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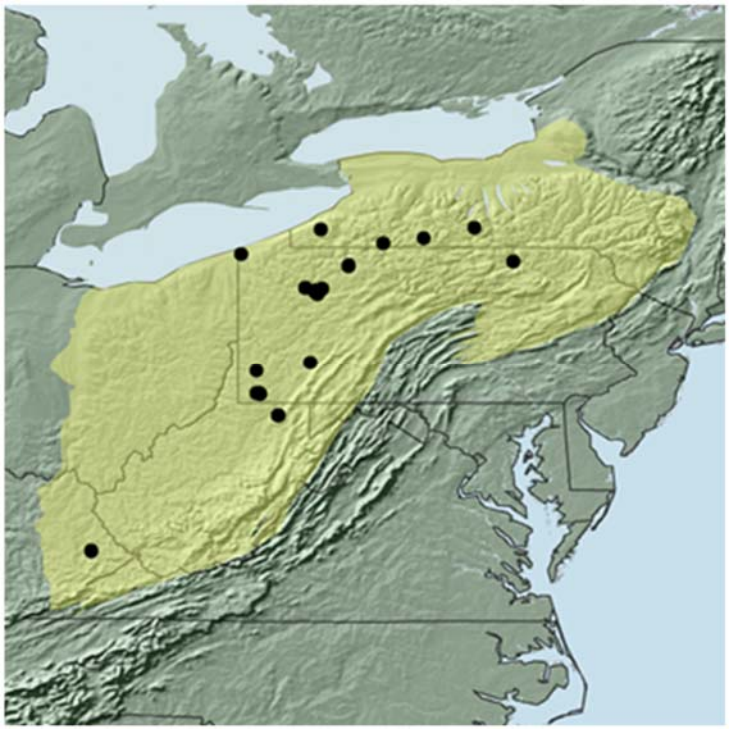

$^{87}Sr/^{86}Sr$ Concentrations in the Appalachian Basin: A Review

16 June 2016

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Cover Illustration: The cover displays the samples sites for the data discussed in this report. The shaded region represents the extent of the Appalachian Basin. Black points represent sample locations.

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$^{87}Sr/^{86}Sr$ Concentrations in the Appalachian Basin: A Review

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Acronyms, Abbreviations, and Symbols

Term	Description
β^- Decay	The emission of an electron and electron antineutrino from an atomic nucleus
ϵ_{Sr}^{SW}	$^{87}Sr/^{86}Sr$ normalized to globally uniform $^{87}Sr/^{86}Sr$ of present day seawater
IDW	Inverse distance weighting
TDS	Total dissolved solids
^{1}H	Hydrogen isotope with a mass of 1
^{2}H	Hydrogen isotope with a mass of 2
^{12}C	Carbon isotope with a mass of 12
^{13}C	Carbon isotope with a mass of 13
^{16}O	Oxygen isotope with a mass of 16
^{18}O	Oxygen isotope with a mass of 18
^{86}Sr	Strontium isotope with a mass of 86
^{87}Sr	Strontium isotope with a mass of 87
^{87}Rb	Rubidium isotope with a mass of 87

Acknowledgments

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EXECUTIVE SUMMARY

This document reviews $^{87}Sr/^{86}Sr$ isotope data across the Appalachian Basin from existing literature to show spatial and temporal variation. Isotope geochemistry presents a means of understanding the geochemical effects hydraulic fracturing may have on shallow ground substrates. Isotope fractionation is a naturally occurring phenomenon brought about by physical, chemical, and biological processes that partition isotopes between substances; therefore, stable isotope geochemistry allows geoscientists to understand several processes that shape the natural world. Strontium isotopes can be used as a tool to answer an array of geological and environmental inquiries. In some cases, strontium isotopes are sensitive to the introduction of a non-native fluid into a system. This ability allows strontium isotopes to serve as tracers in certain systems. Recently, it has been demonstrated that strontium isotopes can serve as a monitoring tool for groundwater and surface water systems that may be affected by hydraulic fracturing fluids (Chapman et al., 2013; Kolesar Kohl et al., 2014). These studies demonstrated that $^{87}Sr/^{86}Sr$ values have the potential to monitor subsurface fluid migration in regions where extraction of Marcellus Shale gas is occurring.

This document reviews publicly available strontium isotope data from 39 sample locations in the Appalachian Basin (Hamel et al., 2010; Chapman et al., 2012; Osborn et al., 2012; Chapman et al., 2013; Capo et al., 2014; Kolesar Kohl et al., 2014). The data is divided into two sets: stratigraphic (Upper Devonian/Lower Mississippi, Middle Devonian, and Silurian) and groundwater. ArcMap™ (ESRI, Inc.) was used to complete inverse distance weighting (IDW) analyses for each dataset to create interpolated surfaces in an attempt to find regional trends or variations in strontium isotopic values across the Appalachian Basin. $^{87}Sr/^{86}Sr$ varies up to ~ 0.011 across the Appalachian Basin, but the current publicly available data is limited in frequency and regional extent, causing artifacts and high uncertainty when interpolating data for locations far from sampling sites. These factors highlight the need for additional strontium isotope sampling across the region.

Identifying potential contamination from hydraulic fracturing fluid in Appalachian Basin groundwater using strontium isotopes would require additional sampling. For a more comprehensive strontium isotope database, samples would need to be collected during pre-fracturing, syn-fracturing, and post-fracturing stages. This would add a temporal component to the spatial data and make tracing of fluid migration with strontium isotopes more accurate. Future research and modeling that incorporates subsurface geology and watershed data would also serve to increase the accuracy and certainty of the interpolations of these analyses. Prospective geospatial Appalachian Basin isotope studies would also benefit from the integration of geologic mapping because surface and subsurface geology influences observed strontium isotope values.

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1. INTRODUCTION

The Appalachian Basin is a large, northeast-southwest trending depositional basin of Paleozoic stratigraphy in the eastern United States that consists of units and formations that vary in age and geographical extent (Faill, 1997; Islas, 2006). Siliciclastic and carbonate deposition in the basin began following uplift caused by the Taconic orogeny. The flux of siliclastics or carbonates usually predominated over the other, but these contrasting compositions often co-mingled. Detritus continued to deposit in the basin until at least the Devonian with occasional interludes of uplift interrupting deposition (Faill, 1997; Swezey, 2002; Islas, 2006). Hydrocarbon-bearing sediments in the basin were deposited between the Pennsylvanian and Ordovician periods (Swezey, 2002; Islas, 2006). During the Allegany orogeny, older metamorphic and igneous rocks were thrust westward over younger Paleozoic sedimentary stratigraphy, creating the Valley & Ridge Provence, a complex of thrust faults that define much of the eastern margin of the Appalachian Basin. The western Appalachian Basin margin is delineated by a mildly sloping, broad homocline that terminates at the Cincinnati Arch (Ryder, 1995).

The Marcellus Shale formation extends through much of the Appalachian Basin and is subject to hydraulic fracturing for hydrocarbon extraction. Hydraulic fracturing entails pumping large volumes of pressurized water and other chemicals into the Earth's subsurface to fracture bedrock. Fracturing increases rock permeability, which allows previously isolated pockets of gas to be extracted. The environmental and public health effects of hydraulic fracturing remain a point of contention between oil and gas companies and many members of the public. The geological and environmental effects of altering subsurface geological structures, pumping chemicals to depth, and spilling at the surface are unknown.

Isotopes are variants of an atom that have the same number of protons but varying numbers of neutrons. Some isotopes are unstable—they will spontaneously decay or break down into constituent components. Other isotopes are stable; these isotopes do not spontaneously decay on a measurable timescale. Strontium isotopes can serve as naturally occurring tracers that allow geoscientists to monitor hydraulic fracturing. ^{86}Sr is a non-radiogenic isotope commonly found in terrestrial environments. ^{87}Sr is a product of electron emission (β^- decay) from the nucleus of ^{87}Rb. The steady β^- decay rate of ^{87}Rb into ^{87}Sr allows the following equation to model $^{87}Sr/^{86}Sr$ through time:

$$\left(\frac{^{87}\mathrm{Sr}}{^{86}\mathrm{Sr}}\right)T_2 = \left(\frac{^{87}\mathrm{Sr}}{^{86}\mathrm{Sr}}\right)T_1 + (e^{\lambda t} - 1)$$

In which T_1 and T_2 respectively denote points of time in the geologic past and present, λ is decay constant of ^{87}Rb (4.92×10^{10} years), and t is a measure of the difference of years between T_1 and T_2 (Chesson et al., 2012).

Strontium isotopes behave differently than many other stable isotopes (e.g., $^{2}H/^{1}H$, $^{13}C/^{12}C$, and $^{18}O/^{16}O$). Unlike other isotopes, $^{87}Sr/^{86}Sr$ ratios are not significantly altered by phase changes, chemical reactions, or biological reactions. In other words, the observed $^{87}Sr/^{86}Sr$ in a sample represents the $^{87}Sr/^{86}Sr$ of that sample's system (Frost and Toner, 2004). As a result, strontium isotopes can be used to identify contamination sources, environmental bio-remediation extent,

specie origins, and precipitate origins (Beard and Johnson, 2000; Hamel et al., 2010; Chapman et al., 2012; Chapman et al., 2013). Strontium isotopes also serve as a means to fingerprint the strata holding groundwater (Frost et al., 2002). Generally, higher geological $^{87}Sr/^{86}Sr$ (> 0.710) indicates older, ^{87}Rb-rich rocks, such as Paleozoic granites, whereas lower geological $^{87}Sr/^{86}Sr$ (0.702–0.706) suggests younger ^{87}Rb-poor rocks, such as young volcanics (Capo et al. 1998; Frost and Toner, 2004). ^{87}Rb's long half-life of 4.92×10^{10} years and varying weathering rates require rocks to be tens of millions of years of age or older in order to observe significant natural variations in $^{87}Sr/^{86}Sr$ (Chesson et al., 2012). Frost and Toner (2004) suggest that groundwater can acquire the $^{87}Sr/^{86}Sr$ of its host rock on the order of days depending on the concentration of Sr in the groundwater, the $^{87}Sr/^{86}Sr$ of the groundwater and surrounding lithology (e.g., due to exchange or precipitation and dissolution reactions).

Formation strontium concentrations in the same region can vary greatly across strata because of differing ages and compositions (Vengosh et al., 2011). For example, the Marcellus Shale and its associated brines have a range of $^{87}Sr/^{86}Sr$ from 0.711200–0.71150. Shallow groundwater aquifers within the footprint of the Marcellus Shale have a wider range of $^{87}Sr/^{86}Sr$ from 0.71201–0.71553.

Directional drilling (vertical and horizontal wells) is one method to increase production from natural gas plays. The techniques of drilling unconventional wells involve fracturing fluids that contain chemical additives and proppants that mix with the formation fluid. Pressurized fluid that returns to the surface after fracturing is referred to as flowback fluid, and post-hydraulic fracturing fluid that contains the natural gas is referred to as produced water (Kolesar Kohl et al., 2014). As these injection fluids are mixed with the formation rock, geochemical reactions allow for ion mobility. Previous studies show that strontium isotope concentrations change in flowback fluid from the Marcellus Shale (Osborn and McIntosh, 2010). Unused hydraulic fracturing fluid has an $^{87}Sr/^{86}Sr$ below 0.71012 (Vengosh et al., 2011). After 20 days of residence, Vengosh et al. (2011) reported that flowback fluid from the Marcellus Shale had an elevated $^{87}Sr/^{86}Sr$ of 0.71122. Vengosh et al. (2011) concluded that even a small intrusion, as low as 1%, of hydraulic fracturing fluid into groundwater or surface water would have a noticeable impact on observed $^{87}Sr/^{86}Sr$. Furthermore, Chapman et al. (2012) indicated that $^{87}Sr/^{86}Sr$ contamination by Marcellus Shale produced waters can be differentiated from waters produced from other geologic units. Warner et al. (2012a,b) based their studies on previous work (Vengosh et al., 2011; Chapman et al., 2012) to use $^{87}Sr/^{86}Sr$ concentrations as natural tracers, concluding that natural faults in parts of the Appalachian Basin already allow interaction between groundwater and Marcellus Shale waters.

In order to understand the significance and reach of using strontium isotopes as a natural tracer in the Appalachian Basin, it is necessary to understand the range and spatial distribution of strontium isotope signatures in different Marcellus-related geologic strata. Due to the sparsity of data for strontium isotopes in this region, this report focuses on changes in understanding of Appalachian Basin strontium isotope ratios over time, and shows that changes in bulk isotope gradients are largely influenced by adding data from samples collected from different geologic units.

2. METHODS

In this review, ESRI Inc.'s ArcMap™ 10.2 geostatistical analysis tools were used to create the interpolated surfaces representing measured strontium isotope ratios. Although the interpolated surface analyses was generated using two methods, Kriging and inverse distance weighting (IDW), only the IDW interpolations are presented here because the Kriging method produced more artifacts. The difference in artifact production was likely a product of how the two interpolation methods treat clustered data differently. Kriging assigns less weight to data in a cluster than IDW, which does not attempt to account for high-density clustered data as it employs an optimal power function that is sensitive to clustering and outliers, minimizing the root mean square prediction error of the interpolated surface. This analytical difference likely accounts for the variation of artifact frequency between the two methods. When artifact occurrence was particularly problematic with IDW a smoothing factor of 1 was used to reduce the prominence of artifacts. This study derived 39 data points from previous literature (Hamel et al., 2010; Chapman et al., 2012; Osborn et al., 2012; Chapman et al., 2013; Capo et al., 2014; Kolesar Kohl et al., 2014). The data were divided into two sets: stratigraphic and groundwater. The minimum and maximum strontium isotope concentrations depicted in the figures come from the minimum and maximum observed strontium isotope concentrations collected from these studies. For certain studies (Hamel et al., 2010; Capo et al., 2014; Kolesar Kohl et al., 2014), exact sample locations were not available, so sample locations were approximated from data available in each article. Specifically, the mine drainage sampling locations from Figure 2 of Hamel et al. (2010) were georeferenced. For the Capo et al. (2014) and Kolesar Kohl et al. (2014) sample locations, the central point of Greene County, Pennsylvania, was selected and the relative distances between wells from Figure 1 in Kolesar Kohl (2014) were georeferenced.

In addition to being expressed as a ratio, strontium isotope values are often expressed as the deviation in parts per thousand of $^{87}Sr/^{86}Sr$ from modern seawater, which is denoted as ϵ_{Sr}^{SW}. The ϵ_{Sr}^{SW} is calculated using a seawater standard and the following equation:

$$\epsilon_{Sr}^{SW} = 10^4 \left(\frac{{}^{87}Sr/{}^{86}Sr_{sample}}{{}^{87}Sr/{}^{86}Sr_{seawater}} - 1 \right)$$

Each of the individual studies compiled for this review had a regionally different focus depending on the study's purpose and isotopes of interest. Some datasets contained dozens of sample locations across a region. Other datasets included multiple measurements for each sampled well over a certain time frame.

For this study, it is difficult to show the strontium isotope variations at a large scale. The geographical extent (Figure 1) of the data covers a large section of the Appalachian Basin. The spatial distribution of sample sites centers primarily in or near Pennsylvania. The data appear to cluster at three points: Greene County, Pennsylvania, with clustered stratigraphic samples; and northern Pennsylvania and northern West Virginia with clustered groundwater samples. The regional Appalachian Basin wellbore data were separated temporally (Figures 2–4). Smaller

interpolated surfaces (Figures 7, 8) were also provided for Greene County, Pennsylvania, between the years 2012–2013, because this localized area experiences changes in strontium isotope data that are not easily visible at the larger scale. The strontium isotope groundwater data has two associated interpolated surfaces. The small-scale (a few miles across) interpolated surfaces provide additional detail not visible from the larger-scale (over 100 miles across) interpolated surface. The groundwater data cluster from the Hamel et al. (2010) study in northern West Virginia were all similar in value, so no smaller scale figure was provided.

3. OBSERVATIONS

Gauging the impacts of hydraulic fracturing on groundwater and subsurface geology will help protect ecological systems and public health. Because strontium isotopes provide a unique indicator for potential mixing between hydraulic fracturing fluids with neighboring groundwater, it was used to infer subsurface fluid flow as well as spills and leaks at the ground surface. Thus $^{87}Sr/^{86}Sr$ was interpolated across the Appalachian Basin using publicly available wellbore and groundwater data. These values are displayed as interpolated surfaces in Figures 2–11. Significant $^{87}Sr/^{86}Sr$ deviations over time suggest the intrusion of a fluid on the sampled system. Unfortunately, each study produces a different precision in measuring $^{87}Sr/^{86}Sr$, so selecting a certain deviation value as significant is challenging. Warner et al. (2012) reported $^{87}Sr/^{86}Sr$ standard error for water samples as high as 0.0039, while Beard and Johnson (2000) report seawater samples within ± 0.00003; however, general $^{87}Sr/^{86}Sr$ sample reproducibility tends to be around 0.0001–0.0002 (Baitelle and Bowen, 2012; Chesson et al., 2012).

Overall, strontium isotope data from bedrock appear to be consistent on a local scale across the same stratigraphic units. However, it is also important to understand the role stratigraphy plays in influencing $^{87}Sr/^{86}Sr$ values. Sampling between different units in the same region produces large $^{87}Sr/^{86}Sr$ differences (~ 0.01). Similarly, groundwater $^{87}Sr/^{86}Sr$ appears to be comparable in value on the large scale; however, on a local scale, $^{87}Sr/^{86}Sr$ can vary by greater than 0.009. The range in $^{87}Sr/^{86}Sr$ over short distances emphasizes the necessity for more $^{87}Sr/^{86}Sr$ groundwater sample locations.

Strontium isotope data of the Appalachian Basin currently available to the public is very limited (Figure 1). With a total of only 39 sample locations and most of the data in or near Pennsylvania, regions distal to Pennsylvania will have a low certainty for interpolated strontium values. Data clusters further complicate geospatial analysis as the presence of data clusters reduce the quantity of data points evenly distributed across the region. The total number of data points available for a given analysis is further reduced as the data was analyzed by sample source (stratigraphic and groundwater).

Several sample locations were only sampled once, while others were sampled periodically over the course of a study. Although strontium isotope values appear to change across the Appalachian Basin from the period prior to 2010 through 2013 (Figure 2–6), changes in interpolated values are more a response to new sample locations rather than a change in strontium isotope values at existing sample locations. The absence of continuous temporal sampling complicated completing analyses on changes in strontium isotope values over time and again underlines the need for additional sampling before strontium isotopes can be widely used as natural tracers for hydraulic fracturing in the Appalachian Basin.

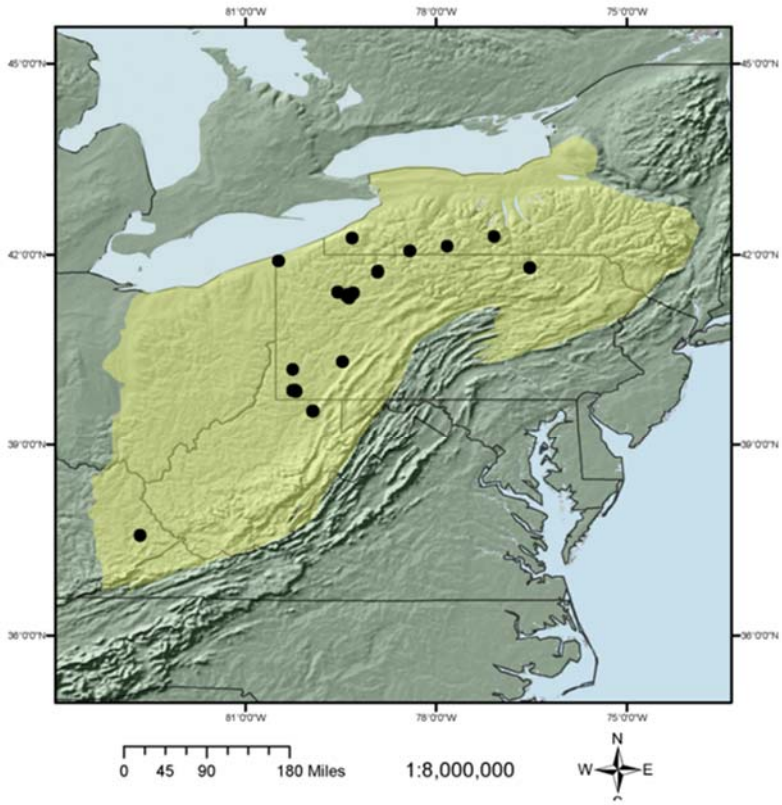


Figure 1: Strontium Isotope locations within the Appalachian Basin

3.1 CHANGES OVER TIME IN UNDERSTANDING OF STRONTIUM ISOTOPE DISTRIBUTIONS ACROSS THE APPALACHIAN BASIN

Visually, it appears that strontium isotope values change over time in the Appalachian Basin when including data from multiple geologic formations within one data set. These changes are primarily due to the addition of more sample locations over time that originate from different geologic units, rather than to significant changes in strontium isotope values over time within the geologic units.

From the pre-2010 data, the highest reported $^{87}Sr/^{86}Sr$ ratios are from samples collected in 2007 in north-central Pennsylvania. The addition of six new data points account for the minor changes in interpolated strontium values between pre-2010 and 2010 data, which includes sampling points from the Middle Devonian and Upper Devonian/Lower Mississippian units (Figures 2, 3). Existing sample location strontium isotope values do not change. Two sources (Osborn et al. 2012; Capo et al. 2014) provide data for the nine pre-2010 sample locations (Figure 2). The 15 sample locations of the 2010 data come from four studies (Chapman et al., 2012; Osborn et al., 2012; Chapman et al., 2013; Capo et al., 2014).

The changes observed between interpolated surfaces from 2010 and 2011 data are the product of two new data points in a tight cluster in southwestern Pennsylvania (Greene County, Pennsylvania; Figures 3, 4). The sample locations existing from 2010 remain unchanged. The

same sources providing data for Figure 3 also provide the data for the 17 sample locations for Figure 4.

Changes in interpolated values between 2011 and 2012 are a product of five new sampling locations from Kolesar Kohl et al. (2014) in southwestern Pennsylvania which include samples from both the Middle Devonian, and Upper Devonian/Lower Mississippian units (Greene County, Pennsylvania; Figures 4, 5). Three existing Greene County sample locations from Capo et al. (2014) experience minor value changes, but only one sample site showed changes greater than 0.0001 (0.711187 to 0.711294).

3.2 CHANGES OVER TIME IN UNDERSTANDING OF STRONTIUM ISOTOPE DISTRIBUTIONS IN GREENE COUNTY

The only changes in reported strontium isotope values between 2012 and 2013 are the addition of a new sample location in Greene County, Pennsylvania, from Kolesar Kohl et al. (2014) and updated strontium values for the existing Kolesar Kohl et al. (2014) data. The minor changes between the 2012 and 2013 interpolated surfaces from wellbore data are a product of slight variations between sample values (Figures 7, 8). Only one sample location experiences an $^{87}Sr/^{86}Sr$ change greater than 0.0001 (0.711187 to 0.711294). Within Greene County, $^{87}Sr/^{86}Sr$ values increased from the Middle Devonian strontium values to the Upper Devonian/Lower Mississippian strontium values. Three sources (Chapman et al., 2012; Capo et al., 2014; Kolesar Kohl et al., 2014) provide data for the nine sample locations in Greene County.

3.3 GROUNDWATER $^{87}Sr/^{86}Sr$: APPALACHIAN BASIN

Publicly available strontium groundwater studies did not resample from the same sample locations over time. The large-scale interpolated surface (Figure 9a) contains data from two studies (Hamel et al., 2010; Chapman et al., 2013), which cluster the data points in the north and the south. The local interpolated surface (Figure 9b) represents data from only Chapman et al. (2013). Hamel et al. (2010) sample locations are so closely clustered that they appear as a single data point, but these sample values are similar enough that they all fall in a single contour shade. Although groundwater $^{87}Sr/^{86}Sr$ can appear ubiquitously similar on the regional scale, the local $^{87}Sr/^{86}Sr$ heterogeneity displayed by the Chapman et al. (2013) data in the north shows that large variation in groundwater $^{87}Sr/^{86}Sr$ can occur over short distances; whereas the consistency of the Hamel et al. (2010) data suggests that $^{87}Sr/^{86}Sr$ variation is not always present on the local scale. An artifact of the interpolation process appears to be present with jagged edges running west-northwest to east-southeast along the center of the larger-scale interpolated surface. Three sources (Hamel et al., 2010; Chapman et al., 2013; Kolesar Kohl et al., 2014) provide data for the 17 sample locations on this map.

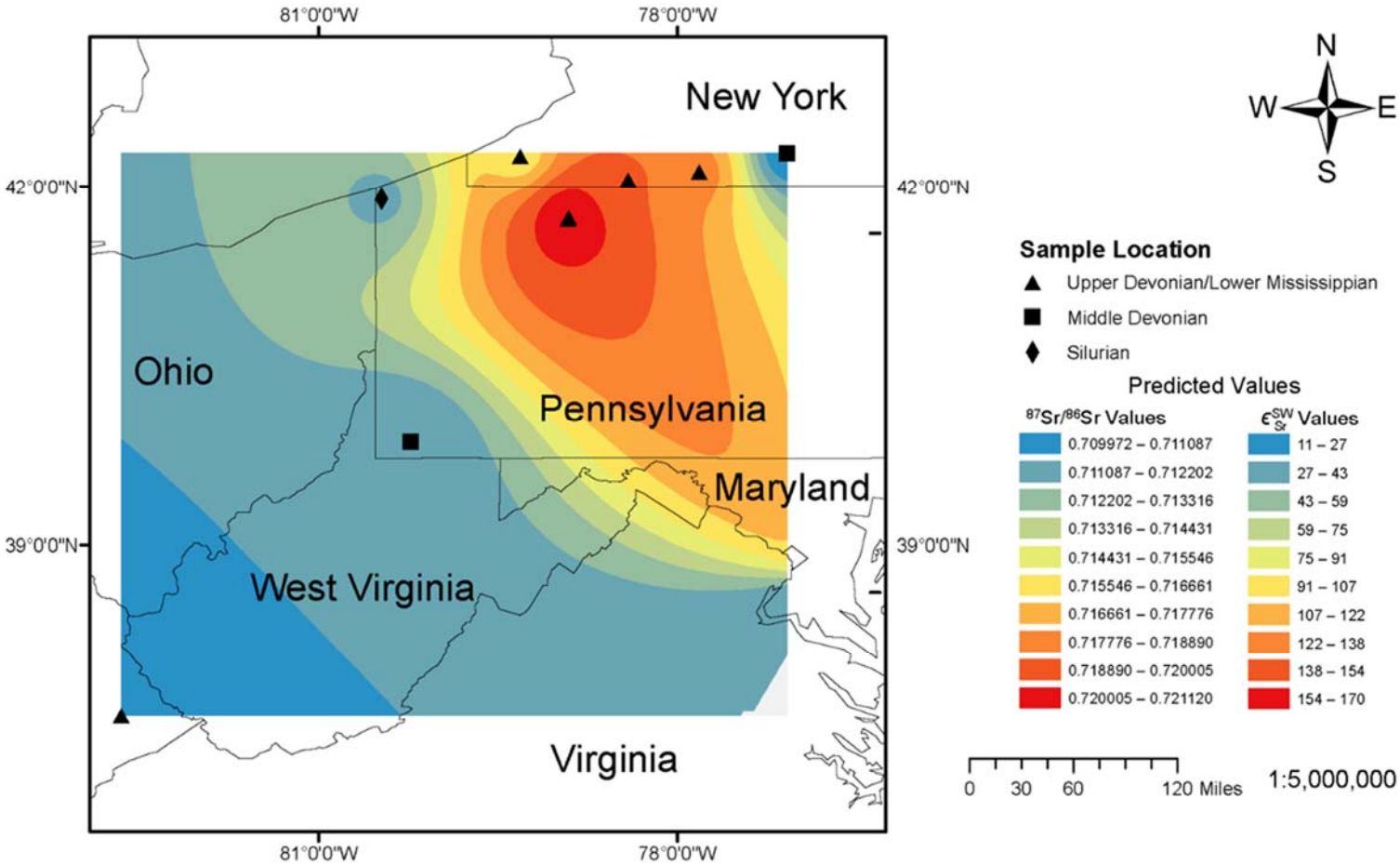


Figure 2: Appalachian Basin $^{87}Sr/^{86}Sr$ (Pre-2010)
This map displays the Inverse Distance Weighted Interpolation of the Appalachian Basin $^{87}Sr/^{86}Sr$ from samples collected before 2010. Previous research measured these isotope values from the depicted sample locations (Osborn et al., 2012; Capo et al., 2014).

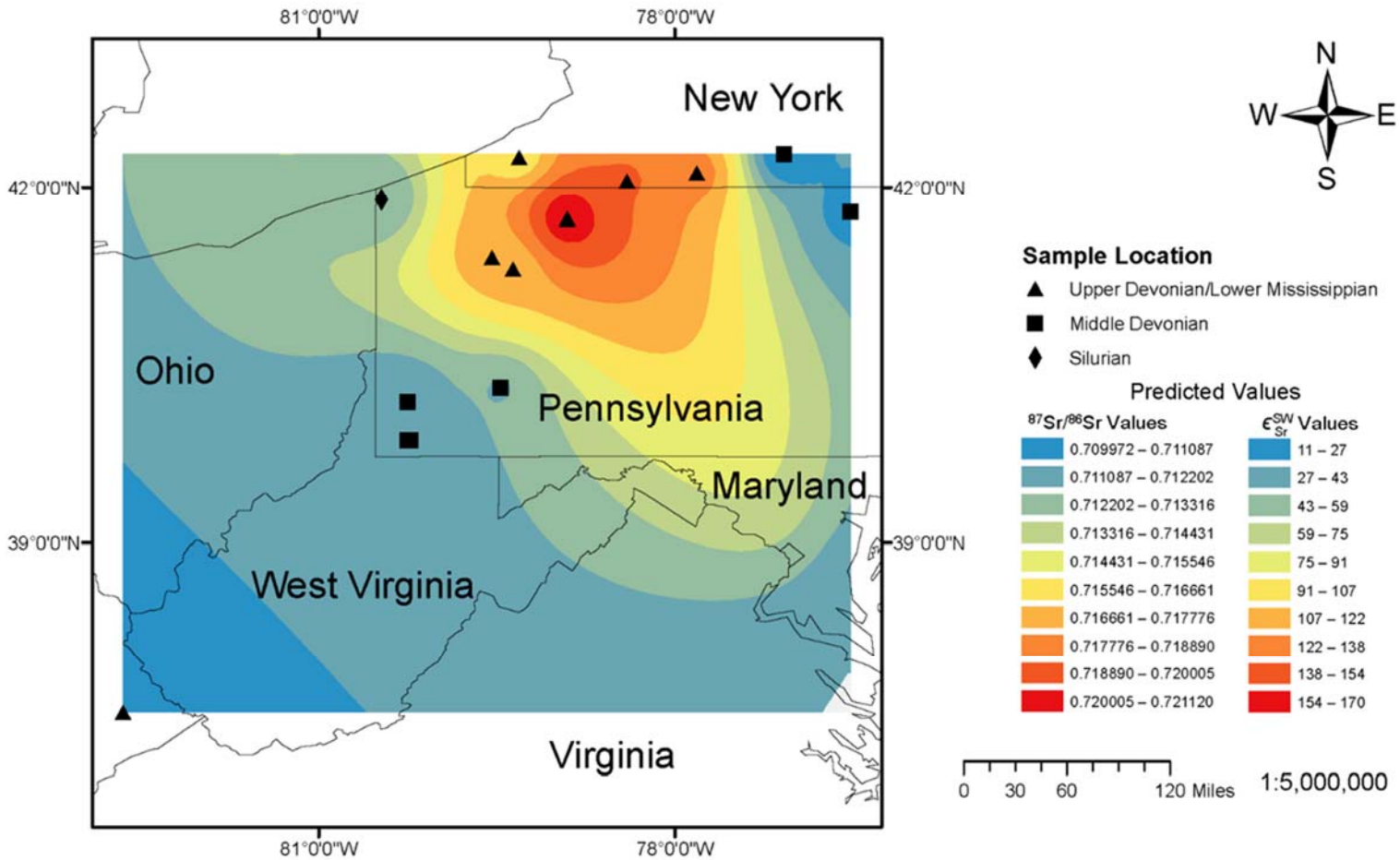


Figure 3: Appalachian Basin $^{87}Sr/^{86}Sr$ (2010)
This map displays the Inverse Distance Weighted Interpolation of the Appalachian Basin $^{87}Sr/^{86}Sr$ from samples collected up until the end of 2010. Previous research measured these isotope values from the depicted sample locations (Osborn et al., 2012; Capo et al., 2014).

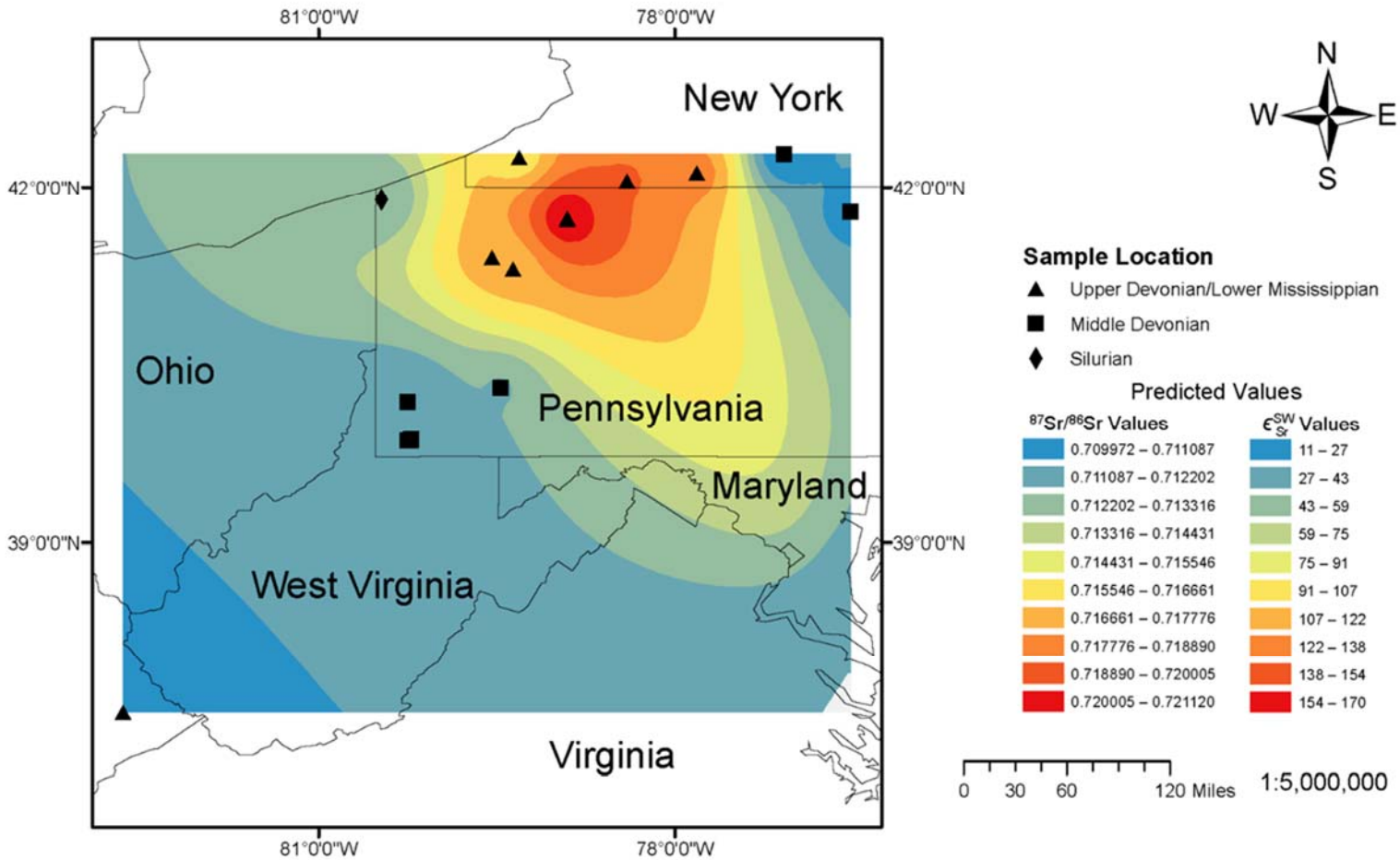


Figure 4: Appalachian Basin $^{87}Sr/^{86}Sr$ (2011)
This map displays the Inverse Distance Weighted Interpolation of the Appalachian Basin $^{87}Sr/^{86}Sr$ from samples collected until the end of 2011. Previous research measured these isotope values from the depicted sample locations (Osborn et al., 2012; Capo et al., 2014).

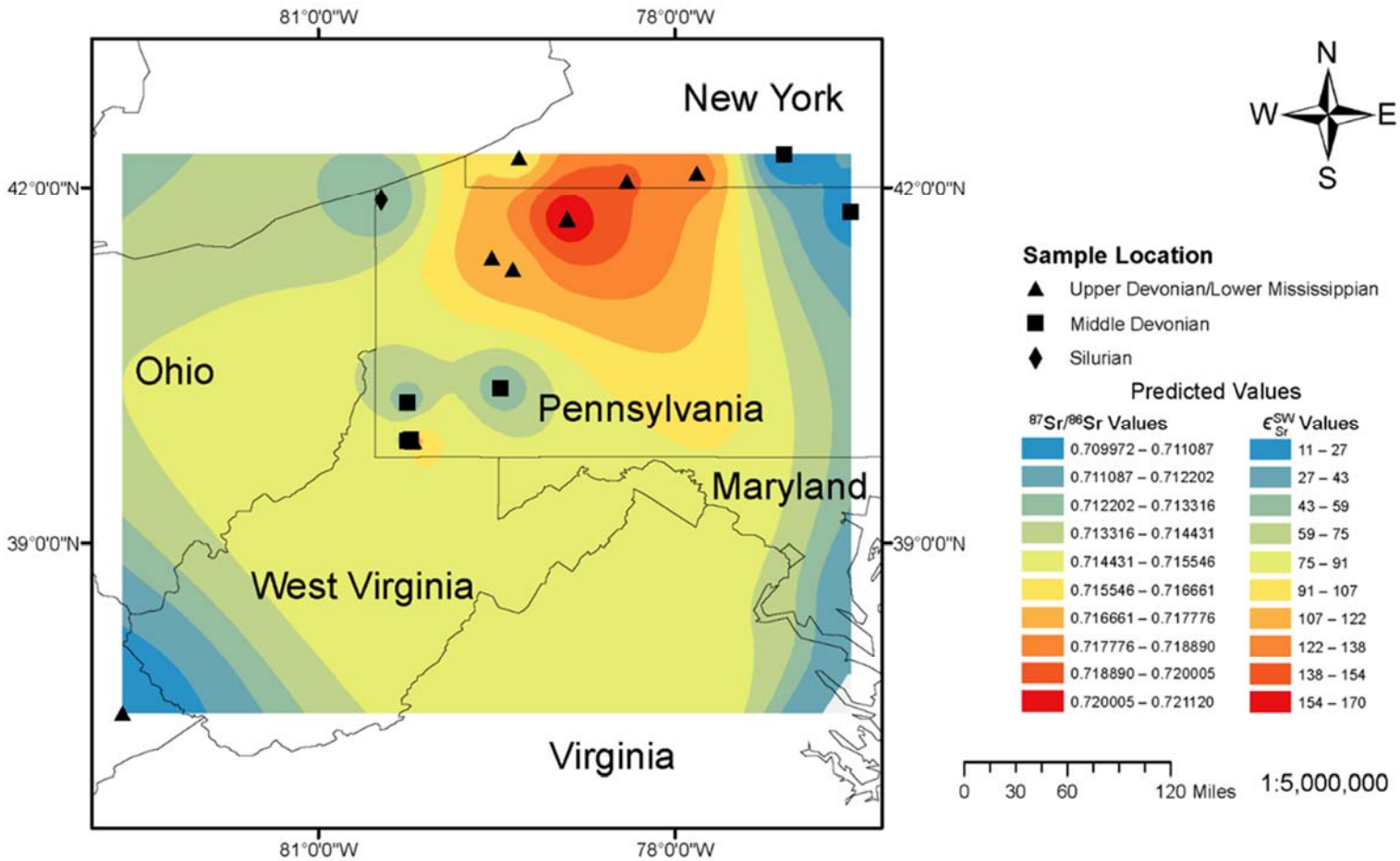


Figure 5: Appalachian Basin $^{87}Sr/^{86}Sr$ (2012)
This map displays the Inverse Distance Weighted Interpolation of the Appalachian Basin $^{87}Sr/^{86}Sr$ from samples collected up until the end of 2012. Previous research measured these isotope values from the depicted sample locations (Chapman et al., 2012; Osborn et al., 2012; Chapman et al., 2013; Capo et al., 2014; Kolesar Kohl et al., 2014).

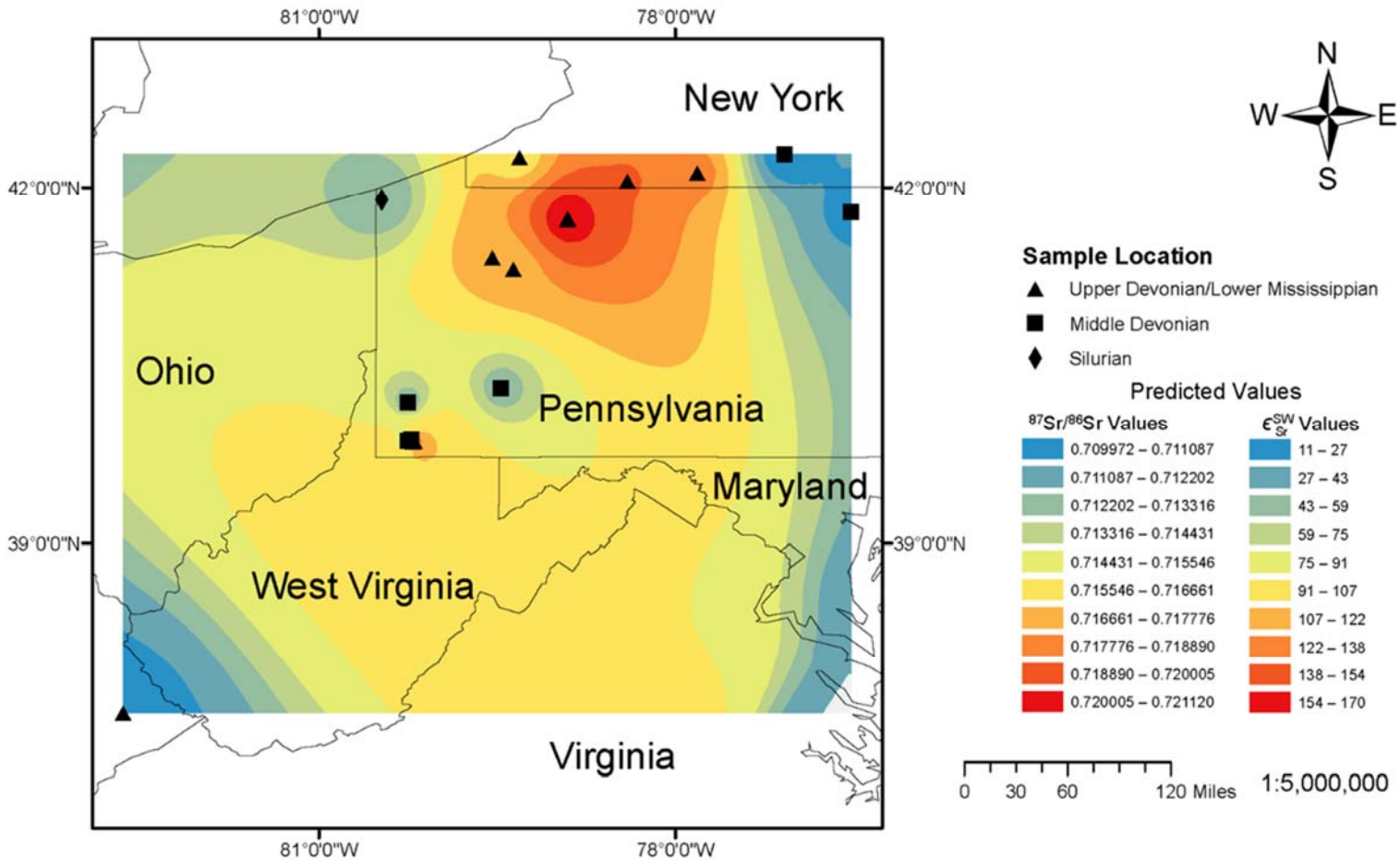


Figure 6: Appalachian Basin $^{87}Sr/^{86}Sr$ (2013)
This map displays the Inverse Distance Weighted Interpolation of the Appalachian Basin $^{87}Sr/^{86}Sr$ from samples collected up until the end of 2013. Previous research measured these isotope values from the depicted sample locations (Chapman et al., 2012; Osborn et al., 2012; Chapman et al., 2013; Capo et al., 2014; Kolesar Kohl et al., 2014).

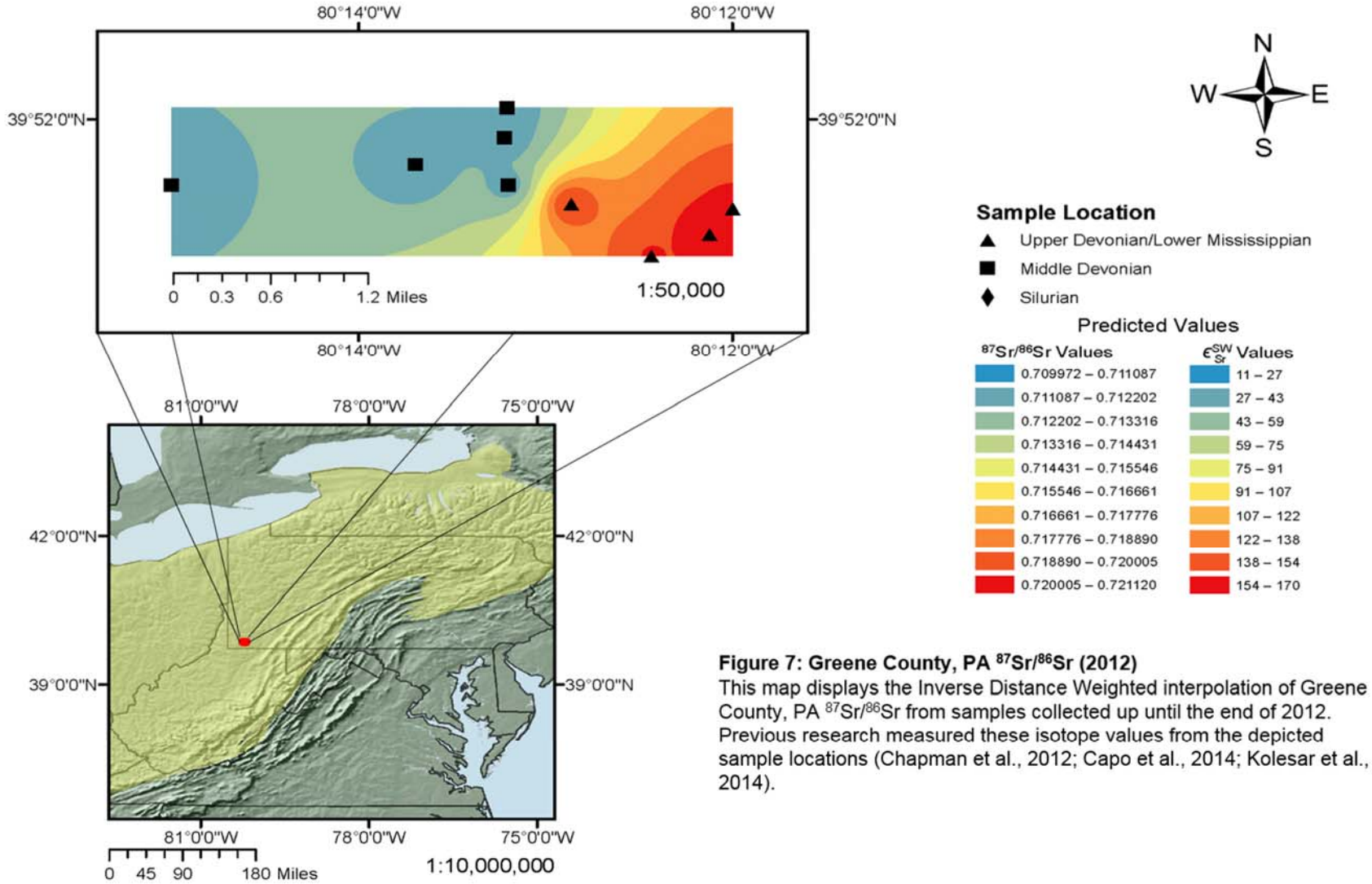


Figure 7: Greene County, PA $^{87}Sr/^{86}Sr$ (2012)
This map displays the Inverse Distance Weighted interpolation of Greene County, PA $^{87}Sr/^{86}Sr$ from samples collected up until the end of 2012. Previous research measured these isotope values from the depicted sample locations (Chapman et al., 2012; Capo et al., 2014; Kolesar et al., 2014).

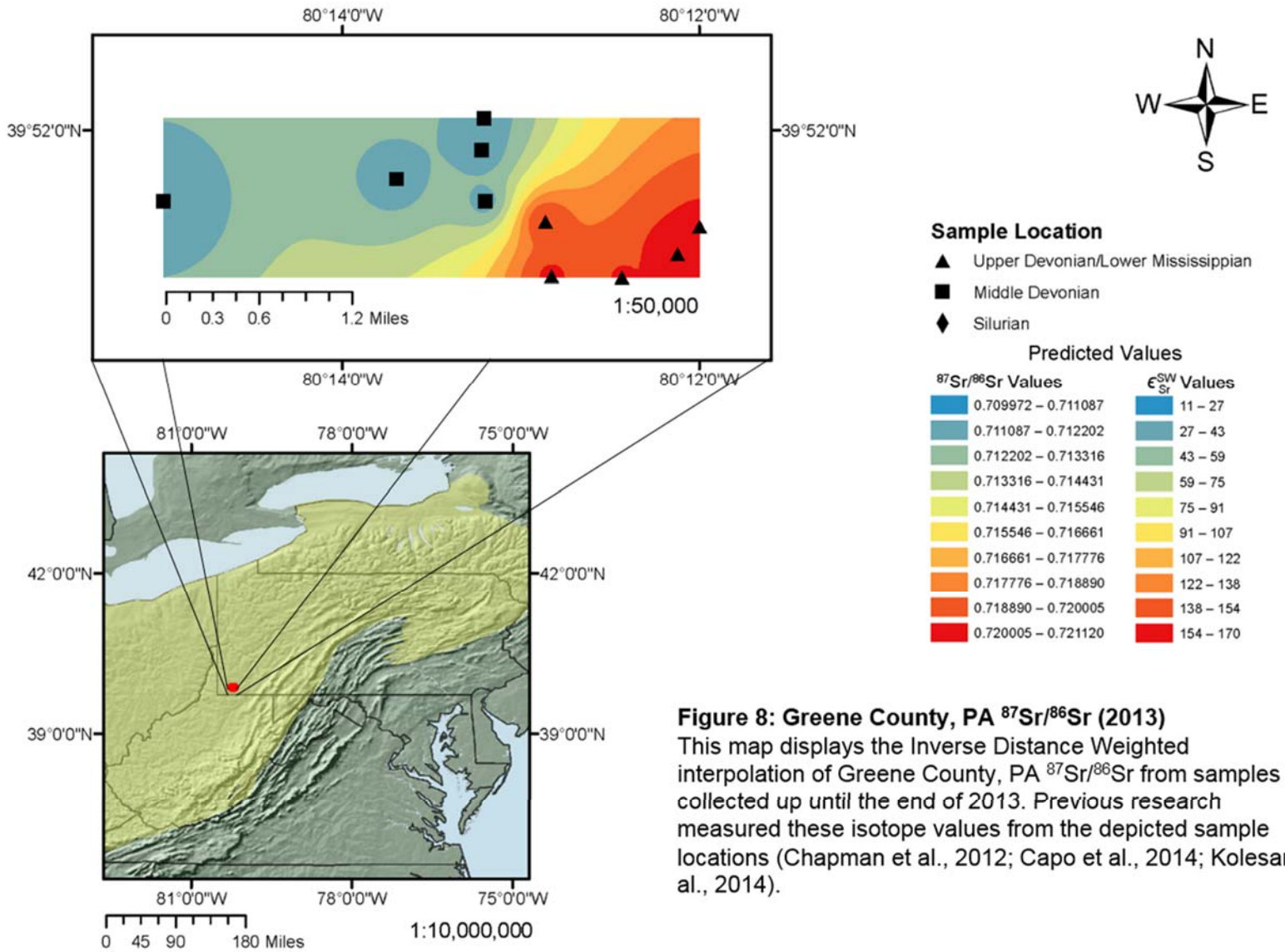
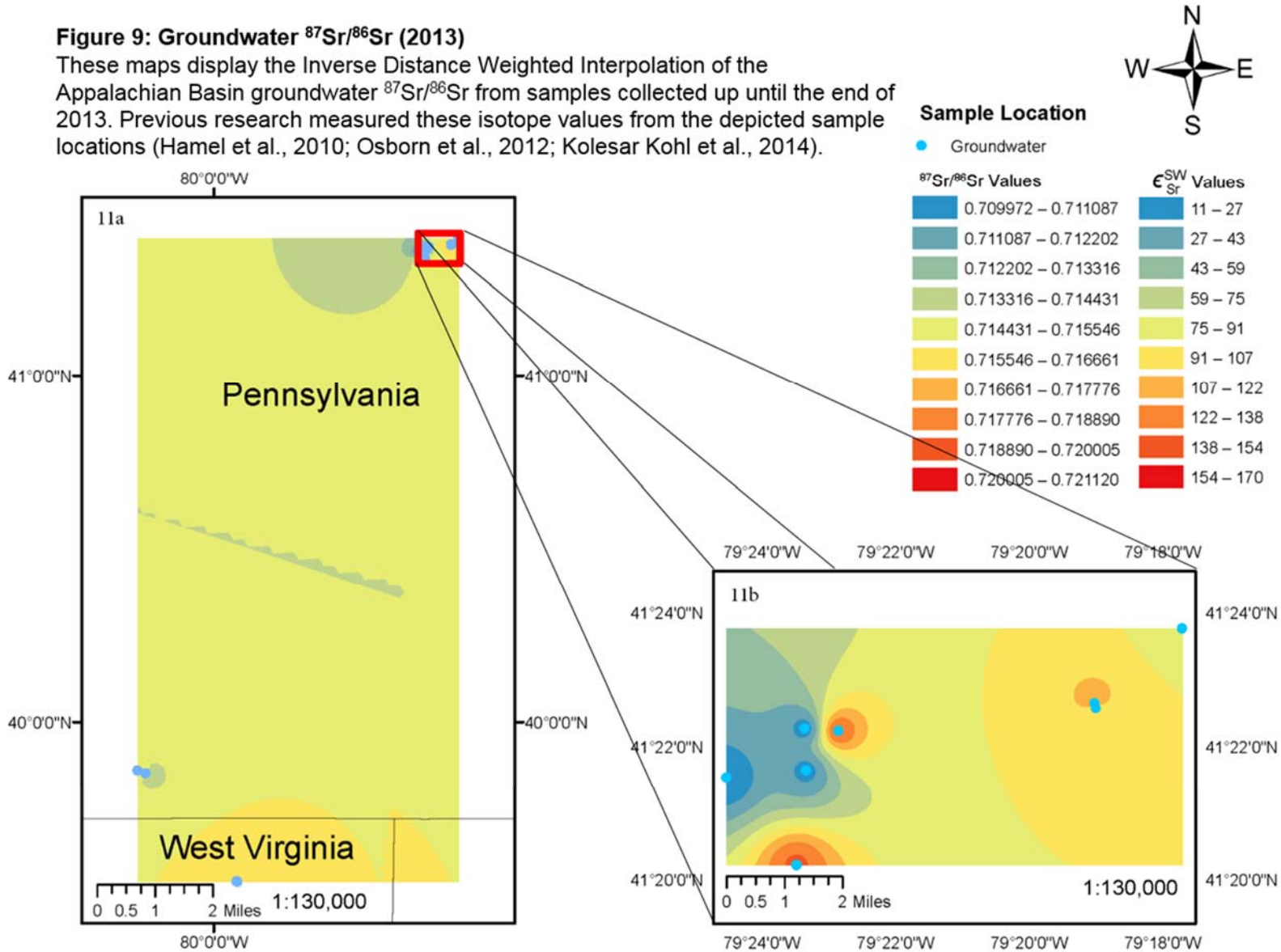


Figure 8: Greene County, PA $^{87}Sr/^{86}Sr$ (2013)
This map displays the Inverse Distance Weighted interpolation of Greene County, PA $^{87}Sr/^{86}Sr$ from samples collected up until the end of 2013. Previous research measured these isotope values from the depicted sample locations (Chapman et al., 2012; Capo et al., 2014; Kolesar et al., 2014).

Figure 9: Groundwater $^{87}Sr/^{86}Sr$ (2013)
These maps display the Inverse Distance Weighted Interpolation of the Appalachian Basin groundwater $^{87}Sr/^{86}Sr$ from samples collected up until the end of 2013. Previous research measured these isotope values from the depicted sample locations (Hamel et al., 2010; Osborn et al., 2012; Kolesar Kohl et al., 2014).



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4. CONCLUSIONS

This study compiled 39 $^{87}Sr/^{86}Sr$ isotopic data points in the Appalachian Basin from six studies and analyzed them with IDW analyses in ESRI ArcMap to create interpolated surfaces in an attempt to find regional trends or variations in $^{87}Sr/^{86}Sr$ isotopic measurements across the Appalachian Basin. To reduce the artifact occurrence, IDW was used to create interpolated surfaces; however, artifacts still exist. While many of the datasets display variations in isotope ratios ($^{87}Sr/^{86}Sr$ up to 0.011; due to geographic location or the geologic unit sampled, or a combination of both factors), the available data are limited in frequency and regional extent. This limits the ability to develop basin-scale predictions on how strontium isotopes may be used to evaluate fluid migration and mixing.

Given the high sensitivity of strontium isotopes to characterize the mixing of isotopically distinct fluids, these natural tracers have potential to identify sources of fluids. This is especially important in cases where fluids high in TDS from different geologic sources (e.g., abandoned mine drainage and Marcellus Shale) require additional analysis for distinguishing the source of contamination. As more data become available for isotope ratios within geologic units of the Appalachian Basin, a combined geospatial and stratigraphic analysis will aid in developing isotope-based predictions for distinguishing sources of contamination in groundwater aquifers. This report serves as a foundation with a hope that as future data emerge from a range of sources, the datasets can be used to reduce uncertainty and develop meaningful spatial results on the applicability of isotope tracers for regional fluid flow monitoring. The data in this report can be accessed from NETL's Energy Data eXchange (EDX) online system (https://edx.netl.doe.gov) using the following link: https://edx.netl.doe.gov/dataset/sr-isotope-data.

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