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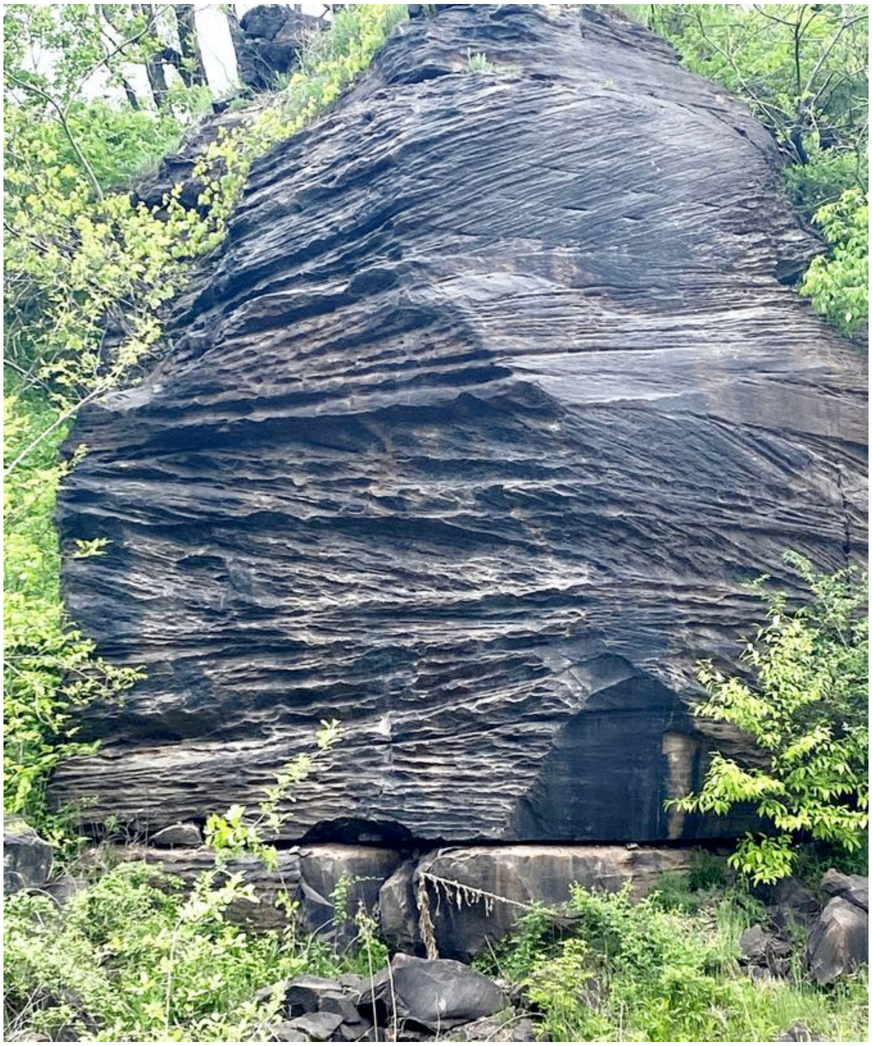

Weathered joint face of crossbedded Loyalhanna Limestone in the Keystone Lime quarry at Springs, Somerset County, Pa. The pink to red coloration, known as the red facies, is produced by its depositional proximity to a Mauch Chunk source area. Vertical scale is approximately 15 feet. (See article on page 4.)

GUEST EDITORIAL

Fifty Years Ago

John H. Barnes, retired
Pennsylvania Geological Survey

In the spring of 1972, the Pennsylvania Geological Survey moved from what is now called the Speaker Matthew J. Ryan Office Building in the Capitol Complex to new headquarters in a low-lying part of Harrisburg: an abandoned channel of the Susquehanna River that is now occupied by a small stream called Paxton Creek. Paxton Creek is normally confined to an artificial channel immediately behind the building that we moved into. On Wednesday, June 21, 1972, after a week of rainy weather and as tropical storm Agnes (no longer a hurricane) was approaching, we watched Paxton Creek rising and wondered how high it would get. Then we went home at the usual time. The next morning, we received word not to report for work because the street in front of the building, Cameron Street, was flooded, which was a common occurrence. Later that day, I drove into the city to see how high the Susquehanna River was, and I was impressed that it was getting close to the level of Front Street. On the way home, I drove across a bridge that carries State Street over Cameron Street and noticed people standing along the railing looking down into the abandoned river channel. Curious, I pulled onto a side street that overlooks Cameron Street and had a clear view of our building with water about halfway up the level of the first floor. I had brief, irrational thoughts, such as wondering if the doors and windows were watertight, but I knew that wasn't the case. Over the next several days, there was no access to the building as the water reached the ceiling of the first floor. Our operations were all on the first floor, so nothing escaped.

We were finally able to return early the following week. It was worse than I had imagined. I had never experienced a flood before and didn't realize that things don't just get wet, they also get coated with mud. In our case, it was even worse than that because thick black oil had escaped from an industrial facility upstream and got into part of our building, coating everything in the executive offices in the front of the building. I was lucky that my office was in the back, so I only had water and mud to deal with.

One of the worst casualties was the bureau's research library. New shelving for the library was on order, so the entire library was still in the cardboard boxes that were used to move it to the new facility. The library was reduced to a pile of pulp. Fortunately, the geological community includes many generous people. A call went out to other geological institutions and many responded with donations of books and journals to give us a start on rebuilding our library.

There were many oddities that we noticed, such as an unbound multipage manuscript that had been left on a desk and stayed together as the current carried it from one location to another. An Erlenmeyer flask floated and was perched perfectly on top of a light fixture in our chemistry lab, with the top of a cardboard box resting on top of it (Figure 1). My wooden desk floated, came down with one leg on a steel side table, and was left with interesting diagonal water-level marks after it was removed from the table (Figure 2). The desk of our Assistant Director, Donald Hoskins, floated out through a large window at the front of the building and was found several blocks down the street.

Recovery took years. In the initial days, important papers were taken to an industrial freezer facility to prevent mold from forming. Later, they were gradually retrieved, allowed to thaw, and the pages were carefully separated and hung on clotheslines strung through our temporary home to dry. That went on for

Figure 1. The bureau's chemistry lab was not yet completely set up after the move when Agnes hit. The water reached all the way to the ceiling and some objects floated (such as an Erlenmeyer flask), landing in interesting places.

Figure 2. The author's office. The wallboard of all the offices was knocked out by the first people to enter the building so that light could enter the interior offices from the offices across the hall. After floating, the desk settled with one corner on the steel table, resulting in diagonal watermarks on the side. The black steel cabinet was cleaned up and is still in use today in the bureau's chemistry lab.

many months. Over the next several years we were moved from one temporary location to another until we found a new "permanent" home on the 8th and 9th floors of a building in downtown Harrisburg. The Bureau Director, Arthur Socolow, was quite insistent that we be in a place where the water would never reach us again. We were there for the next 17 years, but the flood left a lasting impression. We constantly talked about everything in terms of being "pre-flood" or "post-flood." Since then, the bureau has had two more moves, and all of today's staff members were hired "post-flood," but the memory lives on whenever someone encounters a wrinkled, mud-dappled sheet of paper in the records or a specimen having traces of mud that couldn't be completely cleaned off. Agnes left a permanent mark on the Pennsylvania Geological Survey.

To document the destruction experienced by the bureau, a collection of photographs taken during the aftermath of the storm is available for viewing at POWER Library (see page 25 of this issue).

Utilization and Origin of the Loyalhanna Limestone (Chesterian, Upper Mississippian) in Southwestern Pennsylvania

David K. Brezinski[1]
Albert D. Kollar[2]

INTRODUCTION

The streets of Pittsburgh are paved with Loyalhanna Limestone. So are those in Ligonier, Duquesne, Homestead, Turtle Creek, Bellevue, Braddock, and many other towns in western Pennsylvania (Figure 1A–D). Although many are now covered by asphalt, these hand-hewn pavements represent a more classic time in western Pennsylvania's history. The limestone paving blocks, known locally as Ligonier blocks, were used extensively in paving streets in Pittsburgh (Stone, 1932). Locals also called these pavers "Belgian Blocks," but they were often mistakenly called cobblestones, a term used for paving stones naturally rounded and waterworn (Bates and Jackson, 1980, p. 122). The history and ambiance of these paved streets were captured by acclaimed painter of the time John Kane (1860–1934). Kane, who worked for a time as a street paver, portrayed the character of the Loyalhanna Belgian Block streets in his painting "Industry's Increase" (Figure 1A) (McSwigan, 1938).

It is the massive character of the Loyalhanna Limestone that has proven useful in making this rock unit a highly valued dimension stone, paving stone, and decorative stone. The century-old Belgian-Block streets of Pittsburgh attest to the durability of these stones. A close look at them shows that the iconic crossbedding that exemplifies this unit (see cover photograph) is ubiquitous even within the small cut stones of the Loyalhanna (Figure 1E). In fact, the medium- to large-scale trough crossbedding displayed by the Loyalhanna Limestone has made it one of the most recognizable units in the Appalachian basin (Brezinski and Kollar, 2021). These blocks were quarried and cut at several places within Pennsylvania's Laurel Highlands (see photograph on page 26).

Named by Butts (1904) for exposures along Loyalhanna Creek near Latrobe, Westmoreland County, the typical Loyalhanna Limestone displays a "zebra-striped" pattern produced by the differential weathering of alternating quartz- and carbonate-rich layers. In larger quarried blocks and outcrops this crossbedding can be as much as 3 m in thickness. The thickness and festoon style of crossbedding have precipitated a century-long debate as to the origin of the distinctive yet enigmatic unit.

HISTORY OF INTERPRETATION

The question surrounding the Loyalhanna Limestone's depositional origins centers around the iconic trough crossbedding. Early workers, such as Butts (1924, 1945), believed that the crossbedded sandy limestone was formed by eolian processes. Hickok and Moyer (1940), while studying the Loyalhanna in Fayette County, agreed with this interpretation. Wells (1974) described a similar sandstone in Sullivan County, Pa., and attributed its origin to eolian and shallow marine processes. Berg (1980) identified an interval of friable crossbedded sandstone within the lower Mauch Chunk Formation

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Figure 1. The Loyalhanna Limestone "Belgian Blocks" as a Pittsburgh paving stone. A. "Industry's Increase" (1933), a landscape painting by John Kane showing the 10th Street Bridge at Second Avenue in Pittsburgh (painting is in the Museum of Modern Art, New York City). B. Louise Street, Homestead, Pa. C. St. Joseph Drive, Wilmerding, Pa. D. Close-up of weathered paving stone exhibiting crossbedding. E. Center Avenue, Duquesne, Pa.

of Centre County, Pa., and equated it with the Loyalhanna Limestone farther to the south. The trough crossbedding and frosted grains led Berg to infer an eolian origin for that unit.

In examining three outcrops in Pennsylvania and West Virginia, Ahlbrandt (1995) showed that sedimentary structures characteristic of the Loyalhanna, along with the absence of marine fossils, were evidence of eolian origins. Krezoski and others (2005, 2006) and Swezey and others (2012) likewise posited an eolian origin for the Loyalhanna in Somerset County, based on an outcrop near Mount Davis. Recent videos of Laurel Caverns have also promoted the eolian origins for the Loyalhanna at that location (Schmid and Mauer, 2020).

While researchers have proposed an eolian origin for the Loyalhanna for nearly a century, an alternative genesis was proposed even earlier. Campbell (1903) believed that the "siliceous limestone" strata at the top of the Pocono, layers we now call the Loyalhanna, were suggestive of a marine origin. This interpretation was furthered by Flint (1965) based on outcrops in southern Somerset County.

In what is the most comprehensive sedimentologic study of the Loyalhanna, Adams (1970) demonstrated that petrologic, provenance, and paleocurrent attributes of the unit indicate a marine origin. Hoque's (1975) study of paleocurrent orientations in the Loyalhanna led him to conclude that dominant directions of crossbedding suggested tidal flow. Gallagher (1984) identified three lithotopes within the Loyalhanna Limestone of Centre County and suggested that they were formed by marine processes. Brezinski (1984, 1989a, 1999) discussed the regional facies relationships of the Loyalhanna and concluded that the arrangement of lithologies suggested deposition during several successive marine shallowing episodes. Brezinski and Kollar (2006, 2021) discussed and illustrated marine fossils present within the Loyalhanna and suggested that this fauna unequivocally demonstrates a marine origin for the Loyalhanna.

REGIONAL FACIES OF THE LOYALHANNA LIMESTONE

Brezinski (1989a) showed that the Upper Mississippian of the central Appalachian basin consisted of two broadly dissimilar depositional regimes. In the southern half of the basin (southern West Virginia), Mississippian strata consist of interbedded marine and marginal marine limestone and shales of the Greenbrier Group. Conversely, in northeastern Pennsylvania, equivalent strata consist of red alluvial and fluvial deposits of the Mauch Chunk Formation (Brezinski, 1999). Separating these two distinct depositional regimes is a zone of interfingering where marine strata are interbedded with red nonmarine strata. This zone lies in southwestern Pennsylvania, western Maryland, and northernmost West Virginia, an area where the Loyalhanna and Wymps Gap limestones represent thin fingers of the thick carbonate succession to the south (Figure 2).

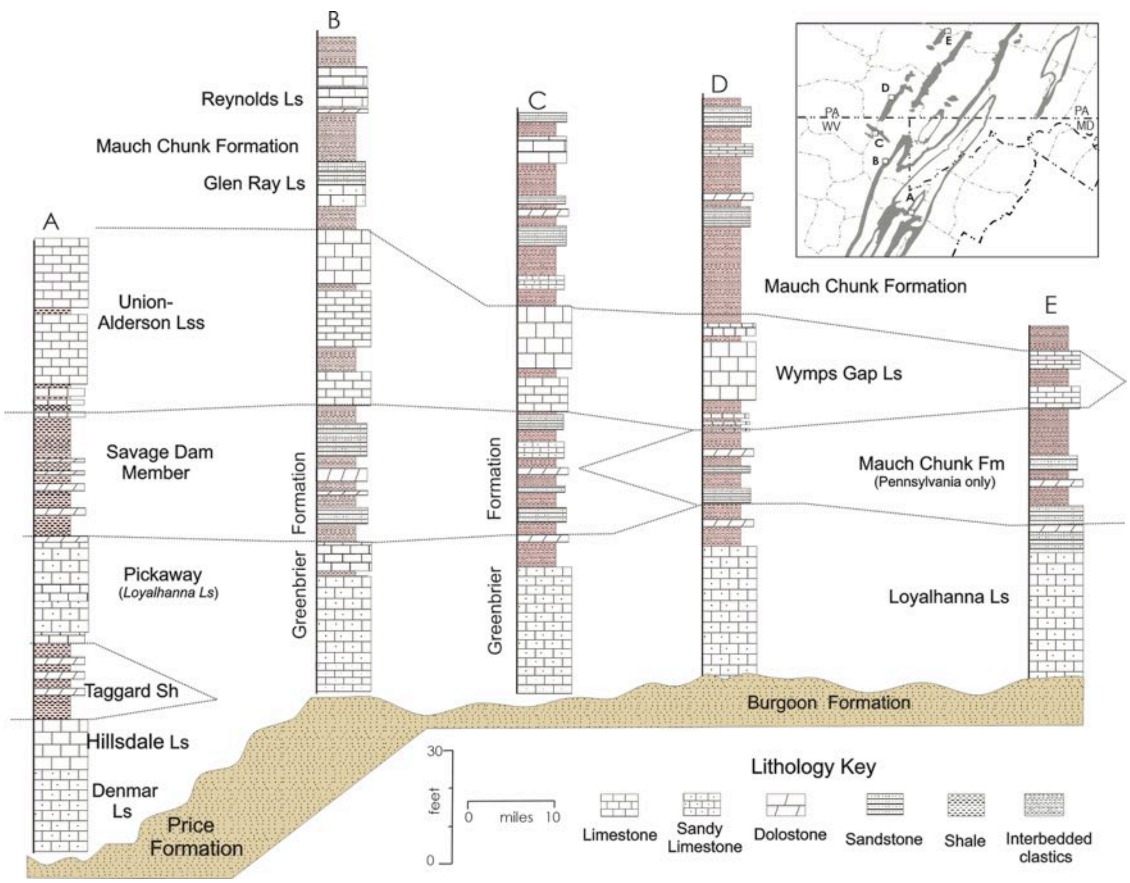

Figure 2. Correlation of Greenbrier and Mauch Chunk units in southwestern Pennsylvania and northern West Virginia. A. West Virginia Route 32, Canaan Valley State Park, W. Va. B. CSXT railroad tracks, Rowelsburg, Preston County, W. Va. C. West Virginia Route 7 and adjacent quarries, Greer, Monongalia County, W. Va. D. Composite section along U.S. Route 40 between Hopwood and Chalk Hill, Fayette County, Pa. E. Norfolk Southern railroad tracks, Bolivar, Westmoreland County, Pa. Sections A, B, C, and E modified from Brezinski (1989c); section D modified from Brezinski (1984).

In southwestern Pennsylvania and adjacent Maryland, the basal Upper Mississippian unit is the Loyalhanna Limestone. Throughout this area the Loyalhanna rests directly on nonmarine sandstones of the Burgoon Formation (Brezinski, 1999) and is overlain by red clastics of the Mauch Chunk or the localized Deer Valley Limestone (Flint, 1965; Brezinski, 1999).

The Loyalhanna is commonly perceived as a massive, crossbedded, sandy limestone that lacks any interbeds or discontinuities. However, Adams (1970) pointed out the presence of localized siltstone interbeds. Brezinski and Kollar (2021) have shown that the Loyalhanna commonly exhibits interbeds of limestone to the south and shale to the north. Furthermore, they have shown that three regional facies are recorded in Loyalhanna outcrops of West Virginia, Maryland, and Pennsylvania.

In western Maryland and northern West Virginia, the Loyalhanna consists of alternating intervals of massive, trough crossbedded, sandy, nodular to ripple-bedded limestone and tan dolomite (Brezinski, 1989b) (Figure 3, section A; Figures 4E, F). Most of the sand grains in this area of the outcrop belt are carbonate in composition. Southward in West Virginia, the Loyalhanna is underlain by additional units of the Greenbrier Group, which serves to separate it from the underlying Price Formation. Near Canaan Valley State Park in Tucker County, the iconic trough crossbedded character is still displayed even though the equivalent lithologies have been assigned to the Pickaway Limestone (Stamm, 2004, fig. 20; Brezinski and Kollar, 2021) (Figure 2, section A).

What is commonly envisioned as "typical" Loyalhanna is present in Fayette, Westmoreland, and Somerset Counties. Here the Loyalhanna consists of greenish-gray, locally reddish, massive, crossbedded sandy limestone (Figure 3, section B). In these facies crossbedding is ubiquitous. The crossbedding consists of low- to high-angle, trough, tabular and wedge-shaped foresets up to 4 m in thickness. There is generally a greater percentage of quartz sand in this area compared to outcrops to the south, and differential weathering produces the characteristic zebra striping on weathered outcrops (Figure 4A). The massive crossbedded interval is often separated by erosion surfaces or lenses or beds of tan siltstone or dolomitic siltstone (Figures 4B, C). Also, commonly present near these erosion surfaces are intervals of brecciated resedimented purer limestone (Figure 4D).

North and northeastward from the type area along Loyalhanna Creek in Westmoreland County, the Loyalhanna displays a distinct interbedding of massive, sandy, crossbedded limestone and red shale; thin-bedded, flaser- and ripple-laminated siltstone; and sandy to silty nodular limestone (Brezinski, 1989c) (Figure 3, sections C–F). This lithofacies is well exposed in the Broad Top basin and along the Allegheny Front in Centre County (Brezinski, 1989a, fig. 5C).

In Lycoming and Sullivan counties in north-central Pennsylvania, the Loyalhanna is separated from the underlying early Mississippian strata by an interval of red clastics assigned to the Mauch Chunk Formation (Faill and others, 1977; Wells and Bucek, 1980). In this area, what is inferred to be the Loyalhanna consists of calcareous, crossbedded, white quartzarenitic sandstones. This is a similar relationship to that known for Luzerne and Lackawanna Counties (Edmunds, 1997).

LOYALHANNA FAUNA

Throughout its history of study, the question about the depositional origin of the Loyalhanna Limestone has centered around the iconic crossbedding (Butts, 1924; Adams, 1970; Hoque, 1975; Ahlbrandt, 1995). Each of these authors noted that the absence of macrofossils is perplexing and sometimes determinative evidence in their genetic interpretations. Petrographic studies have shown a nearly ubiquitous distribution of comminuted macrofauna consisting of pieces of brachiopods, molluscs,

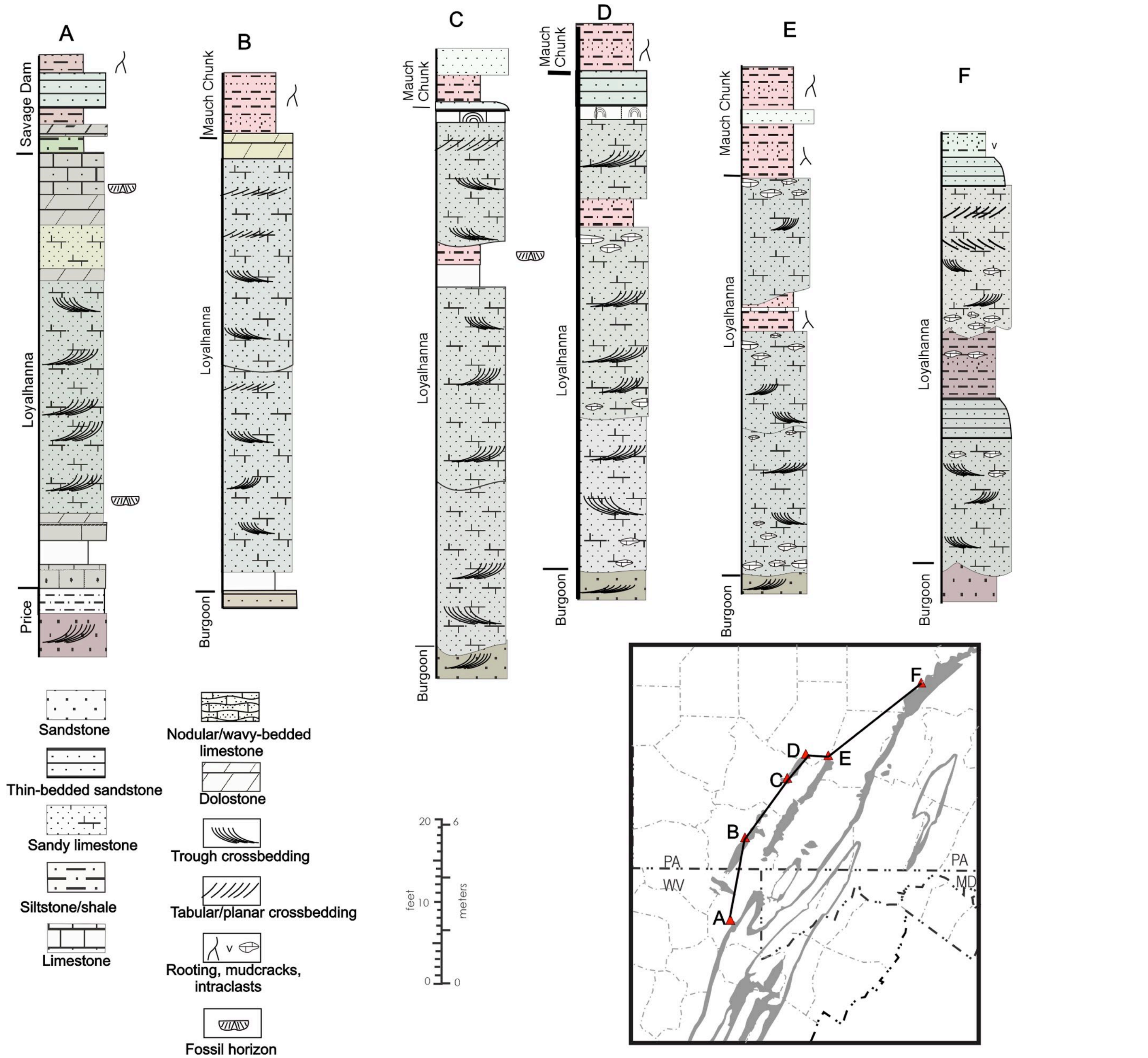

Figure 3. Vertical and lateral changes in the Loyalhanna Limestone shown through a south to north transect. A. CXST tracks, Rowelsburg, Preston County, W. Va. B. Hopwood/Chalk Hill, Fayette County, Pa., composite measurement. C. Loyalhanna Creek, McCance, Westmoreland County, Pa. D. Norfolk Southern railroad tracks, Bolivar, Westmoreland County, Pa. E. Pa. Route 403, Cramer, Cambria County Pa. F. U.S. Route 322, Phillipsburg, near the Centre-Clearfield County boundary, Pa.

bryozoans, and echinoderms (Adams, 1970; Brezinski, 1984) (Figures 5, 6A–E). Furthermore, a common microfossil component is endothyrid foraminifers (Brezinski, 1984, pl. 1, figs. A, E) (Figures 6A, B). Even while fragmental macrofauna were noted throughout the Loyalhanna (Gallagher, 1984; Brezinski, 1989b; Edmunds, 1997), authors attested to the eolian origin of the unit, based at least in part by the absence of macrofossils (Ahlbrandt, 1995).

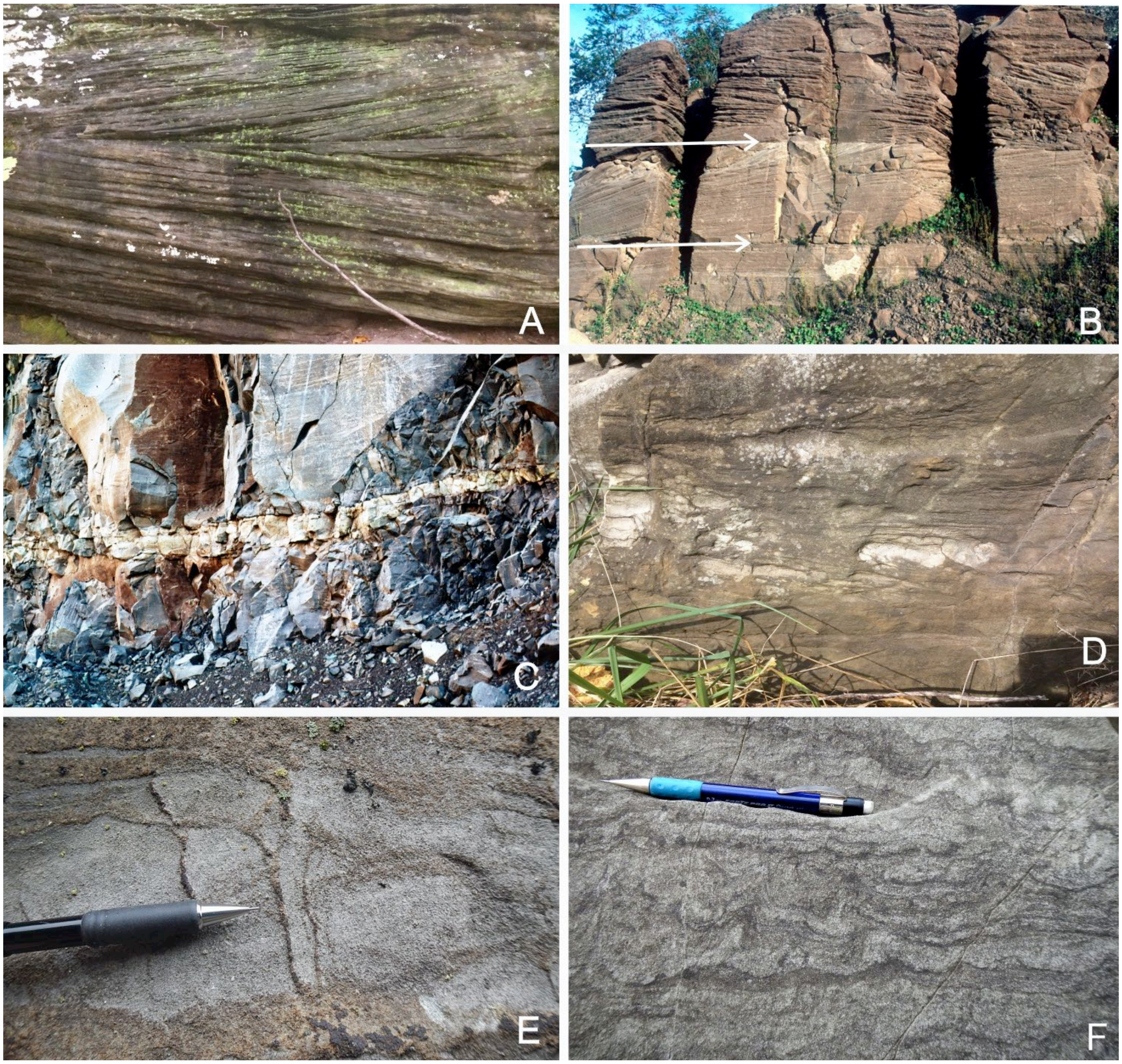

Figure 4. Representative lithologies of the Loyalhanna Limestone. A. Weathered zebra-striped surface characteristic of the Loyalhanna Limestone. B. Joint faces of quarried limestone illustrating boundary activation surfaces between individual crossbedding foresets. C. Tan dolomitic siltstone preserved at boundary layer between two foresets. D. Resedimented clasts of purer limestone. E. Burrow within crossbedded unit. F. Penecontemporaneous water expulsion structures at top of crossbedded unit.

The first articulated macrofauna was noted by Brezinski (1989b) and subsequently discussed and illustrated by Brezinski and Kollar (2006). From those early findings further locations were identified, and marine macrofossils and microfossils are now known throughout the various facies of the Loyalhanna and overlying Deer Valley Limestone (Gallagher, 1984; Brezinski, 1989b; Brezinski and Kollar, 2006, 2021; Rose-Anna Behr, written communication, 2021) (Figures 5 and 6).

Macrofossils have now been recovered from various lithologies of the Loyalhanna from Preston County, W. Va., Garrett County, Md., and Somerset, Fayette, and Westmoreland Counties, Pa. Furthermore, fragmental and unrecovered macrofaunas have been noted in Centre County (Gallagher,

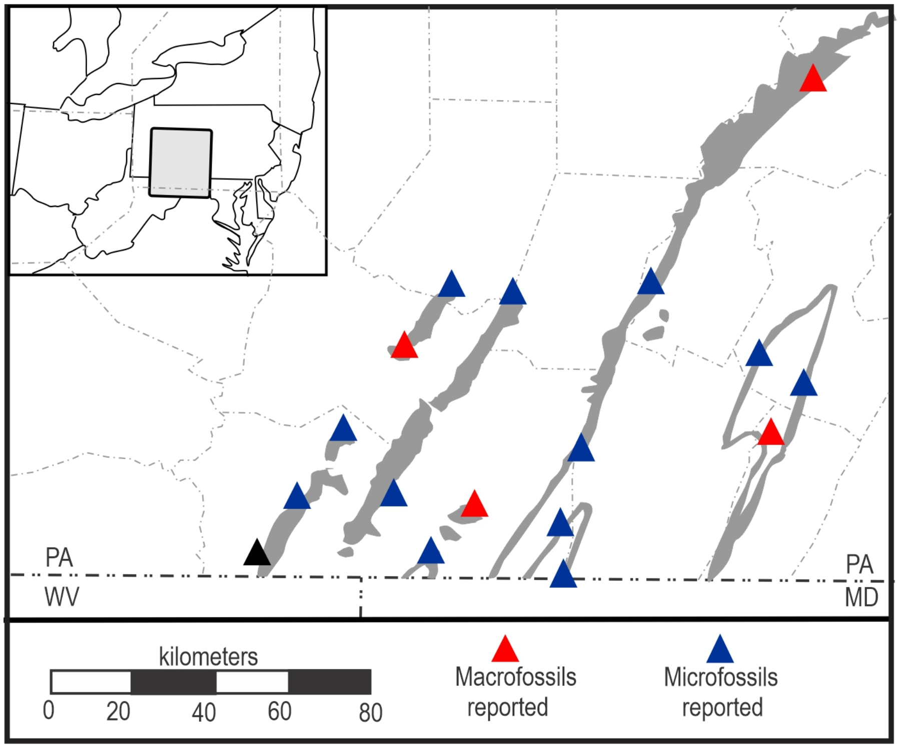

Figure 5. Distribution of Loyalhanna outcrops from which marine microfauna and macrofauna (Figure 6) are currently known or reported.

1984), Luzerne and Lackawanna Counties (Edmunds, 1997) and Fulton County, Pa. (Rose-Anna Behr, written communication, 2021).

Identified brachiopods from massive crossbedded and interbedded limestone lithologies include *Anthracospirifer, Pugnoides, Kitakamithyris, Martinia, Composita, Dielasma,* and *Cleiothyridina* (Figure 6F–L). This fauna typically exists as aggregations and pockets near crossbed foreset boundaries. Also found within this lithology are gastropod shells.

Within the shaly interbeds of the interbedded massive limestone and shale lithofacies a different macrofauna is present. Fauna recovered from this lithofacies include the brachiopod *Composita,* the bivalves *Promytilus, Aviculopectin,* and *Cypricardella?,* and the trilobite *Kaskia* (Brezinski and Kollar, 2021) (Figures 6M–P).

The identification of two different megafaunas is attributed to the differences in substrate and environmental conditions within differing lithofacies of the Loyalhanna. The brachiopod and gastropod faunas were seen and recovered mainly from pockets within the massive crossbedded intervals, while the bivalves and trilobites were restricted to shaly interbeds.

SUMMARY

Authors have utilized many of the Loyalhanna's intrinsic sedimentologic features as indicators of subaerial and eolian derivation. Table 1 compares and summarizes several sedimentologic features and components that characterize subaerial eolian dune fields as compared to submarine tidal dunes. Features common to each of these depositional regimes are compared to those prevalent in the

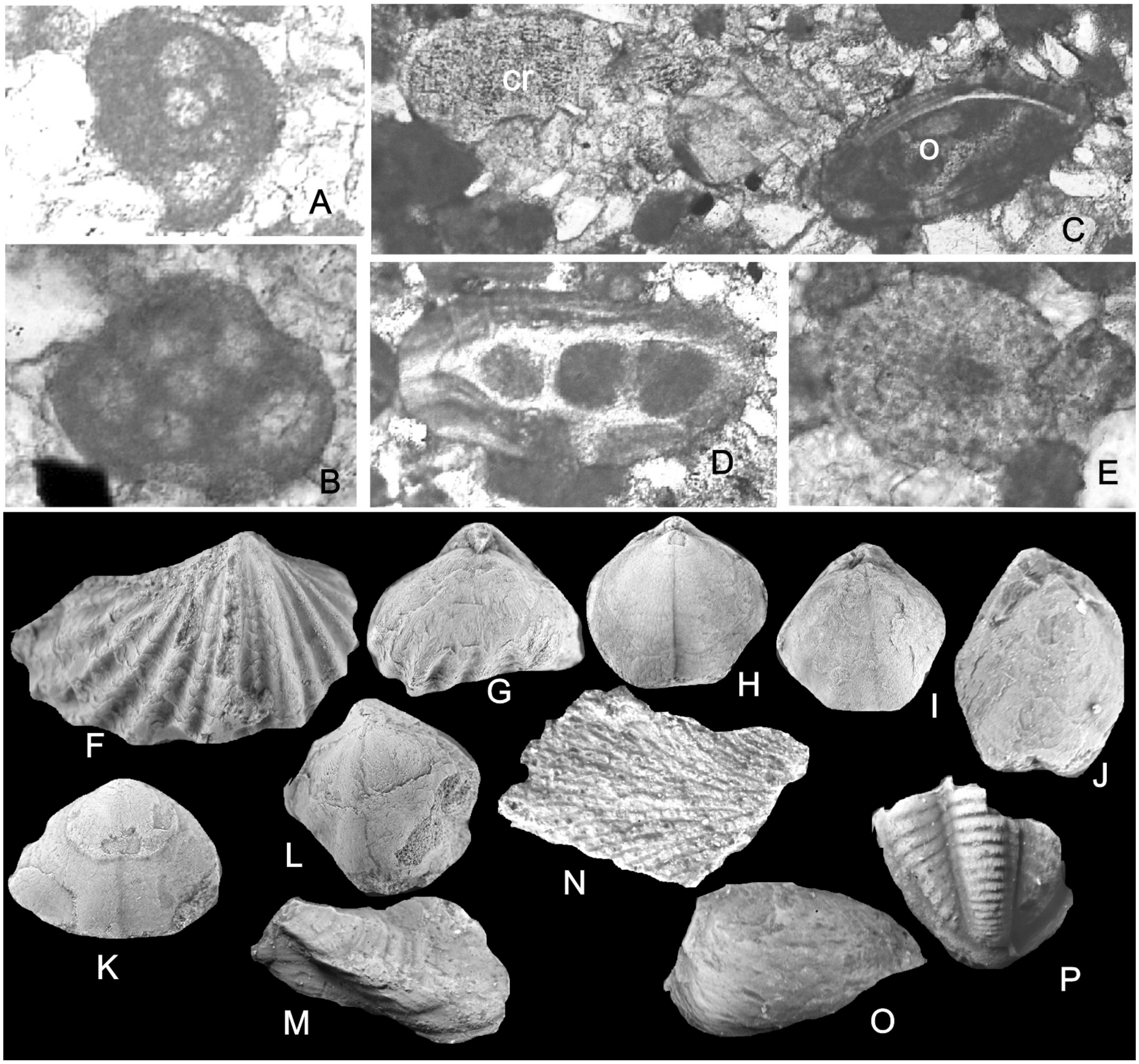

Figure 6. Representative examples of microfossils (A–E) and macrofossils (F–P) recovered from the Loyalhanna Limestone. A, B. Indeterminate endothyrid foraminifers. C. Fragmental ostracode (o) and crinoid ossicle (cr). D. Fragmental indeterminate bryozoan. E. Crinoid fragment. All microfossils are approximately 200 micrometers in diameter. F. Anthracospirifer *sp., CM 53234, x4. G.* Pugnoides *sp., CM 53230, x3. H.* Kitakamithyris *sp., CM 53235, x3. I.* Composita *sp., CM 53232, x3. J.* Dielasma *sp., CM 53236, x2. K.* Cleiothyridina *sp., CM 53231, x2. L.* Martinia *sp., CM 53233, x2. M. Internal mold of bivalve* Promytilus, *CM 53237, x3. N. External mold of indeterminate fenestrate bryozoan, CM 53233. O. Internal mold of bivalve* Cypricardella?, *CM 53238, x3. P. Incomplete pygidium of* Kaskia gersnai, *CM 53241, x4. CM, Carnegie Museum.*

Loyalhanna. By evaluating Table 1, diagnostic subaerial and eolian characteristics can be shown to be absent from the Loyalhanna, and those that are present can also be found in submarine tidal shelf facies. Thus, some of these characteristics are equivocal and not diagnostic at all. Kocurek and Dott (1981) noted that features such as grain flows, crossbedding types, inverse grading, sand-size biomodality, crossbed bounding surfaces, and crossbedding thickness are known from both subaerial and subaqueous dunes.

Table 1. A Comparison of Salient Characteristics of Eolian and Submarine Dunes and Intrinsic Sedimentologic Features of the Loyalhanna Limestone[1]

Characteristic	Eolianite/erg	Tidal shelf	Loyalhanna
Large-scale crossbedding (>8m)	X		
Medium-scale crossbedding (2–5m)	X	X	X
Crossbedding dip up to 30º–35º	X	X	X
Tracks and trails	X		
Frosted grains	X		X
Rooting	X		
Paleosols	X		
Desiccation cracks	X		
Pinstriping	X		X?
Translatent stratification[2]	X		
Festoon trough crossbeds	X	X	X
Reactivation/bounding surfaces	X	X	X
Water escape features	X	X	X
Sand size bimodality	X	X	X
Grain flows	X	X	X
Bioturbation	X	X	X
Marine microfossils		X	X
Marine macrofossils		X	X
Endolithic algal boring		X	X
Ooids		X	X

[1] Data for eolian characters from Mountney (2006) and Kocurek and Dott (1981); for marine tidal dunes from Reynaud and Dalrymple (2012); and for Loyalhanna Limestone from Brezinski and Kollar (2021).
[2]Term proposed by Hunter (1977) for ripple laminations created by tractional or translational movement of sand where the individual layer is inversely graded and whose bounding surfaces are largely parallel to the translational movement.

Authors have regularly employed the absence of fossils as a definitive indicator of the nonmarine origin of the Loyalhanna Limestone (Butts, 1924; Ahlbrandt, 1995). Brezinski and Kollar (2006, 2021) demonstrated that while megafossils are rare, they are widely distributed throughout the Loyalhanna depositional basin. Furthermore, the near ubiquity of marine microfossils such as endothyrid foraminifers and bryozoans argues for a marine origin for this unit.

Figure 7 is a diagrammatic representation of interpreted depositional relationships within the Loyalhanna basin (Brezinski, 1984; Brezinski and Kollar, 2021). It should be noted that because the preponderance of Loyalhanna lithofacies can be attributed to marine conditions it is possible that submarine dunes may have been locally emergent. Such occurrences are common in shallow carbonate regimes (Ball, 1967; Hoffmeister and others, 1967), and are plausible in the Loyalhanna.

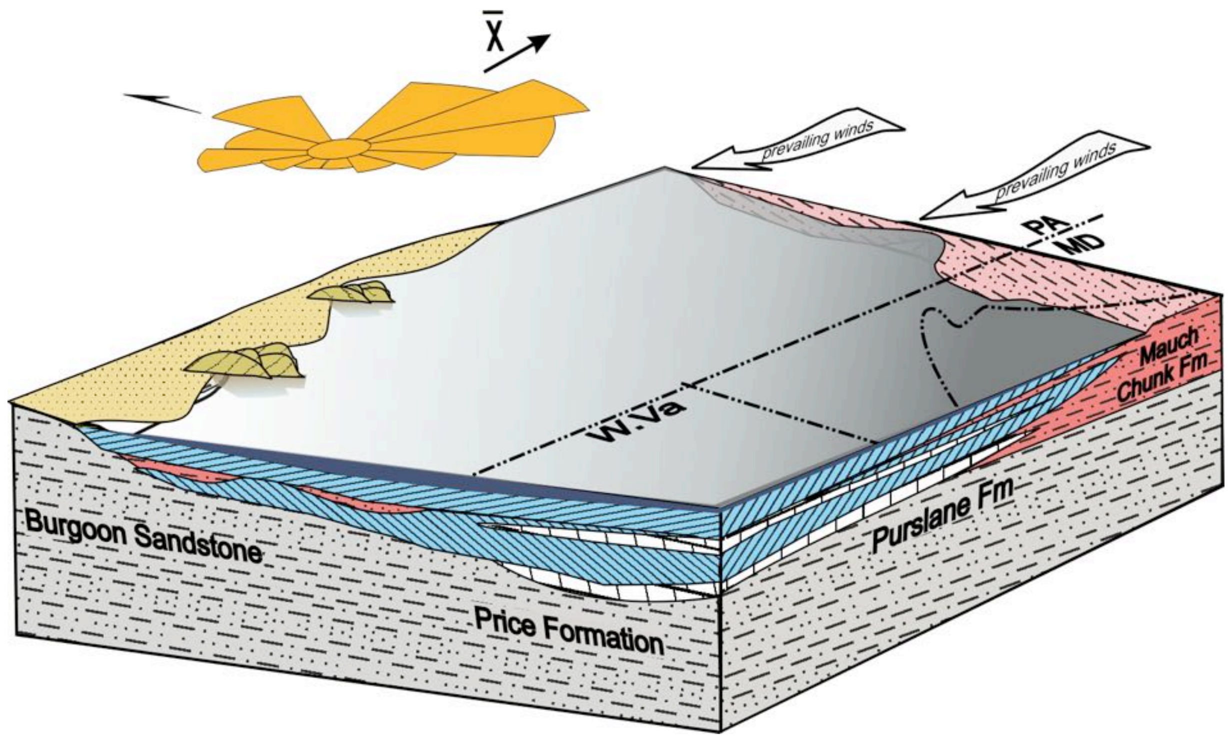

Figure 7. Interpretive three-dimensional diagram reflecting lateral and vertical relationships of the Loyalhanna Limestone. Vector diagram of measured crossbedding modified from Adams (1970, fig. 13). Diagram modified from Brezinski (1984) and Brezinski and Kollar (2021). Interpreted prevailing wind directions are based upon latitudinal projections of the Appalachian basin during the Late Mississippian (Blakey, 2008).

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ANNOUNCEMENT

The 86th Annual Field Conference of Pennsylvania Geologists

The 86th Annual Field Conference of Pennsylvania Geologists will be held in northwestern Pennsylvania on October 6–8, 2022. Participants will examine aspects of recent advances regarding the glaciation of northwestern Pennsylvania, including the early stages of development of an absolute chronology, the drainage evolution in Mercer, Lawrence, and Butler Counties, and recent mapping in Erie County. The headquarters will be at Cross Creek Resort, near Titusville.

A number of sites that have been dated by optically stimulated luminescence, terrestrial cosmogenic nuclides, and radiocarbon methods will be visited. The dates obtained will be discussed in the context of how they contribute to an understanding of the themes of this conference—the absolute glacial chronology, and drainage evolution. Sites in Crawford, Erie, and Warren Counties will be visited during Day 1. Travel and study of the southern part of the glaciated region will be the goal of Day 2. In addition, there will be several informal pre-conference field trips.

Those interested in the Field Conference should check the website frequently (https://www.fcopg.org) for updates and registration information.

New Analytical Geochemistry Instrumentation at the Pennsylvania Geological Survey—The Hitachi SU3900 Scanning Electron Microscope

Adam J. Ianno, Pennsylvania Geological Survey
John H. Barnes, Pennsylvania Geological Survey, retired

SOME EXCITING NEWS!

The Pennsylvania Geological Survey made a significant step forward in improving its capabilities to examine and analyze samples nearly 20 years ago with the purchase of its first scanning electron microscope (SEM) in 2003 (Barnes, 2003). The microscope, which had analytical capabilities, served us well for 20 years, but, in the world of modern electronic technology, 20 years is an eternity. Three years ago, bureau staff began investigating the replacement of this instrument with a more up-to-date one that would allow us to take advantage of the many new capabilities that are offered today. As a result of that investigation, the bureau is now home to a Hitachi SU3900 scanning electron microscope that is equipped with an Oxford Instruments Xplore 30 energy dispersive spectrometer (EDS) (Figure 1) (all figures are located in the Figure Gallery at the end of the text). These instruments are vital in improving our understanding of geochemistry, crystal structure, mineral identification, and characterizing resources of Pennsylvania. As before, we also look forward to continuing to work with students and scientific researchers in the commonwealth who can employ this instrumentation in their studies inside and outside of earth science.

A scanning electron microscope uses a focused beam of accelerated electrons to raster an image of a selected scene of interest. It is broadly similar in function to a standard light microscope; both use electromagnetic radiation and lenses to form magnified images. The advantage of using electrons as a light source instead of visible light is greater resolution, a greater possible magnification, and extra information about a sample, such as its chemical composition, complex zonation patterns, and fluorescence.

Our Hitachi SU3900 has an environmental chamber capable of high-vacuum (<0.01 Pascals, or Pa), and lower vacuum "variable pressure" (6–650 Pa), as compared to atmospheric pressure, which averages 101,325 Pa at sea level. High vacuum is used for analyses of samples that are electrically conductive, whereas variable pressure is used for samples that are electrically insulating.

The sample stage can accommodate samples up to 300 mm (11.8 in.) in size and fully image and analyze samples that fit within a 200 mm- (8 in.-) diameter circle (Figure 2). Samples can be up to 5 kg (11 lbs) in mass and 130 mm (5 in.) in height. In the routine analyses we perform, we gain the best results with samples that have flat surfaces. To accommodate this, the SEM has a tiltable stage that can be used to level samples until they are horizontal.

The SEM contains four installed detectors. Two that are standard on most SEMs are ones that measure backscattered electrons (BSE) and secondary electrons (SE). Additional detectors on our new SEM are an ultra variable-pressure detector (UVD) and the EDS detector. The secondary electron detector functions at high vacuum and is most typically used to observe crystal morphologies or other surface features, as it is sensitive to topography in a sample (Figure 3). The backscattered electron detector can qualitatively measure the average atomic mass of the scanned materials, with more white materials having a higher average mass than more black materials (Figure 4). It also has a topographic mode that can vividly show the relief on samples that are not flat, with apparent illumination coming from any of four directions to emphasize the relief. The ultra variable-pressure detector functions at lower vacuum than the SE detector to show surface features and is most useful as a cathodoluminescence imager for materials that fluoresce visible light under an electron beam (Figure 5). The EDS detects characteristic X-rays that are produced when the electron beam interacts with electrons in the material being scanned.

Although the EDS system is physically connected to the SEM and could not function without it, it acts as an additional instrument that empowers us with different methods to measure chemical composition. This system can generate two types of data that we find useful: visual maps of chemistry (Figure 6), and quantitative measurements of chemical composition (Figure 7). (The color boxes in the explanations of Figures 6 and 8–11 show the colors that the software uses for pure elements. The software can generate maps that show only one element at a time, which would use those colors, but it can also generate composite maps, such as these, that show several elements at once. In this case, the colors for the elements that make up each chemical compound are blended, creating different shades. The software includes analysis tools that can calculate the percentage of each element at any point on the map.) We use these "X-ray maps" to help steer analytical decisions for further analysis, assess whether minerals have variable composition such as zoning (Figure 8), and produce figures for publication and outreach. We use the quantitative information to answer questions about mineral identity and mineral chemistry. These data inform us about the processes that occurred to create these minerals, and they provide insight into what mineral resources are present in Pennsylvania. Traditionally, EDS systems could be used for X-ray maps and for point and line analyses of chemical composition. The new system, however, gives us the additional ability to measure quantification information and make X-ray maps of both irregular areas (Figure 9) and very large composite regions (Figure 10 and Figure 11).

USE AT THE PENNSYLVANIA GEOLOGICAL SURVEY

In most of our research projects, we are more curious about chemical compositions than crystal morphologies, and we usually work with electrically insulating samples. This means that we normally employ BSE images to steer our EDS chemical analyses of samples. One can make a nonconductive rock sample conductive through sputtering an extremely thin carbon or gold layer on the surface of a sample. We have this equipment available when necessary, but these coatings can create interferences with elements of interest or are difficult to remove, so we normally do not use this method. It is also challenging to apply a consistent thickness of carbon coating across all samples and standards to measure at comparable conditions. By analyzing samples at a low-vacuum pressure of 40±10 Pa, we can avoid the need for any coating and still produce excellent imagery and data.

Typical samples that we analyze for our research include petrographic thin sections, polished rock slabs, rough rocks, and mineral mounts. We are already actively looking at samples related to federal critical minerals projects and skarn mineralization. We are also actively supporting our field mapping team this season in their projects (Figure 12 and Figure 13). As always, we look forward to an exciting future of geochemistry for the commonwealth!

REFERENCE

Barnes, J. H., 2003, Replacement of equipment in survey lab means new capabilities: Pennsylvania Geology, v. 33, no. 3, p. 2–12.

FIGURE GALLERY

Figure 1. The Hitachi SEM and Oxford EDS systems as installed at the Pennsylvania Geological Survey. (Back to text)

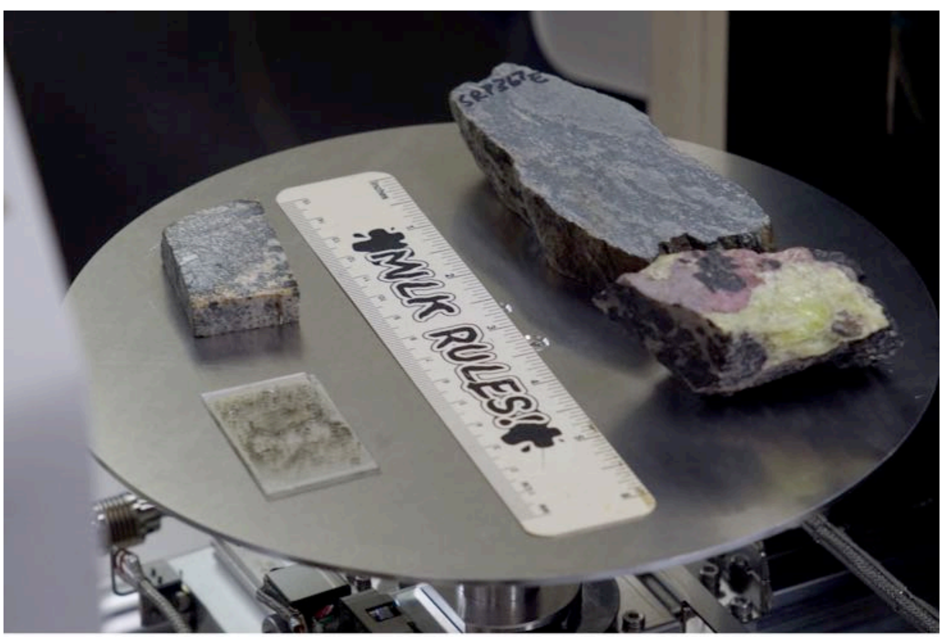
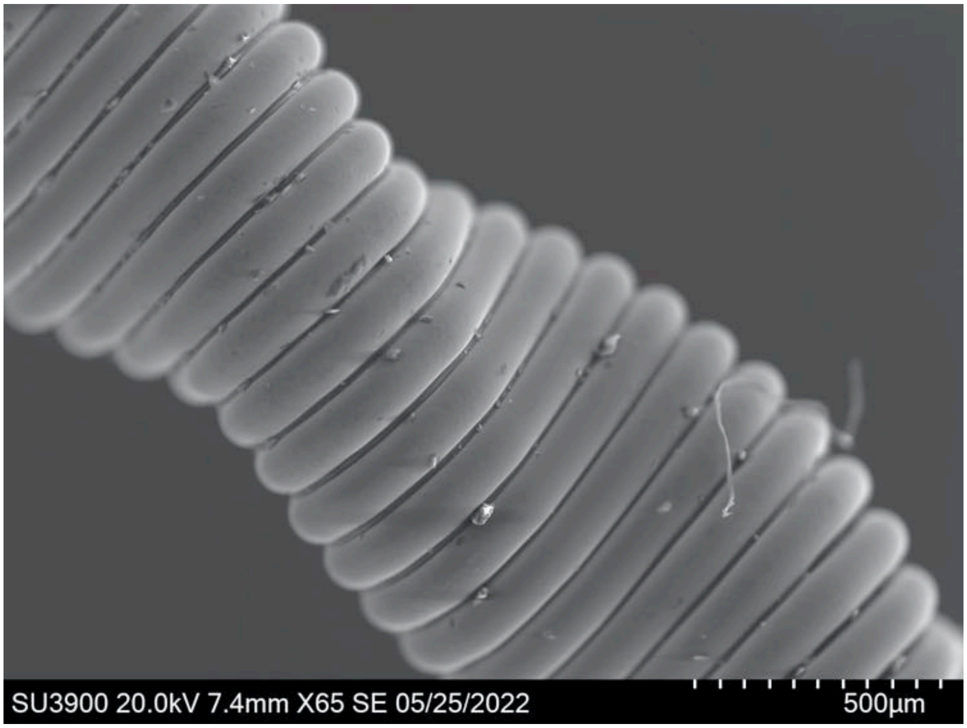


Figure 2. Our largest sample holder (200 mm [8 in.]) can accommodate many samples at one time, including (in clockwise order from bottom left) petrographic thin sections, slide billets, rock slabs, rough rock samples, and plastic rulers with unruly messages. What is shown is not an optimal analysis strategy; analysis is most ideal if the samples in the same batch are similar in height. (Back to text)



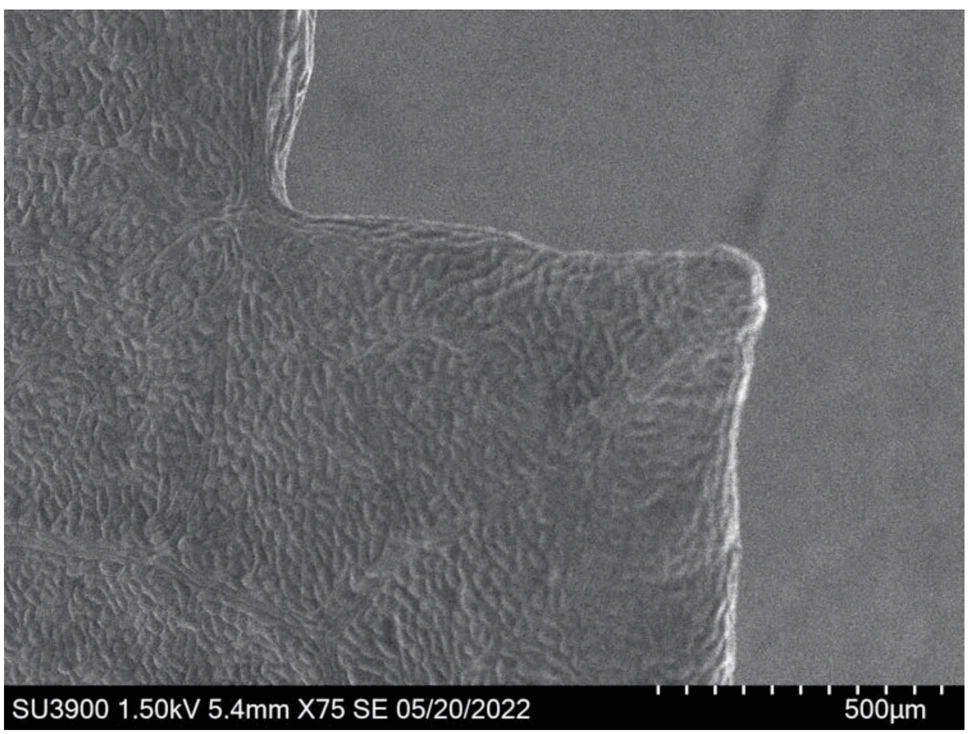


Figure 3. Secondary electron images of decidedly nongeological samples, showing the surface textures of a wound acoustic guitar string (top) and the edge of a freshly picked leaf (bottom). (Back to text)

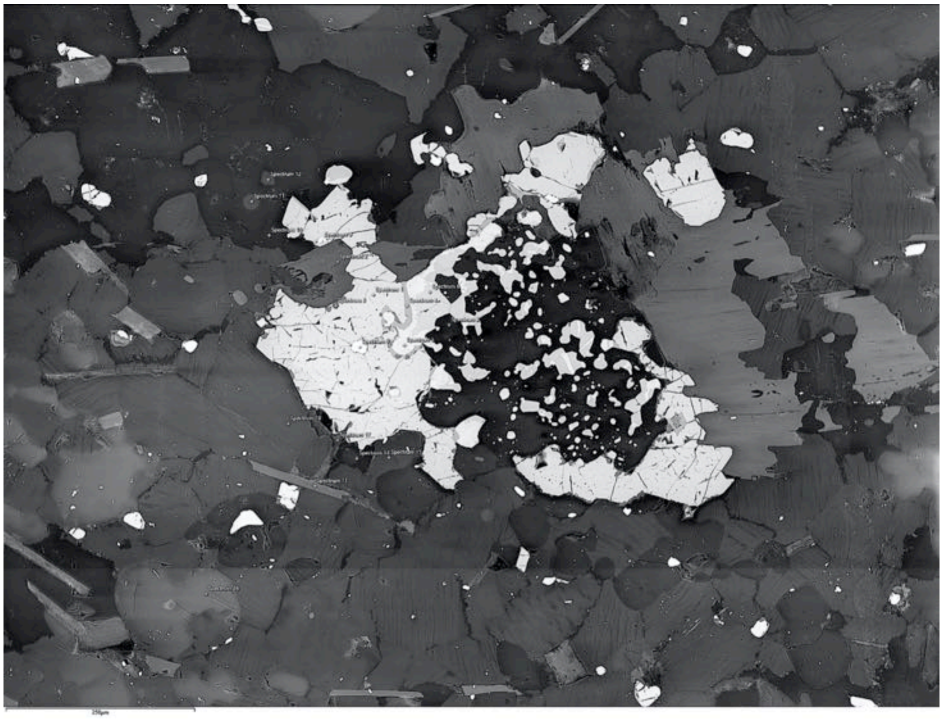


Figure 4. Backscattered electron image of a Fe-Ti oxide within a polished petrographic thin section of a granitoid rock. This image was captured using the Oxford EDS software; notice that the black information bar of the previous figures is replaced with a simple miniscule scale bar at bottom left. The capture of a BSE image through the EDS software allows a user to identify targets of interest for EDS analysis and to overlay geochemical data on top of electron imagery. (Back to text)

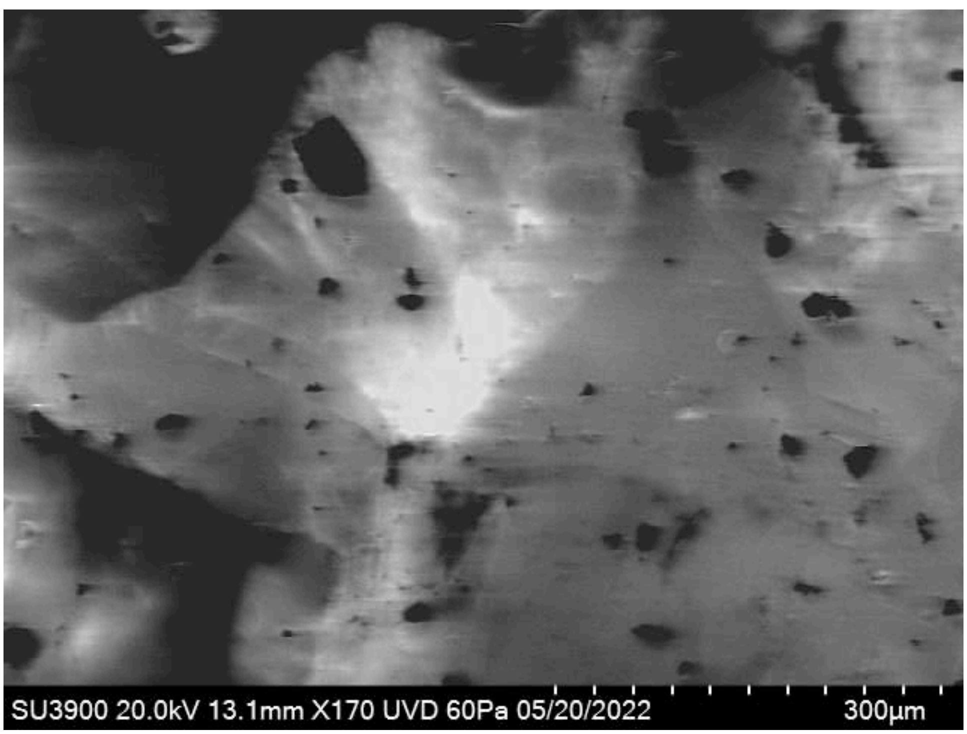


Figure 5. An image collected using the UVD detector on a zinc ore sample from the famous fluorescent mineral district of northern New Jersey. This lighter colored region fluoresces in visible light under an electron beam and is likely a calcite or willemite crystal. (Back to text)

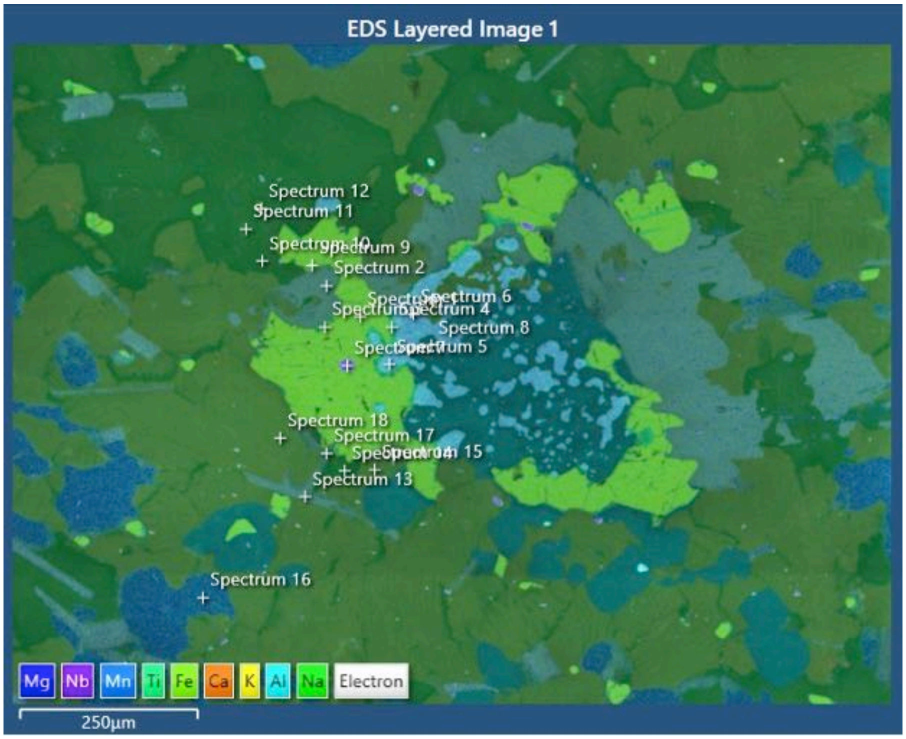
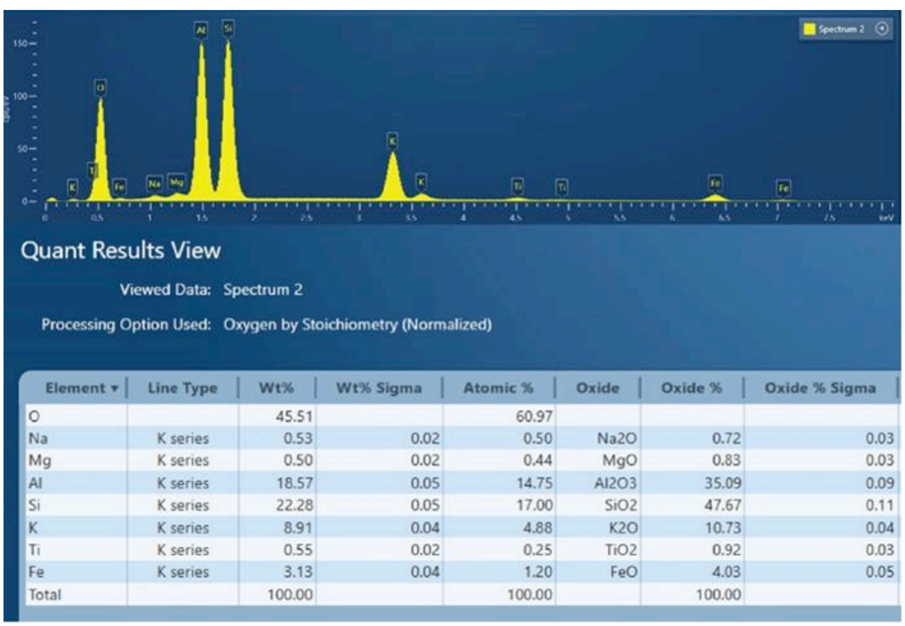


Figure 6. An example of the mapping feature available on an EDS of the analysis site seen in Figure 4. These are colloquially referred to as "X-ray maps" because the weak X-rays emitted from a sample while under an electron beam have specific energies that are associated with specific chemical elements. The + symbols mark locations where chemical analyses were collected using the spot analysis function of the EDS software. (Back to text)



Element	Line Type	Wt%	Wt% Sigma	Atomic %	Oxide	Oxide %	Oxide % Sigma
O		45.51		60.97			
Na	K series	0.53	0.02	0.50	Na2O	0.72	0.03
Mg	K series	0.50	0.02	0.44	MgO	0.83	0.03
Al	K series	18.57	0.05	14.75	Al2O3	35.09	0.09
Si	K series	22.28	0.05	17.00	SiO2	47.67	0.11
K	K series	8.91	0.04	4.88	K2O	10.73	0.04
Ti	K series	0.55	0.02	0.25	TiO2	0.92	0.03
Fe	K series	3.13	0.04	1.20	FeO	4.03	0.05
Total		100.00		100.00		100.00	

Figure 7. Examples of quantitative chemical data that the EDS can produce. At the top is a spectrum of X-ray energies detected. Each element emits X-rays that have specific energies that can be identified automatically through software. At the bottom is a quantitative report generated by software that indicates the percentage of each element or oxide present. (Back to text)

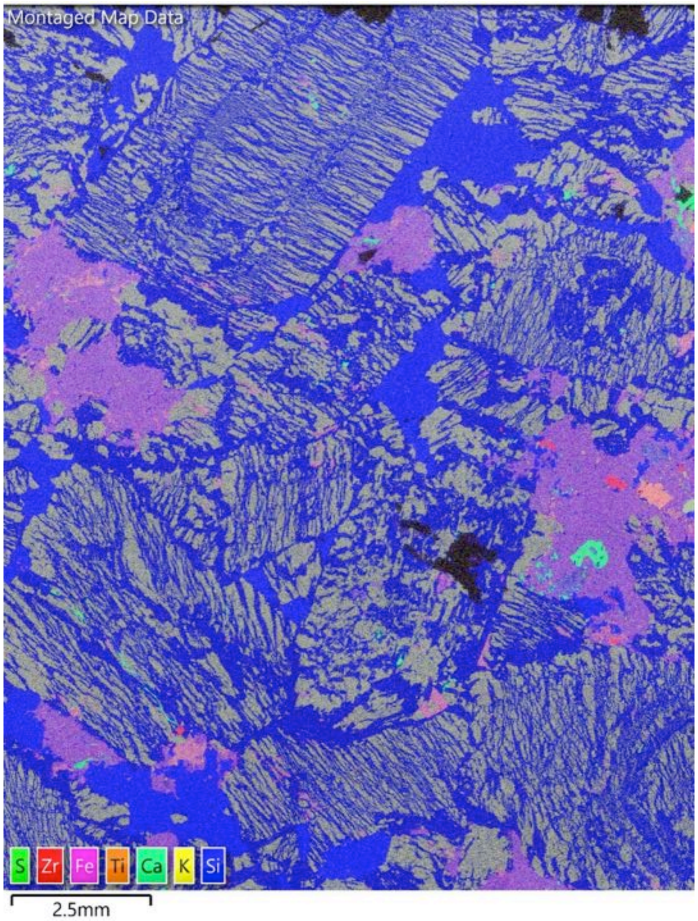


Figure 8. An EDS map of a perthitic granite. Perthitic texture can form in feldspars due to miscibility differences with temperature. Although these large feldspar crystals originally crystallized in a magma chamber as homogeneous grains and can appear as singular crystals in hand sample, with cooling and uplift, the potassium (K) and sodium (Na, not pictured) components separate (or "exsolve") into K-rich and Na-rich striped zones within each crystal. EDS analysis can identify the compositions of the exsolved feldspars producing the blue and yellow striping within the crystals. ([Back to text]())

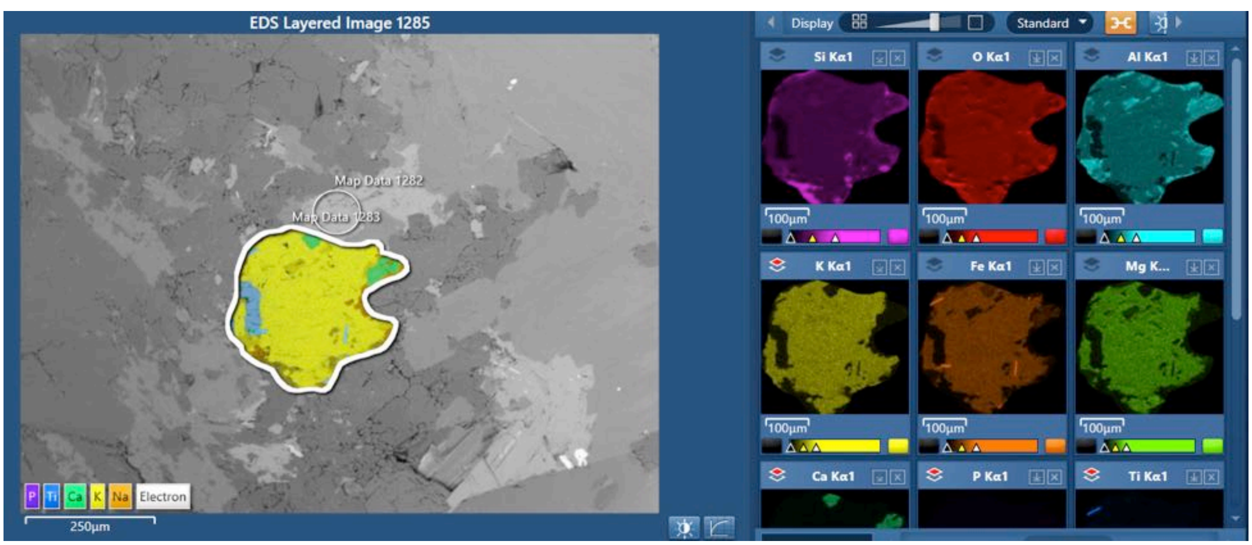


Figure 9. An EDS map of a user-selected region highlighted by a thick white line; this particular region is a portion of a tourmaline crystal and other adjacent minerals. Shown on the left is the composite color image built from user-selected individual element maps on the right. Colors of each element and its specific grayscale shading can be selected for optimal coloration. ([Back to text]())

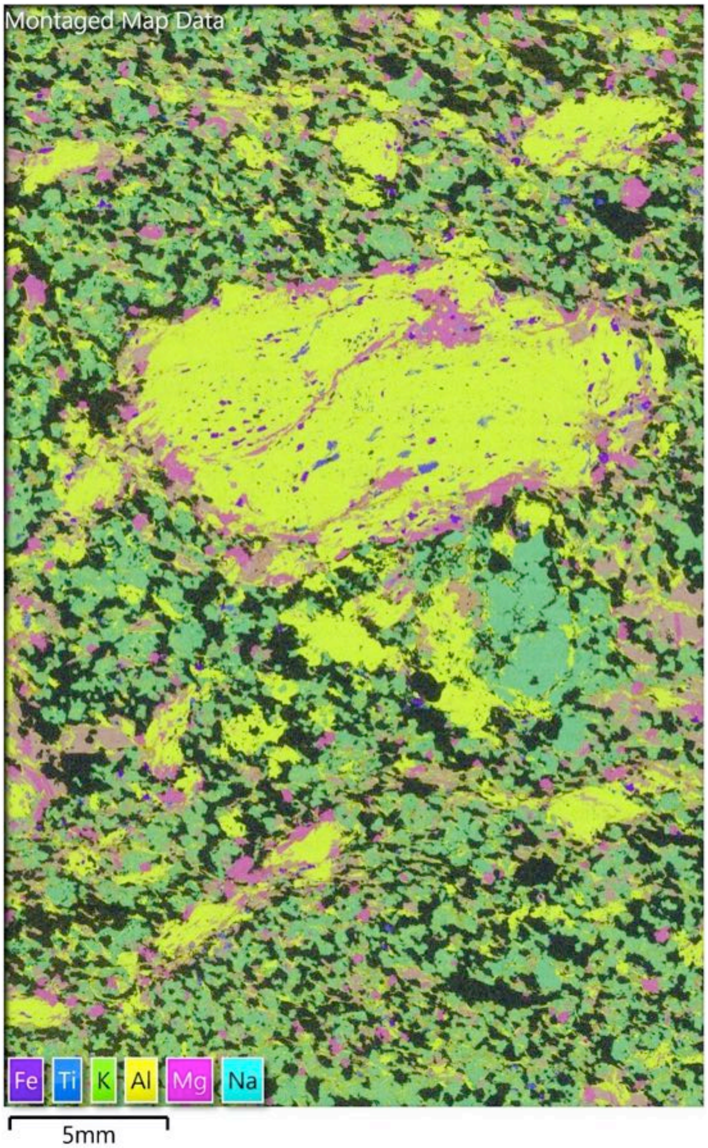


Figure 10. A composite ("montaged") EDS map of a polished petrographic thin section of a metadiamictite associated with serpentinites in Fulton Township, Lancaster County, Pa., provided by Stephen Shank, geologist at the bureau. This image was constructed from approximately 2,500 X-ray maps over the course of 18 hours. Not only can such analyses produce beautiful imagery for publications, but they also provide statistical information on the distribution of elements or minerals within a sample. (Back to text)

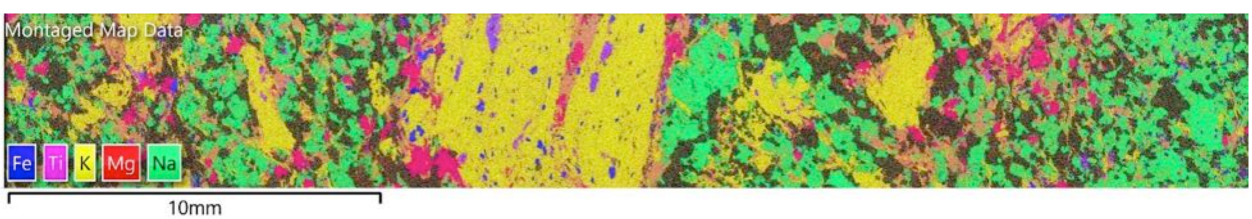


Figure 11. An EDS map survey across a rock slab from the same metadiamictite shown in Figure 10. The more perfectly flat an analytical surface, the more accurate and precise a quantitative measurement. This slab was polished with a 1,000 grit (or 5.8 micron) diamond abrasive, which is very coarse compared to the 0.02 to 0.05 micron polishing media often used for analytical samples. If an analyst's goal is to identify and demonstrate the diversity of minerals present, this method and sample would meet this goal. Viewing the image at its native resolution, however, shows some coloration scatter that may be due to pits and grooves in the sample that result in X-rays not reaching the EDS detector. (Back to text)

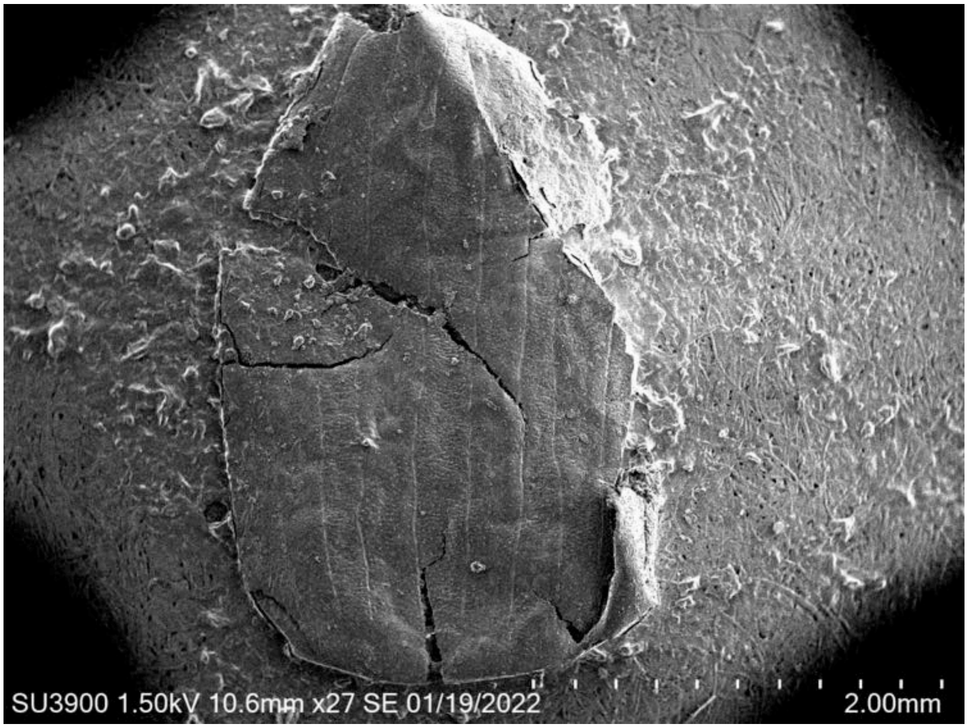


Figure 12. A secondary electron image of Pleistocene beetle fragments sampled from a sand and gravel quarry near Slippery Rock, Pa., by Aaron Bierly, geologist at the bureau. SEM imagery is an excellent tool for capturing small ornamentation in fossils, which can assist in identification of species that are similar in appearance. (Back to text)

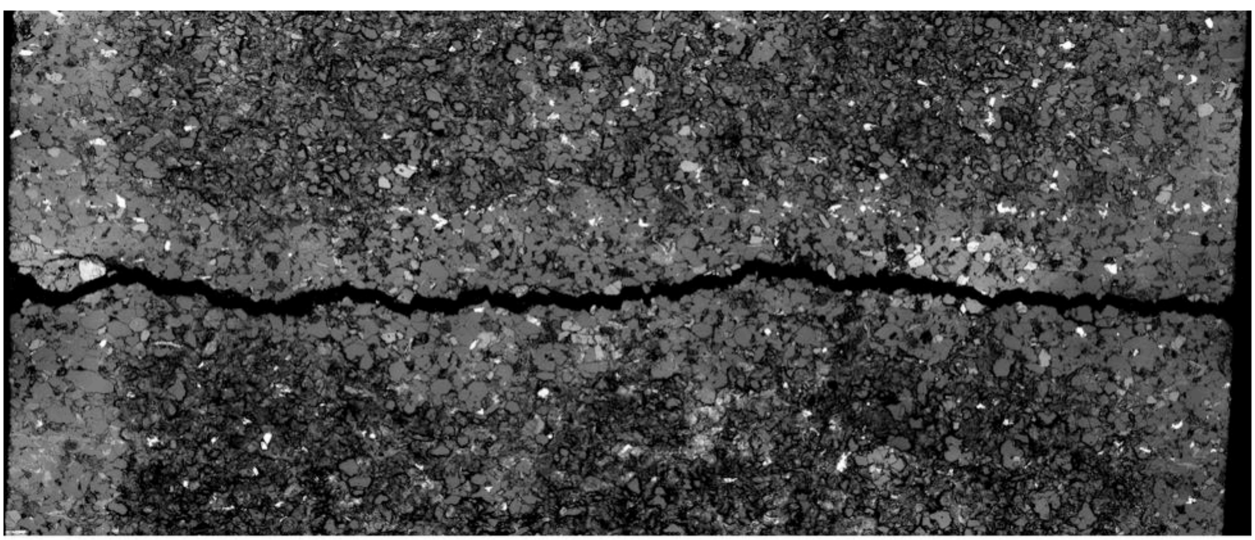


Figure 13. A backscattered electron image of a roughly polished thin section billet (approximately 25 mm across the entire image). This sample is Triassic-aged Stockton Formation, a fine- to medium-grained arkosic sandstone from southern Bucks County, collected by Chris Oest, geologist at the bureau. It was impregnated with epoxy to fill the void spaces and cracks within. We created a composite image across a large area in order to distinguish minerals (gray to white) from pore space (black). This information was put into image processing software to quantify the percentage of black pixels, which is the percentage of pore space shown on that surface. (Back to text)

BUREAU NEWS

New Online Photograph Collection Available from the Bureau Library

June 2022 marks the 50th anniversary of tropical storm Agnes (downgraded from hurricane status by the time it reached this area). At the time of the storm, the bureau offices were located in a building on North Cameron Street in Harrisburg, in the Paxton Creek lowland. After receiving 16 inches of rain over several days, the offices were flooded to the ceiling. Furniture, lab equipment, and the library were completely destroyed by water, oil, silt, and mud. (See the editorial on page 2.)

To document the destruction experienced by the bureau, a collection of photographs taken during the aftermath of the storm is available for viewing at POWER Library (https://digitalarchives.powerlibrary.org/papd/islandora/object/papd%3Aspgsl-hafp), Pennsylvania's Electronic Library (POWER Library is a service of the Office of Commonwealth Libraries, Pennsylvania Department of Education, and is hosted by Hosting Solutions and Library Consulting).

One of the photographs available in the new online collection shows Arthur Socolow, State Geologist during the 1972 Agnes flood, surveying the damage in his office after the flood.

To see more photographs, and to read more about Agnes's effect on Pennsylvania and the Geological Survey, please see the following resources, which are available online or in the bureau library:

- Bailey, J. F., Patterson, J. L., and Paulhus, J. L. H., 1975, Hurricane Agnes rainfall and floods, June–July 1972: U.S. Geological Survey Professional Paper 924, 403 p.
- Barnes, J. H., 2007, 1972—The year of the flood: Pennsylvania Geology, v. 37, no. 1, p. 12–16.
- Fulbright, Jim, 1972, Flood Pennsylvania—1972: Harrisburg, TV Host, Inc., 64 p.
- Pennsylvania Geological Survey, 1972, Agnes devastates Pennsylvania Survey [and other articles]: Pennsylvania Geology, v. 3, no. 4, 32 p.
- Romanelli, C. J., and Griffith, W. M., compilers and eds., 1972, The wrath of Agnes—a complete pictorial and written history of the June, 1972, flood in Wyoming Valley: Wilkes-Barre, Pa., Media Affiliates, Inc., 200 p.

A Look Back in Time

The plant of the New Castle Lime and Stone Company (shown here) is one of the operations in Fayette County that quarried Loyalhanna Limestone. The quarry produced paving blocks and crushed stone for highway construction and railroad ballast. The Loyalhanna Limestone in the quarry (in the background) is overlain by Mauch Chunk strata. This photograph was taken in July 1934 by Survey geologist William O. Hickok, IV. See the article on page 4 for more information about the Loyalhanna.

To see more photographs from the bureau's archives, please visit the library's Historical Photographs collection page.

—Jody Smale, Librarian

RECENT PUBLICATION

Open-File Report (May 2022)

- Bedrock-topography and drift-thickness maps of the Edinburg, Harlansburg, New Castle North, and Slippery Rock 7.5-minute quadrangles, and Pennsylvania part of the Campbell 7.5-minute quadrangle, Butler, Lawrence, and Mercer Counties, Pennsylvania (ZIP)

Calling All Authors

Articles pertaining to the geology of Pennsylvania are enthusiastically invited.

Pennsylvania Geology is a journal intended for a wide audience, primarily within Pennsylvania, but including many out-of-state readers interested in Pennsylvania's geology, topography, and associated earth science topics. Authors should keep this type of audience in mind when preparing articles.

Feature Articles: All feature articles should be timely, lively, interesting, and well illustrated. The length of a feature article is ideally 5 to 7 pages, including illustrations. Line drawings should be submitted as jpg files. Ensure that black and white drawings are not saved as color images.

Articles should be submitted as Microsoft Word files. Feature articles will be reviewed by at least one bureau staff member. It is the author's responsibility to obtain approval for use of any illustrations that are copyrighted, including those taken from the Internet.

Earth Science Teachers' Corner: Articles pertaining to available educational materials, classroom exercises, book reviews, and other geologic topics of interest to earth science educators should be 1 to 2 pages in length and should include illustrations where possible.

Announcements: Announcements of major meetings and conferences pertaining to the geology of Pennsylvania, significant awards received by Pennsylvania geologists, and other pertinent news items may be published in each issue. These announcements should be as brief as possible.

Photographs: Photographs should be submitted as separate files and not embedded in the text of the article. Please ensure that photographs as submitted are less than 10 inches wide in Photoshop or equivalent. Also ensure that black and white photographs are not saved as color images.

Submittal: Authors may send their article and illustrations as email attachments to RA-pageology@state.pa.us if the file sizes are less than 6 MB. For larger sizes, please submit the files on CD–ROM to the address given below. All submittals should include the author's name, mailing address, telephone number, email address, and the date of submittal.

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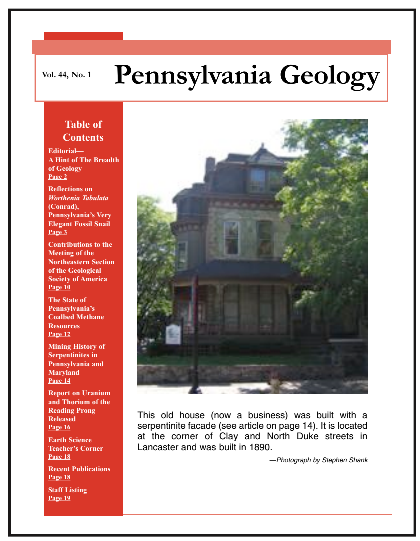
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This old house (now a business) was built with a serpentinite facade (see article on page 14). It is located at the corner of Clay and North Duke streets in Lancaster and was built in 1890.

—*Photograph by Stephen Shank*

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