Central Appalachian Basin Coal-Bed Methane Exploration

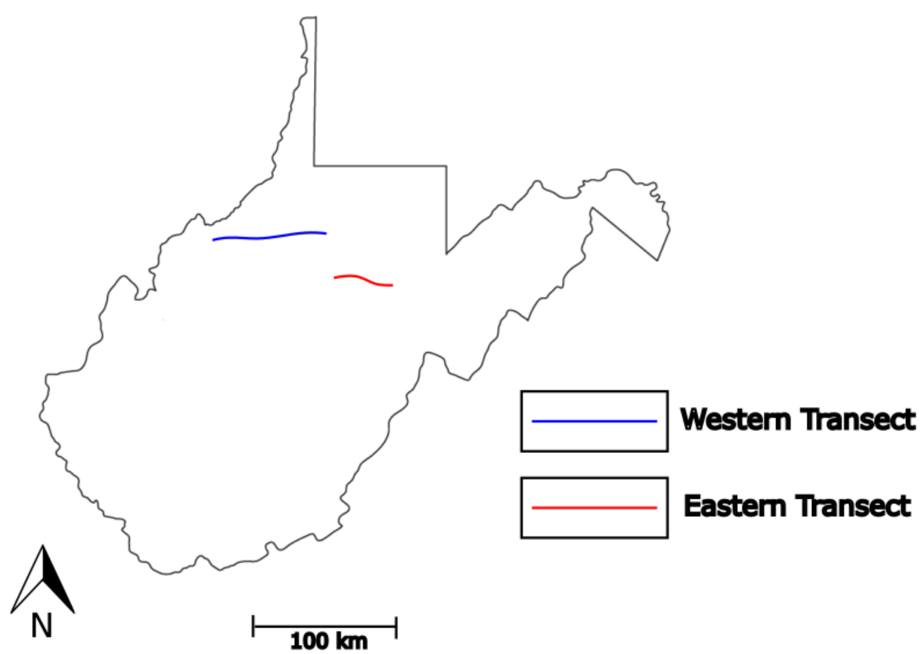
Bishop Brozik
6/15/2020

Introduction & Geologic Background

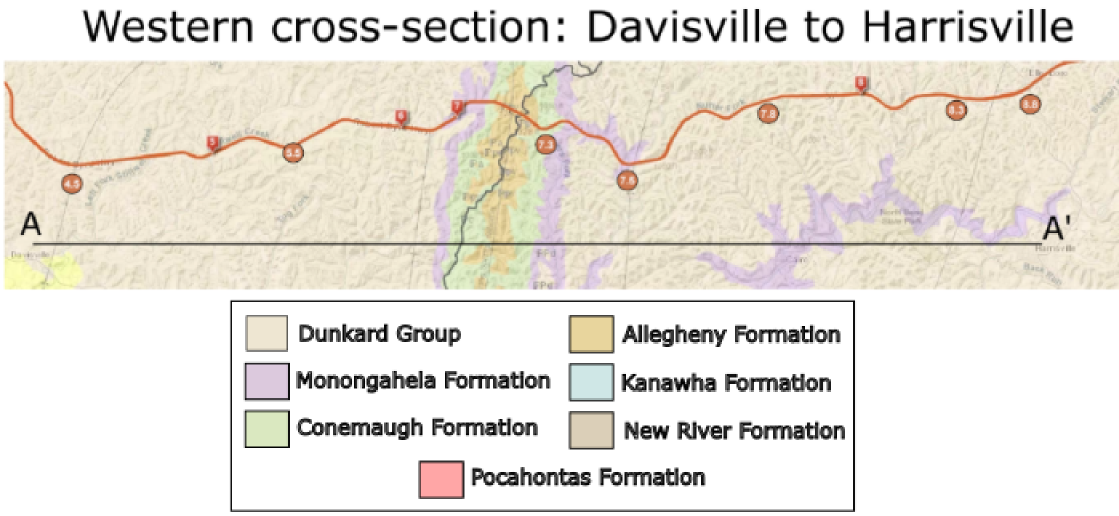
The Appalachian basin is comprised of multiple coal bearing formations due to depositional cyclothems of floodplains, meandering rivers and swamps. These cyclothems produced repeating layers of shale, sandstone and coal. The resulting layers were deformed, folded and uplifted during the Allegheny orogeny between 250 and 325 million years ago creating the formations that are present today.

The units that are seen at or close to the surface within the study area are the Dunkard Group, Monongahela, Conemaugh, Allegheny, Kanawha, and New River formations. These units range in thickness from as little as 400 feet to as much as 2000 feet thick. The youngest is the Dunkard group which is 296 million years old and the oldest is the New River Formation which is 313 million years old (Greb et al. 2008). Some formations are only exposed due to rivers cutting through overlying lithologies. For example, the Kanawha formation is only exposed in the eastern portion of the study area due to rivers eroding the Conemaugh and Allegheny Formations. Others are exposed due to folding and large-scale erosion.

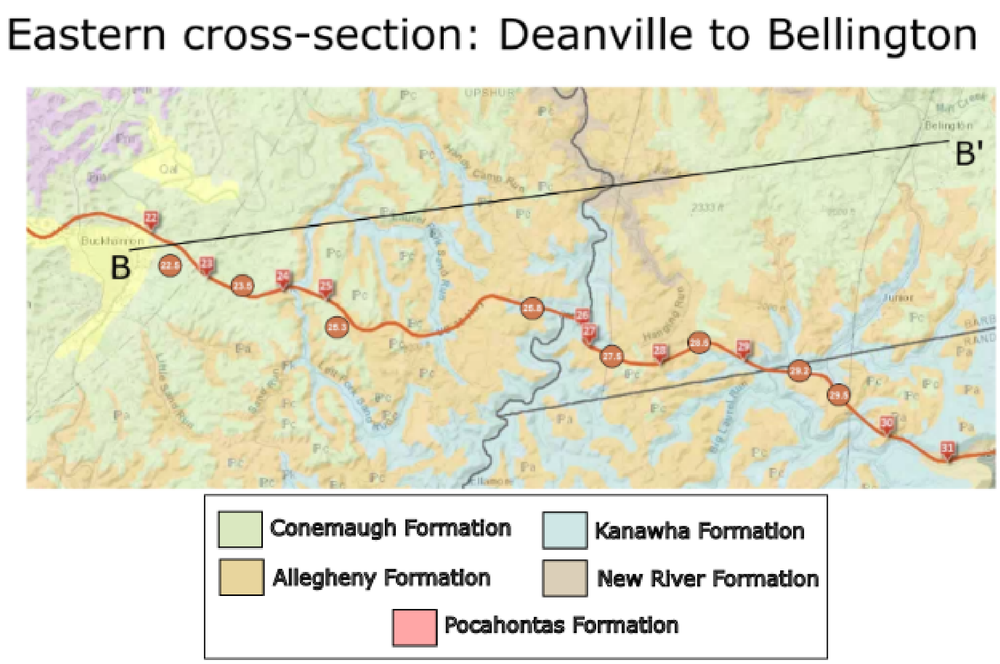
The study area is comprised of two locations: the western transect and the eastern transect. These transects are along I-79 and US 50 between the cities of Davisville to Harrisville and Deanville to Bellington (Fig.1, Fig.1a and Fig.1b). The transect map and outcrop images were received from the West Virginia Geologic and Economic Survey in the form of an ESRI based story map. For each transect the exposed outcrops were studied to get an understanding of the lithologies that made up each formation. These data were then compiled and were used to create the unit descriptions. The end goal is to choose two locations that have high methane potential, and to analyze which units provide the best condition for methane rich coal.



(Fig.1) A map showing the general location of the portions of the Western and Eastern transect sections that were used.



(Fig.1a) A close up image of the Western transect over a geology base map showing the A to A' cross section line



(Fig.1b) A close up image of the Western transect over a geology base map showing the B to B' cross section line

Unit Descriptions

The Dunkard Group

The Dunkard group is 296 million years old (Greb et al. 2008) and 1200 feet thick (Rupert et. Al 2014). It consists of sandstone, siltstone and shale beds. Sandstones are thinly to thickly bedded and range in color from tan to dark gray. Low angle cross bedding is common. The shale and siltstone are less resistive and form slopes that vary in color from reddish brown to dark gray. While siltstone is not present in every outcrop, when it is it is interbedded with the shale. There are no clear sedimentary structures in the shale or siltstone beds. The contacts between the sandstone and shale beds are gradational. The associated coal unit with the Dunkard Group is the Waynesburg Coal, but it is not seen in the outcrops.

The Monongahela Formation

The Monongahela formation is 302 million years old (Greb et al. 2008), 500 feet thick (Rupert et. Al 2014) and consists of sandstone, shale and mudstone. The sandstone beds are thinly bedded and range in color from tan to dark gray. There is a distinct contact between the sandstone and shale beds. The Shale is interbedded with mudstone where the contact is gradational and is a reddish gray color. A coal seam is in contact with a shale bed but is not exposed at the surface. The repetition of the sandstone and shale beds indicates that they were deposited in a flood plain. The Upper Monongahela Formation is in direct contact with the Lower Dunkard Group. The associated coal bed is the Sewickley coal seam.

The Conemaugh Formation

The Conemaugh Formation is 301 to 303 million years old (Greb et al. 2008) and up to 900 feet thick (Rupert et. Al 2014). It is composed mostly of sandstone with some thin layers of shale. The sandstone has variable bedding sizes from medium bedded to thick bedded. In outcrop, the sandstone starts out more thickly bedded at the base and thins upwards becoming less resistant until it reaches a contact with the shale. As such, the contact is gradational. Cross bedding is present in the medium bedded sandstone, but not the thinly bedded sandstone. The associated coal unit is the Pittsburgh coal.

The Allegheny Formation

The Allegheny Formation is 308 million years old (Greb et al. 2008) and 400 feet thick (Rupert et. Al 2014). It is composed of Sandstone, shale and coal which is deposited in a cyclic pattern. The sandstone resistant, blocky, ranges in thickness and displays a lenticular geometry. It is mostly tan but sometimes appears gray due to chemical weathering and has some low angle cross bedding. The sandstone has a gradational contact with overlying brown and gray shale. There are multiple thin beds of coal present ranging in thickness from less than 1 foot thick to 4 feet thick. The coal shares an erosional contact with the sandstone, in some places displacing the coal units upwards and truncating parts of the coal beds. This contact geometry, the lenticular shape of the sandstone beds and presence of low angle cross bedding suggests that this outcrop could be a cyclothem of a meandering river. The coal units associated with the Allegheny Formation are the Upper Freeport, Lower Kittanning and No. 5 Block.

The Kanawha Formation

The Kanawha Formation is 311 million years old (Greb et al. 2008) and up to 2000 feet thick (Rupert et. Al 2014). It is made of medium bedded sandstone that ranges tan to dark gray and multiple coal units. The color variation is due to chemical weathering. While no coal beds can be seen in outcrop, the associated units are the Stockton, Coalburg, Winifrede, Fire Clay, Powellton and Eagle coal beds.

The New River Formation

The New river Formation is 311 million years old (Greb et al. 2008) and 800 feet thick (Rupert et. Al 2014). It is composed of sandstone, coal and shale. The sandstone is medium bedded and ranges in color from tan to dark gray with very low angle cross bedding present. The sandstone is interbedded with coal seams that are approximately 10 feet thick. The shale layer is gray and seemingly folded and is displaying soft sediment deformation. The contact between the shale and sandstone is erosional in the center of the outcrop and is gradational on the outer fringes. The associated coal units are the Sewell, Beckley, and Fire Creek coal beds.

Coal Bed Methane Geologic Evaluation

The goal is to choose the best location for coal bed methane extraction, so the chosen locations at each transect need to meet certain criteria as not all coal beds have the same capability to store methane and not all formations have the right conditions to make excavation viable. Unlike other fluid reservoirs that store gas in open pore space, coal absorbs the methane at its surface. This means that more surface area is preferred. It also means that the methane can be removed from the coal by a change in pressure or by a change in surrounding lithologies. The first and easiest criteria is that the area needs to have a coal rich interval, preferably with multiple large coal beds. So, a formation with just one small coal seam will not be enough.

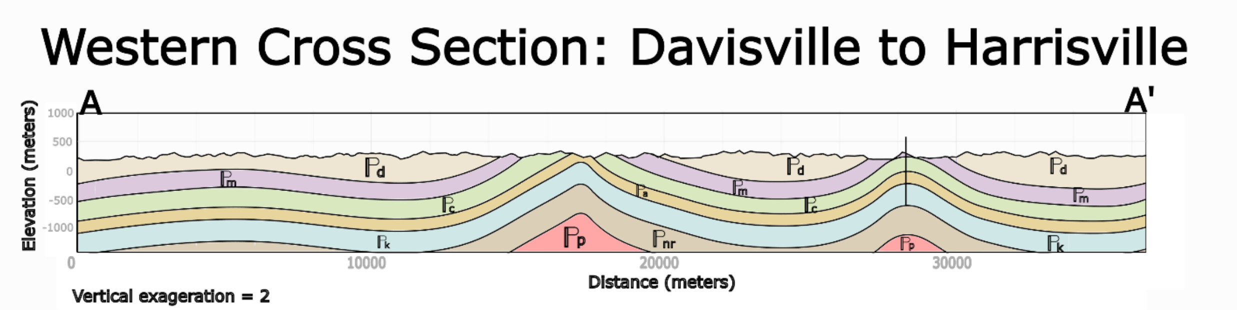
For the best methane extraction results, the coal needs to have a vitrinite reflectance value between 0.5 and 1.1. So, the most ideal coal rank to look for is Bituminous (Evens and Bates 1999). Coal rank works similarly to metamorphic rank. Higher temperature and pressure yield a higher rank. This means that the more burial that occurs, the higher the rank of the coal, and in turn the better chance the coal will be in the right range for coal bed methane extraction.

Next, coal with cleats is preferable over coal with no fractures. The cleats give the coal more surface area which allows more absorption and also allows the methane to escape more easily. Cleats are fractures in the coal, so they form frequently in areas that have been folded and have experienced high stress. This means that the best place to look for cleats would be at the crest of an anticline or the trough of a syncline.

The last criterion that is used is that there still needs to be methane in the coal to extract. There are a couple reasons why a coal bed may already be depleted or have less methane than would be expected. It has to do with the porosity of the surrounding lithologies. Shale has small grain sizes and is able to stop methane from seeping away from the coal. Sandstone on the other hand cannot do this and can actively sap the methane out of the coal. In some cases, the sandstone can also scour into and cut coal beds apart depending on the depositional environment they form in. This not only allows the methane to escape because it is underlying sandstone, but also allows it to escape as it is fractured.

Site 1

In the western transect, the easternmost anticline has the highest potential for coal bed methane resources (Fig. 2). The entire area for the A to A’ cross section is folded forming two steep anticlines and three synclines. This is good for coal bed methane extraction as cleats form more often in folded areas. The easternmost anticline was chosen for three reasons. First, the crest of the anticline experiences the most stress, so more cleats will form here than anywhere else in this cross section. Second, more of the coal bearing units are intact below the ground than the other anticline. Third, deeper burial is beneficial for coal bed methane as deeper burial of coal increases vitrinite reflectance. However, this is not because bituminous ranked coal only forms at a certain depth here. In the portion of the Appalachian basin that is being studied, all the coal is already bituminous rank and already fulfills that requirement.

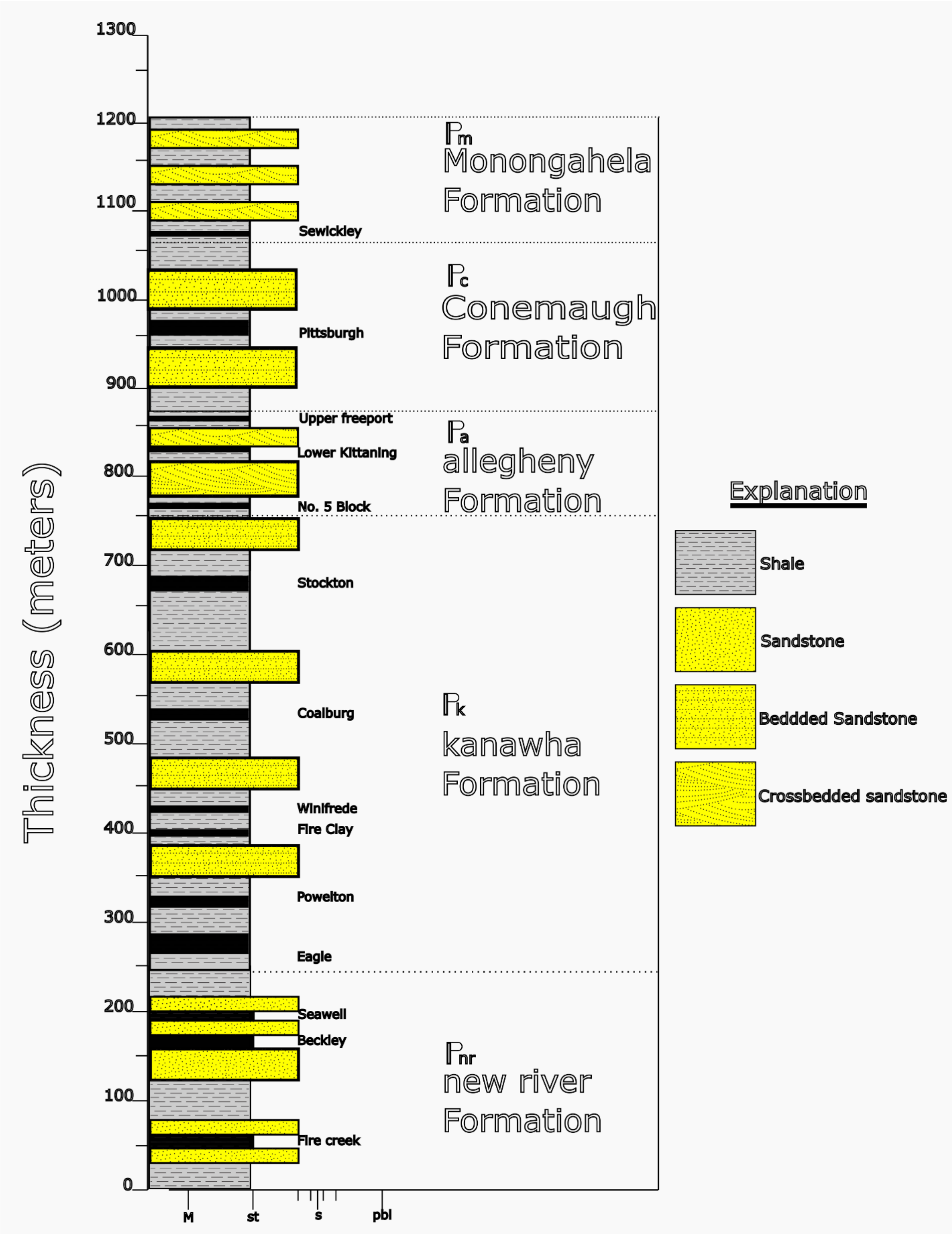


Explanation

Dunkard Group- Thickly bedded sanadstone ranging from tan to dark greywith low angle cross bedding comon as well as grey shale interbedded with brown siltsone . The Waynesburg coal seam is present in this group	Pd	Allegheny Formation- Tan to grey sandstone with low angle cross bedding in contact with grey shale and multiple thin coal seams. The Upper Freeport, Lower Kittaning and No.5 Block coal seams are present in this formation	Pa
Monongahela Formation- Thinly bedded tan to dark grey sandstone with interbedded reddish grey shale and mudstone. The Sewickley coal seam is present in this formation	Pm	Kanawha Formation- Medium bedded sandstone that ranges in color from tan to light grey with no coal present in outcrops but contains the Coalberg, Winifrede,Fire Clay, Powelton and Eagle coal seams at depth.	Pk
Conemaugh Formation- Mostly sandstone with high angle crossbedding and variable bedding sizes with thin beds of shale. The Pittsburgh coal seam is present in this formation	Pc	New River Formation- Medium bedded snadstone interbedded with multiple coal seams in contact with shale layer that has soft sediment deformation. The Seawil, Beckley and Fire Creek coal seams are present in this Formation	Pnr
Pocahontas Formation- Not exposed at the surface. Underlies the New River Formation.	Pp		

(Fig. 2) The western cross section along with an explanation of the units. The proposed methane extraction location is marked with a solid black vertical line

While this location was chosen for its structural geometry and burial depth, not all of the units here are ideal for coal bed methane extraction. On top of the abundance of cleats, vitrinite reflectance, coal grade and burial depth it is also important to choose formations that have abundant coal beds and that those coal beds are not surrounded by porous rocks. As seen in the lithostratigraphic column not all of the formations meet these criteria (Fig.3). For example, The Monongahela formation only has one associated coal bed, the Sewickley coal seam. On the other hand, the New River Formation has multiple thicker coal beds present, but still is not a good candidate. This is because the coal units are surrounded entirely by sandstone. Since sandstone is porous, the methane in the coal will seep out overtime depleting the supply. So, with those restrictions in place, the units with the highest methane potential are the Kanawha and Allegheny formations. The better of the two would be the Kanawha Formation, which has 6 associated coal beds that are not in contact with sandstone, most of which are relatively thick. While the Allegheny formation has less coal beds present, two of the three are detached from the surrounding sandstone beds.

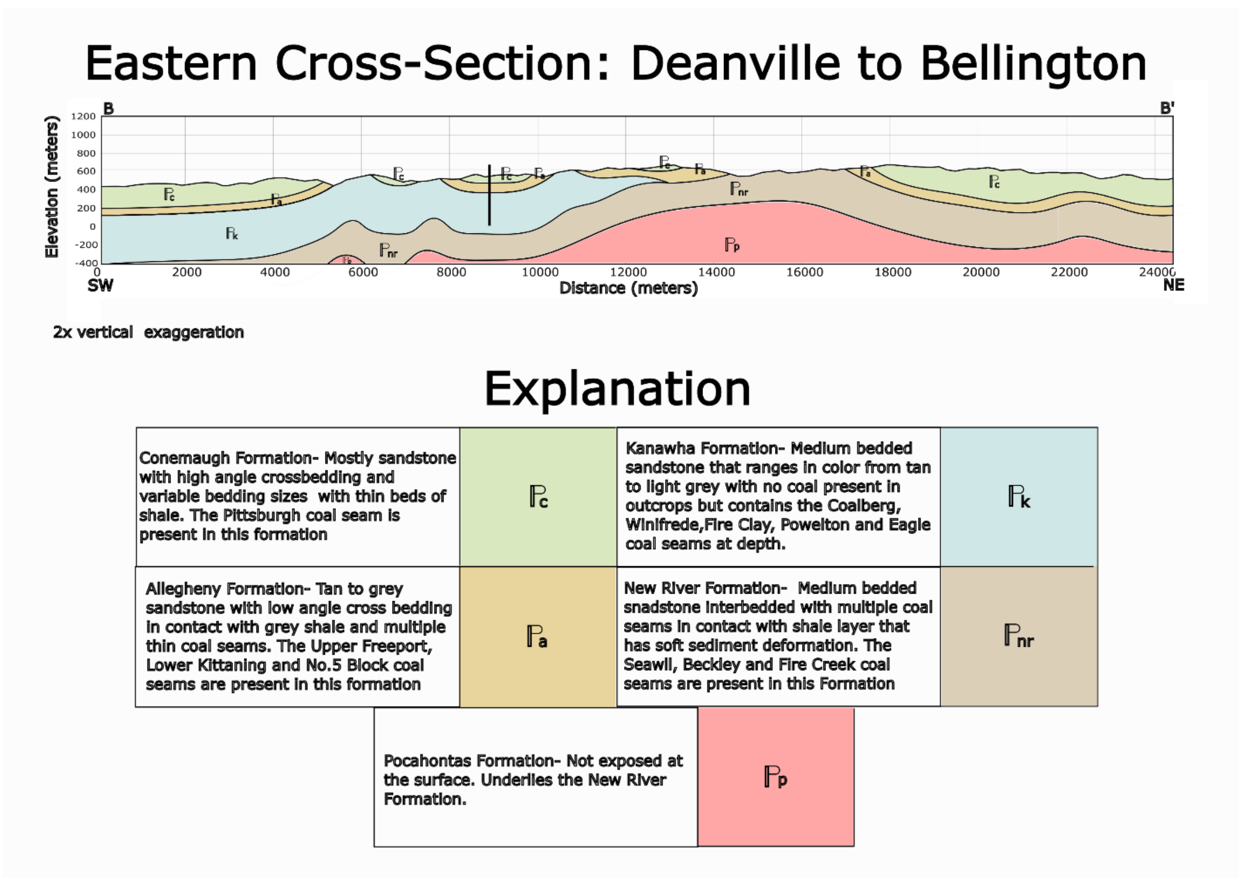


(Fig. 3) A lithostratigraphic column of the western transect cross section.

Site 2

The same criteria were used to choose the location of highest potential for coal bed methane resources in the western transect. Areas that have undergone folding and experienced high stress produce more cleats, which is ideal. Deeper burial and bituminous coal rank are preferred. All of the coal still meets these criteria on this transect as it did in the east. And coal beds that are thicker, more numerous and not in contact with sandstone are still preferred. Although all of the criteria are still the same and the western transect is not too far away from the eastern transect, the chosen location will not have results as good as the chosen location in the west.

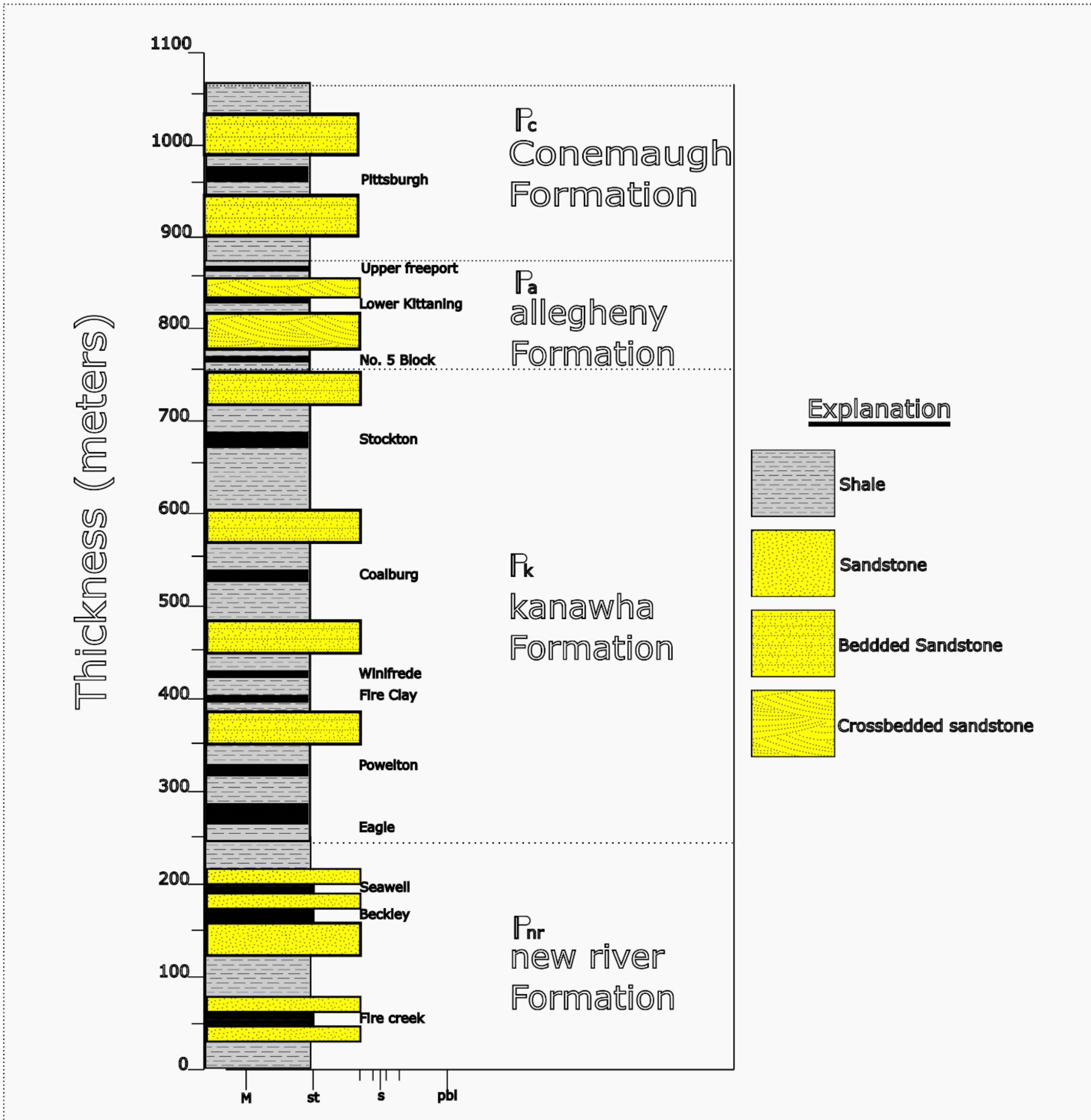
The eastern transect has more complex structural geometry but there is not a location where both of the best coal bearing formations are folded into a nice anticline nor do they satisfy as many criteria as the eastern transect did. The Kanawha and Allegheny formations are still present in the chosen location, but they aren't buried as deeply. For comparison, the base of the Kanawha formation in the east is about 750 meters below sea level where it is only 200 meters below sea level in the west. The Kanawha formation isn't even present through the entire cross B to B' section (Fig.4). This can be seen at the 1300-meter mark to the North East, where the Kanawha formation pinches out due to an erosional unconformity.



(Fig.4) The eastern cross section along with an explanation of the units. The proposed methane extraction location is marked with a solid black vertical line

So, the area with the highest methane potential in the eastern transect is approximately 9000 meters north east along the B to B' cross section line targeting the Kanawha and Allegheny formations between the depths of 200 meters above sea level and 200 meters below sea level.

The Lithostratigraphic column for this location is very similar to the one for the western transect, however the Monongahela Formation and Dunkard Group are not present (Fig. 5)



(Fig. 5) A lithostratigraphic column of the western transect cross section.

Summary

In short, the Central Appalachian Basin is composed of several coal bearing formations. The two best formations in our study area to target for further research and subsequent coal bed methane extraction are the Allegheny Formation and the Kanawha formation. While both the Eastern and Western transect have these formations present in some capacity, the western transect will have a higher potential to contain more methane as the layers have experienced more stress, are buried deeper and are not cut off by an erosional unconformity. So, the ideal location is approximately 2900 meters east along the A to A’ western transect cross section line and between 200 and 700 meters below sea level in the Allegheny and Kanawha Formations.

References

Evans, M.A. and Battles, D.A., 1999. Fluid inclusion and stable isotope analyses of veins from the central Appalachian Valley and Ridge province: implications for regional synorogenic hydrologic structure and fluid migration: *Geological Society of America Bulletin*, *111*(12), pp.1841-1860.

Greb, S.F., Pashin, J.C., Martino, R.L. and Eble, C.F., 2008. Appalachian sedimentary cycles during the Pennsylvanian: Changing influences of sea level, climate, and tectonics. *Resolving the Late Paleozoic Ice Age in Time and Space*, *441*, p.235.

Ruppert, L.F., Trippi, M.H. and Slucher, E.R., 2014. *Correlation chart of Pennsylvanian rocks in Alabama, Tennessee, Kentucky, Virginia, West Virginia, Ohio, Maryland, and Pennsylvania showing approximate position of coal beds, coal zones, and key stratigraphic units:* US Geological Survey: *Chapter D. 2 in Coal and petroleum resources in the Appalachian basin: distribution, geologic framework, and geochemical character* (No. 1708-D. 2).