DEVONIAN CARBONATES AND ECONOMIC RESOURCES: THE BLUE CIRCLE AND CALLANAN QUARRIES

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CRUSHED STONE AND CEMENT PRODUCTION - GENERAL CONSIDERATIONS

The production of crushed stone in New York was 33,500,000 tons 1994 with a value of $196 million. Most of the crushed stone produced in New York is limestone and dolostone with traprock (diabase) and various metamorphic rocks making up the bulk of the remainder. Cement manufacturing amounted to 2,925,000 tons valued at slightly over $149 million. Taken together, crushed stone and cement account for 40% of the value of mineral produced in New York. There is an order of magnitude difference in the price of these two commodities with crushed stone trading for an average of $5.85/ton and cement valued at an average of $50.94/ton. This price difference leads directly to the contrast in mining operations that will be examined. On this field trip, we will visit two quarries operating in the rocks of the Helderbergs. One of these produces crushed stone for construction aggregate and the other produces cement. Although both companies are working in the same stratigraphic section with similar equipment and mining plans, the end use of the rock drives the companies to use very different geologic units within the overall stratigraphic framework. The following brief discussion outlines the processes and constraints on the construction aggregate and cement industries.

Aggregates

Construction aggregates are hard, inert materials suitable for being formed into a stable mass by the addition of cementing materials to produce concrete (portland or bituminous), or by compaction or natural weight to produce a road base or foundation fill. Conditions necessary for a rock deposit to be developed for construction crushed stone and much of the following discussion are given by Herrick (1994) to include:

° Quality - passes specifications for strength and durability;
° Quantity - adequate volume of rock is present to support a production life of 10-20 years;
° Market - must have an adequate market to sustain the costs of a new operation;
° Transportation - costs must be competitive for the intended market;
° Environmental - impacts of mining and attendant operations must be within acceptable limits;
° Permitability - all operations associated with the mine must be permitted by one or more governmental agencies.

Specific chemical and physical properties control the use of a particular rock for crushed stone. Chemically, the rock should be inert and should not change chemically in use. However some rocks contain minerals that are reactive in portland cement, bituminous concrete and other environments. Rocks containing silica in the form of glass, chalcedony, opal, chert, and finely divided quartz may react with high alkali cement to form a gel which, due to the increased volume of the gel, caused deterioration of the concrete. Moderate to high clay content of dolomitic limestones may also react with high-alkali cement. Expansion of the cement appears to be caused by microfracturing throughout the cement and aggregate as well as in reaction rims around the carbonate rock particles (Rogers, 1979). Sulfides such as pyrite, marcasite, and pyrrhotite react with water to form iron hydroxides and sulfates leading to discoloration and weakening of concrete.

In Garver, J.I., and Smith, J.A. (editors), Field Trips for the 67th annual meeting of the New York State Geological Association, Union College, Schenectady NY, 1995, p. 163-171.

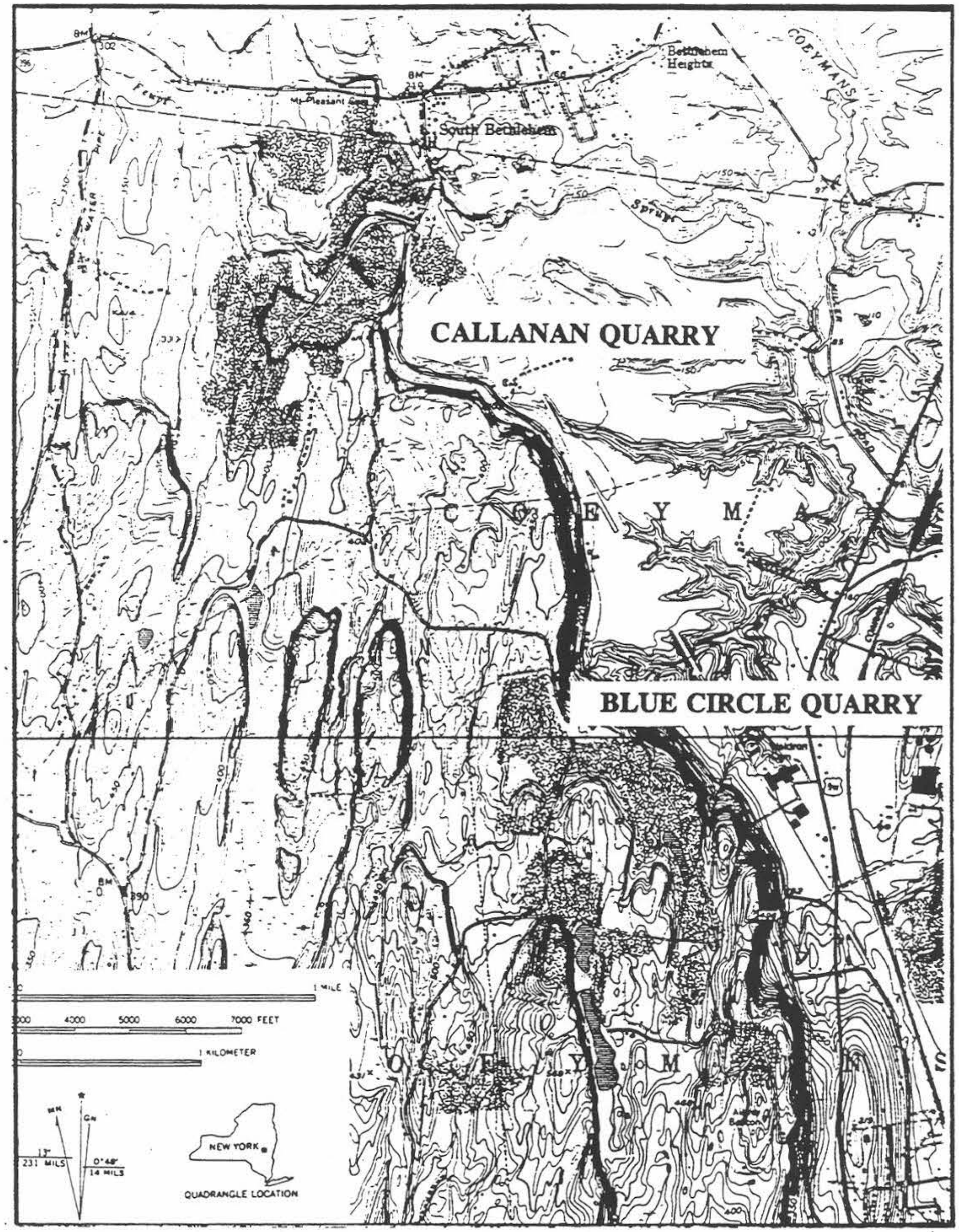

Figure 1. Location of Callanan Industries and Blue Circle Industries quarries.

In bituminous mixes, certain rocks present a problem when the bituminous film separates (strips) from the aggregate. Stripping is related to the electrical charge on the surface of the rock particle because surfaces with a negative charge may attract water and thus promote lack of adhesion of the bituminous film. Rocks with a high quartz content, such as quartzites and some granites, gneisses and schists, may present stripping problems.

Physical properties critical for use of a given rock as construction aggregate are strength and durability, porosity and pore size, and volume integrity - that is, maintaining constant volume when subjected to variable moisture or freeze/thaw conditions. Another important property is the tendency of the rock to break into relatively equant fragments. Large amounts of platy or flat fragments, such as are derived from slate, shale and some schists are not acceptable. Coarsely crystalline igneous rocks, quartzite, or marble may be excessively brittle and too easily shattered. The presence of certain minerals such as olivine or metamorphic amphiboles may create a weak, brittle rock.

Cement

The discussion that follows is adapted from (Ames and Cutcliff, 1983). Although there is much confusion between the terms cement and concrete, cement manufacture is the processing of selected and prepared raw materials into a synthetic mixture, called clinker, that can be ground into a powder having a specific chemical composition and the physical properties of cement. Cement manufacture is accomplished in a number of steps which may vary from plant to plant but it is characterized by a key pyroprocessing (burning) step which brings about the necessary changes in the raw materials. This burning step results in a chemical change. Concrete is a combination of cement, aggregate, and water. Cement, then, is one of the raw materials of concrete.

The primary requirement for making cement is a source of lime (CaO) which is generally available as calcium carbonate in limestone or some close relative thereof. However, other sources of lime have been used including shell, aragonitic sand, slag, anhydrite and feldspar. Secondary raw materials are needed to supply the other chemical components of cement, specifically silica, alumina, and iron. Although the sources of these components may be diverse, the ratios of the chemical constituents must be carefully controlled. Typical sources of these components are sand, silt and clay and their corresponding rocks types. Manufacturing wastes and ash may also be used. In addition to the raw materials listed above, a source of SO_3 is required to control setting times for the concrete made with the cement. Generally, the addition of gypsum is mandatory. The considerable flexibility in selection of raw materials to be blended into acceptable kiln feed lies in the fact that cement making is basically a chemical process. Table 1 lists the raw material used for cement in the United States.

Raw materials and fuels in the cement kiln introduce components other than those sought. Within specified limits, these components are tolerable, even beneficial. However, if present above certain defined levels, these may constitute deleterious impurities. Magnesium compounds are the most familiar and common of these. At low levels, generally under four percent, MgO acts as a fluxing agent and is regarded as innocuous. But at higher levels, magnesium compounds that form cause expansion and ultimately results in disruption of the concrete.

The production of cement involves a large amount of mining activity. Generally, open pit methods are used to produce raw cement materials. All activities associated with crushed stone mining are employed by cement plants including stripping, drilling, blasting and breaking, loading, transportation, and reclamation. The raw materials are then milled and blended. The objective of milling is to prepare sizes and mixtures of raw materials for proper kiln feed. Grinding can be done wet or dry. At Blue Circle, wet milling produces a slurry of ground kiln feed in which water content has been kept as close as possible to the minimum (35-40%) that can be pumped and handled.

Table 1. Raw material used in making cement clinker in the United States.

Calcium carbonate sources	Alumina sources
limestone, including	shale
lithified limestone	clay and mud
chalk	loess
marble	slag
marl	fly ash

oyster shell reef	bauxite
coquina	alumina processing waste
aragonite sand	staurolite
slag	mill fines (granite)

Silica sources	Iron sources
sand, sandstone, quartzite	iron ore
clay and claystone	blast furnace flue dust
shale	pyrite cinder
loess	mill scale
mill fines	fly ash
fly ash	

Pyroprocessing (burning) is the key process in cement manufacture. Burning at high temperature causes the raw materials to react and combine to produce *clinker* - a balanced mixture of synthetic "minerals" and glasses that can be ground into cement. The process is carried out in a rotary kiln.

Rotary kilns are steel cylinders about 25 feet in diameter and up to 760 feet long. They are lined with refractory material, usually brick, which are designed to develop a coating of raw materials so that the finished materials are processed over similar material. Kilns are inclined slightly so that their rotation (50-90 rph) moves the materials from the feed end to the discharge end at the desired rate. Retention time in the kiln is several hours although the burning zone occupies only about 15% of the kiln and burning temperature is much more important than the travel time of the raw material.

The kiln is fueled (with powdered coal, oil or gas) under pressure through a burner pipe positioned at the discharge end and the flame extends well up into the kiln. As the materials move from one end of kiln to the other, they pass through a series of stages. These stages include heating to lose water, calcination of the carbonates (i.e. driving off CO_2) and the fusion, melting and reacting to form clinker. The burning fuel is regulated so that the hottest part of the kiln is 2600° to 3000° F. The kiln zone in which the chemical combination of clinker compounds (Table 2) occurs begins 40 to 50 feet from the discharge end. Clinker leaves the kiln as sand-sized to golf ball-sized rounded particles that are cooled in a variety of ways on their way to finish grinding.

The clinker is relatively unreactive at this point but clinker that is finish-ground hot or old clinker that has become hydrated each produce poorer quality cement. At this point in the manufacturing process, the SO_3 content of the cement must be adjusted. This is critical in providing the desired setting time for the concrete made with the cement. Gypsum (3-6%) is traditionally interground with the clinker to provide the SO_3. Additions of air-entraining agents and other ingredients are metered in at this time. The cement is now ready for bagging or shipment in bulk via rail, truck or, in the case of Blue Circle, by water on self-unloading barges.

Table 2. Cement compounds (adapted from Clausen, 1960)

Compound	Composition	Percent content in Type I cement
Tricalcium silicate	Ca_3SiO_5	45
Dicalcium silicate	Ca_2SiO_4	27
Tricalcium aluminate	$Ca_3Al_2O_6$	11
Tetracalcium-aluminoferrite*	$Ca_4Al_2Fe_2O_{10}$	8

* The composition of the Fe-bearing phase is an approximation and may range from $Ca_2Fe_2O_5$ to $Ca_6Al_4Fe_2O_{15}$.

REGIONAL GEOLOGIC SETTING

The two quarries to be visited on this trip lie within the Helderberg plateau, which rises on the west side of the Hudson Valley. Westward, the Catskill Mountains rise above the plateau to an elevation of roughly 4000 feet. East of the Plateau are the Hudson lowlands and the Taconic uplands. The Hudson River flows southward, at tidal level, a few miles east of the quarries.

The rock units in the mid-Hudson Valley region range in age from Ordovician (≈450 my) to Middle Devonian (≈380 my). The rocks are mainly carbonates and shales with two thin clastic units. Within this sequence is the Lower Devonian Helderberg Group which, in this part of New York is represented by five of the seven Helderberg units. These are, from oldest to youngest, the Manlius, Coeymans, Kalkberg, New Scotland, and Becraft. The youngest units, the Alsen and Port Ewen, are not present here. Figure 2 is a generalized stratigraphic column of the Helderberg rocks and Figure 3 is a diagrammatic cross section of Lower Devonian formations along the outcrop belt. Regionally, the Helderberg rocks are exposed from Cayuga Lake in central New York eastward to the so-called Helderberg Escarpment southwest of Albany and thence southward and southwestward through the Hudson Valley, culminating in the vicinity of Port Jervis.

The rocks in which the quarries are developed lie between the highly deformed rocks of the Taconics and the much less disturbed rocks of the Catskill highlands. Structurally, the rocks in the quarries have been broadly folded with wavelengths of 900-1000 feet and amplitudes of 50 feet. Fold axes generally plunge southward although an anticline in the southernmost face of the Callanan Quarry is nearly horizontal. The folds are broken by several thrust faults that dip 20-30 degrees to the east. Offset on these faults varies from 50 to 200 feet.

FORMATION DESCRIPTIONS

Much of the following discussion is paraphrased from Banino and Brown (1978).

Manlius Formation

The Manlius Formation has a mixed carbonate lithology, ranging from a dark-gray, thin-bedded, shaly limestone to argillaceous, silty, laminated dolomite. The formation has been subdivided into the four members in the Mohawk Valley (Thatcher, Olney, Elmwood and Clark Reservation) but only the Thatcher is present in the Hudson Valley (Rickard, 1962). The Manlius consists of interbedded dolomitic "ribbon" or "paper" limestones and pure massive to biostromal limestones. Fossils, particularly *Tentaculites gyracanthus*, are concentrated in the limestone beds. Primarily for the purposes of mining control in the Hudson Valley cement quarries, this unit has been divided into six units designated (youngest to oldest) M6-M1.

M6 is a transitional unit between the overlying Coeymans and the much darker gray and finer grained Manlius limestone. Typical M6 is a dark-gray, dense, fine-grained material. Bedding is generally two to 12 inches with local shaly partings.

M5 has been called the "paper" or "ribbon" bed of the Manlius. It is a dolomitic limestone that characteristically weathers to a light gray to tarnished green color.

M4 is a dark-gray, finely crystalline, massive limestone. Bedding is typically one to two feet. Near the bottom of M4, algal reef structures have been reported.

M3 is another dark gray, dense limestone. The unit has lamellar partings 1/8-1/4 inch thick containing black shale. Sparry calcite is common in the more massive crystalline beds.

M2 is a unit similar to M5.

M1, the lowest unit, is a dense, dark-gray limestone with interbedded shaly partings. The more crystalline beds increase in thickness towards the bottom of the unit. The lower beds contain cephalopods. The lower contact with the Roundout Formation is recognized by a color change from dark-gray to tan and an increase in Mg-carbonate in the Roundout.

Coeymans Formation

The Coeymans is a pure, bluish-gray, medium- to coarse-crystalline limestone that forms prominent ledges along the Helderberg Escarpment. Generally massive-bedded, individual beds are difficult to recognize. Crinoid stems, locally silicified, are common. The brachiopod *Gypidula coeymanensis* is a very common fossil in this formation and is used to identify the Manlius-Coeymans contact. The clean limestone of the Coeymans is thought to represent more open marine conditions relative to the depositional environment of the Manlius.

Helderberg Group

Formation	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Port Ewen	see New Scotland, below	see New Scotland, below	see New Scotland, below
Alsen	see Kalkberg, below	see Kalkberg, below	see Kalkberg, below
Becraft	see Coeymans, below	see Coeymans, below	see Coeymans, below
New Scotland	fine- to medium-grained limestone that contains clay shale that contains calcium carbonate thin to medium layers of uniform thickness	high number & variety of sea bottom dwellers	deepest water of the Helderberg Sea; below motion of fair-weather waves; bottom agitated by storm waves
Kalkberg	medium-grained limestone rich in clay & silica chert thin to medium layers	high number & variety: bryozoans brachiopods crinoids corals trilobites mollusks ostracodes	deeper water at or near lowest point reached by fair-weather waves bottom occasionally agitated
Coeymans	clean medium- to coarse-grained limestone scattered small coral and stromatoporoid reefs uneven, medium to thick layers cross-bedding	moderate number pelmatozoans corals brachiopods mollusks trilobites ostracodes	shallow water shelf vigorous wave motion well-agitated bottom
Upper Manlius	fine- to medium-grained limestone slightly uneven, medium to thick layers scour & fill, birdseye, ripple marks, cross-bedding	low to moderate number & variety stromatoporoids brachiopods mollusks ostracodes trilobites	shallow water near the shore & near low tide moderate wave motion--protected by a barrier
Lower Manlius	fine-grained limestone & dolostone medium to thin layers; some laminations alternating layers of shale rich in carbonate sediments scour & fill, birdseye, desiccation cracks	low number & variety stromatolites oncolites ostracodes brachiopods gastropods tentaculites	between high & low tides and shallow water below low tide

Figure 2. Stratigraphy of the Helderberg group. Modified from Isachsen et al. (1991)

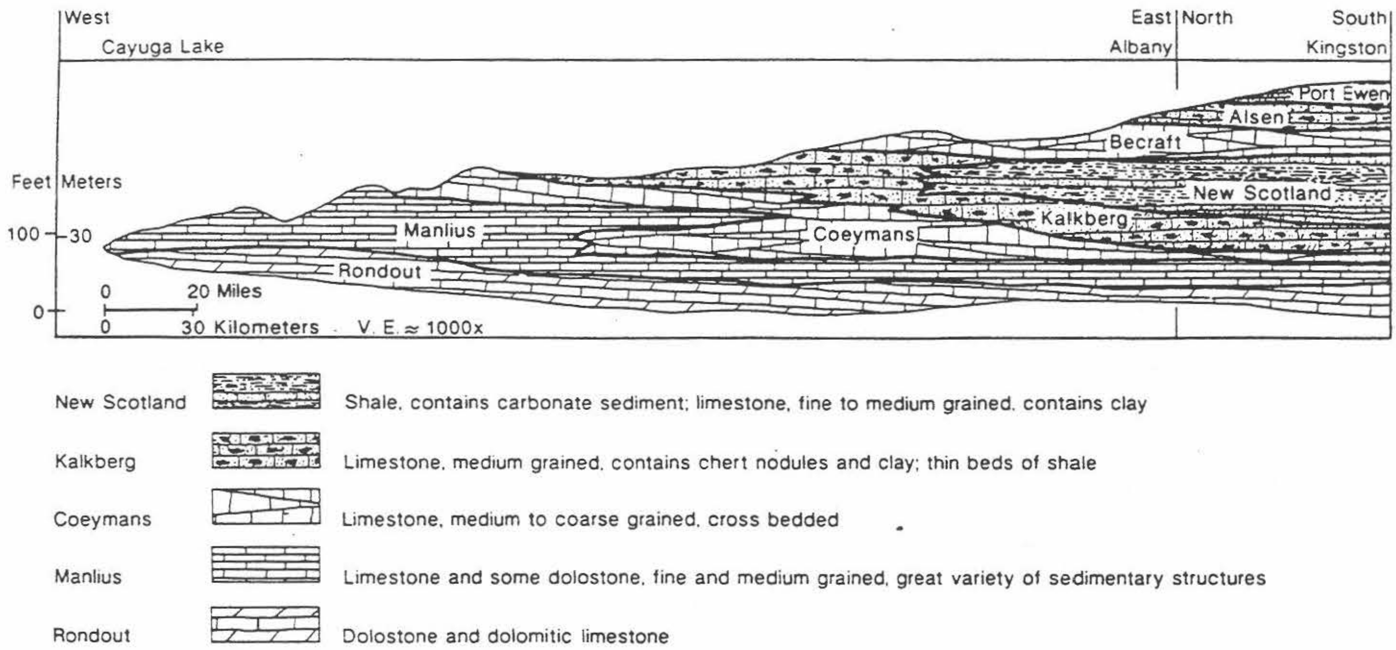

Figure 3. Diagrammatic cross section of Lower Devonian formations, east to west along the outcrop belt from central New York to the mid-Hudson Valley. Figure modified from Isachsen et al. (1991).

Kalkberg Formation

The Kalkberg ranges from a bluish-gray, chert-rich limestone near the base to gray, fine-grained, argillaceous limestone near the top. Lithologically, the formation has been divided into four members from oldest to youngest: the Lower and Upper Hannacroix and the Lower and Upper Broncks Lake. The environment of deposition of the Kalkberg is interpreted to be transitional between a shallow, wave-agitated sea and a deeper, quieter setting represented by the overlying New Scotland Formation.

The Lower Hannacroix is the dominant bluff-forming unit of the Helderberg Escarpment. It is recognized by the prominent black chert nodules and layers spaced about one foot apart, each with a thickness of about four inches. The rock is massive-bedded and is finer grained and darker than the Coeymans. The Upper Hannacroix is a fine-grained, fairly massive, gray limestone with anastomosing argillaceous partings which give a net-like appearance to weathered surfaces. this unit does not contain layers of chert but has numerous small nodules of black and dark gray chert. Except for the presence of chert, this unit is similar to the Coeymans although finer grained and less fossiliferous. the top of the unit is marked by the first appearance of a dark-gray, euxinic shale bed bout two feet thick containing pyrite nodules and small brachiopods.

The Lower Broncks Lake is a fine-grained, bluish gray limestone with beds one to three feet thick interbedded with one to two inch calcareous shale beds. Fossils are abundant in this unit and encrusting bryozoans are common. The Upper Broncks Lake is fine-grained, bluish-gray limestone with beds from three to more than 12 inches and fewer shale layers than the underlying unit. One, two or three thin, black to dark gray chert layers occur near the base.

New Scotland Formation

The New Scotland Formation is composed of alternating medium-gray, very-fine-grained, impure limestone and dark-gray calcareous mudstone and siltstone with variable quantities of chert and pyrite. The mudstone and siltstone at the base grade upward into argillaceous and silty limestone. (The unit has, at times, been described as a calcareous shale.) Though a greater influx of mud occurred during the deposition of the New Scotland than during the deposition of older units, a richer fauna was present including sponges, corals, bryozoans, brachiopods, pelecypods, gastropods, and trilobites.

Becraft Formation

The Becraft Formation is a light-gray to pink, coarsely crystalline, biofragmental limestone. It is massive and bedding planes are often difficult to distinguish. Locally, gray chert occurs near the base and top. Informally two units are sometimes observed in the Becraft. The lower unit is shalier and has a lower lime and higher silica content than the upper. Abundant fossils occur in the Becraft, dominantly crinoids and brachiopods. The environment of deposition is interpreted to be a clean, clear sea.

SITE GEOLOGY

The Callanan Quarry is located primarily in the Town of Coeymans, south of NY Route 396 and the village of South Bethlehem (Fig. 1). The location can be found on the Delmar 7.5' quadrangle. The quarry is owned and operated by Callanan Industries, Inc. All correspondence concerning access should be directed to Mr. Charles A. Stokes, Senior Vice-President, Callanan Industries, One South Street, South Bethlehem, NY 12161. The Blue Circle Quarry is located in the town of Coeymans, east of NY Route 9W (Fig. 1). The location can be found on the Ravena 7.5' quadrangle. Correspondence concerning quarry access should be directed to Mr. Kevin Riley, Quarry Superintendent, Blue Circle Industries, Ravena, NY 12143.

The two quarries described herein are separated from each other by nine miles. Consequently the geology at the two sites is quite similar. Both quarries are developed in the lower and middle units of the Helderberg Group rocks. Here, the Manlius is 54 feet thick and subdivided as described above. Units M1, M3, and M6 are dark-gray, fine-grained to sublithographic, fine to medium bedded, subtidal limestone. Units M2 and M5 are light-gray, fine-grained, thin-bedded, supertidal dolomitic limestone. Unit M4 is medium to dark-gray, massive, intertidal, stromatoporoid limestone. The Coeymans is 27 feet thick, light-gray, medium-grained, massive, non-argillaceous, fossiliferous limestone. It is homogeneous and lacks marker beds.

The Kalkberg is 66 feet in total thickness. The Lower Hannacroix is 11-18 feet thick, medium-gray, medium-bedded limestone with interbedded dark gray to black chert nodules and chert beds one to four inches thick. The Upper Hannacroix is 10 feet thick, fine- to medium-grained limestone. This unit is similar to the Coeymans except that it is less fossiliferous and the fossils are somewhat smaller. The Lower and Upper Broncks Lake total 45 feet in thickness. They are fine- to medium-grained, medium-bedded, argillaceous limestones.

The New Scotland is 100 feet thick and is composed of medium to thick-bedded, argillaceous limestone similar in appearance to the Kalkberg Formation. The uppermost part of the New Scotland is transitional into the overlying Becraft. The Becraft is 40 feet thick, tan to grayish-white with greenish-gray shaly partings. It is a coarse-grained and highly fossiliferous limestone.

Several marker beds and stratigraphic horizons are visible in the quarries and can be used for stratigraphic location. The Coeymans-Kalkberg contact is a key horizon. This contact can be identified by the following characteristics: (1) on a weathered surface, the Coeymans is light-gray to buff and the Kalkberg is medium-gray and is less resistant to weathering; (2) a black, shaly layer, two to six inches thick, commonly occurs between the formations; (3) the Lower Hannacroix of the Kalkberg contains discontinuous bedded black chert.

The contact between the Kalkberg and New Scotland is marked by an increase in siliceous material in the New Scotland giving it a shaly appearance relative to the more massive Upper Broncks Lake Member of the Kalkberg.

The top of the New Scotland contains a transitional zone into the overlying Becraft Formation characterized by alternating beds of crystalline (Becraft lithology) and shaly beds (New Scotland lithology). Also notable at the contact are green shale bands of the Becraft as opposed to the black shale of the New Scotland.

PRODUCTION

The majority of the aggregate produced from the Callanan Quarry in South Bethlehem is used for New York State Department of Transportation (NYSDOT) road construction. Therefore, NYSDOT specifications are most crucial to Callanan's mining. High-friction aggregate, material with greater than 20% non-carbonate content, is used in top-coarse paving material in New York State. High-fiction material commands the highest price, and, for this reason, is the most valuable to producers. Of the five formations mined at Callanan's quarry, only the New Scotland and Kalkberg are approved for high-friction use. As Callanan excavates the New Scotland and Kalkberg, most of the Manlius, Coeymans and Becraft is left behind. These formations are, however, mined for non-friction products, which include commercial uses.

A few miles south, the situation is startlingly different. Blue Circle is discarding in waste piles approximately 85% of the Kalkberg and nearly 100% of the New Scotland that is mined. Callanan's low-valued Manlius, Coeymans and Becraft formations command high value at Blue Circle's quarry. These three formations have a high carbonate content which is extremely important in cement production. So much so that Blue Circle strips up to 160 feet of waste rock (rock which is valuable to Callanan) to get to the Manlius and Coeymans formations. A comparison of the cost per ton of aggregate versus cement in New York, cited above, illustrates the difference in value and explains Blue Circle's mining strategy. The much higher cost (and value) of cement is attributed to a number of factors including processing costs, cost of raw materials (limestone, iron, silica, alumina, gypsum) and market demand.

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ROAD LOG

NOTICE: Specific permission to enter the properties of Callanan Industries Inc. and Blue Circle Industries PLC has been granted to the New York State Geological Association by those companies. DO NOT attempt to revisit the stops on this trip without contacting these companies for permission. This road log begins at the intersection of Interstate Routes 87 and 90 near the Exit 24 intersection on the New York Thruway.

Start	Milage	Cumulative miles
Rt. I-87/I-90 intersection. Travel east on I-90	0	0
Turn south on I-787.	6	6
At the end of I-787, turn right on Rt. 9W (south) also called McCarty Avenue.	3.7	9.7
At third traffic light, Rt. 32 joins Rt. 9W, go straight.	2.9	12.6
Traffic light on Rts. 9W & 32, go straight (Rt. 32 diverges to right, fork to left, remain on Rt. 9W).	0.1	12.7
Traffic light at Feura Bush/Glenmont Rds., go straight on 9W.	1.5	14.2
Traffic light at Wemple Rd., go straight on 9W.	1.5	15.7
Blinking light at Rt. 55, go straight on 9W.	1.7	17.4
Turn right onto Rt. 396 at nest traffic light.	0.7	18.1
Enter town of South Bethlehem.	1.6	19.7
Turn left onto Rt. 101 (South Street).	1.0	20.7
Enter Callanan Industries mine on right.	1.1	21.8
Retrace route to Rt. 9W, turn right (south) on 9W.	4.1	25.9
Turn right onto Fuller Rd.	4.3	30.2
Turn left at "T" intersection.	0.2	30.4
Turn right, sharply uphill, into Blue Circle mine, to "Dead End" sign.	0.7	31.1