Deposition and Structural Features of the Basal Morgantown Sandstone of the Casselman Formation (Pennsylvanian) of the Greater Pittsburgh Region

by

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In southwestern Pennsylvania, exposures of the Morgantown Sandstone (Pennsylvanian) of the Casselman Formation are comprised of generally massive to cross-bedded sandstone that varies between 3 to 20 meters thick. The base of the unit is commonly marked by pebble or cobble conglomerate containing clasts of diverse composition and rounding in a sandy matrix. Underlying units include gray to black shale and unfossiliferous limestone; these may be deformed by folding, loading structures, and/or bedding truncations. Pebble-filled fractures resembling sedimentary dikes rarely cut the underlying carbonate rocks. A thin horizon of coal 2 to 10 centimeters thick commonly crops out within the lowest three meters of sandstone. The coal is generally strongly disrupted by faults that may transect and offset the layer or be coincident, in which case the sheared coal may accommodate sliding and related detachment. Locally the basal conglomerate, which resembles a debris flow, overlies cobbly debris containing platy shale clasts, some of which may be folded. The floating clasts may rarely make rootless, isoclinal folds. Occasionally, folding and other soft sediment deformation is recorded by underlying beds, which may be truncated at the contact. In exposures lacking conglomerate and coal, the base of the sandstone rests directly upon undeformed shale. Wherever exposure is sufficient, the base of the unit is clearly undulating.

The unusual character of the basal Morgantown is documented throughout an area of at least 600 square kilometers. Nearly all of the 24 outcrops visited display structural and

sedimentary features that suggest disruption at the basal contact with the underlying strata. The structural and stratigraphic features at the base of the Morgantown are interpreted as having formed contemporaneously with the deposition of the sandstone as a regional, abruptly emplaced sand flow. Although commonly attributed to accumulation as a channel sandstone, no channel banks or well-sorted traction deposits are known. Furthermore, the thickness of the section between the base of the Morgantown Sandstone and the laterally persistent Ames Limestone of the Glenshaw Formation varies between 10 and 50 meters throughout the Pittsburgh region. This further leads to the conclusion that the base of the Morgantown records scour.

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PREFACE

I am greatly indebted to Dr. Thomas H. Anderson for his time, effort, knowledge, direction, and great patience throughout my graduate studies. I thoroughly appreciate his recommendation of my thesis topic as well his time spent traveling with me throughout the greater Pittsburgh area in search of Morgantown Sandstone exposures.

Additionally, I would like to thank Dr. Charles Jones and Dr. William Harbert, both of the University of Pittsburgh, for agreeing to serve on my examining committee. Much of my gratitude goes to the University of Pittsburgh Department of Geology and Planetary Science and, specifically, Shannon Granahan for her knowledge, organization, and diligence throughout this process. I am also very thankful for the field assistance and geologic expertise provided by Dr. Patricia A. Campbell of Slippery Rock University, as well as Dr. James A. Kilburg.

I am also greatly indebted to both Neil Sullivan and Mäny Emamzadeh, formerly of Sylvan Energy, for their financial and moral support that allowed me to continue my education. I would like to thank the staff of Burnett Oil Company for their support and patience as well.

Last but not least, I would like to thank my wife, Nikki Orsborn, for all of her time, patience, support, organizational skills, suggestions, and motivational techniques throughout the research and writing process. For this I owe you immensely.

1.0 INTRODUCTION

The Morgantown Sandstone of the Casselman Formation (Pennsylvanian) is commonly interpreted by Donaldson (1968), Hutchinson et al (1995), Shultz and Harper (2002), and others as having been deposited as a fluvial channel sand throughout not only the Pittsburgh area, but also throughout the basin in eastern Ohio, southwestern Pennsylvanian, and central to northern West Virginia.

An unusual exposure of Morgantown Sandstone may be observed in northernmost Allegheny County, at Bakerstown Station, about 1.8 miles west of PA Route 8 (Figure 1). At the locality a railroad cut exposes the strata of the middle Conemaugh Group including the Ames Limestone upward through Birmingham Shale and its underlying (Duquesne) and overlying (Wellersburg) thin coal seams and into the Morgantown Sandstone (Ross, 1933; Shultz and Harper, 2002; and Figure 2 section). The lithic-quartz arenite, shale, and coal seams comprise the Casselman Formation of the Conemaugh Group, which crops out along the nearly 250 meter-long railroad cut. These rocks reveal a suite of tilted beds, an angular unconformity reactivated as a fault, listric normal faults, and small-scale folds. The structures, which are not typical of the general sub-horizontal rocks that comprise this region of the Appalachian Plateau, are interpreted to record extension during sliding along multiple detachment faults (Rak et al., 2013; Graves et al., 2014). Shultz and Harper (2002) noted that a graben among the faulted, tilted blocks of Birmingham Shale is filled by dark sandy shale. Within the shale, vaguely distinguished gray cobbles may be present. They further observe that horizontal Morgantown Sandstone overlies the faulted Birmingham strata with angular unconformity. The Morgantown Sandstone and the unconformity are truncated by a younger listric normal fault, along which about 6 feet of displacement is recorded.

Subsequent studies from Rak et al. (2013) and Graves et al. (2014) suggest additional complexity. They note that locally developed within the tilted blocks are small-scale, gentle to open asymmetric detachment folds that record southward transport. The prominent angular unconformity separates the tilted blocks from overlying, sub-horizontal, medium- to thick-bedded cross-stratified quartz arenite. Listric normal faults that presumably underlie the tilted section do not cut the unconformity. Stratigraphically above the small-scale detachment folds and just below the unconformity is a zone of variable thickness composed of disrupted siltstone containing siderite nodules, as well as thin lenses and stringers of coal. Locally, foliation and fragmentation of the coal suggest that the erosional surface was reactivated during detachment of overlying beds. In the sandstone above the unconformity, clastic dikes that cut discontinuous thin, tabular, coal beds (perhaps Wellersburg) and conjugate shear fractures record injection of fluid-rich sandstone and brittle deformation. They conclude that the multiple stages of listric faults and the indications of detachment along the angular unconformity record transport and deformation penecontemporaneous with accumulation of the Casselman Formation. Detachment of lithified beds was followed by sand flows and injections of fluid-rich sand as extension continued and the beds became semi-lithified. Although the paucity of outcrops precludes estimating the amount of movement toward the deeper Appalachian Basin, the presence of foliated sandstone that records folds within meters of sandstone dikes, likely recording injection of fluid-rich sand, suggests significant attenuation associated with extension.

About 30 kilometers to the south a roadcut from Montour Run to FedEx Drive near Moon Township exposes additional enigmatic relationships at the base of the Morgantown. Among these are deformed, fractured carbonate cut by sedimentary dikes filled with pebbles.

1.1 PURPOSE OF STUDY

The purpose of this study is to examine the basal structural and sedimentary features of the Morgantown Sandstone and how they relate to the depositional environment of the greater Pittsburgh and Allegheny County region. Previous work has been done to various degrees to study the depositional setting, and the Morgantown Sandstone is commonly accepted as having been emplaced in a fluvial river system environment. However, after having visited numerous outcrops and observing a unique set of characteristics at the base of the Morganton, the author set out to expand on previous work to re-examine the depositional setting with an alternative hypothesis. The areal extent of previous work was expanded, and the author set out to identify how these basal features and their relationship to the surrounding and overlying sediments tell us about how the Morgantown Sandstone was emplaced. The writer hopes that the ideas and information portrayed in this study can help further the understanding of the Morgantown Sandstone in both the surface rocks and the subsurface.

1.2 AREA OF STUDY

The area studied for this thesis includes the rectangular area bounded by the latitudes 40°10’00” and 40°40’00” north, and the longitudes 79°40’00” and 80°20’00” west. Specifically, the study area consists of exposures almost exclusively within the boundaries of Allegheny County in southwestern Pennsylvania. The corresponding exposures within the study occur in an area of nearly 800 square kilometers. Figure 1 details the outcrops visited by the author, as well as locations studied by previous authors who detailed the stratigraphy of the upper Conemaugh Group, and more specifically the Morgantown Sandstone.

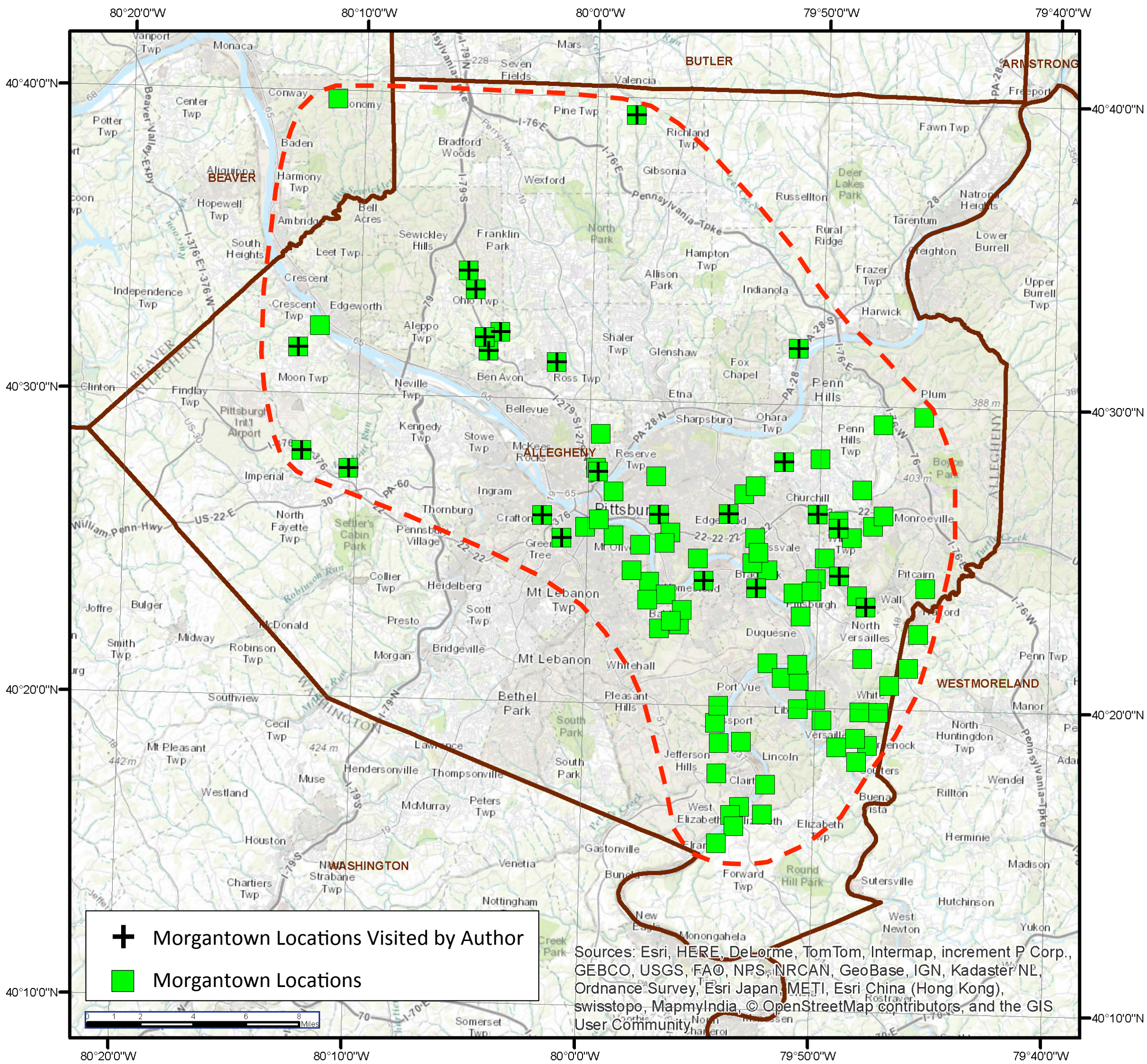


Figure 1: Location of the study (dashed outline). Squares indicate locations visited by previous authors, and crosses indicate locations visited by the author (Source of Topographic Map: ESRI).

1.3 UNIT OF STUDY

The greater Allegheny County area has abundant outcrops thanks to mature rivers and streams that have cut into the hillside and created broad valleys with high relief on the outer extents. Additionally, broad northeast-southwest trending anticlinal and synclinal folds in the foreland of the Allegheny Mountains created a rolling topography throughout the county (Johnson, 1929). These features have created many accessible exposures along the rivers and road cuts throughout the area of study.

The Carboniferous members of the greater Allegheny County region are sedimentary in origin and display a large variability in thickness (Edmunds et al., 1999). Bedrock in the area is consistently composed of thick sandstones and shales of the Monongahela and Conemaugh groups of the Pennsylvanian System, along with thinner beds of clay and coal, as well as marine and non-marine limestone. Flint (1965) subdivided the Conemaugh Group into the lower Glenshaw Formation, which contains several marine units, as well as the upper Casselman Formation, which has few marine units and hosts the Morgantown Sandstone. While on a regional scale these rocks dip to the southwest, locally they gently dip toward the northwest and southeast due to the aforementioned anticlinal and synclinal folding. Because of the variability of the strata within the Conemaugh Group, a generalized stratigraphic column is provided in Figure 2 in order to fully represent formations that may occur throughout the greater Pittsburgh and Allegheny County area.

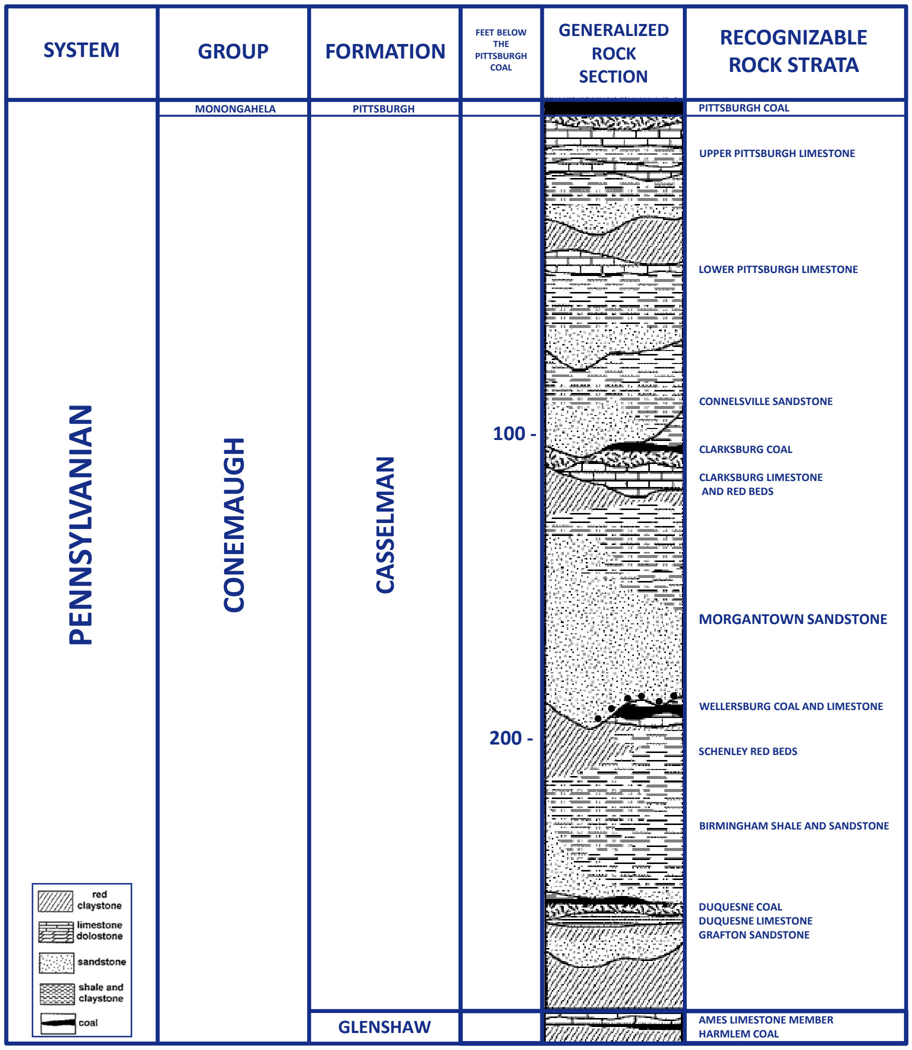


Figure 2: Generalized stratigraphic unit for the Conemaugh Group of the greater Pittsburgh area (Modified from: Harper, 1990).

The Morgantown Sandstone occurs in the middle of the Casselman Formation of the upper Conemaugh Group, which is stratigraphically defined as the rocks between the deeper Upper Freeport Coal and the shallower Pittsburgh Coal horizon (Edmunds et al., 1999). The Morgantown Sandstone rests approximately 150 feet below the base of the Pittsburgh Coal of the Monongahela Group, and nearly 75 feet above the top of the Glenshaw Group, which is bounded by the prominent marine Ames Limestone (Harper, 1990).

In the type locality of Morgantown, West Virginia, Donaldson (1968) describes the Morgantown Sandstone as displaying contrasting characteristics in separate exposures. In a road cut along West Virginia Route 7, the Morgantown Sandstone is described as having a gradational basal contact with the underlying shales, and displaying 2 to 4 inch interbedded fine-grained sandstone and siltstone beds with equal amounts of shale. At the other exposure near the West Virginia University Arboretum, Donaldson describes the Morgantown as being massive, with thick beds of medium- to coarse-grained sandstone. The base features an abrupt erosional contact with the underlying Elk Lick Coal.

Throughout the greater Pittsburgh area, the Morgantown Sandstone ranges in thickness from 15 feet to 75 feet, with an average thickness of just over 30 feet (Frazier, 1950). The Morgantown Sandstone is gray to yellow-brown in color, and is typically massive in the lower section with a distinct change in bedding near the middle (Johnson, 1942). As the sandstone fines upward in the section, it also begins to display thin-bedded sand and shales (Frazier, 1950). The grain sizes range from coarse sand at the base, to medium, to fine near the top. Underlying the Morgantown is the Wellersburg, which typically consists of coal, clay, and occasionally limestone (Johnson, 1929). Often beneath the Wellersburg lays the Schenley Red Beds, as well as the Birmingham shale and sandstone.

1.4 PREVIOUS WORK

Numerous studies conducted throughout the previous century have detailed the wide variability of the Carboniferous strata in southwestern Pennsylvania. Perhaps because of the limited economic value of the Morgantown Sandstone, only a few studies describe in detail the basal features of the Morgantown Sandstone and their relationship to the depositional environment.

A general study of the topography, geology, and mineral resources of the Pennsylvanian system in the Pittsburgh Quadrangle was conducted by Meredith Johnson (1929). Johnson visited many quarries (now covered), along with various outcrops along the river valleys. Due to the numerous exposures in the region, Johnson noted that the Pittsburgh Quadrangle should be the type locality of the Conemaugh Group.

Wayne Johnson (1942) and George McWilliams (1955) studied the mineral composition of the Morgantown Sandstone in order to determine the direction and origin of the source rock. The unit is described as being composed of mostly quartz with variable percentages of feldspar, along with stable minerals, such as zircon and tourmaline. The sandstone was also found to be absent of easily destructible minerals, such as biotite, pyroxene and amphibole. McWilliams (1955) observed no directional trends from the lateral or vertical variations of heavy minerals within the sandstone, but noted that the average particle size increases in an easterly direction. It was concluded by both authors that the direction of sedimentation of the Morgantown Sandstone was coming from the southeast, and that the minerals with which the sandstone is composed had either been deposited in previous cycles of sedimentation, or that the detrital minerals were carried over a very long distance from the source.

Meredith Johnson (1929) recognized the presence of massive basal sandstone of the Morgantown and the cross-bedded sandstone in the upper Morgantown in the Pittsburgh Quadrangle. M. Johnson also noted the undulatory base, and how its relationship with the underlying sediment, as well as its wide areal extent provided no doubt that there is an unconformity. According to Johnson, a short period of erosion took place prior to the deposition of the sandstone. Johnson (1929, p. 80) concludes, "The erosional unconformities at the base of the Morgantown Sandstone…were observed in so many places as to leave little doubt that these unconformities represent periods of widespread land emergence. The land could not have been raised much above sea level however as the relief shown by the unconformable contact is slight."

Samuel Frazier (1950) studied the aforementioned basal unconformity of the Morgantown Sandstone in greater detail in order to determine whether the unconformity should be classified as an angular unconformity, a scour, or a disconformity. Frazier (1950) considered the various features associated with the Morgantown Sandstone and the underlying rocks, and concluded that the unconformity was, in fact, a disconformity of regional scale. According to Frazier, this is due to the relatively parallel beds above and below the basal contact of the Morgantown Sandstone with the Wellersburg, as well as the variability in thickness between the base of the Morgantown and the base of the Ames Limestone. William Tindell (1950, p. 34) also widely observed, "a disconformity is present at the base of the Morgantown Sandstone," which likely accounts for the absence of variable portions of the Wellersburg and underlying sedimentary cycles.

Johnson (1929) originally noted the presence of a basal conglomerate in less than a dozen outcrops in the greater Pittsburgh area, while Samuel Frazier (1950) later encountered many other Morgantown exposures with a basal conglomerate. Johnson (1942, p. 10) noted the horizontal contact of the conglomerate with the Morgantown Sandstone and described it as "containing some carboniferous material." Frazier (1950, p. 26) described the conglomerate as being lense-shaped, 0-18 inches thick, and a well-defined top and a convex downward base. He noted that, depending on the location, the conglomerate can contain limestone clasts the size of pebbles, as well as ironstone nodules (siderite) of pebble- and cobble-size. Additionally, Frazier described the tops of the conglomerates as frequently containing what he interpreted as plant fragments. Finally, he noted the conglomerate included a matrix of coarse sandstone with abundant interstitial calcite cement.

Several studies, noted the presence or absence of an underlying coal and its relationship with the base of the Morgantown Sandstone (Johnson 1929, Tindell 1950, Frazier 1950). Tindell felt that the thin Wellersburg Coal was deposited in a shallow immature swamp. Frazier argued that the Wellersburg Coal is not widespread enough to use as a referenced stratigraphic marker, but provided locations where it is exposed and used its absence as a distinguishing feature of a disconformity.

2.0 METHOD OF INVESTIGATION

As part of this study, previous research on the Morgantown Sandstone and underlying rocks was reviewed in depth and numerous exposures were visited in the field. Because it is common for sandstones and shales to be lack lateral continuity in the Pennsylvanian, it is important that intervals and sequences are used to keep track of the units and their boundaries (Edmunds et al., 1999). Characteristics of the Morgantown Sandstone and its relationship to the rocks of the Wellersburg, Birmingham, and underlying units were noted, measured, and photographed. In order to accurately identify the Morgantown Sandstone in the field, laterally persistent formations and sequences were used as key markers of stratigraphic position. The formations used include the widespread overlying Pittsburgh Coal of the Monongahela Group, as well as the underlying Duquesne Coal of the Casselman Formation and the stubbornly persistent Ames Limestone of the Glenshaw Formation, which is one of the last marine units of the Conemaugh Group in the Dunkard Basin (Edmunds et al., 1999).

Where the Ames Limestone was not exposed or did not crop out, other means of stratigraphically identifying the section were taken by the author. The Greater Pittsburgh Geology Map (#42, Plate 1) by Wagner et al (1975) displayed in detail the stratigraphic position of the Ames Limestone in the study area, and was commonly used to help identify Morgantown Sandstone exposures.

Key structural and sedimentary features in the Morgantown, Wellersburg, and Birmingham units were recorded at each outcrop in order to compare the occurrences and lateral extent of their features. The author was especially interested in identifying a basal conglomerate, as Johnson (1929) noted it as the only major sandstone unit in the Pittsburgh area to have that feature present. Additionally, the following basal observations and features within the Morgantown Sandstone were also noted in the course of the study: thickness, composition of conglomerate clasts, presence of coal beneath or within the sandstone, truncations, folds, shearing, compression, extension, dikes, soft sediment deformation structures, and the undulatory disconformable relationship of the contact to the underlying units.

3.0 DESCRIPTION OF OUTCROPS CONTAINING THE MORGANTOWN SANDSTONE

Twenty-four outcrops were visited over the course of this study, and numerous observations were made where the Morgantown Sandstone was present. Key horizons were used in order to verify the unit of section present at these outcrops, namely the presence of the Ames Limestone, which was widely deposited and very conspicuous in outcrop throughout the greater Pittsburgh region. Other factors were considered when scouting for exposures, including those visited by authors of previous works on the formations of the Conemaugh Group. Recognizable features were observed at the visited sites for spatial comparison. Below is a thorough description for several of the visited outcrops where basal unit of the Morgantown Sandstone and the underlying sediments were observed. These sites, as well as those visited by authors of previous work on the Casselman Formation, can be identified in Figure 1.

3.1 FEDEX OUTCROP - FEDEX DRIVE, MOON TOWNSHIP, PA (40°27'36.00" N, 80°10'20.88" W)

Along FedEx Drive in Moon Township, the Morgantown Sandstone is well exposed at both the eastern and western sides of northwest-southeast trending road cut, which measures approximately 350 meters in length and over 60 meters high in the highest section (Figure 3). Due to the unstable nature of the face of the exposure, the majority of the lower segment of the wall has been, unfortunately, covered with cement and wire mesh to prevent rock falls. This site was visited on several occasions prior to the wall being concealed.

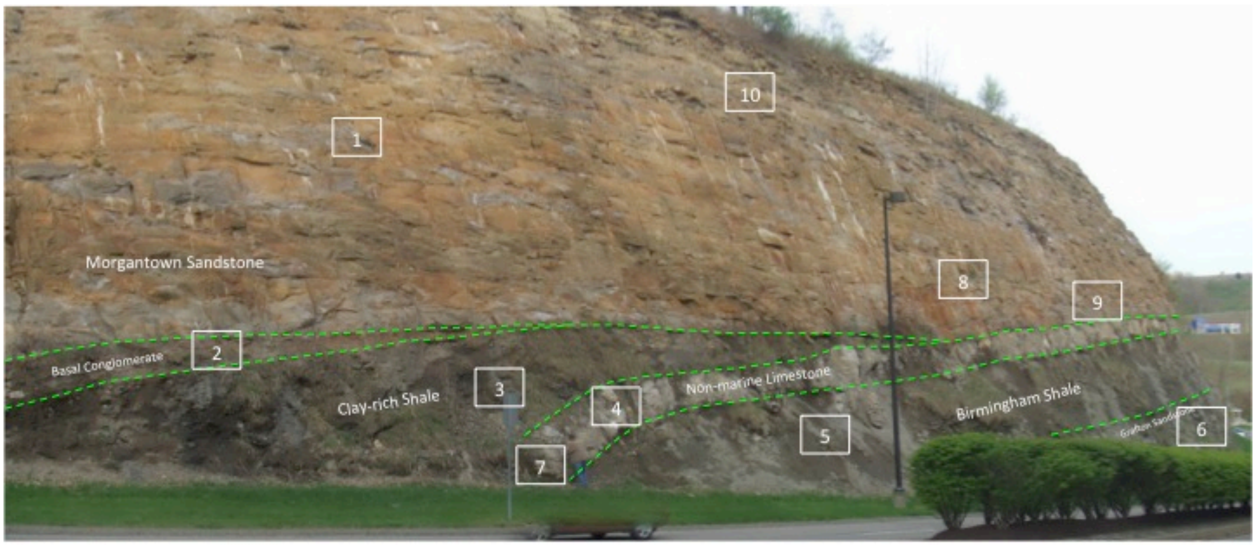
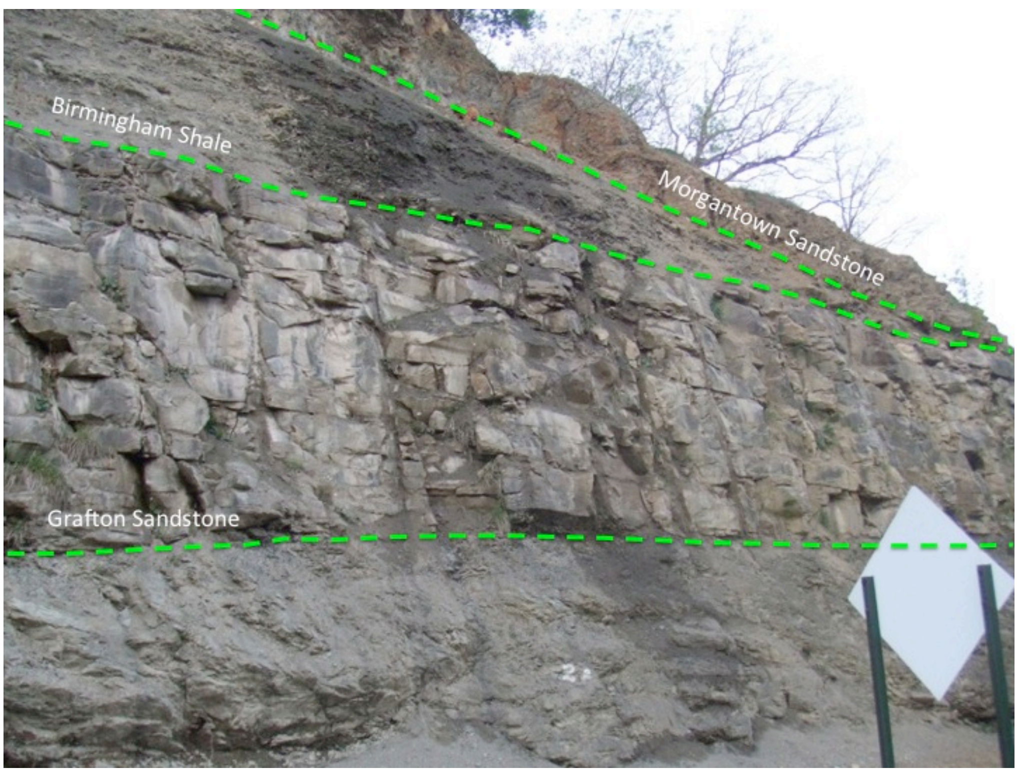


Figure 3: View of the eastern side of the outcrop (facing southeast). Important formations and features seen at this site include: (1.) Massive Morgantown Sandstone (2.) Poorly sorted basal matrix-supported conglomerate with pebble- to cobble-size clasts (3.) Clay-rich Shale and Siltstone (4.) Non-marine Limestone displaying desiccation (mud) cracks (5.) Birmingham Shale (6.) Grafton Sandstone (7.) Vertical clastic dikes through the limestone with pebble clasts (8.) Lenticular coal bands encapsulated within basal Morgantown Sandstone (9.) Vertical clastic dike penetrating through bedding surface of limestone (10.) Upper Morgantown Sandstone showing thin bedding structures.

Nearly 30 meters of the lower Casselman Formation was exposed at the southern end of the FedEx Drive outcrop beneath the Morgantown Sandstone. At road level, this section displays 10 meters of interbedded siltstones and sandstones, with the 10-meter thick medium-grained, cross-bedded Grafton Sandstone unit resting directly above. This unit is overlain by the interbedded Birmingham section, which mainly consists of gray shale and siltstone, and is approximately 5 to 10 meters in thickness (Figure 4). The Birmingham interval is described as the last horizon in the Casselman Formation with fossils, and has been described as possibly having formed under marine conditions (Tindell, 1950). Capping this section is a light gray, non-marine limestone that varies in thickness from 1 to 2 meters due to its irregular base. At the southern end of the exposure, the Morgantown Sandstone rests directly on top of this limestone layer; however, on the northern end of the eastern side of the outcrop, the Morgantown Sandstone rests directly on top of a 2-meter interval of dark gray shale (Figure 3). On the northern end of the exposure, there is a clay-rich shale that lies between the non-marine limestone and a half meter to one meter thick basal conglomerate. Finally, the nearly 40 meter thick Morgantown Sandstone is present.

a.



b.

Figure 4: (a) Road cut facing east (b) Interpretation: The Grafton Sandstone and the Birmingham Shale of the lower Casselman Formation.

The gray non-marine limestone present at the base of the Morgantown Sandstone features obvious desiccation cracks in three-dimensions throughout its entire thickness, which is unlike normal mud cracks seen in outcrop (Figure 5). There were no fossils found in this non-marine limestone, which likely formed in a shallow freshwater lake or bay. The limestone unit is 1 to 2 meters in thickness on both the eastern and western sides of the road cut. The western side of the road cut features the limestone pinching-out to the south (Figure 6), and the eastern outcrop features the limestone nosing down toward the road level to the north (Figure 7).

Figure 5: The desiccation (mud) cracks are visible throughout the non-marine limestone unit (side view).

a.

b.

Figure 6: (a) The western side of the FedEx road cut (b) Interpretation: The gray non-marine limestone unit pinching out between the underlying Birmingham Shale and the overlying Morgantown Sandstone.

a. 

b. 

Figure 7: (a) FedEx outcrop trending northwest (left) to southeast (b) Massive Morgantown Sandstone and underlying units of the Casselman Formation.

Numerous abrupt lateral discontinuities occur in the limestone due to vertical tabular bodies that can be seen along the extent of the outcrop (Figure 8), ranging from several centimeters up to a half meter in width and from 1 to 2 meters in height. Of the 11 vertical bodies noted (Appendix B: Table 3), some display a tabular form with slight variations in thickness (Figure 9), while others display thick upper portions that taper in the lower extent of the feature (Figure 10). These clastic dikes were interpreted as bulbous and bifurcating trunks and roots of trees preserved in situ by Berman et al., (2010, p. 293); however, there are several key characteristics that show that these are indeed clastic injection dikes.

a.

b.

Figure 8: (a) Outcrop features numerous vertical tabular bodies (b) Interpretation: Numerous clastic injection dikes (arrows) seen along the extent of the non-marine limestone at the base of the Morgantown Sandstone.


a.


b.

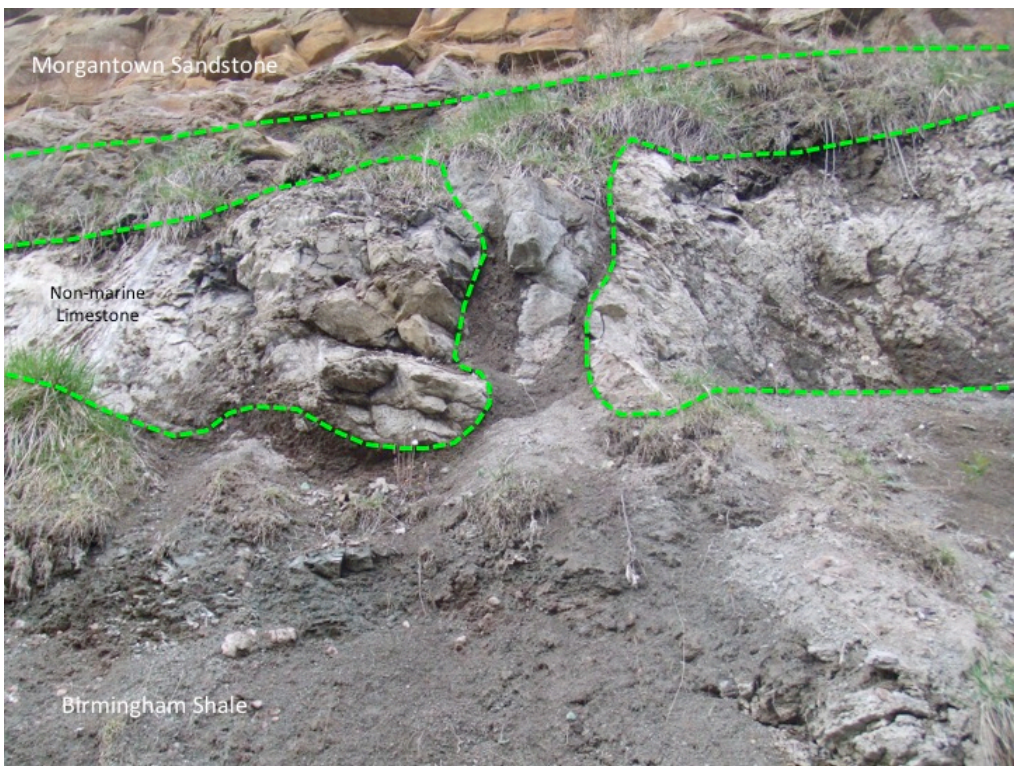
Figure 9: (a) Gray non-marine limestone hosting vertical tabular body (b) Interpretation: A vertical sand- and pebble-filled dike.

a.

b.

Figure 10: (a) Gray non-marine limestone hosting vertical bodies (b) Interpretation: Clastic intrusive dike wide in the upper portion and tapering downward (green arrow) penetrating the limestone bedding surface.

a.

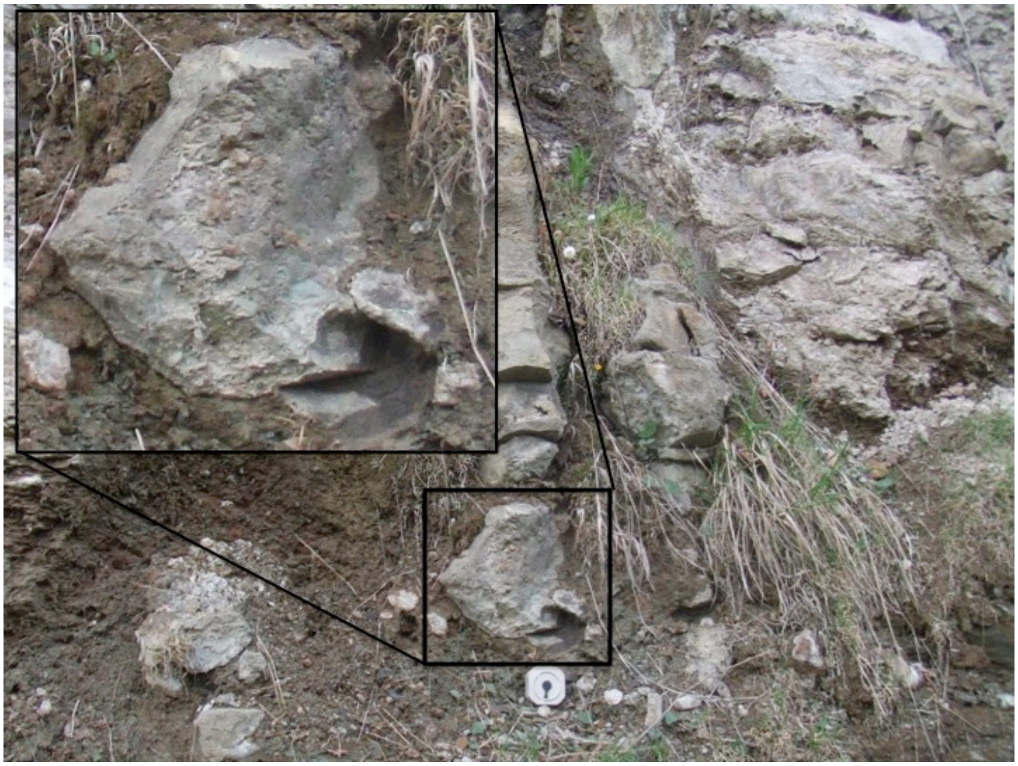


b.

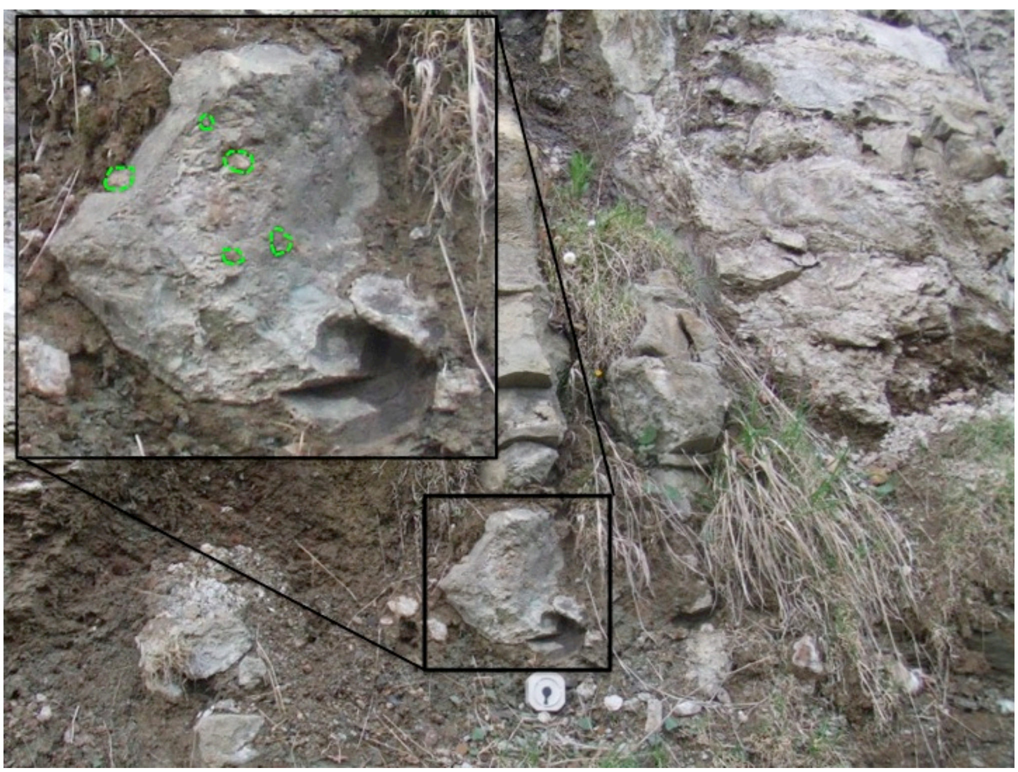
Figure 11: (a) Gray non-marine limestone hosting a vertical body (b) Interpretation: Clastic intrusive dike wide in the upper portion and tapering downward penetrating the limestone bedding surface.

For comparison, Figure 12 is an excellent example of a preserved tree stump in Pennsylvanian-aged sediments (Huddle 1966, p. 36). Notice the sharp contact between the preserved tree stump and the surrounding sediments, as well as the surface texture such as that seen in Lepidodendron, for example. As is typical with clastic dikes, the examples noted at the FedEx outcrop contain infill sediments with granule- to pebble-size clasts (Figure 13). These clasts are matrix supported and are found to be sub-rounded (Figure 14). Additionally, each example of the vertical tabular bodies at this location contains clay and silt-sized sediments lining the walls, which is also typical of clastic intrusive dikes (Fecht 1999) (Figure 15).

Figure 12: Preserved Tree Stump in Pennsylvanian aged rocks in eastern Kentucky. Genus is likely Lepidodendron (Source: Huddle, 1966).



a.



b.

Figure 13: (a) A close-up of Figure 9 (b) Interpretation: Clastic dikes displaying internal granule- to pebble-size clasts.

a.

b.

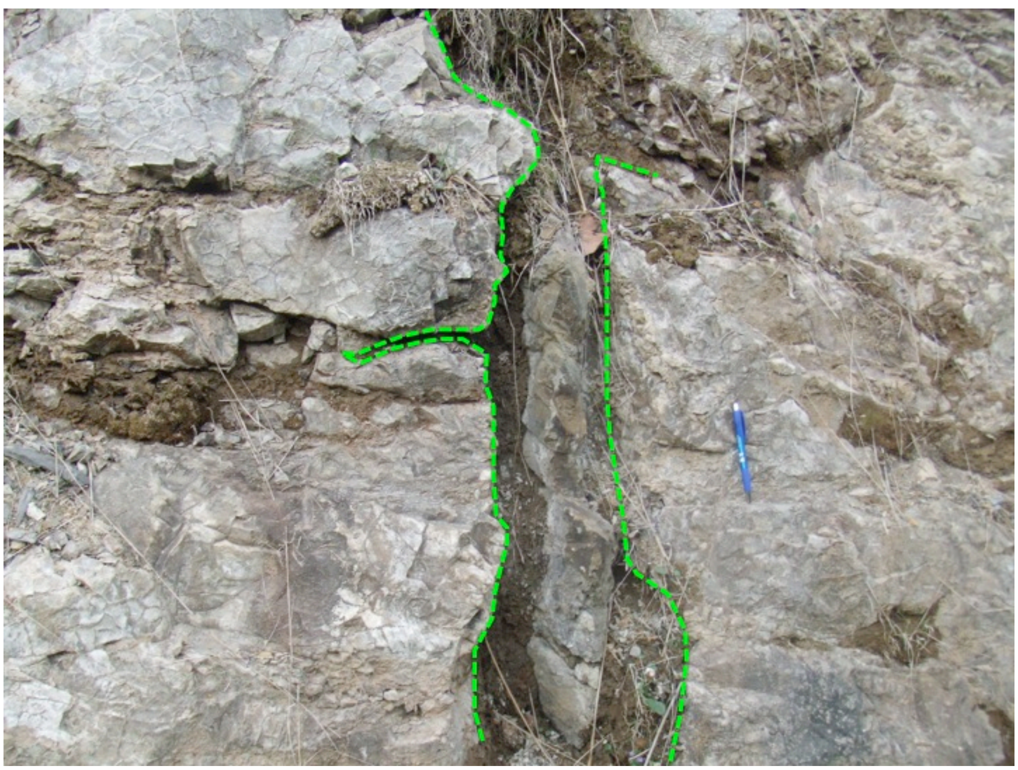
Figure 14: (a) Sample from vertical tabular body (b) Interpretation: Clastic dike featuring matrix-supported granule- to pebble-size clasts.

Figure 15: Clay and silt sediments lining the vertical disruptive bodies interpreted as clastic injection dikes.

On the northern end of the road cut, the tabular disruptive bodies within the limestone unit all terminate either within or at the top of the limestone. Examples of these occurrences are noted in Figure 16 and Figure 17. Moving along the eastern side of the exposure in the southern direction, there are also examples of the tabular bodies potentially penetrating the top of the bedding surface of the limestone unit and depositing the clastic sediments laterally above the limestone, and beneath the basal Morgantown Sandstone (Figure 18 and Figure 19).

The non-marine limestone unit is fairly tabular yet slightly muddled on the southeastern end of the road cut. It becomes increasingly more disrupted as you move to the northwest, and displays a bulbous and undulating base (Figure 20 and Figure 21).

a.



b.

Figure 16: (a) Thin vertical disruptive bodies terminating within the limestone unit (b) Interpretation: Clastic injection dikes with clay and silt lining within the limestone unit.

a.

b.

Figure 17: (a) Thin vertical disruptive bodies terminating within the limestone unit (b) Interpretation: Clastic injection dikes with clay and silt lining within the limestone unit.

a. 

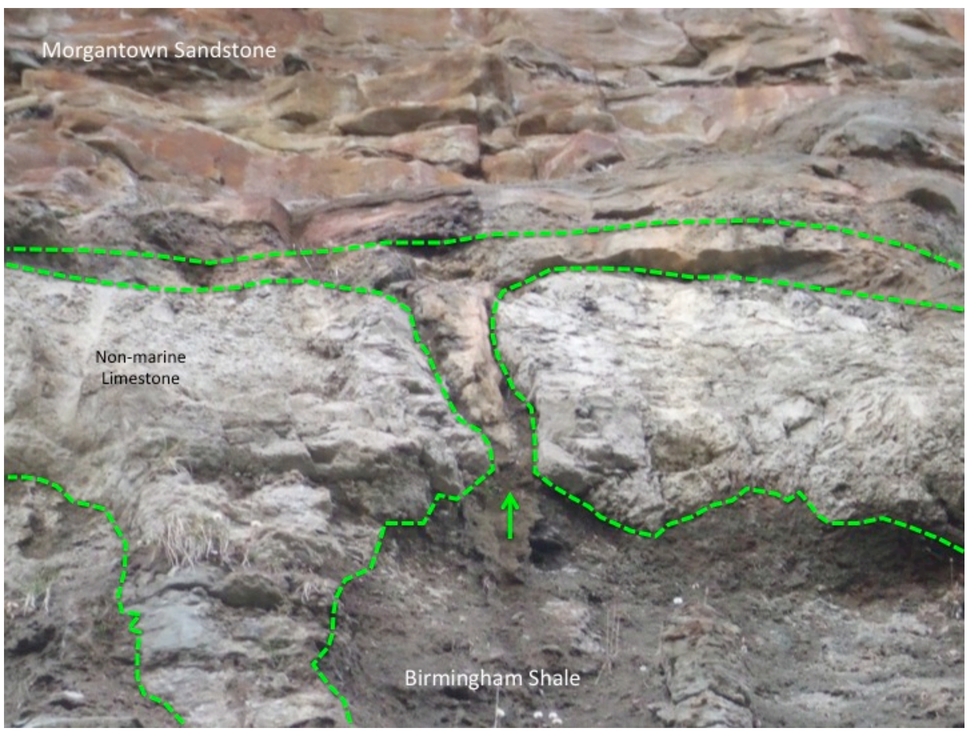
b. 

Figure 18: (a) Tapered disruptive body within limestone unit (b) Interpretation: Clastic injection dikes potentially penetrating the top of the limestone unit and depositing sediment at the base of the Morgantown Sandstone.

a. 

b. 

Figure 19: (a) Tapered disruptive body within limestone unit (b) Interpretation: Clastic injection dikes potentially penetrating the top of the limestone unit and depositing sediment at the base of the Morgantown Sandstone.

a. 

b. 

Figure 20: (a) Non-marine limestone below the Morgantown Sandstone (b) Interpretation: Non-marine limestone becomes increasingly more undulated and scattered toward the north of both sides of the road cut exposer (looking west, left is south).

a. 

b. 

Figure 21: (a) Limestone beneath the Morgantown Sandstone (b) Interpretation: The limestone transitions to more thick, bulbous, and muddled in nature moving north (southeast to the right).

The nearly 40-meter-thick Morgantown Sandstone rests directly on top of the gray limestone along the southern section of the eastern exposure. Moving north along the outcrop, where the limestone dips down toward the road level, the sandstone rests directly upon a wedge-shaped silty-shale layer for nearly 3 lateral meters (Figure 7). Berman et al. (2010) interpret this shale unit as an abandoned stream channel, or some other type of infilling of a topographic low. This shale unit pinches out to the south between the underlying limestone and the Morgantown Sandstone, which rests unconformably above.

Slightly to the north and resting with an abrupt contact on top of the silty-shale unit is a matrix-supported conglomerate about a half meter in thickness, with sub-angular to sub-rounded pebble- to cobble-size clasts. There is a diversity of fragments, both in roundness and in composition, within this poorly sorted basal member of the Morgantown Sandstone unit (Figure 22). The distinction between this unit being considered a breccia versus a conglomerate can be debated due to the angularity of many of the clasts, which are mainly composed of carbonate. However, there are also many rounded clasts, as well as ironstone (siderite) nodules in this unit, especially near the contact with the sandstone.

a. 

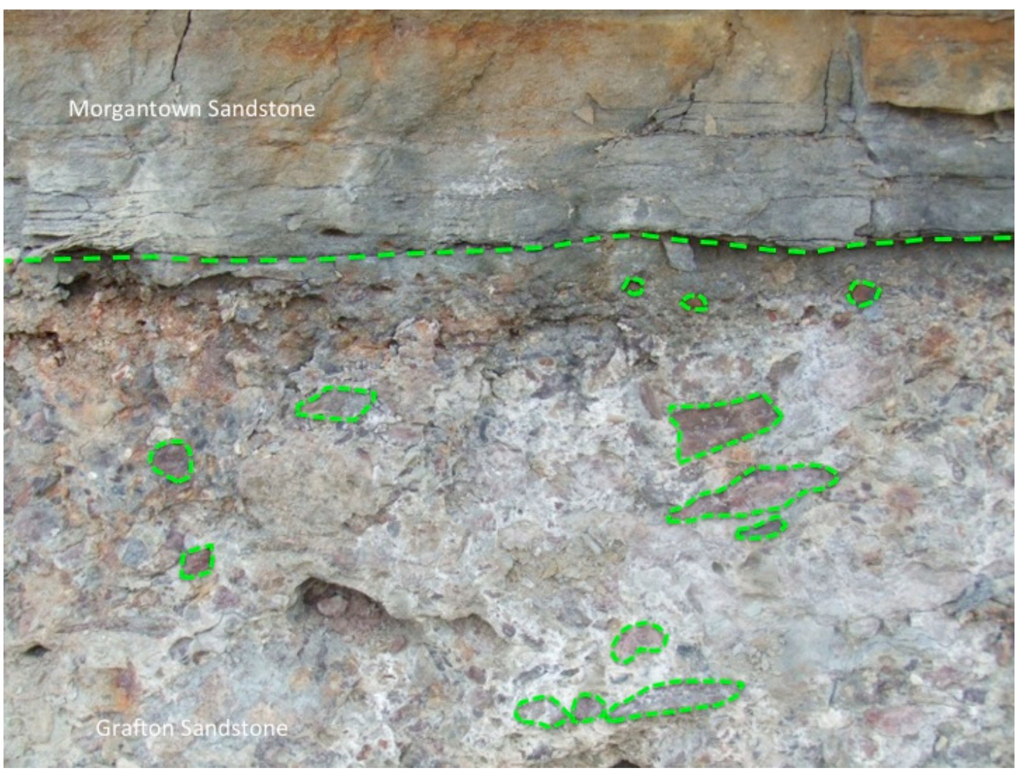
b. 

Figure 22: (a) Contact beneath Morgantown Sandstone (b) Basal conglomerate features sub-angular to sub-rounded clasts composed of carbonate as well as ironstone nodules.

One feature noted at many Morgantown Sandstone exposures is the presence of a thin Wellersburg Coal seam no more than 15 cm in thickness that typically occurs near the Morgantown Sandstone and the basal conglomerate. There is a location nearby (approximately 2.5 km west) that has a very nice exposure of this coal seam. When the tabular coal seam is absent, there will regularly be elongated lenses, and clasts present in the basal section of the Morgantown Sandstone, which is the case at this exposure (Figure 23). The coal lenses are high at this exposure, but are estimated to be between 1 and 3 meters in length, with thicknesses between several millimeters and 10 cm.

The massive basal section of the Morgantown Sandstone is orange, gray, and yellow-brown in color (due to weathering and oxidation), features medium to coarse grains, and is well sorted. This unit fines upward into a thinner bedded section featuring cross-bedding structures (Figure 23).

a.

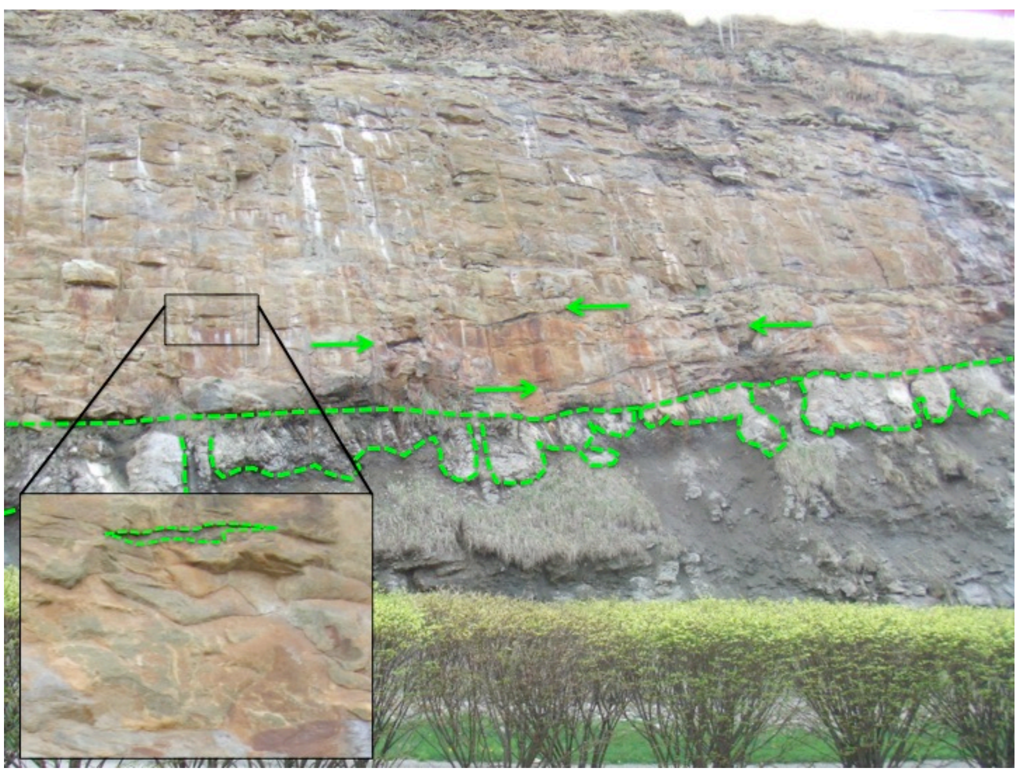

b.


Figure 23: (a) The Morgantown Sandstone and underlying units (b) The basal section of the Morgantown displays thin clasts, as noted by the arrows and inset map.

3.2 376 AIRPORT EXPRESSWAY EXIT 57 OUTCROP – MOON TOWNSHIP, PA (40°28’08.47” N, 80°12’22.94” W)

The 376 Airport Expressway at Exit 57 outcrop runs in an approximately northwest-southeast orientation and spans over 300 meters in length (Figure 24). The Morgantown Sandstone is well-exposed at this site; however, the basal section is only exposed in the southeastern section of the outcrop. This exposure is approximately 2.5 km west of the previously described FedEx Cut.

Figure 24: Panorama of the 376 Airport Expressway Exit Outcrop (Photo credit: C.E. Jones).

Unique to this outcrop, when compared to other exposures in the Pittsburgh region, is the existence of bounding coal seams directly above and below the conglomerate at the base of the Morgantown Sandstone (Figure 25). The tabular lower coal seam, perhaps the Wellersburg, measures nearly 10 cm in its thickest section, but is not laterally continuous throughout the base of the exposure in either direction.

a.

b.

Figure 25: (a) Coal seams and conglomerate beneath the thick sandstone (b) Upper coal seam and lower coal seam (perhaps Wellersburg) bounding a debris flow unit at the base of the Morgantown Sandstone.

Above the lowermost coal is an abrupt contact with the overlying conglomerate, which is again a common feature of the basal Morgantown Sandstone unit. The poorly sorted, matrix-supported conglomerate includes pebble- to cobble-size clasts, which are angular to sub-rounded, and are mainly fragments of white to light gray carbonate as well as siderite nodules (Figure 26). The angularity of many of the carbonate clasts indicate either very short stance of transport or, in light of the matrix, transport within a debris flow.

Additionally, the conglomerate is weathered and iron-stained and, like the coal, is only visible on the southeastern section of the outcrop due to soil and foliage on the northwestern portion. While the conglomerate is up to a half meter thick at this outcrop, it too is not laterally continuous. On the southeastern end of the outcrop, the conglomerate thins dramatically and eventually pinches out beneath the Morgantown Sandstone (Figure 27).

Between the basal conglomerate and the Morgantown Sandstone is another thin tabular coal seam that is no more than 15 cm in its thickest point (Figure 28). The coal is laterally continuous in places, but abruptly truncates within the Morgantown Sandstone (Figure 29). In portions of the basal Morgantown Sandstone where the upper tabular coal seam is absent, there are elongated lenses and clasts of coal, some of which are as long as a meter, with thicknesses between 7 and 15 cm (Figure 30).


a.

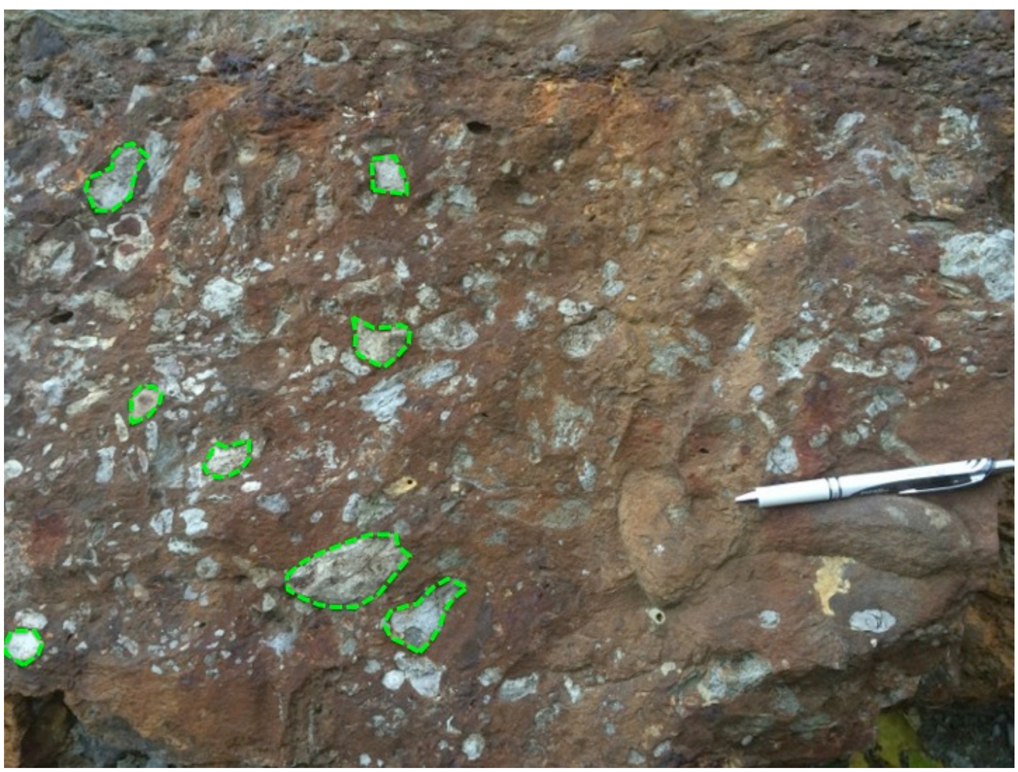
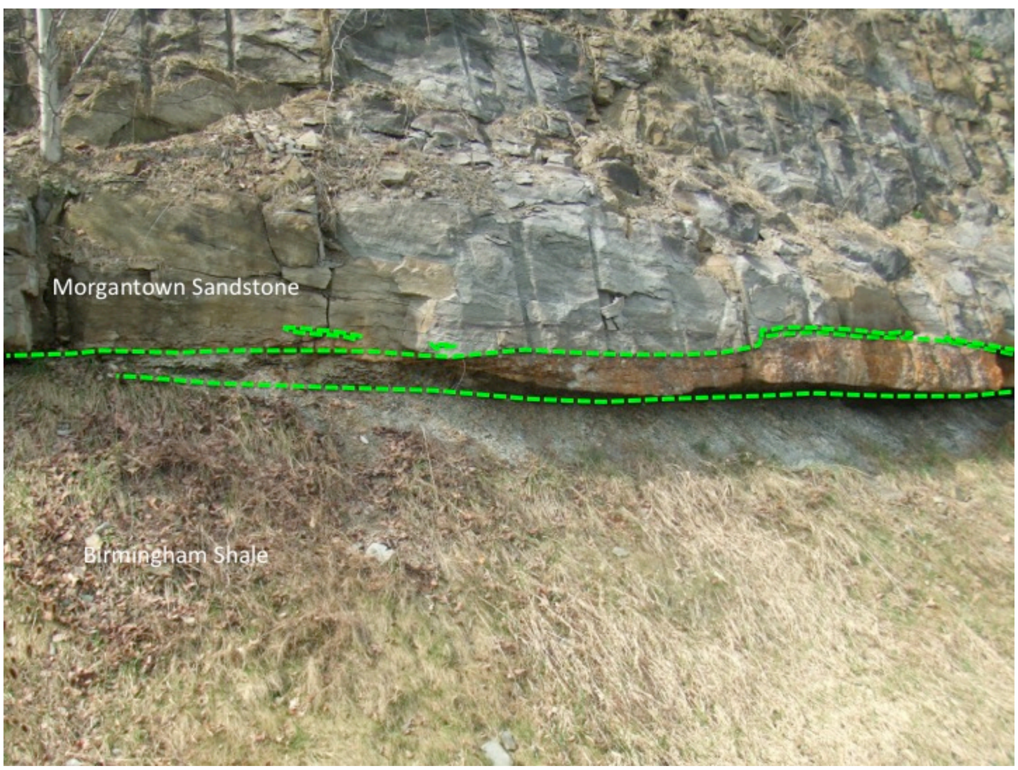

b.

Figure 26: (a) Close-up of angular carbonate clasts (b) Interpretation: Poorly sorted cobble- to pebble-size carbonate clasts that are angular to sub-rounded likely transported within a debris flow.

a.



b.

Figure 27: (a) Basal conglomerate beneath the Morgantown Sandstone (b) Debris flow unit pinching out beneath the Morgantown Sandstone to the southeast (left side of the photo)

a.

b.

Figure 28: (a) Contact of the Morgantown Sandstone with the underlying units (b) Upper tabular coal seam between the basal conglomerate and Morgantown Sandstone (coal seam is approximately 7 cm thick).

a. 

b. 

Figure 29: (a) Coal seam beneath the Morgantown Sandstone (b) Uppermost of two coal seams that bound the basal conglomerate beneath the Morgantown Sandstone. Note the abrupt vertical break in the coal seam (coal seam approximately 7 cm thick on the left side).

a.

b.

Figure 30: (a) Basal conglomerate pinching out to the east (left side) (b) Where the basal coal seam is absent, lenses of coal can be seen above the conglomerate fully enclosed by the basal Morgantown Sandstone.

The Morgantown Sandstone displays a sharp contact with the underlying shale, coal, and conglomerate (Figure 31). The contact gently undulates roughly 10 cm above and below a horizontal plane. Just above this undulation, a horizon of thinly laminated sandstone and shale between 3 to 8 cm thick crops out (Figure 32). This very thin zone is uncharacteristic of the surrounding Morgantown Sandstone.

The Morgantown Sandstone at this site is dominated by over 10 meters of a medium- to coarse-grained and well-sorted massive basal unit that fines upward into 10 meters of thinly bedded sandstone that displays numerous cross-beds, similar to that noted at the FedEx outcrop. The sandstone has a discrete contact between its upper and lower sections. Also of note within the upper Morgantown Sandstone is that there are the several lenses of dark sandstone up to a half meter thick and several meters wide that are enclosed within the greater sandstone body (Figure 33). The lenses are composed of laminated sandstone with thin (~1mm) shale interbeds, unlike anything in the rest of the Morgantown Sandstone. The orientation of the cross-beds and the enclosed sandstone beds indicate that the sediments were being deposited from southeast to northwest.

a.

b.

Figure 31: (a) Basal Morgantown Sandstone (b) Undulatory nature of the base of the Morgantown Sandstone.

a.

b.

Figure 32: (a) Near the base of the Morgantown Sandstone (b) Small lenses of sandstone and coal within the lower Morgantown Sandstone. Just above this zone is a very thin coal seam encapsulated within the sandstone.


a.

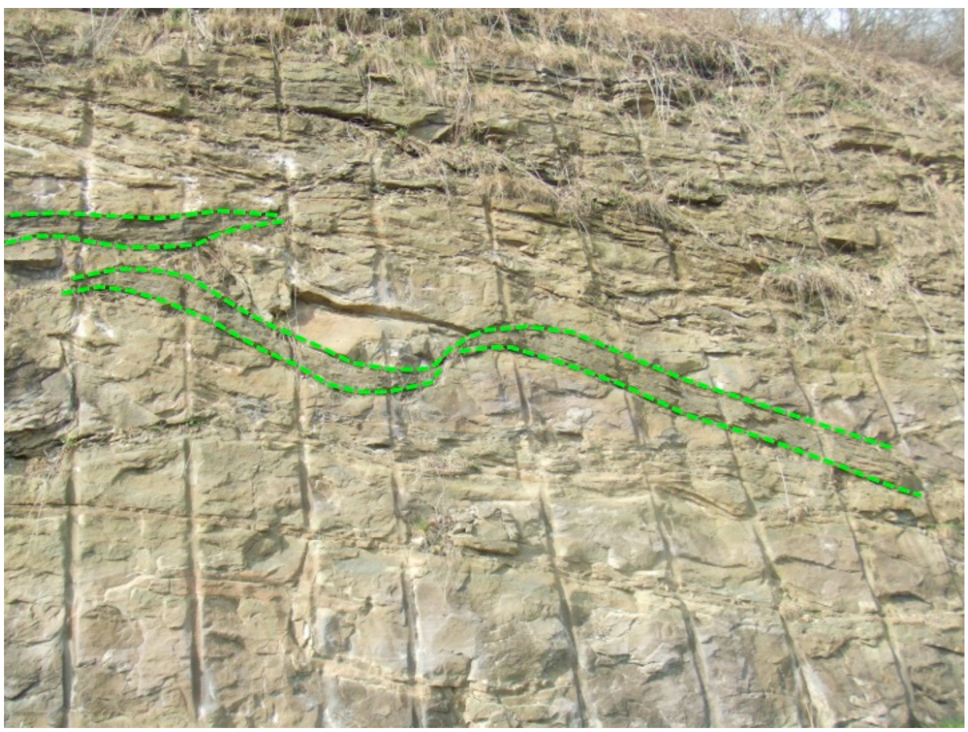

b.

Figure 33: (a) Boundary between lower and upper Morgantown Sandstone (b) Morgantown Sandstone with long, slightly folded lenses of dark sandstone entrenched within the greater unit.

3.3 MONROEVILLE OUTCROP - ROUTE 22 BUSINESS, WILLIAM PENN HWY, PITTSBURGH, PA (40°26’29.30” N, 79°50’11.62” W)

This northwest to southeast trending outcrop is located directly off of the right hand (southern) side ramp of Exit 80 onto Route 22 Business in Monroeville. There is also a secondary road cut approximately 1.6 km to the southeast on the opposite side of Route 22 Business. While you cannot see the entire Morgantown Sandstone, this exposure provides a well-exposed view of the contact of the Morgantown Sandstone with the underlying sediments over approximately 200 meters (Figure 34).

Figure 34: Contact between Morgantown Sandstone and underlying Birmingham Shale at the Monroeville Outcrop.

Below the base of the Morgantown Sandstone lies weathered laminated gray shale—likely the Birmingham Shale unit. The base of the overlying Morgantown Sandstone and associated basal conglomerate is sharp and relatively flat with only slight undulations (Figure 35). The conglomerate is matrix-supported, poorly sorted, and iron-stained. It contains sub-angular to sub-rounded, disc-shaped, pebble- and cobble-size clasts (Figure 36). The thickness of the in situ conglomerate is 15 to 45 cm.

Just above the basal conglomerate lies the Morgantown Sandstone, with abundant coal lenses and seams. At the base are several irregularly shaped lenses of coal with thicknesses of approximately 5 to 10 cm and lengths up to 30 cm (Figure 37). These coal lenses are laterally discontinuous and fully enclosed by the medium- to coarse-grained sandstone. Atop this level in the unit there is a thin, tabular, laterally continuous coal seam that is approximately 3 cm thick (Figure 38). Directly above the thin coal seam are 50 cm of slightly draped and cross-bedded sandstone containing many lenses and clasts of coal or dark organic material. The coal clasts are very angular and irregular in shape, averaging 2 cm in thickness and ranging in length from 2 to 20 cm (Figure 38).

a.

b.

Figure 35: (a) Base of the Morgantown Sandstone (b) Slight undulation at the base of the Morgantown Sandstone and the underlying rocks (perhaps Wellersburg and Birmingham).

a.

b.

Figure 36: (a) Block of Morgantown sandstone with impressions from basal conglomerate (b) The size and shape of the clasts can be noted from the voids and casts.

a.

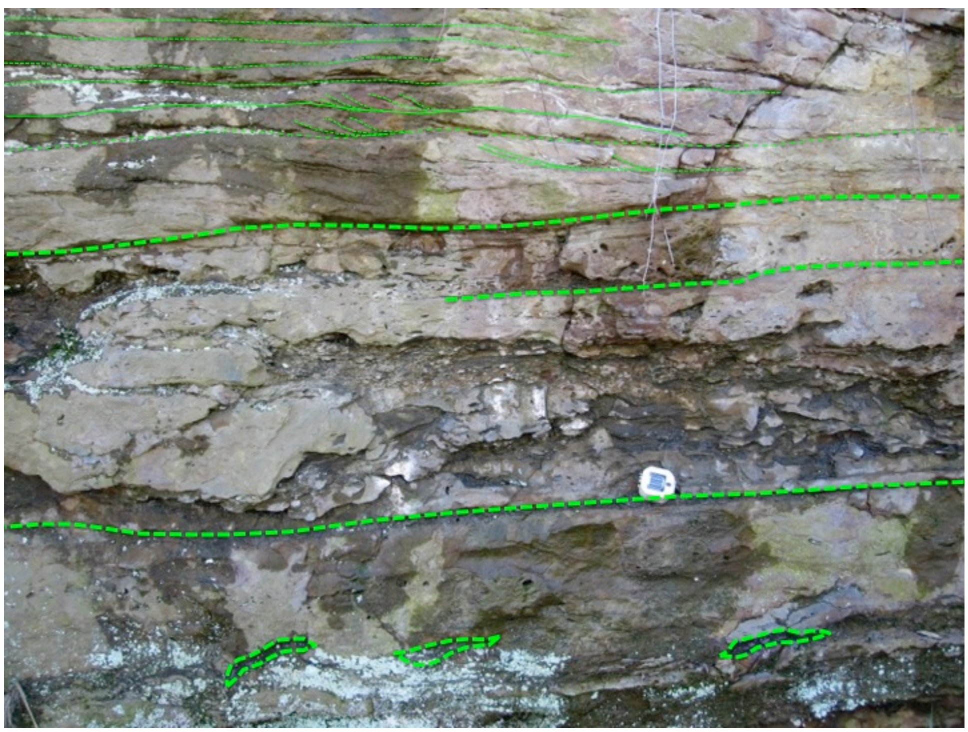

b.


Figure 37: (a) Sedimentary features of the Morgantown Sandstone (b) Pebbly sandstone with lenses of coal. Cross-bedding in upper Morgantown.

a. 

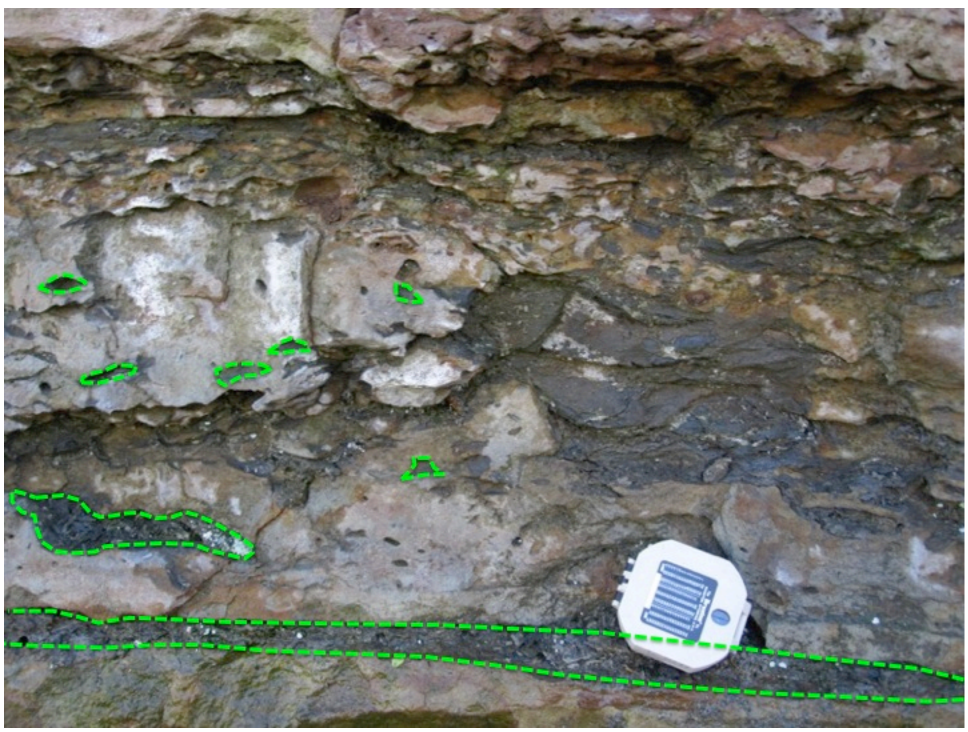
b. 

Figure 38: (a) Close-up of Figure 37 (b) Coal seams entrained in the pebbly sand with thin platy sandstone above.

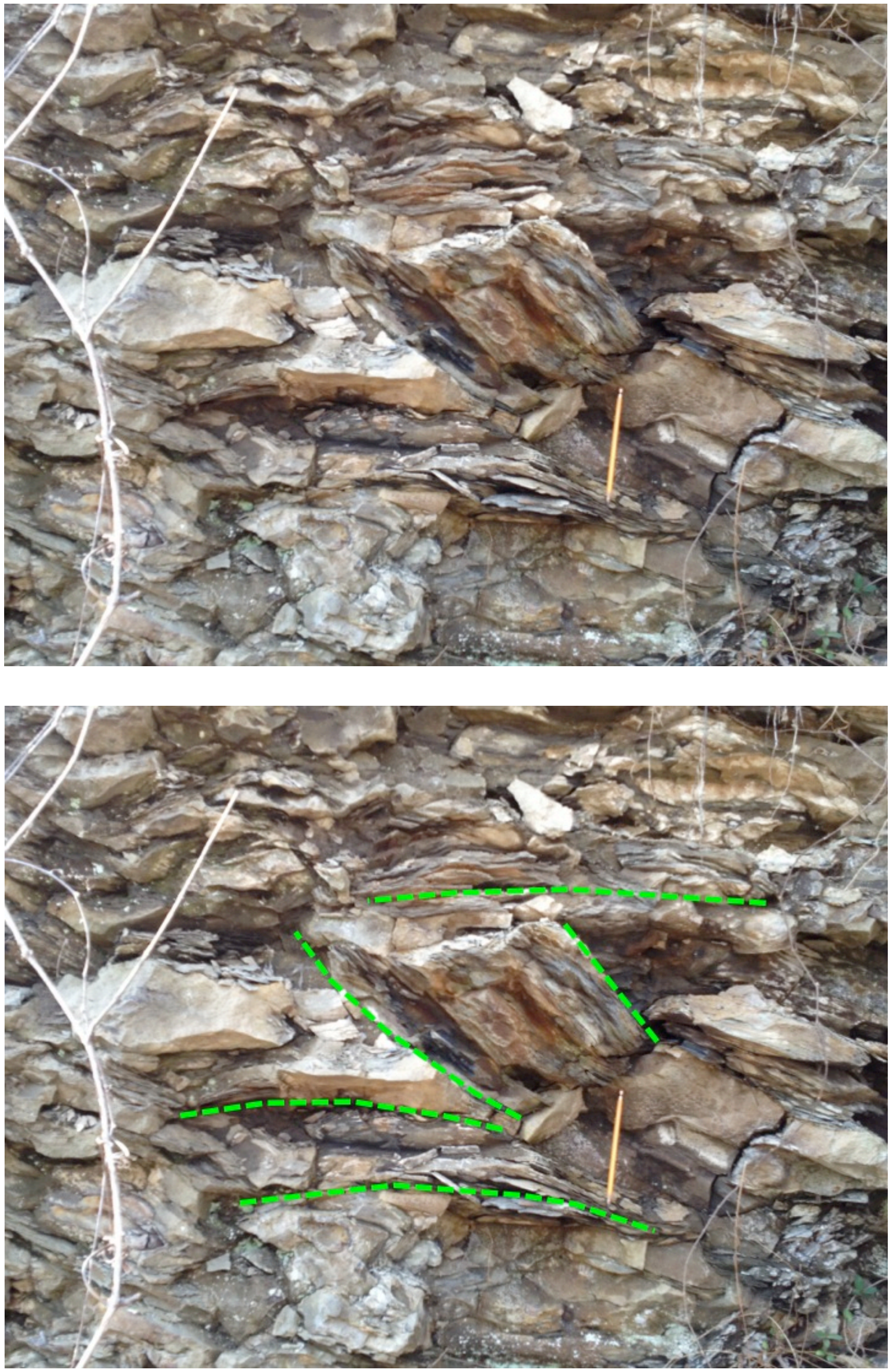
The basal section of the Morgantown Sandstone that is commonly thick in many outcrops throughout the Pittsburgh region contains pebbly sandstone. Adjacent to thin platy sandstone horizons are lenses of coal, some of which are entrained in the pebbly sand. The highly irregular contact between the pebbly sandstone lenses and the adjacent sand is interpreted to record deposition of a fluid-rich sand body followed by flattening and perhaps shearing along the margins (Figure 38). Above the section containing coal is the upper Morgantown Sandstone, which includes examples of fine- to medium-grained, thin-bedded, cross-bedded sandstone.

The underlying units beneath the Morgantown Sandstone include deformed siltstone and sandstone that displays thin laminations, with an isoclinal fold as exhibited in Figure 39. In Figure 40, a zone of folded laminated sandstone is observed within a disturbed unit.

a.

b.

Figure 39: (a) Isoclinal folding within a unit at the base of the Morgantown Sandstone (b) Interpretation: Mass loading of the overlying thick sandstone caused deformation of underlying rocks.



a.

b.

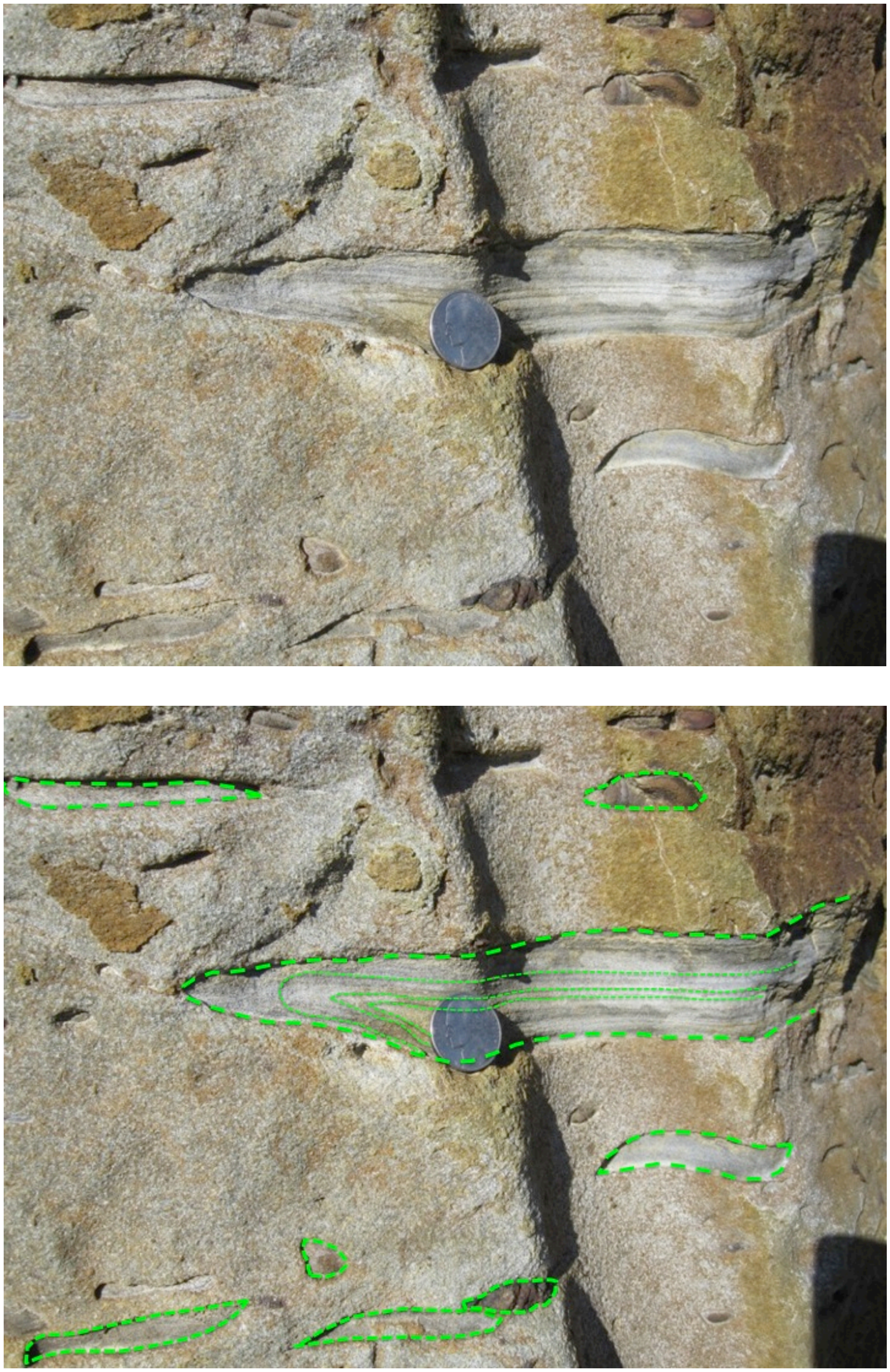
Figure 40: (a) Highly folded unit at the base of the Morgantown Sandstone (b) Interpretation: Mass loading of the overlying thick sandstone caused deformation of underlying rocks.

3.4 TARGET OUTCROP – MT. NEBO POINTE, PITTSBURGH, PA (40°32’12.22” N, 80°03’57.20” W)

A large outcrop is exposed in a cut behind the Target in the Mt. Nebo Pointe shopping center just off of I-279 north of Pittsburgh accessed via the Camp Horne Road interchange. The cut is behind the north side of Target and extends easterly 300 meters along the parking lot. The outcrop is about 20 meters high on average (Figure 41). Whereas this outcrop reveals much of the Morgantown Sandstone, the contact at the base is covered by talus and overgrowth. Key marker beds, such as the Ames Limestone, crop out nearby along I-279 north. Nevertheless the base of the sandstone displays matrix supported conglomerate, siderite nodules, elongated clasts with internal isoclinal folding, thin lenses and bands of coal, boudinage, as well as laminated sandstone and coal that is interpreted as foliated and sheared. These observations and their position within the outcrop are listed in Figure 41.

Figure 41: Target Outcrop Panorama (facing north). Important formations and features seen at this site include: (1.) Massive Morgantown Sandstone (2.) Ironstone clasts and lenticular silty sandstone clasts with internal isoclinal folding (3.) Poorly sorted matrix-supported conglomerate with pebble- to cobble-size clasts (4.) Thin tabular coal beds (5.) Lenticular coal lenses and bands encapsulated within basal Morgantown Sandstone 6. Boudinage pinch and swell structures (7.) Basal thinly laminated shear zone (8.) Upper Morgantown Sandstone showing cross-stratification.

At the eastern extent of the exposure, the medium- to coarse-grained basal unit of the Morgantown Sandstone features ironstone nodules (siderite) that are roughly 1 to 2 cm in thickness and up to 6 cm in length. These nodules are dark red in color and vary in shape from round to oblong (Figure 42). Also present within the basal sandstone are lenses of fine- to medium-grained silty sandstone that measure between 1 to 5 cm in thickness and 10 to 20 cm in length. Very thin laminations can be seen within one of these lenses, displays a westerly trending isoclinal fold (Figure 43). Other lenses within the sandstone show no internal folding, but do show very thin lamination within and commonly taper as if they were pinching out.

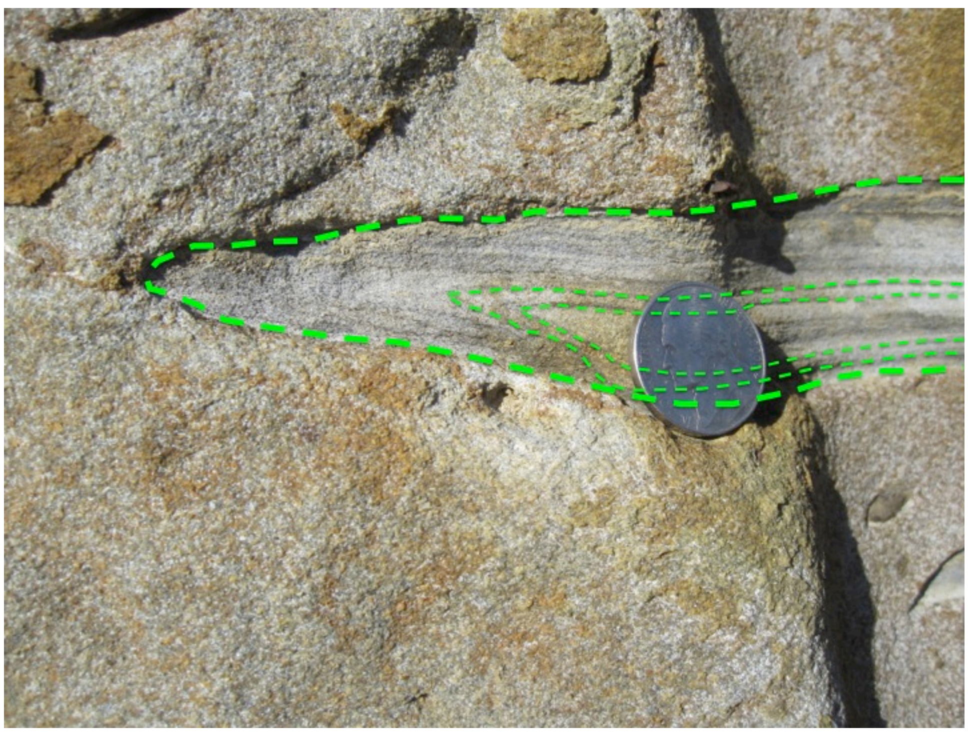


a.

b.

Figure 42: Ironstone (siderite) nodules and silty sandstone lenses enclosed within the basal Morgantown Sandstone. One silty sandstone lense features an internal isoclinal fold.

a.



b.

Figure 43: Close-up of the internal isoclinal folding within the silty sandstone clasts in the basal Morgantown Sandstone.

Just above the sandstone featuring lenses and nodules is a prominent iron-stained, matrix-poor, moderately sorted conglomerate (Figure 44). The clasts are pebble-to cobble-size, commonly sub-rounded, reddish brown, and record no obvious imbrication. The thickness of the conglomerate is about half a meter. This conglomerate is above others in the matrix-rich horizon at the base of the Morgantown Sandstone.

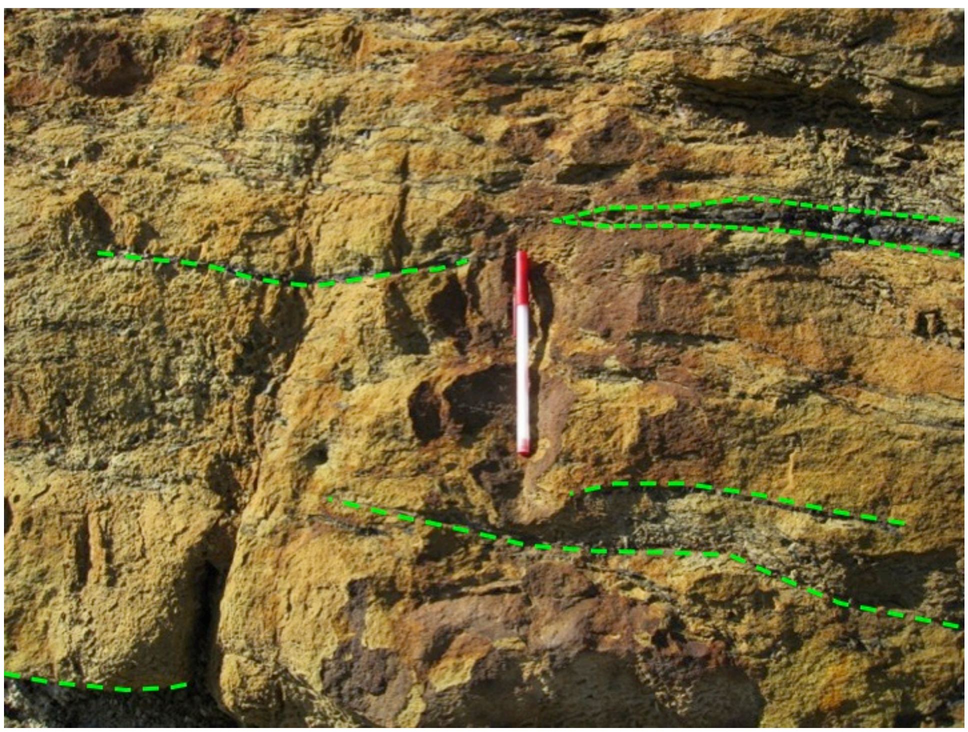
20 meters to the west, abundant coal is present in the form of tabular beds and thinly draped seams, which are perhaps remnants of the Wellerburg Coal. At the base of the exposure, the very thin coal seams are present within the medium- to coarse-grained sandstone. They range from 1 mm to 1 cm thick (Figure 45). Coal beds at the base of the outcrop commonly are thicker, more tabular and have a slight undulation (Figure 46). These coal seams are between 10 and 20 cm thick, and are bounded by sandstone that displays pinch and swell structures (Figure 47).

a.

b.

Figure 44: (a) Conglomerate within the Morgantown Sandstone (b) Matrix-poor conglomerate with sub-rounded clasts.

a.



b.

Figure 45: (a) Morgantown Sandstone (b) Thin coal lenses within the Morgantown Sandstone.

a. 

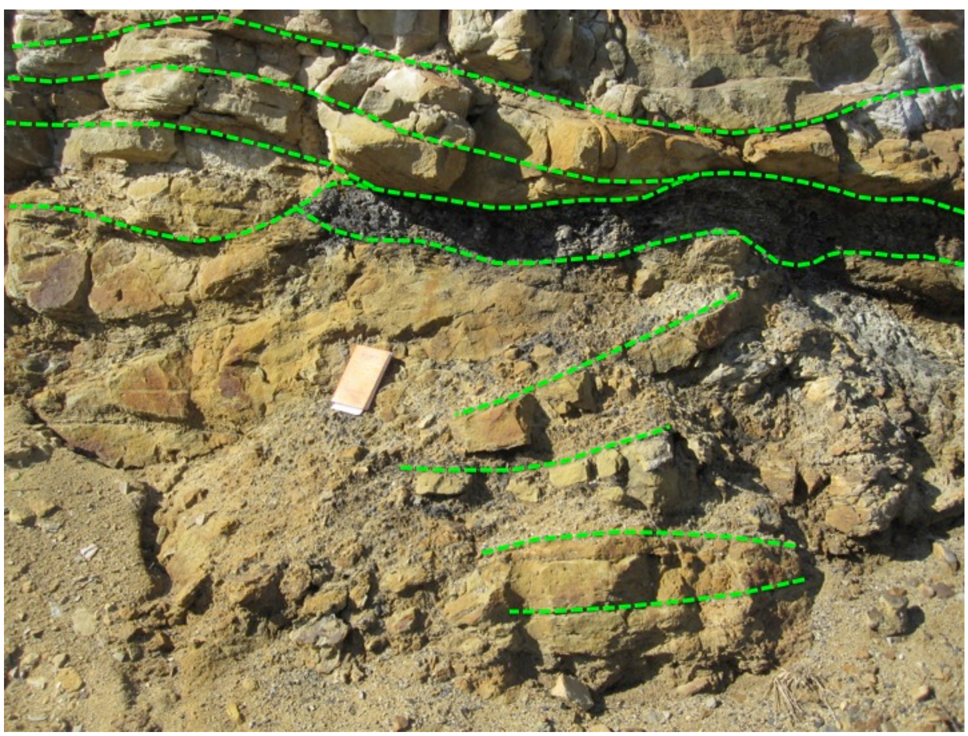
b. 

Figure 46: (a) Base of Morgantown Sandstone (b) Relatively thick undulating coal seam in the basal Morgantown Sandstone that terminates abruptly to the west (left). Note the overlying sandstone layer pinching out above the coal seam and thickening to the west (left).

a. 

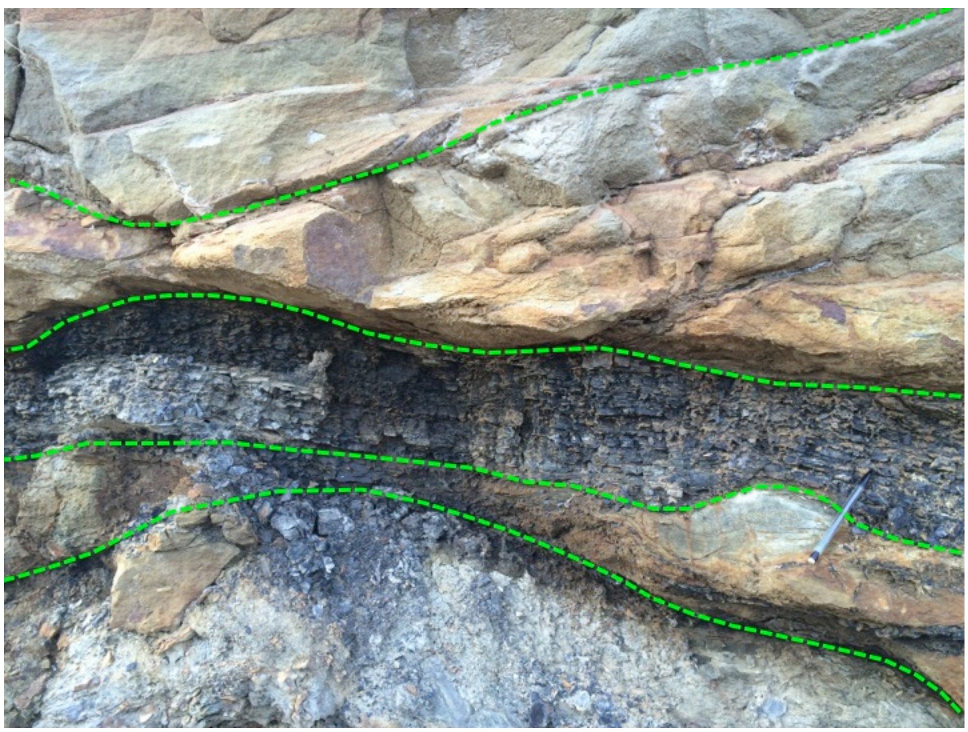
b. 

Figure 47: (a) Base of the Morgantown Sandstone (b) Basal coal seam within layers that pinch and swell.

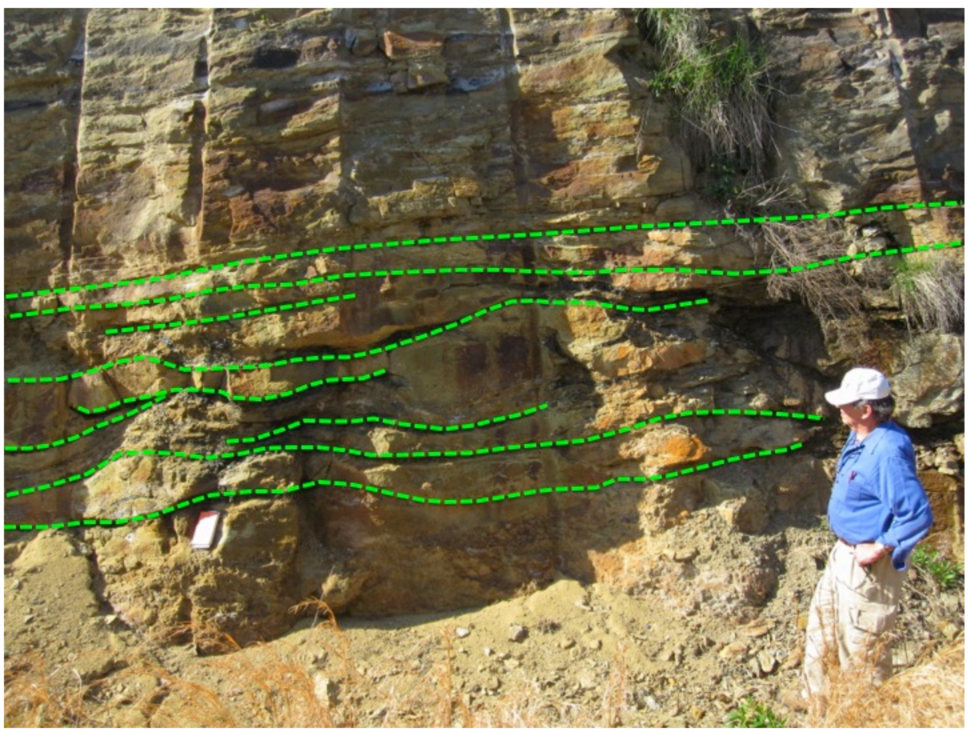
The pinch and swell structures within the Morgantown Sandstone are displayed in an approximately 2-meter thick package that appears west of the conglomeratic zone. The individual sandstone beds undulate, and laterally vary from 15 to 45 cm thick (Figure 49). Although the sandstone beds thicken, thin, and pinch laterally within the overall package, the sandstone layers did not rupture (Figure 49).

Interbedded and draped within the irregular sandstone are lenses of coal that range in thickness from several millimeters up to 20 cm. This coal is mainly deposited horizontally, but is also commonly emplaced at high angles where it pinches out within a single sandstone bed (Figure 50).

Although at times difficult to track due to the talus and soil cover along the basal section, there is a thin zone, approximately 15 cm at its thickest point, which is a shear zone showing foliation (Figure 51). The observed shear zone laminations are locally wavy.

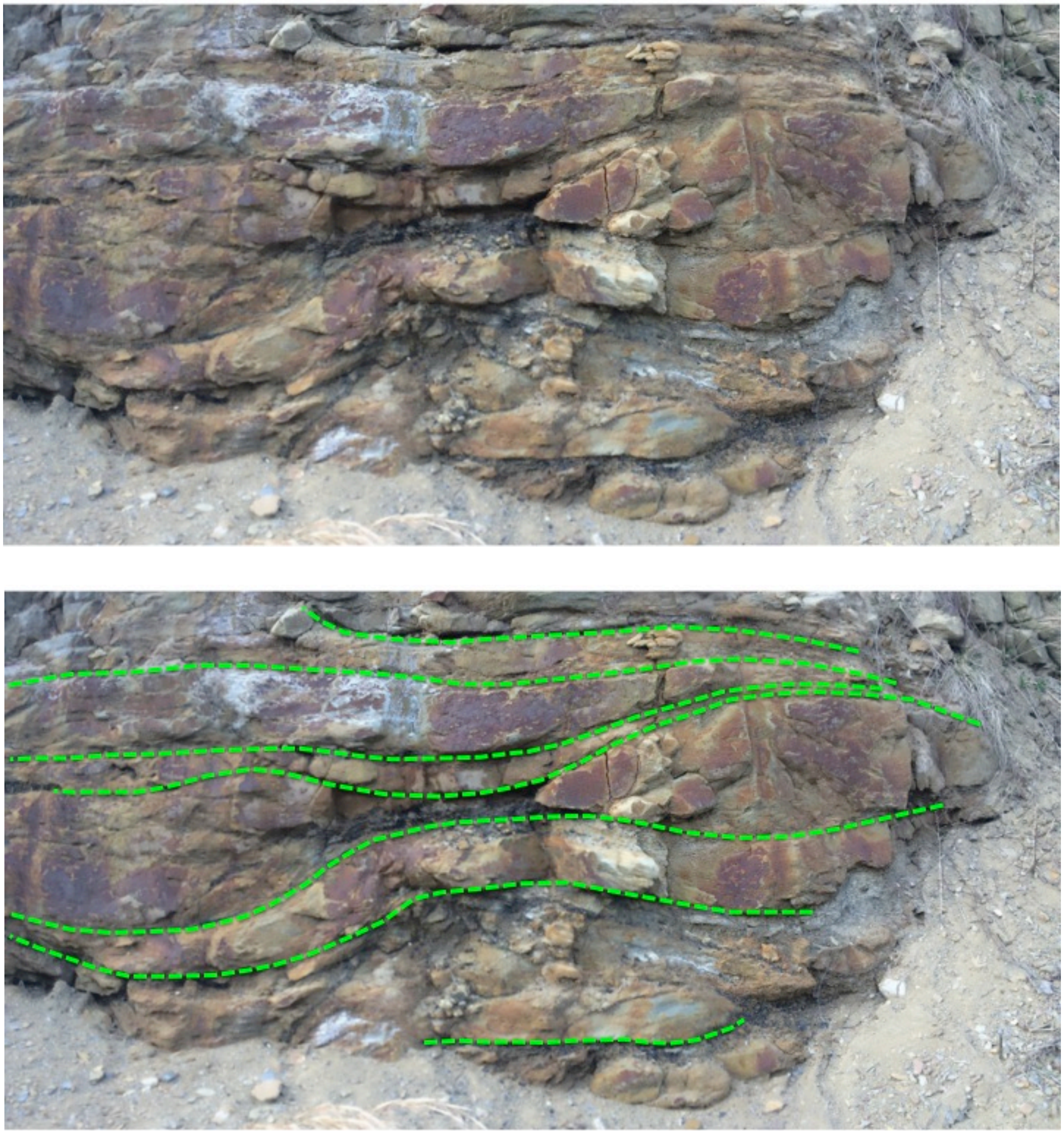
Above the basal Morganton Sandstone, the upper unit reveals the typical overall characteristics of the Pittsburgh area, which includes an upward decrease in grain size and thin units of cross-stratification (Figure 52). The cross-bedding displayed indicates that the sediments were deposited from an easterly direction (as seen in two dimensions). There is also a fairly abrupt transition in between the lower and upper Morgantown Sandstone packages.

a.



b.

Figure 48: (a) Pinch and swell features in a nearly 2-meter thick section of sandstone. (b) Interpretation: Pinched and swelled by ductile deformation processes.



a.

b.

Figure 49: (a) Pinch and swell feature at the base of the Morgantown Sandstone. (b) Interpretation: Boudinage caused by stretching.

a.

b.

Figure 50: (a) Basal Morgantown Sandstone (b) Irregular coal lenses emplaced within the basal Morgantown Sandstone.


a.

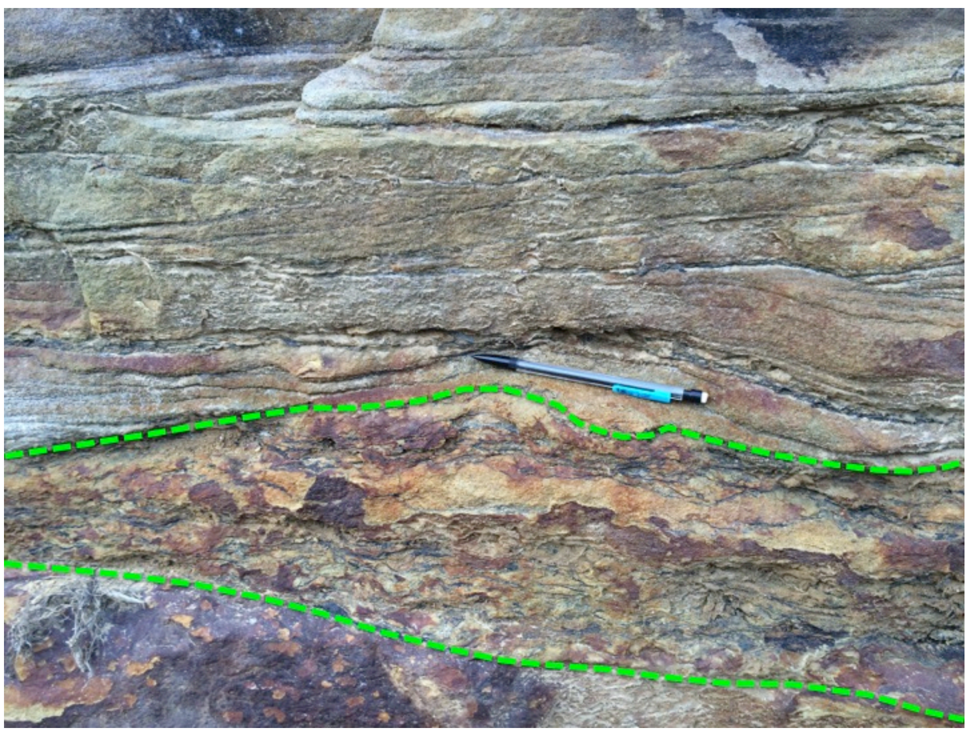

b.

Figure 51: (a) Close-up of the Morgantown Sandstone (b) Zone of laminated sandstone occurring within the basal Morgantown Sandstone.


a.


b.

Figure 52: (a) Upper Morgantown Sandstone (b) The upper Morgantown Sandstone displays thin cross-beds (outcrop oriented west-east).

3.5 KELLY CAR LOT – 5408 UNIVERSITY BLVD, MOON TOWNSHIP, PA (40°31’32.78” N, 80°12’38.62” W)

There is a somewhat concealed outcrop located approximately 1,600 meters to the southwest of the Ohio River and directly across University Blvd from Kelly Cars in Moon Township, PA. The northeast-southwest trending outcrop exposes nearly 10 meters of basal Morgantown Sandstone and the underlying strata over a distance of 50 meters (Figure 53).

There is an abundance of soil and foliage covering the underlying units (presumably Wellersburg and Birmingham), but the base of the exposure clearly displays a 30 cm thick matrix-supported conglomerate that is composed of poorly sorted, sub-rounded pebble- to cobble-size clasts (Figure 54). The conglomerate features an abrupt contact with the overlying medium- to coarse-grained sandstone. This zone of laminated sandstone displays thinning and thickening that is reminiscent of a pinch and swell structure, and measures between 25 cm and approximately 60 cm thick (Figure 55). In the thicker sections, the lower 10 cm of this unit shows no internal structures. The upper 15 to 50 cm of sandstone in this unit displays thin laminations (Figure 56).

Figure 53: Massively bedded Morgantown Sandstone unit slightly dipping to the southwest (right in photo).


a.


b.

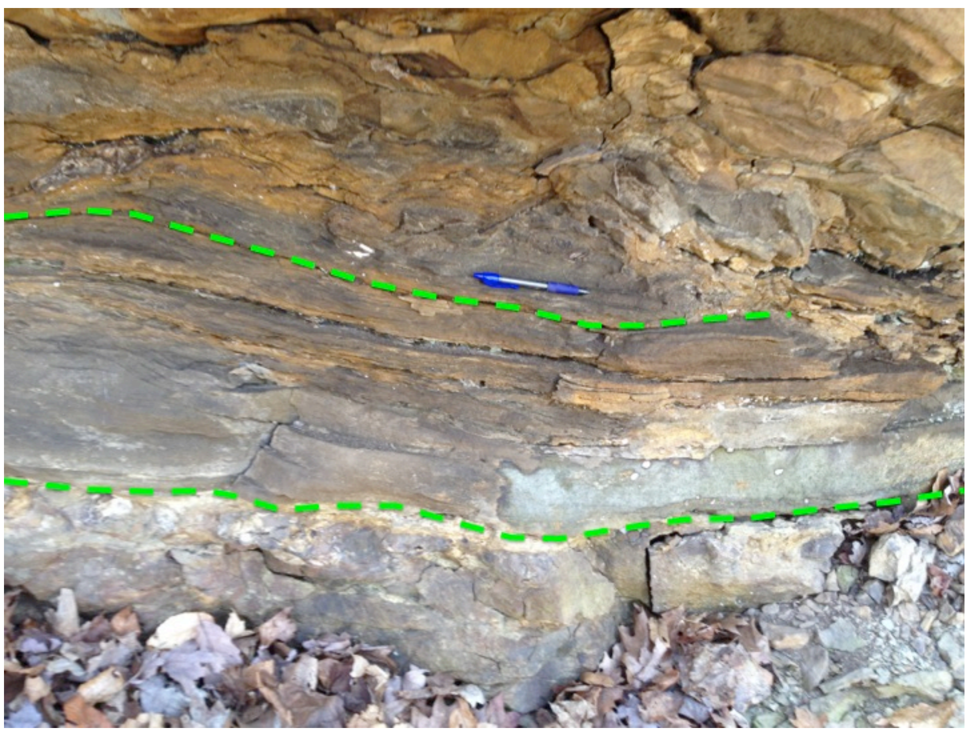
Figure 54: (a) Base of the Morgantown Sandstone exposure (b) Basal matrix supported debris flow unit featuring poorly sorted pebble- to cobble-size clasts (photo facing southeast).

a.

b.

Figure 55: (a) Lower sandstone unit displays thinning and thickening (b) Interpretation: Pinch and swell structures formed from compression and tensional stresses during deposition of the overlying sandstone (photo facing southeast).

a.



b.

Figure 56: (a) Lower Morgantown Sandstone unit shows bedding, with a disrupted overlying sandstone (b) Section above the debris flow displays more bedding and thin laminations (photo facing southeast).

3.6 RT. 51/WOODRUFF ST. OUTCROP - PITTSBURGH, PA (40°25'30.37" N, 80°01'08.28" W)

Near the intersection of Saw Mill Run Blvd (Route 51) and Woodruff Street in Pittsburgh is a conspicuous northwest-southeast trending outcrop exposing the Morgantown Sandstone and the underlying rocks over a distance of nearly 600 meters (Figure 57).

At road level, a weathered gray shale unit is capped by a disrupted non-marine limestone, which varies from 30 cm to a meter in thickness, and displays an uneven base similar to that noted at the FedEx Outcrop (Figure 57b). The limestone unit is present along the entire length of the exposure, and features a fairly sharp contact with overlying unit. On the northwestern extent of the exposure, at the corner of Saw Mill Run Blvd and Woodruff Street, the limestone unit features two vertical disruptive bodies approximately 15 cm in length and between 1 and 5 cm in width (Figure 58). The infilling sediment of the disruptive tabular bodies is composed mainly of gray silty sediments, likely from the underlying unit.

Above the non-marine limestone is a 2 to 3-meter thick light gray shale unit, which like the underlying shale unit at road level, is so weathered as to show no signs of bedding planes. Under cover of soil and foliage is presumably a distinct contact with the weathered shale and the overlying Morgantown Sandstone, which is approximately 7 meters thick. The basal 3 meters of Morgantown is massive, buff-colored sandstone featuring well-sorted medium to coarse grains. In the next 3 meters of the unit, the Morgantown begins to show examples of bedding, and specifically trough cross-bedding (Figure 59).

a. 

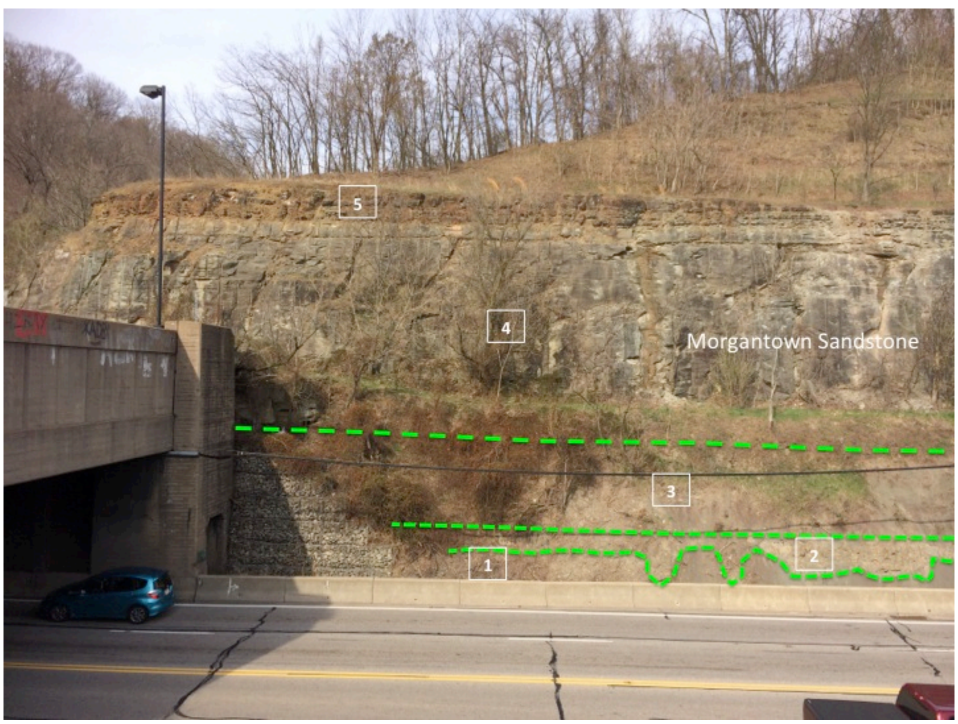
b. 

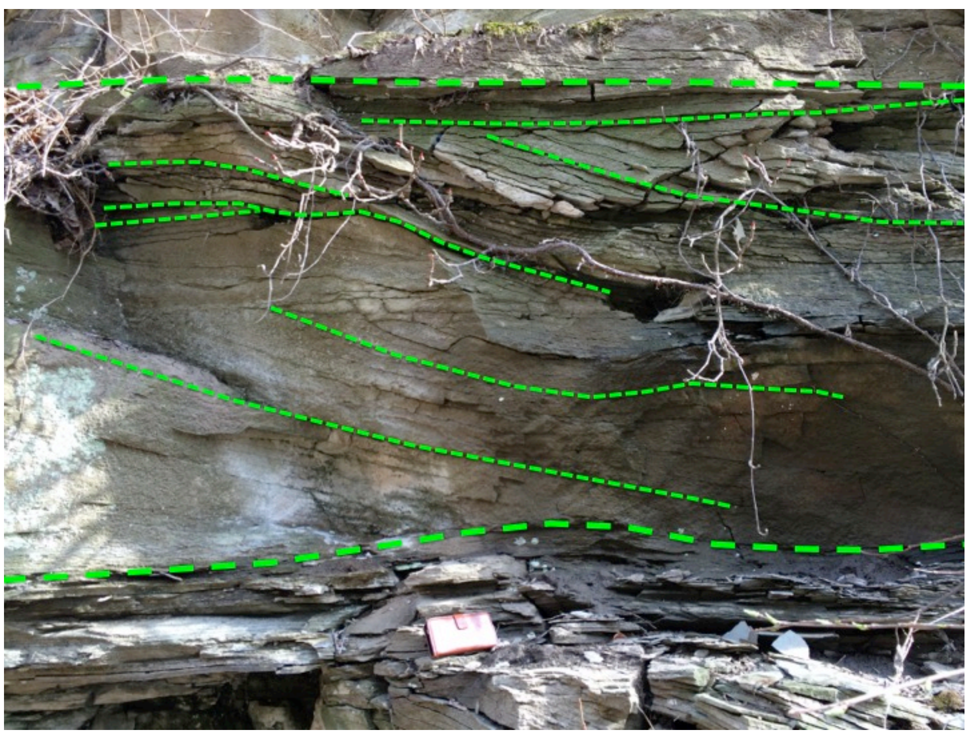
Figure 57: (a) Outcrop along Saw Mill Run Blvd (b) Stratigraphy in the section: (1.) weathered gray shale at road level (2.) muddled non-marine limestone with uneven base (3.) weathered gray shale (4.) thick lower Morgantown Sandstone with no bedding and an inferred base below soil (5.) cross-bedding upper Morgantown Sandstone (facing northeast).

a. 

b. 

Figure 58: (a) Non-marine limestone unit near road level (b) Vertical disruptive bodies within the limestone unit interpreted as intrusive clastic dikes (facing northeast).

a.



b.

Figure 59: (a) Upper Morgantown Sandstone (b) Cross-bedding displayed in the upper half of the Morgantown Sandstone (facing east).

4.0 DISCUSSION AND INTERPRETATION

Donaldson (1968) interpreted the Morgantown Sandstone from the type locality as representing a channel fill deposit, with a channel cutting into the surrounding peat and then subsequently filling with sand. Thin beds of alternating siltstone and shale within the Morgantown were described as representing a natural levee within the channel sequence. Donaldson indicated that due to the ripple and dune cross-beds displayed, the Morgantown Sandstone was likely deposited in a low-flow regime environment with the ancient river depositing sand toward the north.

Edmunds et al. (1999) described the depositional setting of the Casselman Formation as one that suggests a relatively drier alluvial plane setting (versus the lower delta-plain setting of the upper Glenshaw Formation) due to the presence of freshwater limestones, discontinuous coals, and red beds. Hutchinson et al (1995) and Shultz and Harper (2002) interpreted the Morgantown Sandstone originating as a fluvial channel deposit, with the exact nomenclature in question. They described the irregular base as typical of stream channels in that it cuts into the surrounding strata and then subsequently filling with sand.

Due to the accepted interpretation that the Morgantown was deposited as a channel sandstone within a larger meandering river system, criteria and characteristics used by prominent sedimentologists was gathered to compare with the observations noted in outcrop displaying the basal Morgantown Sandstone. Boggs (2006) and Prothero and Schwab (2014) describe the deposition of meandering fluvial systems with the following conditions:

- Sand units are typically lens-shaped, but can migrate laterally to produce tabular, well-stratified bodies
- The energy of moving water goes into cutting the channel sideways, thus allowing the point bar sequences to laterally accrete
- Sedimentary features such as trough cross-bedding and sand ripples are abundant with a thin discontinuous channel lag of gravel and coarse sand
- Sand fines upward from channel lag gravel to sandy point-bar sequence of plane beds, trough cross-beds, and ripple drift, topped by cutting channels or fine muds
- These sandy deposits are narrow belts that lie in a sequence of muddy floodplain and lake deposits

The Morgantown Sandstone occasionally shows some of these characteristics, such as the overall tabular nature of the sandstone and the conglomeratic base. The upper Morgantown displays well-stratified beds that feature trough cross-bedding, but as described previously, the lower Morgantown often displays a unique set of features unlike those of standard channel deposits. These noted unique observations led the author to look at alternative interpretations for the deposition of the unit.

One proposition is that the basal sandstone section was emplaced in a way that is similar to a series of sedimentary gravity flows. There are four types of common sedimentary gravity flows (Boggs 2006), and the author proposes that it is possible that two of these – a debris flow and a fluidized sediment flow – may have taken place during the deposition of the basal Morgantown. Boggs (2006) and Prothero and Schwab (2014) describe in detail the following criteria and characteristics for the deposition of debris flows:

- Massive with lack of internal layering, poor sorting and poor grading, if any
- Display normal grading on occasion, with some beds exhibiting reverse grading (with the coarsest grains on top)
- Fine gravel, sand, or mud matrix containing large clasts (up to boulders) composed of random fabric with no imbrication
- Basal section commonly displays striations and/or zone of "shearing"
- Broad scours of underlying units
- Occur under many climatic conditions, usually initiated after heavy rainfall or other event
- Often initiated on steep slopes (>10 degrees), but can flow considerable distances on gentle slops of 5 degree or less
- May continue over very gentle slopes as low as 1 or 2 degrees (Curry, 1966), due to the matrix serving to lubricate grain irregularities
- Irregular top with large grains projecting

Boggs (2006) and Prothero and Schwab (2014) also describe the general characteristics of a fluidized sediment flow as follows:

- Sediments deposited from suspension typically lack cross-beds, ripple marks, and pebble imbrication, and are commonly characterized by fine laminations
- Water can transport sediment sizes ranging from clay to boulders
- Change in interstitial pore pressure causes the flow of a once firm sand

Various characteristics of sedimentary debris flows and fluidized sediment flows can be observed within the basal portion of the Morgantown Sandstone. For example, the lower

Morgantown Sandstone is observed to be massive with a basal conglomerate that can be described as having poor sorting and grading, with a fine-grained sand matrix. The large clasts are composed of random fabric (e.g. carbonate, shale, and siderite nodules) and display no imbrication. The interpreted shear zone at the Target and Monroeville outcrops, for example, aligns with the characterization of debris flows as well. Above the basal debris flow, the lower Morgantown Sandstone displays fine laminations absent of common sedimentary structures such as ripple marks and pebble imbrication. The section also typically contains clasts and lenses of coal, shale, siltstone, and sandstone.

Numerous studies have been published on the depositional environment of the middle to late Pennsylvanian sediments. During Conemaugh time, an increasingly regressive transition from a shallow sea to that of a shallow water fluvial deltaic system rapidly deposited clastic sediments (Edmunds, 1999). The Ames Limestone, which distinguishes the boundary between the Glenshaw Formation and the overlying Casselman Formation, and, according to Johnson (1929) is stratigraphically the highest marine limestone of the Conemaugh Group, and in all of western Pennsylvania (Edmunds et al (1999) describes the equivalent unit to the Birmingham Shale east of Allegheny County as occasionally containing marine to brackish sediments, but overall the strata above the Ames are those of a fluvial deltaic environment).

Changes in thickness, the frequency and presence of sedimentary features, and other geologic factors noted in outcrops and cored intervals has drawn the accepted conclusion that sediments of the Conemaugh Group were deposited from a southern and southeastern direction (Figure 60). From their detailed studies on the Casselman Formation in the greater Pittsburgh region, M. Johnson, W. Johnson, and Frazier concluded that the Morgantown Sandstone was deposited from sources to the south and southeast as well, with reworked clastics as the principal source of sediments.

One of the earlier descriptions on the deposition of the Morgantown Sandstone was one in which Meredith Johnson (1929) noted, “Evidently the disturbance which caused the widespread deposition of the sand which in its consolidated state we now call the Morgantown sandstone, and which caused faulting on a minor scale in the shale and sandstone beds of the Birmingham horizon, also caused a change in the northern Appalachian Basin from marine to fresh-water conditions.”

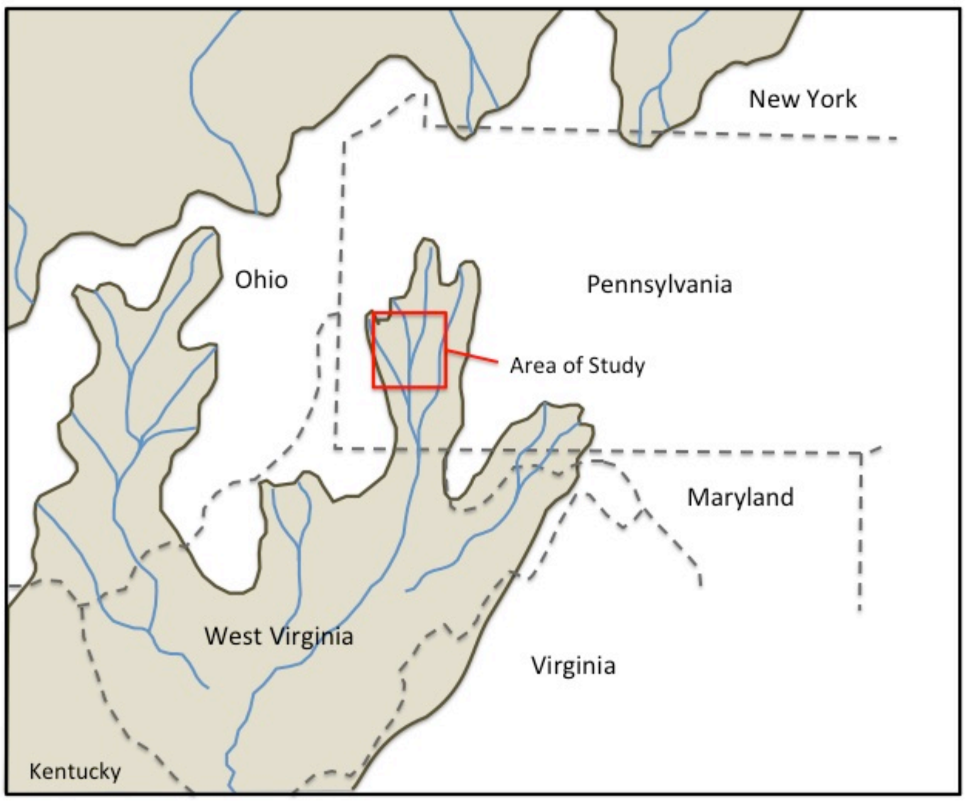


Figure 60: Generalized paleogeographic map for middle to upper Pennsylvanian sedimentation (Source: Donaldson 1974).

As the Morgantown was moving across the Pittsburgh region, it was ripping up sediments from underlying formations that were not fully lithified. The basal conglomerate displayed at the base of the Morgantown sandstone is the direct result of erosion of the underlying sediments. The clasts within the conglomerate or debris flow unit vary slightly throughout the greater Pittsburgh region based on which underlying horizons were eroded. As observed in outcrop, the absence of the non-marine limestone at the FedEx outcrop can coincide with the presence of angular carbonate clasts in the basal unit of the Morgantown Sandstone at the Airport Exit outcrop just kilometers away. Where the limestone unit is present beneath the Morgantown (specifically, at the FedEx outcrop), the clasts within the conglomerate have some angular clasts of carbonate, but slightly fewer. The wealth of sub-angular clasts indicates that the distance these carbonate clasts were transported was minimal, and were likely the result of the limestone being eroded during the deposition of the flow of the basal Morgantown Sandstone.

The presence clastic injection dikes noted at the FedEx outcrop are significant in that they likely formed by the rapid deposition of the mass flow of the Morgantown Sandstone. The underlying limestone unit that is present at this outcrop was may have been deposited on top of the Birmingham Shale section at the time when it was only semi-lithified and contained a significant amount of water. The limestone unit could have been lithified, as the presence of mud cracks indicates that it would have been brittle during the frequent periods of drying very shallow water environment and thus vulnerable to fracturing (Miall, 1996). The cyclical dehydration that typically forms the desiccation cracks provided fractures of weakness for the hydrostatically pressured Birmingham sediments to inject upward toward the overlying limestone unit. Miall (1996) points out that desiccation cracks may be up to a meter deep, which would allow for the cracks to penetrate down toward the underlying sediment. As the

Morgantown Sandstone was rapidly deposited onto the limestone bed, the overlying weight caused the clastic sediments to begin shooting upward into the overlying fractures. Some of these clastic dikes were unable to penetrate the bedding surface of the limestone as seen at the FedEx and Rt. 51 outcrops. Others are interpreted to have been injected upward through the bedding surface of the limestone similar to that of a clastic mud volcano, and were spilled out on top of the limestone bedding surface. Though not confirmed by sample analysis, the sediments of the clastic injection dikes were presumably picked up by the basal flow of the Morgantown Sandstone and were carried until deposited as clasts within the basal debris flow.

The presence of coal leads to the conclusion that the Morgantown Sandstone was deposited over an environment previously occupied by swamps of peat or marshes containing vegetation mats. Due to the somewhat thin nature of the coals witnessed in outcrop, these swamps were likely short-lived. The difference in the how the coal presents itself in outcrop is of importance to the deposition for the basal unit of the Morgantown Sandstone. As the Morgantown Sandstone was being rapidly deposited on the sediments of the Wellersburg and Birmingham units, beds of consolidated peat were picked up, carried, and finally deposited within the lower unit of the Morgantown.

The way in which the basal coal was deposited also provides understanding of the structural stresses that the basal Morgantown Sandstone was under during or after deposition. In areas, such as at the Monroeville and Target outcrops, a zone of highly laminated coal and sandstone is interpreted as a shear zone that accommodated detachment and sliding of the overriding sandstone. There are also examples of compressional and tensional stresses taking place above this shear zone at the Target outcrop. Larry Thomas (2013, p. 49) describes deformation of coal deposits like those in Figure 61 as having been compressed and thus squeezed in and around the sandstone unit. The compression was likely the result of the weight of the overlying sediments and thus compaction of the underlying sandstone and coal beds. Tensional beds, as described previously by the presence of boudinage pinches and swells, are also present in the structurally complex zone. The viscosity contrast of the sediments allows for the sandstone layers to stretch without breaking.

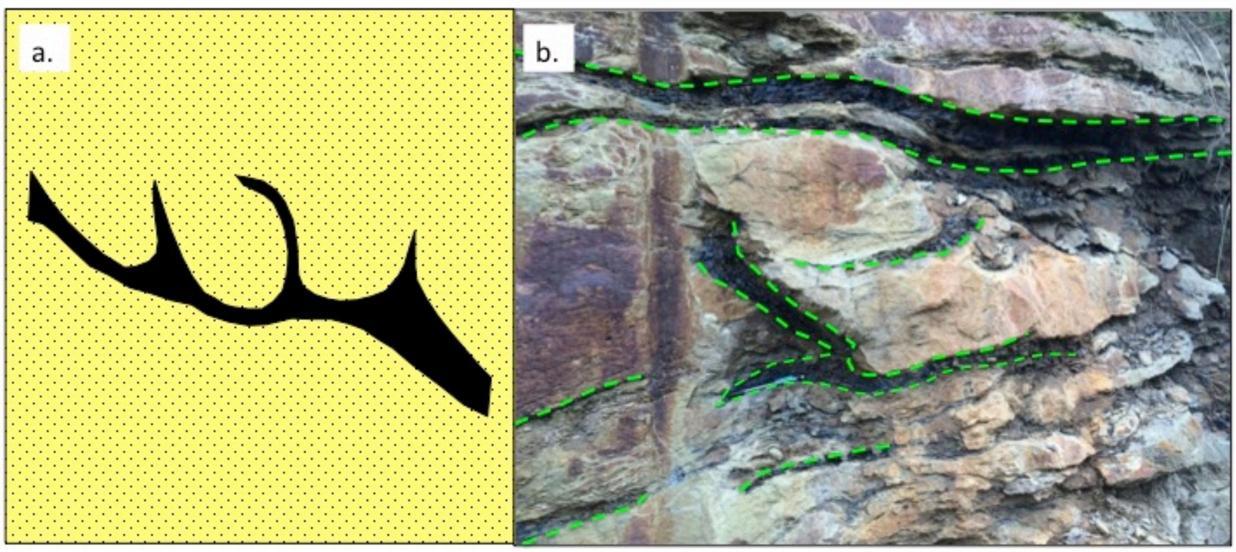


Figure 61: (a) Deformation of coal due to compression. The coal was squeezed into the overlying formation (Modified from: Thomas, 2013). (b) The coal displayed on the right is from the Target outcrop and displays coal seams that have been squeezed into the surrounding Morgantown Sandstone.

In order to observe the amount of erosion of the underlying sediments taking place during the deposition of the Morgantown Sandstone, an isopach map was created to show the change in thickness between the base of the Morgantown Sandstone and the base of the underlying Ames Limestone. The Ames unit was used due to its widespread accumulation prior to the regressive cycle of the Casselman Formation, as well as its high visibility as a marker bed in the Pittsburgh region. The structure map for the base Ames Limestone can be seen in **Figure 62**, and the structure map for the base of the Morgantown Sandstone can be seen in **Figure 63**. Both of these maps were generated using field measurements by the author and authors of previous work.

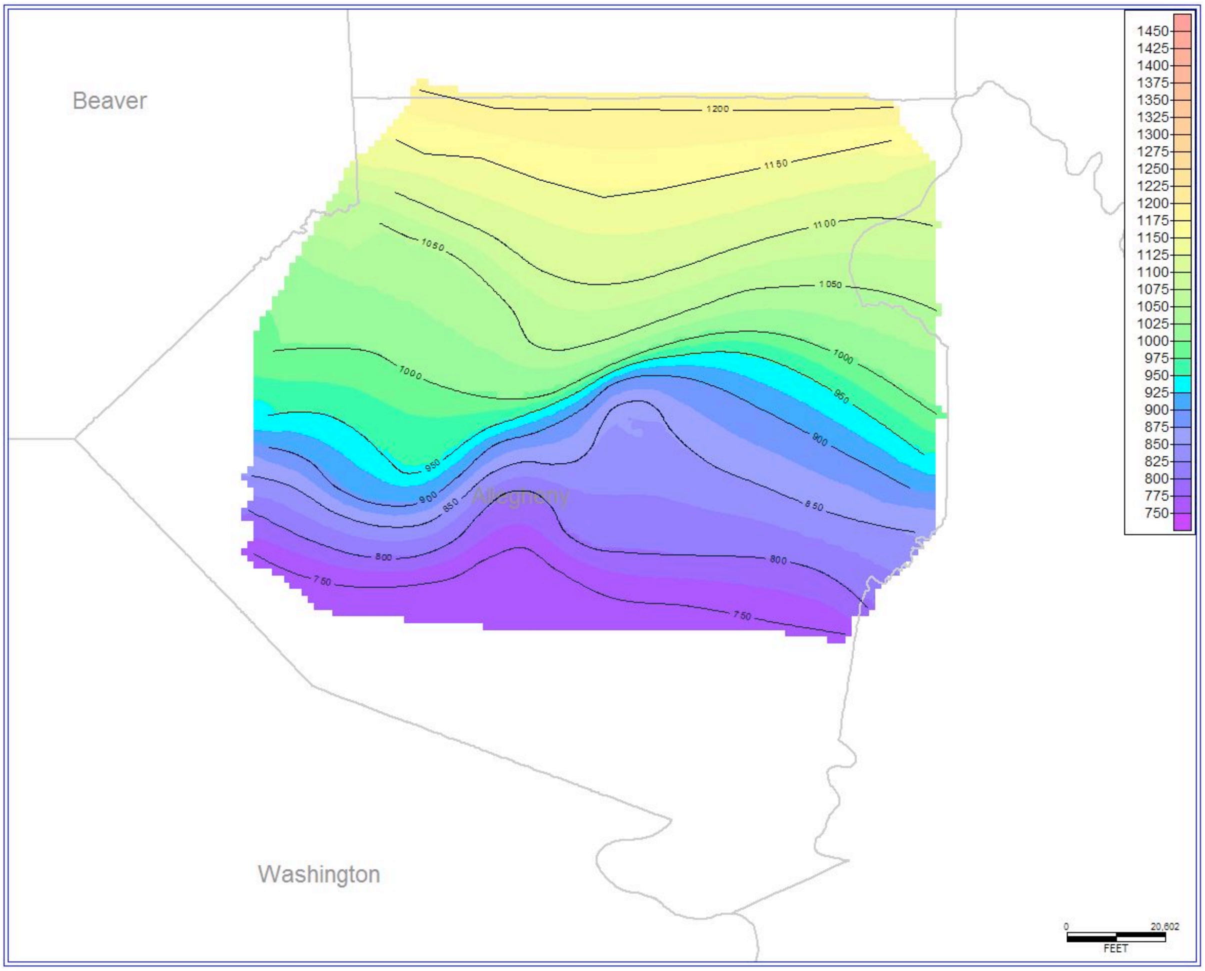


Figure 62: Structural contour map of base of the Ames Limestone (data taken from Table 2 of Appendix A). The steep gradient may reflect a local fault or fold structure, as the relief is too much for the standard deposition of a limestone unit.

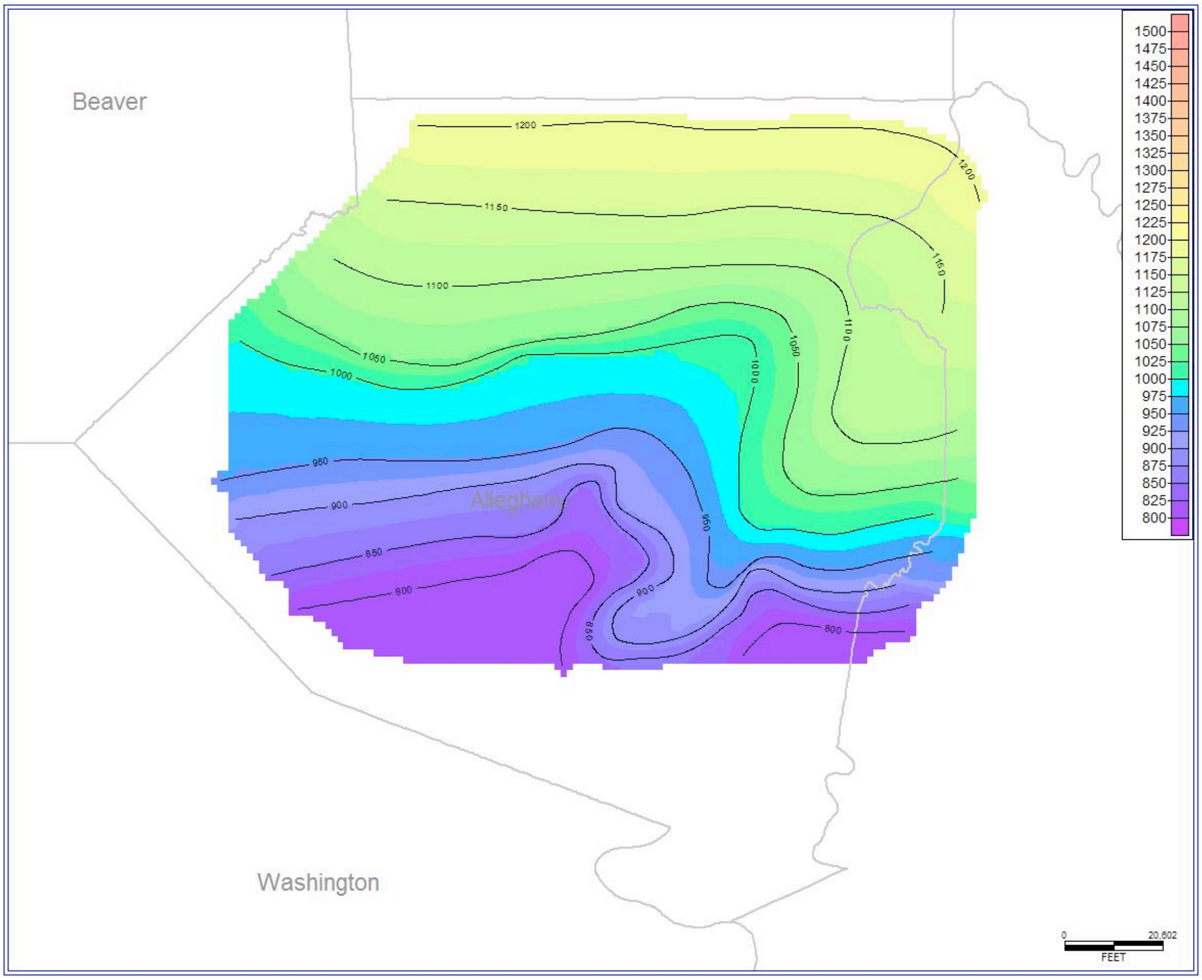


Figure 63: Structural contour map of base of the Morgantown Sandstone (data taken from Table 1 of Appendix A). The moderately steep, east-trending gradient in values to the base of the Morgantown in the southern part of Allegheny County probably record fault offset or fold structures.

As can be seen in the isopach map on Figure 64 the range in thickness between the base of the Morgantown Sandstone and the base of the Ames Limestone ranges from 10 meters to 50 meters, with the thickest portions trending in a southeast-northwest direction.

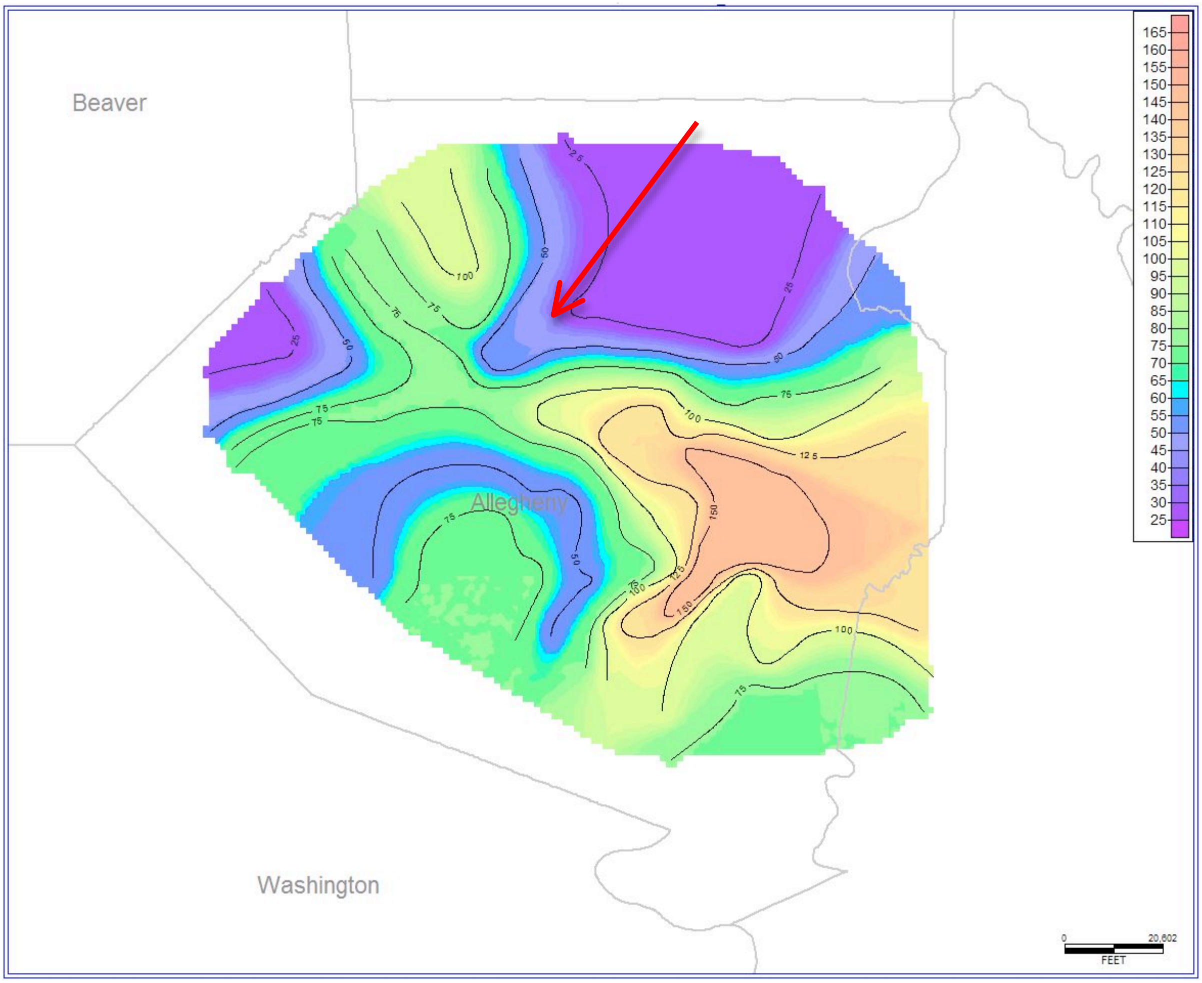


Figure 64: Isopach map portraying the difference in thickness of section between the base of the Morgantown Sandstone and the base of the underlying Ames Limestone in the greater Pittsburgh region (map based on structural contour maps from previous figures). Note the thick interval in the eastern part of the county, which may have been influenced by the structures recorded in Figure 62 and Figure 63. Red arrow indicates the inferred direction of sedimentation of the basal Morgantown Sandstone from the direction of Bakerstown Station.

As mentioned in the introduction, Rak et al (2013) and Graves et al (2014) suggested that gentle- to open-asymmetric detachment folds observed in outcrop at Bakerstown Station record southward transport of sediments. The penecontemporaneous transport and deformation and accumulation of sediment in a southern direction from Bakerstown Station can help to explain the thin interval of sediments between the Morgantown and Ames, as seen on the isopach map in Figure 64. In order for a series of sedimentary gravity flows to begin the movement, erosion, and ultimate emplacement of the Morgantown Sandstone, there would have likely needed to be some sort of event that caused the initial movement, as well as at the very least a gentle topographic relief (between 1 and 5 degrees) that would have allowed the debris and fluidized flows to move. The author infers that there may have been an active positive topographic feature that would have created enough relief in order to allow the sediments to flow across the area of study.

The author also concludes that there were four series of processes that would allow for the rapid deposition of the overall Morgantown Sandstone unit. Chronologically, these include: 1) the detachment, sliding, and stretching of semi-lithified strata; 2) Movement and emplacement of a matrix-supported debris flow 3) Flow of fluid-rich pebbly sandstone 4) Deposition of overlying cross-stratified sandstone deposits. The inferred direction of flow and corresponding sedimentary and structural features of the basal Morgantown Sandstone are displayed on schematic stratigraphic and structural cross-sections in Figure 65 and Figure 66, respectively (Legend for reference in Figure 67).

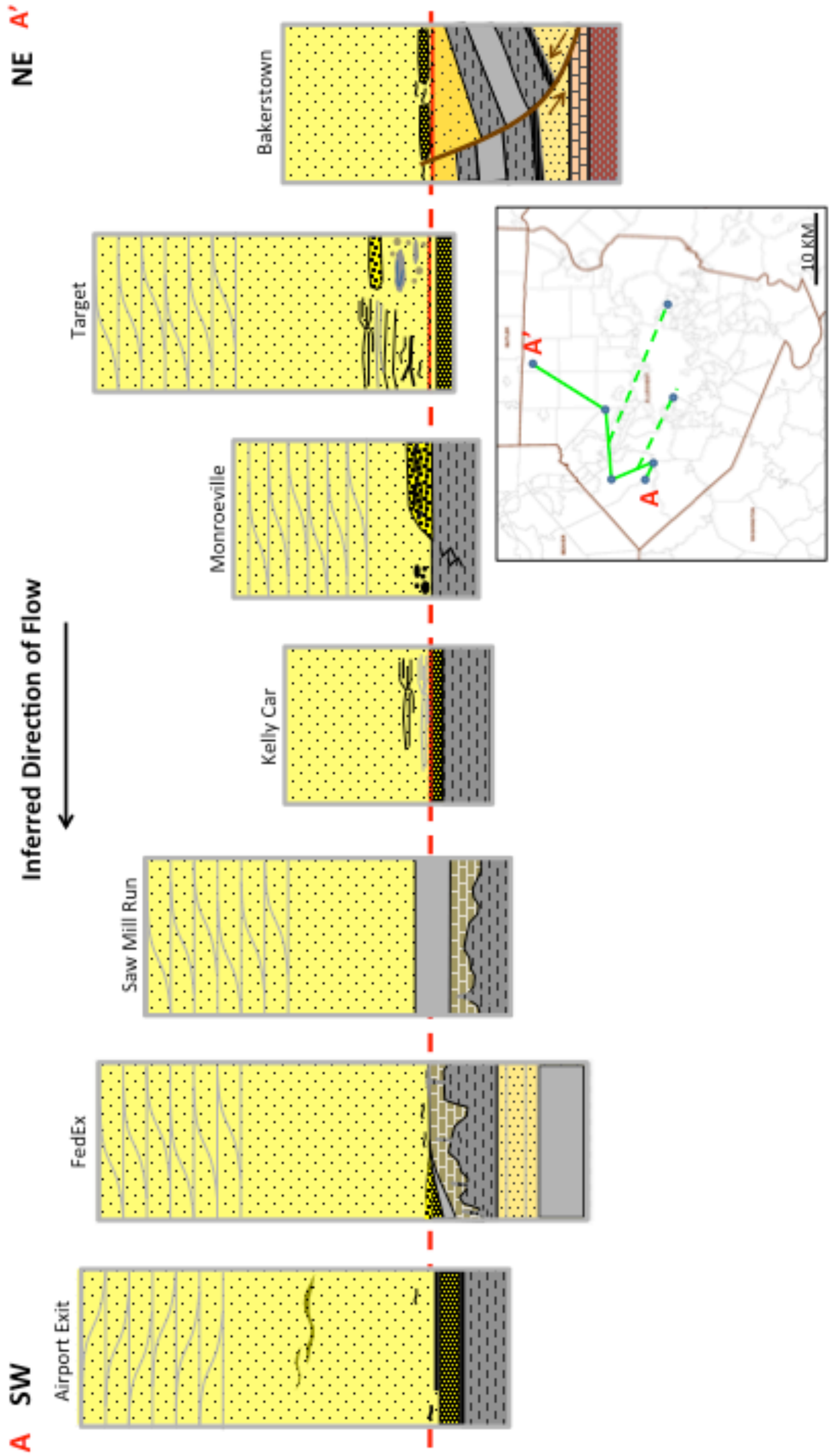


Figure 65: Stratigraphic northeast-southwest cross section hung on sheared zone of detachment, with inferred direction of flow of the basal Morgantown Sandstone from Bakerstown Station to the southwest (left to right).

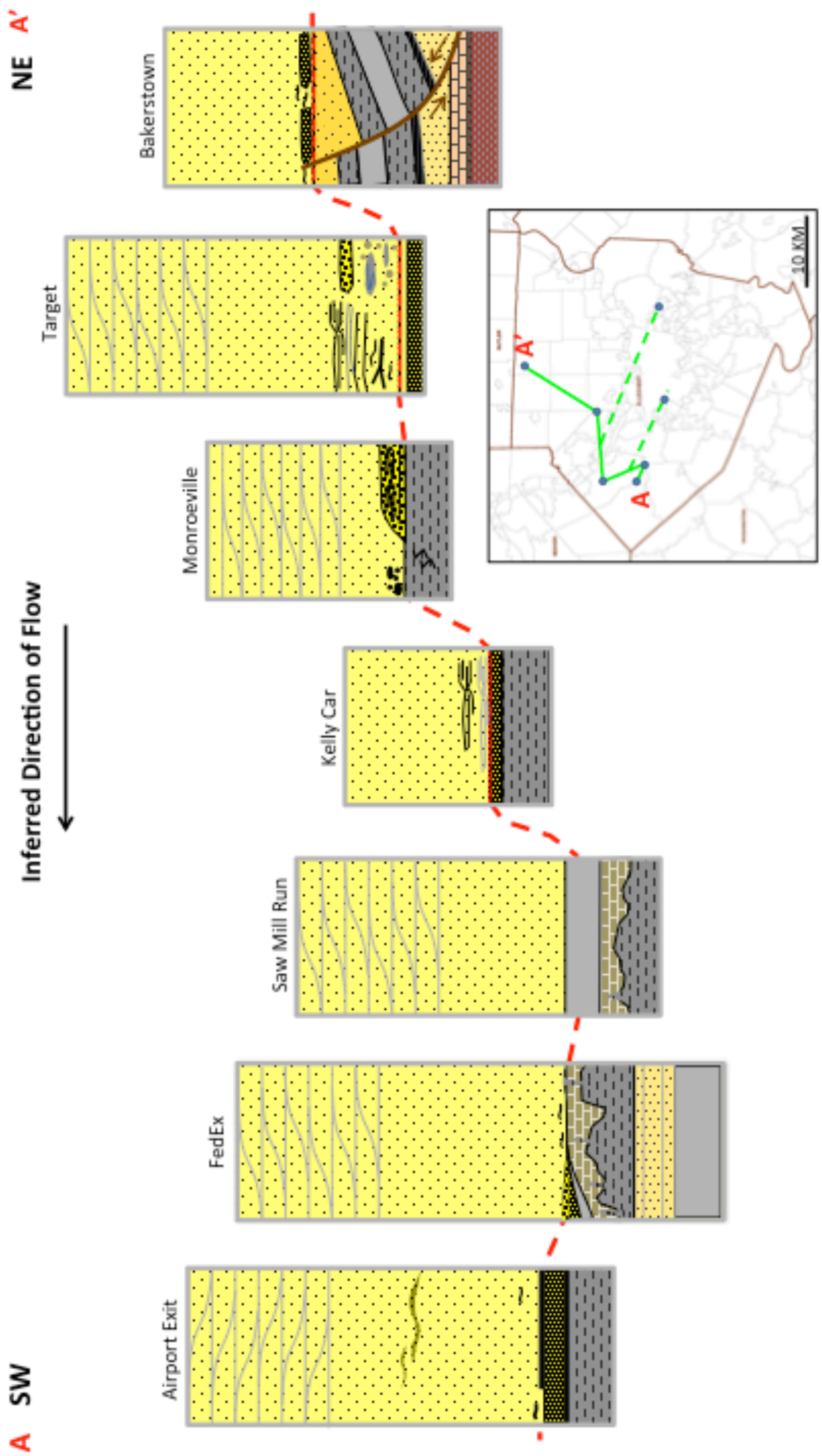


Figure 66: Structural northeast-southwest cross section with dashed red line representing a sheared zone of detachment. The inferred direction of flow of the basal Morgantown Sandstone is from Bakerstown Station in a southwesterly direction (left to right).

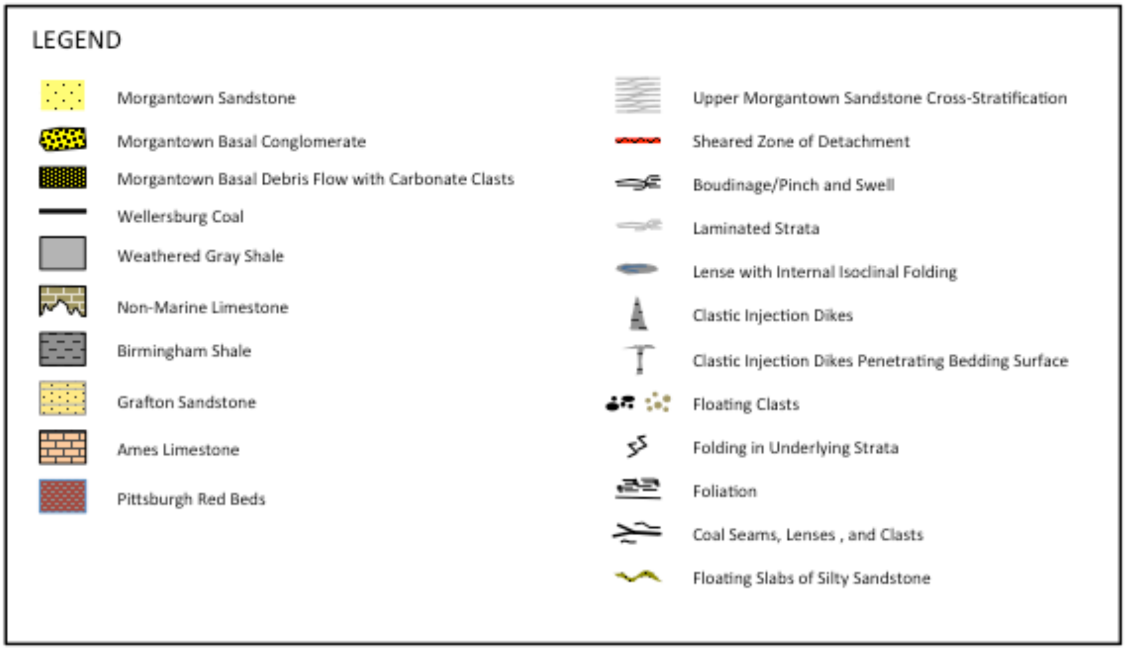


Figure 67: Legend for Figure 65 and Figure 66

5.0 SUMMARY AND CONCLUSIONS

The accumulation of channel-fill sandstones typically displays well-sorted traction deposits and concave channel banks, neither of which were observed. In the greater Pittsburgh region, the basal units of the Morgantown Sandstone of the Casselman Formation includes 1) matrix-rich carbonate clast debris flows; 2) pebbly sandstone; 3) folded platy shale; 4) thin horizons of laminated or foliated sandy shale; 5) local development of boudinage in sandstone. These record the depositional conditions during accumulation of the Morgantown Sandstone. The debris contains sub-angular to sub-rounded pebble- to cobble-size clasts of carbonate in a sandy matrix. Overlying sandstone commonly displays a mixture of coal bands, lenses, and clasts within a sandy matrix. Sheared coal and sandstone may record detachment and sliding for the overlying semi-lithified sandstone mass. The commonly abrupt lower contact of the Morgantown, which truncates and/or bevels some underlying units, suggests scour of the Wellersburg and Birmingham. Folding and loading structures in underlying carbonate strata cut by sedimentary dikes indicates the rapid deposition of the massive sandstone.

Of the outcrops visited, most display structural and sedimentary features that record a disconformity at the basal contact of the Morgantown Sandstone with the underlying strata. Although the erosion is commonly described as having occurred prior to the deposition of the Morgantown, the features seen in outcrop are interpreted as having formed contemporaneously with the deposition of the sandstone during an abrupt regional sand flow.

Furthermore, the thickness of the section between the base of the Morgantown Sandstone and the persistent Ames Limestone of the Glenshaw Formation varies between 10 and 50 meters throughout the Pittsburgh region, compatible with the inferred scour that took place at the base of the Morgantown.

APPENDIX A

LOCATIONS OF OUTCROPS

The outcrops visited by the author and authors of previous work are listed in the tables below. Table 1 lists 93 Morgantown Sandstone exposures with elevations and thicknesses noted where available. Many of the locations listed in the table are from previous authors who only provided vague descriptions and maps with points representing the outcrop. Latitude and longitude values were inferred from these maps, and in some cases where an exposure is still present, the elevation and thickness of the Morgantown was noted. The Morgantown basal elevation values were used to generate a structure map in the greater Pittsburgh area, and in turn used for the mapping of the Morgantown-Ames equal interval map.

Table 1: Morgantown Sandstone elevations, thicknesses, and point location data recorded by the author and previous authors.

Location	Morgantown Elevation	Morgantown Thickness (feet)	Latitude	Longitude
1	951	15	40°27'34.081" N	79°57'05.101" W
2	905	18	40°26'18.780" N	79°56'55.650" W
3	1075	47	40°27'47.693" N	79°59'41.237" W
4	-	15	40°28'55.741" N	79°59'31.478" W

Location	Morgantown Elevation	Morgantown Thickness (feet)	Latitude	Longitude
5	966	20	40°27'02.730" N	79°53'16.319" W
6	-	15	40°27'19.147" N	79°52'46.833" W
7	925	17	40°25'43.883" N	79°56'24.238" W
8	-	30	40°25'35.546" N	79°58'51.409" W
9	860	30	40°25'51.178" N	80°00'05.337" W
10	-	60	40°25'36.391" N	79°52'45.669" W
11	-	30	40°25'22.712" N	79°56'38.191" W
12	-	27	40°25'17.826" N	79°57'42.365" W
13	-	15	40°27'16.352" N	79°48'11.648" W
14	-	35	40°25'41.276" N	79°48'35.606" W
15	-	25	40°26'04.723" N	79°47'40.845" W
16	-	35	40°24'59.587" N	79°49'44.058" W
17	-	25	40°24'24.406" N	79°49'06.410" W
18	-	20	40°24'17.890" N	79°50'06.305" W
19	-	35	40°24'33.527" N	79°52'11.229" W
20	-	65	40°24'46.557" N	79°52'50.589" W
21	-	50	40°25'07.404" N	79°52'35.187" W
22	-	31	40°24'05.754" N	79°57'16.517" W
23	-	18	40°24'53.227" N	79°55'11.283" W
24	890	30	40°24'09.883" N	79°54'56.103" W
25	-	27	40°23'41.395" N	79°56'32.604" W
26	-	25	40°24'26.809" N	79°58'02.599" W
27	-	45	40°22'41.452" N	79°55'56.187" W
28	-	29	40°23'10.782" N	79°55'49.769" W
29	930	35	40°22'33.304" N	79°56'47.525" W
30	-	25	40°22'48.785" N	79°56'17.578" W
31	-	54	40°21'29.741" N	79°52'05.162" W
32	-	35	40°21'01.214" N	79°51'27.727" W

Location	Morgantown Elevation	Morgantown Thickness (feet)	Latitude	Longitude
33	-	55	40°20'56.323" N	79°50'43.875" W
34	-	29	40°21'28.111" N	79°50'48.154" W
35	-	70	40°23'03.450" N	79°50'42.806" W
36	880	75	40°23'48.967" N	79°51'02.672" W
37	-	65	40°23'54.004" N	79°50'16.480" W
38	-	35	40°29'43.260" N	79°45'35.699" W
39	-	30	40°28'15.792" N	79°50'00.864" W
40	-	20	40°26'25.198" N	79°47'14.326" W
41	-	55	40°24'3.843" N	79°45'23.092" W
42	-	40	40°23'46.249" N	79°48'18.500" W
43	920	50	40°23'24.230" N	79°47'55.584" W
44	-	40	40°22'31.950" N	79°45'38.494" W
45	950	27	40°23'57.080" N	79°52'39.868" W
46	-	45	40°26'13.476" N	79°49'10.694" W
47	-	25	40°21'24.410" N	79°46'01.630" W
48	-	20	40°21'42.144" N	79°48'01.421" W
49	-	20	40°19'56.319" N	79°48'05.615" W
50	-	50	40°19'55.906" N	79°47'16.823" W
51	-	32	40°19'38.548" N	79°49'43.200" W
52	-	30	40°20'18.222" N	79°50'00.006" W
53	-	30	40°20'0.452" N	79°50'43.919" W
54	-	20	40°18'46.053" N	79°49'03.624" W
55	-	25	40°18'50.187" N	79°47'43.930" W
56	-	45	40°19'3.415" N	79°48'14.289" W
57	-	18	40°18'18.354" N	79°48'11.036" W
58	-	40	40°18'52.678" N	79°53'09.579" W
59	-	15	40°17'49.384" N	79°54'11.186" W
60	-	40	40°16'43.462" N	79°53'10.435" W

Location	Morgantown Elevation	Morgantown Thickness (feet)	Latitude	Longitude
61	-	22	40°16'27.142" N	79°53'32.682" W
62	-	30	40°16'4.945" N	79°53'23.270" W
63	-	35	40°15'30.992" N	79°54'07.763" W
64	-	43	40°19'29.211" N	79°54'17.175" W
65	-	50	40°20'3.131" N	79°54'10.330" W
66	-	33	40°17'29.152" N	79°52'04.550" W
67	-	60	40°20'49.904" N	79°46'50.500" W
68	-	70	40°18'48.930" N	79°54'05.865" W
69	-	37	40°23'29.970" N	79°57'20.097" W
70	1000	35	40°31'53.834" N	79°51'03.734" W
71	860	-	40°25'28.458" N	80°01'05.294" W
72	870	-	40°26'12.157" N	80°01'57.647" W
73	940	35	40°27'35.274" N	80°10'20.742" W
74	1200	50	40°39'28.621" N	79°58'18.196" W
75	1000	-	40°28'09.004" N	79°51'34.590" W
76	1120	30	40°26'25.889" N	79°50'04.422" W
77	945	25	40°26'22.573" N	79°53'55.439" W
78	1090	30	40°31'34.268" N	80°04'27.095" W
79	1093	30	40°32'12.475" N	80°03'57.896" W
80	1120	-	40°34'12.484" N	80°05'23.922" W
81	1095	-	40°33'35.065" N	80°05'04.386" W
82	1000	-	40°31'32.439" N	80°12'39.346" W
83	-	30	40°16'29.722" N	79°52'10.956" W
84	-	60	40°39'46.423" N	80°11'12.814" W
85	900	25	40°27'40.594" N	79°59'35.245" W
86	-	60	40°32'15.743" N	80°11'45.326" W
87	1080	30	40°32'01.204" N	80°04'37.648" W
88	965	-	40°28'08.427" N	80°12'23.568" W

Location	Morgantown Elevation	Morgantown Thickness (feet)	Latitude	Longitude
89	990	-	40°31'15.551" N	80°01'29.911" W
90	850	-	40°27'02.095" N	79°58'54.427" W
91	850	-	40°26'06.096" N	79°59'29.588" W
92	-	-	40°29'26.357" N	79°47'20.799" W
93	-	-	40°25'59.322" N	79°49'10.462" W

Table 2 features the basal elevations and thicknesses of the Ames Limestone in the greater Pittsburgh area, as well as their respective latitude and longitude values. The elevation values were used to generate the Ames structure map, and in turn the Morgantown-Ames equal interval map.

Table 2: Elevations, thicknesses, and locations of Ames Limestone exposures used for mapping and points of reference by the author and authors of previous works.

Location	Ames Elevation (feet)	Ames Thickness (feet)	Latitude	Longitude
West End Railroad	800	2.25	40°26’41.60" N	80°01’46.87" W
Rt 19	800	1.3	40°26’35.29" N	80°01’43.30" W
Duquesne Bluffs	820	2.83	40°26’05.18" N	79°59’26.18" W
Alluvian Street	800	2.5	40°24’05.56" N	79°56’12.22" W
Kerr Road	955	2.75	Unknown	Unknown
Brilliant Cut	860	2.58	40°28’59.10" N	79°54’20.92" W
Sharpsburg	850	4.58	40°29’49.91" N	79°56’16.26" W
Sharpsburgh East	850	2.83	40°29’51.03" N	79°55’20.68" W
Millvale	850	3	40°28’49.31" N	79°57’57.16" W
Troy Hill	850	4.5	40°27’37.70" N	79°59’04.03" W
West of Bates	820	1.5	40°26’01.10" N	79°57’34.86" W

Location	Ames Elevation (feet)	Ames Thickness (feet)	Latitude	Longitude
Newfield	920	2.33	Unknown	Unknown
Montour Run	890	1.5	40°27’31.43" N	80°11’14.54" W
Moon Run	950	2.83	Unknown	Unknown
Stonedale/I-279	1003	3.25	40°33’09.65" N	80°05’08.37" W
Vassar Gass Run	1012		Unknown	Unknown
Gass Road	1008	1.25	40°31’16.95" N	80°03’39.90" W
Killbuck Run	1000	1.75	Unknown	Unknown
McKnight/Gimbles Store	1050	2.75	40°31’35.74" N	80°00’32.34" W
Nelson Run	1010	1.58	40°30’23.25" N	80°00’24.25" W
Glass Run Road/Glenfield Bridge	800	2.5	40°23’27.72" N	79°56’06.75" W
Wilmerding Road	790	3	40°23’34.27" N	79°48’14.75" W
Pitcairn	820	3	40°23’56.14" N	79°47’17.94" W
Coal Hollow Road	870	2.25	40°28’17.09" N	79°50’51.46" W
Powers Run Road	935	3	40°30’34.21" N	79°51’19.23" W
Campbell Run Road	945	1.5	40°25’32.54" N	80°07’07.52" W
Bakerstown	1180	3	40°39’28.53" N	79°58’18.31" W
Glenfield/79	1005	3	40°32’38.25" N	80°07’16.93" W
Pittsburgh Mills	1060	2	40°34’26.17" N	79°47’16.51" W

APPENDIX B

FEDEX OUTCROP VERTICAL TABULAR BODY LOCATIONS

The latitude and longitude values for the disruptive vertical tabular bodies interpreted as clastic intrusive dikes by the author at the FedEx Outcrop location are listed below in Table 3.

Table 3: Locations of vertical tabular bodies interpreted as clastic dikes at the FedEx Outcrop.

Feature	Latitude	Longitude
Dike #1	40.4608	-80.1728
Dike #2	40.4603	-80.1725
Dike #3	40.4603	-80.1724
Dike #4	40.4602	-80.1724
Dike #5	40.4601	-80.1724
Dike #6	40.4599	-80.1723
Dike #7	40.4597	-80.1723
Dike #8	40.4597	-80.1723
Dike #9	40.4597	-80.1723
Dike #10	40.4602	-80.1727
Dike #11	40.4604	-80.1729

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