Image Analysis of Gas Well Cement Exposed to Coal Mine Water

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Research & Innovation Center

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Introduction

Natural gas wells in Northern Appalachia are often drilled in areas where extensive coal mining has occurred (Fig. 1). Many of these coal mines are abandoned and a large portion of these abandoned mines (~40%) are flooded with water (Donovan et al., 2004). This coal mine water ranges in pH from acidic to circumneutral and could have an effect on gas well cement, which has a basic pH (Gaitero et al., 2008). Coal mine water has the potential to alter the microstructure of gas well cement and compromise the well's zonal isolation (Fig. 2).

This study uses ImageJ, a public domain, Java-based image processing program, to measure and visualize the porosity of cement cores exposed to sampled coal mine water. As a complement to traditional porosity measurements, image processing can produce contextualized measurements that provide visual and localized insight into the interactions taking place between coal mine water and cement.

Mined Areas and Gas Wells in Pennsylvania

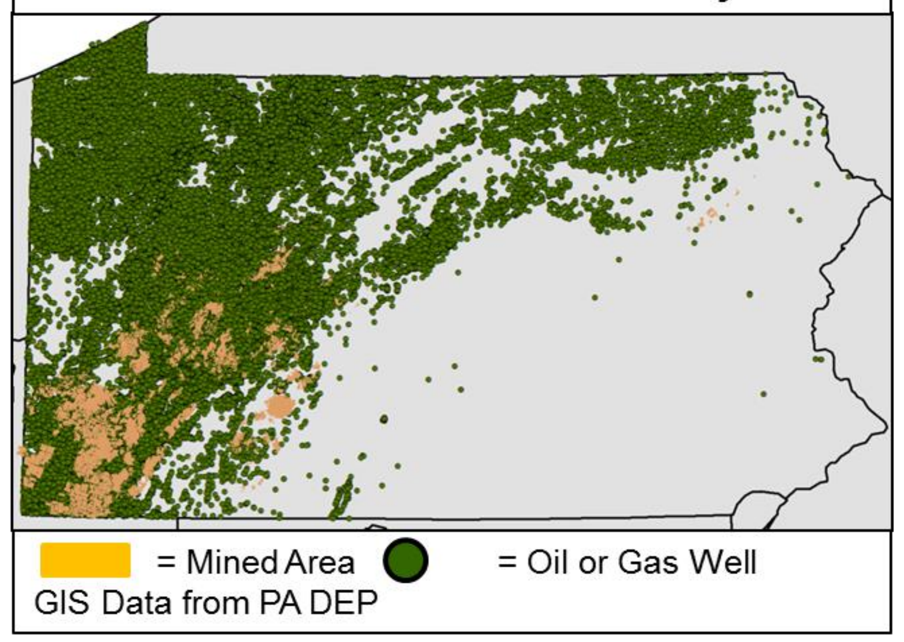


Figure 2. Corroded well casing from a well drilled close to a coal mine. Picture appears courtesy of the Pennsylvania Department of Environmental Protection.

Methods

In this study, lab-generated cement cores (H: 3"; D: 1") were exposed to sampled coal mine water (~120 mL; pH ~6.6) in static reaction vessels for periods of 2, 4, and 6 weeks (Fig. 3a)

After exposure to the coal mine water (CMW), the cement cores were split into six horizontal half-inch subsections (Fig. 3b, 3c). Four of these subsections were imaged using a scanning electron microscope (SEM).

SEM-images of the basal subsections of the cores (Fig. 4a) were then analyzed for porosity using ImageJ. Cement core images were broken down into two primary parts – the rim and the interior (Fig. 4a). One larger square represented the interior while four smaller squares represented the rim. To determine the rim's porosity, between 30 and 40 pore locations were chosen from each of the four rim locations on each sample (Fig 4a).

In order to isolate the pores from the rest of the core, a line selection tool was used to collect grayscale values of the pore and the surrounding cement (Fig 4b). The data collected was used to construct a cross-sectional histogram displaying the values across the line. Low values (0-40) indicated pore space, and high values (80-255) indicated the cement matrix.

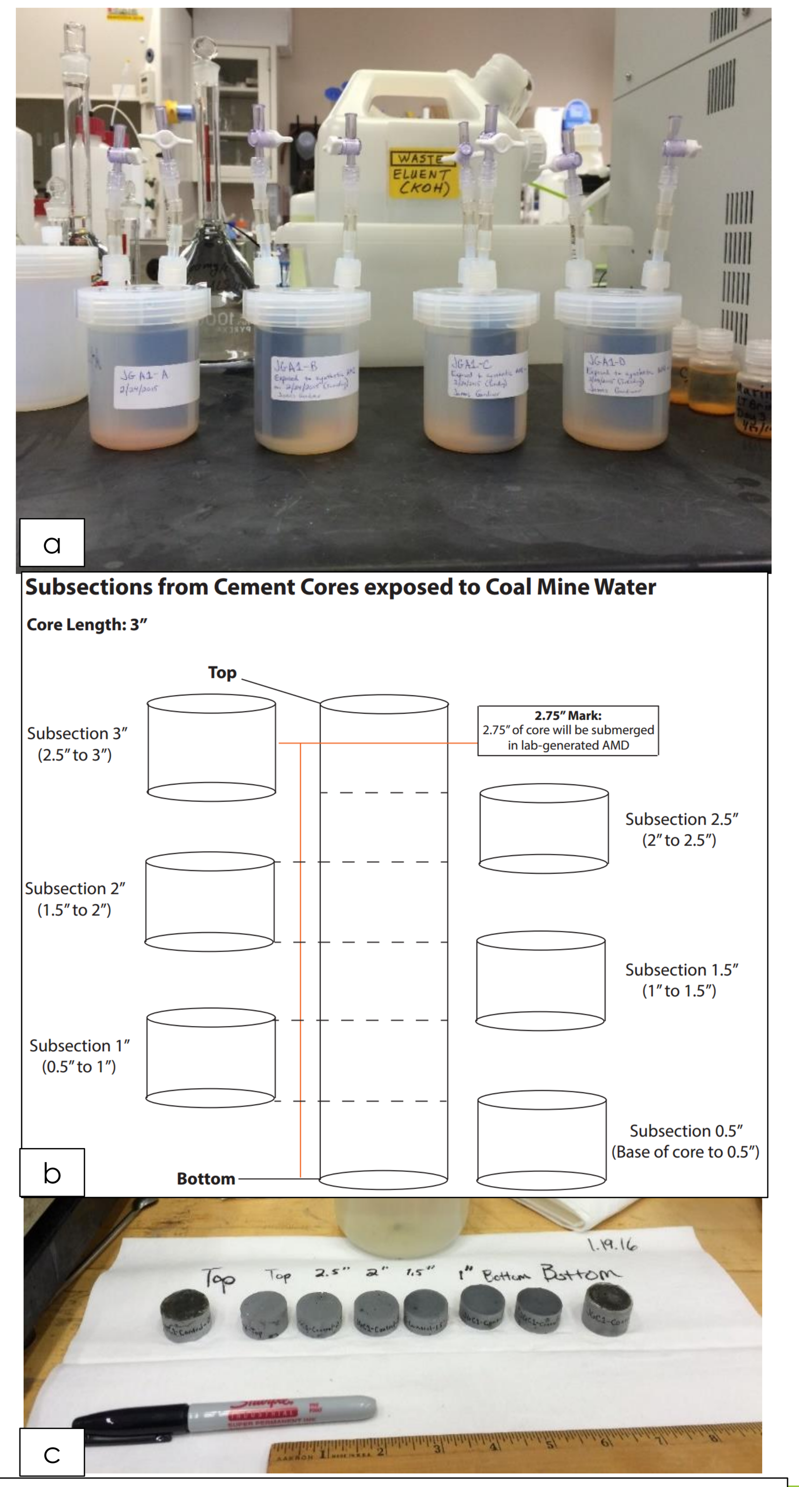


Figure 3. (a) Static reaction vessels where cement was exposed to coal mine water; (b) Schematic illustrating how the cement cores were divided; and (c) a picture of the cement cores cut into subsections after exposure.

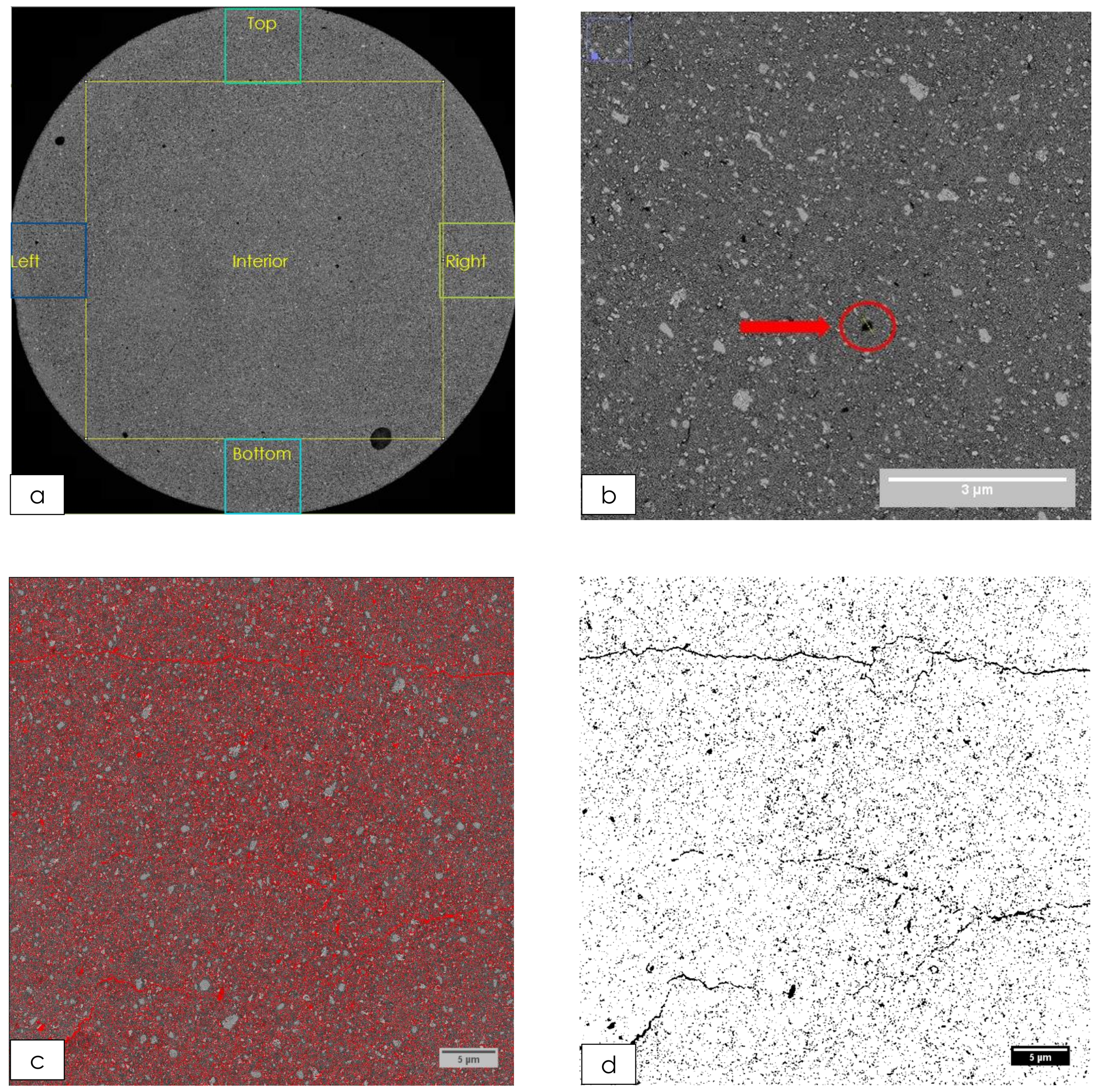


Figure 4. (a) SEM-montage image divided into one interior square and four rim squares; (b) A pore where measured for grayscale values; (c) ; (d) Binary image where black pixels indicate pore space

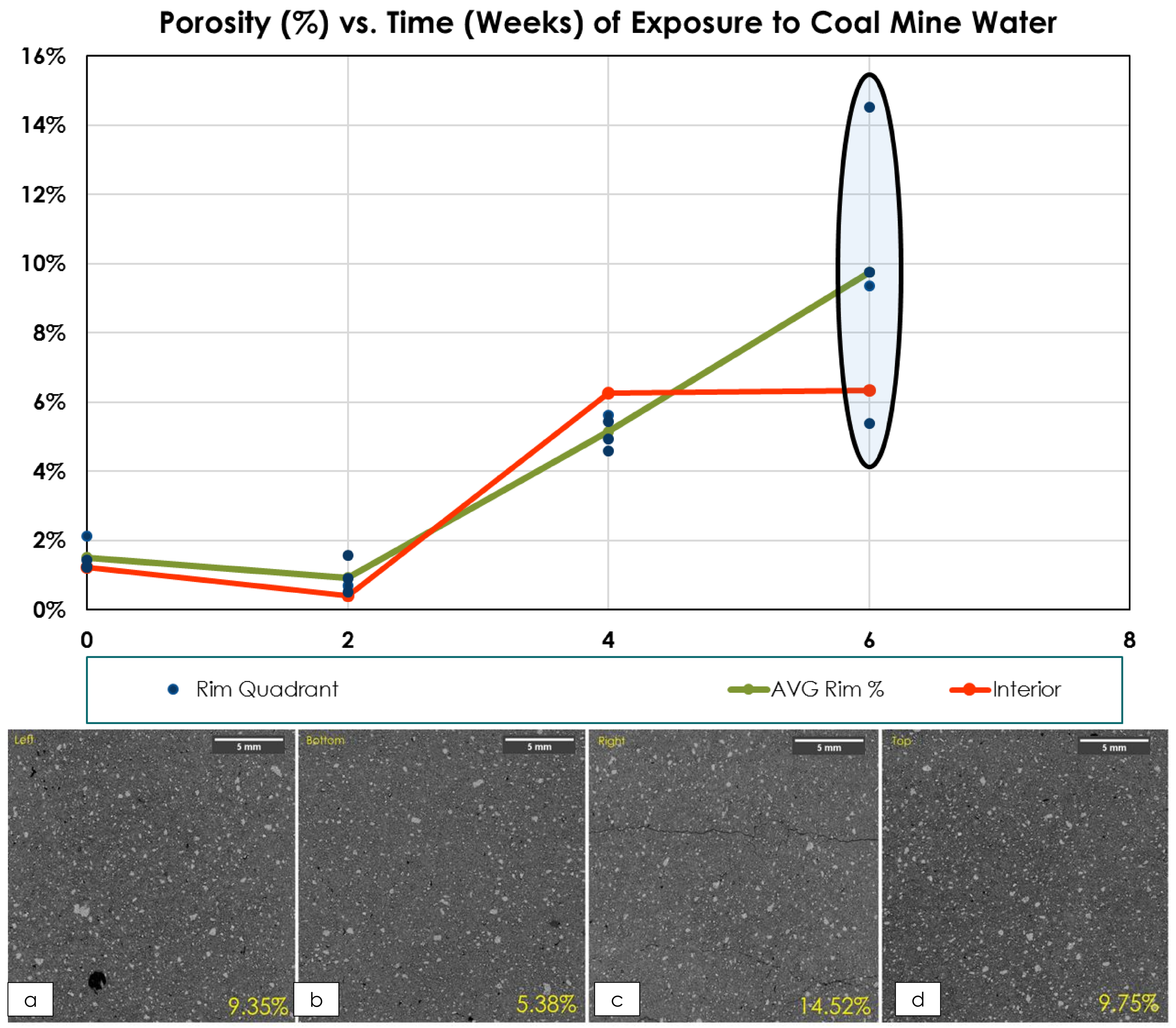
The data was collected and categorized as pore or cement values. While the values were relative to individual images due to certain factors needed to gain the best image such as brightness and contrast levels, the grayscale values were averaged by category to gain a representative output. The pore and matrix average values were then averaged. The resulting value became the threshold limit which determines the pore-cement boundary (Fig 4c). Values above the threshold were representative of cement and values below the threshold represented pore spaces and a binary image was created (Fig 4d)

Results & Discussion

With increased exposure to coal mine water, both interior and rim porosity measurements increased over time (Fig. 5). The measured interior porosity value after six weeks of exposure (6.33%) was higher than either the control (1.21%) or the two-week exposure (0.39%). This increase in porosity suggests that coal mine water infiltrated and altered the cement interior's pore space.

Average rim porosity measurements increased from the control (1.51%) and two-week exposure (0.92%) to the six-week exposure (9.75%), which had the highest porosity measurement in the study. The six-week average porosity measurement had the highest standard deviation (3.24) of all average rim measurements, but its relative standard deviation (33.24%) was within the range of other samples (7.94-44.28%). The relative standard deviation values of the rim measurements reflect the heterogeneity of the cement and how this heterogeneity is manifested in its reactions with the coal mine water. Larger pore spaces and dissolution veins become apparent in samples with increased exposure to coal mine water, suggesting that there are preferential reactions along the cement cores' rims.

While traditional porosimeters measure bulk porosity, the methodology used in this research also highlights localized porosity differences between horizontal slices of sample. These differences were not apparent from the SEM images and were only highlighted by the image processing software. For example, while the average rim porosity in the 6-week exposure is 9.75%, the values have a range between 5.38-14.52% (Fig. 5, Table 1).



While the rim quadrant with the lowest porosity value (5.38%, Fig. 5b) does not exhibit visible pore spaces, the rim quadrant with the highest porosity value (14.52%, Fig. 5c) displays dissolution cracks but does not exhibit any large visible pores, like those visible in Fig. 5a. Image processing software allowed this large difference in porosity to be measured and provided insight into porosity variance across a horizontal slice of sample.

Preliminary Conclusions

This study demonstrates the viability of using image processing software, in this study, ImageJ, to measure porosity of cement cores. In this work, cement porosity increases exposure to coal mine water increases. Not only does porosity increase overall, but image processing analysis suggests that rim porosity increases more than interior porosity specifically due to the development of dissolution veins along the rim. The range of relative standard deviation for rim measurements suggest that the heterogeneous nature of the cement may result in localized reactions that affect porosity. Image processing software provides a method to visualize and quantify the cement alteration process.

References

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Acknowledgments

This work was completed as part of National Energy Technology Laboratory (NETL) research for the Department of Energy's Complementary Research Program under Section 999 of the Energy Policy Act of 2005. This project was supported in part by an appointment to the postdoctoral fellowship program at the National Energy of Technology Laboratory in Pittsburgh, a laboratory of U.S. Department of Energy, administered by the Oak Ridge Institute for Science and Education.

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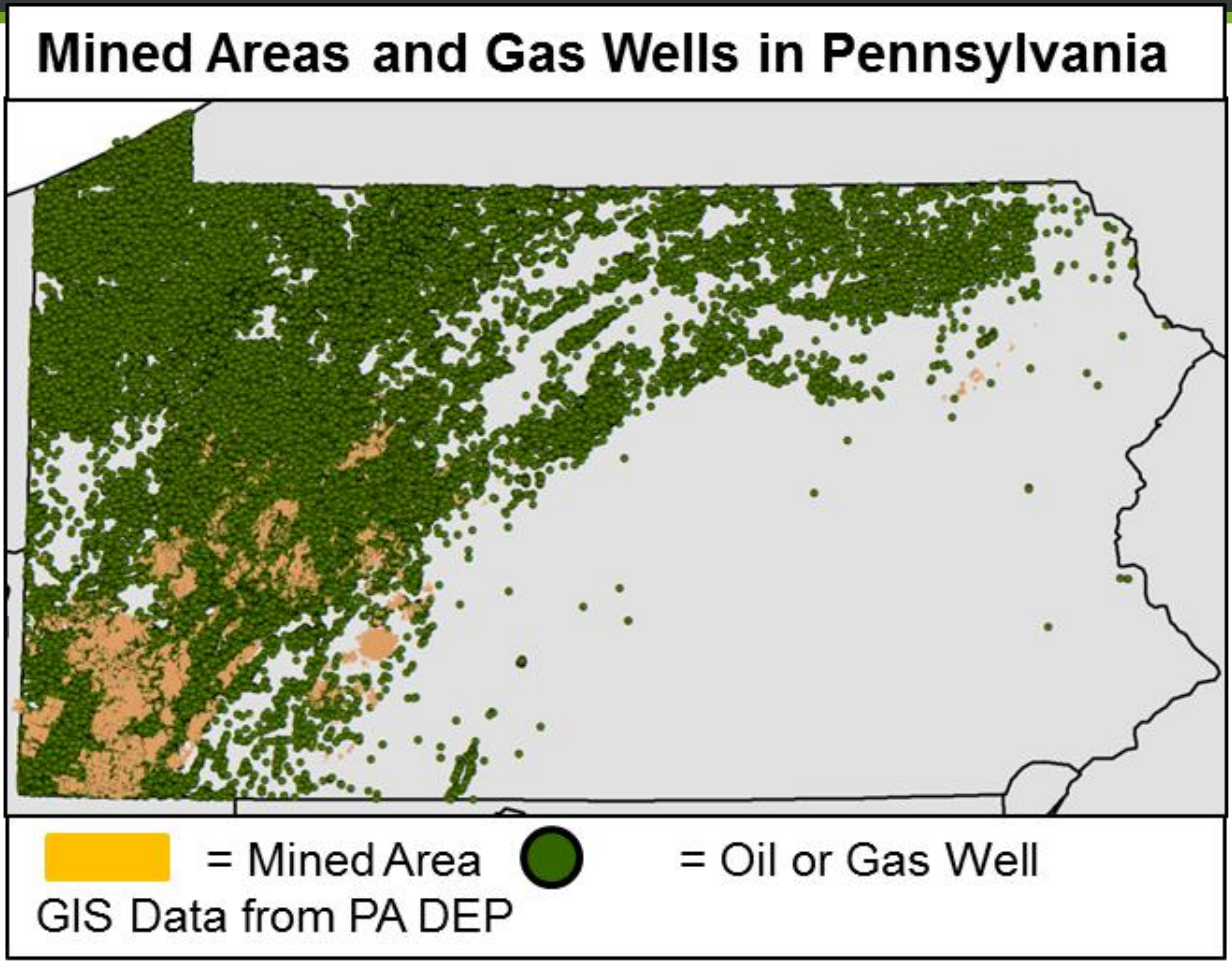
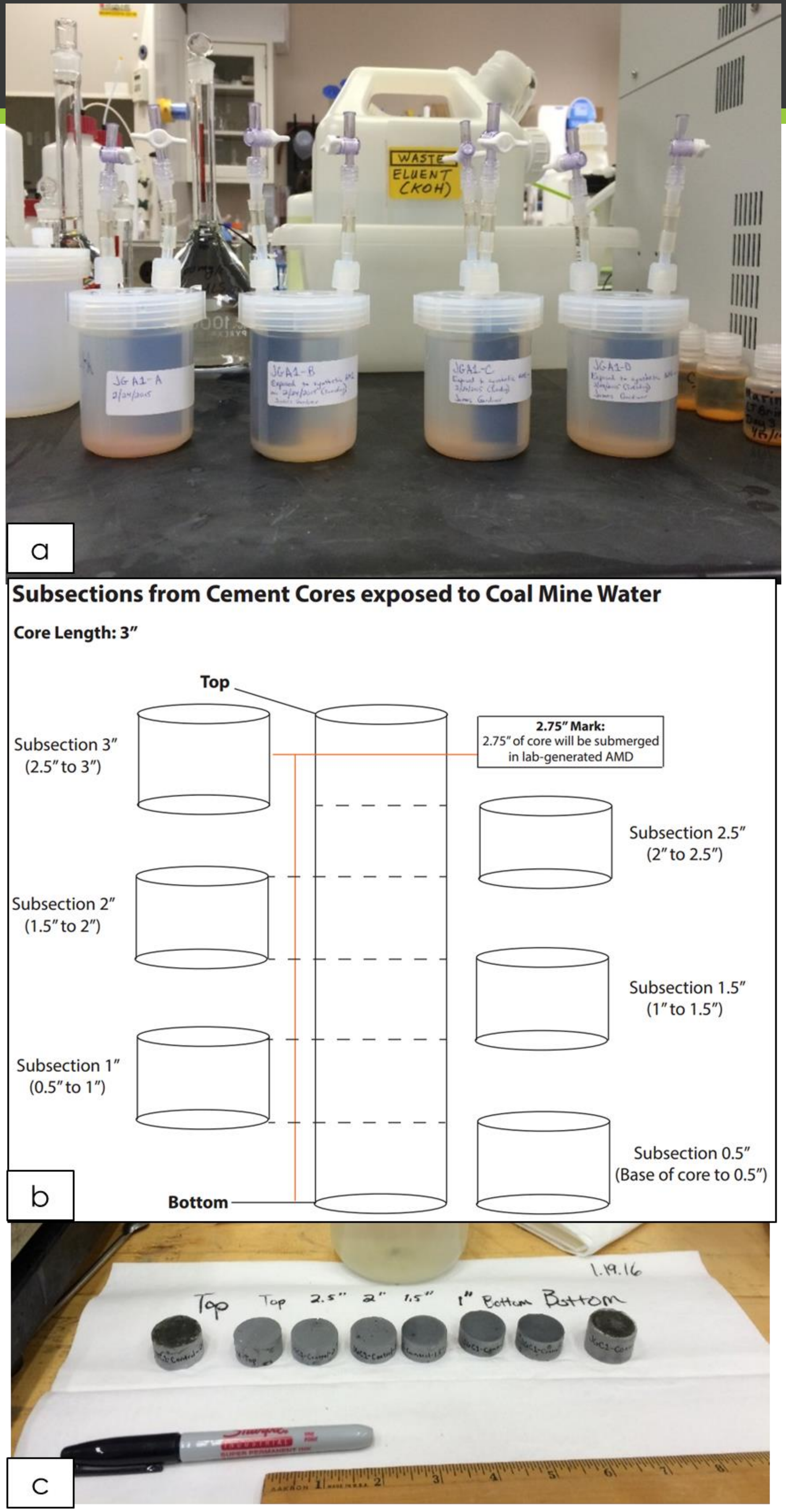


Figure 1. Map of Pennsylvania that features locations of oil and gas wells as well as mined areas.

Figure 2. Corroded well casing from a well drilled close to a coal mine. Picture appears courtesy of the Pennsylvania Department of Environmental Protection.



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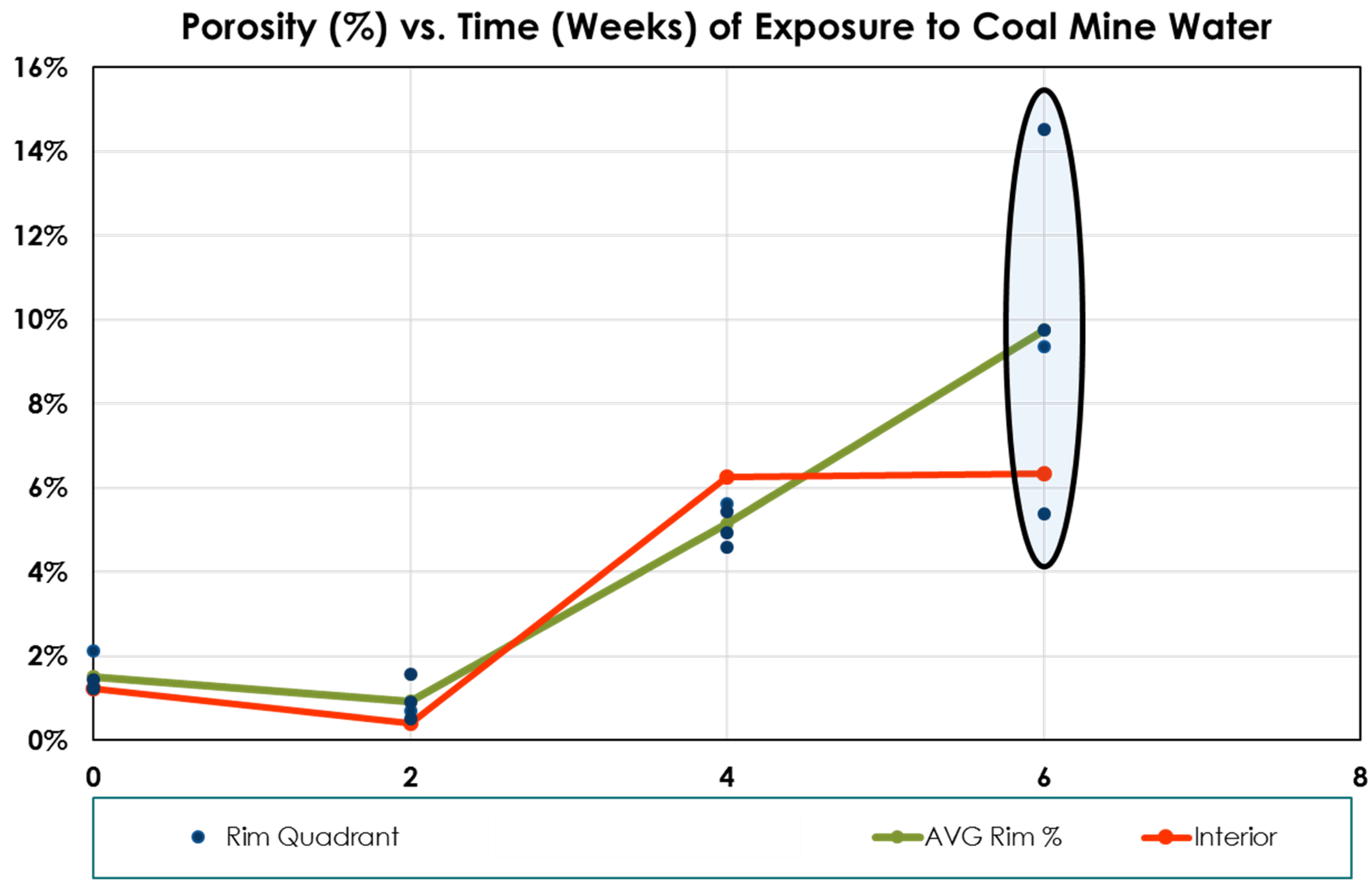
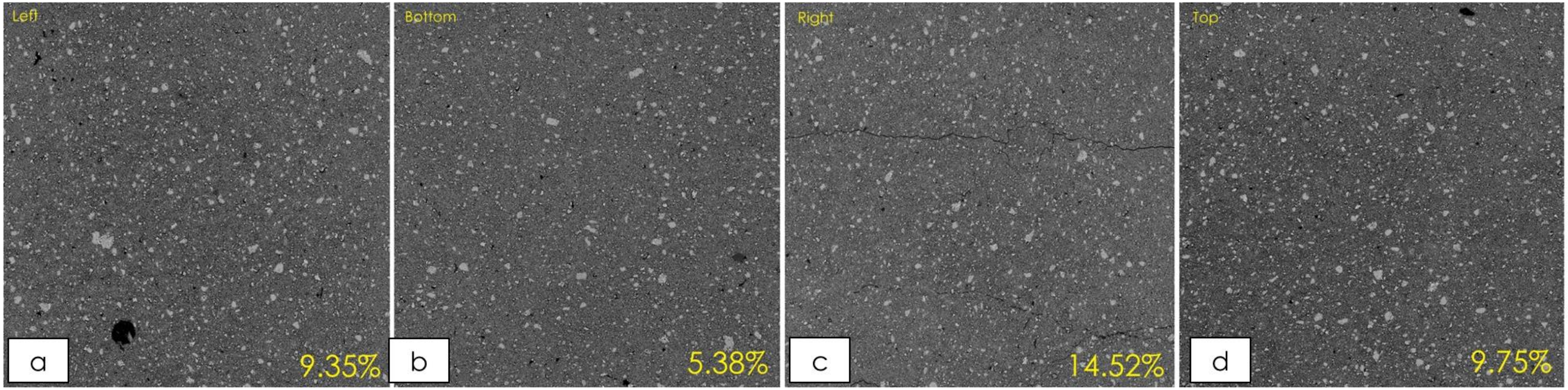

Porosity (%) vs. Time (Weeks) of Exposure to Coal Mine Water
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
2
4
6
8
Rim Quadrant
AVG Rim %
Interior


Left
a
9.35%
Bottom
b
5.38%
Right
c
14.52%
Top
d
9.75%