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PROSPECTING FOR COAL BED URANIUM IN KANSAS THROUGH THE USE OF ARCGIS AND URANIUM PROXIES

Being

A Thesis Presented to the Graduate Faculty
of the Fort Hays State University in
Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

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B.S., Appalachian State University

Date______________________ Approved____________________________________
Major Professor

Approved____________________________________
Chair, Graduate Council

ABSTRACT

The potential implications for the discovery of coal bed uranium in Kansas not only have a significant scientific and human health interest impact, but also a possible future economic one as well. This study sought to look for coal bed uranium within the Cretaceous Dakota Formation located in north-central of Kansas. This study utilized the two coal bed uranium proxies of historic subbituminous coal production and radon, and ArcGIS to produce a field-site selection map. This map was used to pick counties within Kansas to collect samples from. Once samples were collected, they were scanned for radiation using all available settings on two Geiger counter units at Fort Hays State University. Samples collected from all field sites within Cloud, Republic, Jewell, and Pottawatomie counties tested negative for uranium, thorium, and other radioactive materials.

ACKNOWLEDGMENTS

I would like to thank Dr. Schafer, my committee members, and the faculty and staff of Fort Hays State University for their valuable input on the direction of this project. I would also like to thank Debi Aaron for assistance in the field and in establishing landowner contact for field sites. I would also like to thank the landowners for allowing access to field sites and the collection of samples. I would like to extend a thank you to the Fort Hays State University Graduate School for giving me this opportunity. I offer a final thank you to my parents, family, and friends for support in this endeavor.

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INTRODUCTION

Study Objective

This project focuses on investigating the potential existence of coal bed uranium in Kansas. The objective is to find out if coal samples that were field collected according to ArcGIS site selection had any uranium, thus indicating the presence of coal bed uranium in north-central Kansas. There has been little work in investigating the potential presence of coal bed uranium in Kansas, and the value of the knowledge as to whether it is present in Kansas or not warrants further investigation. As a resource, uranium has uses in the energy, medical, food-processing, and military sectors. The potential implications for the discovery of coal bed uranium in Kansas not only have a significant scientific impacts, but also economic ones as well. The harvesting and refining of commercial or weapons grade uranium is a profitable economic venture that has led to the development of companies specializing in the extraction of uranium. If coal bed uranium was discovered in commercial amounts in Kansas, it could lead to an economic boost for the state. Utilizing potential coal bed uranium stores in the state could also be a source for job creation within the state of Kansas. In the current economic situation, job creation and an economic boost could significantly improve the finances of the state of Kansas overall.

In addition to its commercial uses, naturally occurring uranium can be a source of environmental safety and health concerns. Uranium can be dangerous to humans through the release of radiation and radioactive elements as it degrades. Radon, a radioactive element that is produced by radioactive elements such as uranium and thorium as they decay, is linked with a heightened risk of lung cancer in humans (Field et al., 2000; Lyle, 2007). Even from a health and public safety interest standpoint, knowing if coal bed uranium is present in the state of Kansas and in what amounts is an important topic in taking precautions in building and zoning for residential areas. As such, this study has a potential impact on the health and safety of the entire population of the state of Kansas.

For these reasons, identifying its presence in an area is of great importance. Uranium is typically sought after in the form of uranium ore, in which the concentrations of uranium-238 and uranium-235 are in a secular equilibrium with their daughter isotopes. Reactor-grade uranium ore is typically 3.2-3.6% uranium, whereas weapons-grade uranium ore is >90% uranium. Ores can be enriched through the use of uranium-235 to achieve reactor-grade or weapons-grade status (Cantaluppi and Degetto, 2000). In the 1950's, coal bed uranium was discovered in the Wasatch Formation of northeast Wyoming (Love, 1952). Further joint works by the United State Geological Survey and the Atomic Energy Commission sought to identify and measure uranium content in the United States.

Rationale

Coal bed uranium is different from uranium ore in that it is secondarily deposited (James, 1978). While the original uranium can come from different sources, the most common source is igneous rock or ash deposits that leach uranium into surrounding groundwater flows. Within Kansas, there have been at least 18 ash layers representing the Pearlette Ash and the Ogallala Formation that have tested positive for uranium and thorium. These ash layers serve as a potential source of uranium that could then be secondarily deposited in Kansas coal deposits (James, 1978).

Kansas surface geology ranges from Pennsylvanian marine and non-marine subsystems in the east that transition to Permian and then Cretaceous systems in the central region of the state and then Neogene and Quaternary alluvial deposits in the west (see Figure 1) (Merriam, 1963; Zeller et al., 1968). The contacts between these different systems are riddled with unconformities. The Precambrian basement rock is primarily igneous and metamorphic rocks. The Pennsylvanian deposits in Kansas consist of five cycles of marine limestones and shales and alternating non-marine clastic deposits. The coal samples from the Pottawatomie county sample site are traced to coal seams within these deposits. The Cretaceous systems of Kansas are representative of the Cretaceous Interior seaway. The Cretaceous Dakota Formation is the origin of the Jewell, Cloud, and Republic county samples (Merriam, 1963; Zeller et al., 1968). The two stratigraphic sections representing rock units sampled are also shown below (see Figures 2, 3, & 4).

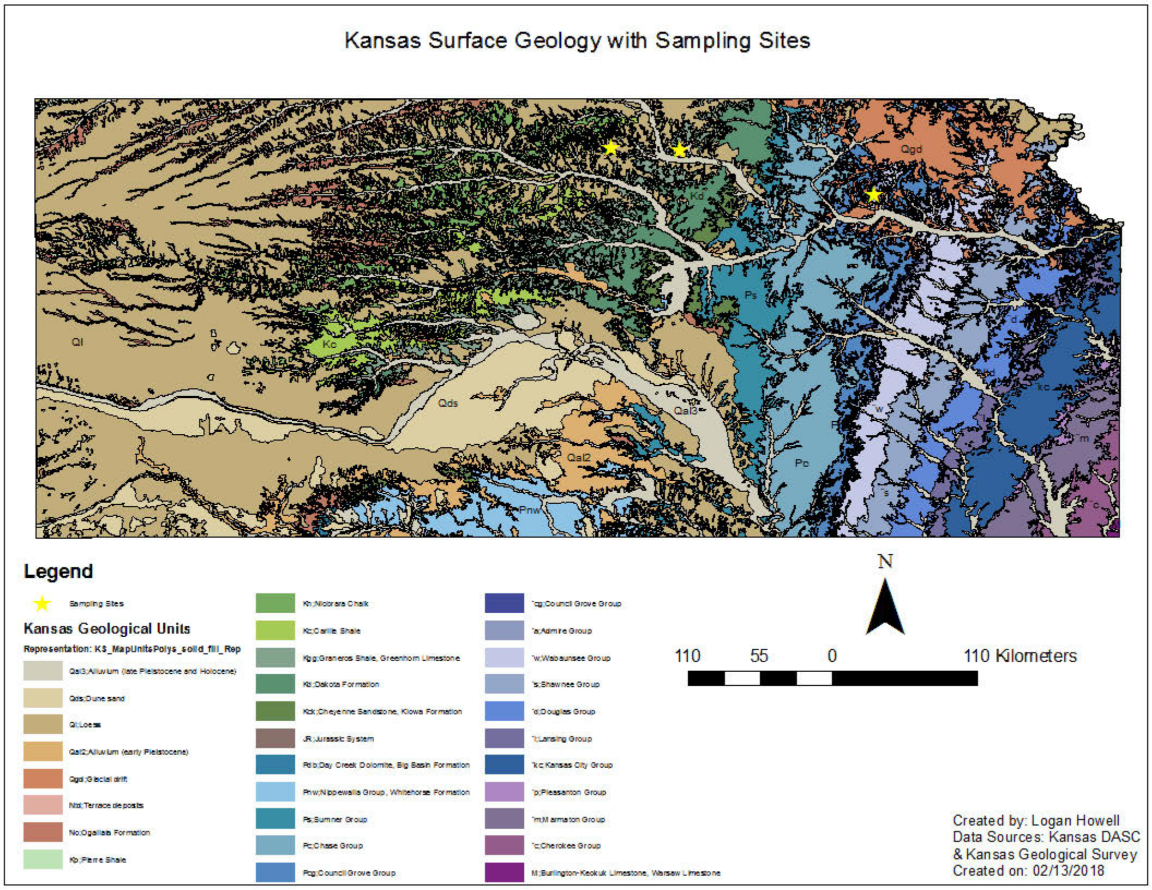

Figure 1:Surface Geology of Kansas (Data from KGS)

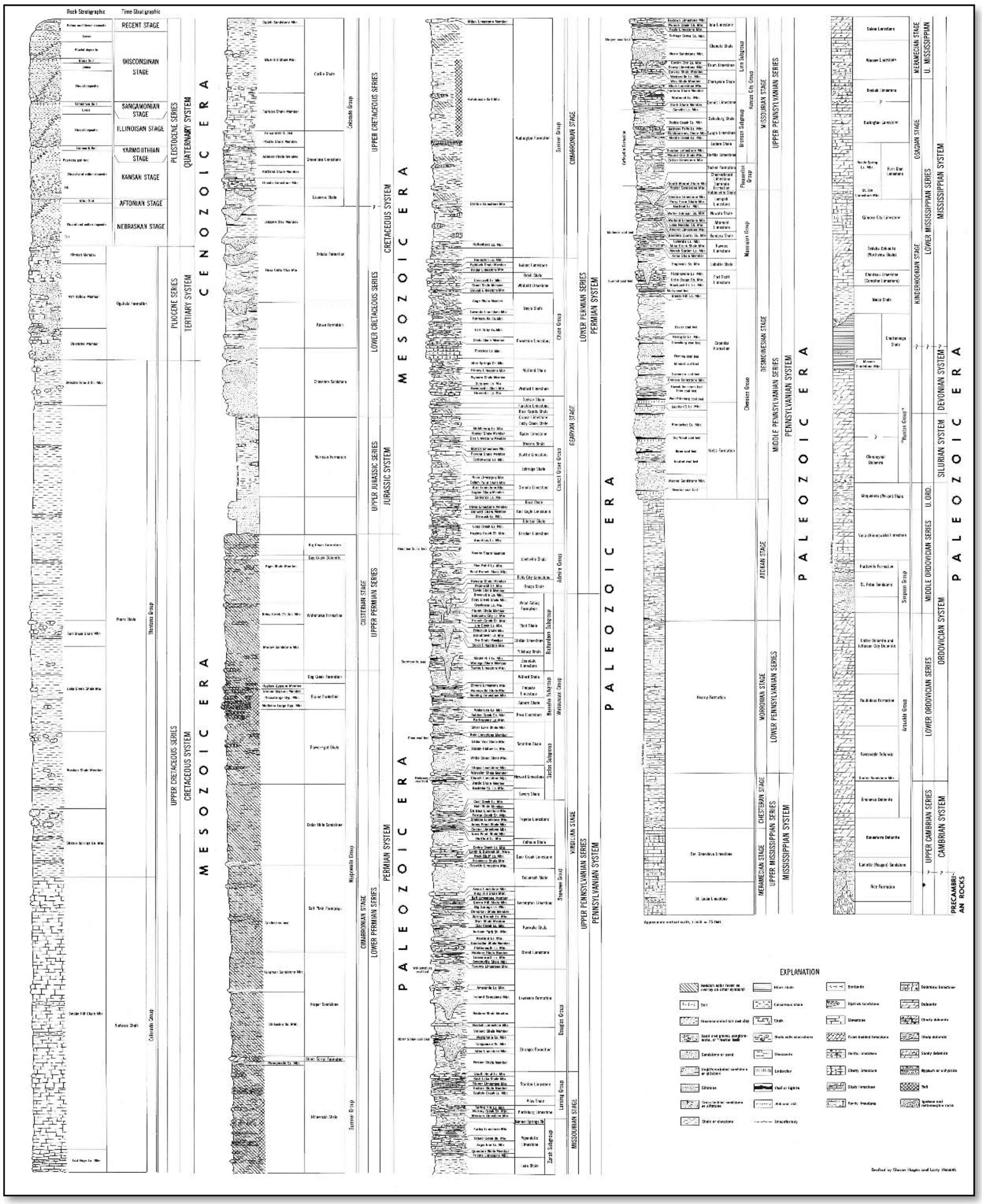

Figure 2:Stratigraphic Column of Kansas (modified from Zeller et al., 1968)

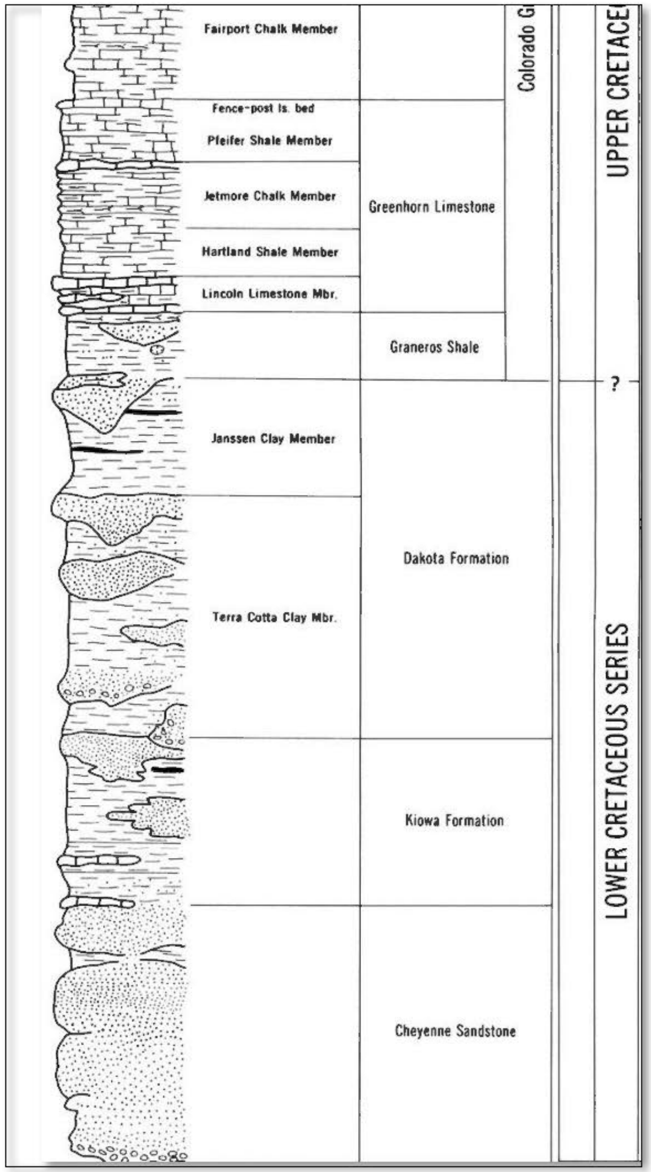

Figure 3:Excerpt of Figure 2 Section with Focus on the Dakota Formation (modified from Zeller et al., 1968)

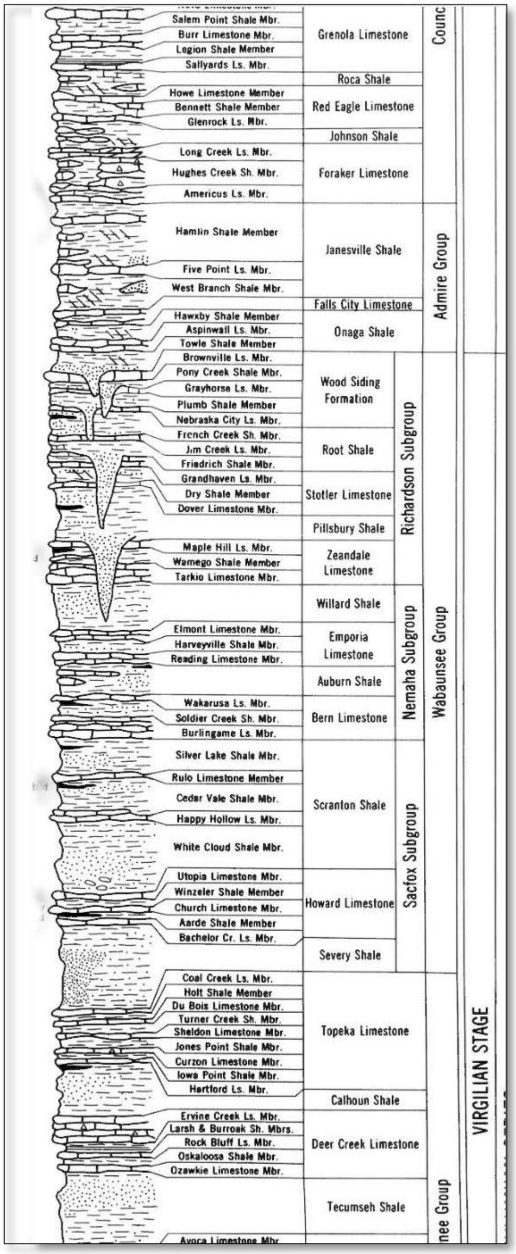

Figure 4: Except of Figure 2 Section with Focus on the Wabaunsee Group (modified from Zeller et al., 1968)

Methodology

The steps used in this project can be broken into three phases. The first phase included obtaining uranium proxies and relevant map data and using ArcGIS to produce a prospecting map to act as a guide for field site selection. This included importing data layers, digitizing elements from non-shapefile sources, raster reclassification, raster calculation, and comparison with data points from the National Uranium Resource Evaluation (NURE) program. The second phase of the project included obtaining permissions from landowners to sample and retrieve coal samples from the chosen field sites for analysis. The third and final phase was the analysis of collected samples via two Geiger counters in the lab at Fort Hays State University.

Literature Review

Coal bed uranium was first discovered in the Wasatch Formation of northeast Wyoming in the 1950's, and the Atomic Energy Commission and the United States Geological Survey began joint research into the study of this phenomena (Love, 1952). These projects sought to locate and measure coal bed uranium in the United States (Denson et al., 1959). These studies were conducted throughout the West and Midwestern regions, but Kansas was not investigated for the potential of coal bed uranium. The closest investigation into this matter was the study by Landis (1959) that indicated that there is uranium in the shale deposits of the Pierre Shale in Western Kansas. Given the commercial and safety concern importance of coal bed uranium and the confirmed presence in neighboring states, it is reasonable and sufficient cause for investigation into the subject of coal bed uranium in the state of Kansas and to further examine the properties of coal bed uranium.

Joint studies of the United State Geological Survey and Atomic Energy Commission studies concluded that coal bed uranium is most typically produced by the chemical breaking down of uranium-bearing rocks (Denson et al., 1959). As these rocks physically and chemically break down, the uranium is released. This free uranium can be picked up by moving groundwater that can then transport it over distance into aquifer systems. These aquifer systems then allow for the transported uranium to integrate with nearby rock layers (Gill, 1959; Mapel & Hail Jr., 1959; Pipiringos, 1961). This process and the reported presence of radon in Kansas groundwater supplies is part of why the presence of uranium-bearing ash deposits in Kansas is such an important indicator of potential coal bed uranium deposits (James, 1978; Kalout, 1996).

The United States Geological Survey and Atomic Energy Commission studies also noted that identified coal bed uranium was most often found in lignite and subbituminous coal varieties. Breger et al. (1955) investigated this phenomena and determined that this may be due to the preferential stability of the uranium and lignite compound. Said study also determined that the metallo-organic compound formed by uranium and the organic components of the lignites was stable and that the organic components of the lignite possesses a chemical structure that is far more accepting of uranium introduced to it. This chemical acceptance and strong bond is unique in that it makes lignites and subbituminous coals more readily able to capture and bond to uranium than other coal varieties; provided that the groundwater can reach the lignite (Breger et al. 1955). Moore (1954) even demonstrated this absorption and bonding ability by submerging a lignite sample into an aqueous solution containing uranium and the lignite was able to extract greater than 99 percent of the uranium from solution. Nakashima (1992) showed that uranium can undergo reduction upon joining with lignite.

Lignite is a subtype of coal that is characterized by high carbon content and low heat production when burned (McCartney & Teichmüller, 1972). Lignite is commonly referred to as “brown coal” and is rated as the lowest quality coal. Lignite is formed from the compaction and heating of peat through the process of coalification. Lignite typically has a higher concentration of volatiles and hydrogen than other coal types, as higher coal grades have undergone more heating and compaction to force out extraneous materials (McCartney & Teichmüller, 1972).

Other researchers, such as Moore et al. (1959) determined that the permeability of the overlying and underlying rock layers can have a significant impact on if and where uranium can be found in coal. If the contacting rock layers are fractured or in some other way permeable, then groundwater can more easily get to the coal layer and interact with it on a chemical level. If a coal bed is underlain by a very impermeable rock, such as a tightly packed sandstone, then any uranium that collects in the coal bed layer will be unable to leach out of it due to meteoric water or groundwater interactions (Moore, 1959). Other studies have sought to identify other rock units that could hold uranium, such as the study by Landis (1959) that indicated that there was uranium present in the Sharon Springs Member of the Pierre Shale in western Kansas.

The investigations of researcher from other countries into the geochemistry and characteristics of coal bed uranium have yielded insights into how uranium most frequently occurs in coal and what attributes contribute to uranium accumulation in various coals. Arbuzov et al., (2011) determined that the five factors affecting the accumulation of uranium in coal are tectonics, source rock chemistry, syndepositional volcanism, coal metamorphism, climatic factors, local hydrology, and hypergenic oxidation of the coals. Russian researchers have concluded that uranium will most often naturally occur in a coal as the minerals uraninite and coffinite, or as trace particles that can occur in different patterns throughout a sample (Arbuzov et al., 2012). The patterns of uranium dispersal through a sediment can be uniform, in star-like clumps, reticular distribution, linear distribution, clusters over phosphate, and inhomogenous distribution. Finch and Ewing (1992) determined that the most common uranium-based mineral, uraninite, undergoes oxidation at a rate that is determined by the amount of lower valence cations that are incorporated into it during formation and radioactive decay.

METHODOLOGY

ArcGIS and Field Site Mapping

In order to prospect for coal bed uranium in Kansas, it was first necessary to develop a map that would be used to select the prospecting sites where coal and therefore coal bed uranium could possibly be gathered. ArcGIS ArcMap 10.5 was used to produce a map that would be accurate to the county level. For the purpose of this project, the imported layer was a Kansas county base map. The proxy layers for coal bed uranium were created using data from the Kansas Radon Program and the Kansas Geological Survey. These proxies consist of radon data for Kansans counties and coal production data for Kansas counties. Radon was chosen as a proxy due to it being an intermediate step in the decay chain of uranium. The Kansas base map was retrieved from the State of Kansas GIS Data Access and Support Center (see Figure 5) (Tiger Census Counties, 2014).

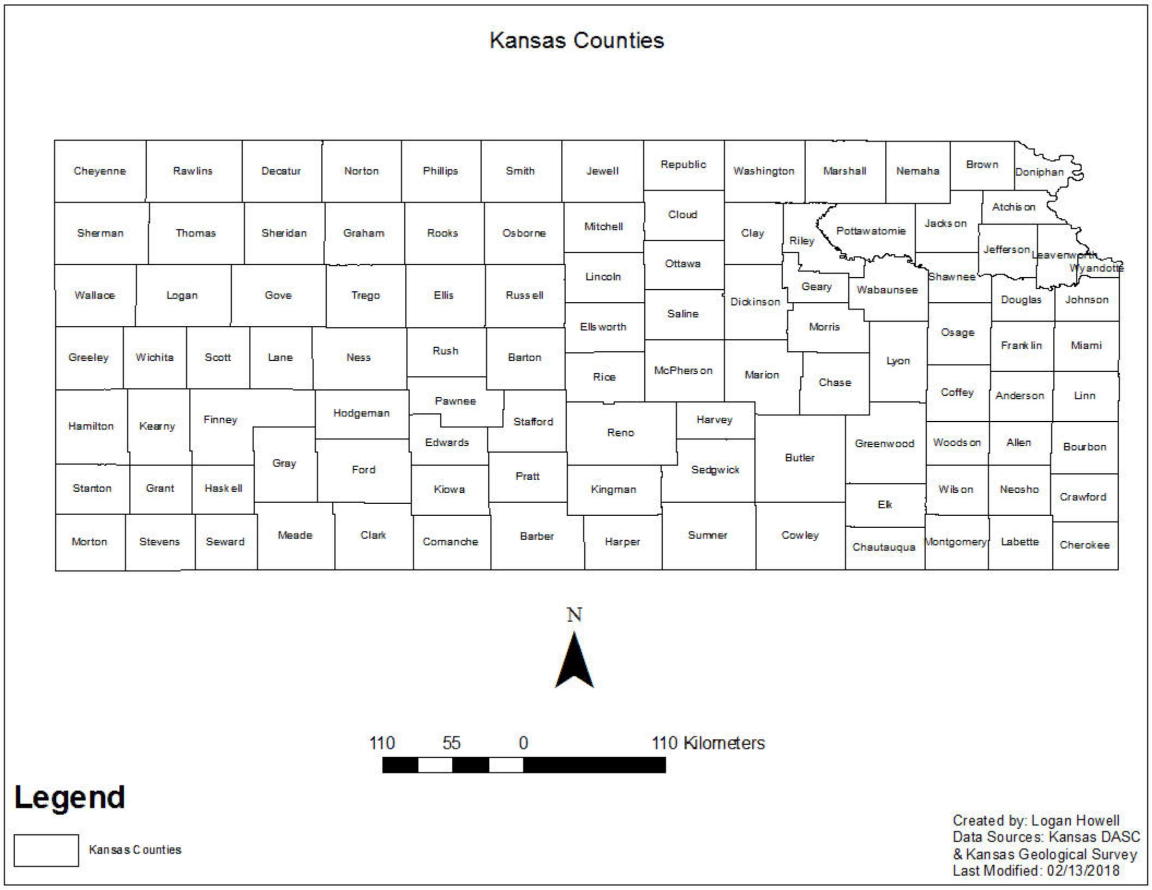

Figure 5: Kansas Counties

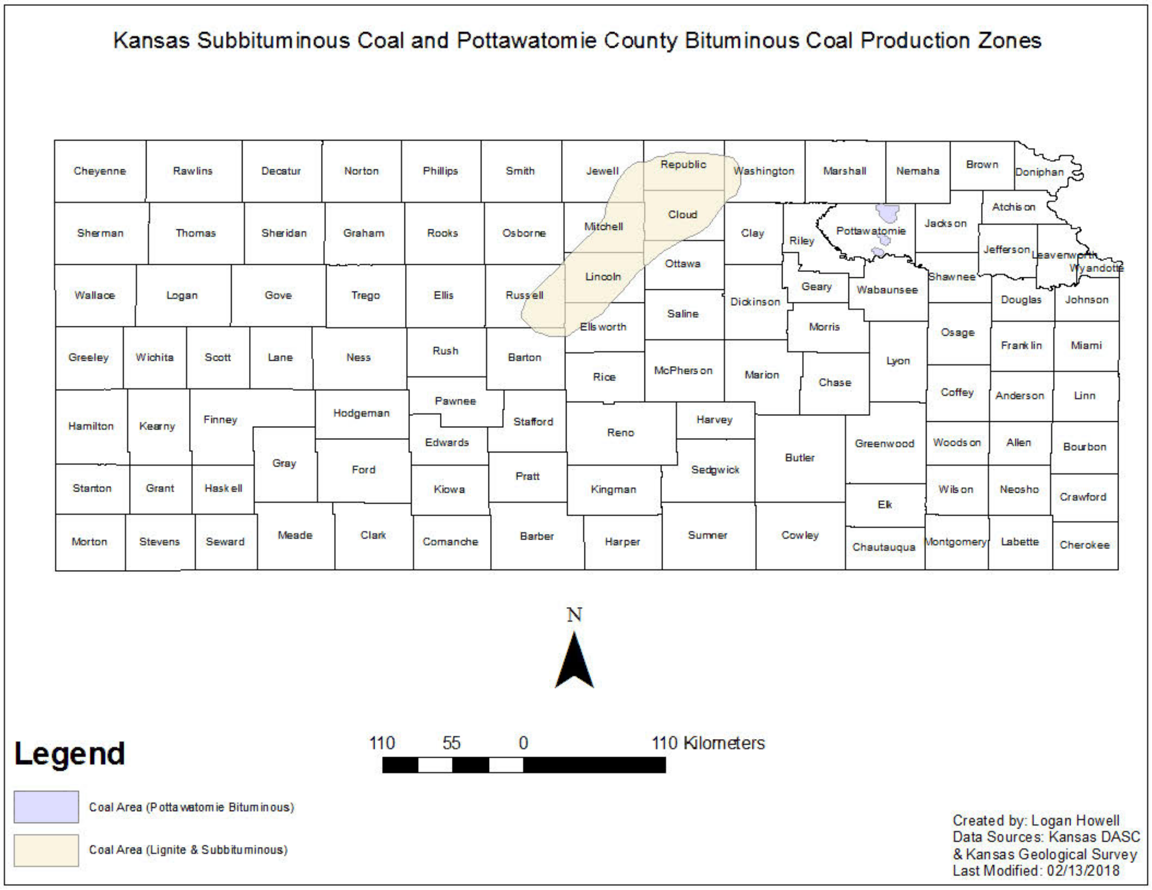

Figure 6: Subbituminous and Pottwatomie County Bituminous Coal Production Zones

After being imported, the data layers were transformed to fit the NAD83 datum. Coal bed maps from the Kansas Geological Survey were used to outline coal exposures within Kansas counties. (see Figure 6) (Schoewe, 1952). To make the coal raster, the coal production map picture was georeferenced using the Kansas base map acquired from the State of Kansas GIS Data Access and Support Center. The georeference tools allows an image to be associated with spatial coordinates to fit the image into the known spatial orientation of the image's subject. Polygons were then drawn based on the overlay of the coal production map image from the Kansas Geological Survey (Flueckinger & Brady, 2010). The original KGS image had both subbituminous and bituminous production zones, though only the subbituminous (yellow) and Pottawatomie bituminous (purple) production zones were digitized into ArcGIS. This was because the subbituminous values were used in the prospecting calculation and the Pottawatomie zones were added in later due to a landowner invitation to sample a bituminous coal seam in Pottawatomie county (see Figure 6). The historic coal production values for the counties within the subbituminous coal production zones were used to produce the coal raster that represented the levels of coal production throughout the state (see Figure 7) (Schoewe, 1952).

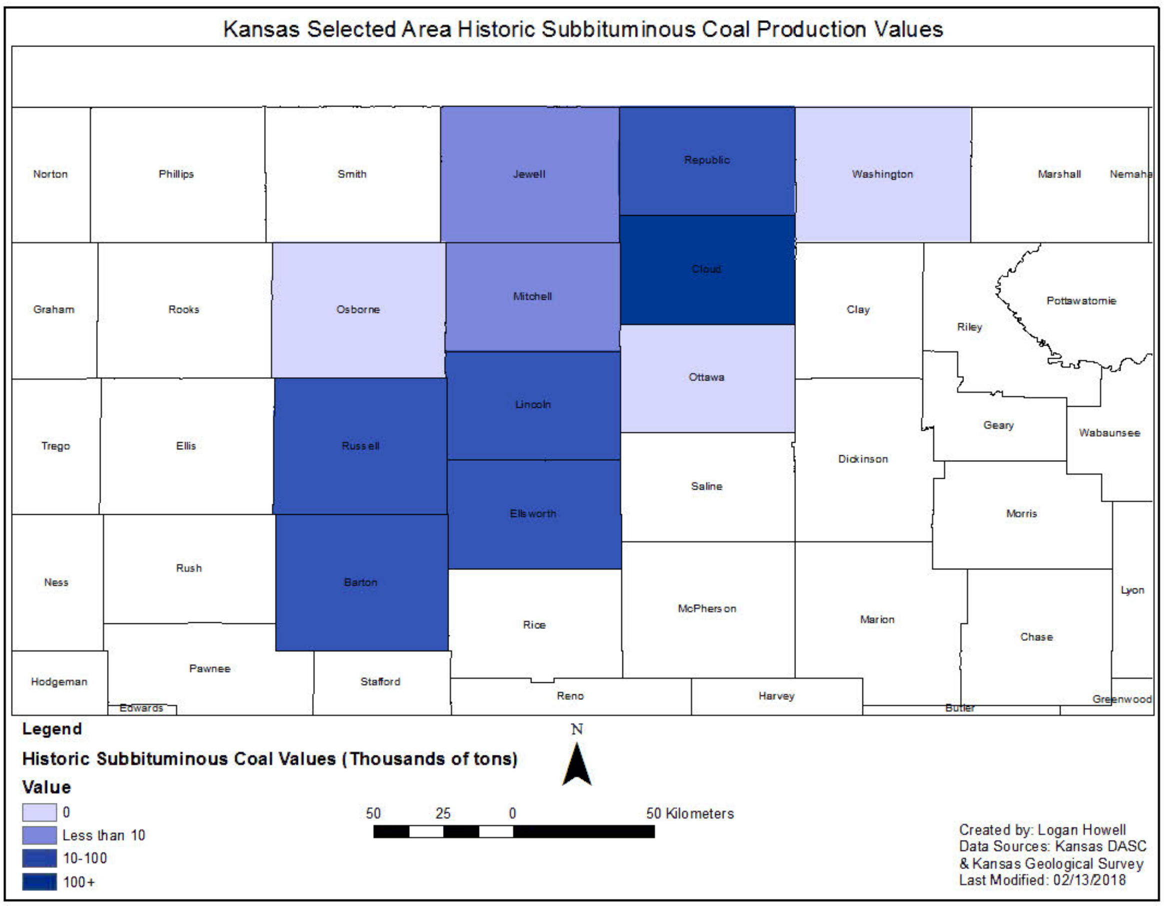

Figure 7: Selected Area Historic Subbituminous Coal Production Values

The Kansas base map data layer had fields added to the attribute table that corresponded to measured radon levels according to the Kansas radon map acquired from the Kansas Radon Program (KRP, 2015). The KRP breaks radon levels into three screening levels based on indoor radon and cause for concern. For the sake of future raster calculation, the breakdown of three categories was preserved. The radon level attribute field data was used to create a raster layer that showed the varying radon levels in Kansas so that it could be used with the coal production raster to establish the best counties to consider for prospecting (see Figure 8). The county base map was used as the tool extent and mask to ensure Arc would not overextend the conversion. An extraction by mask was performed to create a map of radon purely within the counties that fell within the subbituminous coal production zone (see Figure 9).

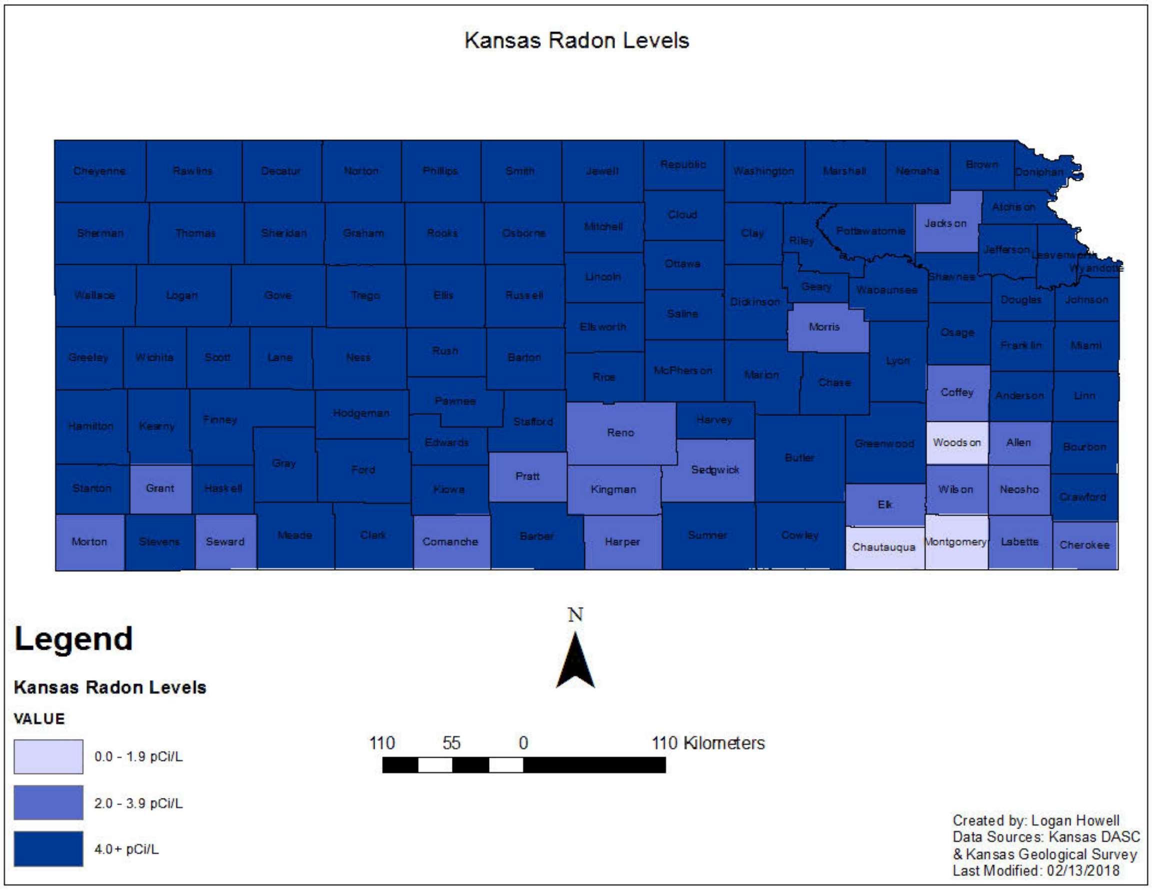

Figure 8:Kansas Radon Levels

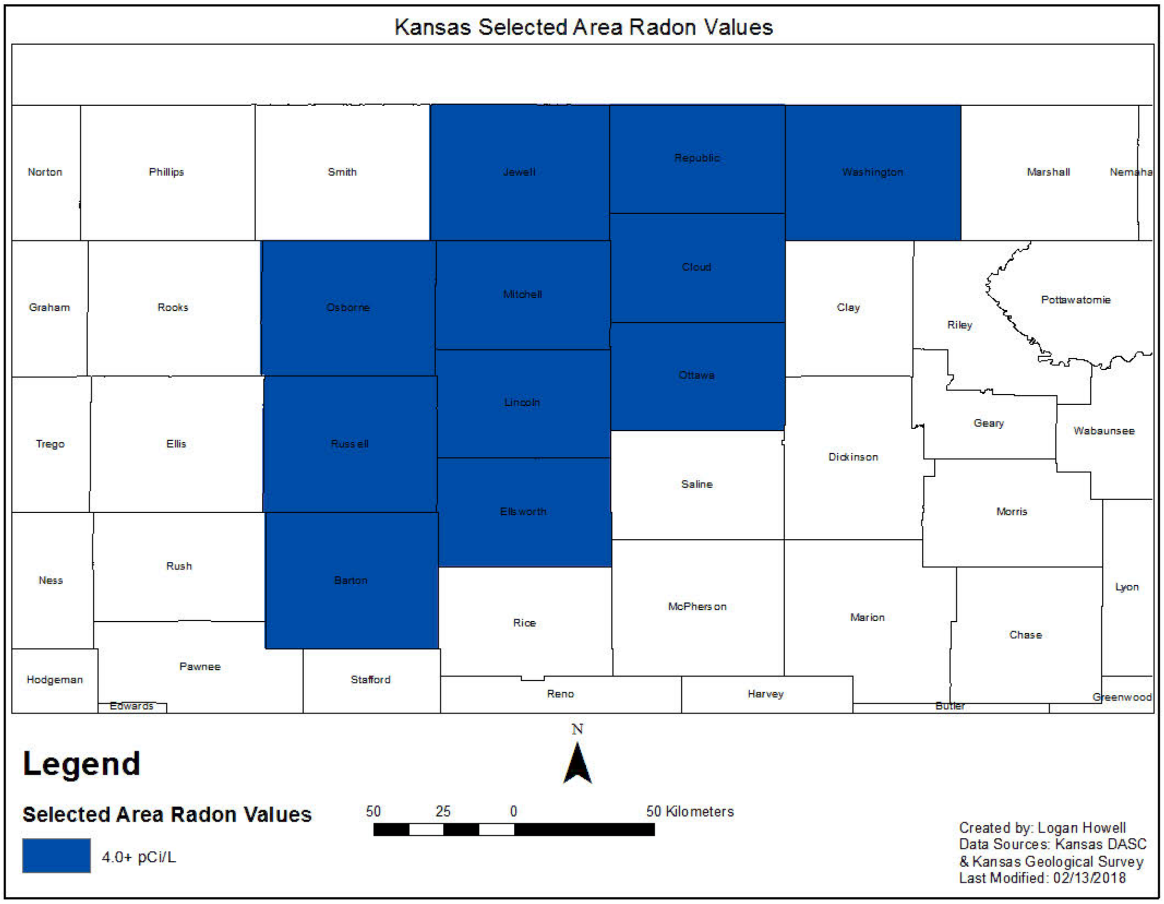

Figure 9:Kansas Selected Area Radon Values

After completing the creation of both rasters, they were each reclassified into basic counts of one, two, and three (see Appendix A). One represented low values (of radon and subbituminous coal production), while two represented medium and three represented high. This reclassification of values allowed for the varying amounts and units to be added together with equal consideration by the program. The radon and coal raster datasets were finally added together using the ArcGIS Raster Calculator tool in order to produce a final raster that represented what areas would be the best sites for prospecting based on their recorded radon levels and coal production (De Smith et al., 2007). In this case, the raster calculator added the attribute values from the coal and radon layers in order to produce a viability layer. The equation used to produce the final map was Coal_Layer + Radon_lvl (see Figure 10). The reasoning behind this is that the areas with the highest amount of reported subbituminous coal production and the highest radon levels would be the best possible location to find coal bed uranium in Kansas. As all counties within the subbituminous coal production area were already classified as having high radon and could have either no, low, medium, or high subbituminous coal production, this meant that the resulting raster representing the viability of finding coal bed uranium placed counties into one of four categories. This resulted in the areas with the highest historic subbituminous coal production and highest radon levels being marked as the best possible locations for the viability of coal bed uranium (see Figure 11) (De Smith et al., 2007).

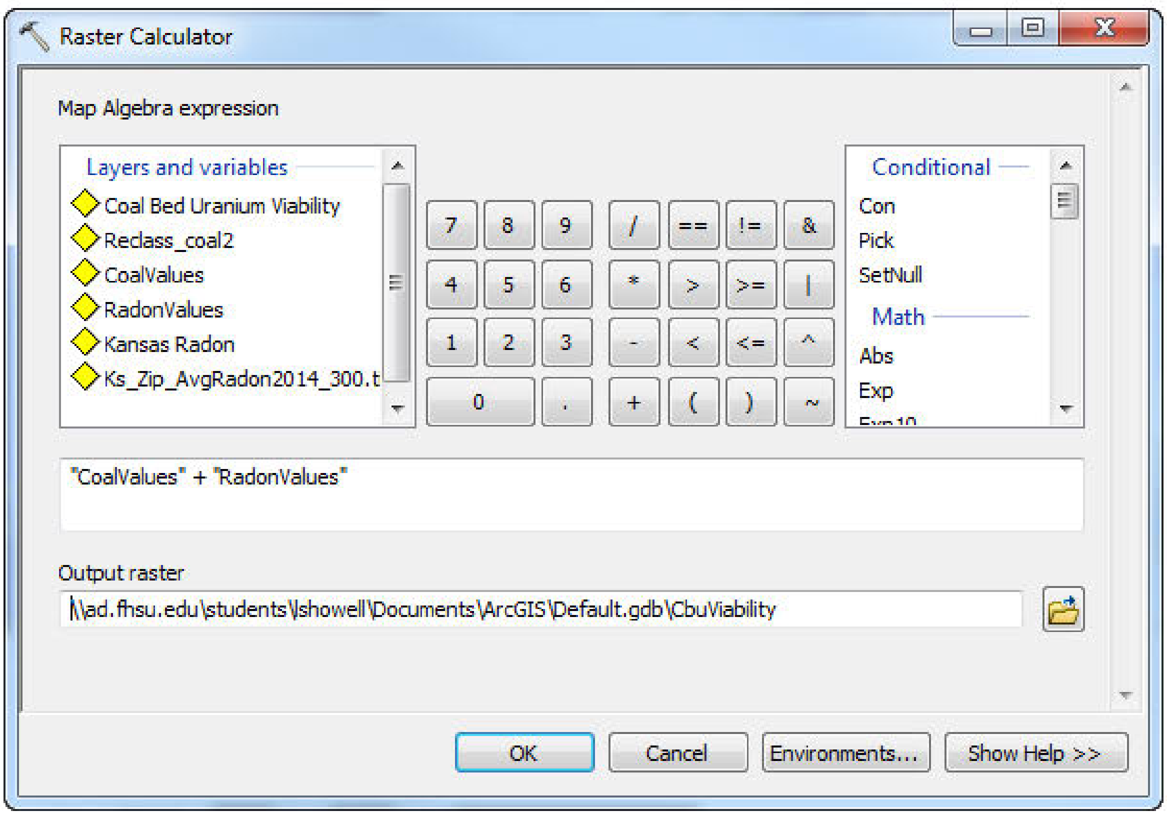

Figure 10: Raster Calculation Equation

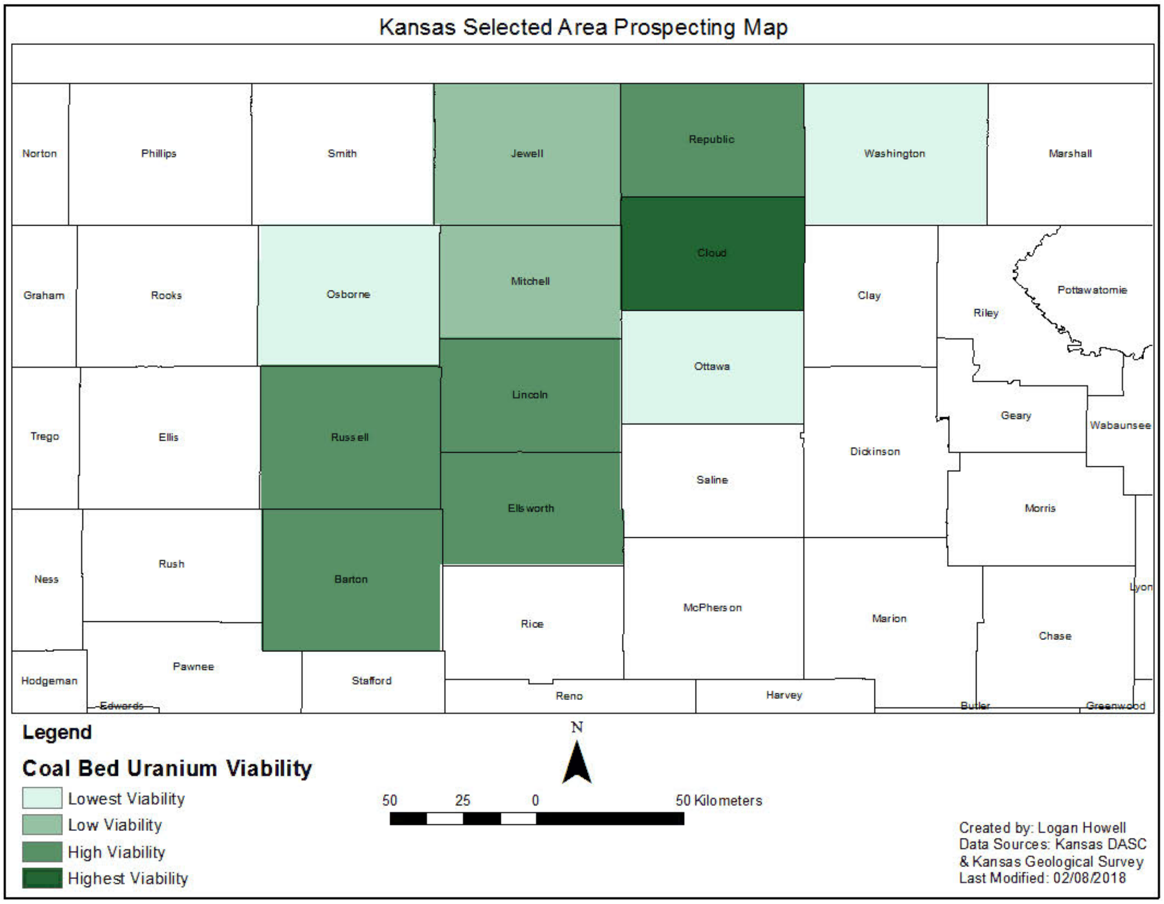

Figure 11: Kansas Selected Area Prospecting Map

The ArcGIS map was compared with the National Uranium Resource Evaluation (NURE) data that was collected by the USGS after sample collection for comparison purposes in order to visualize how the prospecting map lines up with a larger collection of sediment samples. The National Uranium Resource Evaluation is a collection of sediment and water samples throughout the United States that have been examined using various means to test for uranium, though for the purposes of this project, only sediment samples were included in the comparison. There are 333 uranium samples that fall within the viability zone, with yellow and green icons representing samples with higher parts per million uranium values than the surrounding orange and red icons. These were compared visually because of the difficulties in hotspot surface mapping due to the partial nature of the NURE data (see Figure 12) (Smith, 1997).

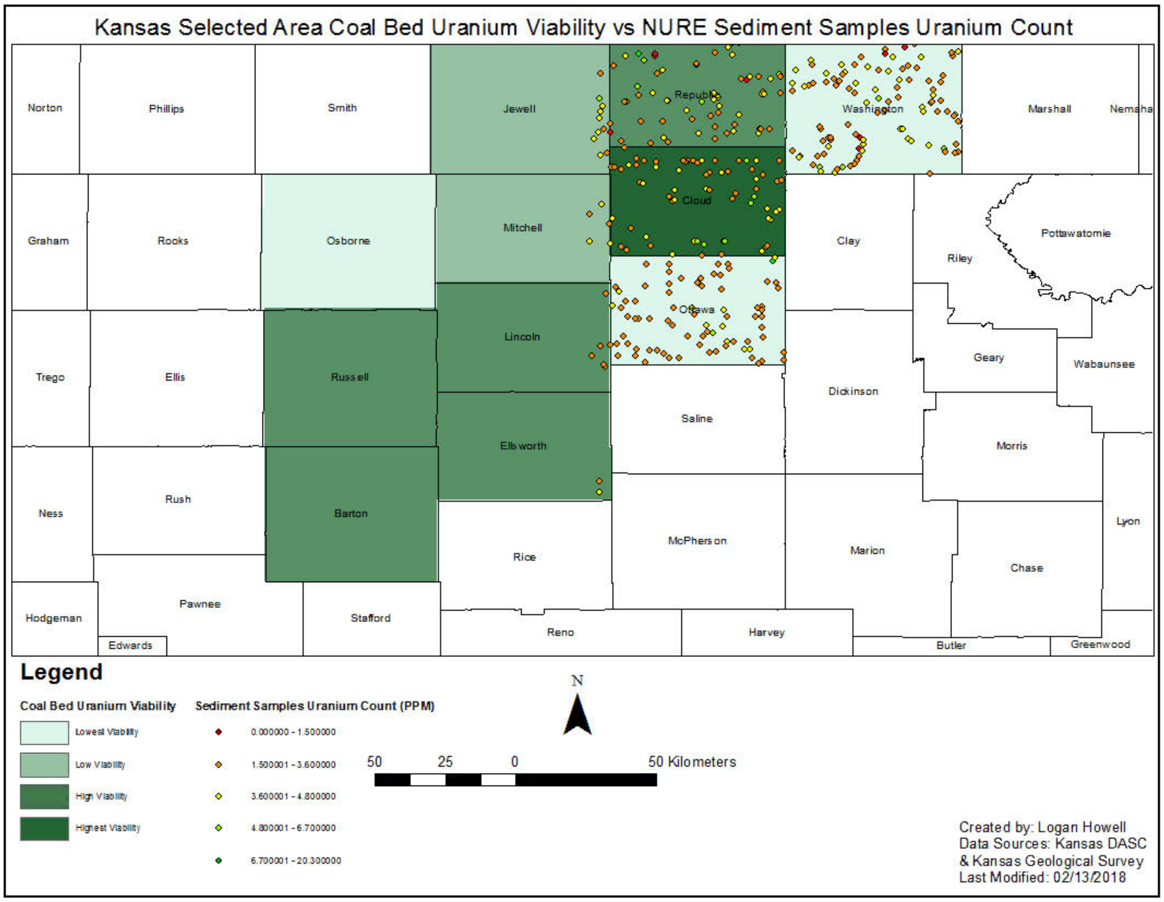

Figure 12:Kansas Prospecting Map vs NURE Sediment Samples Uranium (ppm)

Fieldwork

The map resulting from the ArcGIS analysis was used to pick an initial county to act as a starting point for the field prospecting (see Figure 11). Areas where the raster calculation gave the highest viability of coal bed uranium were highlighted as the best potential areas for prospecting. The locations highlighted on the map were used to select the field sites for the investigation of coal bed uranium for this project and represents both potential commercial use and identifying potential environmental and health safety concerns. Analysis indicated that Cloud County would be the best starting location due to the historically high production of lignite and subbituminous coal and the high radon readings within the county. After an initial prospecting trip to Cloud County, networking resulted in invitations to examine field sites on private property in both Jewell and Pottawatomie counties. Whereas Love (1952) used a Geiger counter and a scintillometer in the field, this study collected *in situ* samples from an exposed coal seam deposits and secondarily deposited samples from mining tailings piles and brought them back to a lab at the Fort Hays State University Geoscience Department to prevent false readings from outside sources. Cloud County samples were recovered from two major tailings piles that were remnants of a pioneer mining operation that was present in the area (see Figures 13 & 14) (Beede, 1897).

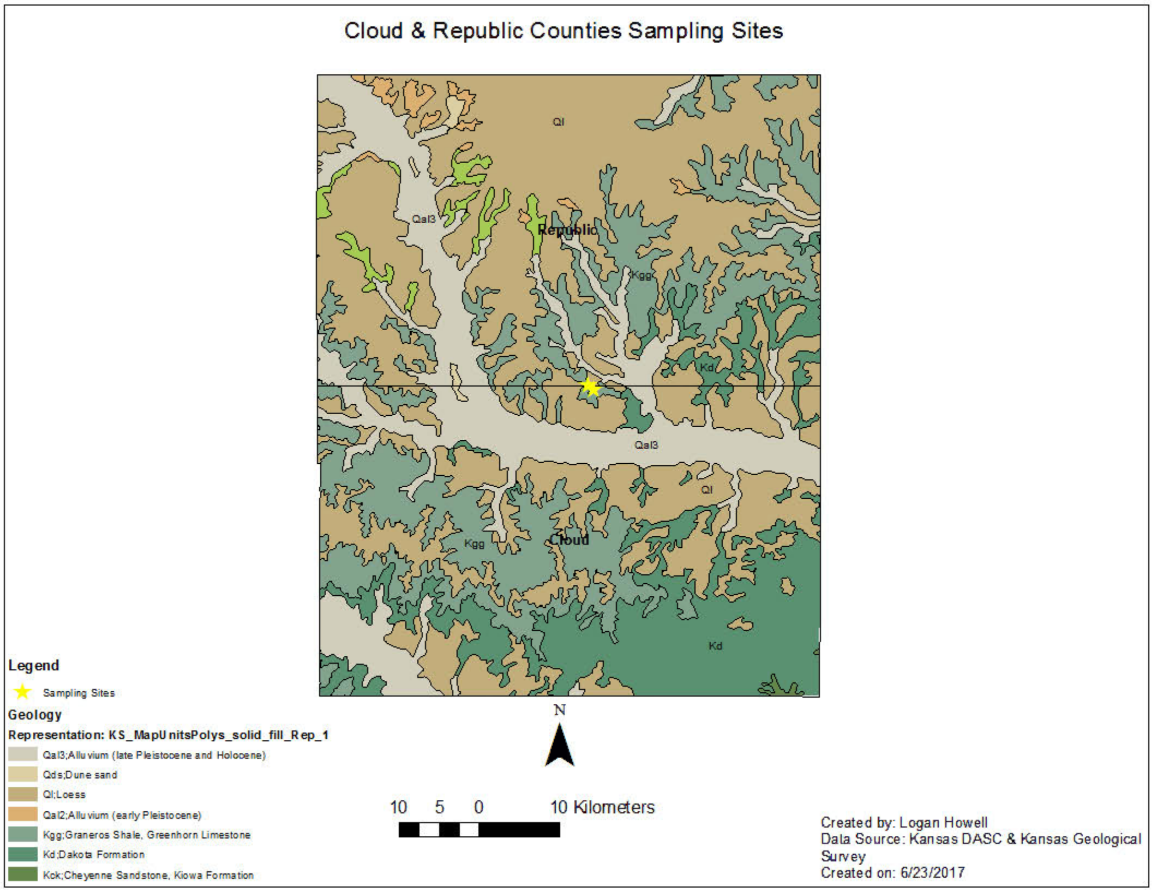

Figure 13:Cloud and Republic Counties Sampling Sites

Figure 14: Cloud/Republic County Tailings Pile (63.5 cm Estwing pickaxe for scale)

The Jewell County samples were recovered from two tailings piles that were the result of previous landowner mining operations that were located in the southeastern portion of the county (see Figure 15). The tailings piles at the Cloud and Jewell county sites were surveyed and fragmentary coal specimens were collected and bagged for analysis back at the lab.

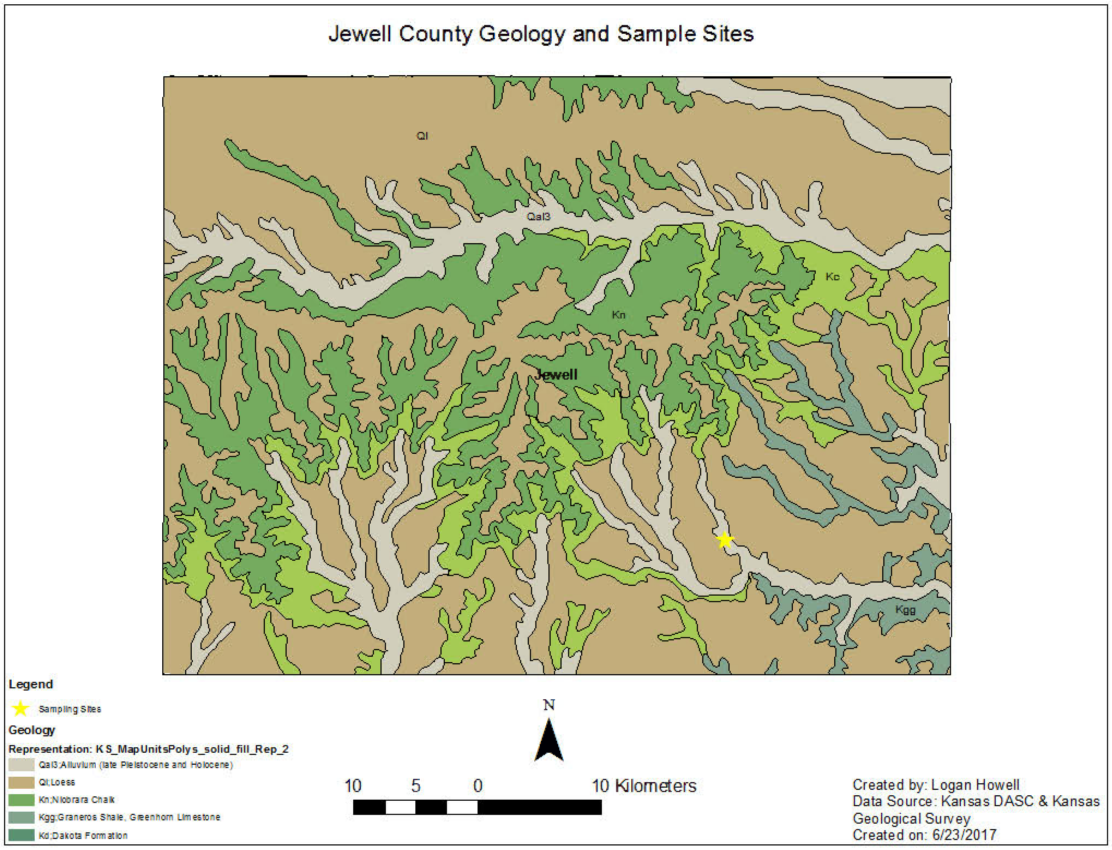

Figure 15: Jewell County Geology and Sample Sites

Samples from the Pottawatomie County site were collected from an exposed coal seam on the bank of a small creek and were collected *in situ*. All sample sites were on private land and specific coordinates have been withheld due to landowner request. The Cloud and Jewell county samples were identified as coming from the Dakota Formation based upon recorded lithology during mining, mine shaft depth, and surficial geology (see Figures 13 & 15).

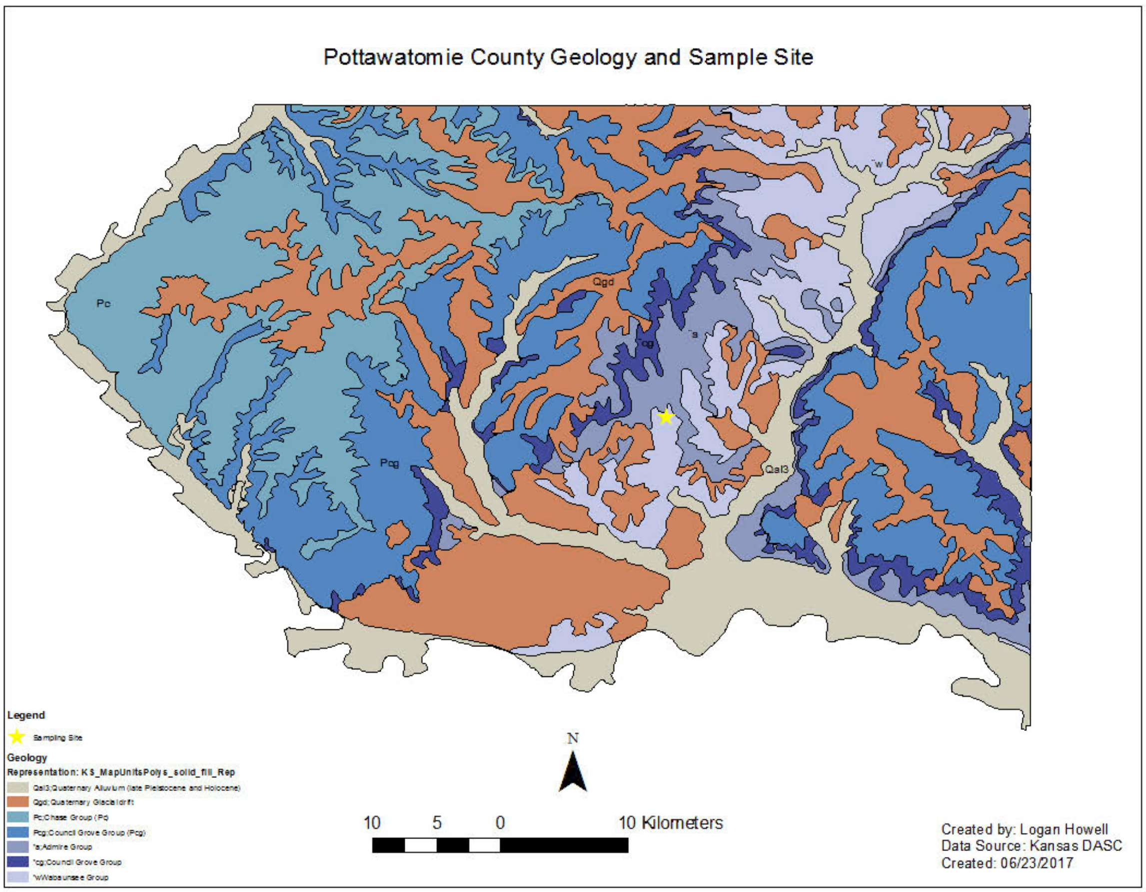

Figure 16: Pottawatomie County Sampling Site and Surface Geology

The Dakota Formation is a Cretaceous age sedimentary system that is distributed throughout the Great Plains and Rock Mountain regions, though for the purpose of this project the focus was on the Dakota Formation within Kansas (Zeller et al., 1968;

Macfarlane et al., 1998). The formation is approximately 200-300 feet thick. It overlays the Kiowa Formation and has a transitional upper contact with the Graneros Shale. The Dakota Formation is comprised of layers of clay, siltstone, and sandstone with lignite seams and channels sandstone deposits. The formation is broken up into the Janssen (also known as the Janssen Clay) and the Terra Cotta (also known as the Terra Cotta Clay) members. The Dakota Formation in Kansas represents alluvial plains and deltas that existed on the eastern side of the Cretaceous interior seaway. The sandstone layers present represent deltaic fronts while the lenses are identified as channel sandstones. The siltstone layers are attributed to alluvial plain sedimentation. The lignites present in the Dakota Formation most likely represent near-coastline swamps (see Figures 17 & 18) (Zeller et al., 1968, Macfarlane et al., 1998).

Figure 17: Coal sample recovered from Jewell County

Figure 18: Coal Sample recovered from Cloud/Republic County

The Pottawatomie County samples were identified as clarain coals from the Wabaunsee Group according to recorded lithology during mining and mine shaft depth (see Figure 19) (Stopes, 1919). The Wabaunsee Group is a Pennsylvanian age group of cyclothems that consists of the Wood Siding Formation, the Root Shale, the Stotler Limestone, the Pillsbury Shale, the Zeandale Limestone, the Willard Shale, the Emporia Limestone, the Auburn Shale, the Bern Limestone, the Scranton Shale, the Howard Limestone, and the Severy Shale (Schoewe, 1946; Merriam, 1963). The Wabaunsee Group is roughly 500 feet thick. The formations of the Wabaunsee Group are comprised of alternating shales and limestones that are representative of both transgressive and regressive oceanic movements. The Wabaunsee Group is primarily composed of shales and limestone, with four major and multiple minor coal beds throughout the group. The four major coals within the Wabaunsee are the Lorton, Nyman, Elmo, and Nodaway coals. The major coal systems can extend up to 200 miles without interruption, indicating that they were most likely the result of coastal swamps (see Figure 4) (Schoewe, 1946; Merriam, 1963).

These units are important relative to this study because they provide the coals for uranium to be absorbed into. The proximity to possible uranium sources such as the Pearlette Ash Bed also makes the depositional environment and stratigraphic context of these units valuable to this study, as they are in stratigraphic position to receive potentially migrating uranium. Being Cretaceous and Pennsylvanian deposits, the age of these units also has allowed for ample time for the migration of uranium from host rocks and for the absorption of any free uranium by nearby coals (Zeller et al., 1968, Schoewe, 1946; Merriam, 1963; Macfarlane et al., 1998).

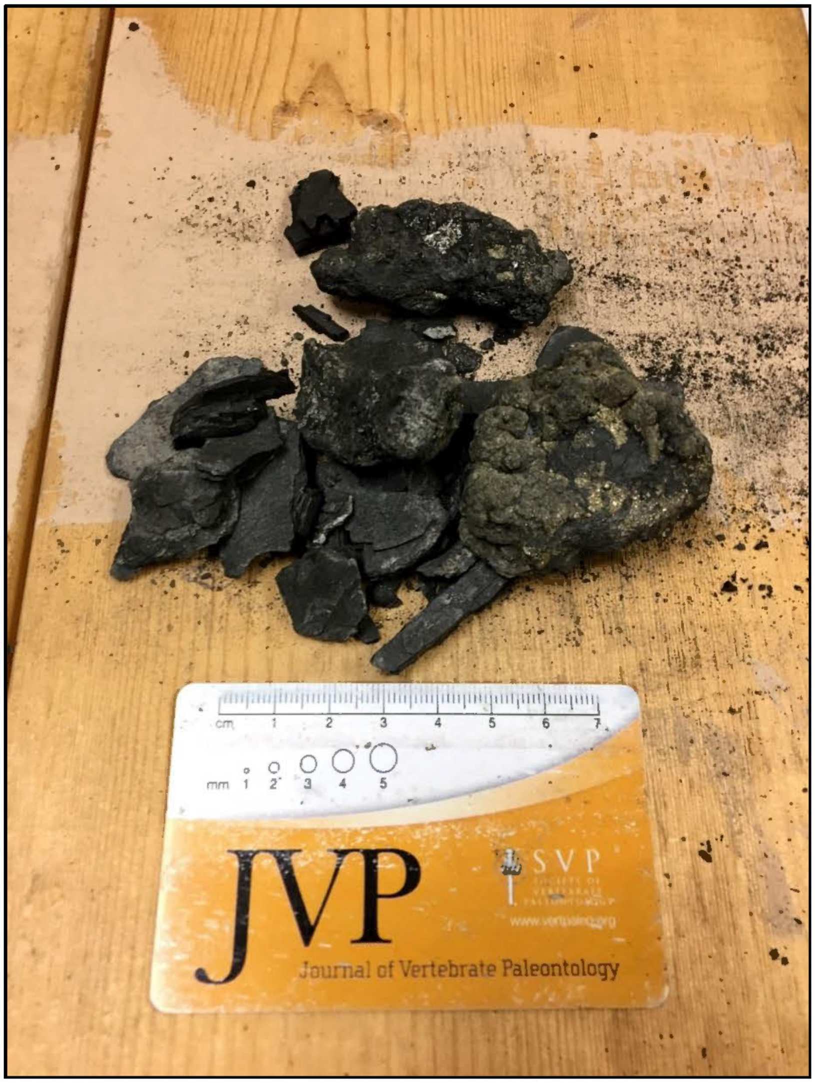

Figure 19: Coal sample from Pottawatomie county featuring pyrite

Lab Work

Coal samples were measured in the *X-ray LAB* of the FHSU Geosciences Department for radioactivity through the use of two Geiger counters. Any radioactivity reading occurring in the coal samples would most likely be due to a natural source, since the field sites were largely isolated locations. The two most common natural radioactive elements are uranium and thorium. Therefore, any radioactive elements detected would most likely be one of these two, though any radioactive samples would have been sent out for full compositional analysis. The first Geiger counter used in the coal analysis was a refurbished Victoreen Instrument Company OCDM CD V-700, Model 6B. The second Geiger counter used was a Radiation Alert brand Radiation Alert Monitor. Both Geiger counters were tested against a known radioactive standard that was provided with the Victoreen instrument and registered the sample as radioactive on all sensitivity settings. Both Geiger counters can register radioactivity ranging from 0-50 milliroentgens per hour (mr/hr). A reading of .5 mr/hr can equate to 0.05 percent equivalent uranium in a sample (McKeown & Klemic, 1954). Once both units were verified as working properly in the identification of radioactive samples, they were used with the coal samples collected from the county field expeditions. Average background radiation according to manufacturer specifications is categorized as 0.01 to 0.02 milliroentgens per hour. Therefore, any readings higher than this would have warranted further investigation. The samples were analyzed on all available settings including X1, X10, and X100. These settings correspond to the actual radiation measured as the reading on the dial multiplied by one, ten, or 100.

RESULTS

The samples from all counties surveyed did not result in any consistent readings from either of the Geiger counters on any of the sensitivity settings. There was no difference in results between fresh seam samples and tailings pile samples. Results for the Geiger counter tests are included in the table below (see Table 1).

Table 1: Results of Geiger counter tests of Pottawatomie (S series), Cloud (1T & 2T series), and Jewell (J series) county coal samples

	Victoreen V-700, Model 6B			Radiation Alert Monitor 4		
Sample	X1	X10	X100	X1	X10	X100
S1	Negative	Negative	Negative	Negative	Negative	Negative
S2	Negative	Negative	Negative	Negative	Negative	Negative
S3	Negative	Negative	Negative	Negative	Negative	Negative
S4	Negative	Negative	Negative	Negative	Negative	Negative
S5	Negative	Negative	Negative	Negative	Negative	Negative
S6	Negative	Negative	Negative	Negative	Negative	Negative
S7	Negative	Negative	Negative	Negative	Negative	Negative
S8	Negative	Negative	Negative	Negative	Negative	Negative
S9	Negative	Negative	Negative	Negative	Negative	Negative
S10	Negative	Negative	Negative	Negative	Negative	Negative
1T-1	Negative	Negative	Negative	Negative	Negative	Negative
1T-2	Negative	Negative	Negative	Negative	Negative	Negative
1T-3	Negative	Negative	Negative	Negative	Negative	Negative

2T-1	Negative	Negative	Negative	Negative	Negative	Negative
2T-2	Negative	Negative	Negative	Negative	Negative	Negative
2T-3	Negative	Negative	Negative	Negative	Negative	Negative
2T-4	Negative	Negative	Negative	Negative	Negative	Negative
2T-5	Negative	Negative	Negative	Negative	Negative	Negative
2T-6	Negative	Negative	Negative	Negative	Negative	Negative
2T-7	Negative	Negative	Negative	Negative	Negative	Negative
2T-8	Negative	Negative	Negative	Negative	Negative	Negative
J1	Negative	Negative	Negative	Negative	Negative	Negative
J2	Negative	Negative	Negative	Negative	Negative	Negative

The results of the comparison of the field site selection map and the United States Geological Survey NURE data are displayed below. NURE coverage is partial in the state of Kansas. What coverage is available indicates uranium values higher than global estimates for coals, which are 2.9 parts per million (ppm) for brown coals and 1.9 ppm for hard coals (Ketris & Yudovich, 2009). Coverage of north-central Kansas that overlays the subbituminous coal production zone includes some of the highest uranium in parts per million readings in the entire area (see Figure 20).

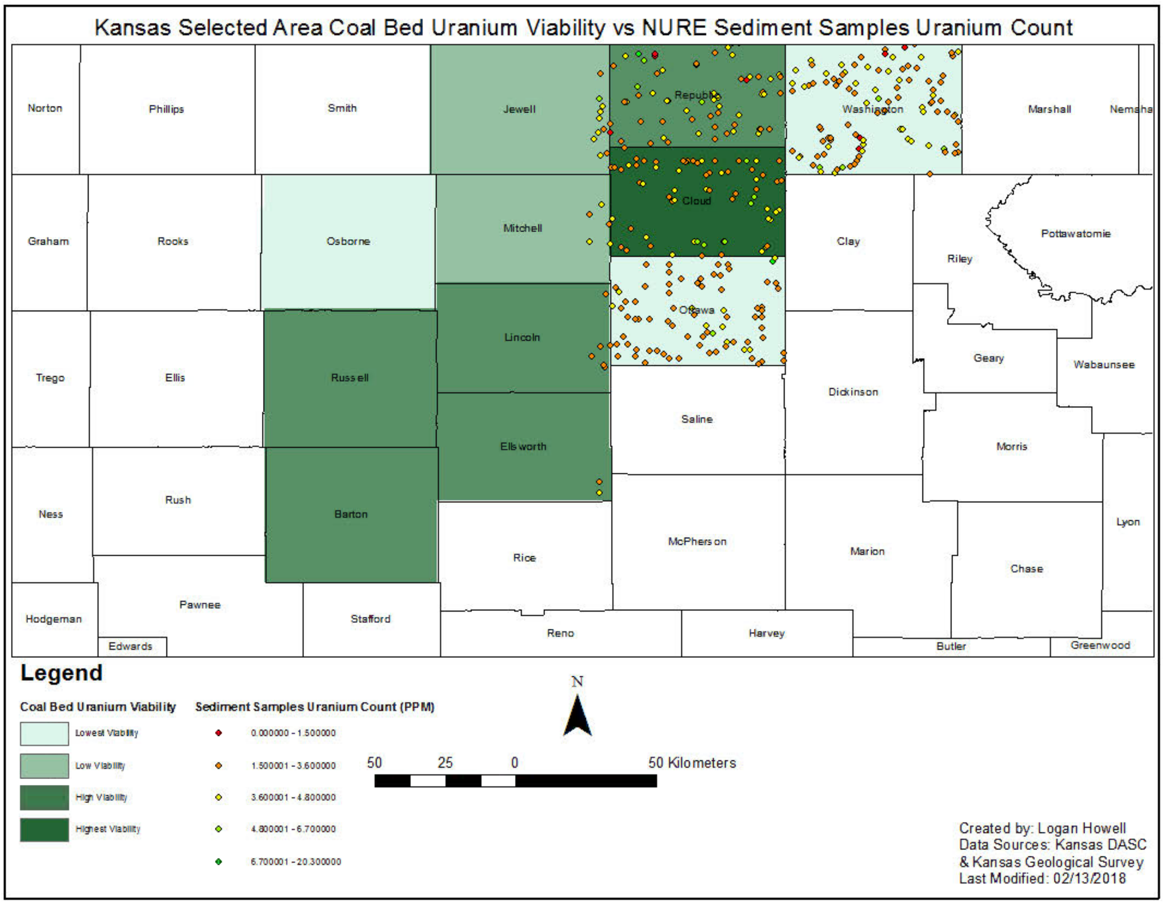

Figure 20: Site selection vs NURE Sediment Sample Comparison Map

DISCUSSION

Conclusions

Given the lack of consistent and significant readings of the samples with both Geiger counters, it can be concluded that the samples obtained from the field study did not contain measurable amounts of uranium nor any other radioactive material. No evidence was found by this study that would indicate the presence of coal bed uranium in Cloud, Jewell, or Pottawatomie counties. Whether this is due to there not being coal bed uranium in the areas investigated or due to the limitations of equipment and survey sites, it cannot be concluded as to whether coal bed uranium is present in North-central Kansas. The comparison between the prospecting map and the NURE data has interesting implications is further study into this methodology. The overlap between the suggested prospecting sites and the higher sediment uranium values (ppm) from the NURE data suggests that the prospecting map and methodology may be useful in future exploration with the addition of supplementary proxies depending on the area.

Limitations

One limitation of the study was the availability of sampling sites, which was impacted by two factors. The first was that the map was also limited in accuracy down to the sub-county level; with radon values being limited to the county level and coal production zones covering large areas within certain counties. The second factor influencing the availability of sampling sites was land availability. The overwhelming majority of land in the state of Kansas is privately-owned. This meant that it was required not only to get permission to take samples for research, but to get the required permission to even go prospecting on the majority of potential sites. This factor also manifested itself in the lack of published data indicating where surface exposures of coal could be found in Kansas. This is even evident in this study as part of gaining permission to sample these locations involved agreeing to withhold specific location information regarding sampling sites from publishing.

The final limitation of this study is that this study only utilized samples collected from the surface *in situ* or collected from tailings piles, which acted as secondary sites located on the surface. Most of these sample location deposits are the result of mining operations that ceased decades ago. This means that the deposits have been exposed to the elements thoroughly. Exposed coal beds can have potential uranium or thorium concentrations affected by exposure to meteoric water. It is possible that any uranium present in the coal sampled from the tailings pile sites was washed away due to exposure to meteoric water. Leaching is a known method of mining for uranium and meteoric water has similar characteristics to the fortified water commonly used in these operations, so it is possible that exposure to meteoric water over time could slowly cause leaching of uranium in coal bed exposures. In leach mining, results can be seen on a scale of months to years. It is possible there was a similar case with the coal sampled from the bank of Adams Creek in Pottawatomie county. As the only reason this coal seam was exposed was due to flooding of the creek due to storms, it is possible that flooding and the significantly increased water flow could have greatly stripped the seam of any uranium it may have possibly contained. Multiple storms were reported in the area by the landowner before a field expedition could be organized, which means that there was more exposure of the seam to meteoric water and possibly more flooding in the area prior to sampling.

Future Work

Further exploration into this methodology could benefit from a larger geographic area with more sampling sites, a stronger link to locals, and consideration of subsurface coal layers. A larger geographic area with more sampling sites could benefit a project like this as it would allow for a greater possibility of finding coal layers that contained uranium. A way of gaining access to a larger amount of sampling sites would be to have a stronger connection with local landowners. In this particular study area, the sampling sites were primarily provided by local landowner networking. A larger network of landowners having knowledge of the project could have yielded more invitations to study potential sites. Finally, there is the possibility that any uranium that was present could have been deposited in coal beds that did not have surface outcrops. The consideration of subsurface coal layers could make future studies more inclusive of the geology of the study area.

Summary

In summary, there was not sufficient evidence provided by this study to support the hypothesis that there is coal bed uranium in Kansas. There were limitations present in the study such as the limited availability of sampling sites, limited map accuracy, limited landowner networking, and degradation of possible uranium due to exposure of surface outcrop to natural elements. These limitations helped to illuminate potential fixes and improvements that could be utilized in future work associated with the project. Future iterations of this project could yield different results with a larger geographic area with more sampling sites, a stronger link to locals, and consideration of subsurface coal layers.

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APPENDIX A

Kansas Counties

NAME	Radon	Radon_Code	Coal_Prod
Greenwood	High	3	0
Doniphan	High	3	0
Republic	High	3	2
Decatur	High	3	0
Phillips	High	3	0
Lyon	High	3	0
Hamilton	High	3	0
Wallace	High	3	0
Riley	High	3	0
Ellis	High	3	0
Pratt	Medium	2	0
Lane	High	3	0
Trego	High	3	0
Greeley	High	3	0
McPherson	High	3	0
Cowley	High	3	0
Osage	High	3	0
Marion	High	3	0
Rush	High	3	0
Stanton	High	3	0
Franklin	High	3	0
Pottawatomie	High	3	0
Sherman	High	3	0
Allen	Medium	2	0
Labette	Medium	2	0
Johnson	High	3	0
Cherokee	Medium	2	0
Cheyenne	High	3	0
Atchison	High	3	0
Cloud	High	3	3
Geary	High	3	0
Russell	High	3	2
Barton	High	3	2
Shawnee	High	3	0
Butler	High	3	0
Jewell	High	3	1
Mitchell	High	3	1
Scott	High	3	0

NAME	Radon	Radon_Code	Coal_Prod
Stevens	High	3	0
Douglas	High	3	0
Comanche	Medium	2	0
Pawnee	High	3	0
Wyandotte	High	3	0
Graham	High	3	0
Morton	Medium	2	0
Sumner	High	3	0
Miami	High	3	0
Gove	High	3	0
Ford	High	3	0
Neosho	Medium	2	0
Linn	High	3	0
Brown	High	3	0
Bourbon	High	3	0
Clay	High	3	0
Lincoln	High	3	2
Smith	High	3	0
Morris	Medium	2	0
Barber	High	3	0
Logan	High	3	0
Chase	High	3	0
Crawford	High	3	0
Woodson	Low	1	0
Jefferson	High	3	0
Rawlins	High	3	0
Thomas	High	3	0
Ottawa	High	3	0
Rice	High	3	0
Ness	High	3	0
Wilson	Medium	2	0
Osborne	High	3	0
Clark	High	3	0
Haskell	High	3	0
Saline	High	3	0
Kingman	Medium	2	0
Stafford	High	3	0
Dickinson	High	3	0
Finney	High	3	0
Montgomery	Low	1	0
Edwards	High	3	0

NAME	Radon	Radon_Code	Coal_Prod
Harvey	High	3	0
Sheridan	High	3	0
Kiowa	High	3	0
Harper	Medium	2	0
Washington	High	3	0
Elk	Medium	2	0
Seward	Medium	2	0
Nemaha	High	3	0
Norton	High	3	0
Coffey	Medium	2	0
Kearny	High	3	0
Ellsworth	High	3	2
Hodgeman	High	3	0
Meade	High	3	0
Anderson	High	3	0
Marshall	High	3	0
Wichita	High	3	0
Grant	Medium	2	0
Leavenworth	High	3	0
Chautauqua	Low	1	0
Rooks	High	3	0
Reno	Medium	2	0
Gray	High	3	0
Wabaunsee	High	3	0
Sedgwick	Medium	2	0
Jackson	Medium	2	0