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THE HIGH CALCIUM LIMESTONES OF THE ANNVILLE BELT IN LEBANON AND BERKS COUNTIES PENNSYLVANIA

BY

CARLYLE GRAY

COMMONWEALTH OF PENNSYLVANIA

DEPARTMENT OF INTERNAL AFFAIRS

WILLIAM S. LIVENGOOD, JR., *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY

S. H. CATHCART, *Director*

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THE HIGH CALCIUM LIMESTONES OF THE ANNVILLE BELT IN LEBANON AND BERKS COUNTIES, PENNSYLVANIA[1]

BY

CARLYLE GRAY [2]

ABSTRACT

This paper describes the results of detailed mapping of the high-calcium Annville limestone in Lebanon and Berks Counties. The use of a detailed stratigraphic breakdown of the associated limestones and dolomites has made possible mapping of small-scale complex structures. The Annville limestone has a stratigraphic thickness of 240 feet, and has uniformly high purity. Mapping has indicated that large reserves of recoverable stone remain in the area. Locally, heavy overburden and groundwater are the principal operating problems. The area is centrally located and is well-served by transportation routes.

INTRODUCTION

PURPOSE AND SCOPE

The Annville belt of high-calcium limestones has been an important source of pure limestone for cement manufacture, blast furnace flux, chemical lime, and agricultural lime for many years. Until now no detailed geologic study has been made of the district and no accurate maps showing the distribution of the high-calcium stone have been available. This paper is a progress report on the results of detailed mapping of the Annville high-calcium limestone in Lebanon County and part of Berks County. Mapping of the westward extension of the belt in Dauphin County has not been completed. This report is based on careful stratigraphic and structural studies, and will be useful to quarry operators in the further development of the district.

The complexity of the area covered by this report is such that it has not been possible to describe the geology in terms familiar to the layman. It is probable that some of the text will be fully understood only by geologists and geologically-trained engineers, but a glossary is appended to aid those readers who have not had geologic training. It should be pointed out, however, that a glossary alone cannot substitute for a background of basic geologic concepts, which can best be gained by systematic study of the science. It is beyond the scope of a report of this type to explain those basic concepts, yet they are considered essential to the full appreciation of the geologic interpretations presented in the report. Readers without geologic training, who are interested in prospecting for, or producing limestone in this area, are urged to secure the advice of a

[1] Technical paper, presented before the Industrial Minerals Division at the annual meeting, American Institute of Mining and Metallurgical Engineers, New York, February, 1952.

[2] Geologist, Pennsylvania Topographic and Geologic Survey.

trained geologist. Specific questions regarding the interpretation of data in this report may be directed to the Pennsylvania Topographic and Geologic Survey.

ACKNOWLEDGMENTS

The writer wishes to thank the Dragon Cement Company, Calcite Quarry Corporation, and the H. E. Millard Lime and Stone Company, for their coöperation. They have generously allowed detailed mapping of their properties and have supplied records of exploratory drilling and sampling, without which much of the detail of this study would not have been possible.

The author was ably assisted in the field by Mr. Alan Geyer. Dr. C. E. Prouty, coöperating geologist with the Pennsylvania Topographic and Geologic Survey, has discussed the stratigraphic problems at length with the author and is responsible for the regional correlations.

LOCATION AND TOPOGRAPHY

The city of Lebanon, the approximate center of the district, is 26 miles east of Harrisburg, 73 miles west of Bethlehem and 82 miles northwest of Philadelphia. The narrow high-calcium limestone belt extends roughly east-west, closely paralleled by the Reading Railroad and highway route U. S. 422 through most of the area mapped.

The high-calcium limestone of the Annville belt lies on the north side of the Lebanon Valley. Bordering the belt on the north, the Martinsburg shale forms an escarpment rising 100-200 feet above the limestone valley. The valley owes its low elevation to the solubility of the limestones and is not occupied by any single major stream. West of Lebanon, surface drainage consists of small streams flowing northward across the valley into Swatara Creek, which flows in the rolling terrain underlain by the shales. East of Lebanon, Tulpehocken Creek follows the strike of the limestone for several miles before turning north. Subsurface drainage is an important factor in the region. Large springs, disappearing streams, and sink holes are common features. Large subsurface channels frequently pose serious water problems to quarry operators.

STRATIGRAPHY

GENERAL STATEMENT

The Annville limestone is the source of all high-calcium limestone quarried in the Annville belt. The deposit occurs near the top of the Cambro-Ordovician limestone sequence of the Great Valley. Description of some of the underlying and overlying formations is necessary as they serve as guides to the location of the pure limestone in areas of limited exposure. The Beekmantown group is the oldest unit that need be considered.

BEEKMANTOWN GROUP

The Beekmantown group as represented in Lebanon County is probably more than 1,000 feet thick, but, in this report, only the upper portion is described in detail. The upper 100 feet of Beekmantown in the Annville district consists almost entirely of dark to light-gray, massive, even-grained dolomite. Weathered surfaces are creamy to buff and occasionally show faint lamination. The beds are commonly intensely veined with calcite, quartz, and dolomite. Some beds show wavy black shale partings or thick stylolites. Very few limestone interbeds occur in this (upper) part of the Beekmantown, except in the easternmost part of the area mapped. Lower in the formation, limestone interbeds are common. The limestones are blue, finely crystalline and usually laminated. Some beds of white crystalline limestone with dark-gray streaks, very similar to the lighter facies of the Annville limestone, have been noted. For a more complete discussion of the Beekmantown in Berks County, see Progress Report 136 (Gray, 1951).

The Beekmantown group is an important source of crushed stone in Lebanon County. It formerly was quarried for agricultural lime. Some of the uppermost dolomite beds are low in silica and are acceptable for use in blast and open hearth furnaces.

ANNVILLE LIMESTONE

The Annville limestone (new name, Prouty, 1951) directly overlies the Beekmantown group in most of Lebanon County. Prouty (1951) has tentatively correlated the Annville limestone with the lower part of the Black River group. This correlation is based on the stratigraphic position and lithology. In the Harrisburg area, a few miles west of the district described, the Annville is separated from the Beekmantown group by the Stones River limestone. The Stones River beds wedge out west of the Lebanon-Dauphin county line and are almost entirely absent in Lebanon County. One bed of vaughnitic limestone containing fossils of possible Stone River age is present in the Calcite Quarry Corp. quarry, 5 miles east of Lebanon. With this one exception, the Annville lies discomformably on the Beekmantown group in the area covered by this report.

The Annville limestone has a normal stratigraphic thickness of about 240 feet. Structural complexities locally reduce the actual thickness to 130 feet and possibly less. East of Myerstown (pl. 1) the limestone thins abruptly, and is only 20 feet thick at Womelsdorf.

The Annville is predominantly a thick-bedded to massive, crystalline, high-calcium limestone, weathering to smooth or fluted surfaces. In the eastern part of the area the beds are blue, with some light-gray and pinkish-gray interbeds. Light-gray and pinkish-gray colors are dominant in the west. The fluting of weathered surfaces, one of the most characteristic features of the lithology, is formed by differential weathering of bedding laminae and locally, cleavage planes. Another persistent feature is the light and dark-gray mottling or banding of the basal beds of the limestone.

The normal appearance of the limestone is altered locally in areas of structural complexity. The rock is bleached and is soft and friable, but does not lose its high purity.

MYERSTOWN LIMESTONE [3]

The Myerstown limestone (new name, Prouty, 1951) overlies the Annville limestone stratigraphically everywhere in Lebanon County. Prouty (1951) has classified the Myerstown limestone as Black River to lowest Trenton in age on the basis of fragmentary fossils, stratigraphic position, and lithologic correlation with more fossiliferous areas. Its thickness varies from less than 50 feet to possibly more than 200 feet without an apparent regular pattern of variation. The limestone is not well exposed in Lebanon County, and much of the variation in thickness may be due to structural complications.

The Myerstown limestone is typically dark-blue to black, dense, thin-bedded graphitic limestone with occasional beds of calcarenite. Calcite grains are commonly scattered through the dense limestone in varying abundance. Three or four metabentonite beds are present in the formation. Weathered outcrops frequently show fluted edges similar to the fluting of the Annville limestone. Float in the soil above the limestone consists chiefly of rounded, platy fragments that ring when struck with a hammer. Dense white vein quartz with a columnar or striated texture is commonly associated with float from the Myerstown limestone. The contact with the Annville limestone is marked by one or more beds of black, very graphitic shaly limestone, which are succeeded by a varying thickness of impure, gray, crystalline limestone in beds six inches to one foot thick. These beds grade upward into the typical lithology of the Myerstown limestone.

HERSHEY LIMESTONE

The Hershey limestone (new name, Prouty, 1951) is poorly exposed in Lebanon County and its relations are not too clear. On the basis of lithology, stratigraphic position, and limited faunal evidence, Prouty has correlated the Hershey limestone with the upper part of the Jacksonburg formation (lower Trenton) of eastern Pennsylvania and New Jersey. No accurate measurements of thickness are possible in Lebanon County, but the width of the belt of outcrop indicates that the Hershey limestone varies from less than 50 feet to several hundred feet thick. The maximum development is north of Womelsdorf in Berks County.

The Hershey is a dark-gray, graphitic, shaly or silty limestone. It is less pure and darker in color than the typical Myerstown limestone. Weathered exposures are typically brownish-gray and show well-developed cleavage. Bedding is marked by shaly laminations. Float derived from the Hershey limestone usually consists of fine chips of light-brown porous shale leached of all calcite. Angular plates of light-gray limestone appear locally in the float. These plates are similar in color to the float of the Myerstown formation, but are more angular and do not ring when struck with a hammer.

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[3] *"Myerstown limestone"* replaces the term *"Upper member, Annville limestone"* used in P.R. 136. Gray 1951.

The base of the Hershey limestone contains beds of conglomerate in the eastern part of the mapped area. In Berks County, the zone containing the conglomerate beds may be more than 100 feet thick and is mapped as a separate member (Gray, 1951). The conglomerate beds consist of angular to sub-rounded fragments of dolomite and magnesian limestone in a matrix of dark-gray, graphitic shaly limestone. The beds vary from one to several feet in thickness and are interbedded with normal Hershey limestone. Where the conglomerate is absent, it is often difficult to locate accurately the contact between the Hershey and Myerstown limestones.

The Annville, Hershey, and Myerstown limestones, together with some younger limestones occurring in the Martinsburg shale, are included in the Leesport formation on the Geologic Map of Pennsylvania (Stose and Ljungstedt (1932).

MARTINSBURG SHALE

The Martinsburg shale was not studied in detail during the present survey, but a number of variations in the lithology were observed along the southern edge of the shale belt adjacent to the Annville district. Most commonly it is soft, buff to yellow shale, frequently iron-stained. Fresh exposures may show dark greenish-gray, sericitic shale, red shale, platy limestone, or siltstone and sandstone. Dense white quartz is abundant in the shale float, but it rarely has the columnar structure typical of the quartz associated with the limestones.

STRUCTURE

GENERAL STATEMENT

Interpretation of geologic structures is essential in prospecting for, and determining the reserves of high-calcium limestone in Lebanon County. Where the structure is complex, the interpretation must be based on careful geologic mapping of surface exposures, supplemented by exploratory drilling. Accurate calculation of reserves and proper quarry planning depend on the structural interpretation. In the discussion which follows, the structural interpretations are based on mapping at a scale of 1:20,000 for the regional work, and 1:4,800 for the more complex areas. Wherever possible the mapping has been supplemented by, and checked against existing records of exploratory drilling. The resulting interpretation of the structure is believed to be essentially correct, but further drilling and quarry operations in some of the very complex areas will undoubtedly alter some features of the interpretation.

Definitions of the technical terms used in the following section will be found in the glossary (p. 14).

REGIONAL STRUCTURE

The Annville belt of high-calcium limestone lies on the north limb of a complex anticlinorium, the exact form of which is not well known. A simplified hypothetical cross section (fig. 1) is drawn through the district on a north-south line west of Annville to show the structural setting of the limestone deposits. Many details of the folding are diagrammatic, but

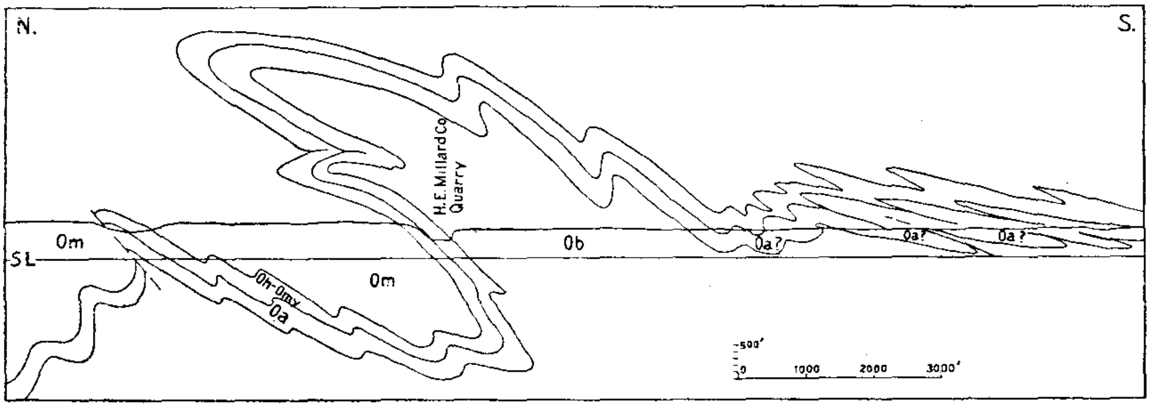


FIGURE 1. Hypothetical cross section, northwest of Annville. **Om,** Martinsburg formation. **Oh-Omy,** Hershey and Myerstown limestones. **Oa,** Annville limestone. **Ob,** Beekmantown limestone.

the section is intended to illustrate the type of structure rather than a complete and accurate interpretation. Within the area of this report, the anticlinorium has no appreciable regional plunge, so the generalized cross section (fig. 1) is representative of sections at most any point in the belt.

The lack of regional plunge is reflected in the overall regularity of the outcrop belt of the Annville limestone, as shown on Plate 1. It will be noted that the belt maintains a quite regular strike, averaging N80°E, with dips usually 30° to 50° south, overturned. Locally, the outcrop pattern is complicated by minor folds. These folds are plications of the anticlinorium, similar to those shown in Figure 1. Faults of various types also cause local complications. Variations in the thickness of the limestone are due to flowage in folding, and to faulting.

It will be noted on the cross section that the Annville limestone is interpreted as cropping out south of the principal belt of outcrop, on the south limb of the anticlinorium. These rocks are of uncertain age, but recent preliminary examination shows that they hold some features in common with the rocks of the high-calcium belt. In the southern belt, however, beds believed to be Annville are not highly pure limestone. This area as yet has not been mapped in detail and therefore is not indicated on the map, Plate 1.

The present investigation is concerned with the distribution of the high-calcium limestone on the north limb of the anticlinorium. The three areas discussed in detail below are presented as illustrations of typical smaller-scale structures associated with the major fold.

DETAILED STRUCTURAL DESCRIPTIONS

Millardsville-Myerstown Area

Detailed study of this area was greatly facilitated by the use of drilling records generously placed at the disposal of the author by the Dragon Cement Company. In addition, the numerous quarry and natural exposures have been carefully studied. The geological map and structural interpretation are shown on Plate 2, Map 1 (see pl. 1 for location).

The principal structure in this area is interpreted as a recumbent fold, complicated by three changes in the direction of plunge of the fold. At the line of section A-A′, the plunge is about 15° west and, a short distance to the east, the overturned limb of the recumbent fold rises above the present level of erosion. At section B-B′, the plunge is to the east. In the intervening structurally low area, the Annville and Myerstown limestones are exposed in the overturned limb of the recumbent fold. A large quarry was opened in the relatively horizontal, but overturned Annville beds. The thickness of Annville in the overturned part of the fold is not known, but, on the south side of the quarry [1], where the root of the fold is exposed, the thickness is about 170 feet. This is 60 feet less than the normal thickness of the formation. The thinning may be due in part to regional stratigraphic thinning to the east and in part to flowage during folding. Exposed in the north bay of the quarry are two low-angle faults which dip less steeply than the bedding. They cause an additional reduction in the apparent thickness of the beds in the overturned limb. It should be noted that the beds in the overturned limb locally dip north [2], that is, they have been rotated more than 180° in folding. This is a typical feature in the recumbent folds of the limestone belt.

Between sections B-B′ and C-C′, the Annville limestone in the overturned limb of the recumbent fold lies above the present erosion surface. At section C-C′, a reversal in the plunge of the fold has again brought the overturned limb down, but here the Annville limestone is almost entirely missing because of stretching, and Beekmantown dolomite of the core of the fold lies directly on the Myerstown formation. This relationship is proved by the drill records. The recumbent fold is here a stretch thrust and the mass of Beekmantown can be considered a klippe, since its connection with the root of the fold has been severed by erosion. The small area of Annville limestone [2], exposed at the surface to the left of the center of section C-C′, is interpreted as a digitation (or minor fold) which projected into the dolomite core of the recumbent fold and was subsequently isolated by the thrust fault.

At the line of section D-D′, the plunge of the fold is still to the west, and in the klippe, part of the normal limb [1] is low enough to have escaped erosion. Drilling information here shows that the Annville limestone rests normally on Beekmantown dolomite. Beds underlying the stretch thrust do not form a complementary syncline but are crumpled into smaller folds. These folds may be large drag folds formed by the movement on the overlying stretch thrust.

At section E-E′, drill records show that the Annville limestone is both underlain and overlain by Beekmantown dolomite [1]. This is interpreted as indicating that the Annville is present in both limbs of the recumbent fold, separated by a core of dolomite. Absolute proof of this relationship is lacking since no one hole penetrates both limbs. Two small detached masses of Beekmantown dolomite entirely surrounded by Annville limestone are shown on the map. These are interpreted as pinched off masses of the dolomite core. Drill records show that they are underlain by limestone at depths of 15 to 20 feet.

West of section E-E′, the fold again rises above the level of erosion. A reversal of plunge brings the recumbent fold down in the old quarry at the west end of the detailed map. The Annville limestone in the overturned limb is crumpled. At one place it dips 30° north, having been rotated 210°. Here the recumbent fold is much smaller, however, and evidently is dying out.

Calcite Quarry Corporation Properties

Map 2, Plate 2, covers the operating and abandoned quarries of the Calcite Quarry Corporation (see pl. 1 for location). The area has no known dominant structure such as the recumbent fold at Millardsville, but many interesting details are shown. The principal problem is the structural setting of the easternmost quarry, known as the Urich-Tice property. B. L. Miller (1934, p. 508) states that the limestone here is in a tight synclinal basin and that all sides of the canoe were exposed. The present writer does not agree with this interpretation. In section A-A′, the structure is interpreted as a synclinal basin, with most of the north limb faulted off. The evidence for this is as follows: 1) On the north side of the quarry, beds are exposed which probably belong to the younger Myerstown limestone and represent, therefore, the center of the syncline. 2) All of the beds exposed in the quarry near the line of section are clearly overturned, as indicated by the attitude of the drag folds. These facts indicate that only one limb of the syncline is present in the main body of the quarry. A puzzling feature of the structure is that the overturned limb of the synclinal basin has been preserved in its full thickness, while the normal limb has been faulted out. Limited exposures north of the quarry make it difficult to determine the exact nature of the fault. At the east end of the quarry, however, the dolomite is seen to wrap around two minor synclines of limestone. A brecciated zone and a covered area separate this section from the main body of Annville limestone. Apparently a cross fault has brought the trough of the structure to a higher level here. The presence of Annville limestone shown at the north end of section A-A′ is indicated by outcrops of Beekmantown dolomite north of the quarry, and occasional pieces of Annville limestone float. The scarcity of float suggests that the limestone may be thinner than normal.

Section A-A′ is only one possible interpretation of the evidence stated above. The structure at section B-B′ suggests a different interpretation. The main part of the quarry here is on the overturned limb of the regional anticlinorium. The Annville outcrop is widened to the south, at the line of section, by a structure which is interpreted as a large drag fold complicated by faulting and shearing. The drag fold consists of an anticline [1] whose Beekmantown dolomite core is well-exposed, and a syncline [2] containing Annville limestone which has been partly quarried out. The dolomite beds in the anticline [1] do not all bend around the crest of the fold, but are in part faulted out at the crest and on the normal (south) limb. Quarrying operations have exposed the Annville limestone in the syncline [2] overlying a faulted contact with Beekmantown beds near the floor of the quarry, and overlain by similar beds at the top of the face. All of the beds exposed between these two contacts are apparently overturned. At the upper contact, there is no evidence of faulting other than two cross faults (see map, just east of south end of section B-B′). Faulting of the lower contact is indicated by: 1) Overturned beds of Annville limestone lying on the older Beekmantown dolomite. 2) Beds of dolomite cut off by the contact. 3) Alteration of the limestone at the contact to a bleached, friable rock.

At both sections, A-A′ and B-B′, evidence indicates that the structure is synclinal and that the normal limb of the syncline is missing. The interpretation of section A-A′ suggests that the trough of an overturned syncline was cut by a high-angle, reverse fault in such a way that only the overturned limb is exposed at the present level of erosion. At section B-B′, it is believed that the action of the mechanical couple which caused the drag fold to form sheared out the normal limb.

At section B-B′, the plunge of the drag fold is west, and it cannot be traced eastward beyond the limits of the quarry. A reversal of plunge to the east would bring the drag fold of limestone down at the present location of the Urich-Tice Quarry. Therefore, as an alternative interpretation, section A-A′ could be drawn as an enlargement of section B-B′. The sections as drawn are considered the best interpretation in the light of the available evidence. The alternative is given to emphasize the uncertainty of interpretation based on limited data and the necessity of keeping an open mind in planning exploration and development.

Section C-C′ shows complex small-scale folding of overturned beds underlying a thrust fault. A distinctive marker bed about 15 feet below the stratigraphic top of the Annville limestone made it possible to map the structure with considerable accuracy. The beds are in the overturned limb of a recumbent fold. Drag, probably the effect of the thrust fault, has crumpled the recumbent beds into minor overturned folds, resulting in local rotation of more than 270°. The thrust fault is exposed in the south face of the quarry, but its throw is not known. It may be the extension of the thrust fault which brings the Beekmantown in contact with the Martinsburg shale at Avon (see pl. 1).

Annville Area

Map 3, Plate 2 (see pl. 1 for location) shows a part of the H. E. Millard Lime and Stone Company property immediately west of Annville. The structure appears to be a recumbent fold, somewhat similar to the one at Millardsville. Here, however, the recumbent anticline is paired with a complementary recumbent syncline. The plunge of the folds, as at Millardsville, is variable, making the map pattern difficult to interpret. The key to the structure of this area is in the exposures in the old quarry just south of the railroad tracks, near the north end of section A-A′. North-dipping beds of Annville limestone in this quarry contain some drag folds with axial planes dipping north at a lower angle than the bedding. Since the Annville limestone is seen to lie normally on the Beekmantown beds in the south face of the quarry, this cannot mean that the beds are overturned to the south. Assuming that the drag folds were actually caused by normal slippage of beds past each other in folding, the present attitude of the folds can be explained by arching of the axial plane of the recumbent fold, as interpreted in cross section A-A′. The outcrop pattern shown on the map, east of section B-B′, favors this explanation and it is consistent with the interpretation of the regional deformation. The existence of a lower recumbent limb as shown in section A-A′ is based only on the anomalous drag folds.

The trough of the recumbent syncline is exposed in the quarries near the south end of the section (A-A′ [1]). The Myerstown limestone core of the recumbent syncline has been almost entirely squeezed out. A remnant is visible in the north face of the quarry, at [2] on section B-B′ and Map 3. The cross fault shown on the map between B-B′ and C-C′ is not visible as a discrete plane in the quarry. The fault is believed to exist because beds in the eastern part of the area are right side up; in the west they are inverted. The rock shows evidence of strong alteration near the postulated fault. It is bleached to light-gray color with darker bands and is very soft. Much of it is easily broken by hand to a pure calcite sand. This condition persists to at least 75 feet below the surface. East and west from the fault, the rock becomes gradually harder, and the normal blue color of the beds returns. In the eastern half of the quarry, it may be observed that the color of some of the beds are bleached only along joints. The color and friability of the rock give an appearance similar to the rock in the shear zone at the Calcite Quarry, so it is believed that the friability and light color of these rocks are due to shearing and leaching in an area of faulting.

Section C-C′ shows the structure west of the cross fault. Here ([3], on map) Beekmantown dolomite is known to overlie Annville limestone which in turn lies on Myerstown limestone exposed in the floor of the quarry. The Annville limestone is only 135 feet thick where measured at [4]. The limited thickness is believed due to stretching of the overturned beds. In the quarry at [4], the beds dip 45-55° south, are overturned, and are very regular in strike. Approximately 2,500 feet west of [4] the measured thickness is 240 feet, which is normal in this area.

ECONOMIC CONSIDERATIONS

Grade

No samples of limestone were collected for analyses in connection with the preparation of this report. Analyses of samples of Annville limestone collected in Berks County were published in Progress Report 136 (Gray, 1950). The Dragon Cement Company, Calcite Quarry Company, and the H. E. Millard Lime and Stone Company generously placed analyses of core, quarry, and drilling samples at the author's disposal.

Analyses of the Annville limestone from all the above sources vary from 88 per cent $CaCO_3$ to over 98 per cent $CaCO_3$. There are no horizons within the formation which consistently carry the purer grade of stone, but the Annville of the western part of the area does appear to have a generally higher $CaCO_3$ content than the eastern part.

Twenty-three samples collected from outcrops of Annville limestone in Berks County averaged 92.70 per cent $CaCO_3$. The range was 90.15 per cent to 95.84 per cent. All the samples were collected from weathered outcrops and may have been slightly impoverished by the solution of $CaCO_3$ (for more detailed information, see Gray, 1950).

Analyses of 90 diamond drill core samples in the Millardsville area average 94.96 per cent $CaCO_3$. They range from 88.85 per cent to 98.27 per cent. These values are probably representative of the area. By careful quarry planning and management, stone averaging over 95 per cent $CaCO_3$ could probably be shipped from this locality.

The stone shipped by the Calcite Quarry Corporation is reported to average between 96 and 97 per cent $CaCO_3$.

Recent diamond drill prospecting and sampling at the H. E. Millard Lime and Stone Company properties indicate that the Annville limestone in that area averages more than 96 per cent $CaCO_3$. The range is from 90 to over 98 per cent $CaCO_3$. The company reports that recent shipments of all sizes average 96.4 per cent. The larger sizes of stone shipped commonly test over 97 per cent $CaCO_3$.

These figures indicate that, in the Annville Belt of Lebanon County, the Annville limestone as a whole averages 95 per cent or better $CaCO_3$. Slightly lower values are the rule in the Berks County area. No data are available on the beds possibly of the same age which are exposed further south in Lebanon County (see discussion on p. 6). While some very pure beds are present there, the formation lacks the uniformity of the northern belt.

RESERVES

No attempt has been made to calculate the reserves of high-calcium limestone in the entire district. In many places the complexity of the geology makes it impossible to calculate even approximate reserves without extensive exploratory drilling. In addition, recoverable reserves may be affected by many other factors, such as local areas of excessive overburden, surface and underground water courses, and cultural features—urban and suburban developments, railroads and highways.

For purposes of comparison, however, the reserves were calculated for a limited area which appeared to be particularly suitable for development. Between State Highway Route 934 and the western edge of the built-up area in West Lebanon, an estimated 33 million tons of stone are available. In this section there are no apparent complicating geologic complexities. The beds vary in dip from vertical to 35° south. An average stratigraphic thickness (measured perpendicular to the bedding) of 240 feet was assumed. The reserves were calculated for a continuous quarry, 100 feet deep, with an average of 20 feet overburden. Recoverable reserves would be somewhat less on account of stone which would have to be left to support roads and streams. On the other hand, in some places deeper quarrying would undoubtedly be practical. It is assumed that additional reserves of stone would be available to underground mining.

The above estimate of reserves for a limited area of relatively simple geology was made to help the reader visualize potential reserves. It should be pointed out again, however, that even in an apparently simple area, geologic interpretation based on all available data—particularly exploratory drilling—is essential to correct estimation of reserves. The duties of a geologist in an exploratory and development program would be as follows:

1. Selection of areas to be drilled.
2. Constant supervision of drilling so that information can be used, as soon as it becomes available, to locate additional drilling sites. In this way drill footage can be kept at a minimum and maximum effectiveness achieved.
3. Planning of quarry development on the basis of completed exploration.

4. Continued revision of geologic interpretation and reserve estimates, as development uncovers additional information.
5. Geological study of operating problems such as groundwater, overburden, support of openings, etc.

QUARRY METHODS

The Annville limestone is worked entirely by open-quarry methods in Lebanon County at the present time. Most of the quarries are in overturned beds dipping 30° to 50° south. The quarries are, therefore, long, narrow pits, usually more than 100 feet deep. The dolomite, which overlies the overturned limestone in many places, must be removed in order to quarry the full width of the limestone. Some of the dolomite is marketable as crushed stone and low-silica dolomite. Clay overburden is generally thickest over the Annville limestone, and, in some localities, more than 30 feet of clay and weathered rock must be removed. The average, however, is less. The upper surface of the limestone is highly irregular and complete removal of the clay is not feasible. In order to maintain high purity, all of the stone quarried is washed in log washers before shipment.

The Annville limestone is worked by underground methods at two operations in Dauphin County, immediately west of the area covered by this report. Mining eliminates the necessity of removing overburden and washing the stone, but increases other problems, particularly that of pumping of underground water. The selection of open pit or underground methods depends on local conditions and personal preference of the operator.

Ground and surface water present major operational problems in the district. Every large quarry sooner or later taps a large flow of underground water. The Annville quarries of the H. E. Millard Company pump from 4,000 to 8,500 g.p.m., depending upon the season. Stand-by pump capacity of 20,000 g.p.m. is maintained for emergency use, in case of flooding by surface waters. The Calcite Quarry Corporation pumps an average of 15,000 g.p.m. The flow reaches 30,000 g.p.m. in wet seasons. In both cases these figures represent totals from connecting quarries a mile or more long. Control measures have been most effective in dealing with surface water. Flumes, dikes, and stream diversions have been employed with considerable success. Attempts to seal-off underground water have not been notably successful in the quarries. The general experience has been that water sealed-off in one place finds other opening and continues to enter the quarry in equal or only slightly diminished quantities.

Progress in control of the groundwater could be made if it were treated as a district problem. The initial step would be a detailed hydrologic and geologic study of the groundwater, based on active coöperation of all the operators in the district. Countermeasures indicated by the results of the detailed study would be beneficial to all.

SUMMARY

The Annville limestone crops out in a nearly-continuous band across the full width of Lebanon County. It has an average stratigraphic thickness of 240 feet. Nearly all of the stone is high-calcium limestone. Large reserves of marketable stone are available in the area. The district is well situated with respect to transportation facilities and markets. These facts indicate that the Annville district will continue for many years as a major source of raw materials used in the cement, steel, and chemical industries.

SELECTED REFERENCES

Gray, Carlyle (1951), *Preliminary Report on Certain Limestones and Dolomites of Berks County, Pennsylvania,* Pa. Geol. Survey, 4th ser., P. R. 136.

Hall, George M. (1934), *Groundwater in Southeastern Pennsylvania,* Pa. Geol. Survey, 4th ser., Bull. W 2.

Miller, B. L. (1934), *Limestones of Pennsylvania,* Pa. Geol. Survey, 4th ser., Bull. M 20.

Miller, Ralph L. (1937), *Stratigraphy of the Jacksonburg Limestone,* Geol. Soc. Amer., Bull., vol. 48, pp. 1687-1718.

Prouty, C. E. (1951), *"Leesport" and "Annville" Formations of Pennsylvania,* Geol. Soc. Amer., Bull., vol. 62, p. 1471 (abstract).

Stose, G. W. (1946), *The Taconic Sequence in Pennsylvania,* Amer. Jour. Sci., vol. 244, pp. 665-696.

Stose, G. W. and Jonas, A. I. (1927), *Ordovician Shale and Associated Lava in Southeastern Pennsylvania,* Geol. Soc. Amer., Bull., vol. 38, pp. 505-536.

Stose, G. W. and Ljungstedt, O. A. (1931), *Geologic Map of Pennsylvania,* Pa. Geol. Survey, 4th ser.

Swain, F. M. (1946), *Geology and Economic Aspects of the More Important High-Calcium Limestone Deposits of Pennsylvania,* Penna. State College, School of Mineral Industries, Bull. 43.

Swartz, Frank M. (1948), *Trenton and Sub-Trenton of Outcrop Areas in New York, Pennsylvania and Maryland,* Pa. Geol. Survey, 4th ser., Bull G 22.

APPENDIX
GLOSSARY

anticline *See fold.*

anticlinorium A major anticline composed of many smaller folds. An anticlinorium must be a large fold, several miles across (see fig. 1).

axial plane *See fold.*

axis (of a fold) *See fold.*

bed A layer of rock bounded top and bottom by planes of separation, or a layer of relatively uniform rock bounded by layers (beds) of recognizably different rock. The thickness of a single bed may range from paper thinness to tens of feet.

Note: At time of deposition, beds normally have nearly horizontal attitudes, and younger beds lie on older beds. The present attitude of beds is therefore an index to their deformation. Extreme deformation may lead to inverted sequences in which older beds lie on younger beds.

bedding plane Not a true plane, but a more or less regular surface of separation between adjacent beds.

Note: Features of the rock, such as color banding, lamination, shaly partings, which are parallel to the bedding planes, are commonly referred to as bedding.

belt (of limestone) The surface or subsoil occurrence of a limestone formation which is appreciably longer than its width (thus presenting a belt-like appearance on the map). The term is especially applicable to outcrops of limestone formations which are so tilted or folded that erosion has leached their edges to form narrow bands.

calcarenite A limestone composed of small, sand-size calcareous fragments.

calcite A mineral, the most common naturally occurring form of calcium carbonate, $CaCO_3$. The principal mineral constituent of limestone.

cleavage The ability of rocks to split along parallel surfaces of secondary origin.

Note: The cleavage referred to in this report is principally slaty cleavage which forms approximately parallel to the axial planes of folds. Figure 2 shows the geometric relation of slaty cleavage to bedding in an overturned fold. Note that in the normal limb *(see fold)* the cleavage dips more steeply than the bedding, while in the overturned limb the cleavage dips less steeply than the bedding. This relationship is of prime importance in recognizing overturned beds in the field.

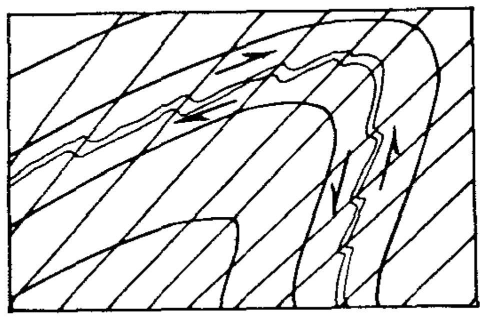


FIGURE 2. Diagram to show relationship of axial plane cleavage to bedding in an overturned fold. Also indicated are drag folds in an incompetent bed. Note that the axial planes of the drag folds are approximately parallel to the cleavage.

cleavage plane A plane, of secondary origin, along which a rock cleaves.

conglomerate A rock made up of pebbles cemented together; a consolidated gravel. Also called "pudding stone." If the pebbles are angular, the term sedimentary breccia is used.

contact A more or less regular surface where two formations are in contact with each other.

cross fault *See fault.*

dip The angle of inclination of a bed, joint, contact, fault, etc., measured from the horizontal. The dip is the maximum angle of slope of a given plane and is measured between that plane and the horizontal in a position perpendicular to the strike. *See strike.*

disconformity *See unconformity.*

dolomite The accepted name for a rock containing a significant quantity (over 50%) of the mineral dolomite, which is a carbonate of calcium and magnesium, $CaMg(CO_3)_2$.

drag fold *See fold.*

fault A break in the continuity of a body of rock attended by movement on one or both sides of the break (the fault surface). The amount of displacement may be a few inches or thousands of feet. Faults are classified both as to type of movement and orientation with respect to the bedding.

strike fault A fault striking nearly parallel to the strike of the regional structure.

cross fault A fault striking perpendicular to, or at a high angle to, the strike of the regional structure.

tear fault A cross fault along which displacement has been parallel to the strike of the fault.

normal fault A fault in which the hanging wall has apparently moved downward relative to the footwall.

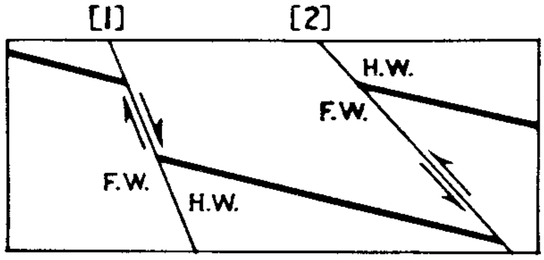


FIGURE 3. Diagrammatic cross-section of normal and reverse faults offsetting a key bed. [**1**] Normal fault, [**2**] reverse fault. **H.W.**, hanging wall, **F.W.**, footwall.

reverse fault A fault in which the hanging wall has apparently moved upward relative to the footwall.

stretch fault A thrust fault which occurs when the inverted limb of an overturned fold becomes so stretched that it finally ruptures. *See recumbent fold.*

thrust fault A reverse fault. In common usage, a reverse fault with low dip.

float Loose fragments of bedrock found in the soil.

fold A fold is a bend in a surface or layer. Only bedded rocks can bend; in fact, it is only in consequence of their laminated character that strata can bend instead of shearing across.

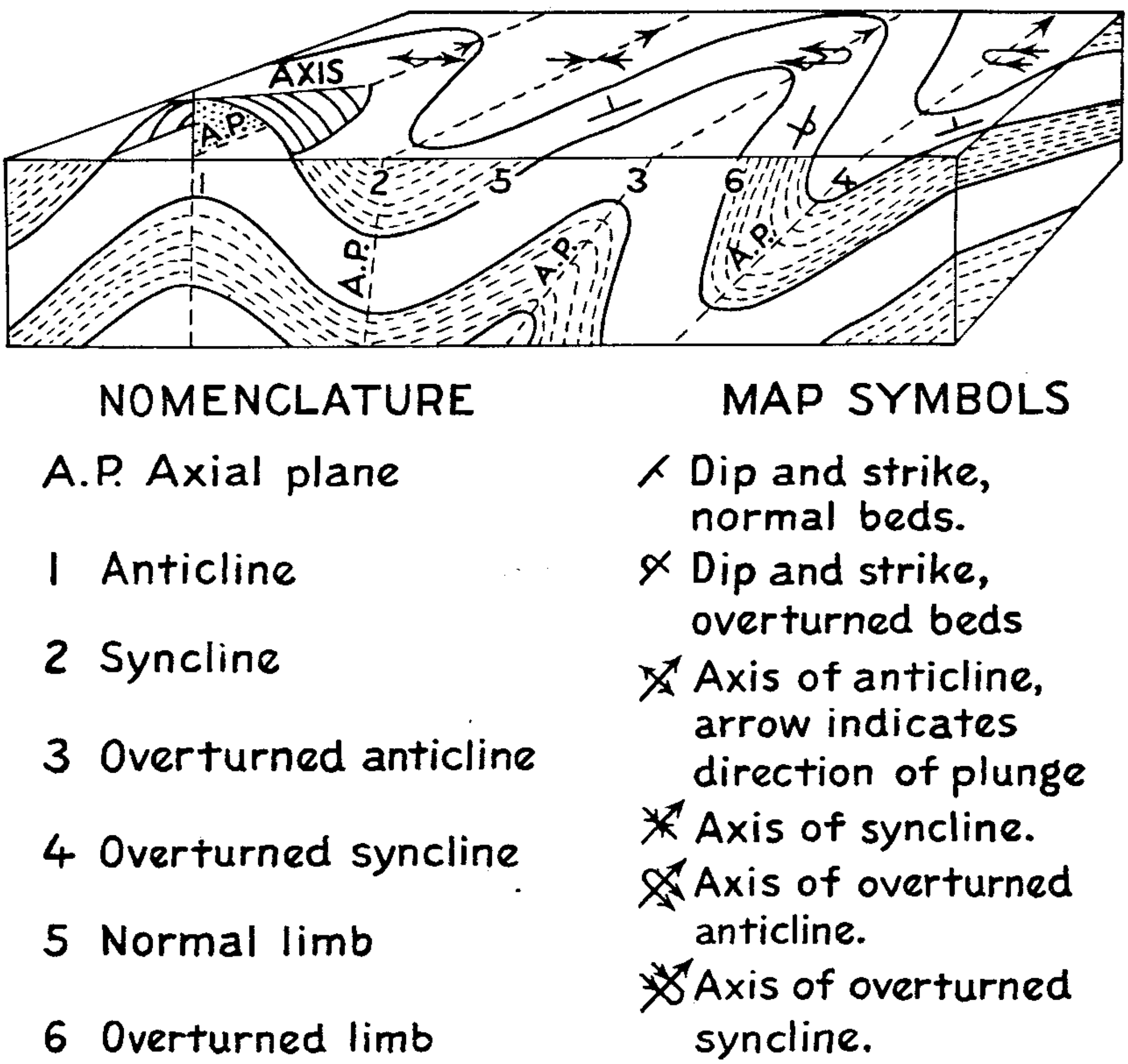


FIGURE 4. Fold nomenclature.

anticline An upfold or arch in the rocks.

axial plane An imaginary plane that divides a fold as symmetrically as possible.

axis The intersection of the axial plane with a particular bed.

crest The line of highest elevation on any bed in an anticline.

drag folds Folds produced in an incompetent (soft) bed by relative movement of two enclosing, more competent (stiff) beds in opposite directions with respect to one another. See Figure 2. Usually of small size, a fraction of an inch to a few feet in amplitude. The term is also used in reference to larger folds formed by similar relative movement of enclosing rocks, as in an anticlinorium or overthrusting. Note in Figure 2, showing relationship of drag folds to regional folding, that the axial planes of the drag folds are roughly parallel to the slaty cleavage. This relationship is useful in determining top and bottom of beds. *See cleavage.*

isoclinal fold A fold in which the two limbs dip at equal angles in the same direction, *i. e.,* the limbs are parallel, or nearly so.

overturned fold One in which the axial plane is inclined, and both limbs dip in the same direction, usually at different angles. The normal limb is right side up, while the overturned limb has been rotated more than 90°.

plunge The inclination of the axis of a fold as measured in a vertical plane containing the axis.

recumbent fold An overturned fold in which the axial plane is essentially horizontal. Special terminology used referring to recumbent folds is illustrated by Figure 5.

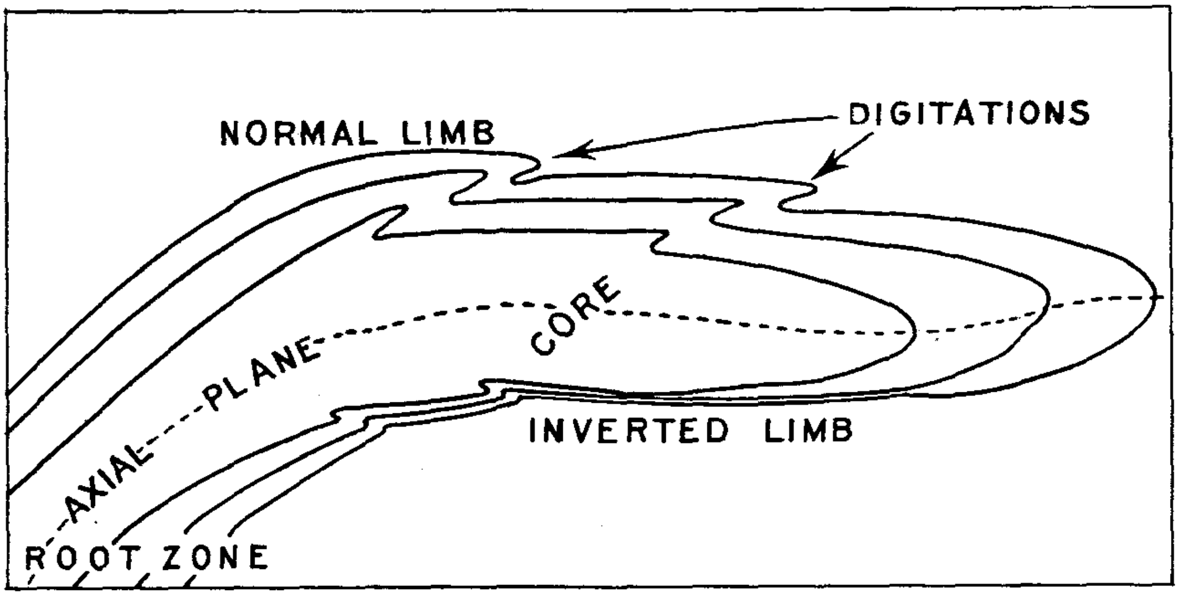


FIGURE 5. Nomenclature of recumbent folds.

syncline A down-fold, or trough in the rocks.

formation A mappable bed, or group of beds; the basic unit in geologic mapping. A formation must have recognizable contacts which are capable of being traced in the field, and it must be large enough to be shown on the map.

joint A parting surface which separates two parts of a once continuous mass of rock, but along which there has been no visible movement. Joints may be vertical, inclined, or horizontal and usually occur in two or more sets which in some cases can be related to processes of rock deformation. The intensity of jointing may vary greatly, depending on type of rock and the history of deformation.

leaching The differential removal of more soluble materials by the action of a dissolving liquid. Limestones are leached by groundwater, or even surface waters, especially those containing high concentration of carbonic acid.

lithology The appearance, mineral composition and textures of rocks.

limestone A sedimentary rock composed predominantly of calcium carbonate ($CaCO_3$). Other constituents may include the mineral dolomite, clay, silica and, less abundantly, iron carbonate and sulphides.

impure limestone Contains more than 5 per cent of insoluble impurities.

pure limestone Contains less than 5 per cent insoluble impurities, and less than 10 per cent $MgCO_3$.

high-calcium limestone Contains over 95 per cent $CaCO_3$.

magnesian limestone Contains 10-30 per cent M_gCO_3.

metabentonite A term used for certain rocks in the Ordovician of the Appalachian region and upper Mississippian Valley which are considered to be altered bentonites. They differ from bentonite in that the constituent clay minerals no longer have the property of absorbing large quantities of water. Bentonite beds are believed to have formed from heavy falls of volcanic ash which more or less contemporaneously covered wide areas, and hence are of use in stratigraphic correlation.

normal fault *See fault.*

overturned fold *See fold.*

recumbent fold *See fold.*

reverse fault *See fault.*

sandstone A clastic sedimentary rock composed of grains 0.2 to 2.0 millimeters in diameter.

shale A very fine-grained clastic sedimentary rock, with laminations parallel to the bedding. Usually lithified clay or silt.

shear zone A zone in which the rock is crushed and brecciated as the result of movement on innumerable, closely-spaced, more or less parallel fractures.

slickensides Polished and grooved surfaces caused by one mass of rock sliding past another, as in faulting. Joint surfaces on which there has been no visible movement are also sometimes slickensided.

stratigraphy The study of rock strata, the conditions of their deposition, their character, age, sequence, and distribution.

stretch thrust *See fault.*

strike The direction (azimuth) of a line formed by the intersection of an inclined surface (e. g. bedding, joint surface) and a horizontal plane. *See dip.*

structure The configuration of rock formations as emplaced or as modified by folding, faulting, etc.

stylolite A stylotic seam in a rock is a contact marked by an irregular, interlocking or mutual interpenetration of two sides. In cross section (as usually seen) the stylolitic surface resembles somewhat the tracing of a stylus, hence the name. The seam is characterized by concentration of insoluble constituents of the rock, e. g. clay, carbon, iron oxides.

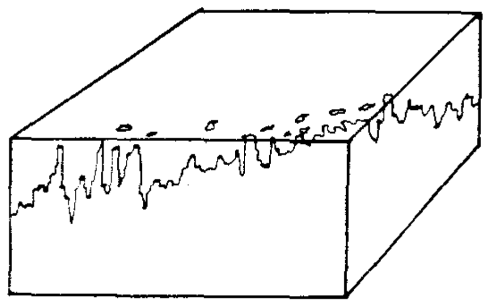


FIGURE 6. Sketch of a block of limestone with a stylolite.

syncline *See fold.*

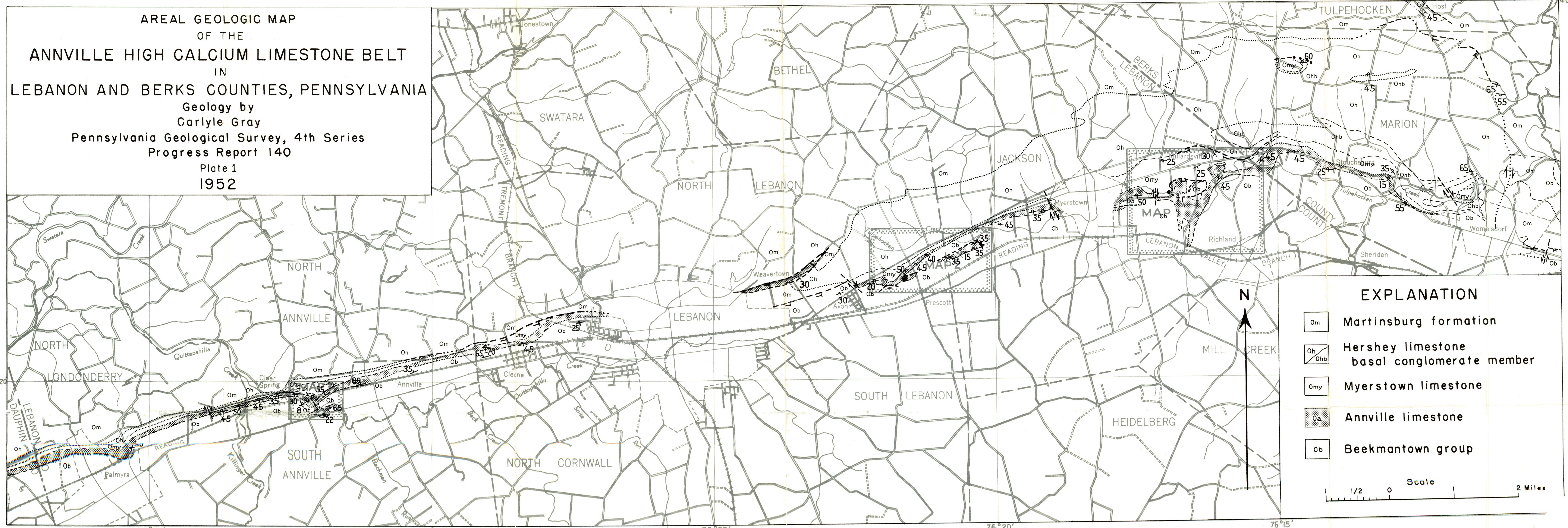
plunge *See fold.*

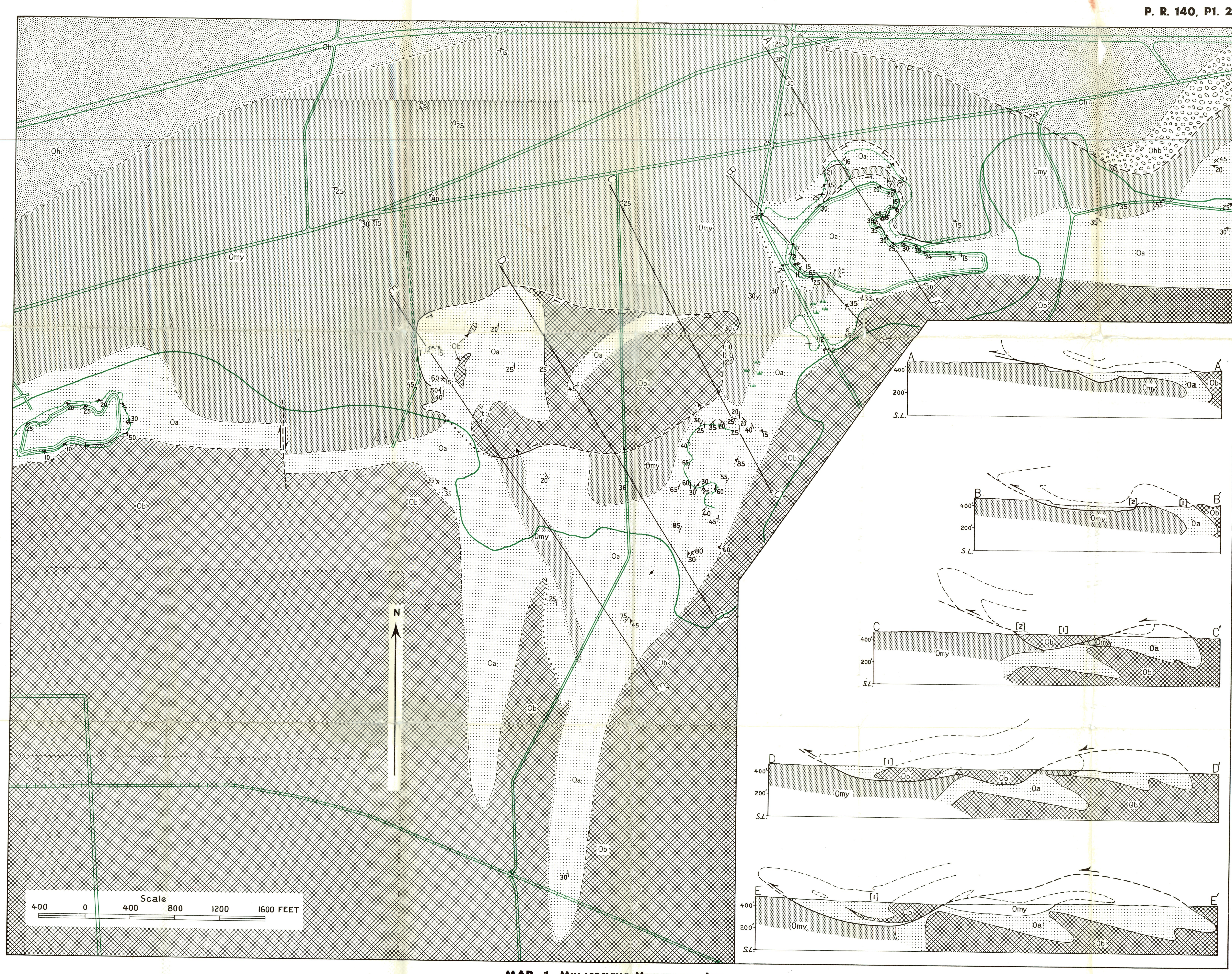
tear fault *See fault.*

thrust fault *See fault.*

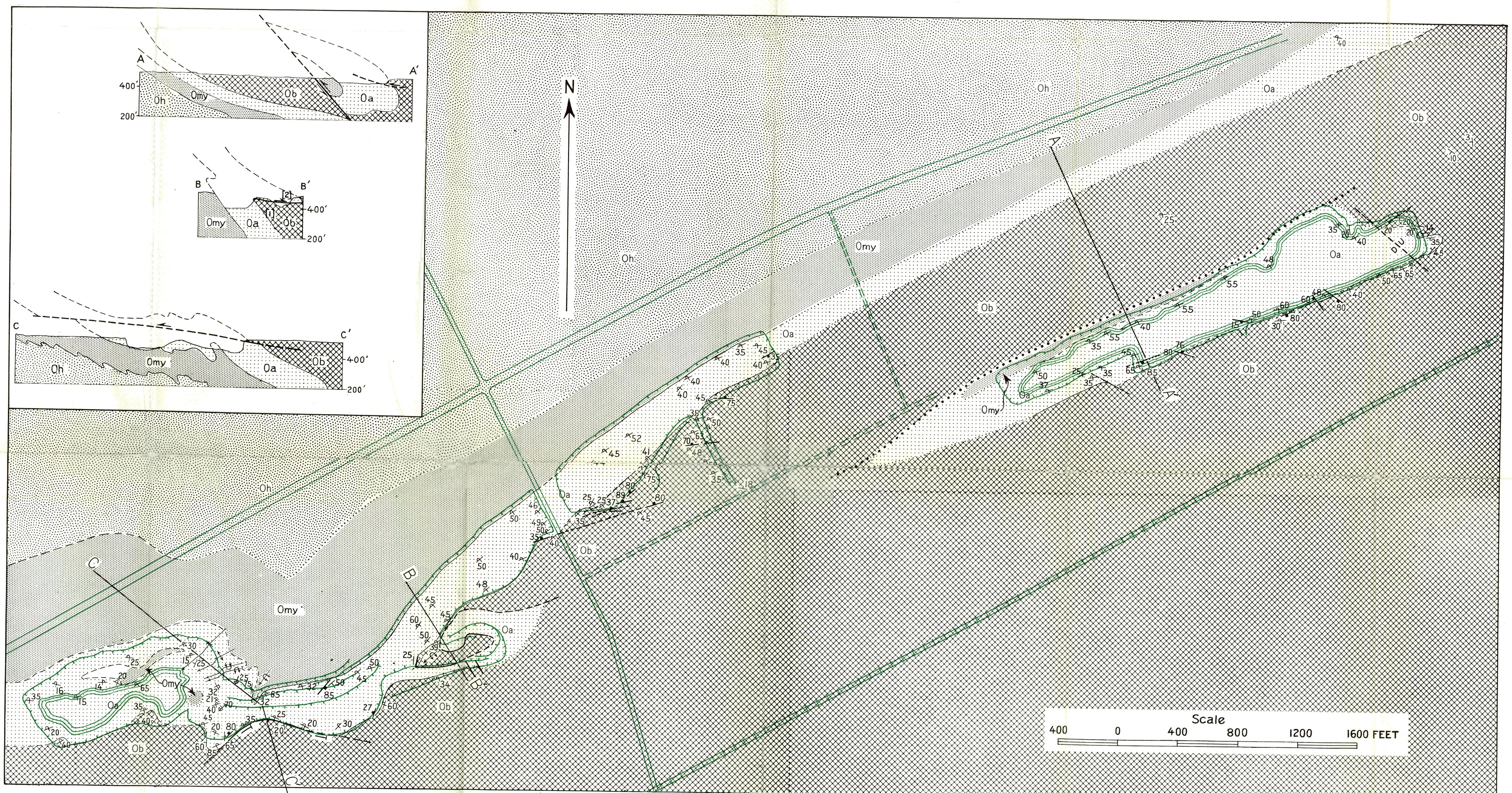
unconformity A buried erosion surface. To form an unconformity requires a reversal of the conditions of erosion and sedimentation; an area once being eroded has become one of sedimentation. The surface separating the newly deposited rocks from the underlying, partly eroded rocks is an unconformity. A disconformity is an unconformity between formations whose bedding is nearly parallel.

vaughnitic limestone A pure, dense, homogenous, dove-colored limestone which breaks with a smooth, conchoidal fracture. Weathered surfaces typically have a white, chalkv appearance.

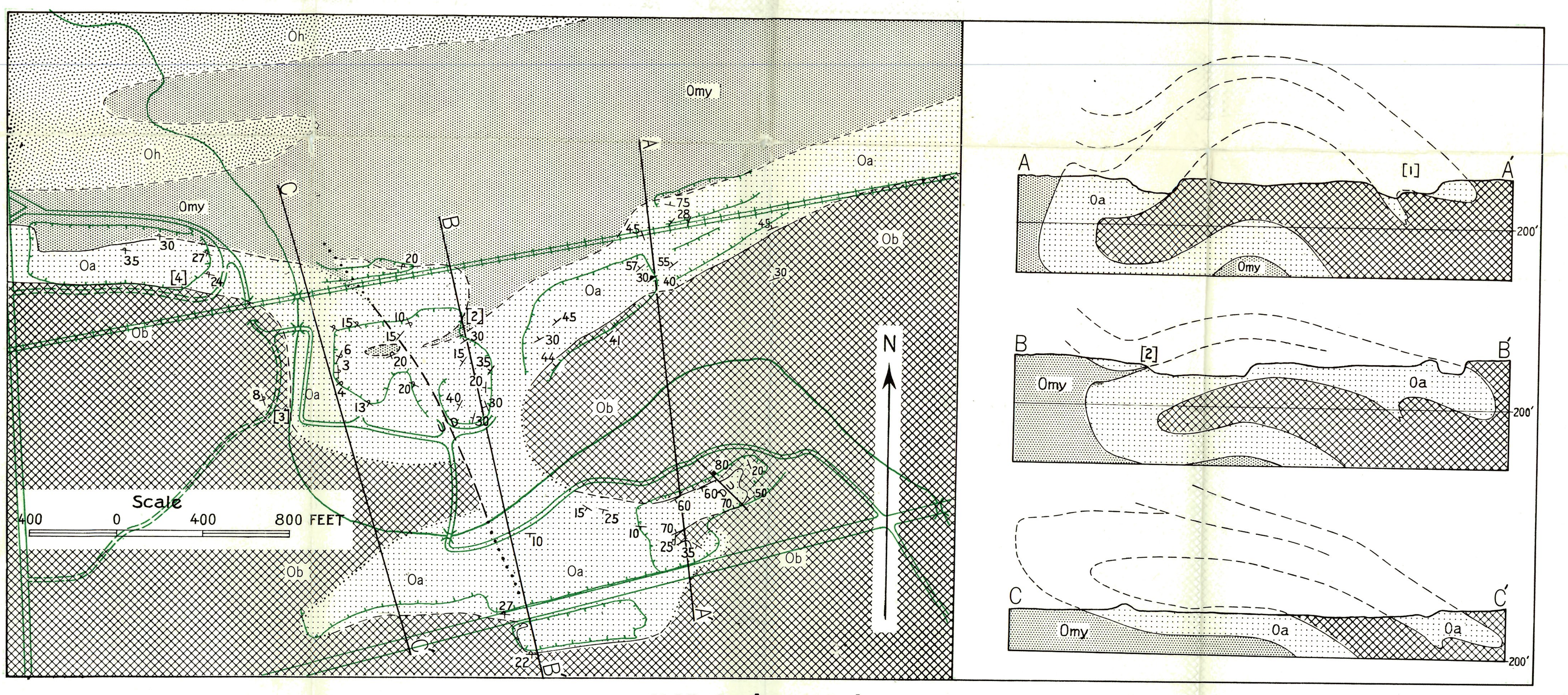

AREAL GEOLOGIC MAP
OF THE
ANNVILLE HIGH CALCIUM LIMESTONE BELT
IN
LEBANON AND BERKS COUNTIES, PENNSYLVANIA
Geology by
Carlyle Gray
Pennsylvania Geological Survey, 4th Series
Progress Report 140
Plate 1
1952
EXPLANATION
Om Martinsburg formation
Oh/Ohb Hershey limestone basal conglomerate member
Omy Myerstown limestone
Oa Annville limestone
Ob Beekmantown group
N
Scale
1/2 0 1 2 Miles
40°25'
40°20'
76°35'
76°30'
76°25'
76°20'
76°15'
TULPEHOCKEN
BETHEL
SWATARA
NORTH LEBANON
JACKSON
MARION
NORTH ANNVILLE
NORTH LONDONDERRY
LEBANON
SOUTH LEBANON
SOUTH ANNVILLE
NORTH CORNWALL
HEIDELBERG
MILL CREEK
LEBANON
DAUPHIN
BERKS
LEBANON
COUNTY
COUNTY
Jonestown
Myerstown
Weavertown
Avon
Prescott
Richland
Womelsdorf
Sheridan
Stouchsburg
Host
Cleona
Annville
Palmyra
Clear Spring
READING
TREMONT BRANCH
LEBANON VALLEY BRANCH
Swatara Creek
Quittapahilla Creek
Killinger Creek
Tulpehocken Creek
Beck Creek
Snitz Creek
Bachman Run
MAP 2
MAP



MAP 1. MILLARDSVILLE-MYERSTOWN AREA



MAP 2. CALCITE QUARRY CORPORATION PROPERTIES



MAP 3. ANNVILLE AREA

DETAILED GEOLOGIC MAPS AND SECTIONS

Pennsylvania Geologic Survey, 4th Series
Progress Report 140
Plate 2
1952

EXPLANATION

ROCKS

Om — Martinsburg formation
Olive and brown shales and sandstones

Oh / Ohb — Hershey limestone, *gray shaly limestone*
Ohb, basal conglomerate member
limestone conglomerate

Omy — Myerstown limestone
dark gray platy limestone

Oa — Annville limestone
blue to light gray, pure limestone

Ob — Beekmantown group
gray, massive dolomite

FORMATION CONTACTS

Exposed, or located with good control
Located with fair control
Located with poor control

STRUCTURE SYMBOLS

Thrust fault, "T" on overthrust side
Fault, principal movement horizontal, arrows show direction of relative movement
Fault, U-upthrown side, D-downthrown side

Dips and Strikes

30 Normal bedding
50 Overturned bedding
200 Bedding overturned more than 180°
30 Cleavage
Fault plane

Folds; arrow shows direction of plunge

5° Normal anticline
4° Normal syncline
3° Overturned anticline
5° Overturned syncline
Anticlinal drag fold
Synclinal drag fold

Base from U.S.D.A. aerial photographs enlarged to 1" = 400'

Geology by Carlyle Gray, 1951