed in large measure of anhydrite. Specimens of the shale associated with the salt at Retsof show anhydrite in distinct layers which have not been so much disturbed as in the Ithaca district. If the calcium sulphate was deposited from aqueous solutions as gypsum, it is quite possible that the subsequent load due to the accumulation of the overlying formations has caused the dehydration of the gypsum, to anhydrite. As erosion brought the surface down by removing the overlying rocks the underground circulations permit the reformation of gypsum. Thus at the outcrop we find gypsum, but at the depth to which the salt shafts penetrate the calcium sulphate exists as anhydrite.

These observations have been substantiated by the group of specimens furnished by Mr Fetherston of the Sterling Salt Company. This suite of rock specimens was taken from a horizon 25 feet above the mine roof and extending down through the minable zone to 40 feet below the mine floor. Many specimens have been thin-

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Suppose to this system of potassium chloride and magnesium sulphate, which produce additional salts by double decomposition, and the formation of double salts and hydrates, we add sodium chloride. Without going into detail, perhaps the reader can imagine what a complicated problem the physical chemist has. And this detailed study of saline substances is still going on. In the *Journal of the American Chemical Society* for August 1924 we find a paper on the system magnesium sulphate-sodium sulphate-water (Archibald and Gale, 1924, p. 1760-71).

All this detailed information at our disposal is at the same time both a help and a hindrance. We are tempted to apply these results in a universal manner to all salt deposits without realizing that they primarily apply to the Stassfurt deposits. There the conditions were comparatively simple, even though it took years for van't Hoff, Myerhoffer and others to work out the involved physical chemistry of these deposits.

The Stassfurt deposits in Prussia, of Upper Permian age, exhibit two or possibly four cycles of evaporation. The first and lowest series of evaporites begins with Zechstein limestone and dolomite, anhydrite and gypsum, which are in turn overlain by rock salt beds. Next a polyhalite zone and kieserite zone, ending in carnallite deposits.

The second cycle, not as complete as the lower, is separated from it by a bed of salt clay. It begins with anhydrite and ends with rock salt. A bed of red clay separates the second cycle from the possible third series, which begins with anhydrite and ends in salt, without the more soluble salts. The last cycle is less complete, in that it contains anhydrite without any deposition of salt; the only indication of the latter is salt cavities in the overlying red clay.

The Stassfurt deposits therefore indicate interruptions of evaporation by influx of clastic materials and a new supply of sea water. The rock salt in the lowest group contains 3000 layers, called annual rings which suggest that "they are due to seasonal fluctuations in the density of the water—a periodic slight reduction in the salinity during a moister period, putting a temporary end to salt deposition and permitting the formation of anhydrite" (Grabau, 1920, p. 236).

"In the hands of van't Hoff and his collaborator . . . the whole question has been . . . developed to such a point that even the temperature of the period at which any particular series of beds was deposited can be determined with moderate accuracy" (Stewart, 1922, p. 61).

Such interruptions, influx of clastic materials, deposition of lime-mud over a deposit of saline minerals seem to have taken place in

the development of the Salina salt of New York, Michigan, Ontario and Ohio.

Before it is possible to apply the principles of salt deposition to the Salina, we must investigate the assumptions upon which they are based.

If we assume that the salt has been derived from sea water by evaporation let us ask what was the composition of the sea water. The same as modern sea water? It is well known that the salinity of sea water varies from place to place; it differs in strength according to depth as well. What was the composition of sea water in the open oceans during Salina times? We do not know. There have been many attempts to arrive at the "age of the earth" by calculating the increased sodium content of the oceans on the basis of the influx of additional supplies by the rivers of the present. Such speculations assume a saltless sea which by gradual accumulation from the decomposition of land areas has reached its salinity in a uniform manner. If we concede this assumption, and I venture to voice the opinion that it is nothing more than an assumption, we are forced to conclude that Salina seas had a different composition. But we do not know what it was, nor do we know whether this different sea water on evaporation would deposit saline substances in the same order under similar circumstances as sea water now existing. Of course, I, as well as others, dislike to state that we are in the dark regarding a number of essential points with which we are greatly concerned in this investigation. The hope of real success is to know what we *do* know and what we do *not* know.

In case of the Stassfurt deposits it would seem that they "were formed by the drying up of a large body of sea water which had become separated from the main ocean by the formation of a land barrier" (Grabau, 1920, p. 61). Then we would hasten to suggest that in New York State a similar basin existed in which a number of cycles of evaporation took place. But a discussion of this matter is deferred to another section.

In the early days of the salt industry the interest taken in the natural brines of Syracuse and Montezuma was intense and a great many chemical analyses were made. The Syracuse brines varied considerably in their mineral content, but more particularly in their strength. The total salts in solution varied from 13 to 14 per cent. Later on with an increase in the depth of the wells the figures rose to 19 and 20 per cent, but during the decline of the Syracuse field the total salinity fell to the neighborhood of 16, which in part accounts for the decline of the Onondaga field.

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give a much more angular appearance than the grains themselves. The chloritic matters are, as a rule, prevented from coming in contact with the pseudo-phenocrysts by these micaceous flakes. They give to the groundmass a "basket-weave pattern." The argillaceous materials in the Lockport are more irregular in arrangement, and are more dense and browner in color. This basket-weave pattern is not common. I have found something similar in certain layers of the Maplewood shale of the Clinton group at Rochester.

In the mottled red and green layers, the Vernon shows the same characteristic basket-weave pattern with fewer pseudo-phenocrysts of dolomitic calcite, but the quartz and occasionally feldspar and garnet grains are present. The red colorization is unquestionably secondary, probably derived from the chlorite. The iron content of the green and red phases of the rock is very likely the same; the difference so noticeable to the eye is due to the state of the iron. In the form of chlorite the iron is principally in the ferrous condition, while the red color is due to ferric iron. The red hematitic matter is apparently amorphous and suggestive of colloidal iron oxides. It obscures the other minerals when present as if a fine network of red matter had been interwoven into the basket weave fabric. In specially prepared slides, ground extra thin and with thin cover glasses, the oil-immersion lens picks out the basket-weave pattern even though masked by the iron oxide. Even in the reddest of the Vernon, this iron net-work is patchy; it is not uniformly distributed (figure 18 *E* and *F*). In certain localities, such as at Oneida and Clinton, the Vernon is spotted with gray green semispherical matters. These show very distinctly the basket-weave pattern and differ from the surrounding red rock in lacking the red colorization.

The cause of these green areas, which are about an inch or two in diameter, is not known. Carbonaceous matter and pyrite are often present in the centers, but do not seem to be universal in these areas, and hence their presence can not be called upon to explain them (figure 18 *H* and *I*).

Thin sections of the red Vernon, when washed by concentrated hydrochloric acid, lose to a large degree the red colorization, leaving the basket-weave pattern, although it is not so distinct as in the originally green rocks. An interpretation is that some of the chloritic minerals have suffered alteration to the iron oxide form. I entertain considerable doubt whether the red colorization is a reliable criterion for terrestrial deposition. My feeling in this matter is that much depends upon the subsequent history of the rock; perhaps more than upon the conditions under which it was first deposited.

The Camillus

The Camillus is a fine-grained lime-mud rock, a calcilutite. The grains of dolomitic calcite are from .01 to .025 mm, and thus range from clay size to rock flour. Argillaceous matter is exceedingly difficult to identify, but it is probably acting, in the majority of specimens examined by the oil-immersion objective, as the cement. Quartz does not fail, but many individual fields are made up exclusively of dolomitic calcite (figure 19 *C, D, E* and *F*). Long flakes of muscovite are frequently found. Horizons of the Camillus that possess a distinct shaly structure, and are more yellow in color, contain more grains of quartz, feldspar, hornblende, serpentine etc. The quartz grains are all below .04 mm in size, are very angular and splintery. Most of them possess a wavy extinction. I would offer the interpretation that they were derived from metamorphic rocks. Yet it may be that they were imbedded in other sedimentary rocks before being transferred to the Camillus. There are too many possibilities to justify a definite conclusion about the sources of these grains.

Carbonaceous matter, pyrite and many other minerals in small quantities are found in the Camillus (figure 19 *F*).

Other horizons are more argillaceous. Grains of sericite, paragonite, chlorite and epidote are interlocked with dolomitic calcite. The latter do not possess the characteristic rhomboidal outlines found in the basal Vernon. These argillaceous substances, together with less definite mineral substance, show considerable reorganization and crystallization. They were probably deposited as colloidal substances with much absorbed salts. Now they are to a large degree anisotropic.

In districts south of Rochester the upper Camillus and Onondaga limestone have been arched into long narrow ridges or buckles. Many suggestions have been made to explain them. One is that either the solution of gypsum in the beds below, or the hydration of the anhydrite, disturbed the overlying strata. Certainly brecciation and slumping is observable in the Camillus along the outcrop. Slides of such material exhibit microfaulting and the rehealing by secondary vein filling by gypsum and calcite.

The Brayman

The Brayman shale of Schoharie county is here considered as the eastern extension of the Camillus. Microscopically it possesses much the same characters as the thicker formation to the west. It is distinctly coarser grained in certain horizons. Water-worn quartz

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during desiccation to some entirely different minerals. Usiglio used five liters of sea water to which he did not add any more during the evaporation. I would, in a less serious mood, suggest that in as much as Usiglio, the celebrated Italian chemist, did not add water to his vats, many have unconsciously concluded that nature does not add new supplies to a playa lake in a desert basin, hence they postulate waters miles in depth. Absurd as this may seem, many have concluded that certain deposits of salt and gypsum could not have been formed by the evaporation of sea water or even playa bitterns because the basins in which they were deposited were not miles deep. Hence many overflow basins are postulated in which the brine having dropped its gypsum in one basin spills over into a convenient and awaiting basin in which salt is deposited. This, of course, helps to explain the absence of gypsum where there is salt and vice versa. The whole trouble with this is that these theories contain enough truth to be confusing.

Some deserts of today are forming nearly pure gypsum, thick enough to call for deep basins. Walther, Andrussov, Hobbs, Grabau and many others are turning our attention to desert phenomena. Playa basins with saline saturated soils are subjected to occasional rains, infrequent rivers, and wind. These agents can and do concentrate gypsum sands. Wind can even form dunes of saline substances which are subsequently leached of their more soluble minerals, including the chlorides of sodium and potassium by rain water. This rain water, containing the more soluble salts, drains away through the sands and dried mud and on evaporation leaves these salts in the interstices of these clastic materials or is absorbed (adsorbed) by them. In New York traces of potash salts have been identified in the salt shales and lime-mud rocks of the Camillus type. The playa lake muds when exposed to the drying action of the sun become mud-cracked, the edges of the polygonal sheets which curl up, become detached and are blown by the wind, ground into small fragments and transported to other places in the desert area. Such materials accumulate in masses, the stratification of which is ordered by mechanical and not by chemical processes. Salt and gypsum by such aeolian activity become patchy and irregular in distribution and exhibit many secondary characteristics. Playa lake waters differ in composition, far more so than sea water. It is not a mere matter of concentration, of halinity or of salinity, but the proportion and presence of various salts in solution. A glance at the composition of Great Salt lake water, which is a sodium chloride brine, and that

of the Dead sea, which is a magnesium chloride brine, indicates this difference. This variation is unquestionably due to many causes, some primary and some secondary. It is impossible to evaluate all of them. One of the factors that is undoubtedly contributory is the kind of rocks the streams encounter in their courses before entering the playa lake basins. Decomposed rocks situated in the drainage basin contributed their soluble salts. Acid igneous rocks, high in potash, may contribute that element. The kind of saline deposit derived from dolomitic limestones would, other things remaining the same, be more magnesian than if the streams drained areas of argillaceous sediments.

Grabau (1920, p. 165-67) has made some suggestive calculations on the amount of sodium chloride locked up in the pore space of marine sediments. On the assumption that limestones of Niagaran and Salina times have a pore space of 30 per cent and that the seas of that time had a salinity of $3\frac{1}{2}$ per cent the same as now, of which 77 per cent was sodium chloride, it follows that the sodium chloride content of marine limestones may reach .365 per cent. This is logical if we accept the assumption on which it is based. Grabau proceeds to calculate that if 50,000 square miles, or an area slightly larger than the State of New York, of such limestones are eroded to a depth of 100 feet and the salt so obtained could be deposited in a basin covering 100 square miles, it would be 182.5 feet thick. This is an attractive theory and may, perhaps, be applied to New York.

A study of the composition of river waters, streams that flow over rocks which may be similar to those rimming the Salina basin, reveals many additional problems. Where do many of the substances they contain go? We see visions of long and tedious investigations, dealing with precipitations and absorptions, of suspensionoids and complex solutions.

Clarke, (1916, p. 177) has pointed out that the water of Lake Lahontan which is fed by streams flowing over igneous rocks differs radically from lake waters situated in regions of sedimentary rocks. The latter are saline while the former are not.

But we do know that if the simple evaporation of a body of sea water isolated from the main ocean by a land barrier, deposits a bed of salt, so does a playa lake in a desert basin into which a few streams enter, flowing over marine limestones. Furthermore, these different modes of origin are *not* mutually exclusive, for there is the possibility, if not a probability, that a cut-off arm of the sea undergoing evaporation may experience replenishment in the form of sea water splashed over a bar, or saline substances may be con-

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