Geochemical Relations of Zinc-Bearing Peat to the Lockport Dolomite Orleans County New York

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GEOCHEMICAL RELATIONS OF ZINC-BEARING PEAT TO THE LOCKPORT DOLOMITE, ORLEANS COUNTY, NEW YORK

By Helen L. Cannon

ABSTRACT

Peat deposits containing as much as 16 percent of zinc and some lead occur near Manning, Orleans County, N. Y. The metals, estimated to total 2,000 tons, have been derived from the Lockport dolomite of Silurian age which crops out adjacent to the bogs. Excessive amounts of zinc in the peat soils have induced yellowing between veins of leaves and dwarfing of plants; in the most toxic areas it has killed all but a few tolerant species. Excessive amounts of lead are stored in the roots of plants, and it is possible that root crops grown in the mineralized peats may be harmful for human consumption. Geochemical studies of soils, plants, and ground water in the area were made by colorimetric methods developed for field testing. Variations in the metal content of glacial till and well water samples suggest the occurrence of mineralized beds in the underlying dolomites. Studies of surface exposures and core from 17 holes drilled in the area establish the presence of recurrent zones in the dolomites that can be correlated over considerable distances.

These zones consist of a clastic bed of partly dissolved fossil debris overlain by recrystallized reef rock containing large algal and coralline forms. The clastic beds were probably bottom muds below wave base that represent periods of quiescence and partial stagnation during which carbonate was dissolved. These formed the substratum for reef building and widespread reef flank deposition. Analyses of the beds show a concentration of lead, chromium, copper, and nickel in the bottom muds, and zinc and strontium in the reef material.

The average content of these metals through the dolomite series is higher than for an average limestone and suggests that the sea water from which the metals were precipitated contained uncommon concentrations of metals. The mineralized beds of the series contain an average of 0.06 percent zinc and 0.002 percent lead. Sphalerite and galena occur throughout the upper and lower parts of the Lockport section as disseminated crystals or are concentrated in certain beds, but have not yet been found in deposits of commercial value in western New York State.

INTRODUCTION

Geochemical studies of zinc-bearing peats in western New York State show them to be related genetically to underlying mineralized beds of the Lockport dolomite of Niagaran age. For a number of years agriculturally unproductive areas had been noticed in certain of the muck soils of Orleans County near Manning, N. Y. In some places the vegetable crops were poor over an area of an acre or more, and smaller spots supported no vegetation (crops or other) whatsoever. Crops planted on these areas came up normally, but soon after the first leaves appeared the plants turned yellow, remained stunted, and eventually died. E. V. Staker, professor of soil technology at Cornell University, proved that the soil contained enough zinc to be toxic to plants. In an intensive field and laboratory study the surface soil of the Manning Muck was systematically sampled and tested for zinc, and the vertical distribution of the zinc throughout the peat profile was studied in detail (Staker and Cummings, 1941; Staker, 1942, 1944). In several spots the zinc content by weight of the air-dried peat was found to be as high as 16 percent.

The high concentration of zinc in the peat and plants of the area offered an opportunity for study of the geochemistry of zinc in soils, plants, and waters under natural conditions and for tracing the zinc to its source. Would it be possible, in line with Goldschmidt's (1944, p. 176) speculations, to use the distribution of zinc in peat as a guide for prospecting more valuable deposits of zinc in the surrounding rocks?

Intermittent field work was begun in the area by the United States Geological Survey in September 1946; after some interruptions, field work was completed in June 1948. In 1950, 1,900 feet of diamond drilling was completed in the area. Geochemical and botanical surface studies were made of the drained and undrained bogs and also of till-covered parts of the area. These were followed by geologic studies of the dolomites of Niagaran age near Manning. In the course of the field studies many hundreds of samples of water, soils, and plants were taken and analyzed chemically both in the field and in the laboratory for zinc and lead. Geochemical data on the relation of peats, soils, plants, and water to the underlying dolomites of the area are presented, and the stratigraphic significance of the occurrence of sulfides in the dolomite series is indicated in this report.

The variety of problems presented required resources of many kinds, and personnel from several branches of the Geological Survey contributed to their solution: John R. Cooper helped with the initial geochemical studies and is responsible for recognition of the sphalerite in the Lockport dolomite as the probable source of the zinc in the peat; Frank Grimaldi made field analyses of well water and soil; and the late V. H. Rockefeller of the Water Resources Division helped in collect-

ing well water samples. R. H. Stewart supervised the drilling program.

GENERAL GEOLOGY AND GEOGRAPHY

Manning is 35 miles west of Rochester and 2 miles west of Clarendon in Orleans County, N. Y. (pl. 1). The area studied is a part of a glacial lake plain that slopes southward at an average of 30 to 50 feet to the mile. In general, the land surface conforms to the dip of the underlying Lockport dolomite of the Niagara series of Silurian age. The truncated northern edge of the Lockport dolomite is marked by a cuesta that extends east-west across the northern part of the area. The cuesta shifts abruptly to the south along a north-south line through the town of Clarendon. Chadwick (1920) describes the break as offset along a normal fault with the downthrown side to the west. The angle of bedding in the eastern part of the area is affected by the fault so that the strike is northwest-southeast, and the dip is about 30 feet to the mile in a southwest direction. The metal content of the dolomite beds does not appear to increase near the fault scarp. An east-west cross fault is postulated to cut the area south of the Manning Muck. The evidence for a fault is repetition of beds at the surface and the offset of beds encountered in drilling. The beds in hole 9 (pl. 1) are 27 feet higher than their position in the section projected from the holes to the north.

Removal of the Salina group of Late Silurian age, which overlies the dolomites of the Niagara series to the south, by glacial action has left a low area across the entire county. This area is occupied by a series of poorly drained swamps which rest on the Lockport dolomite at a more or less uniform distance from the outcrop. Several of these bogs have become sufficiently mineralized by leaching of the sulfides from the underlying dolomites to deserve geochemical study.

GEOCHEMISTRY

METHODS

A study in 1946 of the Manning Muck, shown as an area of drained muck southwest of Manning (pl. 1), was the first investigation undertaken by the Geological Survey using geochemical prospecting techniques, and work on the collection of data from that area was continued intermittently until 1948. Orleans County was thus a testing ground for sampling and analytical methods, and new procedures for both sampling and analyzing were gradually evolved during the course of the field project. The first analytical work was done by F. S. Grimaldi ,who analyzed rock and soil samples gravimetrically, precipitating zinc as ZnS by hydrogen sulfide, in a laboratory made available by the University of Rochester. He experimented with a dithizone test that could be made in the field and was specific for zinc in water.

Later, a simplified test by Huff (1948) for measuring total heavy metals in water samples was developed and used for further studies of well water and surface water. Dithizone methods for testing soils (Lakin, Stevens, and Almond, 1949) and plants (Reichen and Lakin, 1949) for zinc in the field were also perfected and tested in the Manning area. Field studies based on these methods demonstrate that the zinc content of the well waters may be as high as 0.0011 percent, or 11 parts per million (ppm); till, 2,200 ppm; peat 88,000 ppm; and plants, 10,400 ppm; average amounts of zinc are much lower, however. The maximum lead content found in dry peat was 336 ppm. For convenience, all analyses for metals in plants, soil, and water are reported in parts per million rather than in percents.

GEOCHEMICAL STUDY OF THE PEAT BOGS

Abnormal concentrations of metals in peats are frequently reported in the literature. Forrester (1942, p. 126) and Eckel (1949, p. 55) have described copper-bearing peats in Montana and Colorado that developed downstream from areas of copper deposits. A comprehensive study of this phenomenon has also been made by a Finnish geologist, Marti Salmi (1950, p. 1) who spectrographed 63 samples from 50 peat bogs. He found maximum contents of 0.3 percent copper and 1 percent zinc in peats near minable deposits of these metals and concluded that a content in peat ash of 0.1 percent copper, 0.1 percent nickel, or 0.6 percent zinc indicates the occurrence of these metals in the bedrock of the region surrounding the bog.

BOG SOILS

Drained bog soils in the area of this report are referred to as muck, and these soils are used for truck farming. Ries (1903, p. 76) defines muck in this sense as "* * * a peat with a high percentage of mineral matter * * * useful for truck farming when drained." Many of the muck areas in Orleans County have been ditched and are now being intensively cultivated as farm land. Names given to the individual mucks by local inhabitants are used in this report.

Areas of zinc-rich peat occur in the Manning Muck, the western edge of the Clarendon Muck, and the northern part of the Big Muck (pl. 1). Areas of the Shelby Muck and several of the undrained peat bogs are also known to contain appreciable amounts of zinc. The position of these areas in relation to the outcrop of the Lockport dolomite (pl. 1) suggested a stratigraphic correlation of zinc-rich peat with specific beds in the upper and lower parts of the Lockport dolomite. Subsequent detailed geochemical and geologic work has tended to confirm this relationship.

Thickening and thinning of the component parts of the Manning Muck from the surface to bedrock, and data on the zinc-lead distribution both horizontally and vertically are shown in figure 19. (The

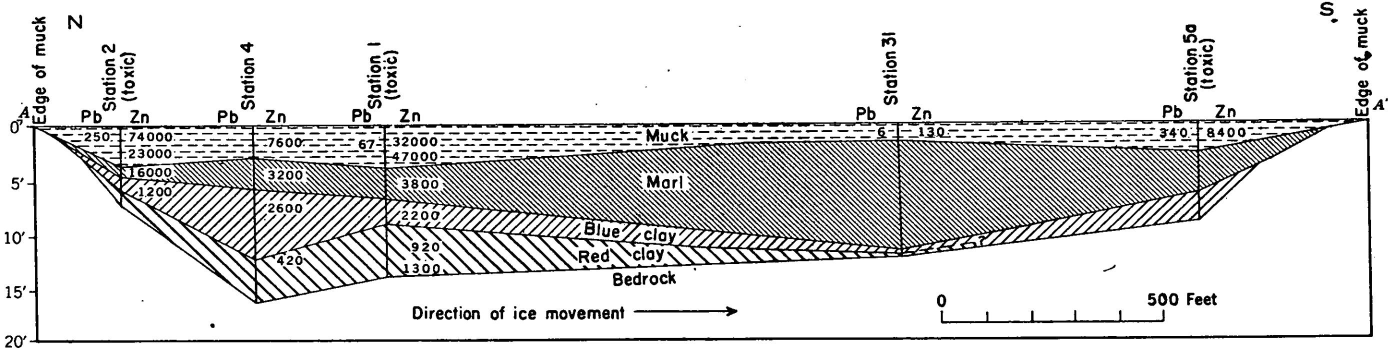

FIGURE 19.—Profile section across the Manning Muck, showing the lead and zinc contents.

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location of the section is shown in pl. 3.) These data were obtained from a series of augered samples taken to bedrock along a north-south line. Peat as thick as 4 feet is underlain by marl ranging from 2 or 3 feet thick in the northern half of the bog to 10 or 11 feet in the southern half. Conversely, the banded red-and-blue glacial clay or rock flour underlying the marl is only a few feet thick in the southern half of the bog but thickens to 11 feet in the northern half. The lake left by the retreating glacier probably filled rapidly from the north with rock flour and clay; and open water was maintained longest near the south end, where a thick formation of marl was slowly deposited as a chemical or organic precipitate. The areas of zinc-rich muck are confined mostly to the shallow edges of the bog, where the peat is not underlain by marl but is in contact with either mineralized zones in the underlying Lockport dolomite or with highly mineralized ground water entering the bog from the sides. Drainage is toward the south through the permeable marl and peat. Zinc-rich areas near the center of the bog are centered around springs.

The localizing of zinc in these areas by ground-water circulation is well illustrated by a change that has taken place in certain zinc-rich areas during the course of the present survey. In 1948 the owner of a strip of the Manning Muck put in a tiled east-west drainage ditch to improve his land. Immediately an area of vegetation on his land began to die, and the owner of the adjoining strip of the muck was able for the first time in many years to produce a crop. Analyses of peat from these spots show a definite change in total zinc content. Because of such fluctuations, the original mapping of zinc-rich areas by Staker in 1941 is no longer accurate in detail, and although data from his map have been used in figure 20, the original map is not reproduced in this paper.

BOG ECOLOGY

To establish whether plants living in the original bog were unusual accumulators of zinc and lead and were therefore responsible for the concentration of these metals from ground waters, studies were made of the past and present plant life of the bogs in this general area. Because the Manning Muck and other zinc-bearing drained mucks have been cleared and planted in cultivated crops and no macroscopic plant remains can be recognized in the peat, an understanding of the history of peat deposition in these muck areas is aided by pollen studies of the peat and comparative studies of undrained bogs nearby on which plant life has remained undisturbed.

A thickness of several feet of peat in the drained mucks is underlain commonly by several feet of marl. Arthur S. Knox of the Geological Survey made pollen studies of the Manning peat, the underlying marl, a second thin peat layer, and the remaining section of marl. The marl section in the eastern part of the bog is broken at a depth of

TABLE 1.—*Pollen analysis, Manning Muck*

[Arthur S. Knox, analyst]

Depth from surface and description of sediment [1]	Tree pollen, in percent of total number														Dominant herbaceous plants	Plant environment
	Ash	Beech	Birch	Chestnut	Elm	Fir	Hemlock	Hickory	Linden	Maple	Oak	Pine	Spruce	Sycamore		
10″–1′. Decayed peat, with fungal hyphae; pollen rare.	0	0	0	0	0	0	24	0	0	0	40	36	0	0	Grasses, ferns	Peat derived from mixed evergreen and hardwood forest.
1′ 4″–1′ 6″. Peat with fungal hyphae; pollen rare.	0	10	1	0	4	0	16	5	0	3	40	21	0	0	Grasses, ferns	Peat derived from hardwood and evergreen forest.
1′ 9½″–1′ 11″. Marl; shells of *Pisidium*, *Musculium*, *Trivolis*, *Lymnaea*; pollen rare.	0	9	0	1	1½	0	33½	1½	1	0	28	24	0	½	Grasses, sedge, pondweed.	Open water and marl.
2′ 1″–2′ 2½″. Sedge peat; many insect remains; pollen rare.	1½	2	0	0	2	0	52	0	1	1½	20	21	0	0	Sedge, grasses, *Lycopodium*.	Sedge mat.
2′ 4½″–2′ 6″. Marl; pollen common and well preserved.	1	1½	½	0	0	0	64	½	0	0	8½	23½	½	0	Grasses	Marl.
2′ 6½″–2′ 8″. Marl; pollen common and well preserved.	½	4	1½	0	1½	½	40½	1½	0	1	13½	35½	0	0	Grasses	Marl.
2′ 9½″–3′. Marl; pollen common and well preserved.	½	½	½	0	2	0	15½	0	1½	0	9	70½	0	0	Grasses, bayberry	Marl (coniferous trees grew nearby).

[1] Sediments were taken from a ditch on the east side of the muck.

8 inches by a second 4-inch layer of peat. The analysis is given in table 1. From his study, Knox (written communication) concludes that the second peat layer is a sedge peat that probably accumulated during a period of lower water level in the pond. A similar peat layer also overlain by marl was described by Stewart and Merrill (1937, p. 248) as occurring in the Bergen Bog 7 miles southeast of Manning. The pollen analyses of the marl and peat in the Manning Muck are interpreted as evidence that the forest around the marl-depositing pond in the early stages of bog development was made up largely of coniferous trees (hemlock and pine); as the pond basin gradually filled, the conifers in the adjacent forest were replaced by hardwood trees (oak, maple, beech, elm, and hickory).

An ecologic study was made of small undrained bogs in the vicinity of Manning for comparison with the drained and cleared Manning Muck. The small bogs studied are under several feet of water in the spring, but usually become dry by fall. Red maples, elm, spicebush, birch, hemlock, oak, and other species now form canopies over the bogs; and creeping juniper, wood ferns, and large clumps of royal ferns cover the floors, which consist of spongy masses of half-rotted leaves and fallen moss-covered tree trunks. On small promontories which extend into the bogs, black currant, highbush cranberry, and dogwoods form shade for wild ginger, violets, baneberry, bishopscap, false Solomons-seal, and winterberry. According to local inhabitants, the original cover was in large part logged off or burned over.

F. J. Hermann and S. F. Blake of the Department of Agriculture identified, except as noted, the following specimens collected from the present cover:

Acer rubrum, L.	red maple
Actaea rubra (Ait.) Willd.	red baneberry
Arisaema atrorubens Blume	jack-in-the-pulpit
Asarum canadense L.	Canada wild ginger
Aspidium spinulosum var. *intermedia* (Muhl.) D. C. Eaton[1]	wood fern
Betula lutea, Michx.	yellow birch
Cornus amomum Mill.	silky dogwood
Dryopteris cristata L. (Muhl.) Gray	evergreen fern
Dryopteris intermedia (Muhl.) Underw.	evergreen fern
Equisetum arvense L.	horsetail
Equisetum fluviatile	horsetail
Ilex verticillata, (L.) Gray	common winterberry
Impatiens biflora Walt.	spotted touch-me-not
Juniperus horizontalis, Moensch.[1]	creeping juniper
Lindera benzoin (L.) Blume	common spicebush
Mitella diphylla L.	common bishopscap
Onoclea sensibilis L.	sensitive fern
Osmunda regalis L.	royal fern
Mitella nuda L.	naked bishopscap

[1] Identified by the author.

Prunus virginiana L.	common choke cherry
Quercus alba L.[1]	white oak
Ribes americanum Mill.	American black currant
Smilacina stellata (L.) Desf.	false Solomons-seal
Thalictrum dasycarpum Fisch and All.	purple meadow rue
Thuja occidentalis L.	arborvitae
Tsuga canadensis (L.) Carr[1]	Canadian hemlock
Ulmus americana, L.	American elm
Viburnum trilobum, Marsh.	highbush cranberry
Viola eriocarpea Schwein.	yellow violet

[1] Identified by the author.

In order to understand how a peat bog is formed, comparative studies were also made of the large Bergen Bog 7 miles southeast of Manning. This bog, also underlain by Lockport dolomite, has been intensively studied as a marl bog in the process of formation by botanists and ecologists and is being preserved as a primitive area by study groups and societies. It has been described by Stewart and Merrill (1937) and by Muenscher (1946) as a late stage in the plant succession which results as an open-water area is gradually filled.

The areal plan of the Bergen Bog shows the center of the bog to be an open marl area that is under water most of the year. From this open marl outward are three concentric belts: The first is of dry marl which supports low-growing plants, the second is of peat in which conifers grow, and the outermost is of thick peat bearing a hardwood forest. Vegetation is sparse in the central marl area and consists of grasses and sedges although a few hummocks of ladyslippers and cattails dot its surface. From its periphery pioneer plants of sphagnum moss, shrubby cinquefoil, and creeping juniper encroach onto the dry marl belt and thus build up a thin layer of humus. The pH of the open marl is more than 7. In the dry marl belt grow low, shrubby tamaracks and arborvitae, Laborador tea, and huckleberries. The belt surrounding the dry marl has a thicker layer of humus which supports conifers—pine and hemlock—and a thick undercover of ferns and mosses. The pH of the coniferous belt is 6. In the outermost concentric belt the peat has become several feet thick and bears a hardwood forest of beech, maple, and elm.

Augered sections taken in the central part of the Bergen Bog consist only of marl and clay. Sections taken near the periphery of the bog penetrate a peat layer of hardwood debris, then a coniferous peat, marl, and clay. The vertical sections taken on the Manning Muck indicate a similar history from open marl pond to hardwood forest cover. Pollen studies suggest that the species of each ecologic bog zone were similar to those observed in the Bergen Bog. All of the plants listed as occurring in the undrained swamps near Manning, which represent a late stage in ecological development, are found in the hardwood peripheral cover of the Bergen Bog. It is probable that the Manning Muck supported a type of vegetation similar at one time to that growing in the Bergen Bog today and that it contained no species which cannot be found in the area.

ACCUMULATION OF ZINC AND LEAD IN THE PEAT

The amount of zinc and lead in the Manning and neighboring peat bogs, estimated at several thousand tons, is probably too great to have been concentrated by accumulator plants; but rather has been concentrated by residual enrichment through decay of plant remains in the peat and by precipitation from the ground water.

Analyses of trees and ground-cover vegetation collected from undrained swamps, drained but uncleared bogs, and drained and cleared bogs, indicate that neither in the past nor present have the peat-forming plants been marked accumulators of zinc or lead. The results of these analyses are recorded in table 6 and show no marked accumulation of zinc among the original bog plants but suggest that conifers, especially the arborvitae and hemlock, may concentrate a higher percent of lead in the dry weight of the plant than is present in the soil.

A few plant samples were taken in the Bergen Bog for comparison of lead and zinc content with that of plants growing on the Manning Muck. The analyses are shown in table 2. The aspen contains more zinc than the peat, and the arborvitae more lead than the peat. However, the values are not high in either the living trees or peat. In fact, the marl in the central zone derived from the Lockport dolomite contains more zinc than the peat.

TABLE 2.—*Soil and plant analyses from the Bergen Bog, in parts per million, dry weight*

	Zinc	*Lead*
Marl from central part of bog	180	2
Peat from arborvitae zone; composite sample of 100-square foot area through first foot of peat	40	13
Leaves of plants growing in peat:		
Thuja occidentalis, L. arborvitae	20	19
Acer rubrum, L. red maple	24	7
Populus tremuloides, Michx. quaking aspen	140	n. d.

The accumulation of lead in the arborvitae may possibly be related to the common belief among the Manning farmers that poisonous substances from the arborvitae are responsible for the toxic areas of the Manning Muck. It is more probable, however, that the prevalence of arborvitae on the toxic areas denotes areas of water-logged land that are in turn associated with mineralized springs and seeps around the edge of the muck. In general, the ratio of zinc content in the dry weight of the plant to that of the soil in which the plant is growing is only 1 to 30. This low ratio suggests that the metals were not originally concentrated by the swamp vegetation from which the peat was formed.

Evidence that the metals were precipitated in the bog before the bog was drained is fairly conclusive. A peat sample from a shallow undrained bog northeast of the Manning Muck tested 8,400 ppm of zinc and 100 ppm of lead. A sample from a shallow undrained bog southeast of the Manning Muck tested 6,700 ppm of zinc and 26 ppm of lead. Although these are not comparable to the highest concentrations recorded for the Manning Muck, they come within the range toxic to vegetation.

The peat contains a high proportion of zinc, lead, and other metals. A spectrographic analysis of the ash of a zinc-bearing peat sample from Manning Muck showed:

Percent	
1+	Ca, Si, Zn, Mg, and Al
0.X	P, Fe
0.0X	Ti, Mn, Ba, Sr, Zr, V, Cu, Ni, B
0.00X	Pb, Co, Cr

The content of heavy metals in the ash of the peat in the Manning Muck correlates well with the content in the dolomite bed which underlies the peat. The content of calcium, magnesium, silica, alumina, titanium, and manganese in the peat is that of an average dolomite. The content of iron, lead, and chromium in both peat and dolomite is high. The content, however, of vanadium, zirconium phosphorus, boron, cobalt, zinc, copper, nickel, and barium in the peat is more than an entire order of magnitude greater in the peat ash than in the mineralized parts of the dolomite. This indicates a selective enrichment in peat of those elements as compared to the amounts available in the dolomite. This suite of metals corresponds closely with that listed by Goldschmidt (1937, p. 656) as being concentrated in coal.

Metals may be concentrated in a peat environment in one of four ways: by adsorption on the organic matter, as true organic compounds, as sulfides precipitated by bacterial action, and as sulfides reduced from sulfate waters by the direct action of the acid peat. When plants die, hydroxides, proteins, and humic complexes are retained partly by adsorption on the humus layer, and partly in the form of organic complexes (Rankama and Sahama, 1949, p. 333). Bremner, Mann, Heintze, and Leis (1946) suggest that the metals exist in an insoluble metallo-organic complex with soil organic matter in a nonexchangeable form. The precipitation of metal under highly reducing conditions in swamps has been demonstrated by Lovering (1927), whose laboratory experiments indicate that copper may be precipitated in bogs through the action of amino acids and other bacterial waste products. Enrichment of the metal content of the peat may be accomplished at a later date from mineralized ground waters by adsorption on the peat or reduction to sulfides through the action of carbon dioxide (Rankama and Sahama, 1949, p. 333).

Conclusive evidence concerning the original form of the lead and zinc in the peat of the Manning Muck and the possible effect of oxidation after the bogs have been drained is difficult to obtain. Staker (1942, p. 389) found that a large part of the zinc in the peat is acid soluble but only a small fraction of this amount is water soluble. The percent of component fractions present in three soils is reproduced in table 3.

TABLE 3.—*Water-soluble, replaceable, and nonreplaceable zinc in peat soils near Manning, N. Y. (taken from Staker, 1942)*

Peat	*pH*	*Water-soluble Zn (ppm)*	*Zn replaceable with N/20 HCl (ppm)*	*Nonreplaceable Zn (ppm)*	*Total exchange capacity (milliequivalents per gram)*	*Saturation with Zn (percent)*
Copeland farm (station 1 on fig. 3)	6.21	75	19,549	2,371	2,866	20.9
Dolfy farm	6.52	39	15,771	2,269	2,974	16.1
Stymus farm (burned) (station 2 on fig. 3)	7.19	195	52,532	48,873	2,306	69.7

Staker determined in 1944 that at least a part of the nonreplaceable zinc is present as zinc sulfide. He found that the ratio between sulfide sulfur and total zinc in 110 soil samples was 1 to 3. In highly unproductive soils, however, he found that the toxicity was due mainly to the soluble fraction. X-ray diffraction studies of one sample of peat from the Copeland property were made by S. B. Hendricks of the Department of Agriculture. The sample contained about 1 percent sphalerite, although neither sphalerite nor galena could be recognized in the peat under a high-powered microscope. From these determinations it may be concluded that the zinc was precipitated at least in part as finely divided zinc sulfide, and where the peat has been drained and oxidized the metal is now predominantly in an exchangeable form.

Oxidation and eventual leaching of the metal are to be expected in peat soils that are above the water-table level. According to Plummer (1945), the organic matter in peat promotes the growth of soil bacteria that are active in the formation of sulfides and sulfur. When the peat is buried or under water, oxygen is practically absent and the sulfides and sulfur remain in a reduced state. When the peat is aerated or drained, the zinc sulfide reacts slowly with oxygen to produce $ZnSO_4$. This generation of sulfate in the soil continues until the sulfides and surfur are completely converted. Rudolfs and Helbranner (1922) conducted experiments to demonstrate the oxidation of zinc sulfide to sulfate through bacterial action. They have shown that a slow chemical reaction proceeds in the absence of bacteria, but that the change is greatly speeded by the introduction of sulfur bacteria and free sulfur.

If zinc and lead are precipitated from solution in the ground water, then the distribution of zinc-rich areas in the peat is dependent upon and related to the proximity of the outcrop of mineralized zones in the Lockport and to ground-water conditions. A test made of peat from an undrained swamp south of Clarendon demonstrates the latter relation (table 4). The correlation of zinc-rich areas of the peat to mineralized parts of the underlying Lockport dolomite is shown in plate 2.

TABLE 4.—*Analyses of peat from an undrained swamp south of Clarendon, N. Y., in parts per million, dry weight*

	Zinc	*Lead*
Peat near entrance of ground water to swamp	6,700	26
Peat 500 feet from edge of swamp	2,100	12

Although the occurence of zinc and lead in the Manning Muck at at the present time is near to the original source of the metal, a certain amount of movement and reconcentration have undoubtedly taken place: First, it is probable that, owing to oxidation, a considerable amount of the zinc as sulfate is leaving the bog through the drainage ditches. It is certainly true that the outgoing drainage contains a greater percent of heavy metals, mostly zinc, than the incoming stream at the north end. If this condition persists, the toxicity symptoms should eventually disappear with the complete oxidation and removal of the metals through surface drainage. Second, the increased mobility of the metals resulting from oxidation since the draining of the muck, is undoubtedly responsible for a shifting of the concentrations, size, and shape of the toxic spots. Third, the metals in certain areas of the muck have been greatly concentrated by muck fires, at least one of which (on the Stymus farm) burned to a depth of 4 feet.

The amount of zinc that presumably has been extracted from the dolomites and deposited in the peat is large. By assuming a dry weight of 200 tons per acre-foot of peat and computing the zinc content of each zinc-rich area separately, it is estimated that there may be 1,000 tons of zinc in the peat of the Manning Muck and an appreciable quantity of zinc in the marl. In addition, there is a minimum of 500 tons of zinc in the zinc-rich parts of neighboring bogs. The muck south of Shelby is known to contain a considerable amount of zinc, and it is possible that there are other zinc-bearing bogs among those that have not yet been drained.

VEGETATION

When it is drained and aerated for farming, the zinc-rich peat becomes oxidized, and the crops develop toxicity symptoms. Staker (1942) demonstrated that the availability of the zinc could be reduced by alkalizing the peat with calcium hydroxide at a rate of 4 tons to the acre. Copper sulfate is also reported to reduce the toxic effects of the zinc. It is necessary, however, to repeat the treatment each year, because the mineral content of the surface peat is renewed with the winter ground-water circulation. Farming on the toxic areas was abandoned after several years of experiment.

A zinc-rich area, when drained, eventually becomes barren of vegetation. The spring-fed area near the center of the Manning Muck is devoid of all vegetation and is encircled by a few weeds limited to a few very tolerant species. Their maximum zinc content is given in table 5. Although only that part of the plant 2 inches or more above the ground was collected, it is possible that a part of the zinc represents contamination by soil or airblown dust.

TABLE 5.—*Zinc content of the above-ground part*[1] *of accumulator plants collected on the Manning Muck, in parts per million, dry weight*

[H. W. Lakin, analyst]

	Zinc
Amaranthus retroflexus L., red root pigweed	2,000
Ambrosis elatior L., common ragweed	4,800
Solanum nigrum, L., black nightshade	10,000
Portulaca oleracea L., common purslane	10,000
Urtica dioica L., bigsting nettle	1,000

[1] Except the 2 inches directly above ground, which were discarded in order to prevent soil contamination.

Ragweed, purslane, and nightshade grow nearest the center of these barren spots, but nettles, the most noticeable weed on the muck, grow waist-high in patches along all drainage ditches. The potato, of the same genus as nightshade, is the most successful muck crop in zinc-rich areas.

These same weeds are also common in many zinc districts in the Eastern United States. Nettles grow in profusion in the old lead pits in the Schullsburg district of southwestern Wisconsin. Stunted ragweed in that area is confined to the piles of dirt thrown out of the pits. Nightshade is a common weed on old mine dumps at Franklin, N. J. The presence of ragweed on the zinc slime ponds at Friedensville, Pa., and the large amounts of zinc that ragweed can accumulate have been reported by Robinson, Lakin, and Reichen (1947).

A common physiological symptom induced in plants by an excess of zinc in the soil is chlorosis, or discoloration. In the early stages of chlorosis the plants are marked by a yellowing between the veins of the leaves. With an increase in zinc content, the leaves become completely yellow and finally turn white near the top of the plant. Under extreme conditions the plants become very brittle and remain dwarfed and stunted.

Experiments in the Geological Survey laboratory have confirmed these findings. Sweet peas, tomatoes, bluegrass, and violets were grown in nutrient solutions to which increasing amounts of copper, lead, zinc, and combinations of the three metals were added as copper sulfate and lead and zinc acetate. Excessive amounts of copper and zinc in the solution produced the chlorotic effects just described and also caused white tips to appear on the roots. Excessive amounts of lead caused the violets and bluegrass to turn dark blue-green. All plants fed large amounts of lead developed brittle roots, and transpiration was restricted to a remarkable degree. When the amounts had been increased sufficiently to kill the plants, the part above ground was harvested and analyzed. Results indicated that all three metals were absorbed by the plants in amounts of several thousand parts per million. When lead and zinc were added in combination, the absorption of zinc was increased at the expense of the lead. Sweet peas that were grown in a lead-zinc solution with a pH of 7.6 absorbed 8,200 ppm of zinc and 6,700 ppm of lead; sweet peas grown in a nutrient solution of the same pH but with no lead or zinc added contained only 61 ppm of zinc and 18 ppm of lead.

Results of similar studies are recorded in the literature (Jensch, 1894). Hewitt (1948, p. 489) has published an authoritative study on the relation of other metals to the iron in plants. His experiments have shown that the intervenal chlorosis and necrosis which develop when zinc and copper are added in excess to the nutrient solution are directly connected to a failure in metabolizing the iron. Dwarfing, however, is a phenomenon due only to zinc toxicity and is not connected in any way to an iron deficiency.

Discovery of sphalerite in the dolomite underlying the zinc peats was made by John Cooper and the author by tracing chlorotic symptoms of zinc toxicity on the Clarendon Muck. A yellow, or chlorotic, streak was clearly defined across a field of potatoes planted there. Nearly every chunk of weathered rock exposed by plowing the field contained visible crystals of sphalerite.

Word was later received from the agricultural agent of Orleans County that a Shelby Muck farmer 12 miles due west of Manning had similar trouble with his crops. The plants were yellowed and stunted. A sample of the muck was found to contain 5,100 ppm of zinc and 18 ppm of lead. A large pile of dolomite boulders which had been plowed out of the muck were largely reef material conspicuously marked with white silicified calcareous algae and contained large crystals of sphalerite. It was possible to define the presence of the sphalerite zone in the meadows and fields of the farm, as well as on the muck, by the chlorotic condition of certain species of plants, and by the algae and sphalerite showing in the boulders of the till. This discovery of a zinc-rich zone in a till- and muck-covered area was accomplished in less than half a day and is described here to emphasize the value of using chlorosis as a means of prospecting in an area in which the character of the mineral deposits is understood.

Conditions are extremely favorable for the absorption of zinc and lead by vegetation growing on the peat. In conjunction with Staker's study of zinc chlorosis in muck crops, many analyses of plant material were made specifically for zinc. He found that the tubers of potatoes have a higher zinc content than the tops, but that carrots and onions contain more zinc above ground than below. The presence of lead was not investigated by Staker. Table 6 shows Geological Survey analyses for both lead and zinc in plants growing in various types of muck. Analyses of vegetation growing on drained and undrained peat soils indicate that the oxidation has little effect on the absorption of lead but that the absorption of zinc is much greater on drained than undrained peats.

The absorption of lead by various plant species differs markedly. On a muck containing 250 ppm of lead, the ragweed, sedge, and burdock absorbed 50, 55, and 58 ppm respectively, while pigweed and nettles absorbed only 6 and 2 ppm; on a soil containing 71 ppm, an elm and a fern absorbed 36 and 30 ppm respectively, while a maple and a jewelweed absorbed only 3 and 14 ppm. Two evergreens were found to contain more lead in the dry weight of the plant than is present in the dried peat: the arborvitae absorbed slightly more than was present in the soil, and the hemlock contained four times that of the peat.

Lead is probably not necessary or beneficial to plant growth, and it is not taken up normally by plants in large enough amounts to be harmful to the plant or to people. However, several of the plants named above approach the content of 60 ppm set by the U. S. Food and Drug Administration as being dangerous for human consumption. Furthermore, this plant material was collected from above ground only; and work by Bonnet (1922, p. 488), Hammett (1928, p. 183), and Hevesy (1923, p. 440) has shown that lead is concentrated in the roots of plants. A plant analyzed by Hevesy having 12 percent of lead in the ash of the leaves had 38 percent in the ash of the roots. Perhaps further work would suggest that farming on the Manning Muck should be confined to aboveground crops.

TABLE 6.—*Partial analyses of plants* [1] *and soils from the Manning area, in parts per million, dry weight*

[W. H. Lakin, F. N. Ward, L. Reichen, Hy Almond, F. Grimaldi, H. Bloom, analysts]

Drained and cultivated muck	Lead		Zinc	
	Plant	*Soil*	*Plant*	*Soil*
Portulaca oleracea L., common purslane	42	67	10, 000	26, 000
Solanum nigrum L., black nightshade	10	67	10, 000	26, 000
Ambrosia elatior L., common ragweed	8	67	4, 600	26, 000
Do	50	250	4, 800	88, 000
Amaranthus retroflexus L., common pigweed	6	250	2, 000	88, 000
Urtica dioica L., bigsting nettle	2	250	1, 000	88, 000
Sedge	55	250	600	88, 000
Arctium minus Bernh., smaller burdock	58	110	390	4, 200
Salix sp., Willow	4	28	860	5, 100
Populus tremuloides Michx., quaking aspen	4	110	860	4, 200
Ditched but undisturbed swamp forest				
Verbascum thapsus L., flannel mullein	6	30	150	1, 600
Impatiens biflora Walt., spotted jewelweed	14	71	230	2, 700
Ulmus americana L., American elm	36	71	80	2, 700
Dryopteris cristata (L.) A. Gray, crested woodfern	30	71	100	2, 700
Acer rubrum L., red maple	3	71	42	2, 700
Undrained swamp				
Dryopteris cristata (L.) A. Gray, crested woodfern	8	12	34	2, 100
Salix purpurea L., osier willow	6	26	290	6, 700
Acer rubrum L., red maple	6	12	71	2, 100
Populus tremuloides Michx., quaking aspen	5	100	140	8, 400
Equistum arvense L., field horsetail	4	100	46	8, 400
Thuja occidentalis L., eastern arborvitae	19	13	20	40
Tsuga canadensis (L.) Carr., Canadian hemlock	40	10	50	190
Quercus bicolor Willd., swamp white oak	10	70	60	425
Ulmus americana L., American elm	15	40	40	330

[1] Leaves of the trees and aboveground parts of smaller plants except the 2 inches directly above ground.

Some species of plants accumulate enough zinc under favorable conditions to reflect zinc-rich areas in the soil, as shown by table 6. Conditions on the Manning Muck are ideal for experimental "prospecting." The muck has been thoroughly tested for zinc by Staker although the zinc distribution has changed slightly as a result of changing drainage patterns, since his sampling. The amount of organic matter and clay, the pH, and the height of the water table at any one time are virtually constant. The surface of the muck is flat, and willow windbreaks are laid out in north-south and east-west rows. For these reasons the area was chosen as ideal for testing a field kit devised by Reichen and Lakin of the Geological Survey (1949) for determining zinc in plants. Reichen spent three weeks in the area and made about 150 analyses. Samples were taken by means of a leaf punch designed to cut a disk one square centimeter in area. A given number of disks were then ashed and analyzed.

The leaves of willows and nettles were used for sampling because of the distribution of these plants and their accumulative capacity. The field results for willow are shown on the map in figure 20. Compara-

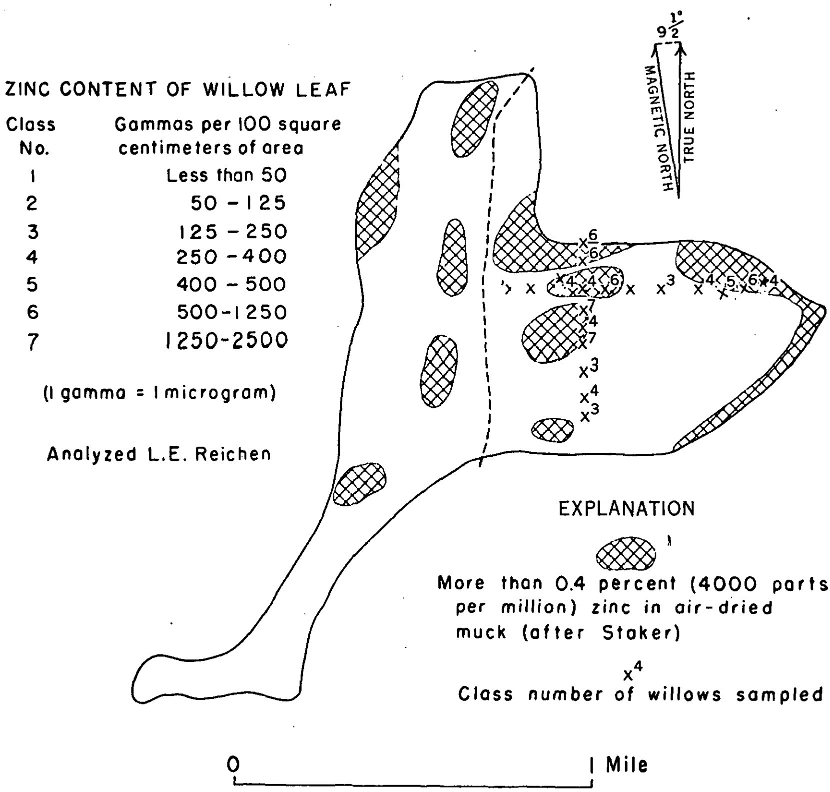

FIGURE 20.—Diagram comparing the zinc content of willow leaves with that of the soil on the Manning Muck.

tive analyses of willow and nettle made in the Washington laboratory are given in table 7. The zinc content of the willows is larger than that of the nettles. This is due in part to the fact that the nettles are rooted in near-surface soils and the willow roots reach the water table. Both plants contain more zinc in areas of higher metal content.

TABLE 7.—*Zinc content of nettles and willows from the Manning Muck, in parts per million, dry weight*

[Laura Reichen, analyst]

Nettle [1]	*Willow* [1]	*Remarks*
70	270	
80	370	Surface soil contains 100 ppm of zinc.
130	470	
140	950	
140	900	
180	900	
200	1,100	Willow rooted in drainage ditch.
280	780	
400	870	
570	930	
1,400	2,400	Soil contains 2.6 percent of zinc at surface, 5.2 percent at 2-foot depth.

[1] Willow and nettle collected from the same locality.

Several other plants were tested in traverse sampling. Sumac and goldenrod proved to be unsatisfactory for field testing because the variations in zinc content were not consistent with those of the soil. Aspens were found to be satisfactory absorbers and were used in a traverse sampling to discover two mineralized zones in the underlying rocks. The first anomaly was in aspens rooted in till and the second in aspens rooted in undrained swamp muck; the zinc in both plant samples was about 400 ppm. The lowest zinc content in aspens on this traverse was 70 ppm.

Results of plant sampling indicate that plants growing on soils of high metal content absorb large quantities of zinc and lesser quantities of lead, but that lead may be a more useful element in prospecting for lead-zinc deposits than zinc. Discrepancies in absorption of zinc may be due either to differences in the base exchange capacity or pH of the soil, or to solution and migration of zinc from its place of origin. Results of botanical prospecting for zinc have been published by Warren and Howatson (1947), Warren and Delavault (1948), White (1950), and Webb and Millman (1951). Warren has found the zinc content of accumulator plants to be consistently higher near known zinc deposits and has based a method of botanical prospecting on this fact. Webb has found lead and silver to be preferred tracer elements in prospecting for zinc deposits by spectographic methods.

GEOCHEMICAL STUDIES IN THE TILL-COVERED AREA SURROUNDING THE PEAT BOGS

TILL AND RESIDUAL SOILS

After preliminary sampling of the muck soils had established the relation of the zinc in the muck to the sphalerite in the underlying dolomites, about 50 samples of the till were taken throughout the area, wherever comparable samples could be obtained of well-drained till at about the same depth of weathering. The localities at which samples were collected and the zinc and lead contents of the sample are shown in plate 2. Their relation to the probable outcrop of mineralized zones in the dolomite is also shown. This relation can be seen most clearly from the cross section *C–C′*. Four zones of stratigraphic significance have been designated by number for ease of reference. Zone 1 is in the lower part of the dolomite series. The position of zinc-bearing soils and muck directly above mineralized zone 4 in the dolomite suggests that the large amounts of zinc present in the bog are of local origin.

The zinc content of the till is greater in low areas near the groundwater table than in well-drained soils of higher altitudes. Lead, however, remains close to the original source, and averages 10 to 50 ppm in the till over unmineralized rock, and 50 to 150 ppm in the till close to mineralized outcrops. Also the mineralized till is not offset in the direction of glacial movement from the host rock. This suggests that either the till has not moved far from point of origin or there has been a migration of metals from bedrock into the till since the till was deposited. Therefore the analysis of till for lead can be an important tool in prospecting for mineralized areas of underlying dolomite.

SURFACE WATER

Surface water samples were collected from Clarendon west to Shelby (pl. 1) and were analyzed for heavy-metal content. The average content is 0.005 ppm of heavy metals where the streams are not in actual contact with the Lockport dolomite but are flowing over glacial till. Where a stream flows over mineralized dolomite or through ditched and aerated zinc-bearing muck lands, the zinc content of the stream may be several parts per million.

The largest drainage system in the area is that of Oak Orchard Creek. The source of the main branch of this stream is a small undrained bog just north of the Manning Muck. At this bog the stream gave a negative test for heavy metals. Flowing south across the Lockport dolomite, it crosses zone 2 (pl. 2) at least twice and picks up 0.06 ppm of heavy metals. The creek then flows across the Manning Muck where it receives water from drainage ditches. The water in these ditches tested as high as 7 ppm, although the main stream leaves the artificial drainage system of the muck carrying only 0.5 ppm. As the stream flows south from the Manning Muck to the Big Muck the content is lowered by dilution to 0.35 ppm, but it is raised to 0.61 ppm in the northwest corner of the Big Muck, where the stream crosses another zinc-rich area. From this point on throughout the stream's meandering 12-mile course westward through the Oak Orchard swamps, the heavy-metal content decreases to 0.1 ppm. During the 6-mile northward course where it recrosses the Lockport dolomite, its content of heavy metals is constant at 0.08 ppm.

WELL WATERS

Ninety-five water wells have been tested in the Manning area for heavy-metal content (pl. 3). Samples from 30 of these wells were taken in 1946 and specifically analyzed for zinc by the standard laboratory dithizone method. In 1947, 16 of these wells and 14 other wells were tested by the Huff (1948) field test for total heavy metals. The amount of copper and lead present in the total heavy metals extracted from the water was very low and for all practical purposes the heavy-metal content was a measure of the zinc in the water.

According to Sergeev (1941), primary lead minerals in the soil normally weather to insoluble carbonates without going through a water-soluble stage. In 1 of the 3 waters tested specifically for lead, however, the water contained 0.2 ppm lead and 8.6 ppm zinc; the amount of lead is roughly one-fortieth of the total amount of zinc. In the other samples tested, the lead content is below the range of sensitivity of the test. In 3 well waters analyzed specifically for copper, none was detected.

Unless the water is completely saturated, the zinc content is greater if the water passes through metal pipes before it is sampled than if it is taken directly from the well. The amount of zinc dissolved from pipes and fittings varies with the degree of saturation of the water, the pH, and the length of time water is allowed to stand in pipes; contamination was reduced to a minimum by collecting water samples at the well head whenever possible or by pumping for several minutes before taking the sample.

The results of this well-water study show that the zinc content of the ground water depends upon the type of rocks through which the ground water flows (pl. 3). Those wells that bottom in the Lockport dolomite contain more zinc than those that bottom in the Rochester shale or in older formations to the east of the Clarendon fault scarp. None of the latter wells contains more than 0.5 ppm of zinc. Shallow wells that bottom in till also contain very little zinc, and because they have no bearing upon the relation of zinc-bearing well waters to Lockport dolomite, they have been omitted from the illustrations.

Plate 3 and figure 21 indicate considerable variation of the zinc content within the Lockport dolomite. Figure 21 is a profile and graph of the wells along the east-west Manning road. Two areas of high content are shown on the graph, the larger being at Manning crossroads. The zinc content of the well water bears an apparent relation to the depth of the well. Because the wells are commonly cased to within 5 feet of the bottom, the source bed can be determined by plotting well depths on a stratigraphic cross section. Thus, zone 2 is the source bed responsible for the higher zinc content in some of the wells. Additional correlations are suggested by a study of a projection plane perpendicular to the strike of the beds. Zones of high zinc content correlate with the zinc-rich areas of the various mucks when they are projected to the surface and their lines of outcrop are traced on a topographic map of the area, as shown in plate 2. This apparent correlation of the well-water data with the distribution of zinc and lead in the till, peat bogs, and outcrops of dolomite has subsequently been proved by a study of 10 holes drilled in the area for geologic information.

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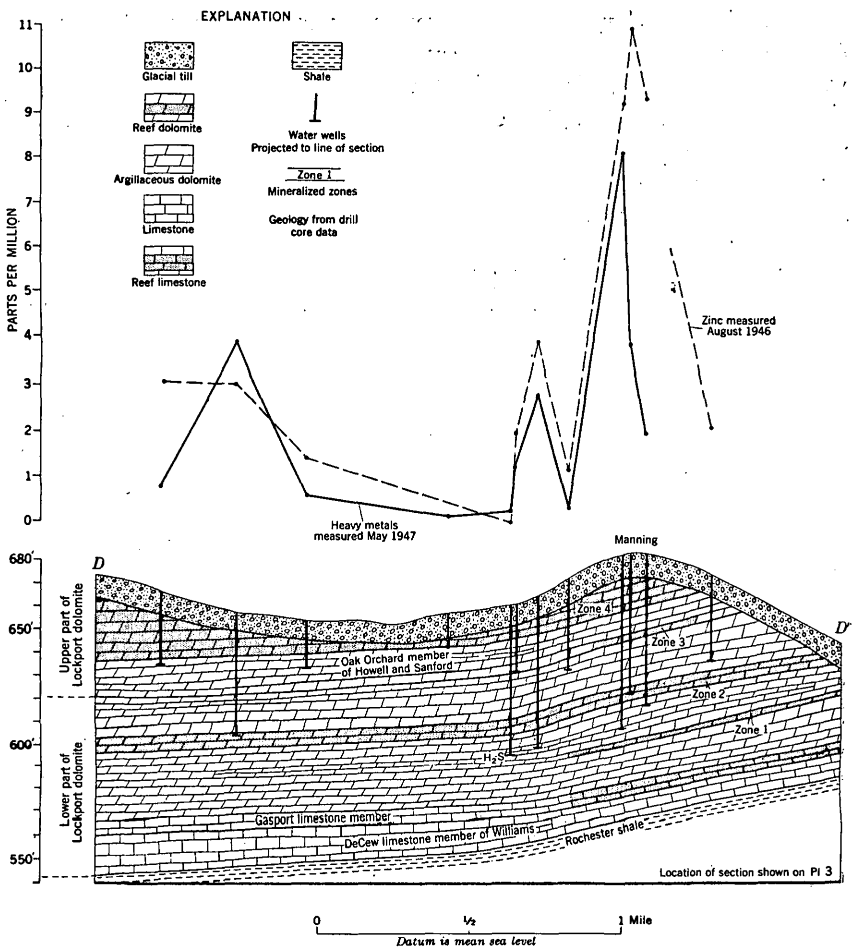


FIGURE 21.—Profile section along the east-west Manning road, with graph of approximate heavy-metal content of well waters.

STRATIGRAPHY

Stratigraphic studies in Orleans County made as a part of this investigation have been confined to the upper and lower parts of the Lockport dolomite of Niagaran age. Surface studies of the dolomite where it is exposed through the till cover along stream channels and in quarries have been augmented by a study of core from 19 holes drilled for geologic information. The locations of these holes are shown in plate 1.

The Lockport in New York State has been described at several positions along the strike. The Niagara Falls section was described by Grabau in 1901 and the Shelby section with its Guelph fossils in 1902 by Clarke, Ruedemann, and Luther, and in 1903 by Clarke and Ruedemann. Chadwick in 1917 studied the Lockport in Rochester during

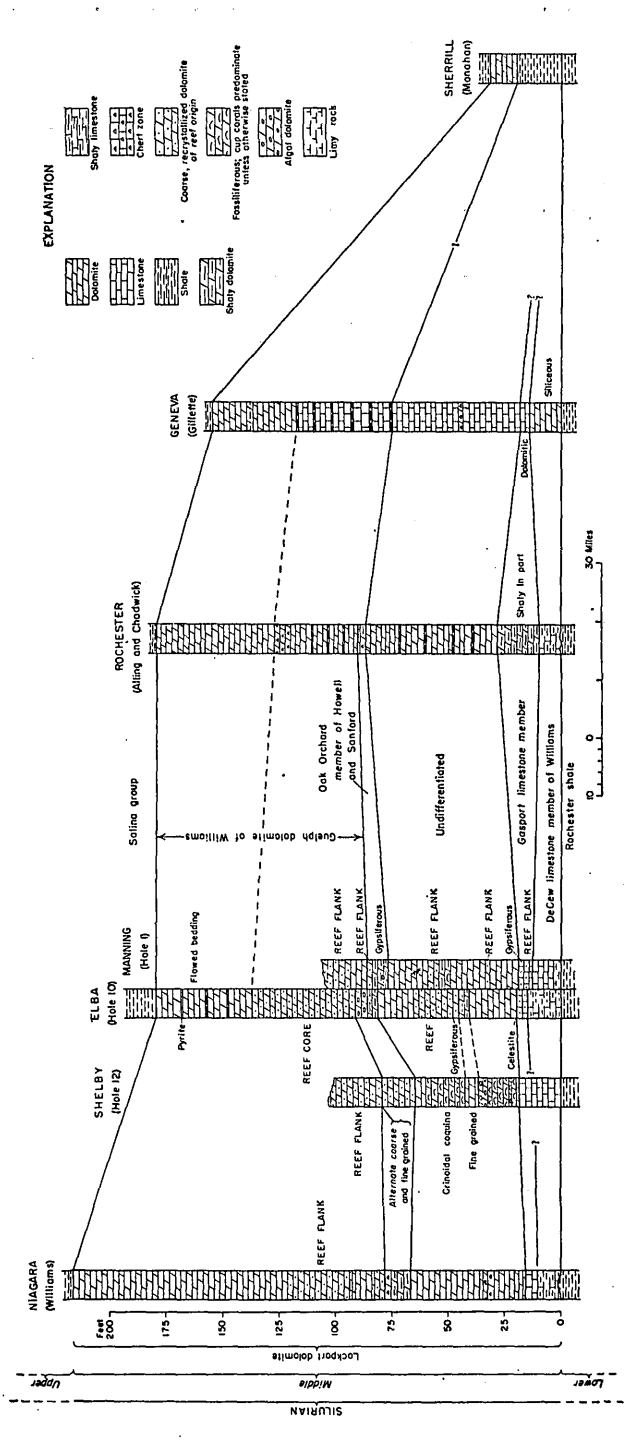


FIGURE 22.—Generalized section of Lockport dolomite across New York State.

the building of the barge canal and agreed with Williams of Ontario that the Eramosa and Guelph equivalents were present. A description of the complete section was not published until 1946 by Alling. Gillette published in 1940 on the Lockport in the Clyde and Sodas Bay quadrangles and described a core from the Geneva area. Sections in eastern New York are described by Monahan (1928). These sections and all other information available have been studied carefully and compared in detail with the dolomites of Orleans County. A stratigraphic section across New York State is shown in figure 22.

The Guelph dolomite of Williams has been found to be equivalent to the upper part of the Lockport dolomite in New York State. There is a recognizable break in the dolomite sequence in the Lockport in New York State that can be correlated with the transitional Eramosa member of Williams. Although litho-facies and consequently the fauna change laterally from Canada to United States, the upper and lower parts of the sequence are mappable units having a distinct time break represented by the Eramosa member of Williams. Detailed studies of this unit suggest a period of reworking and solution of the lower dolomite with an unusual concentration of metals by residual enrichment. Furthermore, in two holes which cut through thicknesses of reef core or centers of reef activity, the reef material extends up from the base of the transition member into the upper part of the Lockport dolomite. For these reasons I have used the name of Oak Orchard member of Howell and Sanford (1947) as the lower unit of the upper part of the Lockport (Guelph of Williams) rather than Eramosa member of Williams (1919) and Chadwick (1917, p. 172) as the upper unit of the lower part of the Lockport.

The lower 30 feet of Lockport dolomite and the underlying Rochester shale, also belonging to the Niagara series, are well exposed just south of the town of Clarendon. Occasional outcrops and drill-core data provide information on the remaining part of the section. Specific zones in the dolomites may be recognized and correlated with those of the Oak Orchard Creek and Niagara Gorge sections to the west and with the Rochester section to the east. A section compiled from outcrop study in the Manning area follows:

Composite section of the upper and lower parts of the Lockport dolomite exposed near Manning, Orleans County, N. Y.

	Thickness (feet)	*Zinc (ppm)*	*Outcrop locality*
Upper part of Lockport dolomite:			
Guelph dolomite of Williams:			
Eroded.			
Zone 4; reef flank bed; dolomite, dark-brown, porous, coarse-grained, containing gypsum and stylolites. Scattered crystals of sphalerite.	4	----	In fields south of Manning; in pastures north of Big Muck.

Composite section of the upper and lower parts of the Lockport dolomite exposed near Manning, Orleans County, N. Y.—Continued

	Thickness (feet)	*Zinc (ppm)*	*Outcrop locality*
Upper part of Lockport dolomite—Con.			
Oak Orchard member of Howell and Sanford (1947):			
Dolomite, dark-gray, fine-grained, containing occasional carbonaceous partings and scattered fossils. *Favosites*.	9	-----	Manning road ditch.
Zone 3; dolomite of reef material, dark-gray, coarsely crystalline, containing many stylolites, sand pockets, and fossils. Siliceous coating on algae. Fluorite, sphalerite, and celestite. Galena in white algal masses.	4	-----	Shepherd farm.
Lower part of Lockport dolomite:			
Undifferentiated beds:			
Dolomite of fossil fragments, fine, carbonaceous.	4	-----	Do.
Dolomite, dark-gray, fine-grained, containing scattered fossils.	21	-----	Inlet stream at north end of Manning Muck.
Zone 2; reef flank bed; dolomite of reef sand, porous, bituminous, recrystallized, brown, containing gypsum, algal material, and *Halysites* corals. Surface blocks pitted with cavities. Sphalerite sparse.	8	-----	Northeast of Manning crossroads.
Clastic sediments, fossiliferous, thin-bedded, argillaceous. Zinc and lead sulfides occurring as groups of crystals in fine groundmass of one thin bed.	2	-----	Do.
Silty beds, gray, thin, 3 to 5 inches thick, which weather to brown. Shale partings and stylolites. Sphalerite in white patches of dolomite.	19	-----	Stream ditch south of Albion.
Zone 1; dolomite, thin-bedded argillaceous with lead sulfide and zinc sulfide in carbonaceous layer near top. Galena in poikiloblastic crystals.	5	-----	Clarendon quarry.
Clastic dolomite, containing sphalerite in siliceous nodules of algal origin. Contains a patch reef of *Halysites* corals, crinoids, algae, etc.	3	-----	Clarendon quarry and stream south of Albion.
Dolomite, laminated, argillaceous, 1 to 4 inches thick, containing dolomite pebbles and a little white chert in fillings and lenses.	4	106	Clarendon quarry.
Gasport limestone member:			
Limestone, dolomitic, reef flank bed, massive, coarse-grained, light-colored; forms ledge containing a small patch reef of corals, algae, *Stromatopora*, and crinoids.	5	53	Do.
DeCew limestone member of Williams (1914):			
Dolomite, medium-grained, porous, argillaceous, in 2- to 6-inch beds, with abundant stylolites. Sphalerite filling coral structure.	3	104	Do.
Same lithology as preceding bed------	2.6	52	Do.

Composite section of the upper and lower parts of the Lockport dolomite exposed near Manning, Orleans County, N. Y.—Continued

	Thickness (feet)	*Zinc (ppm)*	*Outcrop locality*
Lower part of Lockport dolomite—Con.			
DeCew limestone member of Williams (1914)—Continued			
Dolomite, dark-gray, of reef detritus, with shaly partings, channeling, and crossbedding. Fine banding on weathered surface.	3. 4	7	Clarendon quarry.
Organic dolomite or dolomitic shale, gray, fissile, with wavy seams of organic material.	1. 9	7	Do.
Reef detritus, recrystallized and secondary white dolomite in single bed.	. 5	10. 2	Do.
Dolomite, organic, containing irregular shaly seams and fissile partings.	. 5	10. 2	Do.
Dolomite, fine-grained, laminated, crystalline, interbedded with dark impure dolomite in 1- to 4-inch beds. Laminar deposits fill shallow channels in the dolomite.	1. 5	8. 4	Do.
Clinton group:			
Rochester shale:			
Shale, fissile	. 5	30	Do.
Dolomite, impure, in single massive bed; rounded grains. Irregular wavy markings on the weathered surface.	1. 5	50	Do.
Dolomite, fine-grained, laminated, argillaceous, in 2- to 3-inch beds. Bryozoa abundant.	1. 5	5	Do.
Covered	. 5		
Dolomite, fine, sugary, brown, in irregular beds with dolomite grains rounded even on fresh fracture.	5	14	Do.
Dolomite of cemented rounded grains having shale partings and contemporaneous slump structures. Crossbedding in top bed.	5	27	Do.

LOWER PART OF THE LOCKPORT DOLOMITE

The lower part of the Lockport dolomite is made up of gray, argillaceous, thin-bedded, dolomitic beds. They are typically even-bedded, commonly laminated, and contain macerated fossil debris and small patch reefs (Cloud, 1952, p. 2,127) of algal and coral material. The series is difficult to separate into recognizable units and remains largely undifferentiated. The contact of the Lockport dolomite with the underlying Rochester shale is gradational and in most places difficult to distinguish. General descriptions of the units follow.

DECEW LIMESTONE MEMBER OF WILLIAMS (1914)

The Lockport dolomite overlies the Rochester shale, and the lowermost member, or Williams' DeCew limestone member of the Lockport, contains a considerable amount of reworked Rochester shale. The bed represents a period of quiescence during which considerable solution and reworking took place. Spectrographic analyses show the content of potasium, boron, barium, zirconium, gallium, chromium, copper, titanium, yttrium, ytterbium, and lead to be above that of average dolomite in the series. This enrichment in rare earths is particularly significant. According to Rankama (1949, p. 528), "Yttrium is notably concentrated in the insoluble residues formed during the solution of limestones and calcareous shells of marine organisms." Yttrium is also concentrated in the reworked bed at the base of the upper part of the Lockport dolomite.

A fine exposure of Williams' DeCew limestone member can be studied in the Clarendon quarry directly south of Clarendon. In the Manning area the beds are thin-bedded, argillaceous, and dolomitic. The DeCew limestone member of Williams is also exposed south of Shelby in Oak Orchard Creek which is 10 miles west of the area, and in Niagara Gorge.

GASPORT LIMESTONE MEMBER

Williams' DeCew limestone member is overlain in many places in western New York State by a porous buff limestone or dolomite of crinoidal reef detritus, called the Crinoidal of local usage or Gasport limestone member of the Lockport. In the Clarendon quarry the member is represented by a massive 5-foot bed of uniform, light-colored, limestone composed of reef sand. This bed was also observed in core from drill holes Nos. 1–3 and 5 several miles west of the quarry. Its position in the section is marked in many cores by the presence of abundant gypsum. Copper, zinc, and strontium are concentrated in this reef detrital bed. The Gasport could not be recognized in the holes drilled to the south but the position in the section is occupied by beds similar to the DeCew limestone member of Williams in lithology and similarly enriched in potassium, barium, boron, iron, titanium, chromium, copper, gallium, and sodium.

UNDIFFERENTIATED BEDS

The next 60 feet of the lower Lockport dolomite remains undifferentiated in the literature. In general the dolomite is even-bedded, dense, fine-grained, and argillaceous. Ten to 12 feet above the Gasport limestone member, crystals of sphalerite are found in thin gray clastic dolomites, and galena occurs as poikiloblastic crystals and fossil replacements in the rock. These shaley beds, designated as zone 1, are represented by a porous zone in drill hole 1 and can be recognized by sulfide content in several holes. At the same horizon, near Shelby, 10 miles west of Manning, 13 feet of zinc-bearing clastic sediments overlain by an algal zone can be traced in outcrop and drill core for more than a mile. In outcrop sphalerite is concentrated in the porous algal masses which underlie and are responsible for the toxicity of the Shelby Muck. In drill hole 12 (shown on pl. 1), 1½ miles south of the Shelby outcrop, an unexpected 18 feet of crinoidal coquina was found above the algal material.

A characteristic feature of deposition throughout the Lockport dolomite in this area and one that can be used locally for correlation purposes is the contact of clastic beds of macerated small fossil debris, enriched in lead and other heavy metals, with an overlying, porous, light-colored bed of completely recrystallized dolomitic reef sand containing large *Stromatopora*, algae, and corals. The latter commonly contains concentrations of gypsum, zinc, strontium, and barium compounds. Lowenstam's work on the reefs of Niagaran age (1950, p. 461) suggests that the contact may be that of the quiet-water, inter-reef bottom muds with wave-controlled beds of reef outwash. The recurrence of this depositional feature suggests reef building under turbulent conditions with the surrounding bottoms below effective wave base.

In the Manning area, such a fossiliferous clastic layer containing sulfides is identifiable in seven of the drill holes. The dense argillaceous dolomite appears to be more resistant to glacial erosion than the overlying porous recrystallized reef-sand dolomite and, therefore, forms a continuous land surface across much of the area north of Manning. The overlying bed of porous reef rock, designated zone 2 for correlation purposes, is the most persistent marker in the lower part of the Lockport and is identifiable in all holes drilled in the Manning area. The bed contains considerable gypsum. In outcrop, 4-foot blocks of this material, broken up originally by glacial action, are a prominent feature of the landscape. *Halysites* is the predominant fossil. The bed thickens greatly within 1½ miles to the west (see cross section of fig. 21) and also to the south as shown in plate 2. In drill hole 6, 11 feet of reef material was penetrated. In drill hole 10, near Elba, the bed attains a thickness of 20 feet.

The remaining part of the lower part of the Lockport dolomite, as exposed in both areas, consists of gray, compact dolomitic beds.

UPPER PART OF THE LOCKPORT DOLOMITE

OAK ORCHARD MEMBER OF HOWELL AND SANFORD (1947)

A change in lithology marks the contact between the dolomites of the lower and upper parts of the Lockport in western New York. The transitional beds, called the Eramosa member by M. Y. Williams (1919, p. 105–114) and Oak Orchard member by Howell and Sanford (1947), are recognizable in the base of the upper part of the Lockport although the lithology is variable. The clastic beds were formed during a period of reworking and probably solution and appear to have formed the muddy unconsolidated substratum for widespread reef building in late Lockport time. Mineralized beds formed in a restricted environment are exposed along Oak Orchard Creek. Here the Oak Orchard member of Howell and Sanford is 12 feet thick and at the base includes 4 feet of argillaceous dolomites that contain white chert nodules, sphalerite, galena, and a considerable amount of iron, weathered reddish on exposure. Spectrographic analyses show these beds to be enriched in a large suite of heavy metals. Delicate fossils of the Guelph type have been described from the chert nodules of these beds by Clarke and Ruedemann (1903). Cup corals and other fossils are partially dissolved and commonly coated with cryptocrystalline quartz and with galena which also forms poikiloblastic crystals in the country rock.

Depositional features indicate a restricted humid environment as described by Krumbein and Garrels (1952). A partial stagnation of the bottom, a pH of 7, and a negative oxidation potential are characteristic of such an environment. Hydrogen sulfide and sulfur are present, and the calcium carbonate is converted to bicarbonate and carbonic acid. Ferrous iron and sulfides are precipitated. Deposits of similar environment in the Niagara series at the contact of reef flank and interreef bottoms have been described by Lowenstam (1950, p. 461).

Along Oak Orchard Creek, the beds described are separated from the overlying typical, coarsely crystalline reef rock by 5 feet of dense, fine-grained argillaceous dolomite. This dolomite is also present in the core near Manning crossroads but is absent in core from drill holes 6 and 10. In both of these holes, a thickness of reef core is present in Howell and Sanford's Oak Orchard member and is continuous directly upward into the beds of the upper part of the Lockport dolomite or Guelph equivalent. The changes in lateral facies from reef core in hole 6 to reef flank beds in holes 1 and 7 are shown in figure 23. The presence of *Cladopora* coral beds in reef core sections and the restriction of crinoid debris to flank beds are particularly significant. Similar flank beds of crinoidal debris in Niagaran dolomites are described by Lowenstam (1950, p. 456). Galena and sphalerite are present in core from hole 10 from the Oak Orchard member of Howell and Sanford. Uncommon amounts of galena in the same bed are exposed south of the Manning Muck where the mineral is associated with a cryptozoan algal flora. This occurrence is described later.

An excellent section of a patch reef in the transitional member is exposed in the Penfield quarry 10 miles east of Rochester. The patch reef is 5 to 6 feet thick and is composed of large masses of algal material containing sand pockets, recrystallized dolomite, calcite, and a considerable amount of sphalerite, all imbedded in blackish impure dolomite. The bed can be traced across the quarry.

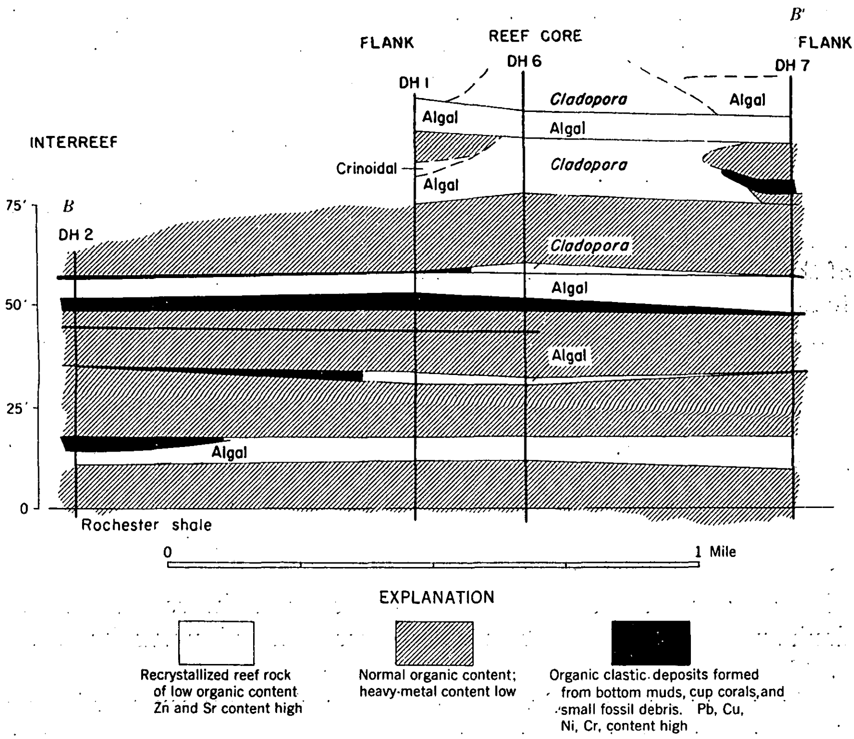


FIGURE 23.—Sketch of lateral reef and faunal changes in Lockport dolomite of the Manning area.

GUELPH DOLOMITE OF WILLIAMS

The dolomite beds of the upper part of the Lockport dolomite (Guelph of Williams) are in general highly recrystallized and bituminous with less argillaceous material than the lower part of the Lockport dolomite. This indicates a period of warmer seas and increased reef building. Toward the end of late Lockport time, the seas became shallow and saline, reef building ceased, and gypsum was precipitated in considerable quantity.

The porous brown dolomite of zone 4 forms the bedrock surface under the till and muck from the crossroads at Manning south to the Big Muck (see pl. 2). Forty-seven feet of such material has been measured in drill hole 10, near Elba. This thickness of porous reef rock, with obscured bedding, contains considerable sphalerite and celestite and is probably reef core. At this locality Howell and Sanford's Oak Orchard member is a 10-foot bed composed of organic detritus which contains an appreciable amount of galena and other heavy metals. A section of reef core was also found in drill hole 6 where it extends upward from the base of the transitional member into the upper part of the Lockport dolomite (fig. 23).

The upper beds of the Lockport dolomite or Guelph equivalent are dense, argillaceous, and calcareous and grade conformably into the gypsiferous shale beds of the lower part of the Salina group. A thickness of 91 feet of the lower part of the Lockport dolomite and 90 feet of the upper part of the Lockport dolomite was measured in drill hole 10, near Elba; the hole was started in beds of the Salina group. Logs of the 17 holes, compiled by Robert Stewart and the author, are given in the appendix.

FAUNAL CORRELATIONS

It should be emphasized that the correlation of the beds just discussed has been made purely on the basis of lithology and mineralogy. The various units and zones of the dolomite sequence can be traced from Canada into New York State and found in their proper sequence in the outcrops and drill cores in Orleans County. The well known "Lockport" and "Guelph" faunas, however, cannot be shown to be restricted to the lower and upper parts of the sequence, respectively, but their presence is probably due to facies changes which recur at intervals throughout the upper part of the sequence.

Fossil forms belonging to the Guelph fauna of Ontario, Canada, were first found in New York State by A. L. Arey (1892) in the Nellis quarry in Rochester. These were finely preserved fossils occurring in siliceous nodules. Later Clarke and Ruedemann (1903, p. 12) described the same forms preserved in similar nodules at Shelby. Because these forms occur at two horizons separated by rocks carrying only the fossils of the Lockport fauna, Clarke and Reudemann concluded that the forms represented two periods of transgression by a northern sea. They named these units the "Upper and Lower Shelby dolomite." Remeasurement of this section by the present writer and review of Clarke's original field notes (Clarke, Ruedemann, and Luther, 1902) make it apparent that a 4-foot covered interval between Clark and Ruedemann's upper and lower Shelby dolomite was inadvertently exaggerated by 20 feet through a typographical error. The two units are found only 12 feet apart, rather than 32 feet.

Nomenclature was further complicated by the publication of a paper by Howell and Sanford (1947) on the trilobites from the Shelby beds at Rochester. The specimens were collected many years ago by Clifton J. Sarle. Howell and Sanford have shown that the name Shelby had been used before, and they proposed to substitute for the upper Shelby the name Oak Orchard member, which member they placed above William's Eramosa member of the Lockport as equivalent to the lower Guelph. Because both Shelby zones are probably in the base of the upper part of the Lockport (or Guelph of Williams), it would seem appropriate to drop the names upper and lower Shelby and to use Howells and Sanford's Oak Orchard member as the basal unit of the upper part of the Lockport dolomite.

It should be emphasized that the upper and lower parts of the Lockport dolomite in New York State are characterized by recurrent beds, composed of outwash from crumbling reefs, that occur at fairly regular intervals in the section and that seemingly can be traced over considerable distances. From the author's stratigraphic studies, it seems likely that the Guelph and Lockport faunas are not separate faunas developed in entirely different seas but represent different facies of the same period of deposition. The Guelph fauna consists of two types of forms: the heavy frame-building stromatoporoids, corals, mollusks, and calcareous algae; and the delicate fine forms that lived in protected areas of the reef. The Lockport fauna consists of the life common to the interreef parts of the sea floor. Work recently published by Lowenstam (1948a, 1948b, 1949, 1950) and by Cumings and Shrock (1928, p. 140) on the Niagara series in the interior province west of the Cincinnati arch describes similar changes of facies.

METALS IN SEDIMENTS

Both geochemical and geological data indicate a lithologic and mineralogic zoning that can be used for correlation purposes in the Lockport dolomite. Disseminated crystals of sphalerite and galena occur in the dolomite from Sherrill, N. Y., to Ontario, Canada, but are concentrated, along with increased amounts of chromium, nickel, copper, yttrium and iron, at particular breaks or changes. These concentrations probably result from diagenetic solution and selective preservation during periods of little or no deposition. Zinc and strontium are also concentrated in recrystallized beds of reef flank material.

Occurrences of sphalerite and galena in outcrop and drill core and the relation of metals to specific zones in the Lockport dolomite are described.

OCCURRENCES OF LEAD AND ZINC IN THE LOCKPORT DOLOMITE

Occurrences of sphalerite and galena in Orleans County have never been reported although both sulfides have been described from the Lockport dolomite in several other counties of New York State. Several mineral localities in the upper and lower parts of the Lockport dolomite in and around Rochester have long been known to mineral collectors and are frequently reported in the literature (Jensen, 1942; Beck, 1842, p. 47; Merrill, 1904, p. 186; and Giles, 1920). Sphalerite has also been reported near Sherrill, Rome, Vernon, and Clinton, (Monahan, 1928) in eastern New York. To the west, sphalerite and galena have been observed at several horizons at Shelby, Lockport, and Niagara Falls (Grabau, 1901, p. 109) and two deposits have actually been mined in Ontario and Iowa. In Wiarton, Ontario, an open cut in the basal Guelph dolomite (equivalent to upper part of the Lockport dolomite in New York State) was worked for several years beginning in 1910, resulting in the shipment of a carload of ore (Williams, 1919, p. 102). A single pocket where the sphalerite has been reconcentrated by ground water in solution cavities of a former cephalopod assemblage yielded 110 pounds of zinc ore. Several tons of lead were also mined from rocks of Niagaran age in Iowa in the early days, according to Calvin (1895, p. 110). He reports that dolomites of Niagaran age in Iowa are all lead-bearing to a certain extent. Sphalerite is known to occur in the same sequence of rocks in Wisconsin and Illinois and has been reported from the limestones of Niagaran age in Ohio (Stout, 1941, and Rogers, 1936, p. 93).

In the Lockport dolomite of Orleans County the abundance of lead and zinc minerals varies with changes in the lithology of the dolomite. Three dolomitic facies were described by Chamberlain (1877, p. 368) and later by Cumings and Shrock (1928, p. 140–145), from the Niagaran series: 1. a compact, fine-grained, thin-bedded dolomite deposited as calcareous mud in quiet, deep water; 2. an irregular, brecciated, conglomeratic dolomite, forming obscurely stratified masses which probably represent reef core; and 3. a pure, porous dolomite of calcareous sand rock derived from reefs by wave action. Chamberlain states that the three facies intertongue and grade into each other laterally, features which indicate contemporaneous deposition. Each facies is recognized in the Lockport dolomite of New York State and contains a distinctive heavy-metal suite. In the first type of dolomite, sphalerite, galena, pyrite, and other sulfides occur as small crystals along stylolitic seams in the dolomite, in poikiloblastic crystals enclosing rhombic grains of dolomite, and as fillings in cup corals or other small fossils. The sulfides are abundant at specific horizons in the section and can be traced along the strike for considerable distances. In the second type of dolomite gypsum, zinc, strontium, lead, and barium compounds are concentrated in small patch reefs. In the third type, flank beds of reef sand, the same minerals are associated with isolated algae, *Stromatopora*, and corals. In the drill core studied, heavy-metal contents are commonly high in a recurring zone of reworked, partially dissolved, clastic dolomite of the first type immediately underlying a thickness of porous reef sand rock.

LOWER PART OF THE LOCKPORT DOLOMITE

BASAL BEDS

Twenty-two feet of Lockport dolomite and 9 feet of Rochester shale were studied in detail in the Clarendon quarry. Fourteen channel samples were cut in the face of the quarry and analyzed for zinc.

The zinc content ranges from 5 to 106 ppm and appears to be highest at or immediately above a minor break or unconformity in the sedimentation. Sphalerite could be identified by hand lens in beds where the channel samples contained 104 ppm and 106 ppm zinc. The sphalerite occurred in siliceous nodules of organic origin characterized by a boxwork on the weathered surface.

Core from holes 2 and 10 drilled through the lower Lockport were spectrographed and analyzed chemically for lead and zinc. The lower beds of the DeCew limestone member of Williams contained unusual concentrations of lead, barium, boron, zirconium, gallium, chromium, copper, titanium, yttrium and ytterbium in a reworked clastic host rock. The overlying reef flank bed of the Gasport limestone member was present in hole 2 and contained 350 ppm of zinc, and was enriched in copper, strontium, and barium.

ZONE 1

Later stripping in the Clarendon quarry exposed both sphalerite and galena in a clastic bed 25 feet above the base of the Lockport. The galena occurred as poikiloblastic crystals in the rock. The bed is called zone 1 of this report. It is also exposed in a drainage ditch south of Albion, which carries water from an undrained bog into the West Branch of Sandy Creek. Sphalerite in this zone was observed in the core from several of the Manning holes, and sphalerite and galena were observed at the same position in the section in Niagara Gorge, at Lockport, and in the section exposed along Oak Orchard Creek near Shelby, 10 miles west of Manning. One-half mile west of the Oak Orchard Creek occurrence, an algal reef rock overlies the sulfide-bearing clastic beds and crops out under a zinc-bearing peat. Considerable amounts of sphalerite are associated with the calcareous algae which are imbedded in a compact subcrystalline rock. The algal masses show as white patches and are completely silicified; the outcrop of this reef can be traced over a considerable area. Two holes (nos. 11 and 12) intersect this zinc-bearing bed along Oak Orchard Creek half a mile east of the outcrop. In hole 11, the bed was 13 feet thick, fine-grained, fossiliferous, and contained an estimated 0.1 percent zinc and a small amount of lead. Less than 3 feet of a similar rock was found a mile to the south, and a 1-foot sample of the core assayed 0.45 percent zinc and contained unusual amounts of copper, nickel, and iron. In both holes the mineralized bed was overlain by porous algal reef rock containing little or no sphalerite. The latter appears to correlate with the algal bed which crops out under the muck.

ZONE 2

A second mineralized zone can be traced throughout the Manning area in surface exposures and drill core. This zone is composed of a 4-foot bed of porous flank reef sand which is underlain by fine-grained, clastic dolomite. In outcrop sphalerite occurs in isolated crystals in the reef rock and as asteroid groups of crystals at definite horizons in the fine-grained clastics. Galena crystals are visible in two of the cores at the same horizon, and analysis showed the clastic beds to be enriched also in chromium and copper.

On the Clarendon Muck, where zone 2 has been brought to the surface by faulting and crops out under the till and muck in an extensive area, a patch reef composed of large masses of *Stromatopora* and *Cladopora* coral is exposed. The *Cladopora* tubes are filled with dolomite, fluorite, and chalky quartz. Where overlain by peat soils, the rock has disintegrated either to a dolomitic sand or to porous, brown, soft dolomite in which the sphalerite crystals stand out.

UPPER PART OF THE LOCKPORT DOLOMITE

ZONE 3 (HOWELL AND SANFORD'S OAK ORCHARD MEMBER)

A fine example of sphalerite and galena in bedded deposits is exposed in Howell and Sanford's Oak Orchard member of the Lockport in the Oak Orchard Creek section at the stratigraphic position of zone 3. Here sphalerite crystals occur in a dark impure dolomite bed which is overlain by 4 feet of a similar dolomite which contains a concentration of galena. The galena occurs as poikiloblastic crystals disseminated in the rock, as fillings in small cup corals, and in silicified algal material. The galena-bearing beds contain a large amount of iron and turn red upon weathering. Six holes were drilled along Oak Orchard Creek to determine the lateral extent of the mineralized ground. Four feet of galena-bearing dolomite was penetrated in four holes and indicates an extension of the lead-bearing bed for a half mile in a north-south direction. Hole 12 drilled 1 mile south of this area penetrated a fossiliferous layer containing sphalerite but no galena. Analyses of samples from four holes are given in table 8. Sphalerite has been observed in the Niagara Gorge section in a corresponding zone, and a considerable concentration is present in an algal patch reef exposed in the Penfield quarry east of Rochester.

TABLE 8.—*Lead and zinc content of core through zone 3 in holes drilled near Shelby, N. Y.*

[H. Bloom, analyst]

Drill hole no.	*Depth (feet)*	*Thickness (feet)*	*Zinc (percent)*	*Lead (percent)*
13	20. 9—22. 4	1. 5	0. 021	0. 160
	22. 4—23. 3	. 9	. 0055	. 015
	23. 3—24. 5	1. 2	. 26	. 210
		3. 6	[1] 0. 0188	[1] 0. 1404
14	11. 0—11. 9	0. 9	0. 076	. 400
	11. 9—12. 8	. 9	. 0025	. 010
	12. 8—15. 0	2. 2	. 035	. 210
		4. 0	[1] 0. 0369	[1] 0. 208
15	8. 2— 9. 6	1. 4	0. 018	. 0575
	9. 6—11. 0	1. 4	. 004	. 050
	11. 0—12. 6	1. 6	. 0085	. 0625
	12. 6—14. 4	1. 8	. 055	. 17
		6. 2	[1] 0. 0231	[1] 0. 859
16	9. 8—10. 4	0. 6	0. 015	. 32
	10. 4—11. 9	1. 5	. 0025	. 01
	11. 9—13. 0	1. 1	. 016	. 05
	13. 0—14. 2	1. 2	. 0125	. 05
		4. 4	[1] 0. 0103	[1] 0. 034
		4. 55	0. 0221	0. 1109

[1] Weighted average.

The position of the Oak Orchard member of Howell and Sanford in the Manning section, as penetrated by hole 1, is marked by a vuggy, porous, sugary dolomite, which contains considerable amounts of gypsum, sphalerite, and galena. The bed is replaced by a dense layer of fossil fragments within a mile both south and west of Manning. A comparatively fresh exposure was found near a small patch of isolated muck lying midway between the Manning Muck and the Big Muck to the south (pl. 2). Here a drainage ditch, blasted into 3 feet of rock, exposed the mineralized zone. The country rock is dense, dark, and fine-grained; and the algal masses are almost pure white and have conspicuous concentric banding. J. Harlan Johnson (personal communication) places them in the cryptozoan group. These algal masses are closely associated with a considerable amount of galena that occurs both as poikiloblastic crystals in the rock and immediately surrounding the algae, and as replacements in the banded structure of the algae. Sphalerite is also present but is less closely associated than the galena with this particular algal form.

In the Elba drill hole, 10 miles south of Manning, the Oak Orchard member of Howell and Sanford consists of 8 feet of bituminous, medium-grained dolomite that contains silicified algae, sphalerite, and galena. The upper bed of nonmetalliferous, fine-grained dolomite which is persistent in the Manning area is absent in hole 10. The galena-bearing bed thus correlates with the lead-algal bed exposed in the drainage ditch just described near Manning. The analyses are given in table 9.

TABLE 9.—*Lead and zinc content of core in hole 10, penetrating zones 3 and 4, drilled 3.3 miles northeast of Elba*

[H. Bloom, analyst]

Description	*Depth (feet)*	*Thickness (feet)*	*Zinc (percent)*	*Lead (percent)*
Zone 4				
170.8–218.1 ft. Dark gray-brown, coarse-grained, porous, recrystallized dolomite. No bedding. Vugs of calcite, selenite, with zinc sulfide crystals	170.8–173.7	2.9	0.15	0.001
	176.6	2.9	.04	.001
	179.6	3.0	.0025	.001
	182.6	3.0	.042	.001
	185.6	3.0	.055	.001
	188.6	3.0	.042	.001
	191.5	2.9	.33	.001
	194.5	3.0	.002	.001
	197.5	3.0	.028	.001
	200.0	2.5	.003	.001
	203.3	3.3	.021	.001
	206.3	3.0	.12	.001
	209.3	3.0	.043	.001
	212.3	3.0	.009	.001
	216.3	4.0	.024	.001
	218.3	2.0	.037	.005
Zone 3				
218.1–225.7 ft. Dark-gray, medium to fine-grained dolomite, with black carbonaceous partings. Algae. Bituminous	218.3–221.3	3.0	.038	.001
	225.7	4.4	.2	.015
		54.9	[1] 0.0688	[1] 0.0022

[1] Weighted average.

ZONE 4 (EQUIVALENT TO GUELPH DOLOMITE OF WILLIAMS)

Zone 4 forms the rock surface under much of the till from Manning south to the Big Muck, as shown in plate 2. Zinc-rich zones in the porous dolomite, which is composed of reef core, recur at intervals of about 18 feet, but the lead content is low throughout the thickness. Variations in zinc content are shown in table 9. Although the zinc content of the individual zones is not great, the total amount of zinc becomes significant if the content of the zones can be considered to remain constant for any distance along the strike.

PETROGRAPHY

The petrography of the sulfide-bearing rocks is known only from study of a few thin and polished sections by John R. Cooper and R. S. Cannon. From their notes certain inferences may be drawn on the petrographic characteristics of fossil algae and dolomitic country rock, the relations of sulfides in the textural fabrics of these rocks, and the sequences of crystallization of the minerals.

Comparison of dark bituminous dolomite with white dolomitic algal material shows distinctive petrographic differences. Algal nodules that are well preserved consist of white, fine-grained, porous magnesio-dolomite having radial structure and concentric banding. The algal banding is brought out by variations in grain size and orientation of the radiating dolomite grains. Where algae are silicified, alternating bands are formed of clear mosaics of quartz and brownish bands of flamboyant chalcedony. The country rock is commonly dark dense dolomite, having a compact mosaic texture of equant sutured grains. In impure facies, euhedral rhombs of dolomite are embedded in a fine-grained matrix of clay minerals, silica, and carbonates.

A characteristic of the dolomitic country rock is the abundance of organic matter that appears as a pervasive brownish stain. Similarly, tiny crystals and aggregates of pyrite, generally less than 25 microns in diameter, are abundantly disseminated through the dolomite but are rarely found within the algae. Contacts between dolomitic rock and embedded algal nodules commonly are marked by stylolites. Sphalerite crystals are common, adjacent to stylolites in the dolomite, and in one thin section where the carbonaceous material of a stylolite splits and goes around both sides of a broken sphalerite crystal, the sphalerite evidently antedates the stylolite. At contacts free of stylolites, certain textural features were observed in several specimens. Along a typical contact the dolomite grains of the country rock have been enlarged 2 or 3 times normal size and protrude rhomb-shaped into the algal nodule. During the process of crystallization, the organic matter from this coarsened layer has been removed and concentrated in a band along its margin. The coarse dolomite crystals are euhedral against a contact filling of chalcedony, cryptocrystalline quartz, or sulfide, and in places against algal dolomite. It is noteworthy that the algal dolomite grains are not enlarged or euhedral against the contact silica minerals.

In certain specimens of reef material studied from zone 3, galena occurs along the algal contact and extends into the country rock in sharp-walled veinlets. In the veinlets the dolomite crystals have been enlarged and the galena is molded on the dolomite rhombs. Along the contact, galena is molded against euhedral dolomite of the country rock but is colloform and convex against chalcedony on the algal side. Sphalerite is molded against the dolomite grains but is euhedral against quartz and galena. Borders of many sphalerite crystals are poikilitic and contain small brown dolomite rhombs.

Conventional intepretation of these textural relations suggests that, first, dolomite crystals were enlarged in the sediments immediately surrounding algal masses; second, sphalerite and then galena, were crystallized; and, finally, the silica minerals, chalcedony and quartz, were formed. These relations do not establish whether the lead and zinc originated in the algal masses, in the bituminous dolomite, or were introduced from some other source. They do suggest, however, that the silica minerals, sulfides, and dolomite may have all crystallized during solution of the algal masses and possibly during the lithification of the sediments. The localizing of galena and sphalerite in and around algae in the reef rock facies implies that the algae, living or dead, may have effected sufficient change in the chemical environment to precipitate the lead and zinc.

ORIGIN OF SULFIDES IN THE DOLOMITE

Although an investigation of the origin of the sulfides was not a primary objective of this study, it is worth recording that certain features in the mode of occurrence and distribution of the lead, zinc, and other metals suggest that the metals may have been precipitated from sea water which contained uncommon amounts, possibly of volcanic origin. The metals are concentrated at periodic intervals throughout the sequence in clastic muddy-bottom sediments and in associated reef material. These metal-bearing beds or pairs of beds can be traced laterally for hundreds of miles. The abundance of elements in the mineralized and unmineralized parts of the Lockport dolomite are shown in table 10. Textural relations suggest that at least part of the sulfides crystallized early in the history of the rocks, possibly even during diagenesis of the carbonate muds. Furthermore, although there is evidence of post-Silurian structural adjustments in the area, no specific relation of metals to these faults could be detected nor is there any specific evidence that these metals were introduced at a later date. Therefore, it seems pertinent to review the conditions under which these metals could be precipitated in unconsolidated sediments.

TABLE 10.—*Abundance of elements in mineralized and unmineralized parts of Lockport dolomite from drill hole 10, in parts per million*

[Amounts determined by semiquantitative spectrographic analyses by A. T. Meyers and P. J. Duncan except as noted]

Elements in order of relative abundance	*Unmineralized Lockport dolomite*	*Mineralized Lockport dolomite*
Mg	±500, 000	Same
Ca	±500, 000	Same
Si	5, 000–50, 000	Same
Fe	±5, 000	±15, 000
Al	500–8, 500	Same
K	<3, 000	3, 000–8, 500
P	<5, 000	Same
Na	500–1, 500	Same
Mn	150–500	Same
Ti	50–500	±1, 500
Sr	50–85	500–5, 000
Zn	[1] 28	580 [1]
Pb	[1] 8	120 [1]
Zr	15–75	Same
B	<20	25–65
Ba	2–15	15–50
V	±25	Same
Cr	2–9	25–45
Cu	2–9	15–50
Ni	2–9	15–85
Y	0	5–15

[1] Averages of chemical analyses made by H. Bloom.

CHEMICAL PRECIPITATION OF METALS

The stratigraphic distribution of sphalerite and galena has already been described and the implications are obvious. The widespread occurrence of metals at specific zones of the Lockport dolomite and Guelph equivalent from eastern New York to western Ontario strongly suggests a syngenetic origin. In these zones some metals have been selectively concentrated in bottom mud sediments and in associated beds of reef origin.

Dolomite derived from reef material and thin-bedded clastics in the dolomites of Niagaran age of Ohio were analyzed by Rogers (1936, p. 133), who found that the pure dolomitic reef rock contains a proportionately large amount of Fe_2O_3 in contrast to the bottom mud dolomites which contain higher percents of FeO, FeS_2, Na_2O, K_2O, P, and SO_3.

Spectrographic and chemical analyses in Geological Survey laboratories show an enrichment of lead, chromium, copper, nickel, iron, boron, potash, and yttrium in the bottom sediments, compared to a concentration of zinc, strontium, and anhydrite in the reef rock.

The average contents of zinc and lead in clastic and reef dolomite in two drill cores are shown in table 11. Within the clastic beds sphalerite is usually abundant in beds stratigraphically lower than those containing abundant galena. Within the reef detrital beds sphalerite is nearly always associated with forms of calcareous algae. The remainder of the rock is pure dolomite of low carbonaceous content. Possibly the masses of reef core below wave base and the reef flank beds were sufficiently oxygenated as to become purified of most organic matter and iron and other metallic sulfates.

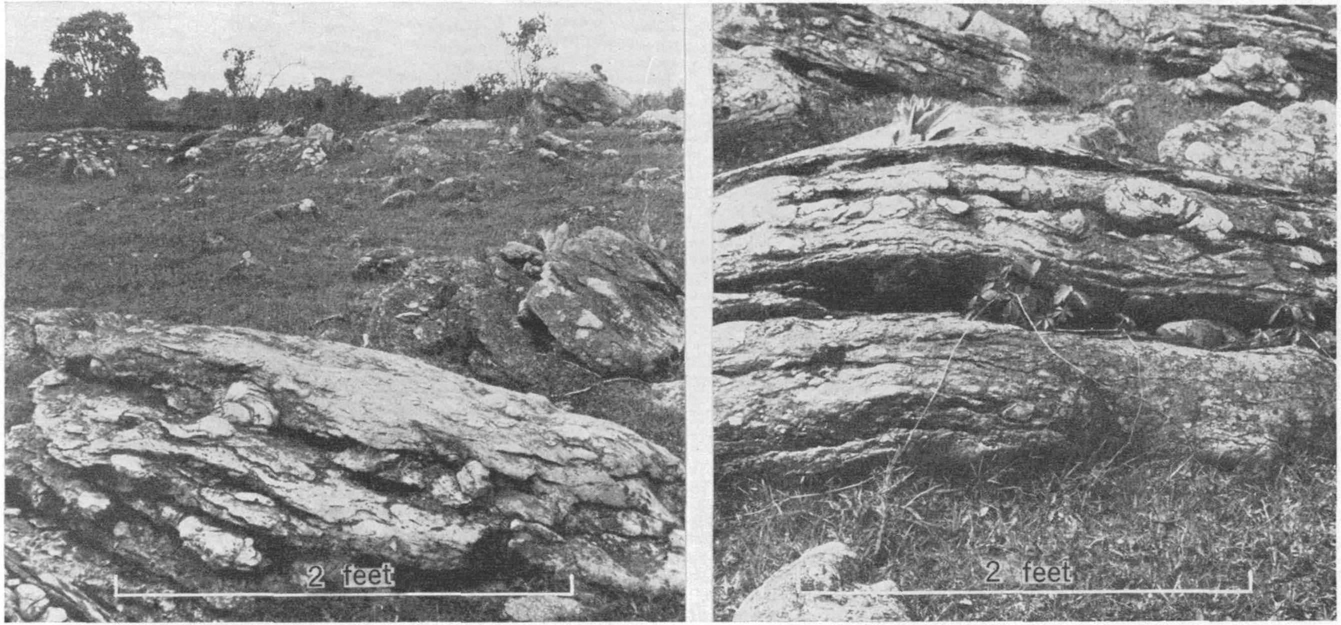
TABLE 11.—*Average contents of zinc and lead in two cores of Lockport dolomite, in parts per million*

[H. Bloom, analyst]

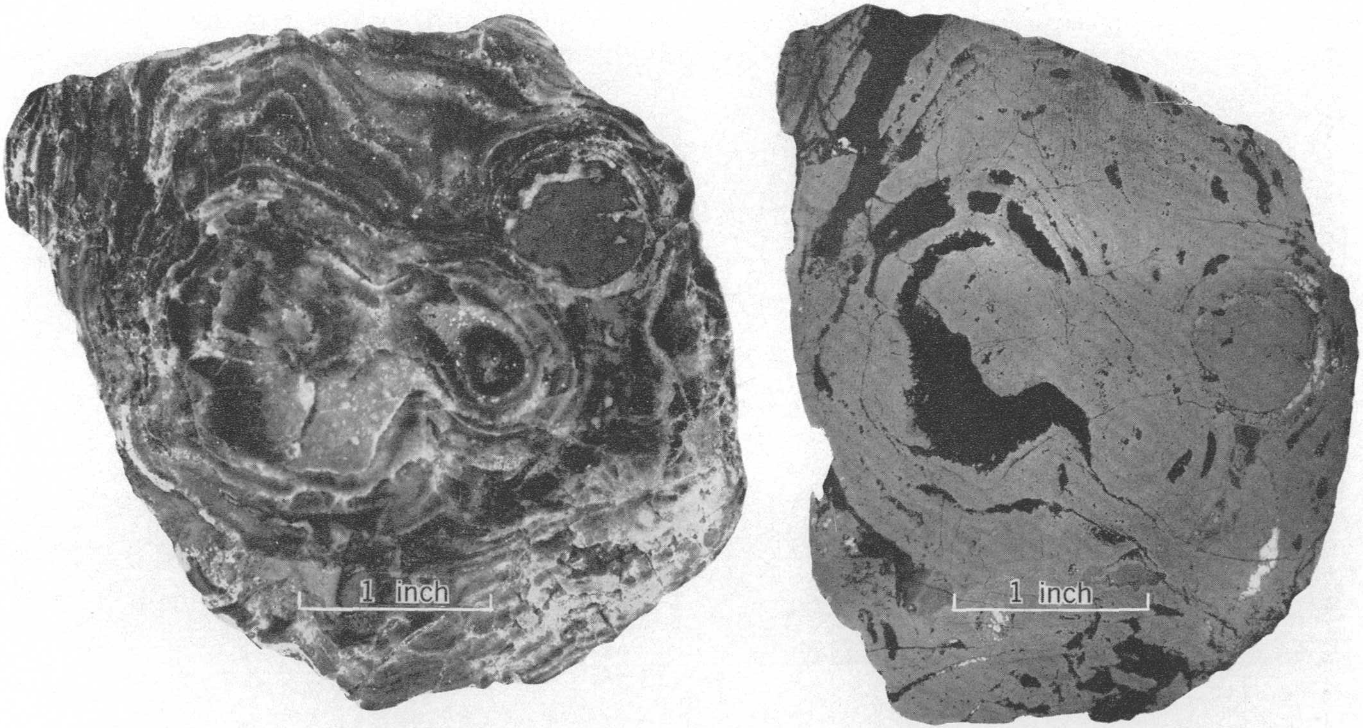
Core	*Zinc*	*Lead*	*Total*
DRILL HOLE 10, 7 MILES SOUTH OF MANNING			
Bottom mud dolomite: 114 ft.	247	128	375
Reef dolomite: 67 feet	386	13	399
Lockport dolomite:[1] 181 feet	298	85	383
DRILL HOLE 2, 0.6 MILE NORTH OF MANNING			
Bottom mud dolomite: 52 ft.	130	29	159
Reef dolomite: 8 feet	319	9	328
Lockport dolomite:[1] 60 feet [2]	156	26	182

[1] Weighted average.
[2] 60 feet of comparable section in core from drill hole 10 contained an average of 173 ppm of zinc and 42 ppm of lead.

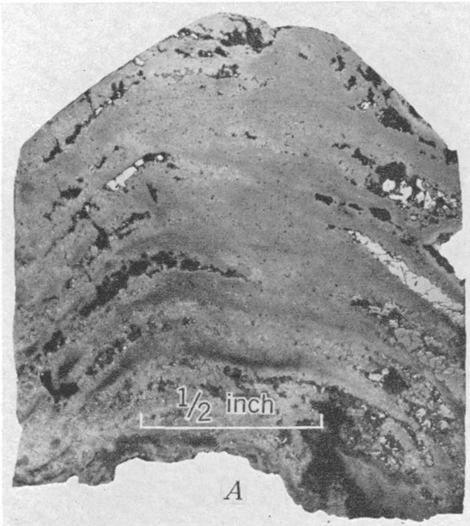
Mortimer (1949, p. 354) has shown that an oxidizing layer which contains positively charged insoluble ferric hydroxide normally exists on the surface of bottom muds. Ferric hydroxide not only adsorbs phosphate, silicate, and other negative ions, but forms complexes with



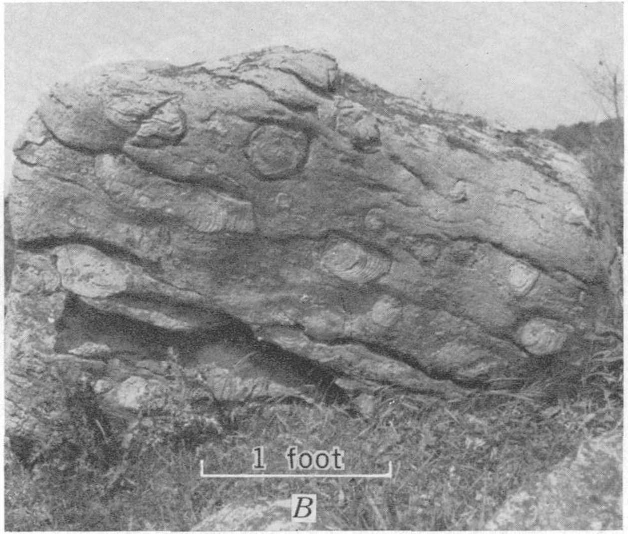
SPHALERITE-BEARING *STROMATOPORA* IN LOCKPORT DOLOMITE SOUTHEAST OF CLARENDON, N. Y.



POLISHED SECTIONS OF *STROMATOPORA* CONTAINING SPHALERITE



A. POLISHED SECTION OF *STROMATOPORA* CONTAINING SPHALERITE



B. *STROMATOPORA* IN ZONE 1 OF THE LOCKPORT DOLOMITE negatively charged humus, in turn capable of adsorbing positive ions from solution. Thus the layer adsorbs both negative and positive ions from the water and, at the same time, blocks free exchange between the water and the lower layers of mud. Below the oxidation layer, the pH and oxidation potential (eh) are lower and the iron hydroxide is present in the ferrous state. All sulfates are reduced to sulfides, and all calcium carbonate is converted to bicarbonate and carbonic acid (Krumbein and Garrels, 1952). Such conditions are accentuated in interreef muddy bottoms below wave base during periods of quiescence and active reef building.

Thus whether the heavy metals are present in the sea water in ionic form or adsorbed to organic matter they may be concentrated in the bottom muds below wave base during periods of quiescence both by active precipitation and by solution of the dolomite; they may be released to the sea water again during periods of turbulence or during aeration and oxidation of sediments above wave base.

BIOGEOCHEMICAL PRECIPITATION OF METALS

Where sphalerite and galena are found in beds of reef detritus and biostrome dolomite, the crystals are most commonly found in algae, and less commonly in *Stromatopora* and corals. This is observed in outcrop and also in unweathered dolomite core. The implication that marine accumulator plants or animals may have first concentrated the lead and zinc needs to be considered. The observable algal structures preserved in this highly recrystallized rock are probably but a small part of the original flora. Algae are believed by Elias (1948) to be indispensable in the building of reefs. Subsequent processes of destruction and recrystallization tend to obliterate the original features and to produce unfossiliferous structural masses. The association of sphalerite and galena with algae bioherms has been described in a previous section. Southeast of Clarendon, headlike silicified *Stromatopora* are exposed in the rock like raisins in a pudding (pls. 4–6). More than one-third of these forms contain visible crystals of sphalerite on the weathered surfaces of the isolated heads, although no sphalerite could be detected in the country rock.

Many instances of association of metal with fossils are reported in the literature. One of the most interesting is that of concretionary masses from the Batesville district, Arkansas (Miser, 1941, p. 28) that have been reported by Ulrich to belong to the genus *Girvanella*, a form of algal growth. These spherical buttons show concentric banding around centers of chert or clay which contain 5.85 percent of manganese, fine crystals of pyrite, barite, and galena. The galena also occurs as masses as large as a man's fist in cavities left by the solution of the fossils and as fine veins in the part of the limestone that still contain the *Girvanella.*

Van Ingen became interested in the association of metallic sulfides with reef deposits in lower Paleozoic rocks and proposed the theory that the reef-building organisms were directly responsible for the primary concentration of sphalerite and galena in limestone deposits of the Mississippi valley type (Van Ingen, 1915, p. 85; Van Ingen and Phillips, 1915, p. 193). As a result of this interest Van Ingen stimulated the research that Phillips carried out on the metal content of the modern marine invertebrates from the Tortugas. Phillips (1917, 1922) analyzed a large number of animals, including corals, for copper, zinc, iron, manganese, and lead, to test the hypothesis that reef-dwelling animals are responsible for significant accumulations of metals. No plants were included in the group. The greatest lead content reported was 2.5 ppm in the liver of a gastropod. As much as 665 ppm of zinc oxide was reported from the livers of horseshoe crabs and various gastropods and as much as 125 ppm from corals.

Studies have also been made of calcareous or rock-forming algae. David E. White (Howe, 1932, p. 61) made a careful study of fresh-water algae collected near Harpers Ferry, W. Va., that were concentrating not only calcium carbonate but also iron and manganese. The black crusts analyzed 12.3 percent Fe_2O_3 and 4.5 percent MnO from water testing only 0.1 ppm of Fe and 0.7 ppm of Mn. It was demonstrated that these elements were precipitated as a byproduct of photosynthesis in which CO_2 is absorbed and oxygen is given off. Concretions formed by the same genus (Roddy, 1915, p. 246) are being precipitated in Little Conestoga Creek of Lancaster County, Pa., which drains the area in which the old Bamford lead-zinc mine is located. Samples of these concretionary balls were taken by the present author near Millersville, several miles downstream from the mine, where the metal content of the stream had been diluted to 0.06 ppm of zinc. The concretions, however, analyzed 46 ppm of zinc and 7.5 ppm of lead.

In order to test further the absorption of metals by algae, green filamentous algae of the *Spiragyra* type were collected from streams below the tailings of the Warren lead-zinc mine in New Hampshire and Ely copper mine in Vermont and below a trench cut in vanadiferous and phosphatic shales, near Montpelier, Idaho. The results are shown in table 12.

TABLE 12—*Metal content of filamentous algae growing in mineralized stream water, in parts per million*

[H. W. Lakin and L. E. Reichen, analysts]

	Water		Algae (dry weight)					
Locality	*pH*	*Heavy metals*	*Cu*	*Pb*	*Zn*	*Ni*	*Mo*	*V*
Warren, N. H.	3.5	16	920	6,600	2,900	n. d.[1]	n. d.	n. d.
Ely, Vt.	------	3	1,100	55	150	n. d.	n. d.	n. d.
Montpelier, Idaho	------	--------	43	<17	306	87	7	261

[1] No determination.

The ash of similar algal material collected from a spring in a deposit of uranium carbonate near Wamsuter, Wyo., contained 39 ppm of uranium and 500 ppm of V_2O_5 although the water contained only 0.1 to 0.4 ppm of uranium. Thus, living algae are capable of concentrating lead, zinc, and other metals from fresh water in appreciable quantities.

Marine noncalcareous algae have been shown by the work of other investigators to take up considerable amounts of heavy metals. The results have been reviewed by Vinogradov (1935, p. 63) and Black and Mitchell (1952) who have made many analyses of algal material. The ability of algae to concentrate metals from sea water is shown in table 12. For example, marine algae are capable of concentrating nickel, zinc, and titanium from sea water by a factor of 500 to 1,000 times. The table shows also a close agreement between the relative abundance of elements in algae with that of an average limestone. The metal content of the entire section of Lockport dolomite, however, is high for nickel, lead, zinc, vanadium, chromium, and titanium, and low for strontium and barium when compared to both the relative abundance of elements in algae and also in an average limestone. The data do not exclude the possibility of the Lockport dolomite being largely of algal origin nor, on the other hand, do they intimate that the excess of lead, zinc, and other metals present in the Lockport dolomite is due to a preferential concentration of these metals by algae.

TABLE 13.—*Comparison of metal content in marine algae, in parts per million dry weight, with that of sea water and the Lockport dolomite*

	Abundance of elements in marine algae[1]	*Abundance of elements in sea water from which algae were collected*[1]	*Abundance of elements in Lockport dolomite*	*Abundance of elements in average limestone*[2]	*Ratio of metal content in dolomite to that of marine algae*	*Ratio of metal content in Lockport dolomite to that of average limestone*
Co	0.79	<.0003	n. f.[3]	0	----	----
Ni	3.3	.005	5	0	2	5.0
Mo	.35	.012	n. f.	----	----	----
Pb	9	<.008	85	10	9	8.0
Sn	1.1	<.005	n. f.	----	----	----
Zn	68	.011	300	50	4	6.0
V	1.7	.0025	20	10	12	2.0+
Ti	19	.008	200	----	10	----
Cr	1.1	.002	13	2	13	6.5
Sr	>1,472	9.5	70	425+ 765	.05	.1
Ba	43	<1.0	20	120	.5	.17
Mn	147	<3.0	400	385	2.5	1.0
Cu	8	<3.0	17	20	1.2	.85

[1] Taken from Black and Mitchell, 1952.
[2] Taken from Rankama and Sahama, 1949, p. 226.
[3] Not found.

CONCENTRATION IN THE PRESENCE OF DECAYING ORGANIC MATTER

In addition to concentration of metals by living algae, metals are probably concentrated around decaying organic matter during, or soon after burial in the sea-bottom sediments. It is known that metals are readily adsorbed by organic matter in the oxidation layer of the bottom muds and that hydrogen sulfide released from decaying matter in beds below the oxidation layer reacts with seawater to precipitate metallic sulfides. Also in oxygenated parts of reefs and reef detrital beds above wave base, reducing conditions are maintained in an environment of decaying organic matter although oxidation is proceeding at the same time in the rest of the reef detrital bed.

SUMMARY

A selective concentration of elements occurs at periodic intervals throughout the dolomite sequence. Lead, iron, chromium, copper, nickel, boron, potassium, and yttrium are enriched in the bottom mud phase, and zinc, strontium, and anhydrite in the reef rock phase of the recurring mineralized lentils, or zones. The reef sediments may have undergone considerable oxidation and purification during which time the metallic elements may have been leached out and redeposited in and around algae and stromatoporoid forms. The metals were probably concentrated further by solution of the carbonates in the bottom muds during periods of quiescence and nondeposition. This is suggested by the presence of yttrium and ytterbium in the mineralized beds of the Oak Orchard member of Howell and Sanford.

Periodic concentration due to a change in the rate of oxidation and without a changing source of metals is possible but does not alter the total amount of lead and zinc in the dolomite sequence. The amounts of lead and zinc present in the Lockport dolomite, particularly in the upper part of the Lockport (Guleph dolomite of Williams) are uncommon for an average dolomite in the earth's crust. Those elements in more than average abundance in the Lockport dolomite are iron, zinc, lead, vanadium, chromium, and nickel. The dolomites are lower than average in strontium and barium.

Algae are known to absorb large quantities of metals from a normal sea water. The relative amounts of metals present in the Lockport dolomite do not differ greatly from those to be expected if the dolomite were largely of algal origin, but are, in general, too high in lead, vanadium, titanium, and chromium and too low in strontium and barium to be directly attributable to algal absorption.

Many features of the dolomites thus suggest that the sulfide minerals may have been deposited originally in sea bottom muds before the sediments were consolidated. An unusual source of these elements, perhaps of volcanic origin, is implied.

CONCLUSIONS

In the Manning area three cycles of selective concentration of metals have taken place. First, specific facies of the Lockport dolomite are enriched in zinc, lead, and heavy metals so as to form mineralized zones of outcrop in the flat-lying dolomites beneath the surface till and peat. Second, zinc, lead, and other metals available in the ground waters have been selectively concentrated in a series of peat bogs in the area. Third, plants rooted in the peat have accumulated toxic amounts of zinc and lead.

Concentrations of zinc of as much as 10,000 ppm dry weight are found in purslane, nightshade, ragweed, pigweed, nettles, aspen, and willow growing on the drained muck lands. Lead is concentrated in hemlock, arborvitae, and ferns.

The contents of strontium, vanadium, zirconium, phosphorus, boron, cobalt, zinc, lead, copper, nickel, and barium are greater in the peat soils than in the underlying mineralized beds of dolomite. This list of elements corresponds closely to that given by Goldschmidt for enrichment in coal. The peat soils contain as much as 16 percent of zinc in areas where the zinc has been concentrated and there is a minimum of 1,500 tons of zinc in the peat bogs of the area.

It is believed that the zinc that occurs in large amounts in several of the local peat bogs has been precipitated from ground water by reducing reactions in the bog, and that the metal present in the ground water has been dissolved from mineralized beds in the Lockport dolomite immediately underlying or adjoining the peat bogs. These beds are shown to recur in a recognizable sequence that can be correlated over wide areas. The outcrop pattern of these zones, as developed from outcrop and drilling data, corresponds generally with the distribution of zinc-rich soils, surface waters, and plants.

Iron, potassium, lead, copper, chromium, and nickel were found to be concentrated in the clastic muddy bottom facies of the dolomite and zinc and strontium in the reef facies. All of these, with the exception of strontium, are present in the Lockport in greater abundance than in an average dolomite of the earth's crust.

It is believed that the metals present in the Lockport dolomite were precipitated from sea water containing uncommon amounts of metal and have been concentrated by solution and redeposition.

The study of the Manning area has lead to the recognition of a wide-spread dissemination of sphalerite and galena in flat-lying carbonate rocks in a region where there has been little igneous activity. The amounts of zinc precipitated in the Manning bog and seen in drill cores from 17 exploratory holes indicate that there is a considerable tonnage of metal in the Lockport dolomite of Orleans County. There is no indication that these deposits contain minable thickness and grade in the region or that the metal content indicated by this study is uncommonly high as compared to other areas in New York State where concentrations have been noted. In general, the grade of material seen in outcrop and analyzed in the core has been low, the best containing not more than 0.4 percent of zinc and 0.4 of percent lead. The lead zone near Shelby may average 0.1 percent of lead through 4 feet of beds in an area one-half mile square. South of Manning an average of 0.07 percent of zinc is found in 55 feet of beds; the area of the beds is not known.

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DRILL LOGS OF LOCKPORT DOLOMITE CORES FROM ORLEANS AND GENESEE COUNTIES, N. Y.

By Helen L. Cannon and R. H. Stewart

Drilling of the dolomites of Silurian age in Orleans and Genesee Counties, N. Y., in 1950 was proposed as a result of geochemical and geologic surface studies. The purpose of the drilling was to investigate further the distribution of lead and zinc in the Lockport dolomite and to acquire stratigraphic information about a flat-lying, till-covered area where there are few outcrops of Silurian rocks. Seventeen holes were drilled, totaling 1,900 feet.

Drill holes 2 and 10 cut a combined section from the lower part of the Salina group through the upper and lower parts of the Lockport dolomite and the Clinton group, to the Albion sandstone. Drill logs of the Lockport in these 2 holes and the complete logs of the other 15 holes are given in the following section, together with assay and spectrographic data. With the chemical methods used, lead values are probably high wherever zinc values are more than 400 ppm. The samples were analyzed for lead and zinc by Harold Bloom, and spectrographed by A. T. Myers and P. J. Duncan, all of the Geological Survey.

In the drill core examined, porous recrystallized dolomite beds of probable reef flank detritus recur at regular intervals that can be correlated over considerable distances. These beds thicken in general to the south. A hole drilled in Genesee County several miles south of the Manning area penetrated 47 feet of reef-derived material which probably represents reef core. Analyses of metalliferous parts of core selected from several holes show a considerable quantity of disseminated sphalerite throughout the section. Galena appears to be concentrated largely along the contact of the upper part of the Lockport (or Guelph dolomite of Williams) and the lower part of the Lockport dolomite.

Drill hole 1, Gaylord property, southeast corner of Manning crossroads

[Depth 125.7 ft, altitude of collar 686.1 ft, depth to water 35 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Mottled reddish-brown and gray till of argillaceous sand and pebbles, with many large boulders.	0.0– 10.2	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Zone 4, reef flank bed; dark gray-brown, coarse-grained, porous dolomite, with quartz-filled and gypsum-filled vugs, stylolites, and algae with siliceous coating.	10.2– 19.0	--------	--------	
Oak Orchard member of Howell and Sanford:				
Gray, medium-grained dolomite less porous than overlying reef flank bed. Small crystals of sphalerite have replaced dolomite at 19.5 ft. Freshly broken core has bituminous odor.	19.0– 21.0	--------	--------	
Dark-gray, fine-grained, dense dolomite, with occasional black carbonaceous partings. Sphalerite at 21.0 ft. Bituminous odor.	21.0– 27.0	--------	--------	
Zone 3; dark-gray, coarse-grained dolomite with stylolites and many crinoid fragments. Bituminous odor.	27.0– 30.0	--------	--------	
Dark-gray, fine-grained, dense dolomite, containing many fossils. Small crystals of sphalerite replacing dolomite at 30.0, 34.5, and 36.7 ft. Finely divided galena replaces dolomite at 36.3 ft. Vugs with gypsum at 33–35 ft. Bituminous odor.	30.0– 37.0	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Gray, fine-grained, dense dolomite. Sphalerite at 53.1 ft.	37.0– 56.0	--------	--------	
Reef flank bed, zone 2; gray-brown, coarse-grained, porous dolomite, with some fossils and abundant gypsum. Bituminous odor.	56.0– 61.0	--------	--------	
Gray, fine-grained dolomite composed almost entirely of fossil fragments. Cup corals and crinoids abundant.	61.0– 64.0	--------	--------	
Dark-gray, fine-grained, dense dolomite, with occasional black carbonaceous partings. Small crystals of sphalerite have replaced dolomite at 79.5 ft.	64.0– 80.6	--------	--------	
Zone 1, reef flank bed; brown, coarsely crystalline, sacchoroidal dolomite, with stylolites.	80.6– 82.8	--------	--------	
Gray, fine-grained dolomite, with black carbonaceous partings. Bituminous odor. Sphalerite at 87.0 ft; in quartz-lined vug at 95.7 ft.	82.8–96.2	--------	--------	
Gasport limestone member:				
Reef flank bed of brown, coarsely crystalline, porous dolomitic limestone, with gypsum and a few black carbonaceous partings. Bituminous odor.	96.2–101.8	--------	--------	
DeCew limestone member of Williams:				
Dark-gray, fine-grained, dense argillaceous dolomite, with many black carbonaceous partings and a few scattered fossils. Bituminous odor.	101.8–111.8	--------	--------	
Alternating thin beds of black shale and dark-gray, fine-grained dolomite. Fetid bituminous odor.	111.8–114.0	--------	--------	
Clinton group:				
Rochester shale:				
Dark-gray, fine-grained, dense dolomite, with some black carbonaceous partings. Fetid bituminous odor.	114.0–115.8	--------	--------	
Alternating thin beds of black shale and dark-gray, fine-grained dolomite, with a few thin calcareous fossiliferous layers. Fetid bituminous odor.	115.8–125.7	--------	--------	

[1] These metals equal or exceed in amount arbitrarily chosen values. The approximate order of magnitude of these values, in percent, is: X.0 for Al and Fe; 0.X for K and Na; 0.0X for Sr and Ti; 0.00X for B, Cr, Cu, and Zr; 0.000X for Ni and Y; and trace for Ag, Ga, and Yb. The asterisk indicates that analyses were made, but if the metals were present they were in amounts below these arbitrary values.

Drill hole 2, Kelsey farm, 0.6 mile north of Manning

[Depth 297.0 ft, altitude of collar 666.1 ft, depth to water 16.0 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals[1]
Alluvium:				
Mottled reddish-brown sand and clay, with some boulders.	0.0— 11.3	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray to black, fine-grained, dense dolomite, with a few black carbonaceous partings. A small crystal of sphalerite in a vug at 13.2 ft. Bituminous odor.	11.3— 15.2	340	18	Cu, Ba
No core recovery	15.2— 16.0	--------	--------	
Dark-gray, fine-grained, dense dolomite, with cup corals in the uppermost 4 in. Sphalerite at 16.9 and 17.0 ft. Bituminous odor.	16.0— 17.2	165	15	*
Zone 2, reef flank bed; dark gray-brown, coarse-grained, porous dolomite, with many small vugs lined with recrystallized dolomite. One small crystal of sphalerite in dolomite-lined vug at 20.4 ft. The porosity of this unit decreases with depth. Bituminous odor.	17.2— 22.3	300	5	*
Medium-gray, fine-grained, clastic dolomite bed of fossil fragments, largely crinoid stems, and cup corals. Sphalerite and galena.	22.3- 26.0	450	124	K, Cr Cu
Dark mottled-gray, fine-grained, dense dolomitic limestone, with black carbonaceous partings. Abundant cup corals at 27.8, 38.2 and 39.0 ft. Small vugs lined with crystalline quartz at 35.3 and 36.0 ft. Sphalerite has replaced dolomite at 29.0 ft. and in a cup coral at 38.2 ft. Bituminous odor.	26.0- 31.0 31.0- 36.8 36.8- 41.0 41.0- 47.0	325 78 20 75	25 19 15 18	K, Cr Cu, Cr * Cu
Dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings. Small crystals of sphalerite have replaced dolomite at 49.2 and 52.8 ft. Bituminous odor.	47.0- 55.4	90	17	Cu
Gasport limestone member:				
Dark-gray at top, grading to light-gray at base, coarse-grained dolomitic limestone, consisting of fossil fragments of corals and crinoid stems, with a few black carbonaeous partings. Small crystals of sphalerite occur in a *Favosites* coral at 55.7 ft. Bituminous odor.	55.4- 58.3	350	16	Cu
Light- to medium-gray, medium-grained, porous algal dolomite, with abundant black carbonaceous partings. The lowermost 2 ft consists of clastic fossil fragments; a large *Favosites* coral head filled with selenite at 60.4–60.9 ft. Bituminous odor.	58.3- 62.7	16	15	Ba, Sr, Cu
DeCew limestone member of Williams:				
Dark-gray, fine-grained, argillaceous dolomite, with abundant wavy black carbonaceous partings. Bituminous odor.	62.7- 67.7 67.7- 73.3	15 9	37 20	Ti, K, B, Ba, Cr, Cu, Ga, Y, Yb, Zr Ti, K, B, Ba, Cr, Cu, Y, Yb, Ga, Zr
Clinton group:				
Rochester shale (contact gradational):				
Dark-gray, medium-grained, massive dolomite, with some areas of darker argillaceous material. Some thin fossiliferous layers. The shale content increases with depth. Occasional partings contain a thin layer of selenite. Bituminous odor.	73.3- 79.6	--------	--------	
Grimsby sandstone of Williams (1914) (through its base).	79.6–297.0	--------	--------	

[1] See footnote on p. 168.

Drill hole 3, Harling farm, 1 mile west of Manning

[Depth 115.4 ft, altitude of collar 661.1 ft, hole caved]

	Depth (feet)	Core analysis: Zinc (ppm)	Core analysis: Lead (ppm)	Core analysis: Other metals [1]
Alluvium:				
Glacial till of reddish sand, gravel, and clay	0.0- 9.0	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Zone 4, reef flank bed: dark-brown, coarse-grained, porous, vuggy dolomite. Bituminous, stylolitic, and fossiliferous. Algal material with silicious coating; stylolites. Sphalerite has replaced dolomite at 11.8 and 12.0 ft, in algae at 13.0 ft. Strong bituminous odor.	9.0- 11.6	20	10	*
	11.6- 14.0	1,500	14	*
	14.0- 16.5	20	6	*
	16.5- 19.0	320	12	*
Oak Orchard member of Howell and Sanford:				
Dark-gray, medium-grained dolomite, less porous than overlying reef flank bed. Bituminous, stylolitic, and fossiliferous. Sphalerite, with selenite, at 19.2, 20.6, and 20.8 ft.	19.0- 21.0	2,000	<10	*
Dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings. Strong bituminous odor.	21.0- 27.0	--------	--------	
Zone 3; fossiliferous bed of dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings. Sphalerite, with selenite, at 27.5 ft has replaced dolomite at 28.0 and 28.2 ft. Strong bituminous odor.	27.0- 30.0	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Medium-gray, fine-grained, dense dolomite, with occasional fossils, and many black carbonaceous partings. Sphalerite has replaced dolomite at 32.3, 33.4, 33.8, and 35.6 ft.	30.0- 51.0	--------	--------	
Zone 2, reef flank bed; dark-brown, coarse-grained, porous dolomite, with few black carbonaceous partings. Corals. Sphalerite has replaced dolomite at 50.6, 51.2, 52.7, 57.4 and 58.1 ft. Strong bituminous odor.	51.0— 59.5	--------	--------	
Dark-gray, coarsely crystalline breccia of fossil fragments and cup corals. Sphalerite in fossils at 59.8 ft. has replaced dolomite at 61.0 ft. Strong bituminous odor.	59.5— 71.0	--------	--------	
Dark-gray, fine-grained dolomite, stylolitic, with some black carbonaceous partings. Strong bituminous odor.	71.0— 90.0	--------	--------	
Gasport limestone member:				
Dark-gray, calciferous coquina of crinoidal material, stylolitic, with some black carbonaceous partings. Strong bituminous odor.	90.0— 96.0	--------	--------	
DeCew limestone member of Williams:				
Dark-gray, fine-grained, laminated dolomite, with many black wavy partings and few fossils. Thin argillaceous seams in the base of the unit. Strong bituminous odor.	96.0—109.5	--------	--------	
Clinton group:				
Rochester shale: (contact gradational):				
Alternating thin beds of black dolomitic shale and dark-gray, fine-grained, dense dolomite, with a few calcareous fossiliferous layers. Strong bituminous odor.	109.5-115.4	--------	--------	

Drill hole 4, Mathes farm, 0.5 mile west of Manning

[Depth 117.0 ft, altitude of collar 667.0 ft depth to water 16.0 ft]

Alluvium:				
Reddish-brown sandy clay, with large boulders of dolomite.	0.0- 9.4	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Reef flank bed, zone 4; gray-brown, coarse-grained porous dolomite, containing silicified algae.	9.4- 14.2	--------	--------	
Oak Orchard member of Howell and Sanford:				
Dark-gray, fine-grained dense dolomite	14.2- 23.1	--------	--------	
Clastic bed of fossil fragments and gypsum	23.1- 23.5	--------	--------	

[1] See footnote on p. 168.

Drill hole 4, Mathes farm, 0.5 mile west of Manning—Continued

[Depth 117.0 ft, altitude of collar 667.0 ft, depth to water 16.0 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Lower part of the Lockport dolomite:				
Unidentified beds:				
Gray, fine-grained dolomite. Sphalerite has replaced dolomite at 46.2 and 47.5 ft; selenite at 38.2 ft. Strong bituminous odor.	23.5– 49.0	--------	--------	
Zone 2, reef flank bed; gray-brown, coarse-grained, porous dolomite. Small crystals of sphalerite have replaced dolomite at 51.1 and 55.3 ft. Strong bituminous odor.	49.0– 55.8	--------	--------	
Fossiliferous clastic bed, with abundant cup corals.	55.8– 57.0	--------	--------	
Dark-gray, fine-grained, dense dolomite, with occasional black carbonaceous partings and fossils. Thin layers containing small cup corals at 59.3 and 63.4–64.4 ft. Galena has replaced part of a cup coral at 59.3 ft. Sphalerite in a cup coral at 60.2 ft has replaced dolomite at 63.2, 67.1, 69.0, 70.6, 84.3 and 84.5 ft. Strong bituminous odor.	57.0– 95.0	--------	--------	
DeCew limestone member of Williams:				
Dark-gray, fined-grained argillaceous dolomite, with abundant wavy black carbonaceous partings, and few fossils. A small amount of marcasite and pyrite at base. Strong bituminous odor.	95.0–105.8	--------	--------	
Clinton group:				
Rochester shale (contact gradational):				
Alternating thin beds of black shale and dark-gray, fine-grained dolomite, with fine black carbonaceous partings. Strong bituminous odor.	105.8–117.0	--------	--------	

Drill hole 5, Tony Cook farm, ⅛ mile northeast of Manning

[Depth 82.5 ft, altitude of collar 657.3 ft, depth to water 7.5 ft]

Alluvium:				
Reddish-brown argillaceous sand	0.0– 8.5	--------	--------	
Lockport dolomite:				
Lower part of the undifferentiated beds:				
Zone 2, reef flank bed; dark gray-brown, coarse-grained, porous, recrystallized dolomite.	8.5– 14.0	--------	--------	
Dark-gray, fine-grained, dense dolomite, with occasional black carbonaceous partings and a few scattered fossils. Sphalerite has replaced corals at 26.0, 30.0, and 30.2 ft. Bituminous odor.	14.0– 31.8	--------	--------	
Medium-gray, fine-grained, dense dolomite, with occasional black carbonaceous partings, few fossils.	31.8– 50.2	--------	--------	
Gasport limestone member:				
Medium-gray, medium-grained, dense dolomitic limestone.	50.2– 54.4	--------	--------	
DeCew limestone member of Williams:				
Dark-gray, fine-grained, dense argillaceous dolomite, with many wavy black carbonaceous partings. Bituminous odor.	54.5– 66.3	--------	--------	
Clinton group:				
Rochester shale (contact gradational):				
Dark-gray, fine-grained, dense massive dolomite.	66.3– 69.7	--------	--------	
Alternating thin beds of black dolomitic shale and dark-gray, fine-grained, dense dolomite, with some thin calcareous fossiliferous layers. Strong bituminous odor.	69.7– 82.5	--------	--------	

[1] See footnote on p. 168.

Drill hole 6, Nick Cook farm, ¼ mile south of Manning

[Depth 130.0 ft, altitude of collar 682.2 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Mottled reddish-brown and gray sand, gravel, and clay.	0.0– 9.2	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Zone 4, reef core; dark gray-brown, coarse-grained, very porous dolomite. Sphalerite in a vug filled with celestite at 19.2 ft. Bituminous odor. Crypto-crystalline quartz coatings.	9.2– 19.6	--------	--------	
Oak Orchard member of Howell and Sanford:				
Reef core; dark, medium-grained, mottled dolomite of algal material, with abundant partings.	19.6– 27.0	--------	--------	
Zone 3, reef core; mottled dark-gray and white dolomite of *Cladopora* coral, with abundant stylolites. Sphalerite in fossils at 27.1 and 29.5 ft. Strong bituminous odor.	27.0– 41.0	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, fine-grained, dense clastic dolomite, with many carbonaceous partings.	41.0– 50.6	--------	--------	
Medium-gray, finely crystalline dolomite. Small crystals of sphalerite have replaced dolomite at 54.5, 54.6, and 55.6 ft. Bituminous odor.	50.6– 56.0	--------	--------	
Fine-grained brown dolomite, with *Cladopora* coral. Selenite at 57.5 ft.	56.0– 61.3	--------	--------	
Zone 2, reef bed; brown, porous, coarse-grained dolomite. Stylolites and algae.	61.3– 67.5	--------	--------	
Fine-grained gray dolomite of fossil debris. Abundant cup corals. Sphalerite has replaced cup coral at 69.0 ft.	67.5– 69.5	--------	--------	
Fossiliferous dolomite, with cup corals. Small vugs filled with amorphous gypsum at 70.5 and 73.2 ft.	69.5– 77.0	--------	--------	
Dark, fine-grained dolomite. Sphalerite at 79.6 and 80.1 ft.	77.0– 87.5	--------	--------	
Zone 1, reef bed; porous, coarse-grained, brown dolomite composed of white algal masses.	87.5– 88.0	--------	--------	
Dark, fine-grained, dense dolomite. Selenite at 94.1 ft.	88.0–100.0	--------	--------	
Gasport limestone member:				
Lighter colored, medium-grained dolomitic limestone, with many selenite partings. Bituminous odor. Gypsum at 107 ft.	100.0–105.9	--------	--------	
DeCew limestone member of Williams:				
Dark-gray, fine-grained, dense, shaley dolomite, with abundant wavy black carbonaceous partings. Strong bituminous odor.	105.9–117.0	--------	--------	
Clinton group:				
Rochester shale (contact gradational):				
Dark-gray, medium-grained, dense dolomite with scattered fossils and occasional black carbonaceous partings. Strong bituminous odor.	117.0–118.4	--------	--------	
Alternating thin beds of black dolomitic shale and dark-gray, fine-grained, dense dolomite, with a few thin calcareous fossiliferous layers. Strong bituminous odor.	118.4–130.0	--------	--------	

[1] See footnote on p. 168.

Drill hole 7, Blockowitz farm, ¾ mile south of Manning

[Depth 120.6 ft, altitude of collar 658.0 ft, depth to water 9.1 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Mottled reddish-brown, gray, and black glacial till, with many pebbles and boulders of dolomite.	0.0– 5.2	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Zone 4, reef flank bed; dark gray-brown, coarse-grained, porous dolomite, with some silicified algae. Bituminous odor.	5.2– 15.0	--------	--------	
Dark-gray, medium-grained, dense dolomite, with abundant fossils and many black carbonaceous partings and stylolites. Sphalerite and fluorite in small vugs at 17.6–18.0 ft. Bituminous odor.	15.0– 22.0	--------	--------	
Oak Orchard member of Howell and Sanford:				
Dark-gray, fine-grained, dense dolomite, nonfossiliferous; some thin black carbonaceous partings. Sphalerite at 23.9 ft.	22.0– 30.8	--------	--------	
Zone 3; dark-gray, fine-grained, dense dolomite, composed largely of fossil fragments.	30.8– 34.0	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, fine-grained, dense dolomite, with fossils at 37.0–38.5 ft. Sphalerite with recrystallized dolomite and gypsum at 38.6 ft. Strong bituminous odor.	34.0– 55.8	--------	--------	
Zone 2, reef flank bed; dark gray-brown, porous dolomite, with many small vugs lined with recrystallized dolomite or filled with selenite.	55.8– 60.5	--------	--------	
Dark mottled-gray, dense dolomite, with many black carbonaceous partings, fossiliferous with cup corals. Sphalerite has replaced or filled some fossils at 79.0, 79.2, 79.3, 79.8 ft, and occurs with selenite in vugs at 65.3 ft. Strong bituminous odor.	60.5– 80.0	--------	--------	
Dark-gray, fine-grained, banded dolomite. Nonfossiliferous, with many stylolites. Sphalerite at 88.7 ft.	80.0– 94.2	--------	--------	
Gasport limestone member:				
Medium-gray, dense dolomitic limestone, with many wavy black carbonaceous partings. Fossiliferous, with small crystals of sphalerite and selenite in a *Stromatopora* at 100.0 ft. Strong bituminous odor.	94.2–103.4	--------	--------	
DeCew limestone member of Williams:				
Medium-gray, dense, nonporous limestone, with many wavy black carbonaceous partings. Strong bituminous odor.	103.4–112.5	--------	--------	
Clinton group:				
Rochester shale:				
Dark-gray to black, dense, massive dolomite, fossiliferous. Strong bituminous odor.	112.5–118.5	--------	--------	
Alternating thin beds of black dolomitic shale, and dark-gray, fine-grained, dense dolomite. Strong bituminous odor.	118.5–120.6	--------	--------	

[1] See footnote on p. 168.

Drill hole 8, Campbell farm, 1 mile south of Manning

[Depth 95.4 ft, altitude of collar 638.0 ft, depth to water 1.8 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Black muck	0.0– 1.6	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Dark-gray, fine-grained, dense dolomite, containing algal material. Stylolitic and bituminous, with a few small crystals of sphalerite at 1.6 ft. Bituminous odor.	1.6– 11.1	--------	--------	
Zone 4; reef bed; gray-brown, medium-grained, recrystallized, porous reef-sand dolomite. Very fossiliferous. Sphalerite at 13.5 ft and in small vug lined with recrystallized dolomite at 14.8 ft. Bituminous odor.	11.1– 19.8	--------	--------	
Oak Orchard member of Howell and Sanford:				
Dark-gray, medium- to fine-grained, dense, thin-bedded dolomite, with black shale partings, very fossiliferous. Small crystals of sphalerite have replaced dolomite at 20.9 ft. Bituminous odor.	19.8— 21.0	--------	--------	
Dark-gray, dense dolomite	21.0— 26.0	--------	--------	
Zone 3; gray, fine-grained fossiliferous clastic dolomite of cup corals, and other fossils.	26.0— 27.3	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Gray, fine-grained, laminated, argillaceous dolomite.	27.3— 44.0	--------	--------	
Dark-gray, fine grained shaley dolomite	44.0— 46.4	--------	--------	
Dark-gray, fine-grained dolomite	46.4— 55.5	--------	--------	
Zone 2, reef flank bed; dark gray-brown, medium-grained, porous dolomite. Very fossiliferous. Bituminous odor.	55.5— 59.0	--------	--------	
Gray, fine-grained dense dolomite	59.0— 65.0	--------	--------	
Dark-gray, fine-grained, dense, thin-bedded dolomite. Bituminous odor.	65.0— 70.6	--------	--------	
Dark-gray, fine-grained, dense, thick-bedded dolomite. Fossiliferous, with bedding thinner toward base. Bituminous odor.	70.6— 82.0	--------	--------	
Alternating thin beds of black dolomitic shale and dark-gray, fine-grained, dense dolomite, with occasional thin calcareous fossiliferous layers. Bituminous odor.	82.0— 95.4	--------	--------	

Drill hole 9, Shepherd farm, 2.0 miles southwest of Manning

[Depth 123.0 ft, altitude of collar 655.4 ft, depth to water about 5 ft]

	Depth (feet)	Zinc (ppm)	Lead (ppm)	Other metals
Alluvium:				
Mottled reddish-gray sand, clay, and boulders	0.0– 3.8	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Zone 4, reef bed; dark gray-brown, medium-grained, porous dolomite, with abundant silicified fossils. Bituminous odor.	3.8– 15.0	--------	--------	
Oak Orchard member of Howell and Sanford:				
Dark-gray, fine-grained, dense dolomite, with abundant black carbonaceous partings and stylolites. Very fossiliferous.	15.0– 16.8	--------	--------	
Zone 3; dark, fine-grained, reef-detrital dolomite and large white algal masses. Sphalerite, celestite, and quartz in algal reef material at 16.9–17.6 and 18.6–19.2 ft. Bituminous odor.	16.8– 19.2	--------	--------	
	(16.8– 18.8)	1,300	50	K, Cr, Cu, Al, Ba, Ni
Dark, fine-grained, even-bedded dolomite	19.2– 27.6	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, fine-grained, dense dolomite, with very few fossils, and some black carbonaceous partings. Sphalerite has replaced alga at 27.6 ft; in silicified coral at 33.8 ft. Small veinlets of sphalerite and dolomite at 34.6, 34.7 and 45.9 ft. Bituminous odor.	27.6– 47.2	--------	--------	

[1] See footnote on p. 168.

Drill hole 9, Shepherd farm, 2.0 miles southwest of Manning—Continued

[Depth 123.0 ft, altitude of collar 655.4 ft, depth to water about 5 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Lower part of the Lockport dolomite—Continued				
Undifferentiated beds—Continued				
Zone 2; reef flank bed; dark brownish-gray, medium-grained porous dolomite, with occasional black carbonaceous partings. Many fossil moulds lined with recrystallized dolomite. A small vug filled with celestite and dolomite at 47.6–47.7 ft. Bituminous odor.	47.2– 57.0	--------	--------	
Fossil-fragment breccia of dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings. Cup corals abundant.	57.0– 58.0	--------	--------	
Gray, fine-grained dolomite. Sphalerite has replaced dolomite at 79.4 ft; small aggregates of recrystallized dolomite at 80.7 and 86.5 ft. Bituminous odor.	58.0– 94.0	--------	--------	
DeCew limestone member of Williams:				
Dark-gray, fine-grained, dense dolomite, with very abundant fine wavy black carbonaceous partings. Bituminous odor.	94.0–102.8	--------	--------	
Dark-gray, medium-grained, dense, massive argillaceous dolomite, with a few scattered fossils. Fine black carbonaceous partings. Marcasite and pyrite. Bituminous odor.	102.8–108.2	--------	--------	
Clinton group:				
Rochester shale (contact gradational):				
Alternating thin beds of black dolomitic shale, and dark-gray, fine-grained dolomite, with a few calcareous fossiliferous layers. Bituminous odor.	108.2–123.0	--------	--------	

Drill hole 10, Arnold farm, 3.3 miles northeast of Elba

[Depth 323.4 ft, altitude of collar 664.6 ft, depth to water 37.0 ft]

	Depth (feet)	Zinc (ppm)	Lead (ppm)	Other metals
Alluvium:				
Mottled brown and gray sand, clay, and pebble till, with some boulders.	0.0– 41.8	--------	--------	
Salina group:				
Upper part of the Lockport dolomite	41.8–129.0	--------	--------	
Guelph dolomite of Williams (contact gradational:				
Dark gray-brown, thin-bedded dolomitic limestone, with some black carbonaceous partings and many selenite partings. Dolomite more porous in basal than upper bed.	129.0–132.5	9	15	K, B, Cr, Ba, Sr
Dark-gray, fine-grained, thin-bedded dolomitic limestone, with abundant black carbonaceous partings. Selenite partings abundant from 135.2–137.5 ft. Sphalerite in a fine carbonaceous parting at 136.0 ft. Pyrite or marcasite, with selenite, in a small vug at 139.5 ft.	132.5–139.5	69	26	K, B, Cr, Cu, Ni Sr, Ba
Dark-gray, fine-grained- thin-bedded, dense dolomite, with abundant black carbonaceous partings. All partings and bedding dip at angle of 45°, indicating proximity to reef core. Flowage indicated in the lower 0.7 ft of unit.	139.5–143.3	10	30	Na, K, B, Ba, Cr, Cu, Ni, Sr
Dark-gray, medium-grained, dense, thin-bedded dolomite, with abundant black	143.3–149.5	21	35	Na, K, Ba, Cr, Cu, Ni, Sr
carbonaceous partings. Several thin zones exhibit flowage structure. White selenite partings.	149.5–154.5	49	560	K, Cu, Sr
Dark-gray, medium-grained, dense dolomitic	154.5–159.6	310	16	Ag, Ba, Sr
limestone, with black carbonaceous and	159.6–163.8	150	100	Sr
thin selenite partings, grading to dolomite	163.8–166.3	580	50	Ag, Sr
at the base. Sphalerite has replaced limestone at 157.1 ft.	166.3–171.8	180	20	*

[1] See footnote on p. 168.

Drill hole 10, Arnold farm, 3.3 miles northeast of Elba—Continued

[Depth 323.4 ft, altitude of collar 664.6 ft; depth to water 37.0 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Salina group—Continued				
Guelph dolomite of Williams (contact gradational)—Continued				
Zone 4, reef core; dark gray-brown, coarse-grained, porous, recrystallized dolomite. No clear bedding evident and few indications of fossils. Small vugs lined with recrystallized dolomite, selenite, fluorite, and calcite. Sphalerite as large and small crystals in vugs at 171.2, 171.5, 171.8, 172.2, 173.0, 174.7, 174.9, 175.3, 175.7, 182.3, 184.4, 184.6, 187.0, 189.4, 189.7, 195.3, 195.8, 196.0, 196.9, 197.5, 202.7, 203.6, 204.3, 214.0, 216.5, and 218.0 ft has replaced dolomite at 176.8 and 208.4 ft. Galena has replaced dolomite at 174.7 ft. Bituminous odor.	171.8–173.7	1,500	10	*
	173.7–176.6	400	9	Sr
	176.6–179.6	25	12	Sr
	179.6–182.6	425	7	*
	182.6–185.6	550	5	*
	185.6–188.6	420	5	*
	188.6–191.6	3,300	7	*
	191.6–194.5	20	7	*
	194.5–197.5	280	5	*
	197.5–200.0	30	5	*
	200.0–203.3	210	5	*
	203.3–206.3	1,200	6	*
	206.3–209.3	430	6	Sr
	209.3–212.3	90	5	*
	212.3–216.3	240	<10	*
	216.3–218.3	370	50	Sr
Oak Orchard member of Howell and Sanford:				
Zone 3; dark-gray, medium-grained dolomite, with many black carbonaceous partings. *Cladopora* coral. Sphalerite, galena, and selenite in silicified fossils at 220.3, 221.2, 223.1, 223.4, 224.0, 224.5, 224.7, 225.0, and 225.7 ft. Bituminous odor.	218.3–221.3	380	<10	*
	221.3–225.0	2,000	150	Cu
Dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings and very few fossils. Sphalerite has replaced dolomite at 226.8 and 228.8 ft. Bituminous odor.	225.0–228.0	230	40	K, Ba, Cr
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, medium-grained, dense dolomite, with black carbonaceous partings becoming more numerous toward base of unit. Sphalerite has replaced dolomite at 235.5 ft; has filled minute fractures at 240.2 and 241.2 ft, and in a fossil at 242.5 ft. Bituminous odor.	229.9–234.2	8	38	Cu
	234.2–239.2	260	1,350	Cr, Cu
	239.2–243.2	390	57	Cu
Reef flank bed, zone 2; dark gray-brown, coarse-grained, porous dolomite, with many small vugs filled with selenite, gypsum, and some recrystallized dolomite. Algal material, with white siliceous coating. Sphalerite, with gypsum, in vugs at 251.9, 252.7, 255.7, 256.1, and 258.8 ft. Bituminous odor.	243.2–251.7	24	13	*
	251.7–256.7	21	12	*
	256.7–263.5	400	23	*
Dark-gray, fine, medium-grained dolomite, with abundant black carbonaceous partings and scattered fossils. Calcareous near base. Bituminous odor.	263.5–269.0	255	18	Fe, Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni, Zr
	269.0–274.7	500	250	Na, K, Ba, Cu, Ni
Dark-gray to black, fine-grained, dense dolomitic limestone. Dark-gray, dense argillaceous dolomite. Fossiliferous layers containing several silicified *Favosites* corals. Sphalerite in silicified coral at 279.1 ft and celestite in silicified coral at 280.6 ft. Sphalerite has replaced some fossils at 285.0 and 290.0 ft, in a small vug at 276.3 ft, and in a celestite filled cavity at 290.6 ft. Galena at 280.3 ft. Bituminous odor.	274.7–279.0	35	43	Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni
	279.0–284.0	430	60	Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni
	284.0–289.0	200	23	Na, K, B, Ba, Cu, Ga, Ni
Gasport limestone member:				
Dark-gray to black, medium-grained, dense dolomite. Bituminous odor.	289.0–294.8	230	26	Na
DeCew limestone member of Williams:				
Dark-gray to black, fine-grained, dense argillaceous dolomite, with abundant wavy black carbonaceous partings, and a few scattered fossils. Black shale partings near base. Bituminous odor.	294.8–298.6	13	33	Fe, Ti, Na, K, B, Ba, Cr, Cu, Ni, Y, Yb, Zr
	298.6–304.8	9	32	Fe, Ti, Na, K, B, Ba, Cr, Cu, Ni, Y, Yb, Zr
	304.8–309.9	16	34	Fe, Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni, Y, Yb, Zr

[1] See footnote on p. 168.

Drill hole 10, Arnold farm, 3.3 miles northeast of Elba—Continued

[Depth 323.4 ft, altitude of collar 664.5 ft, depth to water 37.0 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Clinton group:				
Rochester shale (contact gradational):				
Alternating thin beds of black dolomitic shale, and dark-gray, fine-grained, dense dolomite, with a few thin calcareous fossiliferous layers. Bituminous odor.	309.9–313.5	13	25	Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni, Y, Yb, Zr
	313.5–318.5	24	20	Al, Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni, Y, Yb, Zr
	318.5–323.4	180	18	Al, Ti, Na, K, B, Ba, Cr, Cu, Ga, Ni, Y, Yb, Zr

Drill hole 11, Hartrick farm, 1.35 miles south of Shelby

[Depth 105.3 ft, altitude of collar 613.6 ft]

Alluvium:				
Mottled red and gray sand, gravel, and clay of old river channel.	0.0– 18.7	--------	--------	
Lower part of Lockport dolomite:				
Lead-bearing Oak Orchard member of Howell and Sanford eroded.				
Undifferentiated beds:				
Dark-gray, medium-grained, dense bituminous dolomite, with thin black carbonaceous partings and some cup corals.	18.7– 24.1	--------	--------	
Dark-gray, fine-grained, dense dolomite, with occasional black carbonaceous partings, stylolites, and small vugs filled with selenite or gypsum. Crystals of sphalerite have replaced dolomite at intervals from 24.6–35.9, and 48.9–49.1 ft; in vugs lined with recrystallized dolomite or filled with selenite at 32.6, 36.4, 43.0, 46.0 and 46.2 ft. Freshly broken core has a bituminous odor.	24.1– 49.7	--------	--------	
Zone 1; algal bed; light-gray, fine-grained, algal dolomite, with some thin black carbonaceous partings at the top. Sphalerite has replaced dolomite at 49.7 and 51.2 ft. Bituminous odor.	49.7– 51.4	--------	--------	
Dark-gray to black, fine-grained, dense dolomite, with many black carbonaceous partings; fossiliferous. Cup corals scattered sparsely throughout unit; more numerous near base. Small crystals of sphalerite have replaced fossil fragments at intervals from 51.4–64.5 ft; in a thin carbonaceous parting at 56.0 ft. Galena has replaced dolomite at 57.4 ft. An estimated 0.1 percent zinc in this unit. Bituminous odor.	51.4– 65.0	--------	--------	
Gasport limestone member:				
Dark-gray to black, fine-grained, dense bituminous dolomite, with abundant black carbonaceous partings and scattered fossils. Small crystals of sphalerite in thin black carbonaceous partings at intervals from 65.5–68.3 ft; selenite has filled fossils at intervals from 67.1–70.3 ft. The total zinc content of this unit estimated at 0.1 percent. Fetid bituminous odor.	65.0– 74.0	--------	--------	
DeCew limestone member of Williams:				
Medium- to dark-gray, fine-grained, dense dolomite, with a few black carbonaceous partings. Sphalerite has filled small fractures at 75.3 and 85.2 ft; has replaced dolomite at 77.1 ft. Very strong, fetid bituminous odor.	74.0– 85.2	--------	--------	
Clinton group:				
Rochester shale (contact gradational):				
Dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings. Strong, fetid bituminous odor.	85.2– 95.3	--------	--------	

[1] See footnote on p. 168.

Drill hole 11, Hartrick farm, 1.35 miles south of Shelby—Continued

[Depth 105.3 ft, altitude of collar 613.6 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Clinton group—Continued				
Rochester shale (contact gradational)—Con.				
Alternating thin beds of black shale and dark-gray, fine-grained dolomite, with a few thin calcareous fossiliferous layers. At 102.3 ft the drill struck a fracture containing natural gas that flowed for about an hour until the pressure was lowered.	95.3–105.3	--------	--------	

Drill hole 12, Sheetrum farm, 2.6 miles southwest of Shelby

[Depth 131.2 ft, altitude of collar 609.6 ft, depth to water 0.5 ft]

	Depth (feet)	Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Mottled reddish-brown and gray sand, gravel, and clay.	0.0– 8.8	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Zone 4, reef bed; dark gray-brown, medium-grained, porous dolomite, containing many small vugs lined with secondary dolomite, calcite, and some sphalerite. Small crystals of sphalerite, in vugs with recrystallized dolomite at intervals from 14.6–15.6 and 28.8–30.6 ft, have replaced dolomite at 18.8 ft and filled small fracture at 26.4 ft. Porosity of the dolomite decreases with depth. Freshly broken core has a bituminous odor.	8.8– 31.7	--------	--------	
Oak Orchard member of Howell and Sanford:				
Zone 3 dark-gray, fine-grained, dense dolomite, with some black carbonaceous partings and small fossils. Four thin porous zones at intervals from 40.0–46.1 ft. Crystals of sphalerite in vugs lined with recrystallized dolomite at 37.4 and 38.5 ft. Strong bituminous odor.	31.7– 46.1	--------	--------	
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, fine-grained, dense dolomite	46.1– 50.6	--------	--------	
Reef flank bed; light blue-gray, very coarse-grained, very porous, crinoidal coquina. The dolomite in the crinoid fragments shows calcite twinning. Fetid bituminous odor.	50.6– 68.7	--------	--------	
Medium blue-gray, medium-grained, porous dolomite, very fossiliferous. Fossils as moulds lined with recrystallized dolomite. Fetid bituminous odor.	68.7–74.4	--------	--------	
Zone 1; algal bed; medium blue-gray grading downward to dark-gray, fine-grained, algal dolomite. Silt content increases downward. Black carbonaceous partings. Fetid bituminous odor.	74.4– 78.8	--------	--------	
Dark-gray mottled with white, argillaceous dolomite; very fossiliferous, containing algae, *Stromatopora*, brachiopods, and corals. Abundant thin black carbonaceous partings, some with thin layer of selenite.	78.8– 91.9	--------	--------	
Sphalerite in fossils, fractures, and disseminated dolomite at 81.8, 84.2 and 87.0, 88.2 ft. Fetid bituminous odor.	(86.8– 88.1)	4,500	25	K, Ba, Cu, Ni
Gasport member and DeCew limestone member of Williams:				
Dark-gray, medium to fine-grained, dense dolomite, with abundant wavy black carbonaceous partings and a few scattered fossils. Small crystals of sphalerite, with recrystallized dolomite, at 95.8 ft. Fetid bituminous odor.	91.9–109.5	--------	--------	
Clinton group:				
Rochester shale (contact gradational):				
Alternating thin beds of black dolomitic shale and dark-gray, fine-grained dolomite, with a few calcareous fossiliferous layers. Fetid bituminous odor.	109.5–131.2	--------	--------	

[1] See footnote on p. 168.

Drill hole 13, Grimes property, 1.5 miles south of Shelby

[Depth 32 ft, altitude of collar 615.0 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Glacial lake deposits of mottled brown and gray, laminated, fine sand and clay.	0.0– 12.0	--------	--------	
Glacial till of mottled reddish-brown and gray sand, clay, and boulders.	12.0– 17.1	--------	--------	
Upper part of the Lockport dolomite:				
Oak Orchard member of Howell and Sanford:				
Zone 3, dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings and stylolites. Small crystals of sphalerite have replaced a branching type of coral at 17.3 ft, are found in a stylolite at 18.4 ft, and have replaced dolomite at 20.1 ft. Freshly broken core has a bituminous odor.	17.1– 20.9	--------	--------	
Dark-gray, fine-grained, dense dolomite, with abundant black carbonaceous partings and some fossils. Small amounts of galena have replaced, or filled fossils at 21.0, 21.2, and 22.5 ft. Disseminated galena at 21.8 ft. Sphalerite has replaced dolomite at 23.1 ft. Small vug at 25.3 ft lined with scalenohedral crystals of calcite and some quartz. Bituminous odor.	20.9– 22.4	210	1,600	Fe, K, Ba, Cr, Cu Y
	23.3	55	150	Fe, Cu, Cr, Y
	24.7	260	2,100	Fe, K, Ba, Cr, Cu, Ni, Y
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, medium-grained, slightly porous, fossiliferous dolomite, with black carbonaceous partings and stylolites. Many fine fractures with random orientation. Small crystals of sphalerite have replaced dolomite at 26.3, 30.9, and 31.0 ft. and lined a vug at 31.1 ft. Sphalerite and galena in small vug lined with recrystallized dolomite at 30.9 ft. Bituminous odor.	24.7– 27.0	100	360	Cr
	27.0– 29.5	230	15	*
	29.5– 32.0	190	15	*

Drill hole 14, Moule farm, 1.5 miles south of Shelby

[Depth 26.0 ft, altitude of collar 609.0 ft]

	Depth (feet)	Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Mottled gray and brown sand and gravel	0.0– 11.0	--------	--------	
Upper part of the Lockport dolomite:				
Oak Orchard member of Howell and Sanford:				
Zone 3; gray, medium-grained, dolomite, with abundant fine black wavy carbonaceous partings. Galena has replaced a coral at 11.2 ft, disseminated through dolomite at 11.4 and 11.6 ft. A small crystal of sphalerite has replaced dolomite at 11.7 ft. Freshly broken core has a bituminous odor.	11.0– 11.9	760	4,000	Fe, K, Cu
Black, coarse-grained, dense dolomite, with many cup corals and other fossils. Disseminated galena at 11.9 ft. Bituminous odor.	11.9– 12.8	25	100	Fe, Cu, Y
Medium-gray, medium-grained, dense dolomite, with many black carbonaceous partings; some cup corals and other fossils. Sphalerite has replaced dolomite at 13.6 ft in a small vug; recrystallized dolomite and quartz at 14.0 and 14.5 ft. Disseminated galena at 14.4 ft. Bituminous odor.	12.8– 14.9	350	2,100	Fe, K, Cu
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, medium-grained, somewhat porous dolomite, with many small vugs filled with recrystallized dolomite and selenite. Sphalerite with selenite at 16.5 ft; has replaced dolomite at 16.6 ft. Bituminous odor.	14.9– 18.2	--------	--------	
Dark-gray, medium to fine-grained, dense dolomite, with many black carbonaceous partings, and a few cup corals. Stylolites common throughout. Small crystals of sphalerite have replaced dolomite at 22.2, 23.7, and 26.0 ft and are associated with recrystallized dolomite at 24.8 ft. Bituminous odor.	18.2– 26.0	--------	--------	

[1] See footnote on p. 168.

Drill hole 15, Zarwell property, 1.4 miles south of Shelby

[Depth 24.4 ft, altitude of collar 609.5 ft, depth to water 4.0 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals[1]
Alluvium:				
Mottled gray sand and gravel.	0.0– 3.8	--------	--------	
Upper part of the Lockport dolomite:				
Oak Orchard member of Howell and Sanford:				
Zone 3; medium to dark brownish-gray, medium-grained dolomite, with small vugs as large as 1 in. in diameter, many black carbonaceous partings and stylolites. Crystals of sphalerite in vugs lined with recrystallized dolomite at intervals from 4.0–7.1 ft. Freshly broken core has a bituminous odor.	3.8– 8.2	--------	--------	
	8.2– 9.6	180	575	Cu
Black, coarse-grained, dense dolomite, with many cup corals. Disseminated galena at 9.3 and 9.8 ft. Bituminous odor.	9.6– 11.0	40	500	Fe, Cu, Y
Dark-gray, fine-grained, dense dolomite, with many wavy black carbonaceous partings. Sphalerite in a small vug, with recrystallized dolomite, at 11.0 ft. Disseminated galena at 11.6, 13.0, and 14.2 ft; replaces a cup coral at 12.9 ft. Open vug lined with crystalline galena at 12.7 ft. Bituminous odor.	11.0– 12.6	85	625	Fe, K, Ba, Cr, Cu
	12.6– 14.4	550	1,700	Fe, K, Ba, Cr, Cu, Y
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark gray-brown, medium-grained, moderately porous dolomite, with many black carbonaceous partings and stylolites. Sphalerite at 18.7 ft. Small vugs filled with recrystallized dolomite. Bituminous odor.	14.4– 19.6	--------	--------	
Medium to dark gray, fine-grained, dense dolomite, with many black carbonaceous partings and stylolites. Sphalerite with recrystallized dolomite at 20.1, 20.3 ft. Bituminous odor.	19.6– 24.4	--------	--------	

Drill hole 16, Best farm, 1.3 miles south of Shelby

[Depth 26.7 ft, altitude of collar 610.7 ft, depth to water 5.0 ft]

	Depth (feet)	Zinc (ppm)	Lead (ppm)	Other metals[1]
Alluvium:				
Mottled reddish-brown sand, gravel, and clay	0.0– 4.2	--------	--------	
Upper part of Lockport dolomite:				
Oak Orchard member of Howell and Sanford:				
Zone 3; dark-gray to black, medium-grained, dense dolomite, with occasional black stylolites and black carbonaceous partings. Few scattered fossils. Small crystals of sphalerite replace dolomite at intervals from 4.9–9.6 ft. Disseminated galena at 9.7 ft. Freshly broken core has a bituminous odor.	4.2– 9.8	--------	--------	
Black, coarsely crystalline dolomite, with many cup corals. Black carbonaceous partings. Bituminous odor.	9.8– 10.4	150	320	Fe, K, Ba, Cr, Cu
	10.4– 11.9	25	100	Fe Cu
Dark-gray, medium-grained, dense dolomitic limestone, with many wavy black carbonaceous partings, and some bituminous material. Gelena disseminated through the dolomite at intervals from 12.2–13.8 ft. One small crystal of sphalerite has replaced dolomite at 14.0 ft. Bituminous odor.	11.9– 13.0	160	500	Fe, K, Ba, Cu, Zr
	13.0– 14.2	25	500	Fe, K, Ba, Cu
Lower part of the Lockport dolomite:				
Undifferentiated beds:				
Dark-gray, coarse to medium-grained, somewhat porous dolomite, with occasional black carbonaceous partings, and stylolites. Small crystals of sphalerite have replaced dolomite at 19.4, 19.8, 20.5, 21.0 and 21.9 ft. Bituminous odor.	14.2– 26.7	--------	--------	

[1] See footnote on p. 168.

Drill hole 17, Shepherd farm, 2 miles southwest of Manning

[Depth 30.0 ft, altitude of collar 652.2 ft, depth to water about 5 ft]

	Depth (feet)	Core analysis		
		Zinc (ppm)	Lead (ppm)	Other metals [1]
Alluvium:				
Black sand, gravel, and muck	0.0– 5.2	--------	--------	
Upper part of the Lockport dolomite:				
Guelph dolomite of Williams:				
Reef flank bed, zone 4; dark brownish-gray, coarse-grained, porous dolomite, with many black carbonaceous partings and stylolites. Many vugs lined with recrystallized dolomite and calcite. Occasional silicified fossils, very poorly preserved. Small crystals of sphalerite in vugs at 6.3, 7.5, 8.1, and 14.6 ft. No galena present.	5.2– 15.5	--------	--------	
Oak Orchard member of Howell and Sanford:				
Dark-gray, fine-grained, dense dolomite, with many black carbonaceous partings. Sphalerite in a fracture, with secondary quartz and dolomite, at 17.2 ft. Bituminous odor.	15.5– 30.0	--------	--------	

[1] See footnote on p. 168.

INDEX

A

Page

Accumulator plants.. 128, 132, 134, 135
Acknowledgments........... 120–121
Algae, calcareous, metal content. 145, 146, 152, 156, 159, 160
filamentous, metal content.. 160
marine, metal content...... 161

B

Bacterial action, oxidation of zinc sulfide........... 130
Bergen Bog, description........ 127
zinc and lead in soil and plants............ 128
Blake, S. F., plants identified... 126
Bog, description............... 127
ecology................. 124–128
formation................ 127
soils.............. 122–124, 128

C

Cannon, R. S., cited........... 155
Chlorosis, as a guide to prospecting............ 133–134
causes and symptoms...... 132
Cladopora............. 147, 148, 153
Cooper, John R., cited....... 133, 155
Crinoidal coquina, in Gasport limestone member. 170
in undifferentiated lower part of Lockport dolomite....... 146, 178

D

DeCew limestone member of Williams.... 144–145, 152
Dithizone tests for heavy metals........... 121–122
Drill logs and core analyses.. 167–181

E

Eramosa member............ 142, 146
See also Oak Orchard member.

F

Page

Faulting..................... 121
Fauna, correlations............ 149
Fieldwork.................... 120
Flora. *See* Plants.

G

Galena, occurrence.......... 150–151, 153, 154, 156
Galena. *Also see under metals in individual beds.*
Gasport limestone member, described.......... 145
Geology and geography of area.. 121
Ground water, content of zinc and lead....... 138–140
movement................ 124
Guelph dolomite of Williams.. 148–149

H–K

Halysites, in zone 2............ 146
Hendricks, S. B., cited......... 130
Hermann, F. J., plants identified. 126
Johnson, J. Harlan, cited....... 154
Knox, Arthur S., pollen studies. 124–125

L

Lakin, W. H., cited............ 135
Lead, absorption by plant species. 134
effect on plant growth..... 134
in waters............... 138–139
toxic effect on plants...... 133
See also under zinc.
Lockport dolomite, abundance of elements......... 157, 161, 162, 168–181
composite section........ 142–144
facies, metals in.......... 158
described........... 151
general features and correlation.......... 140–142
land surface conforms to dip............ 121

Lockport dolomite—Continued Page
lateral reef and faunal changes 148
lower part, described 144–146
occurrences of zinc and lead 150–151
section across New York 141
upper part 146–149

M

Manning Muck, comparison of zinc in willow leaves and soil 136
favorable features for prospecting 135
profile section 123
Metals, biogeochemical precipitation 159–161
chemical precipitation 158–159
comparison of amounts in mineralized and unmineralized dolomite 157
concentration around decaying organic matter 161–162
cycles of concentration 162
methods of concentration in peat 129
occurrence. *See* Drill logs of Lockport dolomite cores.
origin in the dolomite 157
revealed by spectrographic analysis of Manning Muck 129
Muck, defined 122
Also see Bog.

O

Oak Orchard member of Howell and Sanford 146–147

P

Patch reefs 144, 147
Peat, correlation of zinc-rich with specific beds 122
metals found by analysis of zinc-bearing sample 129
methods of concentration of metals 129
zinc and lead in undrained 131
Also see Bog *and* Muck.

Petrography of sulfide-bearing rocks Page 155–157
pH of bog soils 127
Plants, accumulator 128, 132, 134, 135
present cover listed 126–127
tested for prospecting 135–137
zinc and lead contents, Manning area 135
zinc as a cause of chlorosis 132
Pollen studies of the mucks 124–126
Prospecting, chlorosis as a guide 133–134
geochemical methods 121–122
importance of till 137–138
plants tested 137
use of willow and nettle leaves 135–136
Purpose of study 120

R

Rare earths, in DeCew limestone member 145
Reef core beds 147, 148
Reef flank beds 147, 148, 153
Reichen, L., cited 135
Rochester shale, partial section 144

S

Shelby dolomite 149
Soils, zinc and lead contents, Manning area 135
Sphalerite occurrence 150–151
See also under metals in individual beds.
Staker, E. V., cited 130
Stromatopora 146, 153, 159, pls. 4, 5, 6
Sulfides, origin in the dolomite 157
oxidation 131
Surface water 138

T–Y

Till, sampled for zinc and lead 137
Yttrium, concentration 145

Z

Zinc, causes chlorosis of plants 132–135
concentration by ground-water circulation 124
content in surface water 138
content of willow and nettle leaves 136
estimated amounts in peat and marl of Manning Muck 131

Zinc—Continued Page
in composite section of Lockport dolomite... 142–144
maximum content in plants growing in drained areas............ 132
oxidation and leaching in peat soils......... 130
soluble and nonreplaceable fractions in peat... 130
toxic effect on plants..... 132–133
Zinc and lead, content of certain substances........ 122
content of ground waters. 138–140
content of Manning Muck.. 123
Zinc and lead—Continued Page
content of peat and marl compared........ 128
content of plants compared. 128
occurrences in Lockport dolomite........... 150–151
partial analyses of contents in plants and soils from Manning area 135
till sampled for........... 137
Zone 1, description.......... 145, 152
metals.................. 152
Zone 2, description............ 146
metals.................. 153
Zone 3, description and metals. 153–155
Zone 4, description and metals... 155

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