Stratigraphy of Cayugan Series in Northwestern Pennsylvania

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ABSTRACT

The Cayugan Series in the Plateau Province of Pennsylvania is very similar to the better-known correlative rocks in Michigan, Ohio, and New York. It contains dolomite, shale, and salt in repetitive sequences. The control of the Cayugan sedimentation in the northwestern part of the State resulted from the boundary conditions of a basin slowly diminishing in size.

INTRODUCTION

The Cayugan Series (Late Silurian) in northwestern Pennsylvania is a significant volume of buried rocks to which little attention has been paid by geologists taking inventory of the State's natural resources. Across the borders of Pennsylvania, in Ohio, West Virginia, and New York, are correlative volumes of rocks which are very much the same as those found in northwestern Pennsylvania, and which support active mineral industries engaged in the extraction of crystalline salt and brine. No such industrial exploitation exists in Pennsylvania at the present time. Knowledge of the Cayugan Series in northwestern Pennsylvania comes to us as a result of drilling activity by the natural gas industry, in the course of which the Cayugan rocks must be penetrated on the way to one of the currently attractive gas reservoirs in the region, the Medina (Early Silurian) sands.

Making up the Cayugan Series in northwestern Pennsylvania are rock units called Bass Island and, beneath that unit, Salina. It is the Salina Group which attracts our attention especially because it embraces tremendous volumes of bedded halite. Salt deposits of this sort in nearly identical association have, as geologists and mining engineers need not be reminded, intrinsic value as mineral deposits plus the attractive potential as repositories for disposable wastes and other materials.

GEOGRAPHICAL EXTENT OF THE SALINA BASIN IN PENNSYLVANIA

The basin in which the Salina rocks are found is one extending from Michigan to New York and West Virginia, embracing both the Michigan Basin and a part of the Appalachian Basin. The most recent definition of the boundaries of this area of deposition was the excellent one by Alling and Briggs (1). Pennsylvania has a share of that part of the Appalachian Basin in which evaporite facies were deposited closest to the trough where the Cayugan Series is thickest, as well as a part of the shallower platform connecting the Michigan and Appalachian basins. Figure 1 illustrates isopachs of the total Salina Group -- the major rock unit of the Cayugan Series in northwestern Pennsylvania; it also shows the position of the wells used in the cross-section of Figure 2.

The limits of the basin to the north and west were controlled by structures or topography in the underlying Guelph-Lockport Group. To the east, towards the center of the Appalachian Basin,

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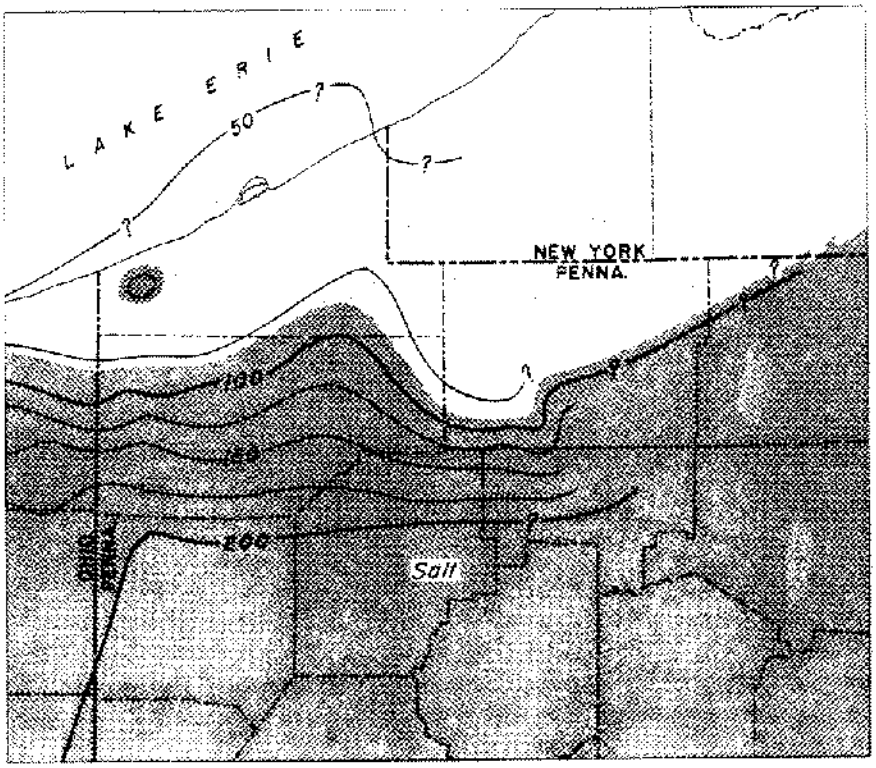

Figure 1. Isopachs of total Salina Group.

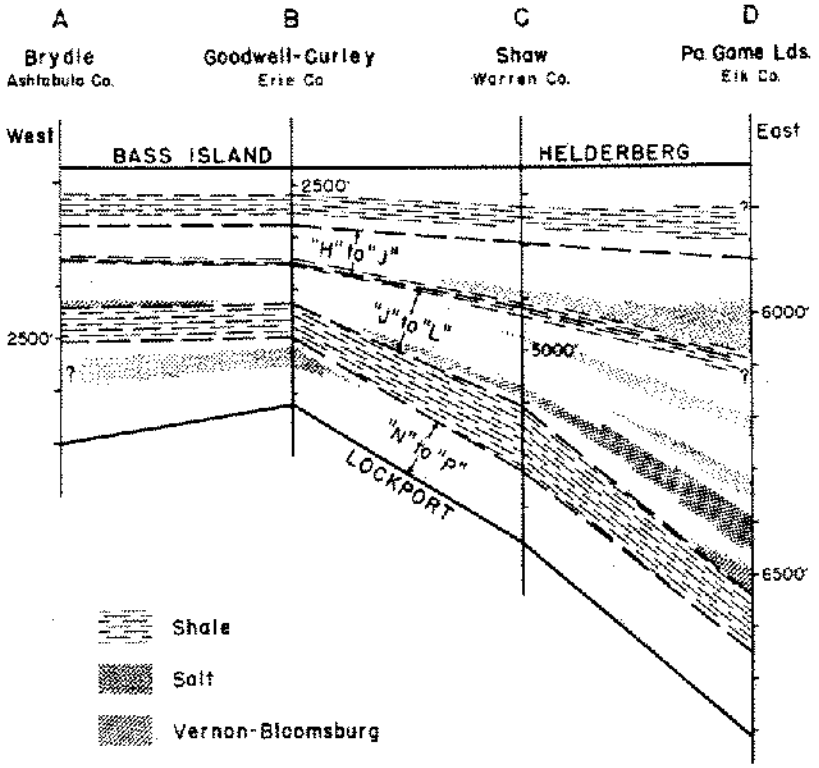

Figure 2. Cross-section of Salina in northwestern Pennsylvania region. (See Figure 1 for location of wells.)

the precipitation of evaporites was restricted by the encroachment of clastic sedimentry wedges (Vernon or Bloomsburg Formation) poured into central Pennsylvania before and during Salina deposition.

The present-day depth to the top of the Salina becomes greater in a southeasterly direction -- at Lake Erie the depth is about 1,000 feet below sea level and in Elk County it is more than 4,000 feet below the sea. The slope of the top of the Salina is that of a monocline, with but minor crenulations, in northwestern Pennsylvania.

The term "Salina" needs definition in the Appalachian Basin. The rocks to which the term is applied in Pennsylvania are differentiated from correlative ones by the presence within the unit of significant amounts of evaporite minerals -- specifically halite and anhydrite. Where the minerals are not present the names of such rock units as "Tonoloway" and "Wills Creek" are more appropriate than "Salina." The Salina, as understood in Pennsylvania, is strictly a subsurface term; this is not the case, however, in New York where it applies equally to surface exposures.

STRATIGRAPHIC RELATIONSHIPS

In northwestern Pennsylvania current usage in the subsurface does not differentiate between the various rock units of the Salina. Figure 2 shows markers which have been used by the Pennsylvania Geological Survey for differentiation in recent studies. It has not been found practical to subdivide the Salina in Pennsylvania into those units which are defined as making up the outcrop section in New York; more specifically — the Camillus and underlying Syracuse members of New York's section have not been given formal recognition in Pennsylvania's subsurface — they are instead embraced by the general lithologic term "Salina." The Vernon (or Bloomsburg, in Pennsylvania) lithology is not a part of the subsurface section in northwestern Pennsylvania; its westernmost extent is suggestively illustrated in Figure 1.

There are two categories of information available to the stratigrapher working in the Cayugan in Pennsylvania. One is subsurface data and the other is outcrop data. A glance at Figure 1 will make apparent the relative density of subsurface information from wells; the location of the outcrop belt in central Pennsylvania is not shown but it is about 20 miles to the east of, and roughly parallel to, the basinal axis of Cayugan sedimentation shown on the same illustration. It is a fact that a great geographical gap exists between the clumps of subsurface and surface information in Pennsylvania, and in this gap conjecture and intuition have as much validity as any other geological tool. Correlation of units used by workers detailing stratigraphy in these separate areas has not been definitely established; as a consequence two sets of nomenclature for the Cayugan have grown up and appear on most stratigraphic columns. In the subsurface of northwestern Pennsylvania the following is the sequence: Salina Group at the base and Bass Island Formation at the top; to the east in Pennsylvania, in the outcrop belt, we find the sequence: Vernon (or Bloomsburg Formation) at the base, Wills Creek, Tonoloway, and Keyser formations.

Below the Cayugan is the Niagaran Series. The Niagaran in northwestern Pennsylvania is represented by the Guelph-Lockport dolomite, and in the outcrop section in central Pennsylvania its correlative is the McKenzie shale and limestone.

Cummings and Shrock (2) years ago investigated the presence of reefs in the Niagaran in Indiana and adjacent states; subsequent workers have conducted similar investigations in the Niagaran region — among them Lowenstam (3), Evans (4), Floto (5), and Alling and Briggs (1).

The Niagaran has long been regarded in northwestern Pennsylvania as a rather homogeneous unit of fine to coarsely crystalline dolomite, but, doubtless, it is not that homogeneous. The possibility that reefal material may be present on the margins of the evaporite basin adjacent to Pennsylvania has never been proven, though there has been widespread speculation on this point. Supporting evidence is in the form of thickness variations in the Niagaran and in the overlying Cayugan. At this time petrographic study of well cuttings by the author (with binocular microscope) neither supports nor refutes the existence of bioclastic, biohermal, or other reef-forming carbonate material along the margin of the evaporite basin. Presumably this evaluation of the evidence would be aided if cores were available or if it were easier to determine the original nature of the highly dolomitized rock.

The boundary relationship of the Salina and the Niagaran is apparently nearly conformable, with onlapping and offlapping evaporites above the postulated reefal mounds of Guelph-Lockport around the margins of the evaporite basin. The Salina is in facies relationship with the fine clastics of the red Bloomsburg Formation to the east in Pennsylvania. The term "Bloomsburg," it should be added, is correlative with the term "Vernon," the former having been proposed by I. C. White in 1883 for a part of the Cayugan exposed in central Pennsylvania, and the latter being a formational designation proposed in 1903 by Clarke for similar-looking rocks in the lower part of the Salina in the New York outcrop section. Recent work by Hoskins (6) demonstrates the boundary relationships of the Bloomsburg (in Pennsylvania outcrop section) with the underlying McKenzie Formation (Niagaran) and the overlying Wills Creek Formation (Cayugan).

The youngest unit in the Cayugan Series in northwestern Pennsylvania is the Bass Island Formation. Its correlative to the east is assumed by many to be the Keyser Formation at the outcrop. Both of these carbonate units apparently are conformable with the next oldest units of the Cayugan found in Pennsylvania — the Salina in the subsurface and the Tonoloway in the area of surface exposures. Woodward (7) calls attention to a faunal hiatus between the Keyser and the Tonoloway in West Virginia and suggests its equivalence with the Silurian-Devonian boundary. The validity of a disconformity between these two units, as well as the location of the systemic boundary, must be kept open for discussion by those stratigraphers concerned, for it will be some time before we become sophisticated enough to evaluate the data available. Paleontologists who are well-versed in the ecology of the fauna which lived in the Silurian and Devonian seas, as well as stratigraphers who can put together paleogeologic maps will make considerable contributions to the solution of this vexing problem.

The boundary between the lithology assigned to the Bass Island and the Salina in Northwestern Pennsylvania is not difficult to pick. The Salina has vugular and bedded anhydrite in a matrix of dark-colored argillaceous dolomite; the Bass Island is light to buff crystalline dolomite with only finely disseminated anhydrite present in the lower part. The boundary between the base of the Salina, on the other hand, and the top of the underlying Guelph-Lockport (or, to use popular terminology, simply the "Lockport" — for we find it more difficult to differentiate between the Guelph and the Lockport than the Ontarians do) is more difficult to pick than the one at the top of the Salina. This boundary is, where it has been examined in Pennsylvania, a gradational change over 50 or more feet from crystalline dolomite, with only minor amounts of argillaceous interbeds and anhydritic material included, to crystalline dolomite with no argillaceous interbeds and gradually diminishing amounts of disseminated anhydrite crystals. A gamma log marker coincident with the lowest persistent shale bed ("P") has arbitrarily been chosen to designate the top of the Lockport in well sections that have been logged.

DEPOSITION OF EVAPORITES

Briggs (8) has done much to aid in our understanding of evaporite facies in the Appalachian and Michigan basins and no departure from his general thesis is herein proposed.

The shallow Salina sea which left a record of its evaporitic environment from Michigan to West Virginia, Pennsylvania, and New York had specific limits imposed on it by the sediments of the preceding Niagaran sea. The transition from Niagaran to Cayugan time in the marine realm of northwestern Pennsylvania was a gradual one. Reef banks and "pinnacle" reefs may be part of the Niagaran record here but indisputable proof of their existence awaits further study. The author believes that organic activity in the Niagaran seas, perhaps continuing into the earliest of Cayugan time, provided the framework for the basin in which Salina evaporites were deposited. Archipelagos, islands, and headlands in the shallow, warm Niagaran sea restricted communication from the separately subsiding Michigan and Appalachian basins, though channels of communication were maintained throughout the period when the Salina was accumulating.

In the following paragraphs three separate units of the Salina will be discussed. The definition of each unit has been made so that each includes a major salt bed, along with associated anhydrite and dolomite beds. The discussion of the units begins with the lowest one. The boundaries of the units are designated by letters: N to P, J to L, and H to J. (See Figure 2.)

During that time when the first of the Salina rocks was being deposited it is likely that communication between that part of the Salina sea which was mainly in Ohio and the area to the west and that which was in New York and central Pennsylvania was across a threshold or sill, somewhere near the Venango-Clarion County boundary in west-central Pennsylvania. (See Figure 3.) The basin to the west was limited by reef banks in Lockport rocks. Isopachs of the unit suggest that the deepest part of the basin crossed into Pennsylvania along the western Crawford County line. Two northeast-southwest trending headlands almost pinched off the lagoon which projected into Pennsylvania from Ohio. Meager evidence suggests that the southern headland, along the Ohio-Pennsylvania line, persisted in modified form throughout much of Cayugan time. The eastern evaporite basin -- that which lay to the east of the threshold in central Pennsylvania and New York, was bounded on the east by a previously accumulated and then-accumulating thick wedge of Vernon-Bloomsburg which had been poured in from the east by rivers disgorging into the lagoons and estuaries of the Niagaran and Cayugan seas. In the two areas on either side of the threshold subsidence accompanied deposition, but subsidence was decidedly more pronounced on the eastern side, an area in which, unfortunately, only a few wells have been drilled to give us data control. The edges of the salt, (halite) for this unit are shown in Figure 3; apparently

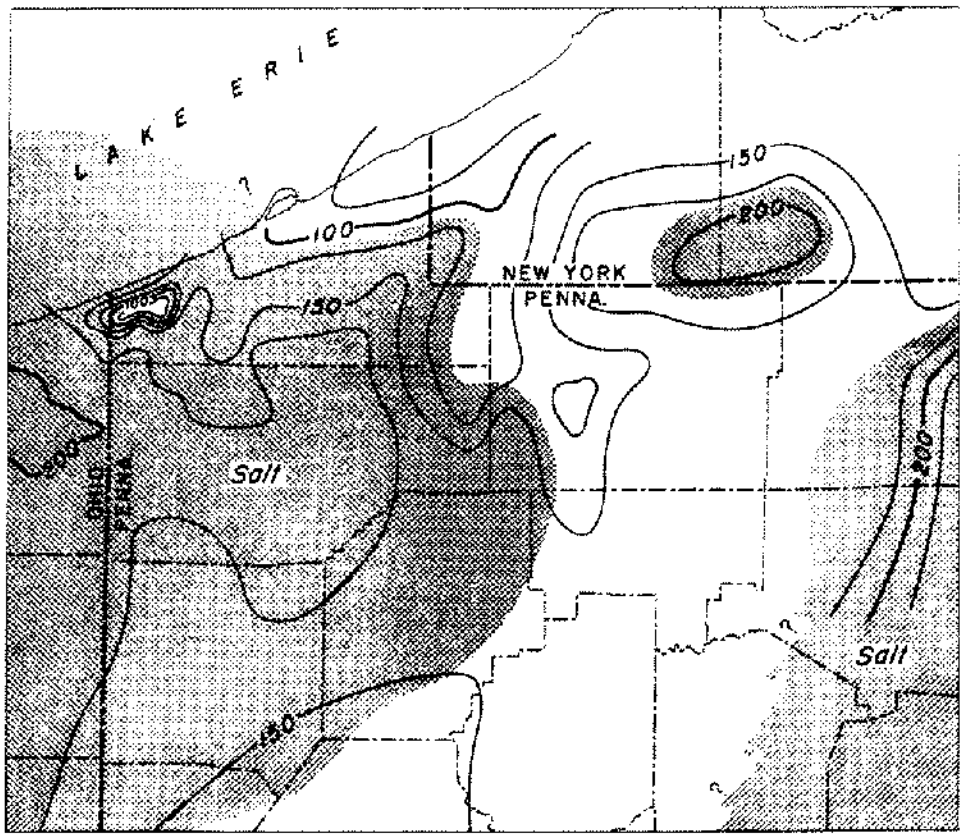

Figure 3. Isopachs of unit "N" to "P," showing presence of salt.

there is a salt-free area which approximates the position of the threshold. Whether or not salt ever was deposited farther up on the margins of the basin than it is now found in the subsurface is not known. Circulating ground waters are known to leach subsurface deposits of salt -- e.g., the phenomenon of the Mackinac Breccia in Michigan, and basin margins are also known to be unlikely places for the densest brines to accumulate and precipitate salt. The author believes that the present configuration of the salt limits is due to both depositional control and post-depositional leaching.

A small anomaly in western Erie County should be pointed out. It is an area in which the salt normally found in the N to P interval is missing. At first glance it looks like an anomaly caused by a reef, or at least a reefal mound, but Lockport isopachs do not confirm this possibility. Well-control, incidentally, in the immediate vicinity does not allow very exact definition of the area. Minimum (observed) thinning of the N to P unit is 85 feet less than a mile; it could, in fact, be much more than that. The theory here advanced to explain the anomaly is that a wedge of salt was dissolved from under accumulating sediments soon after deposition of the N to P interval. No collapse breccia has as yet been observed. Examination of subsequent units in the Salina seem to lend support to the hypothesis of leaching and subsequent down-warping of the anomaly, for it can be demonstrated that the J to L unit (Figure 4) thickens over the area, and the even later H to J unit (Figure 5) exhibits an isolated patch of salt which was probably left in the depression formed by the removal of the older salt.

Another anomaly exists along the Pennsylvania-New York boundary — this one is a positive salt anomaly. Presumably its presence resulted from the deposition of salt in a small appendage-like basin which was briefly connected with the eastern basin.

The actual salt beds in unit N to P are near the top of the unit and are interbedded with dolomitic shale, anhydrite, and dolomite. The maximum aggregate thickness of this salt in Pennsylvania is about 50 feet -- made up of beds which individually are 15 feet or less thick.

Following deposition of the N to P unit there was an incursion of the sea, carrying fine clastics and spreading over parts of at least three states. This episode interrupted the evaporation which had been going on; there were several such interruptions during Salina deposition. This particular incursion of the sea resulted in the depositing of a rather uniform blanket of argillaceous material about 60 feet thick. In the Michigan Basin this interval is designated as the "C" unit -- according to terminology proposed by Landes.

Then once again there followed a period of dessication and evaporation, during which salt precipitated in the J to L unit and the sea was relatively free of clastic-bearing influx. The precipitation of salt in the shallower parts of the basin closely followed the accumulation of shale, but in the deeper parts of the basin carbonate and anhydrite deposition intervened between the shale and the salt. The salt that was deposited in this interval was that salt which is now being mined by Morton Salt Company's shaft mine near Painesville. It is an almost solid bed of salt of fairly consistent thickness (about 30 feet) over a wide area of northern Ohio and Pennsylvania. This salt, and the interval J to L of which it is a part (shown on the isopach map of Figure 4), were deposited by a sea which was not restricted in the same way as the one which had deposited the preceding interval; the western and eastern basins were now connected, and only a headland reminiscent of the old threshold projected into the sea. To the east of this persistent headland the basin dropped off sharply. Thick intervals of evaporites and minor carbonates accumulated in a supersaturated "briney deep." Salt beds more than 100 feet thick are common in the deeper parts of this basin. The lack of a discernible cycle in the sediments in this area serves to remind us of the dynamic processes operating during evaporite deposition and of the delicate balance of physical — chemical processes — temperature, pressure, relative solubilities, turbidity, Eh, pH, etc., which govern the precipitation of the minerals we find today.

The interval H to J is very much the same as that which preceded it. The evaporite basin in Pennsylvania, however, became more quiescent and less mobile -- there was not nearly as much sagging of the basin to the east of the old headland in Warren County (Figure 5). As mentioned earlier there apparently still was a shoal paralleling the Pennsylvania-Ohio boundary which had persisted at least since Niagaran time; its shape and influence in the region south of the latitude of Youngstown, Ohio, will be known only when we have more data from that deeply buried part of the basin.

The youngest Salina rocks contain no salt. An interval of more than 200 feet of shale, argillaceous dolomite, and anhydrite was deposited while the basin was becoming less and less restricted and the replenishment of brines from the open ocean was preventing the concentration from reaching the point at which salt would precipitate.

At that point in time which is represented by the change in deposition from what we call "Salina" to what we call "Bass Island" there must have been a rather pronounced change in the

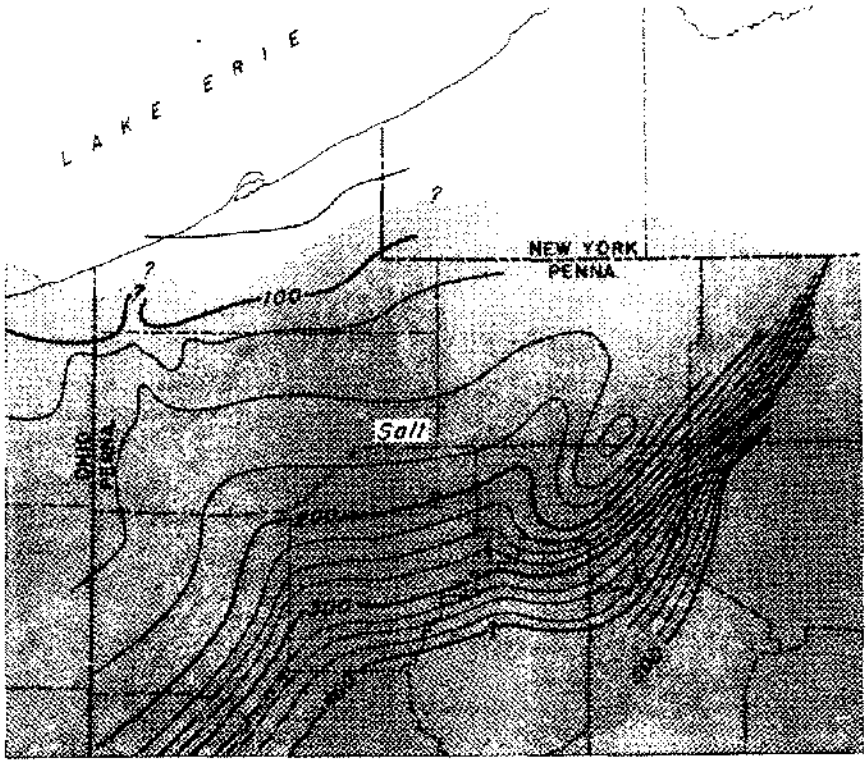

Figure 4. Isopachs of unit "J" to "L," showing presence of salt.

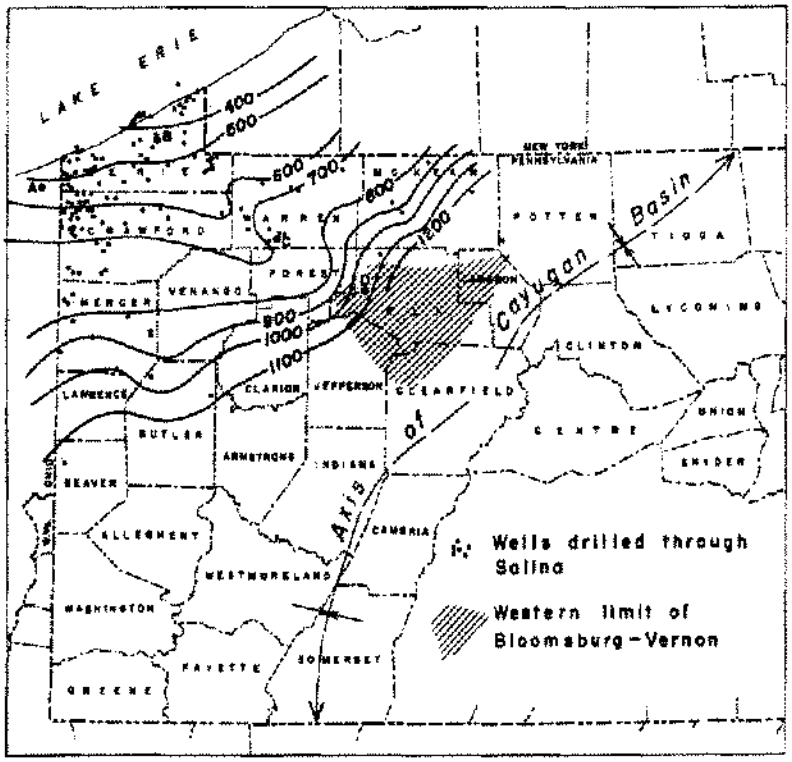

Figure 5. Isopachs of unit "H" to "J," showing presence of salt.

configuration of the basin in northwestern Pennsylvania. The precipitation of anhydrite rather quickly tapered off, implying that thresholds and headlands no longer restricted circulation; the incorporation of argillaceous material with the precipitate no longer occurred, also implying that marine currents were sweeping that part of the basin and allowing only chemical precipitates to accumulate.

The Bass Island "regime" changed only slightly when Helderberg (Early Devonian?) sediments began to accumulate in the region. At a later time the forces of erosion stripped the Helderberg off the Bass Island in much of northwestern Pennsylvania — but that is part of another story.

CONCLUSION

A great deal of work remains to be done investigating Cayugan stratigraphy. A special need is felt for detailed work on the Niagaran, with a view toward understanding the conditions which set the stage for Cayugan sedimentation.

An understanding of the Salina has economic significance in terms of the exploitable minerals involved, and also because it may provide clues to structural anomalies in both the underlying and overlying rocks which have significance to both petroleum and academic geologists. It has been suggested recently, and publicly, that structures in the younger Paleozoics may bear a relationship to the presence and absence of salt in the Appalachian Basin — this especially in the mobile parts of the Appalachian miogeosyncline where flowage of salt and the lubrication of glide planes by salt may have contributed to the formation of structures. Collapse zones, salt anticlines, and reefs are other features which may be discovered as investigation continues.

To date we know:

1. that the Cayugan sea which existed in northwestern Pennsylvania was very similar to, and a part of, that which existed as far west as Michigan;
2. that the basin in which the Salina sediments accumulated changed somewhat during the course of Cayugan time;
3. and that specific anomalies were created as a result of the behavior of sedimentary units within the Salina, or just below it.

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