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MINERALS IN THE NIAGARA LIMESTONE OF WESTERN NEW YORK

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CONTENTS

Introduction *

The minerals occurring in the Niagara (Lockport) limestone of western New York have long been of great popular and scientific interest because of their variety, beautiful crystal forms, and abundance. Many of the species were described long ago by James Hall; and the literature of later date contains numerous references to the Niagara minerals, however the descriptions of Hall remain still among the best and most complete. The object of this study was to bring together all of the published material bearing on the

* The author wishes to express his indebtedness to Mr. Jacob Schuler of Rochester for the loan of his extensive and excellent collection of minerals from the Rochester region; and he desires to acknowledge his obligation to professors H. L. Fairchild, T. L. Watson, and G. H. Chadwick for suggestions and criticism which have been fully utilized in the progress of the study.

subject of Niagara minerals, and to add the facts and data that are new. The present seems a very appropriate time for this study, for recent excavations for the barge canal and building sites have revealed a wealth of material. It is hoped that this paper will serve as an incentive to the people of western New York who are scientifically inclined to make collections of these minerals. Such collections will further increase our knowledge of the minerals and, when brought together in course of time, will constitute an extensive and complete collection of the minerals of a region that has become classic in American geology.

List of Minerals

Name	Composition	Crystallization
Anhydrite	$CaSO_4$	Orthorhomic
Aragonite	$CaCO_3$	Orthorhombic
Barite	$BaSO_4$	Orthorhombic
Calcite	$CaCO_3$	Hexagonal
Celestite	$SrSO_4$	Orthorhombic
Chalcopyrite	$CuFeS_2$	Tetragonal
Dolomite	$CaMg(CO_3)_2$	Hexagonal
Fluorite	CaF_2	Isometric
Galena	PbS	Isometric
Gypsum	$CaSO_4 . 2H_2O$	Monoclinic
Magnesite	$MgCO_3$	Hexagonal
Malachite	$CuCO_3 . Cu(OH)_2$	Monoclinic
Marcasite	FeS_2	Orthorhombic
Pyrite	FeS_2	Isometric
Quartz	SiO_2	Hexagonal
Rutile	TiO_2	Tetragonal
Siderite	$FeCO_3$	Hexagonal
Sphalerite	ZnS	Isometric
Strontianite	$SrCO_3$	Orthorhombic
Sulphur	S	Orthorhombic

Manner of Occurrence

The minerals are found completely or partially filling solution cavities in the limestone, lining the walls of cavities and forming beautiful drusy surfaces, cementing breccia fragments of the limestone (8) and partly or wholly filling joints and other cracks penetrating the limestone. Beautiful geodes with their interiors lined with perfect crystals occur, but are rare. Certain minerals have also replaced the limestone, in some cases extensively, and other minerals are found on the exposed surfaces of the rock. Fossils have been found completely replaced and in many the interiors are filled with crystals. Large areas of the limestone have been recrystallized, forming cleavable mineral masses.

Important ore minerals, such as galena and sphalerite, are of common occurrence in the Niagara limestone, but they are too widely disseminated and too small in amount in this formation to be of economic importance.

Description of the Minerals

In the following descriptions the minerals are divided into two groups,—those of major importance being described first. In both groups the minerals are described in the order of their importance in the formation.

Minerals of Major Importance

CALCITE

Importance.—Calcite is the mineral occurring most abundantly in the Niagara limestone.

Form *—The commonest crystal form is the rhombohedron, generally acute. These crystals are small, in fact many are so minute as to be seen distinctly only with the hand lens. From this extreme they range up to forms that measure nearly an inch along the edges. Many of the acute rhombs exhibit rounded edges, and some of the larger acute rhombs have been formed by the oscillatory combination of smaller rhombs. Many of the smaller obtuse rhombs closely resemble cubes. Very acute rhombs terminated by the basal pinacoid, positive and negative acute rhombs in combination, and acute rhombs modified by the scalenohedron, are combinations that occur but are not common.

Contract rhombohedral twins, twin planes $(01\bar{1}2)$ and (0001), are sometimes found. Groups of scalenohedrons, dog tooth spar, are common, the scalenohedrons being rarely more than 1½ inches long, and in the majority of specimens they are less than 1 inch

*All of the forms described in this paper have been determined megascopically, an ordinary Bausch and Lomb lens (15x) with a focal length of about ⅜ inch being used.

in length. Many of the scalenohedrons, like the acute rhombs, have been formed by the oscillatory combination of the smaller crystals. Scalenohedrons modified by the trigonal bipyramid and scalenohedrons terminated by very small rhombs are rarer combinations that occur. Six sided prisms of calcite have been found, as at Goat Island, but this form is very rare (1). The trigonal bipyramid is another rare form in which the calcite crystallizes. Massive crystallized calcite is of very common occurrence and is found in a variety of situations.

Color.—Many of the rhombohedrons are colorless and transparent, and many others are white. Some are amber, some honey yellow, and others are yellowish white. The scalenohedrons vary from white to yellowish white, a few crystals being golden yellow or amber. The massive calcite is sometimes colorless and transparent, but is usually white or gray, rarely red.

Association.—The crystals of calcite are associated with dolomite crystals in most specimens, the two together forming strikingly beautiful drusy surfaces. Yellow and purple fluorite cubes occur with the rhombs of calcite, more rarely galena and sphalerite crystals. The surfaces of cavities may be thickly sprinkled with crystals of calcite and of other minerals which project into beautifully crystallized and transparent selenite that has completely filled the cavities. Again crystals of calcite may be completely segregated and surrounded by selenite. Cleavable anhydrite, celestite, barite, and pyrite, with a few other minerals, are more rarely found in association with calcite. The white massive cleavable calcite is generally mixed with dolomite.

Occurrence.—The crystals occur singly and in groups. The groups may be rosettes of acute rhombs or scalenohedrons, or parallel growths of scalenohedrons or acute rhombohedrons, or of both together. The rhombohedron is the crystal form commonly found on drusy surfaces, and this is the form usually found embedded in selenite, the latter making excellent cabinet specimens. Joints and other cracks wholly or partially filled with massive, cleavable or amorphous calcite are very characteristic of the limestone. Joints lined with massive cleavable calcite, the inner surfaces of which, terminating in dog tooth spar large enough to show individual crystal faces, forming comb structure, are frequently seen. Limestone fragments composing the breccia may be cemented by massive cleavable calcite, and solution cavities may be wholly or partially filled with the same material. Calcite entirely replacing fossils—*Caninia* and *Halysites* especially—and preserving the original structure, is found, and rhombs of calcite studding the interior of fossil shells are of common occurrence. Massive cleavable calcite also occurs replacing the limestone; locally considerable masses have been so replaced. Also over considerable areas the original rock has been so extensively recrystallized to coarse calcite and dolomite that it will take a polish and has been sold under the trade name of Lockport marble. The dog tooth spar is more abundant in the darker colored limestone, and rhombohedrons in the lighter colored limestone.

DOLOMITE

Importance.—Next to calcite dolomite is the commonest mineral in the Niagara limestone.

Form.—The crystal form of dolomite most often seen is the rhombohedron, generally with curved faces. Twin rhombs are not of rare occurrence, the twin being the common butterfly type, twinning on the steep negative rhombohedron $(02\bar{2}1)$; and polysynthetic twinning according to the same law—twin plane $(02\bar{2}1)$—is common giving rise to fine striations on the cleavage faces parallel to the short and long diagonals of the rhomb; also twin rhombs with twinning plane $(10\bar{1}1)$ are occasionally encountered. Acute rhombs are plentiful, and in a few specimens these rhombs are terminated with the basal pinacoid. Both obtuse and acute rhombs, with plane surfaces, are of frequent occurrence. The rhombohedrons are small, generally measuring less than 3/16ths of an inch along the edges, and as with calcite, many are so small as to be seen clearly only with a good hand lens. Many of the smaller obtuse rhombs closely resemble cubes, as in calcite. Massive dolomite occurs in quantity and in many different situations.

Color.—Many of the rhombohedrons are colorless and transparent, and many are white. Pink rhombs are also common, and specimens exhibiting a delicate pink (pearl spar) are of common occurrence. The massive dolomite is colorless to white. Reddish brown dolomite rhombs occur sparingly, and have been interpreted as both siderite and ankerite.

Association.—The mineral associates of the dolomite are the same as for calcite.

Occurrence.—Dolomite occurs as single crystals and as groups of crystals, as crystals embedded in selenite, a very common and strikingly beautiful occurrence, as vein filling and vein lining, cementing breccia, and wholly or partially filling cavities. The massive dolomite occurs in the latter situations and is usually mixed with calcite.

GYPSUM

Importance.—Gypsum occurs in abundance in the Niagara limestone.

Form.—A number of varieties of gypsum have been found, many of them making beautiful cabinet specimens. The commonest variety is selenite, which occurs beautifully crystallized, pieces a foot in length being not uncommon, however distinct crystals are rare. Complete or partially complete crystals, when found, are of the simple tabular or prismatic habit characteristic of selenite. The common crystal forms are the unit prism, clinopinacoid, and negative unit hemi-pyramid in combination, and very rarely the crystal is modified by the positive hemi-orthodome. Extremely small but perfect selenite crystals found enclosed within transparent crystals of celestite exhibited a combination of the clinopinacoid with positive hemi-orthodome, unit prism and apparently the hemi-pyramid, although it is possible the last form was the negative hemi-orthodome, the extreme minuteness of the crystals making the determination of the form uncertain. The characteristic swallow tail twin—contact, with the orthopinacoid (100) the twin plane—is rare. Fibrous gypsum or satin spar is very rare, although a few excellent specimens have been found. Compact to granular gypsum (alabaster) is very common. Loose, flaky (snowy) gypsum also occurs, and massive rock gypsum is found in quantity.

Color.—Most of the selenite is colorless and beautifully transparent. Some of the selenite is of a decided silvery color, and when admixed with slight amounts of clay, as sometimes happens, is grayish brown. The satin spar has the characteristic white color with silky lustre, and the rock gypsum is a dull gray.

Association.—The varieties of gypsum are associated with the minerals found in the solution cavities of the rock. With the gypsum, especially the selenite, are found calcite, dolomite, cleavable anhydrite, sphalerite, galena, celestite, fluorite and barite. A noteworthy association has already been described—the presence of rhombs of calcite and dolomite within the selenite. Besides these, crystals of sphalerite, galena, barite, celestite and fluorite occur in the selenite. This is the most characteristic mineral association in the Niagara limestone, and specimens illustrating this association are of great beauty. Selenite may grade into snowy gypsum, and perfect tabular crystals of selenite are found embedded in both snowy gypsum and alabaster. Silvery selenite may contain irregular patches of clay, and tiny prismatic crystals of selenite may be distributed through alabaster giving the appearance of a typical felt. Extremely small and perfect crystals of selenite were found within perfect, transparent crystals of celestite, and the latter in turn were contained within transparent selenite, indicating two generations in the crystallization of the selenite.

Occurrence.—Satin spar occurs only in solution cavities. Both the selenite and alabaster fill cavities and are common minerals binding the limestone fragments composing the breccia, especially the selenite. Veins of selenite and occasionally alabaster are found, but are not common. Selenite occurs filling cavities in fossils, and replacing fossils. Both the selenite and alabaster replace the limestone, and the rock gypsum is found replacing the limestone and in solution cavities.

FLUORITE

Importance.—Fluorite is a common mineral in the Niagara limestone.

Form.—The mineral occurs almost always in distinct crystals, which are generally perfect. The common crystal form is the cube. The cube modified by the octahedron is also relatively common, while the octahedron alone and the dodecahedron are very rarely observed in this formation. The penetration twins of fluorite, twin plane (111), are very rare also. Crystals up to 1½ inches, measured along the edges, have been found, although crystals over

1 inch are rare. Granular fluorite is sometimes found, as well as fluorite in cleavable masses.

Color.—Many of the crystals of fluorite have an exquisite finish, with very bright splendent surfaces. Many crystals are colorless and perfectly transparent. Purple crystals are common, often a dark purple, while green and yellowish green crystals and crystals of a delicate straw yellow color are not so common. In the purple crystals the color may be evenly distributed through the crystal, or "patchy," the rest of the crystal being colorless or but slightly purple.

Association.—The mineral is associated especially with calcite, dolomite, anhydrite, sphalerite, galena, selenite and celestite. A characteristic association has already been mentioned—the presence of perfect crystals embedded in selenite.

Occurrence.—Fluorite occurs either in isolated crystals, or as clusters of crystals, especially cubes, in solution cavities or in joints, often forming beautiful drusy surfaces with other minerals.

GALENA

Importance.—Galena is a common mineral in the Niagara limestone, however it is too widely disseminated and too small in amount to be of economic importance.

Form.—The form of galena that is generally found is the cube, small and perfect. The cube modified by the octahedron, as well as the cube, octahedron and dodecahedron in combination are sometimes encountered. Other forms are very rare. Crystals up to 1 inch are found, but most crystals measure less than ½ inch. The mineral also occurs in small cleavable masses.

Color.—The color is from light to dark gray. Crystal surfaces sometimes show a beautiful purple tarnish with iridescence due to the superficial alteration (oxidation) of the mineral.

Association.—The usual mineral associates are calcite, dolomite, fluorite, sphalerite and gypsum. Perfect crystals of galena occur embedded in selenite.

Occurrence.—The mineral occurs as distinct crystals on the walls of solution cavities, also as threads and thin veins, and filling cavities. A mass weighing several hundred pounds was found at

Rochester in a single cavity, during the excavation for the old Erie canal (2). The mineral is also found apparently replacing the limestone.

SPHALERITE

Importance.—Sphalerite is a common mineral in the Niagara limestone, however, like galena, it is too widely disseminated and too small in amount to be of economic importance.

Form.—The mineral is nearly always beautifully crystallized, but perfect crystals are rare, nearly all being distorted, generally flattened with rounded angles. The dodecahedron in combination with the trigonal tristetrahedron is of very common occurrence, the crystals being rounded in most cases to produce hopper-shaped forms. The dodecahedron alone and the octahedron are other common forms. Positive and negative tetrahedrons in combination, and the tetrahedron in combination with the cube, are occasionally found, the crystals being flattened. Twin crystals—contact, with the composition face parallel to the face of the octahedron (111)—are sometimes found. All crystals are small, less than ½ inch in size in most cases. Small cleavable masses of the mineral also occur.

Color.—The mineral varies greatly in color. Transparent crystals are rather common, as well as translucent honey to wax yellow crystals. Other specimens are light to dark brown, reddish brown, and some are black. Nearly all specimens exhibit a brilliant resinous lustre.

Association.—The usual mineral associates are galena, calcite, dolomite, fluorite and gypsum. Perfect crystals occur embedded in transparent selenite, and crystals were found upon the surfaces of rhombs of dolomite.

Occurrence.—The mineral occurs as individual crystals, groups of crystals, and in small cleavable masses, partly or wholly filling solution cavities. The crystals are confined to the solution cavities. Cleavable sphalerite is found that apparently replaces the limestone, judging from megascopic examination. The mineral also serves as a binder of the limestone breccia, and sometimes completely fills the cavities in fossils. Sphalerite seems to be more abundant in the darker portions of the limestone (2).

PYRITE

Importance.—Pyrite is a common mineral in the Niagara limestone.

Form.—Crystals are common, the cube and the cube in combination with the octahedron being common forms. Pyritohedrons singly and in combination with the dodecahedron are of frequent occurrence too. Many of the crystal faces are striated. The crystals are small, less than 1 inch, in most cases less than ½ inch measured on the edges. Nodules and irregular masses are also found.

Color.—All specimens are a bright brass yellow.

Association.—The mineral occurs alone or associated with calcite, dolomite, galena, sphalerite and gypsum. A pyritohedron was found on a prism of marcasite, and several crystals were studied that were developed on the surfaces of rhombohedrons of dolomite.

Occurrence.—Distinct crystals and crystal aggregates are found lining the walls of solution cavities, while irregular masses showing crystal faces and nodular masses are found partially or wholly filling solution cavities.

BARITE

Importance.—Barite is a common mineral in the Niagara limestone.

Form.—Individual crystals of barite are rare in this formation, yet in this study a number of very small but perfect crystals were found that exhibited the following combinations: (1) Macrodome with brachydome, (2) basal pinacoid, macrodome and brachydome, (3) unit prism and basal pinacoid, (4) basal pinacoid, macrodome and prism, (5) basal pinacoid, bipyramid, macrodome and brachydome. Most occurrences of the mineral are masses composed of tabular and prismatic aggregates, the individuals being elongated parallel to the basal pinacoid and the *a* or brachyaxis. Hence nearly all individual crystals exhibit the basal pinacoid and brachydome, but the terminations are indefinite, often being buried in the limestone matrix, or broken off. Fine striations lengthwise of the crystal faces are characteristic. Crystal masses are found 2 to 6 inches in length and make beautiful cabinet specimens. Fibrous and lamellar nodules occur as well as massive barite.

Color.—The color is white to light gray and bluish gray, many of the crystals being translucent and some perfectly transparent.

The fibrous and lamellar nodules often exhibit a reddish color (1). The massive barite is snow white.

Association.—The mineral occurs alone or with fluorite, calcite, dolomite, celestite and gypsum. Perfect crystals are found embedded in selenite. Intergrowths of crystals of this mineral with crystals of celestite are also common.

Occurrence.—Barite is found partially or wholly filling solution cavities, cementing the limestone fragments composing the breccia, as vein filling, and rarely replacing the limestone.

CELESTITE

Importance.—Celestite is relatively common in the Niagara limestone.

Form.—The mineral occurs in crystals which are either prismatic or tabular due to the preponderance of the basal pinacoid. The common forms are the unit prism, brachydome, basal pinacoid and macrodome in combination. In this study the following combinations also were found: (1) Macrodome with brachydome, (2) prism, basal pinacoid and macrodome, (3) basal pinacoid, macrodome and brachydome, (4) basal pinacoid, macrodome and brachypinacoid. Most crystals are elongated in the direction of the *a* or brachyaxis, rarely in the direction of the macroaxis. The crystals may be single, but often specimens exhibit a crested divergent arrangement of a number of tabular crystals. Cleavable masses and also nodular masses of the mineral are also found, as well as fibrous aggregates. The fibers are coarse, almost friable, and may be straight, divergent, or bent in various directions and forms (1).

Color.—The crystals may be white, bluish white or blue, and are opaque to semitransparent. The fibrous variety is snow white.

Association.—The mineral occurs chiefly with calcite, dolomite, gypsum, barite, and anhydrite, or alone. Specimens often effervesce in acid due to an intimate admixture with calite. Transparent selenite sometimes contains beautiful groups of perfect crystals.

Occurrence.—The mineral is found as individual crystals, but groups of crystals are much more common, some of these groups being several inches in length. The mineral is also found in solution cavities and binding limestone fragments composing the breccia.

ANHYDRITE

Importance.—Anhydrite is a relatively common mineral in the Niagara limestone.

Form.—The mineral may occur as massive fragments or in crystallized and cleavable masses. The cleavage is the typical orthorhombic, pinacoidal (pseudo-cubic) type characteristic of anhydrite. Foliated masses also are found (1).

Color.—The specimens range from dark gray to blue, and are transparent to translucent. The non-cleavable massive anhydrite is dull gray and opaque.

Association.—The mineral is associated especially with calcite, barite, celestite, dolomite, and gypsum, and may show alteration to gypsum locally. It is often mixed with calcite, so that fragments effervesce on contact with acid.

Occurrence.—It occurs in solution cavities, as replacement of the limestone, and as a binder of the limestone fragments composing the breccia.

STRONTIANITE

Importance.—In comparison with the minerals already discussed strontianite is a relatively rare mineral in the Niagara limestone.

Form.—It occurs in small and imperfect crystals rudely spear-shaped or acicular, also in radial aggregates. Crystalline masses of the mineral have also been found.

Color.—The specimens are white and translucent to opaque.

Association.—The mineral is associated with celestite, galena, calcite, dolomite, barite, and gypsum.

Occurrence.—It is found lining joint surfaces and in solution cavities.

ARAGONITE

Importance.—Aragonite is a relatively rare mineral in the Niagara limestone.

Form.—It is found in small aggregates of prismatic crystals, and at Lockport as *flos ferri* coating gypsum (1).

Color.—The specimens are colorless and transparent to the snow white characteristic of *flos ferri.*

Association.—The mineral is associated chiefly with calcite, dolomite and gypsum.

Occurrence.—Aragonite is restricted in its occurrence to solution cavities in the limestone.

MARCASITE

Importance.—Marcasite is a relatively rare mineral in the Niagara limestone.

Form.—It occurs in small granular aggregates and as minute crystals only a small fraction of an inch in size. The crystals are tabular and wedge shape, or short to long columnar. Extremely small striated columns occur that appear to be perfectly terminated, however the terminal faces are too small to be deciphered megascopically. On some of the larger crystals the following combinations were determined with certainty: (1) Prism with brachydome, the brachydome being greatly elongated, (2) prism and basal pinacoid with brachydome.

Color.—The color of the crystals is the characteristic pale bronze yellow.

Association.—The mineral associates are in most places pyrite, galena and sphalerite. The extremely small columnar crystals discussed above were found upon the surfaces of rhombs of dolomite.

Occurrence.—The mineral is found lining the surfaces of cavities and occasionally on the exposed surfaces of the limestone.

Minerals of Minor Importance

SULPHUR

Sulphur is a rare mineral in the Niagara limestone, but, when found, it is almost always beautifully crystallized. Many of the crystals are perfect acute bipyramids which are associated with bipyramids that are distorted, in most cases flattened. On some of the crystals bisphenoid faces may be recognized, and some of the very tabular crystals owe their shape to the preponderance of the basal pinacoid. The crystals are confined to the solution cavities in the rock, and are sulphur yellow to straw yellow in color, and translucent to almost transparent. They are associated with calcite, dolomite, sphalerite and fluorite. An interesting association discovered was the intergrowth of long tabular crystals of the sulphur with the prismatic crystals of barite. The mineral also occurs as incrustations or coatings on the surfaces of solution cavities, joint surfaces, and on exposed surfaces of the limestone. Flakes and small grains of sulphur occur in similar situations, and under the lens are seen to be imperfect crystals, however they are so small that the determination of the crystal forms is impracticable with the hand lens.

SIDERITE

Siderite is a rare mineral in this formation, however cleavable masses and rhombs of the mineral are occasionally found. It is probable that much of this material is ferruginous dolomite, and possibly some of it may prove to be ankerite. The mineral is restricted to solution cavities in its occurrence.

QUARTZ

Quartz is a rare mineral in the Niagara limestone, if the amorphous cherty nodules found in solution cavities are excepted. Only one example of crystallized quartz was found in the large collection studied by the writer. The surface of this specimen was composed of innumerable and extremely minute quartz crystals, resting on a base of crystallized dolomite, and apparently representing the inner lining of a geode. The crystals were transparent, perfect and simple, the only forms found being the hexagonal prism terminated by the hexagonal bipyramid.

MAGNESITE

Small white cleavable masses of this mineral are sometimes found, however the mineral is very rare.

RUTILE

Rutile is sometimes found in solution cavities as long delicate prismatic crystals of dark brown color which appear like black hairs that are either attached to or penetrate calcite and dolomite crystals. The crystals are striated longitudinally, and possess a high vitreous, almost metallic lustre, with surfaces tarnished in some specimens. The mineral is fusible to a black globule which is attracted by the magnet. This property has led some observers to identify the mineral as acmite, rather than rutile. The mineral also occurs in the efflorescence on the exposed surfaces of the limestone.

CHALCOPYRITE

Chalcopyrite has been reported from the Niagara region where it occurs in cavities in the limestone associated with malachite (4).

MALACHITE

Small masses of this mineral occur in the solution cavities in the limestone in the Niagara region (4), and elsewhere. The mineral is also found as a green stain coating the surfaces of the limestone in joints and cavities. Like chalcopyrite it is a rare mineral in the Niagara formation.

Mineral Associations

The mineral associations have been discussed in the case of each mineral of importance in the Niagara limestone. There remain only certain generalizations and conclusions to be emphasized. Calcite and dolomite occur together nearly always; the same is true of galena and sphalerite, celestite and barite, pyrite and marcasite, and gypsum and anhydrite. Again an intimate association of all or most of the important minerals found in the Niagara formation will be revealed in a single small cavity. Apparently there is no law governing this association, which makes collecting the more fascinating for each find illustrates different combinations of minerals. The presence of crystals of various minerals within transparent selenite has been repeatedly mentioned. It is possible to explain this intimate association in two ways: (1) The minerals embedded in the selenite crystallized upon the limestone walls of solution cavities and later these walls were replaced by selenite, the solutions finally entirely filling the cavities, leaving the crystals within the selenite mass. (2) The solutions precipitated the selenite on the rock walls around the bases of the crystals and the latter were wedged off by the force of crystallization of the growing selenite masses to be completely surrounded by selenite with the final filling of the cavities.

Origin of the Minerals

The minerals of the Niagara limestone have arisen for the most part by precipitation from percolating ground water long after the formations were elevated above the sea and consolidated. In most cases their origin postdates the formation of the solution cavities characteristic of the limestone, hence they are relatively recent geologically. None was deposited by magmatic waters. A few individual specimens, possibly some of the fluorite, were deposited from connate waters. Some of the anhydrite has been altered to gypsum. The sulphur may represent the oxidation of hydrogen sulphide either introduced from above by underground water that has circulated through decaying organic matter near the surface, or formed in the oxidation of the sulphides galena and sphalerite, minerals found in association with the sulphur. The sulphur may also have originated in part by the reduction of such sulphates as celestite, barite, gypsum and anhydrite, the reducing agent being the bituminous matter in the limestone, soluble and easily decomposed sulphides being formed which readily yielded hydrogen sulphide that has oxidized to form sulphur. The malachite represents in part at least the carbonation and hydration of chalcopyrite.

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