NORTH CAROLINA
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
BEN E. DOUGLAS, DIRECTOR

DIVISION OF MINERAL RESOURCES
JASPER L. STUCKEY, STATE GEOLOGIST

Information Circular 12

A PRELIMINARY GEOLOGIC REPORT ON THE

COMMERCIAL ROCKS OF THE VOLCANIC-SLATE SERIES, NORTH CAROLINA

BY

RICHARD J. COUNCILL

Doc
TN24
.N8
C683
1954

RALEIGH
1954

NC DENR LIBRARY
1610 MSC
RALEIGH,NC 27699-1610
919-715-4161

C8
4:12

880277

CONTENTS

CONTENTS - Continued

A Preliminary Geologic Report on the

COMMERCIAL ROCKS OF THE VOLCANIC-SLATE SERIES, NORTH CAROLINA

By

Richard J. Councill

****

INTRODUCTION

The importance of commercial stone production to the mineral wealth of North Carolina has provided the subject for many geologic and economic reports published by the State. The deposits of granite, gneiss, sandstone, crystalline limestone, and marl which have been quarried on a commercial basis are treated in publications by the North Carolina Department of Conservation and Development; however, little attention has been given in reports to the commercial utilization of the stone resources of the Volcanic-Slate series, an extensive group of rocks occupying a large part of Piedmont North Carolina. Within this series of rocks, large amounts of crushed stone for use as concrete and bituminous aggregate, road metal, and railroad ballast are produced in Davidson, Union, Cabarrus, and Durham Counties and marketed in south central and east central North Carolina. In recent years, the production of flagstone, building stone, and cut-stone specialties from quarries in Davidson and Montgomery Counties has increased appreciably and now constitutes an important stone industry. The newest and perhaps the most unique use of rocks from the Volcanic-Slate series is in the production of a superior-quality lightweight aggregate which has wide application in the building industry. This material is produced in large quantities in Stanly County.

Purpose and Scope

Because of the increased importance of stone production in the Volcanic-Slate series during the past few years and the lack of literature dealing with the utilization of certain types of these rocks, this circular is intended primarily to acquaint those interested with the physical and chemical properties, geologic occurrence, and general distribution of the commercial rocks along with the uses of the various products from the quarries. A comparison of the physical and chemical properties of the rocks with similar rocks in other areas is discussed briefly and shown in tables. Thin sections, cut from representative samples of stone from several quarries, were examined to determine mineral content and fabric of the principal rocks. General structural features of various deposits are considered also and are summarized in table form on page 29.

Acknowledgments

The writer wishes to express his gratitude for the courtesies and unlimited cooperation extended him during the fieldwork by Messrs. A. L. McAuley, G. T. McAuley, and R. B. Harris of the Jacobs Creek Flagstone Company; Mr. D. L. Wagoner of the Wagoner Flagstone Company; Mr. W. G. Ross of the Superior Stone Company; and Messrs. J. S. Gunn and R. F. Gibson of the Carolina Solite Company. Dr. Jasper L. Stuckey, state geologist, under whose supervision the fieldwork was conducted, and Mr. S. D. Broadhurst, assistant state geologist, offered valuable suggestions during the course of the investigation. Bulletins 21 and 22 of the North Carolina Department of Conservation and Development were consulted frequently during the preparation of the report.

LOCATION OF QUARRIES

The principal commercial quarries described in this report are developed in metasedimentary rocks belonging to an extensive series of volcanic and sedimentary rocks, referred to as the Volcanic-Slate series, which occupy large areas of the central and eastern Piedmont Plateau section of North Carolina. Large-scale production of crushed stone is made in central Davidson County, southern Stanly County, northeastern and southern Cabarrus County, central Union County, and northern Durham County, whereas flagging material, building stone, and other cut-stone specialties are produced in southern Davidson and southwestern Montgomery Counties. In addition to these quarries, building stone is produced intermittently in central Orange County for specialized building at Duke University.

TABLE I - PRINCIPAL PRODUCERS OF STONE FROM THE VOLCANIC-SLATE SERIES

Company	Principal Product	Location
Blue Ridge Stone Company		
Gold Hill Quarry	Crushed Stone	Near Gold Hill
Carolina Solite Company		
Aquadale Quarry	*Crushed Stone	Near Aquadale
Jacobs Creek Flagstone Company		
Woodard Quarries	Flagstone and Cut-stone	Near Denton
Mt. Gilead Quarry	Building Stone	Near Mt. Gilead
Nello Teer Company		
Teer Quarry	Crushed Stone	Near Durham
Superior Stone Company		
Bakers Quarry	Crushed Stone	Near Monroe
Midland Quarry	Crushed Stone	Midland
Thomasville Quarry	Crushed Stone	Near Thomasville
Wagoner Flagstone Company		
Wagoner Quarries	Flagstone and Cut-stone	Near Denton
Mt. Gilead Quarry	Building Stone	Near Mt. Gilead
Duke University		
Duke Quarry (Noncommercial)	Building Stone	Near Hillsboro
State of North Carolina		
(Noncommercial)	Crushed Stone	Various Localities

* For the manufacture of lightweight aggregate.

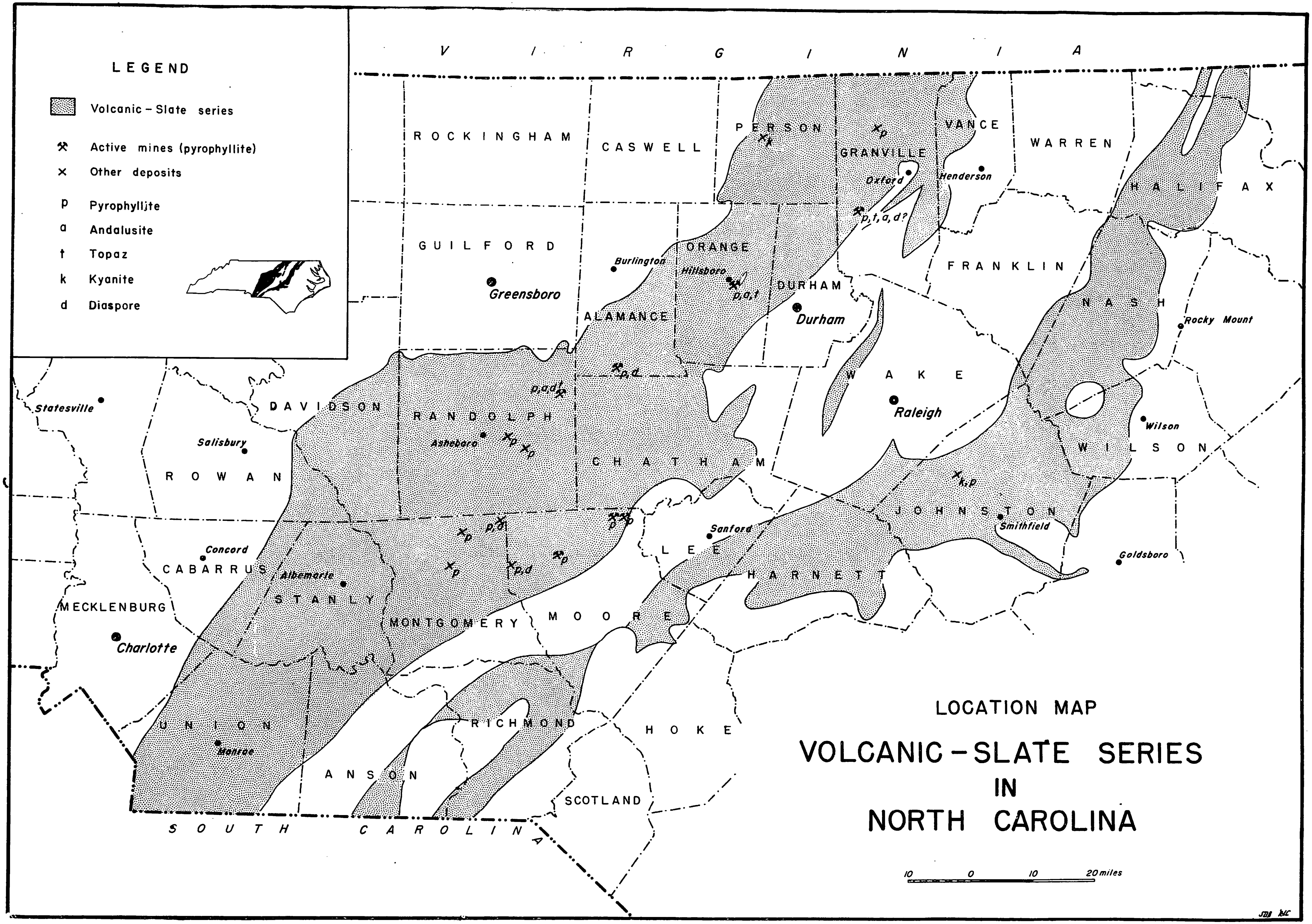
THE VOLCANIC-SLATE SERIES

Areal Distribution

The Volcanic-Slate series, extending from south central Virginia southward into central South Carolina and perhaps into Georgia, is present in North Carolina as two broad belts, which begin in the central Piedmont Plateau and extend eastward to the fall line of the Coastal Plain and for an unknown distance beneath the Coastal-Plain sediments. The east-west continuity of the series is broken by intervening sandstones, shales, granites, and gneisses. The western and larger belt of rock contains the only commercial quarries in the series in North Carolina. Figure 1 shows the areal distribution of the Volcanic-Slate series and the general location of the principal quarries utilizing certain types of these rocks.

General Geology

The rocks of the Volcanic-Slate series consist of rhyolitic, dacitic, and andesitic flow rocks, tuffs and breccias, tuffaceous shales (argillites), slaty rocks, sedimentary breccias, and - to a lesser extent - conglomerates. The various rock types are intricately interbedded and in some instances have been slightly to strongly silicified, thus devitrifying the glassy rocks. Reconnaissance work indicates that tuffs and tuffaceous argillites and "slates" are the most common rock types, followed - in relative abundance - by sedimentary breccias, flows, and pyroclastic breccias. Conglomerates are found in many parts of the series but do not constitute a major rock type. Acid rocks are more common than basic types. The rocks have been intruded by granite, diorite, gabbro, diabase dikes, and vein quartz. Detailed descriptions of the principal rocks are given by Laney (1910), Pogue (1910), and Stuckey (1928). The rocks show the effects of regional dynamic metamorphism, which, except for localized areas, has been very slight to moderate. The presence of the typical


LEGEND
Volcanic-Slate series
Active mines (pyrophyllite)
Other deposits
p Pyrophyllite
a Andalusite
t Topaz
k Kyanite
d Diaspore
VIRGINIA
SOUTH CAROLINA
ROCKINGHAM
CASWELL
PERSON
GRANVILLE
VANCE
WARREN
HALIFAX
GUILFORD
ORANGE
DURHAM
FRANKLIN
NASH
ALAMANCE
WAKE
WILSON
DAVIDSON
RANDOLPH
CHATHAM
JOHNSTON
ROWAN
LEE
HARNETT
CABARRUS
STANLY
MONTGOMERY
MOORE
MECKLENBURG
UNION
ANSON
RICHMOND
HOKE
SCOTLAND
Greensboro
Burlington
Hillsboro
Durham
Raleigh
Oxford
Henderson
Rocky Mount
Wilson
Statesville
Salisbury
Asheboro
Concord
Albemarle
Charlotte
Monroe
Sanford
Smithfield
Goldsboro
p,t,a,d?
p,a,t
p,d
p,a,d,t
k,p
LOCATION MAP
VOLCANIC-SLATE SERIES IN NORTH CAROLINA
10 0 10 20 miles

low-rank metamorphic minerals, chlorite, biotite, and chloritoid, coupled with the lack of intermediate temperature minerals characteristic of regional metamorphism, suggests low heat during periods of metamorphism. Commonly, the rocks are warped into gently undulating folds, and regionally broad, shallow, synclinal structures are suggested. Normal faulting of small displacement is rather common throughout the series, but faulting of major proportions has not been observed. In localized areas the rocks are strongly sheared.

The tuffs and tuffaceous metasediments in many localities exhibit a well defined bedding cleavage and in some instances a true slaty cleavage, whereas the other rock types show a generally less developed cleavage or schistosity. The presence of cleavage or schistosity in the rocks, especially in the fine-grained tuffs and laminated tuffaceous slates and argillites, has prompted the use of the term "slate belt" when referring in general terms to the entire series, thus the names Carolina Slate Belt and, more recently, Volcanic-Slate series have come into widespread use in North Carolina.

COMMERCIAL ROCKS

FLAGSTONE

Definition: Flagstone is a general term applied to fine-grained rocks possessing the ability to be split into slabs or sheets thicker than slate but like slate in that two or more sheets split from the same block of stone will show a remarkable similarity. The sheets must also be suitable for flagging work without finishing or smoothing along the cleavage plane. From this definition, it is clear that a specific mineral or chemical composition is in no way requisite for the application of the term flagstone to any rock which possesses the structural features given above. Deposits of rock exhibiting flaggy and slaty cleavage have widespread occurrence in the Volcanic-Slate series; however, in most areas deep chemical weathering and, in some instances, profuse jointing of the rocks render them useless as commercial deposits. The notable exception is a small area in southern Davidson County, 7 miles SSE. of Denton, where quarries are developed in fresh, fine-grained, tuffaceous "slates" having well defined cleavage which permits straight and remarkably smooth breaks one-half inch or more in the quarried stone. In some instances, the stone will split without difficulty into sheets less than one-fourth inch in thickness and can properly be called slate, but pieces less than one-half inch are seldom marketed by either of the two producers.

Structural Considerations: The distinction between commercial slate and flagstone is based primarily upon the spacing of closed planes along which the rock will break into similar pieces. Because the flagstone of Davidson County is similar to commercial slates except for the frequency and attitude of cleavage planes, it seems proper to compare it with commercial slates in considering its physical and chemical properties.

The commercial slates, such as those utilized as roofing material, possess a closely spaced and well defined cleavage which lies at various angles, from near parallel to 90° to the bedding. This ability to cleave along uniform and closely spaced parallel planes gives slaty rocks their economic value and is the direct result of compression during dynamic metamorphism, which acts upon fine-grained rocks such as shales or argillites. Under these stress conditions, the principal mineral constituents of the rocks are recrystallized and/or reoriented along common parallel planes, formed at right angles to the compressive forces. The parallel orientation of these minerals permits a splitting of the rock along parallel planes. These planes are usually independent of bedding. Cleavage of this origin is commonly called slaty or flow cleavage, and rocks in which it is developed may be classed as slates or flagstones, depending upon the thinness to which the rocks can be separated along successive parallel planes. The commercial flagstones in Davidson County possess a well developed and uniform cleavage, which permits splitting into smooth slabs of one-half inch and up; however, the direction of cleavage, unlike that of true slates, is consistently parallel to the bedding planes in the rocks. Furthermore, microscopic studies by Laney (p. 27, 1910) and Pogue (p.41, 1910) of rocks similar to the flagstone and by the author on a representative sample of the flagstone have shown conclusively that no consistently parallel arrangement of recrystallized or metamorphic minerals is present in these rocks. A cleavage such as that characteristic of the flagstone is commonly referred to as bedding cleavage or bedding schistosity and, according to Billings (p. 218, 1942), may be the result of isoclinal folding, mimetic recrystallization, or flow parallel to bedding. Daly (p. 375-418, 1917) attributes bedding cleavage to load metamorphism. Preliminary studies of structure in the flagstone area suggest that the cleavage was formed by isoclinal folding, however this supposition is not to be interpreted as the absolute cause since it is based upon reconnaissance work during which a dozen or so strikes and dips were determined. Throughout the principal quarries, the planes of cleavage are open at intervals of 3 inches to 1 foot.

Figure 2 shows the position of bedding, cleavage, and the principal joints cutting the flagstone deposits of southern Davidson County. The relationship of the flagstone to the overlying and underlying rocks is shown diagramatically in Figure 3.

<u>Bedding</u>: Bedding in the flagstone is extremely thin, ranging from 1 mm. to 1 cm., with the material composing individual beds or laminae showing very little difference in grain size. Usually, the thinnest beds are composed of the coarsest material, which itself rarely exceeds the spherical dimensions of coarse silt (0.062 mm. to

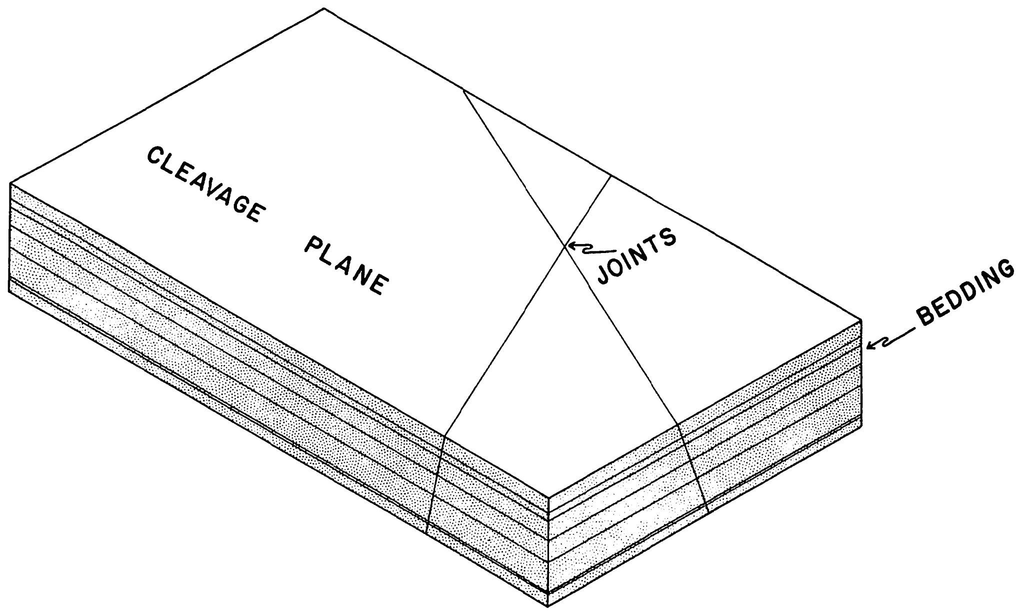


FIGURE 2. BEDDING, CLEAVAGE, AND JOINTS IN THE FLAGSTONE DEPOSITS

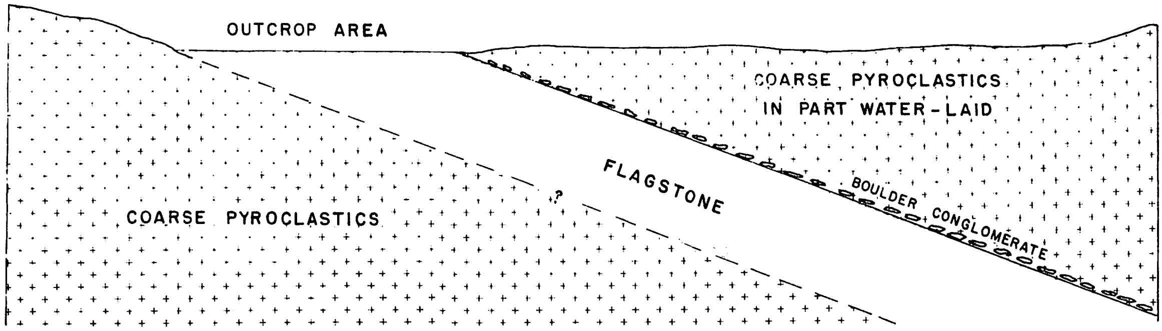


FIGURE 3. RELATIONSHIP OF THE FLAGSTONE TO ADJACENT ROCKS

0.031 mm.), whereas the thicker beds are a mixture of clay and silt-size material with clay predominating. Thin-section analyses of the flagstone and related rocks show a prominent concentration of magnetite and, in some instances, chlorite and/or chloritoid in the coarser beds and along the bedding planes. These minerals often show a roughly parallel alignment. Cleavage in the rocks often occupies a plane common to these thin laminae but is not restricted to them.

The fine laminae are distinct lines or zones of dark material, separating the "thick" beds; and, upon close observation, they appear to have been invaded by solutions, possibly active during the development of the cleavage. It is not uncommon to trace one of these laminae for several feet, only to have the dark color "pinch out" and reappear after being absent for a distance of only a few inches. This condition, coupled with the presence of the oversized grains composing them, suggests that recrystallization and/or secondary growth of the grains has taken place along these planes. However, a thorough microscopic study of the laminae will be necessary to determine if such is the case.

Sedimentary Structures: Sedimentary structures other than bedding are very rare in the flagstone deposits. However, certain irregularities in the bedding, noted in two instances in the Wagoner Quarry, are believed to represent minor slumping of the beds following deposition. In both instances the slump zone can be traced for several feet and has distorted the beds through a thickness of 6 inches to 1 foot. Fracture cleavage in the deposits following these irregular zones prevents the quarrying of smooth slates of stone. When a zone such as this is encountered during quarrying, it is avoided by moving several feet across the strike. Quarrymen refer to these irregular zones as "boulder zones."

The only other structure noted in the flagstone is a flat, spiralshaped accretionary mass growing along the bedding planes. These structures, seen in quarried stone at the Woodard Quarries, range from 2 inches to 5 inches in diameter and are considered secondary.

Mineralogy: The flagstones contain quartz, orthoclase, plagioclase, sericite, scattered grains of magnetite, chlorite, biotite (?), a few grains of epidote and rutile, and very small amounts of pyrite. Clinozoisite is reported by Pogue. Of these minerals, quartz and feldspar are the most abundant, forming a dense, chert-like, mosaic groundmass in which sericite is a prominent secondary mineral. Chlorite and biotite (?) are rather evenly distributed, as is magnetite and sometimes pyrite. Grains of epidote (?) and rutile are widely scattered through the thin sections examined and usually occur as outsized grains. A few glass shards, containing minute inclusions, were observed in the thin sections. Some of the feldspar shows strong kaolinization, and the sericite constituent has a tendency to align in a parallel fashion; however, this property is inconsistent even in the small field covered by the high-power lens of the microscope. With the exception of the outsized grains of epidote, rutile, and quartz, outlines of the minerals are ragged and indistinct. In one thin section, irregular or patchy areas of dark material appearing very much like fragment vestiges were quite prominent; but, upon closer examination, these areas proved to be composed of material identical to the groundmass but of a finer grain size.

Quartz and feldspar, both fresh and sericitized, and much unidentifiable dark dust-like material compose approximately 75 percent of the flagstone, while sericite accounts for roughly 20 percent and chlorite, biotite (?), magnetite and/or pyrite, epidote, and rutile amount to 5 percent. Feldspar is far more abundant than quartz, constituting perhaps 75 percent of the total for both. This estimate of mineral composition compares to an average of roofing slate as given by Bowles (p. 230, 1934), as follows:

Mica (sericite)	38-40
Chlorite	6-18
Quartz	31-45
Hematite	3-6
Rutile	1-1½

The most notable differences in the mineral composition of the flagstone when compared with the "average" roofing slate are: (1) paucity of sericite and quartz, (2) magnetite in place of hematite, and (3) presence of feldspar in large quantities. Since sericite is derived from potash-bearing clay and feldspar during intense dynamic metamorphism, it would seem probable that in the case of flagstones only the potash-bearing, clay-size material was converted to sericite, while the feldspar was only partially altered to that mineral. This would tend to indicate that the metamorphism of the material from which the flagstones were derived was less intense than that resulting in the formation of the "average" roofing slate. That the composition of the sediments converted to flagstone was somewhat different from normal argillites or shales is also apparent and is considered under "Origin of the Flagstone Deposits."

<u>Chemical Properties</u>: Though considerable differences in the mineral compositions of Davidson County flagstone and the average for commercial slates exist, the chemical compositions are similar in many respects. Table II shows the chemical compositions of the flagstone and an average analysis of 22 clay slates from various localities, along with an average for 51 shales, which is the parent material forming slates, a well known commercial slate from Pennsylvania, a slaty rock from near Gold Hill in the Volcanic-Slate series, and the range in composition of slate. The latter probably includes an analysis of the volcanic ash slates of California or England.

TABLE II

	1	2	3	4	5	6
SiO_2	65.00	61.90	60.15	60.32	62.46	50-67
Al_2O_3	17.33	16.54	16.45	23.10	16.10	11-23
Fe_2O_3,FeO	7.34	6.36	6.94	7.05	6.63	1.0-16
CaO	1.30	1.07	1.41	-	2.27	0.3-5
MgO	2.58	2.99	2.32	0.87	0.36	0.5-5
Na_2O	2.02	2.57	1.01	0.49	2.16	0.5-4
K_2O	2.27	3.15	3.60	3.83	2.85	1.5-5.5

1 Nor-Carla Bluestone, Jacobs Creek Flagstone Company, Davidson County, N.C., analysis by Froehling and Robertson.
2 Average of 22 clay slates, modified after Clarke.
3 Average of 51 Paleozoic shales, modified after Clarke.
4 Roofing slate, Lancaster County, Pa., modified after Merrill.
5 Banded blue "slate," Gold Hill, modified after Wheeler.
6 Range in composition of slate, modified after Bowles.

As shown in Table II, the composition of the flagstone, column 1, closely parallels the averages for clay slates as given in column 2 and to some extent the Paleozoic shales as given in column 3. It falls well within the range given for slates in column 6; but, when a comparison is made with a specific slate of known primary sedimentary origin (column 4), the differences which show only slightly in columns 2 and 3 are readily apparent. The differences, especially noted in the lime (CaO), magnesia (MgO), soda (Na_2O), and alumina (Al_2O_3) content, can best be explained by the cycle of weathering through which the two rock deposits have passed and is discussed briefly in the following section of this report. The differences in mineral and chemical composition of the flagstone, as shown by the comparison with analyses of commercial slates, are in no way detrimental to the utility of the stone.

Physical Properties: In physical properties the flagstones compare favorably with commercial slates. Listed in Table III below are the results of tests performed on representative samples of "Nor-Carla Bluestone" (Davidson County flagstone) by Froehling and Robertson, Inc., inspection engineers and chemists. These determinations may be considered applicable to flagstone from any quarry in the Davidson County area.

Table III**

*Modulus of Rupture, lbs./sq.in.	
Parallel to bedding	5736
Perpendicular to bedding	4890
*Compressive Strength, 2" cubes, lbs./sq.in.	
Parallel to bedding	15,750
Perpendicular to bedding	32,375
*Absorption, % by weight	0.08
*Specific Gravity, bulk	2.795
Resistance to Acids, Loss, gms./sq.in.,18 hrs. at 70° F.	
50% Sulphuric Acid	0.0053
Concentrated Hydrochloric Acid	0.0039
Concentrated Nitric Acid	0.0018
Aqua Regia	0.0126
Resistance to Alkali, Loss, gms./sq.in., 18 hrs. at 70° F.	
20% Sodium Hydroxide	0.0027
Abrasion Resistance (Tabor, 1000 gms., 100 cycles, CS17 Calibrase Wheels)	
Loss in grams	0.1104

* Tests made in accordance with A.S.T.M. Standards.
** Furnished by Jacobs Creek Flagstone Company, Mt. Gilead.

The color and hardness of the rocks vary only slightly throughout the many quarries visited during the investigation. Medium to dark gray with a faint bluish tint is the predominant color, while dark grays with a slight greenish tint are sometimes encountered. A permanent lighter bluish-gray color is obtained by sanding the stone on large rotary sanding tables or by hand buffing with steel wool. The hardness of the rock is uniformly about $3\frac{1}{2}$ on Mohs' scale of hardness.

ORIGIN OF THE FLAGSTONE DEPOSITS

The metasedimentary rocks, especially the flagstones and related rocks, in the Volcanic-Slate series are unique in their mode of formation. It is usual to attribute the deposition of fine-grained noncalcareous rocks, such as shale, argillite, and their metamorphosed equivalents, roofing slate and flagstone, to the accumulation in relatively quiet water of fine-grained clastic material which has undergone the "normal" cycle of mechanical and chemical disintegration. Most deposits of such rocks are formed in this way; however, the flagstones of Davidson County, as well as the building stones of Montgomery County and the deposits used in crushed-stone production in Union, Cabarrus, Stanly, and Davidson Counties, were formed in a manner considerably opposed to the "normal" processes.

That the flagstones were derived from the direct settling into water of airborne tuff (volcanic ash) of small, approximately equi-dimensional grain size and the intermingling of eroded and stream trans-ported poorly weathered tuffaceous material of small grain size seems established by the following facts:

1. Glass shards contained in the rocks.
2. Ragged outlines of the nonrecrystallized minerals in the rocks.
3. The equal or greater proportion of soda (Na_2O) over potash (K_2O), as shown in chemical analysis of the rocks (Table I).
4. The presence of overlying and underlying rocks of volcanic origin.
5. Uniformity of fine-grain size of the rocks.

Perhaps the most convincing of these data which attest the abnormal method of formation of these rocks is gathered from chemical analyses. During the normal cycle of chemical weathering of igneous rocks from which all argillaceous, clastic materials are formed primarily, the rate of loss of the various compounds of the original rocks has been estab-lished (Goldich, 1938 after Leith and Mead), as follows: CaO (lime) is the first to be lost, followed by Na_2O (soda), MgO (magnesia), K_2O (potash), SiO_2 (silica), Fe oxides (iron), and Al_2O_3 (alumina), assumed constant due to its resistance to solution. As shown in Table I, the relative abundance of soda, a compound readily soluble, and the likewise relative paucity of potash, a compound moderately to highly immune to solution, immediately suggest that the materials forming the flagstones have not undergone the normal weathering processes. This discrepancy is shown in many analyses of slaty rocks in the Volcanic-Slate series by Pogue, Laney, and Stuckey. Assuming a mode of deposition of the pyroclastic materials forming the present flagstone deposits and the establishment of their relatively unweathered condition at the time of deposition, the writer believes that the parent tuffaceous materials were largely of dacitic and rhyolitic composition. Individual beds (laminae) in the deposits can be traced for considerable distances without interruption, thus bespeaking a deposition of the material in quiet and probably deep water.

BUILDING STONE

Montgomery County

Building stone is the term applied by the producers to a tuffaceous argillite quarried 2.75 miles west of Mt. Gilead, in southwestern Montgomery County. The rock is quite similar to the flagstone of Davidson County but is thicker bedded and does not possess the closely spaced and well defined cleavage present in the flagstone.

Bedding and Other Sedimentary Structures: Individual beds in the building stone range from 1 mm. to 3 inches and are composed of grains less than 0.062 mm. in diameter, or silt and clay-size material. Like those of the flagstone, the thicker beds are separated by thin, dark colored laminae composed of slightly larger grain size material. Throughout the quarry area, the beds are frequently distorted slightly by spheroidal shaped, calcareous accretions (nodules), which show elongation parallel to the bedding. These nodules are composed of approximately 25 percent calcium carbonate and 75 percent fine sand, silt, and clay-size material. Upon weathering, the material leaves a residue having the appearance of decayed wood. A few layers of relatively pure limestone, up to 3 inches in thickness, found in the deposit may have furnished the calcium carbonate forming the nodules, however it is believed that these layers resulted from the coalescing of a series of nodules along a common plane.

Structural Consideration: Cleavage in the building stone is here classified as fracture cleavage, or closely spaced jointing. This system of open fractures was developed during anticlinal folding of the rocks. The most pronounced direction of splitting in the rocks lies parallel to the plane of bedding and is present as open planes at intervals of 2 inches to 1 foot. A second direction of cleavage, offering some facility in splitting, lies at an angle 60° to the bedding cleavage with spacing about equal to it. This plane parallels the axial plane of the fold in which the quarry is developed. A third direction of jointing, being perpendicular to the bedding, determines the width of the blocks which can be quarried. The quarried stone breaks with greatest facility along the plane perpendicular to the bedding, but the breaks thus obtained are very hackly.

Mineralogy and Origin: Thin-section analyses were not made on the building stone, however the rock appears to have a mineral composition similar to the flagstone. As in the flagstone, sedimentary structures other than bedding, minor slump, and the accretionary masses are absent. Color and hardness are identical to the flagstone, and other physical properties, were they determined, would likely be quite similar. As to origin, it is apparent from the foregoing data that the building stone was formed under the same conditions existing during the deposition of the flagstone.

Orange County

Building stone of a type considerably different from that produced in Montgomery County is quarried 0.5 of a mile west of Hillsboro, in central Orange County, for specialized building at Duke University. The rock deposit in which the quarry is developed contains conglomeratic breccia, tuffaceous sandstone, siltstone, and relatively iron-rich argillite. All of the various grain-size rocks in this deposit are known to be utilized.

Bedding and Other Sedimentary Structures: Bedding in the deposits ranges from fine-grained units 1 cm. in thickness to beds of conglomeratic breccias several feet thick. The breccia contains angular to rounded fragments of quartzitic rocks and cryptocrystalline slate-like material, showing a slight flattening or elongation parallel to the bedding and principal direction of jointing in the deposit. Other fragments in the breccia are flattened to such an extent as to retain little of their original thickness. These are believed by the writer to represent flattened fragments of tuff or pumice. Many of these flattened fragments collected from various parts of the quarry were examined and found to consist of identical material - an altered, fine-grained, ashy-looking rock. Because they are always flattened, a condition much opposed to the slight distortion shown by the pebbles and fragments of quartzitic rock and slate, and because of their uniformity in composition and appearance, their classification as tuff or pumice fragments seems difficult to doubt. The fragments composing the breccia range from 2 to 4 mm. to 3 inches in diameter. The matrix is a poorly sorted aggregate of clay, silt, and fine to medium sand-size tuffaceous material.

Overlying and interbedded with the breccia are thin beds of argillite and siltstone, containing an occasional thin bed of tuffaceous sandstone. These sandy beds often show cross-bedding(?), flattening of the coarser grains, and a prominent development of chloritoid. These finer grained units are equally as abundant and are used for building material more extensively than the breccia.

Mineralogy: The fine-grained units in the exposed portions in the quarry consist of dark gray to black rocks, containing relatively large amounts of hematite and other iron minerals. Rutile is a common accessory in the rocks. The sandstones and conglomeratic breccias generally show lighter colors, ranging from tan to pinkish tan and pinkish gray. These various colors are attributed to mineralizing solutions which have permeated the rocks and, further, to the effects of normal weathering.

Crushed specimens of representative samples of all size classifications given the rocks were examined under the microscope and show significant amounts of hematite, chloritoid, sericite, large amounts - perhaps 65 percent - of quartz and feldspar, and a few needles of rutile. The sericite is more conspicuous in the conglomeratic breccias, imparting a phyllitic look to these units, but is also a principal constituent of the finer grained layers.

Origin: The rocks are considered to have been formed in relatively shallow water through the deposition of airborne ash and larger ejecta fragments and considerable amounts of stream-transported debris, including quartzitic and slate pebbles. Equally large fragments of waterworn pumice and tuff and erosion products of sand, silt, and clay-size materials also are believed to have been included in the stream-transported debris. Changing sedimentary cycles are inferred by the alternation of thick and thin beds as well as the significant changes in the grain size of the material composing the beds.

CRUSHED STONE

Superior Stone Company

The largest production of commercial crushed stone is made from deposits of metasedimentary rocks very similar in physical properties, mineralogy, chemical composition, and mode of origin to the building-stone deposits of Montgomery County. In the three principal quarries of the Superior Stone Company, located 7 miles southwest of Thomasville in central Davidson County, at Midland in southern Cabarrus County, and 3.75 miles northwest of Monroe in central Union County, perhaps the greatest difference noted was the degree of shear and/or folding affecting the rocks and the thickness of individual beds.

Bedding and Other Sedimentary Structures: Bedding is quite similar but usually thicker than in the Montgomery County building-stone deposits, however sedimentary structures, such as, minor slump, accretionary masses, and thin dark colored laminae "separating" the thicker beds, are essentially the same. The general grain size of the materials composing the beds or laminae are megascopically identical with the material making up the building stone, though occasionally sandy beds are encountered in these quarries.

Mineralogy: Thin sections cut from representative samples of rock from the Bakers Quarry and the Thomasville Quarry and hand specimens from the Midland Quarry are described briefly, as follows:

Bakers: The section shows a cryptocrystalline to microcrystalline, chert-like rock containing large amounts of feldspar, both fresh and partially sericitized, ragged particles of sericite, and a considerable amount of quartz, which occurs as outsized recrystallized(?) grains of coarse silt-size dimension. Accessory minerals include very small amounts of epidote(?), chlorite, apatite, magnetite, pyrite, and biotite(?). The sericite has a strong tendency to align itself parallel to the bedding and also to segregate in a ragged or patchy manner. Occasional outsized grains of feldspar, surrounded by sericite, show in the section as a "micro-augen structure." With the exception of the recrystallized quartz, the grains in the rock are very ragged and contacts are indistinct. Coatings of calcite, chalcopyrite, and epidote are commonly found on the joint surfaces in the deposit. An analysis of the Bakers stone shows a free silica content of slightly more than 11 percent.

Thomasville: In this section, feldspar, sericite, and quartz also represent the principal mineral constituents. Quartz and particularly feldspar are more abundant than in the Bakers stone, whereas sericite is less, smaller grained, and shows no preferred orientation. Chlorite, apatite, biotite(?), magnetite, pyrite, and epidote(?) again appear as the accessory minerals. The texture, cryptocrystalline, is somewhat finer and more uniform than the Bakers Quarry rock but is otherwise identical.

Midland: The rocks of the Midland Quarry are cryptocrystalline to microcrystalline and show a prominent development of sericite, formed during strong shearing of the rocks. Beds of coarse-grained feldspathic rocks containing a large percentage of calcite are prominent in some parts of the quarry. Numerous small veins of quartz and calcite are prevalent in the quarry. The finer grained rocks generally have a pronounced phyllitic appearance, whereas the coarser grained units often appear arkosic.

Chemical and Physical Properties: In Table IV, an incomplete analysis of a representative sample of the crushed stone from the Bakers Quarry in Union County shows a composition much like the flagstone of Davidson County. The abundance of lime (CaO) as shown by the analysis suggests an unweathered condition of the materials forming the rock, the possibility of a large percentage of plagioclase feldspar or perhaps an abundance of amphiboles and pyroxenes in the mineral composition.

TABLE IV*

SiO_2	63.24
Al_2O_3	18.58
Fe_2O_3	7.50
CaO	2.27
MgO	1.86
SO_3	Trace
Free SiO_2	11.16

* Analysis furnished by Superior Stone Company, Raleigh, North Carolina

The principal physical tests performed on crushed stone are concerned with bulk specific gravity and resistance to abrasion. Listed in Table V are the results of such tests on stone from the Bakers, Midland, and Thomasville (Bluestone) Quarries of the Superior Stone Company.

TABLE V*

Quarry	Abrasion Resistance (Loss)** A	B	C	Specific Gravity Average
Bakers	16	15	17	2.81
Midland	22	20	22	2.79
Thomasville	17	16	17	2.81

* Furnished by N.C.S.H & P.W.C. and the Superior Stone Co.
** Determinations made in accordance with A.S.T.M. Standards.

According to these determinations, the crushed stone produced from these deposits compares very favorably and in most instances exceeds the abrasion resistance offered by other types of crushed stone. In comparing the figures in Table V with those given for commercial granites, gneisses, pebble aggregates, and limestones in various publications, it is noted that only rarely are figures indicating higher resistance to abrasion to be found. The colors and hardness of the rocks for crushing are identical with those of the commercial flagstone and building stone.

Nello Teer Company

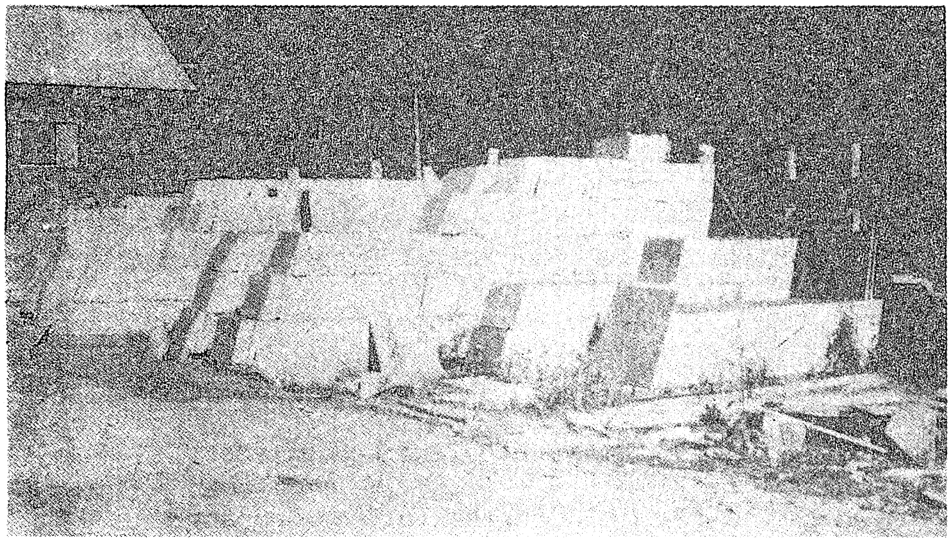
The rocks of the Volcanic-Slate series quarried at Braggtown, 1 mile north of Durham in Durham County, for the production of crushed stone are rather thick-bedded, highly silicified metasedimentary(?) rocks. These rocks are dark gray to black and look very much like bedded chert, or novaculite. The rock in which the quarry of the Nello Teer Company is developed appears uniform in grain size and other physical characteristics throughout the quarry area.

Chemical and mineralogical analyses of the rocks were not available for this report, however the results of Los Angeles abrasion tests performed by the North Carolina State Highway and Public Works Commission indicate that this stone is the most resistant to abrasion of any commercial crushed stone produced in North Carolina. These determinations show losses of only 12, 12, and 13 percent for tests A, B, and C, respectively.

Carolina Solite Company

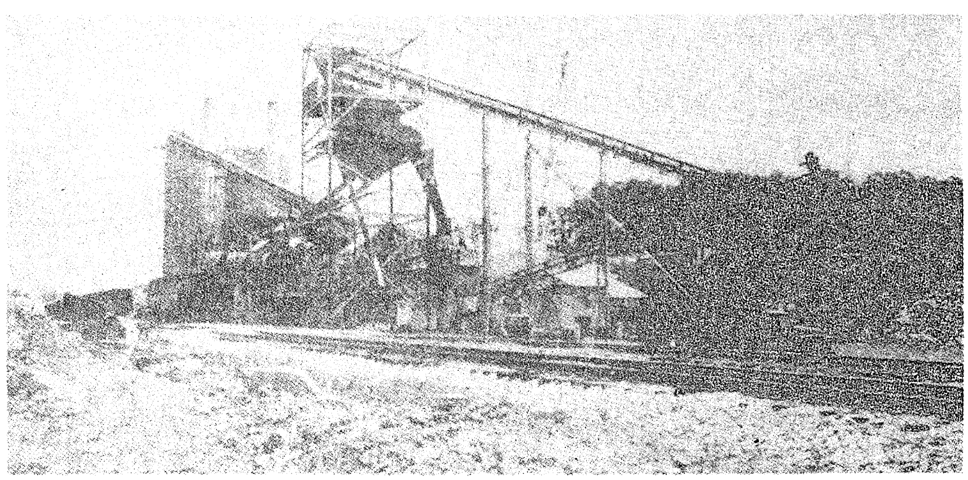
Solite is the trade name for a superior quality lightweight aggregate produced 1 mile west of Aquadale in southern Stanly County by the Carolina Solite Company. The quarry from which the raw material used in the manufacture of this product is obtained is developed in metasedimentary rocks of the Volcanic-Slate series, which differ considerably from those used in the production of crushed stone in Davidson, Cabarrus, and Union Counties.

Bedding and Structural Considerations: The rocks utilized in the manufacture of "Solite" are generally thicker bedded than any previously considered in this report, averaging about 12 inches in thickness. The thinnest units seen in the quarry measured 2 inches, while the thickest



CUT FLAGSTONE
JACOBS CREEK FLAGSTONE CO.

CRUSHED STONE
SUPERIOR STONE CO.



LIGHTWEIGHT AGGREGATE
PLANT OF CAROLINA SOLITE CO.

are near 18 inches and are far more common than the thin beds. A widely spaced and well developed fracture cleavage, more properly called a bottom joint system, parallelling the bedding gives a false impression of very thick-bedded strata. Two planes of near vertical jointing intersect the bedding and bottom joint plane, dividing the rocks into roughly rectangular-shaped blocks, but are not nearly so well developed as the system of bottom joints. The rocks fracture in a conchoidal or hackly manner, never along well defined planes. As in the commercial rock deposits previously discussed, the thinnest beds in this quarry are composed of the largest grain-size material. Beds composed of material of very fine sand-size dimensions (-0.125 mm.) are not rare, though most of the units should be placed in the siltstone-argillite size classification. The bedding along with minor slump deformities constitute the only sedimentary structures observed in the deposit. The beds are inclined only 4° from the horizontal, making them among the least disturbed in the entire series.

Mineralogy: Thin sections of the rocks were not prepared, however it is believed that the mineral composition is very similar to that of other commercial rocks. The principal and most conspicuous difference is the comparative abundance of various sulphide minerals. Pyrite seems to be the principal sulphide present and occurs as disseminated grains through most of the beds and as coatings, or smears, on the joint surfaces. The presence of these sulphide minerals apparently gives the rocks their "bloating" qualities, since pyrite-free rocks of similar character will not expand sufficiently to be classed as lightweight aggregate.

Chemical and Physical Properties: Listed in Table VI are the ranges in percentage of the various compounds as determined by chemical analyses of "Solite rocks." Colors in the quarry area range from light to medium bluish gray to dark bluish gray, whereas hardness is uniform at about $3\frac{1}{2}$ on Mohs' scale. The rock is extremely tough.

TABLE VI*

	Maximum	Minimum
SiO_2	67	61
Al_2O_3	22	14
Fe_2O_3 and FeO	10	4
CaO and MgO	5	1
K_2O and Na_2O	2	0.5
Sulphur	Less than 1	-

* Furnished by Southern Lightweight Aggregate Corporation, Richmond, Virginia.

Origin: The figures given in Table VI indicate wide differences in character of the materials composing the individual beds in the deposit. The abnormally high amount of alumina and iron oxide and low amounts of alkali earth compounds suggest to the writer that the materials composing some of the beds were derived from maturely weathered material, however since only the extremes in composition are given, it is very difficult to formulate definite conclusions concerning parent materials. Significant, however, is the consistently low percentage of potash and soda, indicating again the possibility of maturely weathered detrital material forming a large part of some bedding units, or an unweathered material greatly different from that normally expected in this type rock. In considering all the properties available and the examination of the rocks in the field, it is probable that they were derived from materials physically similar to those forming the other metasedimentary commercial rocks, that is, land-derived erosion debris intermingled with ash-fall material. The undisturbed condition of the beds indicates quiet and perhaps deep-water deposition.

Blue Ridge Stone Company

The rocks quarried for the production of crushed stone in northeastern Cabarrus County near Gold Hill are rather thick-bedded argillites and tuffaceous sandstones, with the finer grained rocks predominating. Measured thicknesses show beds ranging from 3mm. to 6 inches, and in many of the thicker beds slump deformities and cross-bedding(?) are fairly common.

The rocks are light bluish gray to dark gray and are badly fractured by many planes of jointing. Because the quarry is filled with water, detailed studies of the bedding, jointing, and minor folding in the rocks could not be made. Results of Los Angeles tests performed by the North Carolina State Highway and Public Works Commission show that crushed stone from this quarry is quite resistant to abrasion. Losses of 18 percent for tests A, B, and C are shown in the report.

Though the rocks comprising the deposit are generally coarser than those of the Solite Company, they appear similar in mineral composition and physical properties but are believed to have been deposited under alternating deep and shallow water conditions.

USES AND PRODUCTION OF THE COMMERCIAL ROCKS

Flagstone: Rough quarried flagstone is produced at the rate of approximately 500,000 sq. ft. annually, with approximately 65 percent of the total production being marketed as uncut stone. The greater part of this total is used for flagging, while small amounts are utilized as strip rubble building material. Cut stone, constituting 35 percent of the total production, is used as flooring, for window stools and sills, hearth and mantle sets, facing and spandrell material, coping material, treads and risers for exterior use, and for use in masonry and steel casement stairs. Among the most recent uses found for the stone is in the construction of chemical laboratory sinks, for which it seems admirably suited.

Building Stone: Both rough and cut building stone from the Mt. Gilead quarry in Montgomery County has found wide application in exterior construction. Among its principal uses are in the construction of chimneys and walls, and it is used extensively as a trim stone in both interior and exterior construction. Production figures are not available but are believed to be only a fraction of the total for flagstone.

<u>Crushed Stone</u>: Crushed stone from quarries in the Volcanic-Slate series is used primarily as concrete and bituminous aggregate, road metal, and railroad ballast. In recent years, production from the five principal quarries producing crushed stone has averaged well over 400,000 tons annually. Crushed and sized stone from the Solite company's quarry in Stanly County is expanded in rotary kilns at temperatures above 2000° F. to produce a partially vitrified lightweight aggregate of exceptional quality. The expanding, or bloating, process reduces the weight of the raw material by approximately 65 percent. This aggregate is used principally in structural concrete, refractory concrete, and floor systems. According to Mr. J. S. Gunn of the Carolina Solite Company, weekly production of lightweight aggregate averages over 40 carloads.

BEDDING, CLEAVAGE, AND JOINTING OF THE ROCKS

The attitude of bedding, cleavage, and principal joints in the various deposits is summarized in Table VII, which appears on the next page.

NONCOMMERCIAL PRODUCTION

Noncommercial crushed-stone production is made in many localities in the Volcanic-Slate series by the North Carolina State Highway and Public Works Commission. These locations are designated and shown in Figure 1, page 5, as noncommercial quarries. Many of the various rock types mentioned earlier in the report are utilized by these quarrying operations, which during the past few years produced approximately 350,000 tons of crushed stone annually for road and highway improvement in North Carolina.

****

TABLE VII - ATTITUDE OF BEDDING, CLEAVAGE, AND JOINTING IN THE PRINCIPAL QUARRIES IN THE VOLCANIC-SLATE SERIES

Quarry	Owner	Bedding		Cleavage		Joints	
		Strike	Dip	Strike	Dip	Strike	Dip
Aquadale	Carolina Solite Company	N. 25° W.	4° SW.	N. 25° W.*	4° SW.	N. 65° E. N. 72° W.	- -
Bakers	Superior Stone Company	N. 12° W.	21° NE.	N. 12° W.*	21° NE.	-	-
Duke	Duke University	N. 50° E.	65° NW.	N. 50° E.	65° NW.*	N. 35° E.	35° SE.
Gold Hill	Blue Ridge Stone Company	Quarry filled with water					
Midland	Superior Stone Company	N. 40° E.	32° NW.	N. 10° E.	75° NW.	Profusely jointed	
Mt. Gilead	Jacobs Creek Flagstone Co.	N. 30° E.	38° NW.	N. 30° E.*	38° NW.*	N. 30° E. N. 60° W.	58° SE. 90°
Mt. Gilead	Wagoner Flagstone Company	N. 30° E.	38° NW.	N. 30° E.*	38° NW.*	N. 30° E. N. 60° W.	58° SE. 90°
Teer	Nello Teer Company	Indistinct		None		N. 42° E. N. 48° W.	53° E. -
Thomasville	Superior Stone Company	N. 85° W.	44° SW.	N. 35° E.*	54° NE.	-	-
Wagoner	Wagoner Flagstone Company	N. 30° W.	22° SW.	N. 30° W.	22° SW.	N. 32° E. N. 31° W.	80° NE. 70° SE.
Woodard	Jacobs Creek Flagstone Co.	N. 83° E.	22° SE.	N. 83° E.	22° SE.	Not determined	

* Fracture cleavage.

BIBLIOGRAPHY

Behre, Charles H., Jr., 1933, Slate in Pennsylvania: Penn. Geol. Survey Bull. 16.

Broadhurst, S. D., and Councill, R. J., 1953, High-alumina minerals in the Volcanic-Slate series, North Carolina: N. C. Dept. Cons. and Devel. Info. Cir. 10.

Bowles, Oliver, 1939, The stone industries: McGraw-Hill Book Co., New York.

Clarke, Frank W., 1924, The data of geochemistry: U. S. Geol. Survey Bull. 770.

Dale, T. Nelson, and others, 1914, Slate in the United States: U. S. Geol. Survey Bull. 586.

Goldich, S. S., 1938, A study in rock weathering: Jour. Geology, vol. 46, no. 1.

Grout, Frank F., 1940, A handbook of rocks: D. Van Nostrand Co., Inc., New York.

Laney, F. B., 1910, The Gold Hill mining district of North Carolina: N. C. Dept. Cons. and Devel. Bull. 21.

Pogue, J. E., Jr., 1910, A report on the Cid mining district of North Carolina: N. C. Dept. Cons. and Devel. Bull. 22.

Stuckey, J. L., 1928, The pyrophyllite deposits of North Carolina: N. C. Dept. Cons. and Devel. Bull. 37.

____________, and Steel, W. G., 1953, Geology and mineral resources of North Carolina: N. C. Dept. Cons. and Devel., Ed. Series 3.