GEOLOGY OF THE PORTERFIELD QUARRY AREA,

SMYTH COUNTY, VIRGINIA

by

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INTRODUCTION

Acknowledgments. The writer wishes to express his appreciation to the members of the Department of Geological Sciences of Virginia Polytechnic Institute who gave encouragement and helpful suggestions. Each has made himself available for consultation both in the field and in the laboratory. Special thanks are due to Dr. B. N. Cooper for the suggestion that the problem was worthy of study and for the whole-hearted support that he offered.

Appreciation is also extended to the Olin Mathieson Chemical Corporation of Saltville, Virginia, for granting the use of many of their facilities. Mr. H. Clinton Rapp and Mr. R. S. Weaver of the Worthy Mine were most helpful and to these two men go the writer's sincere thanks and respect. The writer is grateful to Dr. G. A. Cooper of the U. S. National Museum for the opportunity to discuss with him the rocks in the Porterfield Quarry area from which he collected a large fauna of brachiopods, many of which were described by him as new species (Cooper, 1956).

Purpose of investigation. The purposes of this study were: (1) to determine the lithofacies relationships that exist in the quarry area, (2) to determine the extent of the low-silica biohermal limestone in the vicinity of the quarry and, (3) to investigate the origin of the biohermal limestone.

Methods of investigation. The study of the area in the vicinity of the Porterfield quarry was conducted during the summer of 1957. A topographic base map on a scale of 1:100 was furnished the writer by the Olin Mathieson Chemical Corporation. This map with minor modifications was used for a base. All the lithologic divisions were mapped by the plane-table and alidade on a scale of 1 inch equals 100 feet. The areas that lie immediately south, east, and west of the quarry were mapped on a 1:660 air photograph to determine more about the regional setting. Various sections were measured by traverse with a Brunton compass and steel tape to aid the determination of the lithofacies relationships of the different lithologic units.

Faunas were collected from the various lithologic zones mapped. The lowest of these faunas occurs just above the major disconformity between the Knox Dolomite and the overlying Middle Ordovician limestones. The youngest of these faunas came from the limestone-shale member of the Rich Valley Formation. Many species of these faunas have been identified and correlated with faunas from other localities. The immediate vicinity of the Porterfield quarry has yielded many well preserved fossils (G. A. Cooper, 1956).

A detailed petrographic investigation of the biohermal limestone was made in connection with the field study. Honed surfaces were studied along with thin-sections to determine more fully the textural relationships of this limestone. Thin-sections and honed surfaces were cut nearly perpendicular to bedding planes of the specimens. Surfaces were ground to a hone finish with fine carborundum powder.

A solution of hydrochloric acid added to a freshly prepared solution of potassium ferricyanide emphasized the compositional differences and the structural relationships of the carbonate minerals on honed surfaces. Steidtmann (1917) noted that dolomite would stain blue and that "primary" calcite (not vein calcite) would remain unstained when subjected to the stain mentioned above. The blue stain which adheres to the dolomite is due to the ubiquitous occurence of iron in the crystal lattice.

The potassium ferricyanide staining method was rejected by Rogers (1940) on the basis that the presence of iron was necessary to obtain effective results. Hobbs (1957) used this staining method exclusively in his study of dolomite-bearing carbonate rocks and found it to be satisfactory. As noted by Hobbs (1957, p. 17) the use of the potassium ferricyanide stain includes these advantages: "no masking of features, no cracking of precipitates, ease of preparation, rapid development of stain, and lasting quality of stained surfaces."

Previous work. The amount of geologic work that has been done in the vicinity of the Porterfield Quarry area, or for that matter, in the Rich Valley belt is very limited.

Dr. Charles Butts in 1933, visited the area and referred to the quarry in his two principal contributions to the geology of the Appalachian Valley in Virginia (1933, pp. 15-16; 1940, pp. 129, 151-152, 160, 164), but his work consisted of a general reconnaissance survey of the geology. Dr. Butts collected fossils from various formations and made a general correlation of the limestones in the Rich Valley belt with those in other areas of the Appalachians in Virginia and Tennessee, as identified by E. O. Ulrich.

In May of 1939 the area was visited by G. A. Cooper, Charles Butts and Josiah Bridge (G. A. Cooper, 1940). G. A. Cooper identified the main quarry rock as a fossil reef, but this interpretation was not shared by Dr. Butts. After this first expedition several others were made, many of them with Dr. B. N. Cooper. Dr. B. N. Cooper and Dr. G. A. Cooper, working independently, had arrived at the same facies picture for the Middle Ordovician stratigraphy in the Appalachians. In 1941 the two collaborated and applied their ideas to the sequences of Virginia, Tennessee, Georgia, and Alabama. During 1941 and 1957 seven expeditions were made through the southern Appalachians. On one such trip, which included the study of the beds in and near the Porterfield quarry resulted in the naming of the Rich Valley Formation.

Various specific references may be found in the literature to the Porterfield Quarry area. The localized occurence of the biohermal Effna Limestone has been referred to by many writers in connection with the problem of Ordovician stratigraphy and facies changes in Virginia and Tennessee. However, until the time of this report no detailed geology had been done in the Porterfield Quarry area.

Nomenclature. The Middle Ordovician lithologic units in the Rich Valley belt were described by Butts (1940), and by Butts and Edmundson (1944) who used: Mosheim Limestone, Lenoir Limestone, Whitesburg Limestone, Holston Marble, Athens Shale, and Moccasin Formation for the Middle Ordovician formations. In Tazewell County, Butts identified two different limestones as the Mosheim equivalent. Later work (Cooper and Prouty, 1943, pp. 852-853) showed these supposed Mosheim equivalents to be at different stratigraphic levels and separated by at least 400 feet of beds. The beds which Butts (1940, pp. 139-148) called Lenoir in

Virginia included more than the equivalent of the type Lenoir, and in many sections the beds that Butts assigned to the Lenoir are all younger than any part of the type section of the Lenoir City-Philadelphia belt of eastern Tennessee.

The Whitesburg Limestone in Virginia as described by Butts (1940, pp. 154-156) is actually only a part of the beds which Ulrich named the Whitesburg near Bulls Gap, Hawkins County, Tennessee. As defined by Ulrich the Whitesburg is essentially synonymous with the Liberty Hall Limestone. The thin black, cobbly to platy limestones at the base of the Liberty Hall, which Butts has referred to as Whitesburg, has been renamed the Effna Limestone in southwestern Virginia (Cooper, 1944, pp. 59-65), and the Botetourt Limestone member of the Edinburg Formation in the Shenandoah Valley of Virginia. Cooper and Cooper (1946, p. 71) give evidence why the name Whitesburg should not be used in Virginia. In the Porterfield Quarry area the beds described by Butts (1940, pp. 154-156) as Whitesburg are referred to as the Botetourt Limestone in this report.

The name Holston Limestone, or Holston Marble as it is sometimes referred to, has been applied to several different zones of gray to pinkish coarse-grained crinoidal limestone. This variety in the usage of the name Holston has rendered it almost useless as far as any specific stratigraphic significance is concerned. In the Porterfield Quarry area the beds described as Holston Limestone by Butts (1940, pp. 148-154) are referred to as Effna Limestone in this report. The name Holston was applied by Butts because of the close similarity of the beds to the type

Holston Marble of Tennessee. Butts did note, however, that in Virginia the Holston lacks the typical red color that makes it desirable as a commercial marble; thus, the lithologic name limestone is applied in that state.

The Effna Limestone is approximately the same as the Botetourt Limestone member of the Edinburg Formation. Locally, black shale and limestone of the Liberty Hall or nodular impure limestone similar to the "Upper Lenoir" (Cooper, in Twenhofel et al, 1954, p. 268) compose much of the formation. Butts considered the Holston to be almost essentially homogeneous everywhere in Virginia, with the possible exception of exposures in the Porterfield quarry and in Catawba Valley. In the Porterfield Quarry area Butts recognized a 30-foot bed composed of black gratoliferous shale and of small lenses of limestone of ordinary Holston type so coated with carbonaceous film that the entire bed stands out distinctly in the middle part of the Holston in the face of the quarry.

In his interpretation of the Holston Limestone at the Porterfield quarry, Butts did not consider the possibility of the biohermal structure that is present. Concerning the thickness of the formation, Butts stated, "..., it is apparently 280 feet thick but a fault may cause some repetition here."

The dark nodular siliceous limestone beds which underlie and intertongue with the Effna Formation are referred to as the Arline Limestone in this report. The Arline is post-Lenoir in age and may be correlated with beds of similar age in both the Effna Formation and the Botetourt Limestone.

The shale and silty limestone beds that overlie the calcarenitic facies of the Effna and enclose the biohermal facies were originally described by Butts (1940, p. 164) as belonging to the Athens Formation. Butts considered the lower fifty feet of the formation at the Porterfield quarry to be composed of limestone. Later work by G. A. Cooper (1956) assigned the name Rich Valley to the beds Butts called Athens. The beds described in this report as Rich Valley Shale are the lower and characteristic part of the unit widely identified by Butts and others as Athens Shale. The Rich Valley of the Porterfield Quarry area is similar to the Liberty Hall black-limestone, black-shale members of central and western Virginia.

The stratigraphic names used in this report for the lithologic units found in the Porterfield Quarry area are as follows: Knox Dolomite, Mosheim Limestone, Lenoir Limestone, Arline Limestone, Effna Limestone, Botetourt Limestone, and Rich Valley Formation. The Effna Limestone has been subdivided on the basis of its lithologic aspects into two lithofacies which are referred to as the calcarenitic and the biohermal facies.

Definitions. The term reef as originally used applied to solid masses of calcium carbonate built up by organisms up to, but not higher than the level of high tide, at which point it intercepted waves. Based on this original usage some authors have limited the term reef to strictly wave resistant structures. The term bioherm was proposed by Cummings and Shrock (Cummings, 1932, p. 333), "for reeflike, lenslike, moundlike, or otherwise circumscribed structures of strictly organic origin, embedded in rocks of different lithology." In this report both the terms reef and bioherm will be used when referring to ancient, wave resistant structures composed of the remains of organisms, mainly colonial, that have accumulated approximately in the position of growth and which form non-bedded masses of solid rock, while bedded normally fragmental sedimets were accumulating on all sides (Pia, 1933, p. 11-12). At the Reef Symposium held at the 1949 Annual Meeting of the American Association of Petroleum Geologists, Wilson (1950) gave a lengthy and detailed definition of the term reef as it is applied to our present day geologic thought on the subject. Wilson's definition of a reef is basically similar to the one given above, and it was accepted by a majority of the members of the symposium. It is notable that those who accepted Wilson's definition for a reef, were workers who used the terms reef and bioherm as synonyms. In the writer's opinion the interchange of these two terms is appropriate. In view of our present trends of thought on the subject, however, it appears that the term bioherm does not carry as descriptive a connotation as does the term reef.

The term biostrome will be used in this report as it was originally defined by Cummings (1932, p. 334). Cummings proposed the term biostrome for "purely bedded structures, such as shell beds, crinoid beds, coral beds, etc., consisting of and built mainly by sedentary organisms, and not swelling into moundlike or lenslike forms." As pointed out by Cummings (op. cit.) many of the so-called reefs such as the Louisville reef on the Jeffersonville Limestone of Indiana and Kentucky are actually biostromes. Most of the so-called Cryptozoon reefs of the Cambrian and Ordovician are bedded structures. The algal beds of the pre-Cambrian, built by Collenia, Newlandia, etc., apparently usually form beds and should therefore be classed as biostromes.

It has been suggested that the term klint might be used in place of reef or bioherm. Cummings (1932, p. 335) states, "The klintar of Gotland and the Wabash valley are merely erosional forms produced by the denudation of rocks containing bioherms, which, because of their superior durability, etch out in relief. They are strictly topographic features, whereas a bioherm is a bioherm whether it affects the topography or not."

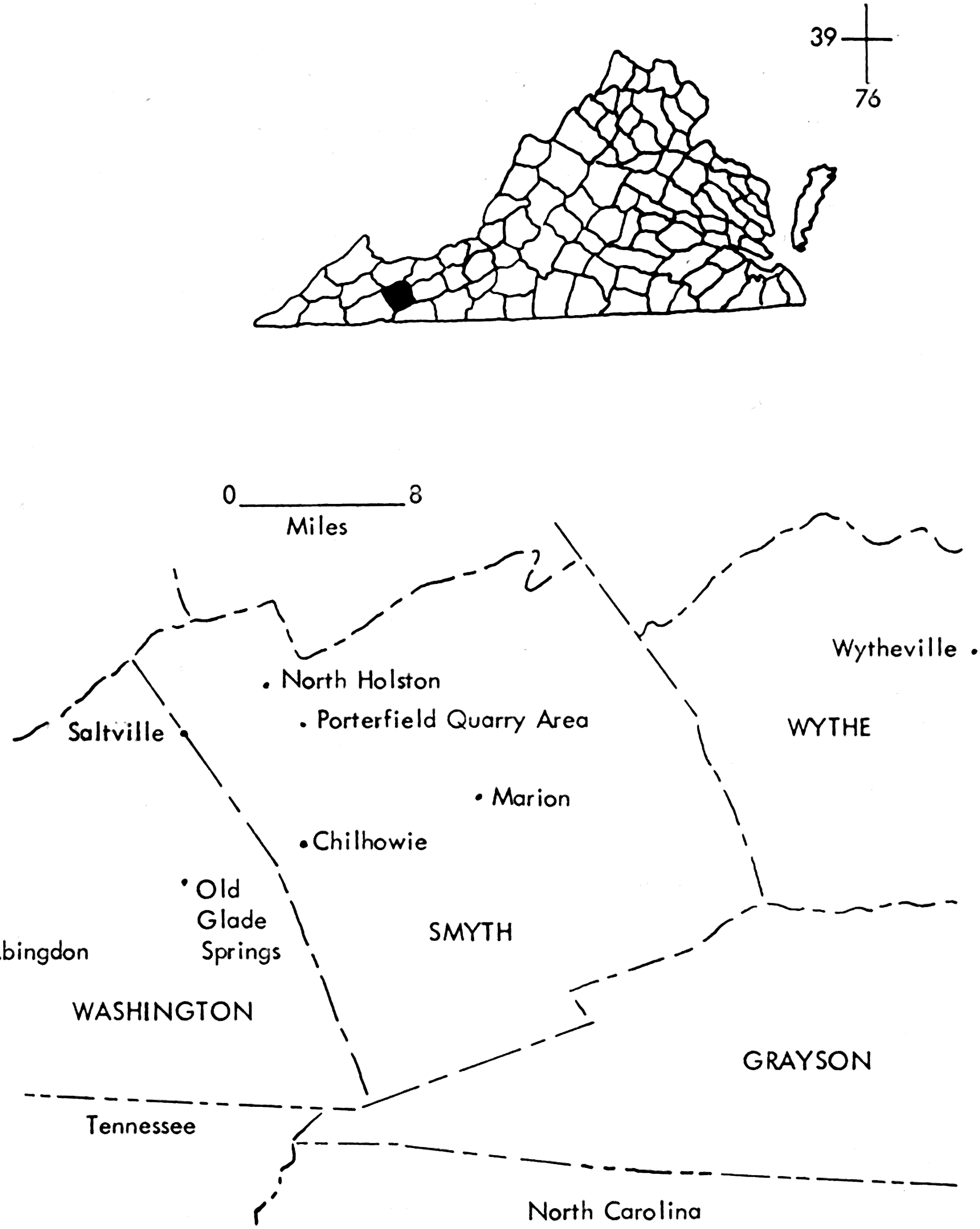
The terms facies, lithofacies, biofacies, lithotope, and biotope as used in this report are based on the usage given for the terms by R. C. Moore (1948, p. 310).

GEOGRAPHY

Location. The Porterfield Quarry area is located in Rich Valley about 8.5 miles southeast of Saltville, Smyth County, Virginia. It is in the southcentral section of the 7½ minute Maccrady quadrangle of the Tennessee Valley Authority. The area is accessible from the town of Saltville by traveling on various secondary routes. Beaver Creek, a northwestwardly flowing tributary of the North Fork of the Holston River, drains the immediate vicinity of the Porterfield Quarry area. A large part of the surface water empties into a system of limestone caves that presumably run in an east-west direction and connect with Beaver Creek in the northeastern corner of the area.

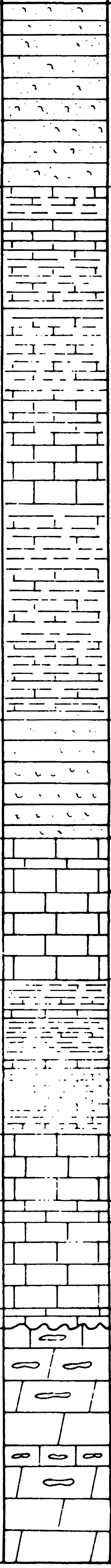
Regional setting. The Porterfield Quarry area is located in the

Plate No. 3



Location of the Porterfield Quarry Area, Smyth County, Virginia

Plate No. 4

System	Formation	Columnar section	Thickness in feet
Upper Ordovician	Juniata Sandstone		450
	Martinsburg Formation		1500
Middle Ordovician	Bays Sandstone		350
	Wassum Limestone		150
	Chatham Hill Limestone		270
	Rich Valley Formation		440
	Effna Formation		190
	Arline Limestone		50
	Lenoir Limestone		200
	Mosheim Limestone		50
Lower Ordovician / Upper Cambrian	Knox Dolomite		[illegible]50

Columnar section of the bedrock formations exposed in the Porterfield Quarry area and the outcrop slope of Walker Mountain, Smyth County, Virginia.

Appalachian Valley and Ridge province. Structurally, the area is southwest of the Saltville fault and the Greendale syncline. Walker Mountain, one of the major ridges in the southern Appalachians, lies just south of the Porterfield Quarry area. This mountain trends northeast and southwest in direction and is topped in many places by Silurian sandstones. A cross-section across Rich Valley through the Porterfield Quarry area and up the outcrop slope of Walker Mountain would reveal strata ranging from Cambrain to Uppermost Ordovician in age. The rock strike approximately N.60°E. and have an average dip of 30°SE. In the vicinity of the biohermal structure of Effna Limestone, the dip of the flanking strata is much greater than the average for the area, with some beds being almost vertical. Plate 4 shows an idealized columnar section of the regional stratigraphy.

DESCRIPTION OF THE ROCKS

General statement. Seven rock units ranging from early Canadian to Champlainian age are present in the Porterfield Quarry area. The rocks present are of three main types; dolomite, limestone, and shale. Dolomite, the oldest rock type found in the area forms the upper part of the Knox Dolomite of Canadian age. A major erosional unconformity is present between the Knox and the overlying basal member of the Lenoir Formation, the Mosheim Limestone. The Lenoir Limestone in the area is succeeded by a thin tongue of the impure Arline Limestone which is exposed across the entire width of the area. The Arline underlies and intertongues with the Effna Formation.

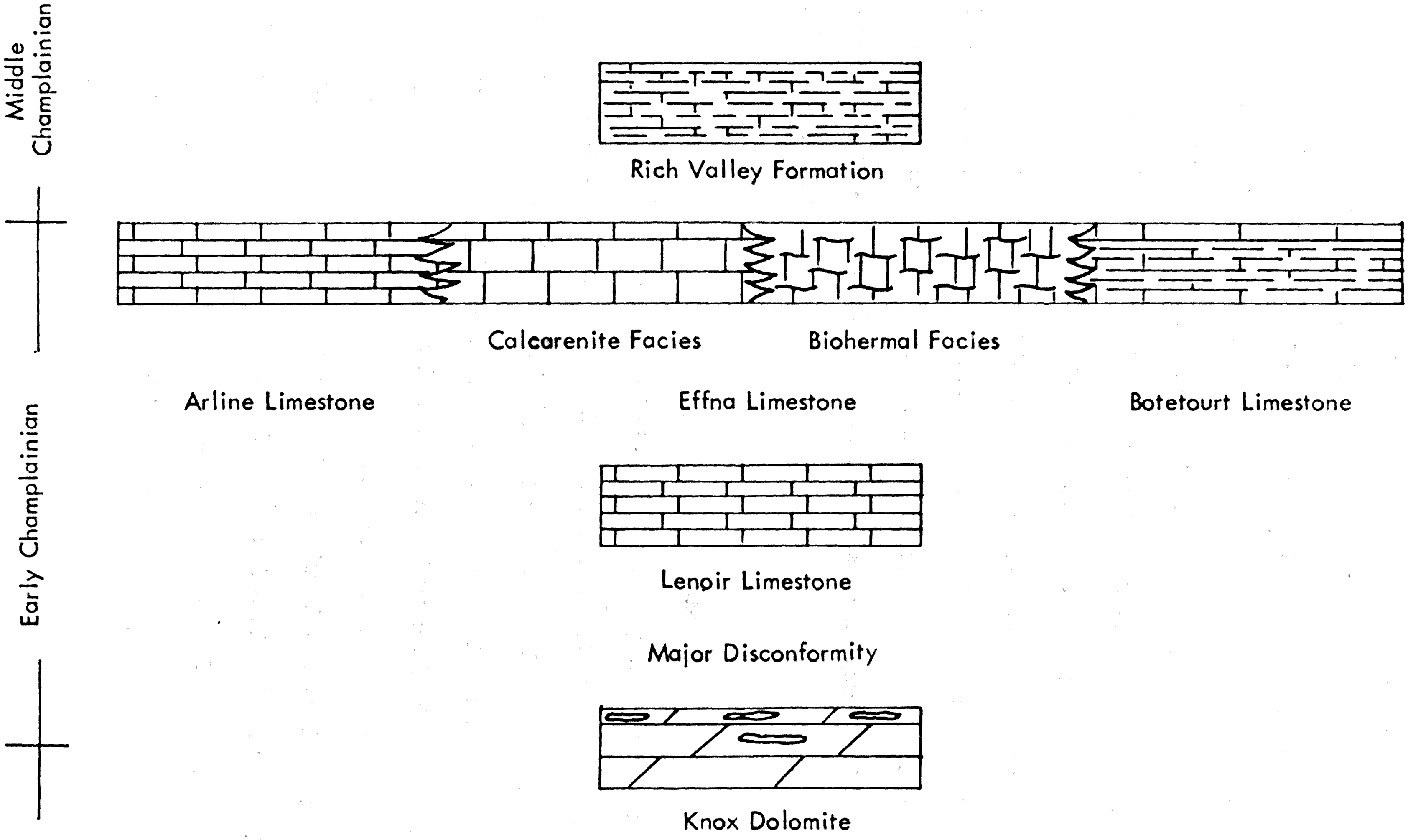


Plate No. 5 Stratigraphic relationships of the rock units in the Porterfield Quarry area, Smyth County, Virginia.

The Effna Formation has been subdivided on the bases of its lithologic aspects into two lithofacies. These lithofacies have been designated as the calcarenitic and the biohermal facies of the Effna Limestone. Overlying and intertonguing with the Effna is the Botetourt Limestone, however, this unit is very restricted in its lateral extent. The Arline, Effna and the Botetourt Limestone are all more or less contemporaneous units, indicated by the intertonguing that is present. The boundaries of these three units are, in some places, transitional with one another to such a degree that very detailed mapping was needed to infer any contact lines.

The youngest unit in the area is the Rich Valley Formation, which is composed of a basal limestone member underlying alternating beds of black limestone and shale. The limestone-shale member of this unit surrounds the biohermal facies of the Effna Limestone. A large tongue extends almost through the biohermal facies where it is transitional with the calcarenite. Plate 5 shows the stratigraphic relationships of the rock units in the Porterfield Quarry area.

Knox Dolomite

The Knox Dolomite was named by Safford (1869, pp. 151-159, 204) for outcrops in Knox County, Tennessee. The Knox Dolomite, according to Wilmarth (1938, pp. 519, 1114), includes the late Cambrian Copper Ridge Formation and formations of early Canadian age. In the Porterfield Quarry area only the uppermost part of the Knox is exposed. The top of the Knox is marked by a major erosional unconformity which in many places has removed much of this formation.

The Knox Dolomite varies in its lithology. It may be represented as dolomite, dolomitic-limestone, limestone or as interbeds of these types. The limestone interbeds in the Knox are commonly thin bedded, blue, and fine-grained. The grain size may vary from coarse to fine with most of the dolomite showing sutured grain contacts.

The Knox in the area that was mapped is composed primarily of dolomite, although there are a few interbeds of light-blue limestones present. The dolomite is medium-to-coarse grained and compact. Weathered surfaces of most of the outcrops have a very distinctive fret-work appearance and are characteristically dark-brown or yellowish-gray in color. Fresh surfaces of the rock range from medium-to-dark bluish-gray. The Knox in the area mapped is medium to thick bedded. Some beds in the area have a sandy appearance where weathering has been extreme. In thin-section the sutured contacts of the angular to sub-angular grains of dolomite may be seen. A few of the grains are rhom-bohedral in shape. Except for the few limy beds of Knox that are present in the area, none of the outcrops gave an appreciable efferescence when treated with dilute hydrochloric acid.

The belt of outcrop of Knox Dolomite is largely covered with a thick mass of residual chert, which is a very characteristic feature of the formation. The chert is medium-gray to white and has a blocky appearance. The blocks of chert range in size from 1 inch up to 12 inches in diameter. One chert block was noted that measured approximately 16 inches at its largest diameter. Many of the blocks contain the remains of gastropods and cephalopods along with small and generally rhomb-shaped holes that are probably molds of dissolved dolomite crystals. The chert is almost all of secondary origin formed by the dissolution and redeposition of silica already present in the dolomite.

The beds of Knox in the area are not richly fossiliferous. The fauna is almost wholly composed of gastropods and coiled cephalopods.

To the north or the Porterfield Quarry area the Knox Dolomite overlies limestones and shale of St. Croixian age. It is overlain in the area, unconformably, by the Mosheim Limestone member of the Lenoir Formation. The Knox Dolomite in the Porterfield Quarry area is considered to be of Canadian age.

Lenoir Limestone

The Lenoir Limestone was named by Safford and Killebrew (1876, pp.130-131) for exposures at Lenoir Station, Loudoun County, Tennessee. In the Porterfield Quarry area, the Lenoir with its basal Mosheim Limestone member crops out in a long narrow belt ranging in thickness from 55 to 110 feet. The beds strike approximately N. 60° E., roughly parallel to the northern margin of the area, and dip approximately 30 degrees to the southeast.

The Lenoir is composed of three distinct types of limestone. The Mosheim Limestone is the lowest member of these three types, and is therefore referred to as the basal Lenoir Limestone. Ulrich (1911, pp. 413-414) originally considered the Mosheim to be a formation separate and distinct from the Lenoir as seen at Mosheim Station, Greene County, Tennessee. However, Cooper and Cooper (1946, pp. 51-52) give evidence that the type Mosheim in Tennessee occupies the same stratigraphic position as the basal Lenoir in its type locality, and therefore is probably an early facies of the Lenoir Limestone. In this area the Mosheim is a calcilutite ranging in color from a light-to-dove gray. Numerous small white calcite veinlets and vugs are very pronounced on the weathered surfaces. In general, the Mosheim is a very compact, dense and thin bedded limestone which breaks with a conchoidal fracture.

By far the most abundant type of limestone in the Lenoir Formation is a very fine-grained, light-gray, silty type. The silty limestone member of the Lenoir is composed of impure shelly beds containing an abundance of Billingsaria parva. Many of the fossils have been silicified and stand out in relief on the light-gray weathered surfaces. This member contains a large amount of medium to coarse clastic material enclosed in the fine-grained matrix. This particular member contains grayish-brown, laminated, silty partings, which weather a light-brown and give the outcrops a net-like appearance.

The third type of limestone in the Lenoir Formation is medium-grained and thick bedded. The member is characteristically dark-gray in color and locally contains small nodules of black chert. Fossils are especially numerous in this medium-grained limestone, which contains a profusion of Maclurites magus. Bryozoan and crinoid fragments are also present, but not numerous, and most of these are broken and abraded. Both the medium and fine-grained members of the Lenoir have a definitely petroliferous odor when broken. The Lenoir Limestone in the Porterfield

Quarry area is considered to be of Chazyan or early Champlainian age.

Geologic Section 1. - Lenoir Limestone in the Porterfield Quarry area, Smyth County, Virginia.

	Thickness Feet
Arline Limestone	
Lenoir Limestone (110 feet)	
9. Limestone, dark-gray to black, medium-grained, with thin, wavy, silty, partings	20
8. Limestone, dark-gray, medium-grained, medium to thick bedded, containing Maclurites magus . . .	10
7. Limestone, dark-gray, impure shelly beds, medium to coarse-grained clastic material enclosed in fine grained matrix	6
6. Limestone, dark-gray, fine-grained, thin bedded, silty lamination; containing silicified fossils	14
5. Limestone, medium-gray, silty partings which weather light brown	10
4. Limestone, light-gray, very fine-grained	10
Mosheim Limestone member (40 feet)	
3. Limestone, calcilutite, light-gray, numerous small white calcite vugs	15

Geologic Section 1. - (Cont.)

	Thickness Feet
2. Limestone, dove colored, compact and dense, weathers with chalk crust (vaughanite), scattered angular fragments of chert in basal beds	25
Knox Dolomite	
1. Dolomite, unexposed to base	--

Arline Limestone

The Arline Limestone was named by Cooper for exposures of limestone along a small stream tributary of Gallagher Creek, two miles southwest of the railroad switch at Arline, Tennessee. It may be located on the Concord (T. V. A. 138-SW) and the Louisville (T. V. A. 138-SE) Quadrangles of Tennessee.

The Arline Limestone in the area studied is dark-gray, medium to fine-grained limestone. The weathered surfaces have a rough texture and a definite cobbly appearance. Wavy clay partings which enclose plates or cobbles of limestone which weathers out on exposure. When subjected to thorough weathering, the nodular to cobbly limestone breaks down to produce a soil with a distinctive yellow-brown color. Fresh surfaces reveal a large quantity of fine clastic material and numerous silicified fossils enclosed in the coarser matrix. These features are so persistent throughout that there is generally no difficulty in recognizing the Arline.

In the Porterfield Quarry area the Arline Limestone is present as a thin unit lying below the light colored calcarenitic facies of the Effna Limestone. The Arline is underlain by the dark, medium-grained limestones of the Lenoir Formation. It should be noted that the contact between the Arline and the overlying Effna calcarenite is transitional, and the two limestone interfinger with one another.

The fauna of the Arline Limestone is characteristically different from that of the Lenoir Formation. The nodular Arline contains Calliops declivis, and numerous other fossils not found in the typical Lenoir. The Arline was placed with the Lenoir in the National Research Council's report on Ordovician stratigraphy (p. 274) and referred to as the "Upper Lenoir," signifying that no correlation with the real Lenoir is implied. Cooper (1956, p. 42) noted that the thin tongue of Arline which underlies the Effna calcarenite at the Porterfield quarry contains many elements of the Arline fauna, and a suite of species related to, but not identical with, those of the typical Arline Limestone.

Cooper (1956, p. 42) lists the following fossil brachiopods as occurring in the Arline Limestone in the Porterfield Quarry area: Leptellina transversa, Opikina matutina, Palaeostrophomena subtransversa, Sowerbyella silicica, S. silicica nana, and Valcourea semicarinata. All of the above are new species of brachiopods named by G. A. Cooper (1956). The writer found all of the species listed above in addition to the following: Bimuria superba Ulrich and Cooper, Oxoplecia plicata

Cooper, Oxoplecia sp. and Sowerbyella sp. The species Bimuria superba is one of the leading guide fossils of the Arline Limestone.

The Arline Limestone contains some faunal elements which are also found in the Effna and Botetourt Limestone (Cooper, 1956, pp. 42-43). The occurence in the Porterfield Quarry area of similar faunal elements in the Arline, Effna and Botetourt limestones, and the transitional and interfingering boundaries of these units make it clear that they are at least partial equivalents in this area. On the accompanying geologic map of the area in the general vicinity of coordinates: East 29000, South 4800, an example of the interfingering is well illustrated. In this general area the Arline Limestone interfingers laterally to the west with beds of Botetourt Limestone, and to the east with the calcarenitic facies of the Effna Limestone. Cooper (op. cit.) states "... the Effna Formation appears to be a reefy development of the Arline." The Arline Limestone in the Porterfield Quarry area is considered to be of early Champlainian age.

Geologic Section 2. - Arline Limestone in the Porterfield Quarry, Smyth County, Virginia.

	Thickness Feet
Effna Limestone	
Arline Limestone (45 feet)	
3. Limestone, dark-gray, medium to fine-grained, impure, containing silty partings	15

Geologic Section 2. - (Cont.)

	Thickness Feet
2. Limestone, dark-gray, impure, silty partings enclosing cobbles and plates of limestone, rough texture; containing <u>Bimuria superba</u> Ulrich and Cooper, <u>Oxoplecia plicata</u> Cooper, <u>Oxoplecia sp</u>., and <u>Sowerbyella sp</u>.	30
Lenoir Limestone	
1. Limestone, dark-gray to black, medium-grained, with thin, wavy, silty partings	--

Effna Limestone

The name Effna Limestone was proposed by B. N. Cooper (1944, p. 59) for beds overlying the Lincolnshire Limestone and underlying the "Whitesburg" Limestone along the northwest base of Walker Mountain. The type section for the Effna is at McNutt quarry about 1.5 miles southwest of Sharon Springs, Virginia. This is the locality from which Raymond (1925) collected most of his so-called Holston fossils. In the Porterfield Quarry area the beds defined as Effna are essentially those referred to by Butts (1940, pp. 148-154) as Holston Limestone. In Virginia the name Holston has lost all usefulness as far as any specific stratigraphic significance is concerned.

The Effna Limestone of the Porterfield Quarry area is of early Champlainian age. In the area it is at least partially equivalent to the Arline and the Botetourt Limestones. The Effna is approximately the same as the Botetourt limestone member of the Edinburg Formation, but it is characterized by biohermal inclusions which are not present in the Botetourt. The Effna is not a homogeneous formation as Butts considered it to be everywhere in Virginia, with the possible exception of exposures in the Porterfield quarry and in Catawba Valley. Locally, black shale and limestone of Liberty Hall facies or nodular impure limestone like the Arline Limestone of Friendsville, Tennessee, compose much of the formation (Twenhofel, et al, 1954, p. 268). B. N. Cooper (Twenhofel, et al, 1954, p. 268) stated, "The calcarenitic limestones are localized deposits of abundantly fossiliferous material deposited in bioherms or along their margins during early stages in the deposition of the Liberty Hall black sediments and clayey limestones of the 'Upper Lenoir'."

In the area covered in this report two distinct lithofacies of the Effna Limestone are present. The two facies are very well exposed in the area and consist of a basal coarse-grained clastic limestone, the calcarenitic facies; and the overlying mainly fine-grained, compact limestone which is present in the form of a bioherm, hence the biohermal facies.

<u>Calcarenitic facies</u>. The calcarenitic facies of the Effna Limestone in the Porterfield Quarry area is a white to light-gray, coarse-grained

limestone. It is composed almost wholly of shell fragments of brachiopods and bryozoans. These shell fragments are tightly cemented together in a coarse-grained matrix of calcite. Numerous oval to rounded patches of very fine-grained, bluish-to light-gray masses of calcite are present in this type rock, and are believed to be of algal origin. The size of these fine-grained patches varies from three or four inches to twelve inches in diameter. The intermittent presence of structures formed through the agency of algae (stromatolites) suggest a maximum possible depth of about 100 fathoms, and their local development favors a depth of less than 15 fathoms (Cloud, 1942, pp. 370-371, p. 2134).

The average thickness of the calcarenitic facies is approximately 240 feet. The beds strike to the northeast and southwest from the quarry proper and dip to the southeast at an angle of about 30 degrees. Along the strike to the northeast the thickness of the calcarenite decreased to about 35 feet; however, to the southwest the calcarenite maintains its average thickness for approximately one-half mile.

The weathered surfaces of this limestone are medium to dark-gray in color. Numerous uneven conchoidal fractures are also present in the weathered outcrops. These fractures have been filled with coarse-grained, clear white calcite grains which range in size from two to six mm. in diameter. The coarse-grained, calcite-filled fractures are very prominent on weathered surfaces because of the contrast offered by the drab limestone matrix in which they lie. Stylolites are abundant in this facies. They occur as a single seam having a very minute diameter or an undulose honeycombs of bifurcating or anastomosing seams.

Thin-section study of the calcarenitic facies of the Effna reveals that the rock is composed chiefly of anhedral grains of carbonate minerals, with almost a complete absence of silica and clay minerals. The non-carbonate material never composed more than one per cent of the total composition of this rock. The shell material of the fossil fragments contained in the calcerenite is composed of either fibrous calcite or coarse granular anhedral twinned calcite. Numerous shell fragments have been at least partly destroyed by the growth of grains of dolomite. Numerous fossils were observed to be contained in a fine matrix of ragged carbonate anhedra commonly less than 0.03 mm. in maximum diameter but in places exceeding 0.05 mm. Although the matrix may be more or less dolomitized than the shell remains, the main difference between the matrix and the shells is the size of the composing grains. The shell fragments appear darker because they are composed of relatively small grains. Vugs and small cavities are filled with clear, crystalline calcite or dolomite. In some specimens the matrix is calcite and the contained fossils are replaced by dolomite, as determined by differential staining of honed surfaces.

Biohermal facies. The biohermal facies of the Effna Limestone in the Porterfield Quarry area is a light-gray to nearly white, fine to medium-grained, highly recrystallized limestone. This facies lies directly above and is transitional with the underlying calcarenitic facies.

The biohermal facies is well exposed on the surface, and in the abandoned quarry which affords many exposures which would have otherwise remained concealed. The Worthy Mine is presently being operated in the biohermal facies by the Olin Mathieson Chemical Corporation. The writer made two excursions through this mine to investigate the biohermal facies, and where possible, its relationships to the surrounding rocks.

Exposures indicate that the actual outline of the bioherm itself is highly irregular. Its thickness may only be approximated because of the transitional boundary at its base with the underlying calcarenite. The maximum thickness considering this transitional basal boundary is 450 feet. This thickness was measured along the hypothetical axis of the bioherm, which if shown on the accompanying map would trend southeast. It would seem that instead of "growing" upward in a nearly vertical direction, in relation to the surrounding sea floor, that the bioherm grew more or less upward and to the east. The bioherm does not have the "typical" mushroom shape used so often when referring to structures of this nature. The width varies with the maximum being approximately 950 feet. The width seems to be consistent down to a depth of 375 feet below the surface; however, there is no way of determining if any change in shape occurs with depth. A study of the outline of the bioherm on the surface indicated that growth was directed upward in the initial development; then, for some reason the direction of maximum growth was upward and to the east. No line of symmetry can be drawn which would divide the structure into two equal halves because growth and expansion on the eastern side exceeded that of the western margin.

The biohermal structure trends in a southeasterly direction with an average dip of its crest approximately 31 degrees. It is overlain and flanked by the shale and limestone interbeds of the Rich Valley

Formation. The flanking beds of Rich Valley dip away from the bioherm at relatively steep angles and locally are nearly vertical. A large intertongue of the Rich Valley underlies the eastern portion of the bioherm which has developed outward from the base. This intertongue separates the calcarenitic and biohermal facies of the Effna Limestone, and indicates that the bottom surrounding the reef during its development was a site of deposition of black limy muds. Smaller intertongues of shale are present on the western side of the bioherm.

The central portion of the bioherm is almost completely devoid of any bedding or related structures. However, some exposures on the peripheral portion show a crude stratification where the biohermal facies is flanked by bedded calcarenitic facies. The central portion, or core, of the bioherm contains very few recognizable fossils or fragments of fossils. A few brachiopod shell fragments and crinoid columnals may be found, but for the most part dissolution and recrystallization have obliterated much of the organic material. The core contains a profusion of oval to rounded patches of very fine-grained bluish to light-gray limestone masses, which are considered to be of algal origin. Many such masses may be found in outcrops having a diameter of ten inches. Cloud (1942, pp. 370-371; p. 2134) has noted that the local development of structures formed through the agency of algae (stromatolites) favors a depth of water less than 15 fathoms. It is possible, however, that the depth of optimum photosynthesis, which controls algal development, may have been reduced by intermittent turbidity, resulting from the stirring up of the calcium carbonate mud by more active organisms on the

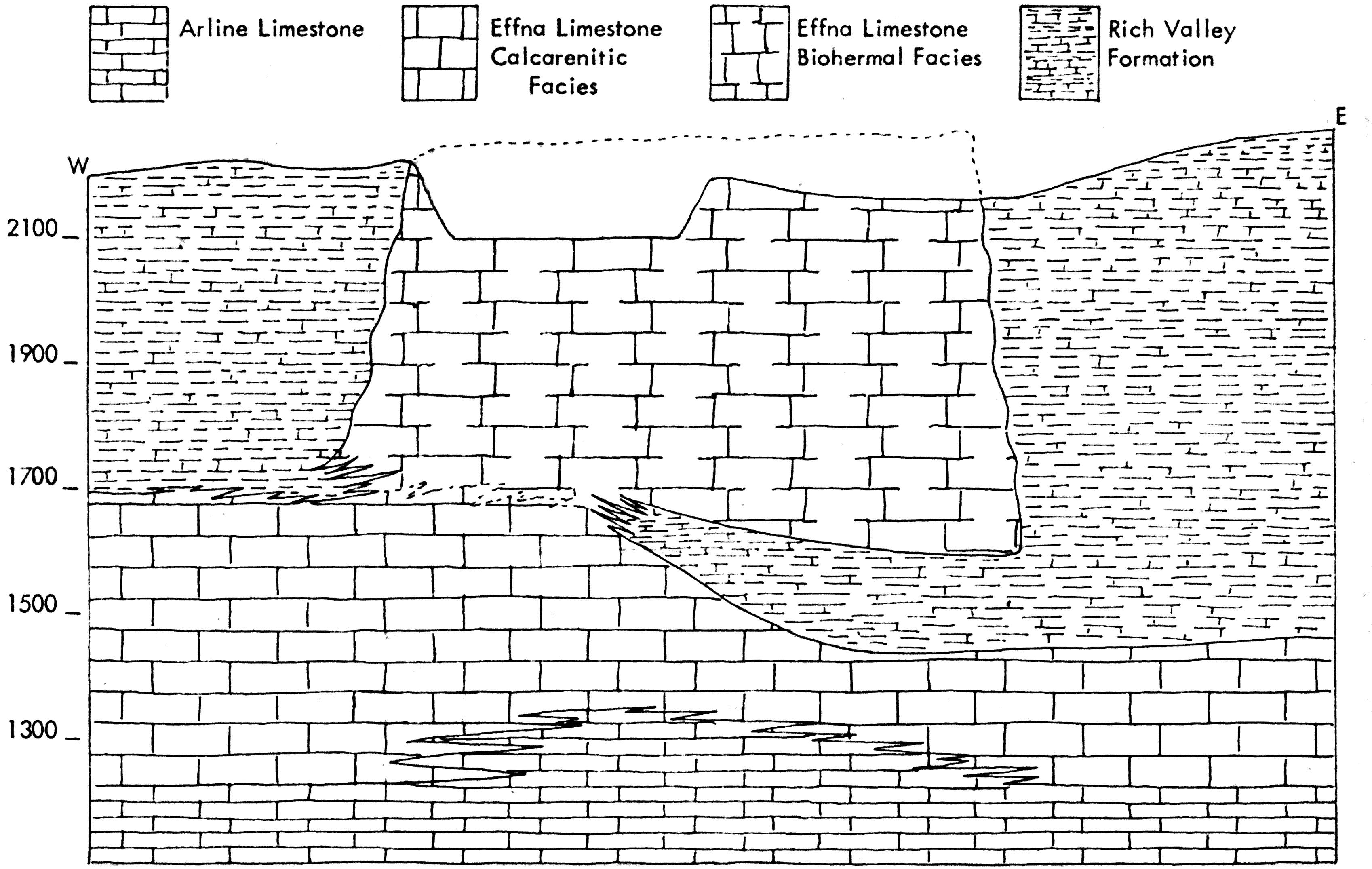


Plate No. 6 Reconstructed transverse section of the Porterfield reef. Horizontal and vertical scale approximately 1 inch equal 250 feet.

reef. On the weathered surfaces of the limestone these algal colonies appear as nodular or hemispherical forms the upper surfaces of which are finely or coarsely rounded.

Thin-sections reveal that these algal structures are invariably more or less recrystallized, and commonly they are aphanitic. The algal masses commonly show a more advanced recrystallization than the associated brachiopods and crinoids. In many places the masses are barely distinguishable from the matrix.

Stylolites are exceedingly abundant in the reefy facies of the Effna and much more so than in the calcarenitic facies. Very few of the stylolites occur as single seams without any connection with one another. When single seam stylolites do occur, they are very minute in size, and usually five or six such stylolites form an in echelon pattern. Most of the stylolites occur as undulose network of anastomosing or bifurcating seams. Many of the larger seams are filled with anhedral grains of calcite or dolomite, and all of the stylolites are lined with a brown to brownish-black material that is undistinguishable with the petrographic microscope. This material may be some type of residual organic compound. In many cases the laminated algal masses have been destroyed by the formation of single seam stylolites or by a network of such seams. Honed surfaces that have been stained show that a large amount of dolomite is concentrated along both sides of most of the stylolites. It was also noted on the honed surfaces that the stylolites tended to obliterate or at least distort any fossil fragments with which they came in contact.

An unusual feature of this reefy limestone facies are the fine-grained nests of dolomite which are found throughout the entire mass. On weathered surfaces the nests are light tan in color and range in size from extremely small irregular patches to round or oval shaped masses with a diameter of approximately five or six inches. The nests occur spasmodically and show no definite arrangement or orientation. They contain no fossil fragments or sedimentary detritus and are composed wholly of anhedral grains of dolomite and disseminated iron sulfide. The absence of fossil fragments and detritus would suggest that the dolomite was concentrated after the surrounding limestone matrix had been deposited. Many but not all of the dolomite nests contain up to 25 per cent of iron oxides and sulphides in the form of limonite and pyrite.

The only relatively recent dolomitic materials so far known to occur in significant volume are the clearly secondary dolomites of certain islands in the Pacific and Indian oceans and some of the organic reefs of the Red Sea (Dana, 1849; Skeats, 1903, 1918b; Walther, 1888; Ladd et al., 1953, pp. 2269-2272). In fact, to state a widely held conclusion in the words of Twenhofel et al, (1932, p. 339) "no examples of primary deposition of dolomite are known and ... primary deposition of this sediment lies entirely within the realm of theory."

It is known from Steidtmann's work (1917, p. 439) that, "The replacement of aragonite and calcite by dolomite has been effected experimentally at ordinary temperatures by solutions comparable to sea water." Irving (1926, p. 441) points out that, "Magnesium hydroxide is precipitated from sea-water by addition of small amounts of alkali and, that both magnesium and calcium are in delicate equilibrium where slight changes in alkalinity and carbon dioxide tension may cause precipitation." In a personal communication to Wallace (1927, p. 65), Irving states, "that if increase in alkalinity results from increase in free base alone, the magnesium is rapidly precipitated as the pH rises above 10, and that there is a possibility of salt waters naturally approaching a pH value of 10, permitting the precipitation of both calcium and magnesium" (compounds not specified). He also remarks (in Wallace, 1927, p. 65) that, "whereas $CaCO_3$ is relatively insoluble and $MgCO_3$ relatively soluble (in saline waters), $Ca(OH)_2$ on the contrary is quite soluble as compared with the insoluble $Mg(OH)_2$."

In summary, the relative solubilities of the various compounds of calcium and magnesium that might occur in sea water favor the theory that penecontemporaneous or later diagenetic alternation of calcium carbonate sediments is a more likely dolomitization process than is primary precipitation.

Many of the masses of fine-grained dolomite that occur in the biohermal facies of the Effna Limestone are considered to have been formed at the same time as the reef itself. This origin would involve reaction between original calcium carbonate muds, which were extremely abundant on the bioherm, and magnesium compounds which are aboundant in solution or suspension in the sea water. The scattered euhedral dolomite rhombs found in the limestone probably resulted from reaction at the sea floor with waters not having a sufficient excess of magnesium for more extensive dolomitization, or from recrystallization from connate waters in the unconsolidated lime muds on the reef. The warm shallow water environment of the reef, which was originally a structure of high porosity and permeability, was ideal for the formation of "pre-emergent" dolomite. The scattered irregular distribution of the dolomitic patches is proof of dolomite formation by reactions within the sediments. It is conceivable in theory, of course, that a current from which carbonate minerals were being precipitated might locally be sufficiently depleted of calcium or have its pH increased to such an extent as to permit the precipitation of $CaMg(CO_3)_2$. However, a more likely direct precipitation product would be $Mg(OH)_2$, the mineral brucite, not dolomite.

The upper peripheral portion of the bioherm is composed almost entirely of broken and abraded fragments of crinoids cemented together in a matrix of medium to fine-grained calcite. Thin sections have revealed that many of the fossil fragments have been almost completely destroyed by the growth of grains of dolomite. Differential staining has shown that microcrystalline grains of dolomite have completely filled many of the fossil shells and small voids in the limestone. Irregular patches and stringers of the fine-grained limonite are also present in the crinoidal limestone which grades evenly into the surrounding carbonate material.

The crinoidal phase of the biohermal Effna limestone, although now crystalline texture, was deposited as a fragmental sediment, a crinoidal sand, the size distribution of which is portrayed graphically by Plate 7. The size distribution of the crinoidal debris was measured by thin-section honed surface, and by simple measurement of the columnals and other plates standing out in sharp weathered relief on rock surfaces. The crinoidal sediment shows only a fair degree of sorting, as to size, 90 per cent of the grains being spread through four size classes, granule through medium sand. The modal class, that showing maximum frequency, is the very coarse sand class (2-1 mm.). At the time of deposition the crinoidal sediment would have been classified as a very coarse to coarse sand. After deposition and burial it assumed a crystalline texture as a result of cementation and recrystallization, and thus may now be classified as very coarsely to coarsely crystalline limestone.

The average shape of the crinoid columnals and other plates may be divided into three types: disc-shaped, oblate spheroidal, and bladed disc. The disc-shaped columnals are dominant in this limestone. The crinoidal sediment thus shows fair to poor sorting as to shape, the majority of the grains being spaced through two or three shape classes of Zingg's shape classification. This condition is due to the fact that the grains are of heterogeneous derivation, some representing little transported organic debris while others definitely have undergone several cycles of transportation.

The original surface texture of the crinoidal particles has been greatly altered as a result of post-depositional recrystallization, solution, and cementation. The columnals and other plates stand out in sharp relief on weathered rock surfaces and are dull in luster and have a rough surface relief marked by etched, striated, and pitted irregularities. The crinoidal limestone shows a random orientation of individual

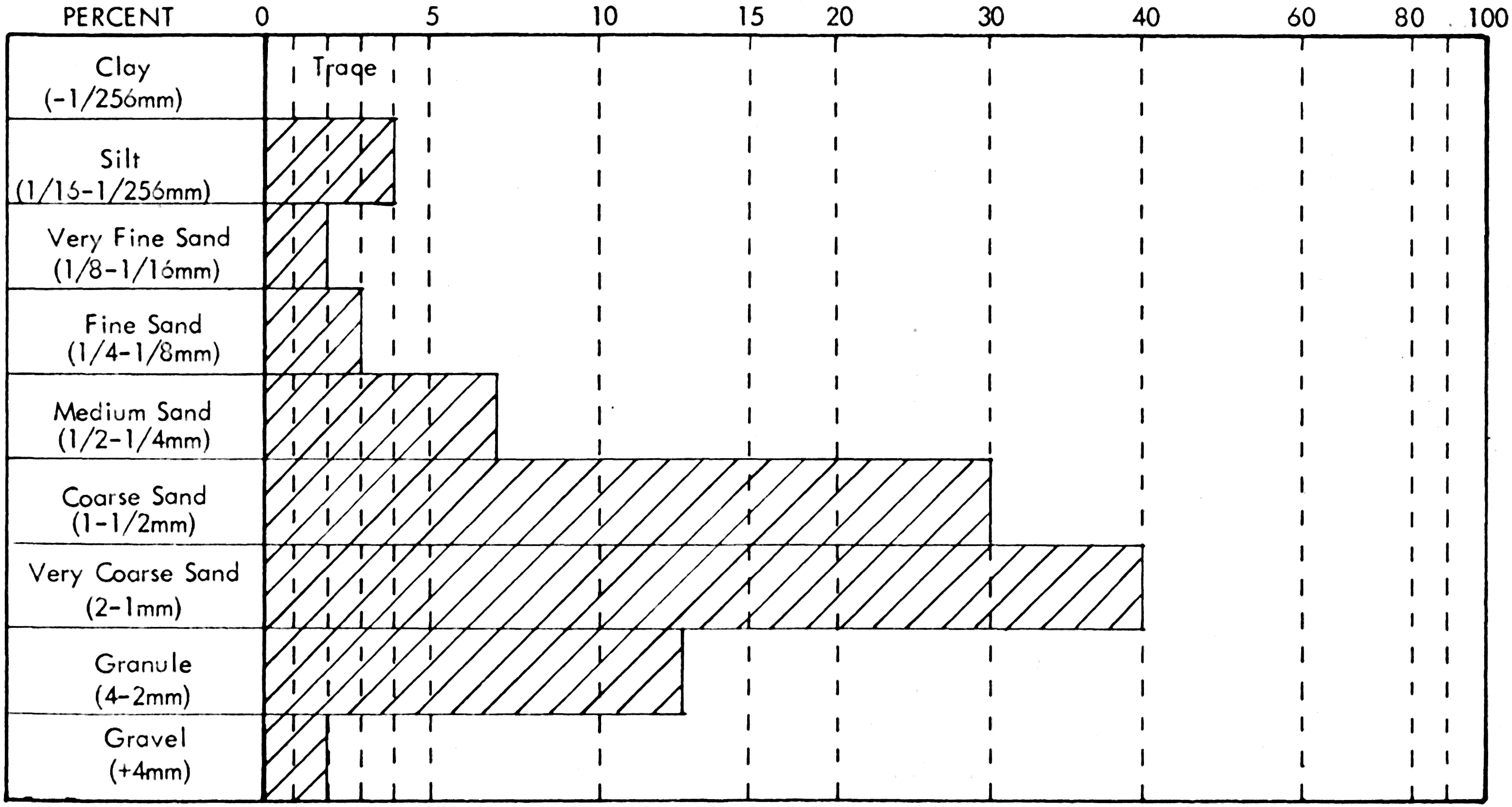


Plate No. 7 Size distribution of the crinoidal phase of the biohermal Effna Limestone. Average of 12 sets of samples collected at 1-foot vertical intervals from section exposed in the Porterfield Quarry area, Smyth County, Virginia.

components with respect to both their maximum projection planes and their long diameter.

The crinoidal limestone displays good cementation by a crystalline-textured cement consisting of very finely crystalline calcite. This fine calcite probably was deposited as a fragmental sand and later cemented by epigenetic calcite precipitation.

The fauna of the Effna is essentially that of the Arline of Tennessee and the Botetourt limestone (Cooper, 1956, pp. 60-61). Cooper (1956) in his study of Chazyan and related brachiopods lists the following species from the biohermal facies of the Effna limestone in the Porterfield Quarry area:

Brachiopods:

Bimuria superba Ulrich and Cooper
Camerella minuta Cooper
Christiania subquadrata (Hall)
Camotreta cuspidata Cooper
C. plana Cooper
C. triangulate Cooper
Cyrtonotella grandistiata (Willard)
Dactylogonia sp. 5
Doleroides ? ponderosus Cooper
Eridorthis inexpectate Cooper
Glyptambonites glyptus Cooper
Glyptoglossa sp. 1
Glyptomena pervula Cooper
Glyptorthis glypta Cooper
Laticrura pionodema Cooper
Leptellina pulchra Cooper
L. tennesseensis Ulrich and Cooper
Lingullela lirata Cooper
L. subparallela Cooper
Lingullela sp. 4
Obolus ? virginiensis (Willard)
Obolus sp. 5
Oxoplecia abnormis Cooper
O. depressa Cooper
O. gibbosa Cooper

Brachiopods: (Cont.)

O. holstonensis Willard
Pachyglossa pachydermata Cooper
Perimecocoelia semicostata Cooper
P. triangulata Cooper
Petrocrania ? magna Cooper
Phragmorthis buttsi Cooper
Pionomena ? dubia Cooper
Productorthis agilera (Raymond)
Protozyga tumida Cooper
Pseudobolus sp. 1
Ptychoglyptus virginiensis Willard
Ptychopleurella medicostata Cooper
P. rectangulata Cooper
Scapthorthis perplexa Cooper
Schizambon cuneatum Willard
Schizotreta pannea (Willard)
S. shuleri (Willard)
Skenidioides transversus Cooper
Sowerbyella negritus (Willard)
Spondylotreta ? declivis (Willard)
Taphrorthis peculiaris Cooper
Titanambonites crassus Cooper

Butts (1940, p. 152) presents a fauna list prepared by Ulrich from the "Holston" in the Porterfield Quarry area. The fossils listed by Ulrich are as follows:

Cystida:

Echinosphaerites sp?

Brachiopods:

Christiania sp.
Crania (Petrocrania) sp.
Dinorthis? sp.
Multicostella cf. M. platys (Billings)
Ptychoglyptus virginiensis Willard
P? 1 or more sp.

Gastropods:

Subulites sp.
Trochonena sp.

Cephalopods:

Cameroceras, 3 sp.
Spyroceras sp.

Trilobites:
Amphilichas, several other sp.
Glaphurus sp.
Hyboaspis shuleri Raymond

Raymond (1925) has published descriptions of the trilobites from rocks that are now considered to be Effna Limestone. Those species described as occuring in the "Holston" are as follows:

Trilobites:

Acrolichas minganensis (Billings)
A. prominulus Raymond
Ampyx camurus Raymond
Arthororhachis elspethi Raymond
Basilicus laeviculus Raymond
Bronteopsis gregaria Raymond
Bumastus longiops Raymond
B. lioderma Raymond
B. dispassus Raymond
Ceraurus granulosus Raymond & Barton
C. hudsoni Raymond
Cybeloides sp.
Eoharpes sp.
Homotelus obtusus (Hall)
H. indentus Raymond
Hyboaspis shuleri Raymond
Illaenus fieldi Raymond
I. protuberans Raymond
I. lautus Raymond
Nileus scrutator Billings
Onchaspis confrage Raymond
Pterygometopus transsectus Raymond
P. holstonensis Raymond
Sphaerexochus discrepans Raymond
S. parvus Billings

A comparison of the fauna shows the Effna Limestone is related to the Arline and the Botetourt Limestones. <u>Ptychoglyptus</u> appears to be confined to these formations, and a few other species such as <u>Bimuria</u>

superba occur in all three units. Cooper (1956) states that specimens of Kullervo, Leptellina pulchra, Oxoplecia holstonensis and Perimecocoelia emphasize the correlation of the Effna, Arline and the Botetourt Limestones.

Botetourt Limestone

The name Botetourt Limestone was used by Cooper and Cooper (1946, p. 80) for, "brown-weathering, impure granular limestone overlying the Lincolnshire Formation and lying below beds of Liberty Hall type." The type locality of this limestone is about 0.25 miles south of Dunkard Church and 6.9 miles southwest of Natural Bridge, Virginia. The beds referred to in this report as Botetourt constitute essentially the same unit which Butts (1940, pp. 154-158) identified as the Whitesburg Limestone. The Whitesburg was named by Ulrich (1930, p. 2) from Whitesburg, Hawkins County, Tennessee, 10 miles northeast of Morristown. The change of name from Whitesburg to Botetourt was necessitated by the fact that as originally defined by Ulrich (op cit) the Whitesburg is synonymous with Athens as he used it.

In the Porterfield Quarry area the Botetourt occurs as a bluish to dark-gray, medium to coarsely crystalline limestone composed mostly of fossil fragments. The fragments of brachiopod shells and trilobite carapaces are cemented together by fine calcite. The Botetourt contains a profusion of Echinosphaerites which locally "shell out" of the limestone upon weathering. The weathered surfaces of the rock have a rough texture and a rusty brown color. The bedding is characteristically thin, and, locally, thin intercalations of buff-weathering silt are present. The maximum thickness of the Botetourt in the area is approximately 30 feet. In some places, along the lateral extent of the beds, which is only about 600 feet, the shelly limestone narrows to 10 feet in thickness.

In the Porterfield Quarry area the Botetourt is a transitional unit between the Effna Limestone and the Arline Limestone. The Botetourt interfingers with the Arline and the Effna Limestone in the vicinity of coordinate E. 29000 and S. 4800 on the accompanying map. It is overlain by the Rich Valley Formation.

It has been noted under the discussion of the Effna Limestone and Arline Limestone that the fauna of these three units are very similar. In view of this faunal similarity and the interfingering of the three units, the Botetourt in the Porterfield Quarry area is considered to be of Champlainian age.

Cooper (1956, pp. 49-50) lists the following brachiopods from the Botetourt Limestone:

Acanthambonia virginiensis Cooper
Atelasma sp. 2
Bilobia virginiensis Cooper
Bimuria immatura Cooper
B. superba Ulrich and Cooper
Camerella minuta Cooper
Christiania subquadrata (Hall)
Conotreta ? altirostra Cooper
C. multisinuata Cooper
Cyrtonotella grandistriata (Willard)
C. virginiensis Butts
Cyrtonotella sp.
Dactylogonia transversa Cooper
D. sp. 2
Doleroides ? ponderosus Cooper

Brachiopods: (Cont.)

Elliptoglossa ovalis (Bassler)
Eoplectodonta ? dubia Cooper
Glossella sp. 1
Glyptorthis equiconvexa Cooper
Hesperorthis ? costellata Cooper
H. sp. 1
Isophragma biseptatum Cooper
Kullervo punctata Cooper
Leptellina pulchra Cooper
L. tennesseensis Ulrich and Cooper
Limbimurina brevilimbata Cooper
Multicostella bursa (Raymond)
Opikina ? dubia Cooper
Orthambonites brachiophorus Cooper
O. pervicrassicostatus Cooper
O. tennesseensis Cooper
Oxoplecia holstonensis Willard
Pachyglossa pachydermata Cooper
Palaeostrophomena angulata Cooper
P. ? rugosa Cooper
Paterula perfecta Cooper
Paurorthis catawbensis Butts
Perimecocoelia semicostata Cooper
Productorthis americana Cooper
Ptychoglyptus virginiensis Willard
Scaphorthis perplexa Cooper
Schizambon cuneatum Willard
Schizotreta shuleri (Willard)
Taphrorthis peculiaris Cooper

Geologic Section 3. - Botetourt Limestone in the Porterfield Quarry area, Smyth County, Virginia.

	Thickness Feet
Rich Valley Formation	
6. Shale with intercalated black, fine-grained, dense limestone beds	—
Botetourt Limestone (30 feet)	

Geologic Section 3. - (Cont.)

	Thickness Feet
5. Limestone, brownish-black, fragmental rusty weathering, shelly	9
4. Shale, friable, buff-weathering	1
3. Limestone, bluish-black, thin intercalations of buff-weathering, friable shale	6
2. Limestone, brownish-black, impure, composed mainly of fragments of brachiopod shells and trilobite cephals in fine calcite cement, thin bedded, rough texture	14
Effna Limestone	
1. Calcarenite, light-gray, thick bedded, coarse-grained	--

Rich Valley Formation

The Rich Valley Formation was named by Cooper and Cooper. The type section is immediately south of the Porterfield quarry and Worthy Mine of the Olin Mathieson Chemical Corporation (Cooper, 1956, p.86), and is the section described below. The beds described in this report as Rich Valley are essentially those referred to by Butts (1940, p. 164) as belonging to the Athens Formation. Butts considered the lower fifty feet of the formation of the Porterfield quarry to be composed of limestone. The beds described in this report as Rich Valley shale are the lower and characteristic part of the unit widely identified by Butts and others as Athens Shale. The Rich Valley in the Porterfield Quarry area is similar to the Liberty Hall black-limestone, black-shale members of central and western Virginia.

The basal portion of the formation is composed of thin-bedded, limy, chocolate-brown shales. The basal, shaly member of the Rich Valley lies upon the calcarenitic facies of the Effna Limestone, and overlies the Botetourt and Arline Limestones near the western margin of the area. These thin shale beds contain an abundance of graptolite impressions, and many well preserved specimens of trilobites. The brown, friable shale beds grade upward into beds of black shale with interbeds of black, dense, fine-grained limestone. The limestone interbeds vary in thickness from six to eight inches, and in many places are lenticular in form. This black shale-limestone member of the Rich Valley Formation caps the biohermal structure in the quarry. The shale and interbedded limestones fill the depressions or pockets which are present on the irregular surface of the bioherm. In many places along this contact the beds of the Rich Valley assume nearly a vertical dip due to the steeply dipping reef rock on which they were deposited. The dip of the beds decreases as the distance away from the biohermal structure increases.

Disseminated pyrite is common throughout the beds of shale and limestone. The black color of the beds is due to the large amount of contained iron sulfide. The fauna of the shale-limestone member of the Rich Valley consist of a profusion of Normanskill graptolites, brachiopods, and trilobites. The following trilobites are abundant in this unit:

Telephus latus Ulrich, Ampyx americanus Safford and Vogdes, A. sp. and Ampyxina scarabeus Butts.

The black shale-limestone member of the Rich Valley constricts the base of the bioherm. This large tongue separates the calcarenitic and the biohermal facies of the Effna Limestone on the eastern margin of the structure. Smaller interfingerings occur at various points along the contact of the beds of Rich Valley and the biohermal limestone, especially along the western border of the bioherm. Since the environment in which the black shales and limestones were formed was a reducing one, it seems very likely that the deposition of this material around the base of the bioherm during its initial development probably retarded the growth of the structure somewhat. At least part of the shale-limestone member is contemporaneous with the basal reef limestone as evidenced by the intertonguing of the two. The presence of the black shale-limestone member surrounding and interfingering with the basal reef rock indicates that two contrasting areas of deposition must have existed over a relatively small area. The accumulation of organic matter had to be more rapid than the rate of oxidation, if oxidation was going on at all. The conditions favoring an environment of optimum reef growth are directly opposed to those mentioned above for the accumulation of the black shale-limestone member of the Rich Valley. The writer believes that an environment in which there is a complete lack of circulation and oxygen is hardly possible in an area adjacent to active reef growth. Ruedemann (1935) suggested the deposition of black shales and limestones in an area of comparatively free circulation. It is possible that the stagnated water around the base of the reef and over the adjacent bottom may have been sealed off from the atmosphere by a density stratification of the waters produced by a layer of relatively fresh water overlying more saline waters.

The black shale-limestone member grades upward into relatively thicker beds of dark-gray limestone with thin interbeds of light-tan to gray shale. The limestone beds become increasingly shaly higher in the section. This member makes up the upper one-third of the Rich Valley Formation in the area, and may be found along the entire southern boundary of the area. The low and rolling hills at the base of Walker Mountain to the south of the area studied in this report are underlain by this shaly-limestone member of the Rich Valley Formation.

Genetic Significance of Porterfield Bioherm

Fossil organic reefs were formed under narrowly limiting conditions by intense metabolism of plants and animals in agitated clear and shallow waters. The fossil communities of reef dwelling organisms are among the most complex and specialized found anywhere in the sea. Characteristically, these communities occupy an area surrounded and isolated by contrasting environments. For this reason fossil reefs contrast strikingly with the adjacent rocks in both lithologic and paleontologic characters. In many instances these contrasts are helpful in recognition and classification of facies, but they also involve complex stratigraphic relations. Ordinarily, there is a high order of correlation between assemblages of fossils and lithologic facies of the containing rocks because both lithofacies and biofacies are commonly dependent on the same related environmental factors.

The concept of biocoenotic type is analogous to the concept of lithologic type. Just as a sedimentary deposit is an assemblage of sedimentary components representing a response to external conditions and to each other, so a biocoenoses is an assemblage of co-existing and ecologically related animal and plant species likewise representing a response to external conditions and to each other. A fundamental principle of ecology might be stated here, as its implications are clearly represented in the case of living as well as fossil reefs. This principle states that, under given environmental conditions the sea will tend to produce organic assemblages of similar nature (similar biocoenotic type) regardless of difference as to species and genera available. This same principle could be modified to apply equally as well to sediments, in which case the sea will tend to produce, under given environmental conditions, sediments of similar textural character regardless of difference as to source and type of material being supplied. The expression, similar textural character, implies that the fundamental attributes, properties, and structures will be similar, excepting those which are functions of mineral composition.

The biohermal facies of the Effna Limestone in the Porterfield Quarry area contains a algal-crinoid-brachiopod biocoenoses. This association occurs in Ordovician, Silurian and Devonian rocks in many regions. A notable comparison may be made between the reef in the area studied and the Silurian reefs of Gotland described by Hadding (1950).

In the case of the Silurian reefs, however, the biocoenoses also contained corals such as Favosites and Heliolites, which were more abundant during the Silurian period.

The governing factors in reef formation and development may be summarized as follows:

1. Factors Pertaining to the Substratum
   A. Composition and character
   B. Inclination
   C. Character and activities of benthonic life

2. Factors Pertaining to the Medium
   A. Motion of the medium
   B. Dissolved gas content
   C. Salinity
   D. Character of suspension load
   E. Temperature
   F. Light intensity
   G. Depth

3. Factors Operating above the Substratum
   A. Movement of suspended sediment
   B. Character and activities of pelagic life

Fossil reefs are known to occur on numerous types of substrata, and these types affect the growth and development of a reef in various ways. The Porterfield bioherm developed on a foundation of massive, relatively strong calcarenitic limestone, which offered sufficient support for reef growth. The evidence which affirms the support offered by the underlying calcarenite is the fact that no slumping or downwarping of the underlying sediment has occurred. The Silurian reefs were built up on a marly substratum and also on banks of calcareous sand. Hadding (op cit.) reports that all of the Silurian reefs have sunk down into the substratum even though they were also supported somewhat by the sediments being deposited around their margins.

The inclination of the substratum is significant in regions such as the margins of reefs. Sedimentary material and unattached living organisms may exist on a highly inclined substratum if the slope does not exceed their maximum angle or repose. The calcarenitic facies of the Effna Limestone underlying the bioherm appears to have been nearly horizontal when reef growth was initiated. This is indicated by the evenness of the bedding and the lateral uniformity of the calcarenite.

The organisms whose skeletal remains make up the major part of a fossil organic reef are of two types; those organisms which constitute the relatively rigid framework of the reef, (sediment binding organisms), and those organisms that live on the reef or in very close proximity to it but which are not sediment binding in nature. The organisms responsible for the somewhat rigid framework of a reef are permanent dwellers on it and their exoskeletons and secretions remain to make part of it after their death. As the structure develops by the building of the forming organisms, it has considerable rigidity. The entire structure is reinforced by the overlapping colonial growth, and this reinforcement enables the accumulation to grow upward at much steeper angles than is possible for most sedimentary materials. It is possible for the outer margins of the reef to be inclined past the vertical. The cavities and depressions in the reef that form between the actual reef building organisms are usually filled by non-colonial type organisms. These non-colonial organisms add greatly to the total volume of the reef structure.

The sediment-binding, or reef forming, organisms of the Porterfield reef are algal colonies, and to a lesser extent crinoids and bryozoans. The algal structures are not specific fossils but are assemblages of blue-green algae. Any generic name given to these structures would actually be invalid, since the name would apply to various types of blue-green algae represented by the accumulation of entrapped sediment. At the time of initial development of the reef on the calcarenitic facies, the bottom was densely populated by algae, crinoids, bryozoans and brachiopods. The conditions favoring the development of this organic community cause the successful growth and repopulation of the organisms. As older individuals die the skeletons remain more or less in place, and new individuals develope upon the old. The organisms that build reefs are food for other organisms, and where food is abundant, as it is likely to be on reefs, there are those to devour it. After the death of the reef-builders, their constructions may be riddled by boring animals in their search for food or to construct cavities in which to live. In this way the framework of the structure may be greatly impaired and reduced in part to calcareous sand or mud. This destruction may be so complete that the resulting material may show little evidence of once having been a rigid framework.

The inability of the reef-forming organisms to live out of water stops the vertical development of the reef at a point just below sea level. Any drop in sea level would be effective in halting the growth of the reef vertically; however, growth might still continue in a horizontal direction. The reef began its development as an elongated mound which trended southeast and northwest in direction. In this reef, as in the Silurian reefs of Gotland, there is evidence of alternate spreading and narrowing of the structure. Spreading was greatest on the eastern side of the structure, leaving the reef in no way symmetrical and without the "typical" bulbose shape so often referred to when speaking of the shape of a reef.

During the development of the Porterfield reef there were two contrasting marine environments present. One environment on the reef itself was of the oxidizing type with flourishing life. The reducing environment produced the black shale-limestone beds of the Rich Valley Formation. The fossils found in the shale-limestone were probably reef dwellers that were washed from the reef and preserved in the black muds that were being deposited around the reef. It is obvious from the intertonguing of the black shale-limestone beds with the reef rock that they are at least partial equivalents. The deposition of black muds around the reef, although it did not halt reef growth, may have retarded the growth of the reef.

The circulation of water directly influences the amount of oxygen, other dissolved gasses and sediment which are carried by the water. The intense organic activity on a reef demands that a large amount of oxygen be present. In the areas around the reef where black muds were being deposited, the water was definitely moving slower than on the reef, and the bottom water was probably stagnant. The lack of circulation of the water around the reef created the reducing conditions that existed there, while good circulation on the reef proper supplied oxygen and food to the reef-building organisms. Areas swept by strong, continuous currents are not favorable for the growth of algae and crinoids, as the free-swimming larva have little opportunity to affix themselves to the bottom. Some species of algae grow best where they are protected from the ocean breakers and strong currents; others thrive best in regions just below the pounding breakers. In any case, for vigorous growth such as on the reef in the area studied, there must be circulation that will continually supply fresh water.

The temperature and salinity of the water around an active reef are important factors, which control the rate of growth and development of the reef. Seasonally warm temperature and a salinity in the range of 33 to 35 per cent favor reef development. The mean annual temperature of the water must be above 70 degrees Fahrenheit. The water in which the Porterfield reef developed must have met the requirements for salinity and temperature given above. The large density of shell life indicates a large quantity of calcium salts in the water. Warm water is suggested by the abundance of algal forms and crinoid remains that are present on the reef. The factor of temperature, which is of maximum importance in reef growth, may be evaluated for an ancient environment only by uncertain analogies between living and fossil animal and plant types.

The character of the suspended material in the water, including composition, grain size, and volume of suspended material affects organisms and bottom sediments. If the suspended load becomes too great, it may limit organic growth and make it impossible for certain species to inhabit an area. This does not seem to be the case in the vicinity of the Porterfield reef. The free circulation of the water on the reef would remove most of the material in suspension; otherwise, the growth of the reef-building organisms, such as the algal colonies, would be seriously impaired. The fine-grained particles of black mud which were deposited were carried in suspension. The fine-grained material indicates that the position of the reef must have been relatively far from the source area, or in an area of calm water. The fine sand and silt moved intermittently during times of stronger currents and must have settled to the bottom during periods of calm.

The depth of water in which the Porterfield reef developed may have varied slightly throughout the life of the reef, but, generally speaking, the water was shallow. The bottom was probably less than 100 fathoms deep, and probably at most times and places 15 fathoms or less. The environment was thus wholly neritic during reef growth.

The local development of structures formed through the agency of algae (stromatolites) favors a depth of less than 15 fathoms (Cloud, 1942, pp. 370-371). Black (1933) shows that colonies of sediment-binding algae that are now building structures comparable to some of the crinkled stromatolites of the Porterfield reef actually have their optimum development in tidal flats, or even above normal high tide, on near-shore flats that are periodically inundated by marine waters.

The type and amount of pelagic life in the vicinity of the Porterfield Quarry reef during its development is unknown. In view of the extremely large benthonic community that was present in the area, and the amount of planktonic food demanded by this community, it is assumed that a large volume of microplanktonic food was available to support the benthonic life. It is impossible to evaluate these biotic factors in other than a general way because, the zooplanktonic food supply and organic interrelationships can not be interpreted from the paleontologic evidence.

After evaluating the various lithologic and biologic aspects of the reef in the Porterfield Quarry area, and, after making a detailed review of the literature on the subject of reefs, it is evident that the reef in the area studied is a "typical" one. The use of the greatly over-used word "typical" implies that the reef in the area studied has numerous general attributes and properties found in similar structures as described in the literature. The Porterfield reef compares in much detail with the Silurian reefs of Gotland described by Hadding in 1950. Comparisons may also be found in the literature with present day reefs in the Bahama Islands, and the West Indies.

Summary of Conclusions

The lithologic and petrographic study of the Porterfield Quarry area has given rise to many facts, particularly in reference to the biohermal limestone in the area. The important observations gained from this study are listed below together with supporting evidence. References are also made to pages and plates of this report which support the conclusions stated below.

A. Conclusions

1. The calcarenitic and biohermal lithofacies of the Effna

Limestone, the Arline, and the Botetourt Limestones are all partial time equivalents. This is evident from the interfingering relationships of the units shown on the accompanying geologic map in the vicinity of coordinates; S. 4800, E. 29000.

2. The calcarenitic and biohermal lithofacies of the Effna Limestone, the Arline and the Botetourt Limestones are all faunally very similar. This may be shown by a comparison of the faunal lists for the various units in the text on pages 21, 36, 38.

3. The black shaly-limestone member of the Rich Valley Formation that surrounds the base of the reef is a time equivalent of the basal reef rock. This is suggested by abundant evidences of interfingering of the two units shown on the accompanying geologic map in the general vicinity of coordinates; E. 27000, S. 4000.

4. The reef does not have the "typical" mushroom shape used so often to describe reefs. The Porterfield reef is overdeveloped on its eastern side, and no line of symmetry can be drawn dividing the reef into two parts which are any way near the same shape. See accompanying geologic map; and page 27 of the text.

5. The thickness of the reef measured from the transitional boundary at its base with the underlying calcarenite to the contact with the black limestone-shale member of the

Rich Valley formation which caps the reef is 450 feet. See accompanying geologic map.

6. After the initial development of the reef as a small southeasterly trending mound on the sea bottom, growth continued upward with expansion primarily to the east. This expansion is suggested by the interfingering that is present between the reef rock and the surrounding strata. See accompanying geologic map.
7. The calcarenitic lithofacies of the Effna Limestone afford sufficient support as a foundation for the reef. This conclusion is suggested by the fact that no slumping or downwarping of the calcarenitic lithofacies can be seen in the field. See accompanying geologic map in the vicinity of coordinates; E. 26500, S. 4500.
8. Some fossil shells and fragments have been destroyed by the formation of stylolites. (Plate no. 14-A, B; 15-B).
9. The stylolites in the Effna Limestone are composed largely of dolomite, pyrite, and submicroscopic matter. (Plate no. 14-A; 18-A, B).
10. Calcium carbonate has been deposited between the laminae of the algal masses by percolating solutions. (Plate no. 21-A, B).
11. The biohermal lithofacies of the Effna Limestone is composed largely of anhedral grains of recrystallized

calcite and dolomite that range in size from 0.5 to 1.5 mm. in diameter. (Plate nos. 16-B; 17-B).

12. The biohermal limestone has a sutured texture as a result of recrystallization. (Plate no. 16-B; 17-B).

13. Recrystallization has almost completely destroyed all of the organic forms in the core of the reef. (Plate no. 17-B; 18-A, B).

14. Many of the grains of dolomite contain "ghost" centers of calcium carbonate, which are similar to the matrix which encloses the dolomite grain. This suggests the formation of the dolomite after the enclosing matrix of calcium carbonate. (Plate no. 15-A).

15. It appears that if a sufficient supply of magnesium had been introduced over a long enough period, that all the calcium carbonate could have been converted to dolomite. (Plate no. 15-A).

16. The presence of dolomite in varying amounts, the greatest amount occurring in the fine-grained calcite, suggests that the opportunity for dolomite to form varied with porosity, and is directly related to the diffusion of magnesium ions in static pore water within the enclosing calcium carbonate matrix.

17. Numerous interstitial voids in the reef have been filled by fine-grained, black dolomite. The interstitial voids were found to be lined with coarse-grained recrystallized

calcite, which was surrounded by the biohermal lithofacies of the Effna Limestone. (Plate no. 19-A, B; 20-A, B).

18. The black color of the dolomitic filled interstices is due to the presence of finely disseminated iron sulfide which was present along with the dolomite in the percolating solutions. (Plate no. 20-A, B).

19. The dolomite filled interstices contain up to thirty per cent of iron sulfide. Many of the filled interstices appear to be branded due to the presence of iron sulfide in greater or lesser amounts. (Plate no. 19-A; 20-A, B).

20. The iron sulfide that is present in the dolomite nest could only have originated outside the reef proper where black muds were being deposited. The iron sulfide could only have entered the interstitial voids by the action of solution. The presence of the iron sulfide in the dolomite nest indicates that the nests were in the process of forming while a reducing condition existed around the reef proper. (Plate no. 19-A, B; 20-A, B).

21. The band of recrystallized, coarse-grained calcite that is always present surrounding a dolomite nest is generally thicker below the nest than above. This suggests that the recrystallization was initiated by the action of solutions. (Plate no. 20-A, B).

22. In numerous specimens of biohermal limestone micro-

stylolites were found between the contact of the dolomite nests and the recrystallized calcite band that surrounds the nest. These stylolites suggest the action of solution under pressure. (Plate no. 19-A).

23. Thin-section study of the recrystallized calcite bands that surround the dolomite nests show that the calcite grains have been subjected to stress. This is indicated by the bending of the twinning planes of the calcite grains. (Plate no. 19-A).

24. In a few thin-sections of the dolomite nests grains of recrystallized calcite were found within the dolomite with an interlocking contact between the two. This suggests that the dolomite may be replacing the calcite by growth outward. (Plate no. 19-A).

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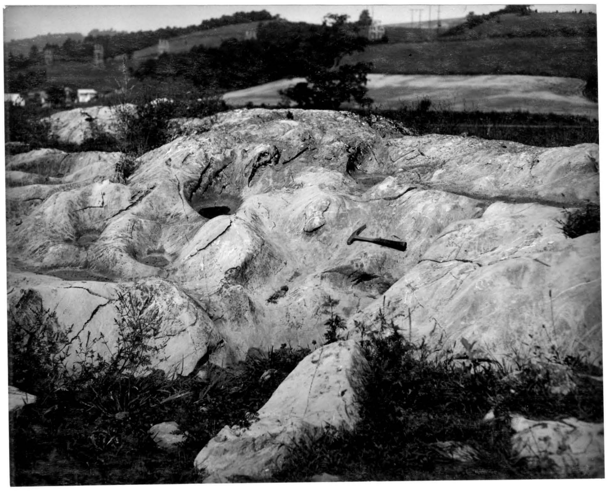
Plate no.8

A.

Looking northeast at an exposure of Lenoir Limestone just west of the Porterfield Quarry area.



B.

Exposure of the Botetourt Limestone in the Porterfield Quarry area approximately at coordinates E. 28600, S. 4800, on accompanying geologic map.

Plate no.9

A.

Chocolate-brown shale member of the Rich Valley Formation, coordinates E. 27900, S. 4500 on accompanying geologic map.

B.

Chocolate-brown shale member of the Rich Valley Formation, showing the relationship between the bedding and cleavage planes.

Plate no.10

A.

Black shale-limestone member of the Rich Valley Formation (top) interfingering with the biohermal lithofacies of the Effna Limestone, coordinates E. 26600, S. 5400 on accompanying geologic map.

B.

Black shale-limestone member of the Rich Valley Formation (top left) interfingering with the biohermal lithofacies of the Effna Limestone, coordinates E. 26600, S. 5400 on accompanying geologic map.

Plate no.11

A.

Looking east at the black-shale-limestone member of the Rich Valley Formation which forms a nose between the biohermal and calcarenitic lithofacies of the Effna limestone. Located at coordinates E. 26550, S. 5700 on accompanying geologic map.

B.

Looking south (from the Calcarenitic side) at the black shale-limestone nose of Rich Valley Formation.

Plate no.12

A.

Black shale-limestone member of the Rich Valley Formation overlying the biohermal lithofacies of the Effna limestone. Located at coordinates E. 27100, S. 5050 on accompanying geologic map.

B.

Looking southeast at the black shale-limestone member of the Rich Valley Formation overlying the biohermal lithofacies of the Effna limestone.

Plate no.13

A.

Black shale-limestone member of the Rich Valley Formation standing nearly vertically upon the biohermal lithofacies of the Effna Limestone.

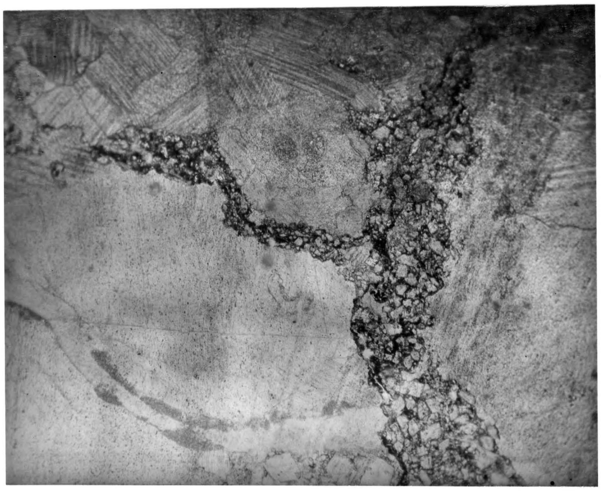
B.

Black shale-limestone member of the Rich Valley Formation (left) standing nearly vertically upon the biohermal lithofacies of the Effna Limestone. Located at coordinates E. 27150, S. 5075 on accompanying geologic map.

Plate no.14

A.

Thin-section of calcarenitic lithofacies of the Effna Limestone, x10, which shows a stylolitic seam composed largely of dolomite, pyrite, and submicroscopic matter that has partially destroyed the fossil shell in the lower right.



B.

Thin-section of calcarenitic lithofacies of the Effna Limestone, x10, which shows a fossil shell completely filled and surrounded by grains of calcite and dolomite and partially destroyed by these grains. The shell is composed of fibrous calcite, and the filling in the shell constitutes a geopetal fabric.

Plate no.15

A.

Thin-section of the calcarenitic lithofacies of the Effna Limestone, x10. The large dolomite grain in the lower right contains fine-grained calcite in its center.

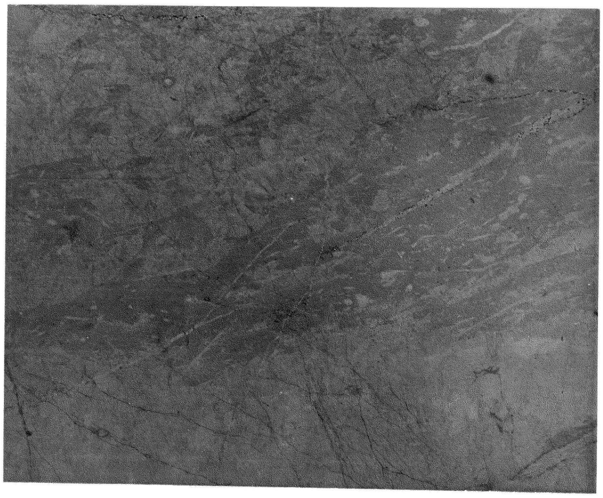
B.

Thin-section of the calcarenitic lithofacies of the Effna Limestone, x10. The growth of grains of calcite and dolomite have partially destroyed the upper and lower surfaces of the bryozoan fragment.

Plate no.16

A.

Unstained honed surface of the biohermal lithofacies of the Effna Limestone, x2, containing recrystallized fossil fragments and sedimentary detritus.



B.

Thin-section of the biohermal lithofacies of the Effna Limestone, x10.

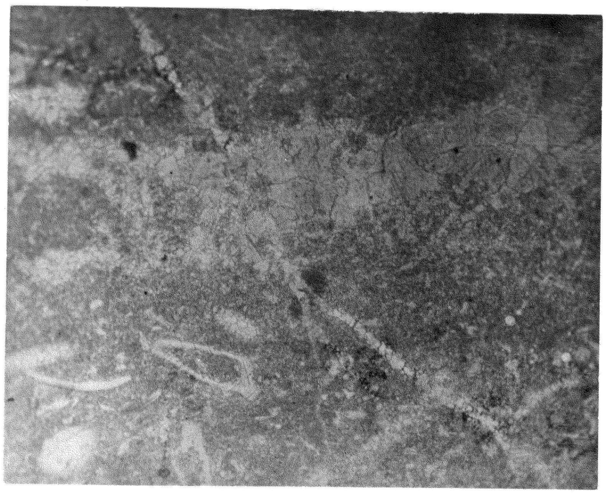
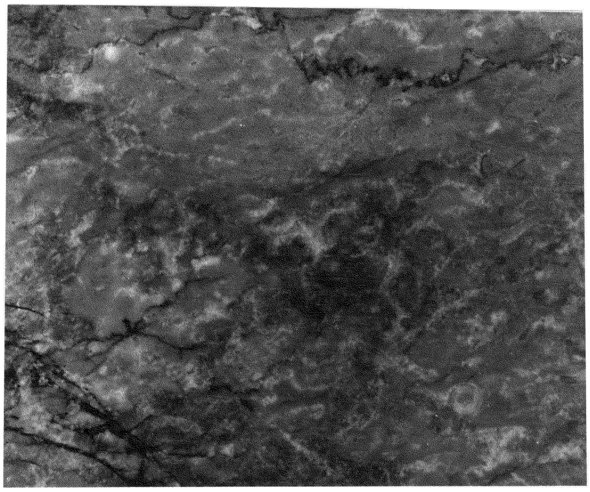


Plate no.17

A.

Unstained honed surface of the biohermal lithofacies of the Effna Limestone, x2.



B.

Thin-section of the biohermal lithofacies of the Effna Limestone, x10.

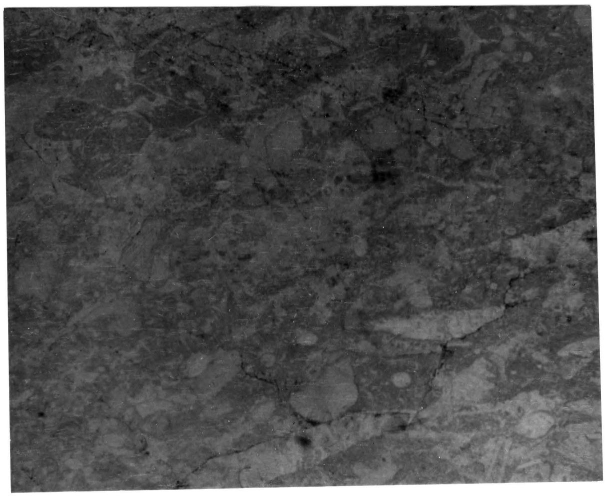


Plate no.18

A.

Unstained honed surface of the biohermal lithofacies of the Effna Limestone, x2.

B.

Unstained honed surface of the biohermal lithofacies of the Effna Limestone, x2.

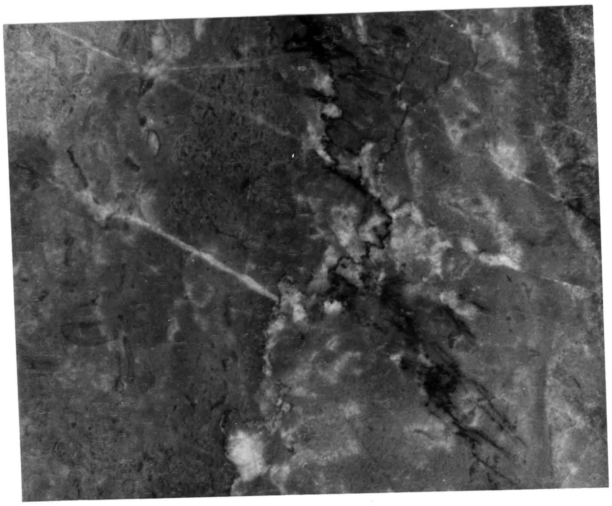
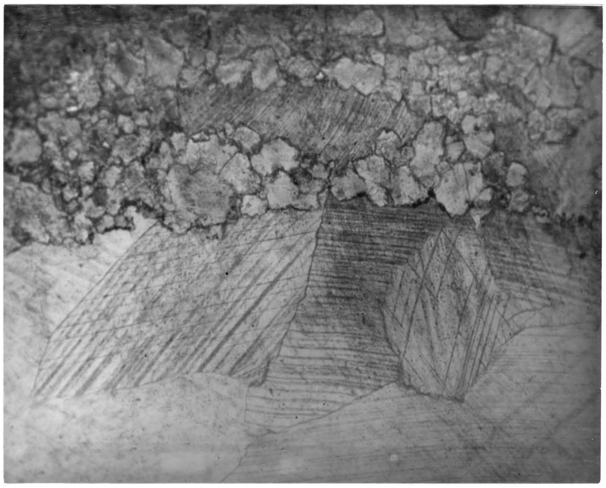


Plate no.19

A.

Thin-section of the biohermal lithofacies of the Effna Limestone, x15, which shows the contact between fine-grained dolomite nest (top) and coarse-grained recrystallized calcite. The black material surrounding the grains of dolomite is finely disseminated iron sulfide. A micro-stylolite is present between the dolomite nest and the band of recrystallized calcite that surrounds the nest. The calcite grains show evidence of straining.



B.

Thin-section of the biohermal limestone, x15. The structure in the center of the picture is of organic origin and composed of fine-grained calcite and dolomite. A dolomite nest is present to the left of the structure and recrystallized calcite to the right.

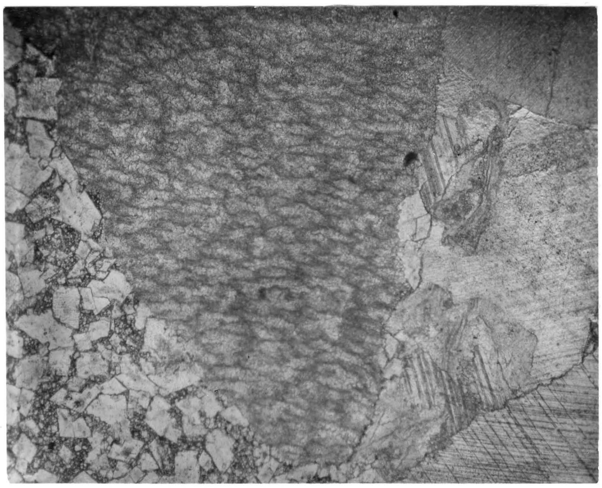
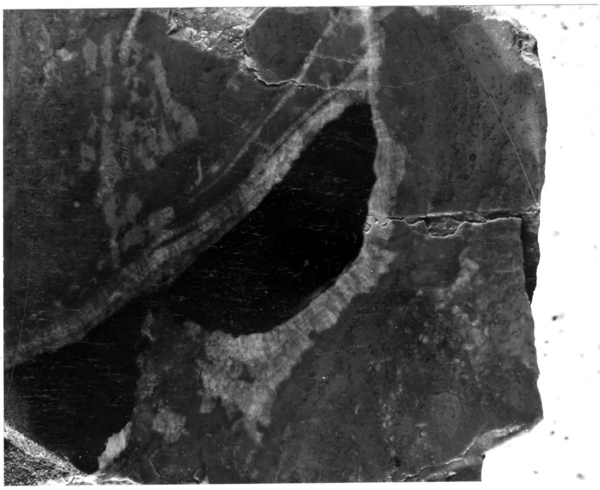


Plate no.20

A.

Unstained honed surface of biohermal limestone, x1.5, showing a black dolomite nest surrounded by coarse, recrystallized calcite. The rock matrix is medium-grained recrystallized limestone.



B.

Unstained honed surface of biohermal limestone, x1.5, showing black dolomite nest. The picture shows that recrystallization of the limestone matrix has been greatest beneath the dolomite nest. The black color of the nest is due to disseminated iron sulfide.

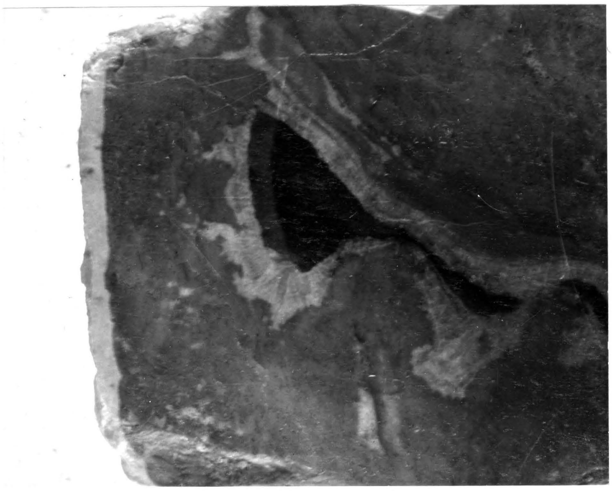
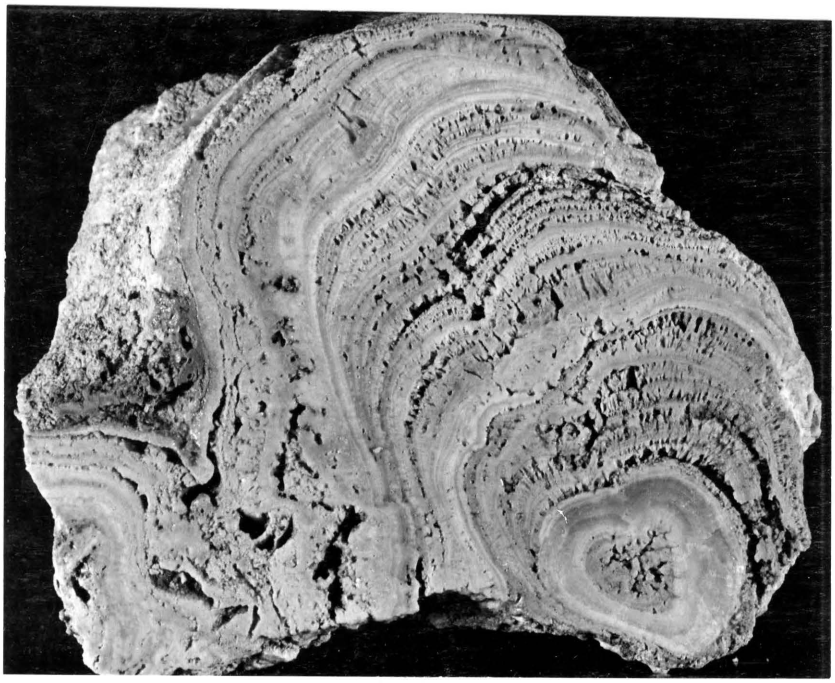


Plate no.21

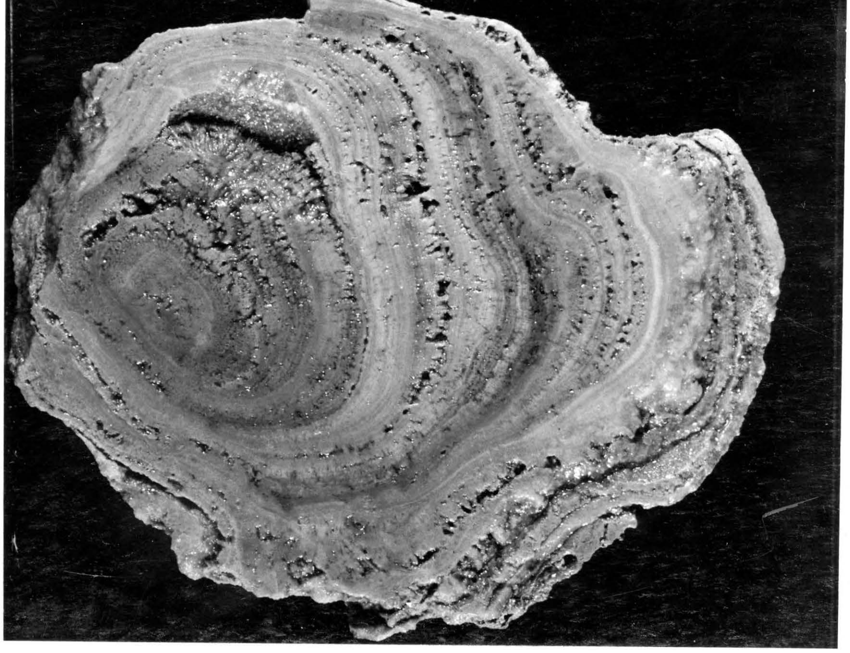
A.

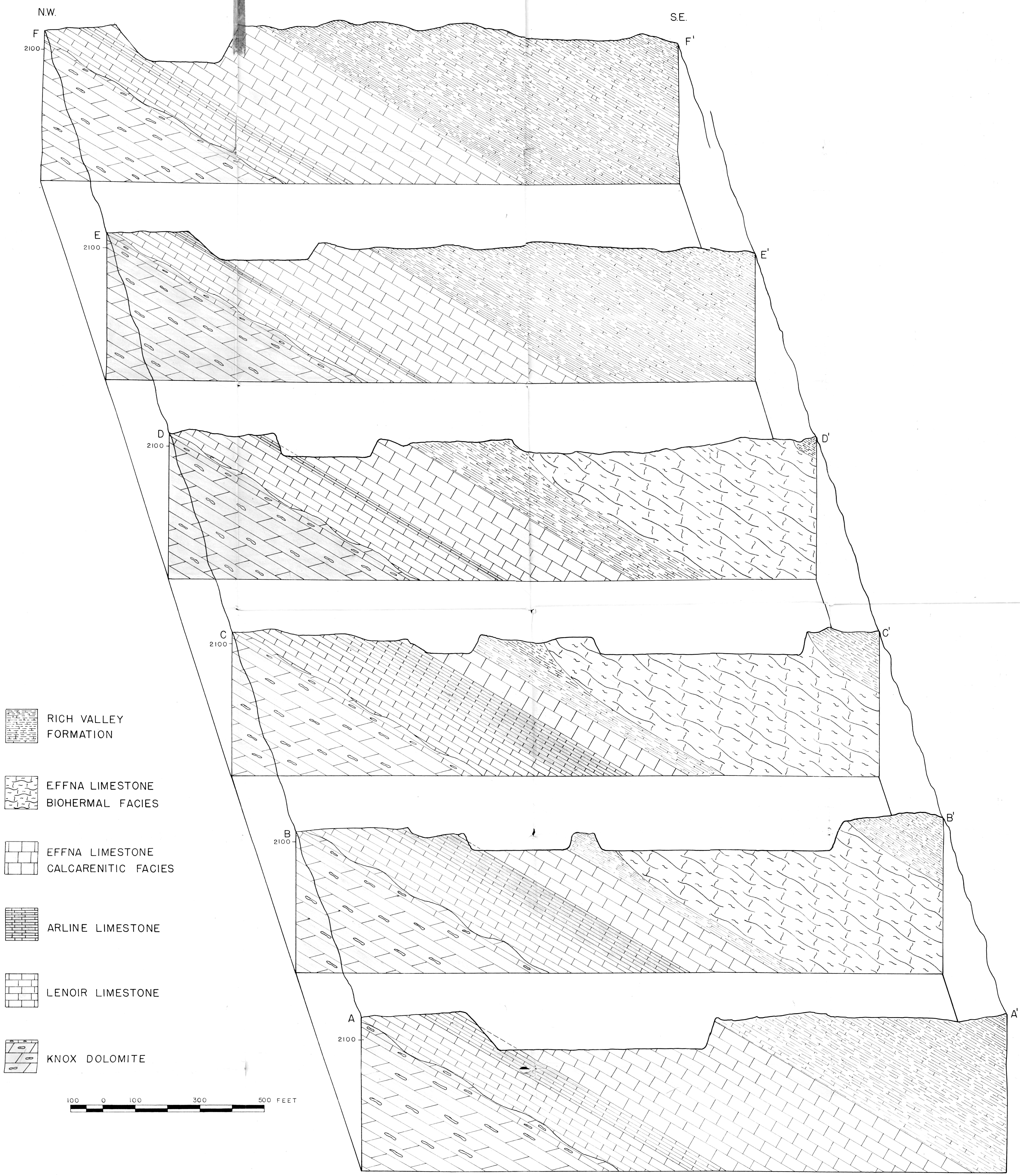
Polished surface of a laminated algal mass from the biohermal Effna Limestone.



B.

Polished surface of a laminated algal mass from the biohermal Effna Limestone.





STRUCTURE SECTIONS OF THE PORTERFIELD QUARRY AREA, SMYTH COUNTY, VIRGINIA

GEOLOGIC MAP OF THE PORTERFIELD QUARRY AREA, SMYTH COUNTY, VIRGINIA