Interdisciplinary Interactions Between Humans and the Natural World

by

Tyler Griffin Smith

A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
August 3, 2024

Keywords: Geoscience Education, Geocognition, Virtual Field Experiences, Environmental Risk Perceptions, Environmental Geochemistry

Approved by

Dr. Karen McNeal, Chair, Professor, Department of Geosciences
Dr. Ming-Kuo Lee, Professor, Department of Geosciences
Dr. Cissy Ballen, Associate Professor, Department of Biological Sciences
Dr. Jordan Harshman, Department of Chemistry and Biochemistry

Abstract

Humans interact with nature in a variety of different ways. The goal of this work is to examine these interactions through three distinct disciplines: environmental psychology, geoscience education, and environmental geology. Here, quantitative and qualitative analyses are used in projects that consider the ways humans think about, learn about, and are affected by the natural world. The first study examines on environmental risk perceptions related to changes in outdoor activity during COVID-19 legislative shutdowns and finds that environmental awareness and pro-environmental behaviors are more closely tied to societal values, worldviews, and political leaning. The second project explores the motivations, benefits, and barriers of implementing virtual field experiences in geoscience-related educational spaces. The results indicate that filling the instructional gap caused by canceled field trips and field courses due to COVID-19 regulations was the primary motivation behind virtual field experience implementation. Accessibility for students who otherwise may not have been able to participate was the primary benefit cited, while the most noted barriers were a lack of time, software development skills, and access to technological resources. Finally, the third project focuses on the source, distribution, and attenuation of radon in private groundwater wells in two rural communities of northeast Alabama that saw a higher-than-average occurrence of several types of cancer. Using laser ablation inductively coupled plasma mass spectrometry we found uranium and thorium—potential radioactive parents of radon—at concentrations higher than average levels in Earth's crust in the areas around the communities. Periodic groundwater sampling from two small-scale water filtration systems and a background water well indicates the ability of the filters to effectively remove radon from groundwater with regular filter replacement.

Acknowledgments

I have so many people to thank in so many ways, for so many things. I did this FOR myself, but certainly not BY myself, and the full list of ‘thank yous’ that deserve to be handed out is far too long to include here.

I must begin with my advisor, Dr. Karen McNeal: Thank you for taking a chance on me! I had only a vague idea about how any of this worked when I got to Auburn and could not have asked for a more patient guide on this path. Profound thanks, also, to Dr. Ming-Kuo Lee for serving as a committee member, entrusting me with continued data collection and conducting new analyses for the Fruithurst project, and for his leadership of the Department of Geosciences during such an unprecedented time.

Many thanks to Dr. Cissy Ballen, Dr. Jordan Harshman, and Dr. Eric Burkholder, my external reader, for their invaluable advice and feedback as committee members and as part of the Auburn DBER group. Classes and conversations with you and your lab groups have deepened my understanding of the work we do, and I hope to take that forward.

I am extremely grateful to the current and former members of the Auburn Geocognition Lab: Elijah Johnson, Steph Courtney, Nick Soltis, Ally Brown, Lindsay Maudlin, Akilah Alwan, Hang Song, and of course, my BEMC 2077 officemates Haven Cashwell and Haylie Mikulak (sorry for all the mustaches). You all have given me friendship, feedback, advice, support, and encouragement throughout this journey, and I am truly thankful to have worked with you.

I appreciate the support and opportunities provided by the Department of Geosciences faculty and staff during my time at Auburn. Thanks to Dr. David Brink-Roby and Dr. Steph Shepherd who gave me all the support and materials I needed to succeed as I began taking on my own classes. Thanks to Dr. Laura Bilenker, Dr. Brennan van Alderwerelt, and Dr. David Brink-Roby for letting me tag along as a field camp TA; it is one of my favorite experiences at Auburn. Also, thank you to Dr. Laura Bilenker and Dr. Zeki Billor for their time and guidance with the laser and XRD. And I cannot leave out Ashleigh, Amy, Tony, and Kiley. Thanks for keeping me enrolled, paid, fed, connected, and informed. We could not navigate all the ins and outs without you.

I owe tremendous thanks to past colleagues and advisors. To Dr. Warner Cribb, who has been a friend and mentor throughout my academic career and has allowed me to drive across the country and back, stopping to hike, camp, and look at rocks along the way, and Dr. Clay Harris, who encouraged me to "think more like a scientist" and saw that I was more capable than I thought. Also, to Chris Green, the first geologist I ever met professionally, who encouraged me to take this route.

I would, of course, be lost without my friends. The people who pushed, guided, and argued with me, and gave me room to grow. To my #3GOP brothers Bishop Wagener and Zachary Blair, who forced me to become friends with them, then convinced me we should all get master's degrees: thank you, but next time let's just get matching tattoos or something. To my "COVID pod": I would never have survived without you. Elijah, Haven, Nick, Connor Cain, Pedro Montalvo, Nora Lopez-Rivera, Lucas Monroe, and Morrighan O'Connell—I will always be thankful to call you friends. To Marisa Barefoot, Dogancan Yasar, Elyssa Rivera, Ozan Sinoplu, and Sara Speetjens, thanks for being some of the best people to sit with around a campfire. Beans, thank you for everything—I love you.

Finally, I say my biggest thank you to my family, starting with my grandfather, Tom Hilton, Sr., the original family geologist. To my parents, Dan and Becky, my siblings, Lindsey

and Austin, in-law siblings, Jayson and Jayme, and all the nephews and nieces: I know you have no idea what I do or why I chose to do it, but you have all loved and supported me no matter what. I could not be more appreciative.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

CFA	Confirmatory Factor Analysis
CtN	Connectedness to Nature
EFA	Exploratory Factor Analysis
ERP	Environmental Risk Perception
LA-ICP-MS	Laser ablation inductively coupled plasma mass spectrometry
MTurk	Mechanical Turk
TAM	Technology Acceptance Model
VFE	Virtual Field Experience
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

CHAPTER 1: Introduction

Humans interact with nature in complex and multifaceted ways that can significantly influence the health and well-being of community members, as well as their attitudes and behaviors toward the natural world, including their ability and willingness to learn more (Hartig et al., 2014; Liu et al., 2020; Moon & Blackman, 2014; Stern, 2000). Multi- and interdisciplinary studies combining natural and social sciences (including geoscience education) seek to understand the connections between ideas and behaviors shaping the ways humans think about, learn about, and approach nature.

Geoscientists strive to better understand complex Earth system processes and interactions on a variety of scales (Manduca & Kastens, 2012) and through the lenses of many different disciplines (Blake & Liou-Mark, 2016; Perkins, 2011). This integration facilitates and encourages collaboration among all branches of the natural sciences (i.e., chemistry, biology, physics, and astronomy) and other STEM disciplines (Blake & Liou-Mark, 2016). Conversely, social scientists focus on human thoughts, behaviors, and societal interactions through disciplines like psychology, economics, and anthropology (Cohen, 2013; Cooper & Michie, n.d.; Rosenberg, 1988). By combining these broader fields, researchers focus on topics like the effects of natural hazards and changing climate on ancient and modern civilizations (Dearing, 2006; Diamond, 2005; Rambo, 1983; Walsh, 2014) and the impacts of ever-advancing human civilization on the natural world (Bohle, 2015; Stern, 1993).

The projects discussed below are unique in their own ways but are connected by an overarching framework of human-nature interaction. Using quantitative and qualitative approaches, this research considers the ways humans think about (Project 1), learn about (Project

2), and are affected by (Project 3) the natural world. Each study is introduced through a literature review, methods, and results, and discussed individually. References and corresponding tables and figures are included throughout each chapter.

Project 1: Environmental Risk Perception

The Connectedness to Nature theoretical framework examines how people view nature as part of who they are and the life they lead. It suggests that the amount of time someone spends participating in outdoor activities can be tied to levels of importance placed on environmental sustainability and their tendency toward pro-environmental behaviors. Based on this framework, the first project used Amazon's Mechanical Turk crowdsourcing service to collect data from over 1,200 U.S. residents regarding environmental risk perceptions, employment changes due to the COVID-19 pandemic, comparative frequency of outdoor activity before and during the early stages of the pandemic, societal and political views, and demographics. Exploratory and confirmatory factor analyses were used to validate a survey created using new and existing questions. Hierarchical regression analysis was used to evaluate how changes in the amount of time Americans spent outdoors during COVID-19 shutdowns, societal worldviews, and demographics may have influenced perceptions of environmental risk.

Project 2: Virtual Field Experiences

Outdoor field experiences are considered by many to be the cornerstone of geoscience-related education. The onset of the COVID-19 pandemic forced geoscience and other related academic departments to abruptly cancel field trips and field courses or quickly rethink how they might be structured and executed going forward. Based on the Technology Acceptance Model theoretical framework, the second study collected primarily qualitative survey data from heads of geoscience-related departments and instructors who led field courses or regularly included field trips in class curricula. The responses were used to examine the awareness level and use of virtual field experiences (VFEs) to supplement or replace traditional, in-person geoscience field trips or field courses. An embedded mixed-methods approach was used to better understand the motivations for using these programs before and during the COVID-19 pandemic, any barriers faced before or during implementation, and recognized benefits resulting from VFE use. This work was published in *Journal of Geoscience Education* (Smith & McNeal, 2023).

Project 3: Radon Source and Attenuation in Private Well Water

Many residents in the small, rural communities of Fruithurst and Muscadine, Alabama, rely on private groundwater wells that draw from aquifers located in fractured geologic formations. In the mid-2010s, eight individuals in these communities were diagnosed with leukemia or lymphoma. In small, rural communities such as these, with a combined population of less than 2,000 residents, this cancer occurrence rate (0.5%) is much higher than the 0.075% national average reported by the Leukemia & Lymphoma Society. Previous research in the area found high radon levels in private groundwater wells in the area and found that it may have played a contributing role in the high rates of cancer. This study attempted to build upon that work by investigating potential geogenic sources of uranium and thorium in the area, potential radioactive parent elements of radon, using laser ablation inductively coupled plasma-mass spectrometry. Additionally, it examined the effectiveness of small, 5-stage and 2-stage residential-scale water filtration systems in reducing radon levels in drinking water during short-term, high-flow rate use, and over regular, long-term use.

Ch1. References

Blake, R. A., & Liou-Mark, J. (2016). Authenticating interdisciplinary learning through a geoscience undergraduate research experience. In: Lansiquot, R. (Eds.) *Interdisciplinary Pedagogy for STEM: A Collaborative Case Study* (pp. 105-125). Palgrave Macmillan, New York. https://doi.org/10.1057/978-1-137-56745-1_6

Bohle, M. (2016). Handling of human-geosphere intersections. *Geosciences, 6*(3), 11p. https://doi.org/10.3390/geosciences6010003

Cohen, R. S. (Ed.). (2013). *The natural sciences and the social sciences: Some critical and historical perspectives* (Vol. 150). Springer Science & Business Media.

Cooper, C. L., & Michie, J. (n.d.). *Perspective on social sciences (1): What are the social sciences and why do they matter?* Academy of Social Sciences. Retrieved October 26, 2023, from https://acss.org.uk/perspectives-on-social-sciences-1-what-are-the-social-sciences-and-why-do-they-matter/

Dearing, J. A. (2006). Climate-human-environment interactions: Resolving our past. *Climate of the Past, 2*(2), 187-203. https://www.clim-past.net/2/187/2006/

Diamond, J. (2005). *Collapse: How societies choose to fail or succeed.* Penguin Group.

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health, 35,* 207-228. https://doi.org/10.1146/annurev-publhealth-032014-182443

Liu, H., Fang, C., & Fang, K. (2020). Coupled human and natural cube: A novel framework for analyzing the multiple interactions between humans and nature. *Journal of Geographical Sciences, 30*(3), 355-377. https://doi.org/10.1007/s11442-020-1732-9

Manduca, C. A., & Kastens, K. A. (2012). Geoscience and geoscientists: Uniquely equipped to study Earth. *Geological Society of America Special Papers, 486*, 1-12. https://doi.org/10.1130/2012.2486(01)

Moon, K., & Blackman, D. (2014). A guide to understanding social science research for natural scientists. *Conservation Biology, 28*(5), 1167-1177. https://doi.org/10.1111/cobi.12326

Perkins, S. (2011). Geosciences: Earth works. *Nature, 473,* 243-244. https://doi.org/10/1038/nj7346-243a

Rambo, A. T. (1983). *Conceptual approaches to human ecology.* East-West Environment and Policy Institute.

Rosenberg, A. (1988). *Philosophy of social science.* (Vol. 2). Westview Press.

Smith, T. G., & McNeal, K. S. (2023). Assessing motivations, benefits, and barriers of implementing virtual field experiences in geoscience-related disciplines. *Journal of Geoscience Education,* 1-12. https://doi.org/10.1080/10899995.2023.2258760

Stern, P. C. (1993). A second environmental science: Human-environment interactions. *Science, 260*(5116), 1897-1899. https://www.jstor.org/stable/2881407

Stern, P. C. (2000). Psychology and the science of human-environment interactions. *American Psychologist, 55*(5), 523-530. https://doi.org/10.1037/0003-066X.55.5.523

Walsh, K. (2014). *The archaeology of Mediterranean landscapes: Human-environment interaction from the Neolithic to the Roman period*. Cambridge University Press.

CHAPTER 2: Environmental risk perception related to changes in outdoor activity

Abstract

Legislative orders resulting from the rapid spread of COVID-19 across the U.S. significantly impacted employment throughout the nation. This work explores whether employment changes led to fluctuation in outdoor activity during the pandemic, and how that influenced environmental risk perception. Through the framework of Connectedness to Nature, we surveyed over 1,200 U.S. residents about their frequency of participation in outdoor activities before and during COVID-19 orders, social and political views, environmental risk perceptions, and demographic information. Our findings showed an overall decrease in activity, which did not significantly influence environmental risk perception. The strongest predictors of environmental risk perception were self-transcending societal values and liberal-leaning political orientation, highlighting the relationship between societal worldviews and environmental awareness, which persisted through the pandemic.

Introduction

In the spring of 2020, as the COVID-19 pandemic began to take hold across the U.S., state and local authorities across the country issued legislative orders in response to social distancing recommendations from the World Health Organization and the U.S. Centers for Disease Control and Prevention, limiting residents' ability to gather in public spaces (Callow et al., 2020; Husch Blackwell, 2021; Lin & Meissner, 2020). These orders led to the temporary closure of many businesses considered non-essential, especially those with high potential for personal contact (Buera et al., 2021), and resulted in the permanent closure of some businesses with others undergoing drastic operational changes (Crane et al, 2020). Employers were forced to quickly adapt and implement new approaches to doing business, including allowing employees to work from home while others were forced to furlough or lay off workers entirely (Brynjolfsson et al, 2020). In April 2020, unemployment in the U.S. peaked at 14.8% (Congressional Research Service Report, 2021) and the highest percentage of residents working from home reached an estimated 70% (Lardieri, 2021).

Given this unprecedented phenomenon of working from home and the widespread nature of employment changes during the spring and summer of 2020 as a result of COVID-19 protocols, we hypothesized that U.S. residents had more accessible time to pursue various outdoor activities. Furthermore, we postulate that the potential increased time spent outdoors, combined with a heightened awareness of overall risk leads to increased attention paid to environmental issues, influencing perceptions of environmental risk. Risk perceptions, in general, are socially created concepts involving ideas about adverse consequences or danger to an individual, a community, or society that may result from some action or event (Böhm & Tanner, 2018). Environmental risk perceptions focus more specifically on environmental issues such as climate change, contamination, pollution, or habitat loss (Weber et al., 2000). Often, these perceptions are not based on firsthand experience, but on secondhand information learned through media or other sources (Böhm & Tanner, 2018; Weber et al., 2000).

Theoretical Framework

We examined these hypotheses through the lens of Connectedness to Nature (CtN), a broad framework with origins in biophilia and ecopsychology research practices (Fromm, 1964; Roszak, 1995; Wilson, 1984). CtN looks at how humans include the natural world in their everyday lives and view it as representative of who they are (Schultz, 2002). It suggests that there may be some relationship between time spent outdoors, personal views regarding environmental sustainability, and participation in pro-environmental activities (DeVille et al., 2021; Mayer & Frantz, 2004; Zylstra et al., 2014).

The framework is considered multidimensional and includes individual and group cognitive, affective, and behavioral factors (Ashmore et al., 2004; Schultz et al., 2004). Cognitive factors pertain to the way individuals or groups think about and perceive their connection to nature and include views based on political leaning (i.e., hierarchical-egalitarian and individualistic-communitarian; Kahan et al., 2007; Kahan et al., 2012) and societal values (i.e., biospheric/altruistic and hedonic/egoistic; Steg et al., 2011; Steg et al., 2012). Affective factors are associated with emotional responses to environmental risks (Schultz et al., 2004). Behavioral factors include the actions that are taken in response to environmental threats (Slovic et al, 2007).

CtN suggests that prior knowledge and experience with nature (e.g., environmental education and time spent outdoors) may strongly affect a person's connection. Additionally, interaction with others who openly express their interest and concern for environmental topics may influence a person's connection with the natural world through the development of feelings of community (Klassen, 2010; Steg and Vlek, 2009).

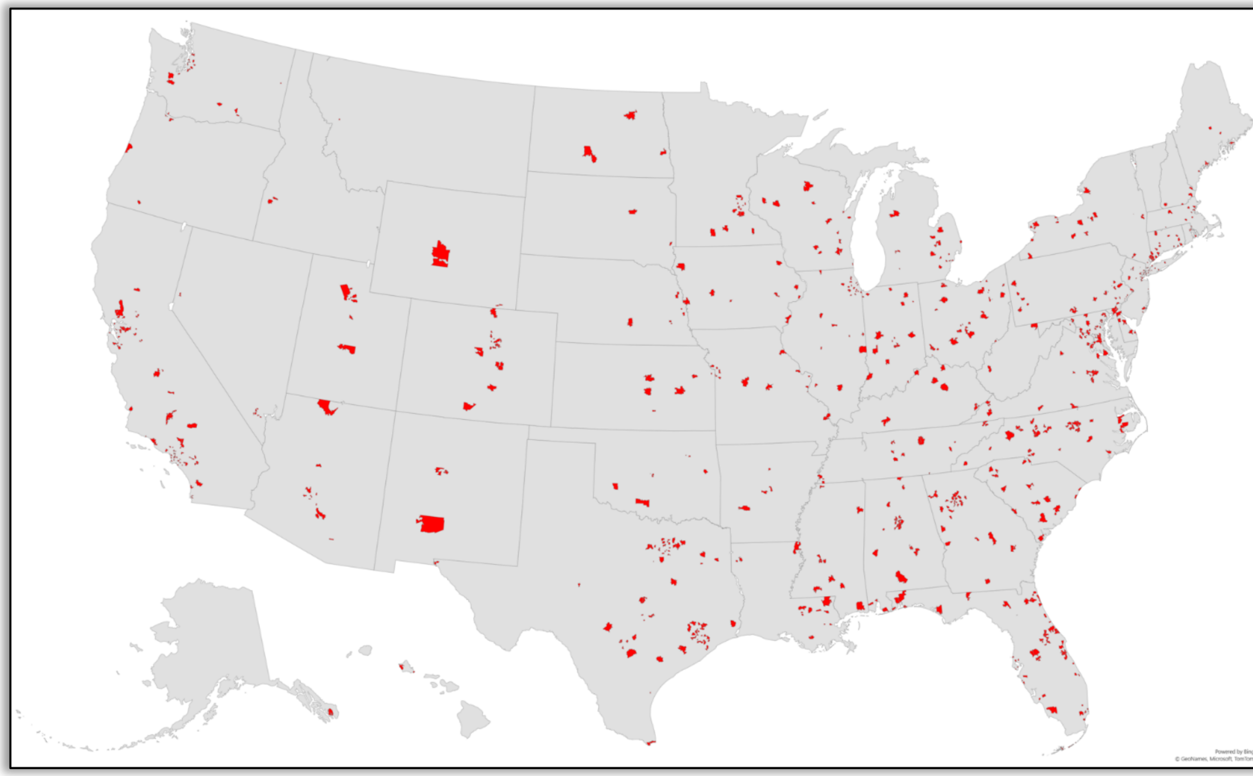
Using the CtN framework and employing a combination of previously deployed and newly created survey questions this work seeks to answer the following research questions:

i) Did U.S. residents spend more or less time outdoors as a result of COVID-19 legislative orders?

ii) How does self-reported change in outdoor activity from before to during COVID-19 shutdowns predict environmental risk perception?

iii) How do other variables (e.g., demographics, societal values, measures of societal importance, etc.) predict the perception of environmental risk?

Figure 2-1. Map of respondent distribution across the United States.



Methods

After receiving approval from Auburn University's Institutional Review Board (Protocol #20-359 EX 2007), we collected survey responses from U.S. residents (Figure 2-1) aged 18 or older (M_{age} = 39.42, SD = 12.18) using Amazon's Mechanical Turk (MTurk), a crowdsourcing service used to collect data in social science fields by having "workers" complete a variety of tasks, like surveys, in return for small monetary compensation (Paolacci et al., 2010; Shank 2016). The survey comprised 47 questions and included previously established and newly developed items. Established questions focused on perceptions of environmental risk (Libarkin et al., 2018; Weber et al., 2000; Yapici et al., 2017), climate knowledge (Libarkin et al., 2018), and societal values and worldviews (Kahan et al, 2012; Steg et al., 2012). Newly developed questions explored interest in and concern for environmental topics, personal impacts of COVID-19 (e.g., employment status, health), and frequency of participation in 16 outdoor activities before and during COVID-19-related legislative orders (i.e., daily, weekly, monthly, yearly, never). Rounding out the question set were questions regarding sample population demographics including age, gender, race and ethnicity, education, employment field (generally STEM or non-STEM employment), political ideology, and ZIP Code. We included two questions as attention checks and a third required respondents to provide an MTurk worker identification number. The full survey can be found in Appendix 1. Table 2-1 displays participant demographic data. All statistical analyses were conducted in Jamovi for R (The jamovi project, 2022) and RStudio (Posit team, 2024).

Table 2-1. Demographic variables for survey participants recruited from MTURK (n=1202).

Demographic	N	% of Total
Age Groups		
18-24 years	38	3.2 %
25-34 years	459	38.2 %
35-44 years	323	26.9 %
45-54 years	218	18.1 %
55-64 years	114	9.5 %
65-74 years	45	3.7 %
75+ years	5	0.4 %
Race/Ethnicity		
White	917	76.3 %
Black/African American	124	10.3 %
Hispanic/Latin American	78	6.5 %
Asian/Pacific Islander	53	4.4 %
American Indian/Alaska Native	18	1.5 %
Multi-Racial	6	0.5 %
Prefer not to answer	4	0. 3 %
Middle Eastern/North African	2	0.2 %
Gender		
Male	651	54.2 %
Female	551	45.8 %
Education Level		
Less than high school	2	0.2 %
High school diploma/GED	79	6.6 %
Some college	104	8.7 %
2-year degree	74	6.2 %
4-year degree	712	59.2 %
Master’s or professional degree	219	18.2 %
Doctoral or medical degree	12	1.0 %
Career Field		
STEM Field	669	55.7 %
Non-STEM	533	44.3 %
Political Leaning		
Very liberal/progressive	109	9.1 %
Somewhat liberal/progressive	204	17.0 %
Moderate/middle-of-the-road	244	20.3 %
Somewhat conservative	410	34.1 %
Very conservative	235	19.6 %

Reliability and Validity Analyses

In October 2020 we distributed a pilot survey to collect responses for preliminary validity and reliability analyses. Out of 296 started surveys, 258 were completed and 238 answered attention checks correctly and provided the required worker ID number. Exploratory factor analysis was conducted for these responses to determine the suitability of the survey for additional study. The data failed to meet the assumption of normality as indicated by the Shapiro-Wilk test ($p < .001$). Due to the non-normality of the data, we used principal axis factoring and an oblique (direct oblimin) rotation method based on the results of Bartlett's sphericity test suggesting correlation among items ($p < .001$). We used a combination of Kaiser's criterion and scree analyses (i.e., elbow method) to determine the number of factors. A loading threshold of .30 or higher was used to determine which variables were loaded onto individual factors. The exploratory factor analysis yielded five factors (environmental risk, outdoor activity, societal values, societal importance factors, and COVID-19 impacts) plus demographics. Several variables were removed due to cross-loading or failure to load on a factor. Reliability analysis of all included items produced a Cronbach's alpha of 0.955 and a McDonald's omega of 0.968 indicating high reliability and internal consistency. No changes were made to the survey before redeployment.

In December 2020, we redeployed the survey to collect additional responses for confirmatory factor analysis. Of 1,147 started responses, 1,007 were completed with 964 answering attention checks correctly and providing the required worker ID number. Due to the non-normality of the data, we applied the robust weighted least squares estimator to this larger dataset during confirmatory factor analysis using the lavaan package (Rosseel, 2012) in RStudio (Posit team, 2024). Outdoor activity was divided into two factors, differentiating variables by activity participation before and during COVID-19-related shutdowns. The societal values factor was split into conservative and liberal factors to resemble the work of Kahan et al. (2012) more closely. The societal importance factor was divided into self-enhancing and self-transcending values, as DeGroot and Steg (2007) and Steg et al. (2012) described. These adjustments resulted in a total of eight factors. Measures such as goodness of fit (χ^2), comparative fit index (CFI), Tucker-Lewis index (TLI), standardized root mean square residual (SRMR), and root mean square error of approximation (RMSEA) were used to check for model fit and, together, indicate a good model fit (Table 2-2) (Byrne, 1994; MacCallum et al., 1996).

Table 2-2. Fit measures for confirmatory factor analysis.

χ^2	df	p
16033.019	5642	< .001

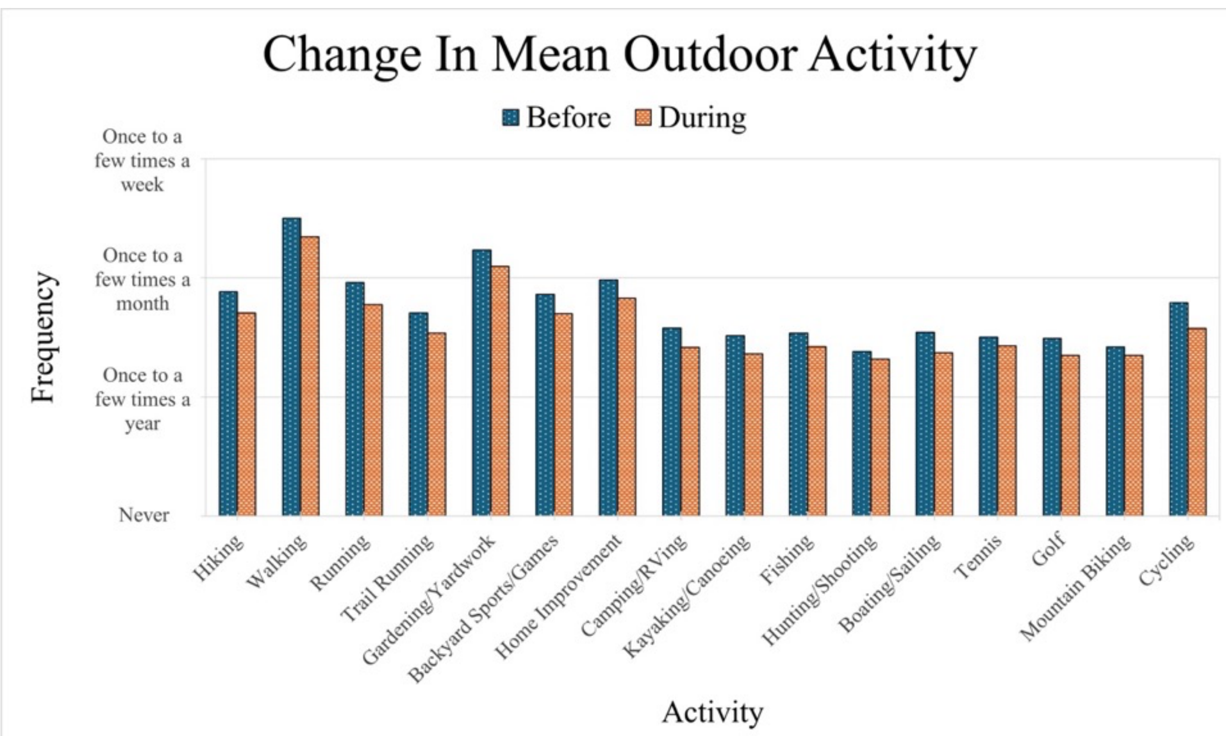
				RMSEA 90% CI	
CFI*	**TLI***	**SRMR***	**RMSEA***	**Lower**	**Upper**
0.940	0.938	0.076	0.071	0.069	0.072

**Thresholds: CFI ≥ 0.9 (Byrne, 1994), TLI ≥ 0.9 (Byrne, 1994), SRMR < 0.08 (Byrne, 1994), RMSEA <0.08 (MacCallum et al., 1996).*

Regression Analyses

We used hierarchical regression to explore relationships between i) outdoor activity during the early stages of the COVID-19 pandemic, ii) social, and iii) demographic factors to explore how these variables predict environmental risk perception. The Jamovi software (The jamovi project, 2022) was used to analyze the survey response data. To determine whether the amount of time Americans spent outdoors increased or decreased, we calculated the difference between outdoor activity-during and outdoor activity-before for fifteen activities then calculated the average difference to create a mean activity difference variable. A mean value for environmental risk perception was calculated using forty-one specific environmental risk variables. This variable, total ERP mean, was used as the criterion variable in all three regression models. The predictor variable for model 1 was the mean outdoor activity difference before and during COVID-19. Predictor variables for model 2 were mean values for conservative societal values, liberal societal values, self-enhancing societal importance, and self-transcending societal importance. Predictor variables for model 3 were age (7 groups), gender (2 groups), race/ethnicity (8 groups), education level (7 groups), political leaning (5 groups), and whether a person worked in a STEM field (2 groups).

Figure 2-2. Change in reported frequency of outdoor activities before and during COVID-19 legislative orders.



Results

Participants in this study were asked a variety of questions about their interest in and concern for environmental topics (e.g., water quality, air quality, climate change, recycling, etc.), their thoughts on the risk of COVID-19 to the health and well-being of themselves or their families, the effects that COVID-19 legislative orders had on their employment, and their perception of environmental risk due to the pandemic. Approximately 95% of respondents indicated at least moderate interest in environmental topics, while about 94% expressed moderate or higher concern. Pandemic legislative orders affected the employment of 62.5% of respondents with 56.3% indicating that they were laid off or furloughed and 80.4% working from home. Over 64% of survey respondents indicated they had tested positive for COVID-19 and 67.7% saw it as a high health risk for themselves or their families. 56.2% of participants saw a greater environmental risk due to the pandemic.

Survey responses indicated less time spent outdoors during COVID-19 legislative orders ($M = -0.143$, $SD = 0.519$) (Figure 2-2). Hunting and other shooting sports ($M = -0.064$, $SD = 1.07$), mountain biking ($M = -0.068$, $SD = 1.12$), and tennis ($M = -0.073$, $SD = 1.20$) were the activities with the least amount of average change.

Table 2-3. Model fit measures and model comparisons for regression analysis.

Model Fit Measures

				Overall Model Test			
Model	**R**	**R²**	**Adjusted R²**	**F**	**df1**	**df2**	**p**
1	0.0744	0.00554	0.00471	6.68	1	1200	0.010
2	0.7529	0.56688	0.56507	313.07	5	1196	< .001
3	0.7611	0.57920	0.56842	53.73	30	1171	< .001

Model Comparisons

Comparison							
Model		**Model**	**ΔR²**	**F**	**df1**	**df2**	**p**
1	-	2	0.5613	387.52	4	1196	< .001
2	-	3	0.0123	1.37	25	1171	0.105

Table 2-3 shows model fit measures and model comparisons for all three regression models. For hierarchical regression model 1 (Table 2-4), mean activity difference was entered as the sole predictor variable and total ERP mean as the criterion variable. The equation was statistically significant in this model ($F_{1,1200}$ = 6.68, p = .010), and mean activity difference was a statistically significant predictor of environmental risk perception (B = -.106, β = -.074, t = -2.58, p = .010) but accounted for only about 0.6% of the variance (R^2 = .006, Adj. R^2 = .005).

Table 2-4. Regression results for model 1.

Omnibus ANOVA Test

	Sum of Squares	df	Mean Square	F	p
Mean_Activity_Diff	3.62	1	3.625	6.68	0.010
Residuals	650.93	1200	0.542		

Note. Type 3 sum of squares

Model Coefficients - Total_ERP_Mean

Predictor	Estimate	Std. Error	t	p	Stand. Estimate
Intercept [a]	3.607	0.0220	163.64	< .001	
Mean_Activity_Diff	-0.106	0.0410	-2.58	0.010	-0.0744

[a] Represents grand mean

For model 2 (Table 2-5), we added conservative and liberal societal values, and self-transcending and self-enhancing societal importance as predictor variables. The equation for model 2 was also statistically significant ($F_{5,\,1196} = 313.1$, $p < .001$). Combining these predictors with mean activity difference accounted for about 57% of the variance in total ERP mean ($R^2 = .567$, Adj $R^2 = .565$). Adding these variables increased the explained variance by approximately 56% ($\Delta R^2 = .561$). The increase was statistically significant ($F_{4,1196} = 387.5$, $p < .001$). Of the added variables, liberal societal values ($B = .054$, $\beta = .064$, $t = 2.97$, $p = .003$), self-transcending societal importance ($B = .268$, $\beta = .653$, $t = 24.7$, $p < .001$), and self-enhancing societal importance ($B = .054$, $\beta = .130$, $t = 5.39$, $p < .001$) were significant predictors of environmental risk perception. However, the mean activity difference variable was no longer a significant predictor ($B = .032$, $\beta = .023$, $t = 1.18$, $p = .239$).

Table 2-5. Regression results for model 2.

Omnibus ANOVA Test

	Sum of Squares	df	Mean Square	F	p
Mean_Activity_Diff	0.330	1	0.330	1.390	0.239
Cons_Val_Mean	0.136	1	0.136	0.574	0.449
Mod_Val_Mean	2.089	1	2.089	8.813	0.003
Self_Transcending	144.835	1	144.835	611.015	< .001
Self_Enhancing	6.889	1	6.889	29.065	< .001
Residuals	283.499	1196	0.237		

Note. Type 3 sum of squares

Model Coefficients - Total_ERP_Mean

Predictor	Estimate	Std. Error	t	p	Stand. Estimate
Intercept [a]	1.1559	0.0891	12.979	< .001	
Mean_Activity_Diff	0.0323	0.0274	1.179	0.239	0.0227
Cons_Val_Mean	-0.0135	0.0178	-0.758	0.449	-0.0168
Mod_Val_Mean	0.0539	0.0182	2.969	0.003	0.0643
Self_Transcending	0.2680	0.0108	24.719	< .001	0.6534
Self_Enhancing	0.0543	0.0101	5.391	< .001	0.1295

[a] Represents grand mean

For model 3 (Table 2-6), we added the demographic variables age, gender, race/ethnicity, education level, STEM career, and political leaning. The equation for model 3 was also statistically significant ($F_{30, 1171} = 64.15$, $p < .001$). Combining these predictors with those from models 1 and 2 accounted for about 58% of the variance in total ERP mean ($R^2 = .579$, Adj. $R^2 = .568$). Adding these variables increased the explained variance by approximately 1% ($\Delta R^2 = .012$). This was not a statistically significant increase ($F_{25, 1171} = 1.37$, $p = .105$). Of the added variables, the 18-24 age group ($B = -.501$, $\beta = -.679$, $t = -2.13$, $p = .034$), the 25-34 age group (B

= -.458, β = -.621, *t* = -2.06, *p* = .040), and very liberal political leaning (*B* = .120, β = .162, *t* = 2.00, *p* = .045) were significant predictors of environmental risk perception.

Table 2-6. Regression results for model 3.

Omnibus ANOVA Test

	Sum of Squares	df	Mean Square	F	p
Mean_Activity_Diff	0.21511	1	0.21511	0.91453	0.339
Cons_Val_Mean	0.08624	1	0.08624	0.36666	0.545
Mod_Val_Mean	1.52287	1	1.52287	6.47447	0.011
Self_Transcending	108.13745	1	108.13745	459.74489	< .001
Self_Enhancing	6.88503	1	6.88503	29.27163	< .001
Gender	0.14092	1	0.14092	0.59913	0.439
Race_Ethnicity	2.14049	7	0.30578	1.30004	0.247
Education_Level	0.95449	6	0.15908	0.67633	0.669
STEM_Career	0.00107	1	0.00107	0.00453	0.946
Political_Leaning	1.34454	4	0.33613	1.42907	0.222
AGE - AgeGroup	3.67008	6	0.61168	2.60055	0.017
Residuals	275.43309	1171	0.23521		

Note. Type 3 sum of squares

Model Coefficients - Total_ERP_Mean

Predictor	Estimate	Std. Error	t	p	Stand. Estimate
Intercept [a]	1.35306	0.1285	10.5268	< .001	
Mean_Activity_Diff	0.02665	0.0279	0.9563	0.339	0.01873
Cons_Val_Mean	-0.01152	0.0190	-0.6055	0.545	-0.01438
Mod_Val_Mean	0.04806	0.0189	2.5445	0.011	0.05732
Self_Transcending	0.25442	0.0119	21.4417	< .001	0.62038
Self_Enhancing	0.06184	0.0114	5.4103	< .001	0.14753
Gender:					
Male – Female	-0.02271	0.0293	-0.7740	0.439	-0.03076

Model Coefficients - Total_ERP_Mean

Predictor	Estimate	Std. Error	t	p	Stand. Estimate
Race_Ethnicity:					
White – Prefer not to answer	0.09174	0.2444	0.3754	0.707	0.12427
American Indian or Alaska Native – Prefer not to answer	0.05886	0.2702	0.2178	0.828	0.07973
Hispanic or Latina/Latino – Prefer not to answer	0.17798	0.2502	0.7114	0.477	0.24108
Middle Eastern or North African – Prefer not to answer	0.20903	0.4223	0.4950	0.621	0.28314
Asian or Pacific Islander – Prefer not to answer	0.21711	0.2535	0.8563	0.392	0.29409
Black or African American – Prefer not to answer	0.14894	0.2484	0.5996	0.549	0.20175
Multi-racial – Prefer not to answer	0.44418	0.3142	1.4135	0.158	0.60167
Education_Level:					
High school diploma/GED – Less than high school	-0.04222	0.3509	-0.1203	0.904	-0.05719
Some college – Less than high school	-0.11757	0.3503	-0.3356	0.737	-0.15926
2-year degree – Less than high school	-0.09162	0.3517	-0.2605	0.795	-0.12411
4-year degree – Less than high school	-0.11709	0.3476	-0.3369	0.736	-0.15861
Master's or professional degree – Less than high school	-0.13562	0.3485	-0.3892	0.697	-0.18371
Doctoral or medical degree – Less than high school	-0.30678	0.3762	-0.8154	0.415	-0.41555
STEM_Career:					
Yes – No	-0.00223	0.0331	-0.0673	0.946	-0.00302
Political_Leaning:					
Very liberal – Moderate/Middle of the road	0.11964	0.0597	2.0039	0.045	0.16206
Somewhat liberal – Moderate/Middle of the road	0.03295	0.0478	0.6900	0.490	0.04463

Model Coefficients - Total_ERP_Mean

Predictor	Estimate	Std. Error	t	p	Stand. Estimate
Somewhat conservative – Moderate/Middle of the road	-0.01259	0.0410	-0.3068	0.759	-0.01705
Very conservative – Moderate/Middle of the road	0.02890	0.0472	0.6128	0.540	0.03915
AGE - AgeGroup:					
18-24 – 75+	-0.50105	0.2358	-2.1253	0.034	-0.67871
25-34 – 75+	-0.45836	0.2227	-2.0584	0.040	-0.62087
35-44 – 75+	-0.41995	0.2230	-1.8828	0.060	-0.56885
45-44 – 75+	-0.32635	0.2236	-1.4595	0.145	-0.44206
55-44 – 75+	-0.44007	0.2253	-1.9536	0.051	-0.59610
65-74 – 75+	-0.38169	0.2322	-1.6438	0.100	-0.51702

[a] Represents grand mean

Discussion

Past research suggests an apparent connection between environmental perception and behaviors, participation in outdoor activities, and connectedness to nature (DeVille et al., 2021; Fang et al., 2017; Junot et al., 2017; Kil et al., 2014; Restall and Conrad, 2015). However, an unprecedented event like the COVID-19 pandemic provides opportunities to explore new variables that may profoundly affect this relationship.

This work examined a possible connection between environmental risk perception and a change in outdoor activity resulting from employment changes due to COVID-19 legislative orders. A majority of our survey participants saw employment changes due to pandemic legislative orders. Many indicated they were laid off or furloughed from their jobs, and others were sent home to work remotely. However, this did not appear to result in increased time spent outdoors by our sample group. It is possible, as Chi (2022) suggests, that COVID-19 risk perception played a moderating role in outdoor activity. Ultimately, change in outdoor activity alone proved statistically significant, but weak predictor of environmental risk perception among our participant set.

Our results suggest that societal values and worldviews meaningfully predict environmental risk perception. Steg et al. (2011, 2012) combine biospheric/altruistic values and hedonic/egoistic values into self-transcending and self-enhancing societal importance views, based on value theory work done by Schwartz (1992, 1994). As might be expected, biospheric and altruistic values relate to the way individuals advocate for the environment or others (Stern and Dietz, 1994), while hedonic or egoistic values focus more on the interests and comfort of the self (Wang et al., 2021). In our study, self-transcending societal importance (biospheric/altruistic values) appears to be a strong predictor of environmental risk perception, in agreement with the findings of previous works like Liobikienė and Juknys (2016) and Slimak & Dietz (2006) that self-transcending values predict environmental risk perception and pro-environmental behavior.

The self-enhancing societal importance variable (hedonic/egoistic values) was also a statistically significant predictor of environmental risk perception, though not as strong as self-transcending societal importance. While this is not a common outcome in studies that use self-enhancement or its hedonic/egoistic factors as predictors of environmental risk perception and pro-environmental behavior, it is not abnormal. Urien and Kilbourne (2011) found similar results indicating that generativity, the belief that current actions have effects that last well into the future (i.e., legacy) (Erikson, 1950), may play a role in the relationship between self-enhancement and environmental behavior. This means that those respondents who score higher on the self-enhancing societal importance scale may have future generations in mind.

In addition to a direct question regarding political orientation, we used a portion of the scale developed by Kahan et al. (2007), based on the cultural theory of risk by Douglas and Wildavsky (1982), and used in his later work on climate change risk perceptions (Kahan et al., 2012). In these, the authors identified two intersecting scales that focus on the importance of social rankings linked to authority based on traits like gender or social standing (hierarchical – egalitarian) and whether success and welfare should be the responsibility of the individual or the community as a whole (individual-communitarianism). Kahan et al. (2012) found a correlation between hierarchical individualists and those who identified as moderate-conservative leaning, as well as egalitarian communitarians and those who identified as moderate-liberal leaning. Our study found that holding more liberal-leaning political views was a statistically significant, but not strong predictor of environmental risk among our participants. Our findings are consistent with other works that have found statistically significant, but weak or indirect relationships between political ideology or party affiliation and environmental risk perception (Casper et al., 2021; Leiserowitz, 2006; Mayer et al., 2017 Pröpper et al., 2022) with factors like religious belief or social interaction having a mediating effect (Cohen, 2003; Kahan et al., 2010; Kahan et al., 2012; Slimak & Dietz, 2006).

Conclusion

This study provided an opportunity to build on the already abundant body of literature involving environmental risk perception, but to do it through the lens of a once-in-a-lifetime event. The ubiquity of the effects of COVID-19 legislative orders on the U.S. population and workforce may never again be seen at that scale. Our goals were to examine whether sudden employment changes due to legislative orders increased the amount of time Americans spent outside and whether an increase had an effect on their perceptions of environmental risk. The findings of our work showed that our participant group spent less time participating in outdoor activities, and that change did not have a meaningful impact on environmental risk perceptions. Like past studies, we found that environmental risk perceptions and pro-environmental behaviors are tied to political leaning and cultural worldviews and that they remained closely related even through an unprecedented event such as COVID-19.

Limitations and Future Considerations

While the results of our survey are reliable, this study is not without its limitations. Data collection interferences that may have influenced the quality of the results are discussed here.

Recall Bias

The survey asked participants to reflect on and compare the frequency of outdoor activity participation before and during COVID-19 legislative orders. Respondents may have relied on generalized recollections and rough estimates to answer these questions instead of detailed memories. This recall bias may have affected the accuracy of data collected for, and used, as a major predictor variable.

Response Bias

Because of the circumstances surrounding the survey, it is possible that the respondent pool consisted mostly of those whose jobs were impacted by COVID-19 shutdowns and were likely to be searching for additional sources of income. This extra time spent completing tasks online could have resulted in decreased time spent participating in outdoor activities.

Survey Fatigue

The questionnaire consisted of 47 questions with six that included multiple and extensive subparts. The average time spent completing the survey was 19.4 minutes (min = 2.47, max = 182). Excess time spent answering questions for this study, combined with the fact that MTurk workers may be involved in responding to multiple surveys per day, even simultaneously, may have contributed to the quality of data collected. Survey fatigue from a) too many surveys, and b) too many questions and response choices may have led participants to rush through the poll and not take the time to consider each question or sub-question fully before selecting an answer.

Survey Content

Given time and the benefit of hindsight, we realize some uncollected and incomplete data may have provided deeper context to this study. For example, ZIP Code information tells us how widely our survey was distributed but does not provide enough information on how residents in those areas perceive environmental risk. Additional questions about socio-economic status, residence area (urban, suburban, or rural), proximity to parks or greenspaces, and access to risk information may have provided more insight into the environmental awareness of our respondents.

We included a limited number of climate-related questions from Libarkin et al. (2018) designed to serve as a proxy for content knowledge. However, responses were not included in the final regression models because they did not load on any of the initial five factors derived from exploratory factor analysis. Work by Aksit et al. (2018) indicates the significance of knowledge and understanding of climate and environmental topics on risk perception. The inclusion of a more robust set of content knowledge questions would be useful in future studies.

In the future, a more streamlined set of quantitative questions, paired with a significant focus on qualitative responses regarding employment changes, effects of COVID-19 orders, and the type and frequency of outdoor activity would allow for more detailed, individual-scale data collection as a mixed-method investigation.

Acknowledgments

The authors would like to thank the members of the Auburn Geocognition Lab for their review and input, as well as all those who took the time to participate in the surveys.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding Statement

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ch2. References

Aksit, O., McNeal, K. S., Gold, A. U., Libarkin, J. C., & Harris, S. (2018). The influence of instruction, prior knowledge, and values on climate change risk perception among undergraduates. *Journal of Research in Science Teaching, 55*(4), 550-572. https://doi.org/10.1002/tea.21430

Ashmore. R. D., Deaux, K., McLaughlin-Volpe, T. (2004). An organizing framework for collective identity: Articulation and significance of multidimensionality. *Psychological Bulletin, 130*(1), 80-114. https://doi.org/10.1037/0033-2909.130.1.80

Böhm, G., & Tanner, C. (2018). Environmental risk perception. In L. Steg & J. I. M. de Groot (Eds.), *Environmental Psychology: An Introduction* (pp. 13-25). Wiley. https://doi.org/10.1002/9781119241072.ch2

Brynjolfsson, E., Horton, J. J., Ozimek, A., Rock, D., Sharma, G., & TuYe, H. Y. (2020). *COVID-19 and remote work: An early look at US data* (No. w27344). National Bureau of Economic Research. https://www.nber.org/papers/w27344

Buera, F. J., Fattal-Jaef, R. N., Hopenhayn, H., Neumeyer, P. A., & Shin, Y. (2021). *The economic ripple effects of COVID-19.* (No. w28704). National Bureau of Economic Research. https://www.nber.org/papers/w28704

Byrne, B. M. (1994). Structural equation modeling with EQS and EQS/Windows. Thousand Oaks, CA: Sage Publications.

Callow, M. A., Callow, D. D., & Smith, C. (2020). Older adults' intention to socially isolate once COVID-19 stay-at-home orders are replaced with "safer-at-home" public health advisories: A survey of respondents in Maryland. *Journal of Applied Gerontology, 39*(11), 1175-1183. https://doi.org/10.1177/0733464820944704

Casper, J. M., McCullough, B. P., & Smith, D. M. (2021). Pro-environmental sustainability and political affiliation: An examination of USA college sport sustainability efforts. *International Journal of Environmental Research and Public Health, 18*(21), 5840. https://doi.org/10.3390/ijerph18115840

Chi, N. T. K. (2022). Environmentally responsible behaviour in outdoor recreation: The moderating impact of COVID-19 related risk perception. *Journal of Tourism Futures*, 1-16. https://doi.org/10.1108/JTF-09-2021-0234

Cohen, G. L. (2003). Party over policy: The dominating impact of group influence on political beliefs. *Journal of Personality and Social Psychology, 85*(5), 808-822. https://doi.org/10.1037/0022-3514.85.5.808

Congressional Research Service. (2021). *Unemployment rates during the COVID-19 pandemic.* https://crsreports.congress.gov/product/pdf/R/R46554

Corraliza, J. A., & Berenguer, J. (2000). Environmental values, beliefs, and actions: A situational approach. *Environment and Behavior, 32*(6), 832-848. https://doi.org/10.1177/00139160021972829

Crane, L. D., Decker, R. A., Flaaen, A., Hamins-Puertolas, A., & Kurz, C. (2022). Business exit during the COVID-19 pandemic: Non-traditional measures in historical context. *Journal of Macroeconomics, 72,* 103419. https://doi.org/10.1016/j.jmacro.2022.103419

DeGroot, J. I. M., & Steg, L. (2007). Value orientations and environmental beliefs in five countries: Validity of an instrument to measure egoistic, altruistic, and biospheric value orientations. *Journal of Cross-Cultural Psychology, 38*(3), 318-332. https://doi.org/10.1177/0022022107300278

DeVille, N. V., Tomasso, L. P., Stoddard, O. P., Wilt, G. E., Horton, T. H., Wolf, K. L., Brymer, E., Kahn, Jr., P. H., & James, P. (2021). Time spent in nature is associated with increased pro-environmental attitudes and behaviors. *International Journal of Environmental Research and Public Health, 18*(14), 7498. https://doi.org/10.3390/ijerph18147498

Douglas, M., & Wildavsky, A. B. (1982). *Risk and culture: An essay on the selection of technological and environmental dangers*. Berkeley: University of California Press.

Fromm, E. (1964). *The heart of man: Its genius for good and evil.* Open Road Media.

Hu, L-t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55. https://doi.org/10.1080/10705519909540118

Husch Blackwell. (April 15, 2021). State-by-state COVID-19 guidance. https://www.huschblackwell.com/state-by-state-covid-19-guidance

Junot, A., Paquet, Y., & Martin-Krumm, C. (2017). Passion for outdoor activities and environmental behaviors: A look at emotions related to passionate activities. *Journal of Environmental Psychology, 53*, 177-184. https://doi.org/10.1016/j.jenvp.2017.07.011

Kahan, D. M. (2012). Cultural cognition as a conception of the cultural theory of risk. In S. Roeser, R. Hillerbrand, P. Sandin, & M. Peterson (Eds.), *Handbook of risk theory* (pp. 725-759). Springer Science & Business Media. https://doi.org/10.1007/978-94-007-1433-5

Kahan, D. M., Braman, D., Gastil, J., Slovic, P., & Mertz, C. K. (2007). Culture and identity-protective cognition: Explaining the white-male effect in risk perception. *Journal of Empirical Legal Studies, 4*(3), 465-505. https://doi.org/10.1111/j.1740-1461.2007.00097.x

Kahan, D. M., Jenkins-Smith, H., & Braman, D. (2010). Cultural cognition of scientific consensus. *Journal of Risk Research, 14*(2), 147-174. https://doi.org/10.1080/13669877.2010.511246

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change, 2,* 732-735. https://doi.org/10.1038/nclimate1547

Kil, N., Holland, S. M., & Stein, T. V. (2014). Structural relationships between environmental attitudes, recreation motivations, and environmentally responsible behaviors. *Journal of Outdoor Recreation and Tourism, 7*, 16-25. https://doi.org/10.1016/j.jort.2014.09.010

Klassen, M. (2010). *Connectedness to nature: Comparing rural and urban youths' relationships with nature* [Master's thesis, Royal Roads University]. Library and Archives Canada.

Land, K. C. (1969). Principles of path analysis. *Sociological Methodology, 1,* 3-37. https://www.jstor.org/stable/270879

Lardieri, A. (2021, February 12). *Poll: Americans like working at home.* U.S. News & World Report. https://www.usnews.com/news/national-news/articles/2021-02-12/majority-of-americans-work-remotely-a-year-into-coronavirus-pandemic-poll-finds

Leiserowitz, A. (2006). Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Climatic Change, 77*, 45-72. https://doi.org/10.1007/s10584-006-9059-9

Libarkin, J. C., Gold, A. U., Harris, S. E., McNeal, K. S., & Bowles, R. P. (2018). A new, valid measure of climate change understanding: Associations with risk perception. *Climatic Change, 150,* 403-416. https://doi.org/10.1007/s10587-018-2279-y

Lin, Z., & Meissner, C. M. (2020). *Health vs. wealth? Public health policies and the economy during COVID-19.* (No. w27099). National Bureau of Economic Research. https://www.nber.org/papers/w27099

Liokikienė, G., & Juknys, R. (2016). The role of values, environmental risk perception, awareness of consequences, and willingness to assume responsibility for environmentally-friendly behaviour: The Lithuanian case. *Journal of Cleaner Production, 112*(4), 3413-3422. https://doi.org/10.1016/j.jclepro.2015.10.049

Lleras, C. (2005). Path analysis. In K. Kempf-Leonard (Ed.), *Encyclopedia of Social Measurement* (Vol. 3) (pp. 25-30). Elsevier.

MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychological Methods, 1*(2), 130-149.

Mayer, A., Shelley, T. O., Chiricos, T., & Gertz, M. (2017). Environmental risk exposure, risk perception, political ideology, and support for climate policy. *Sociological Focus, 50*(4), 309-328. https://doi.org/10.1080/00380237.2017.1312855

Paolacci, G., Chandler, J., & Ipeirotis, P. G. (2010). Running experiments on Amazon Mechanical Turk. *Judgement and Decision Making, 5*(5), 411-419. https://doi.org/10.1017/s1930297500002205

Posit team (2024). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. URL http://www.posit.co/

Pröpper, H. Y. L., Geiger, S., Blanken, T. F., & Brick, C. (2022). Truth over identity? Cultural cognition weakly replicates across 23 countries. *Journal of Environmental Psychology, 83*, 101865. https://doi.org/10.1016/j.jenvp.2022.101865

R Core Team (2021). *R: A Language and environment for statistical computing*. (Version 4.1) [Computer software]. Retrieved from https://cran.r-project.org. (R packages retrieved from MRAN snapshot 2022-01-01).

Restall, B., & Conrad, E. (2015). A literature review of connectedness to nature and its potential for environmental management. *Journal of Environmental Management, 159,* 264-278. https://doi.org/10.1016/j.jenvman.2015.05.022

Rosseel, Y. (2012). lavaan: An R package for structural equation modeling. *Journal of Statistical Software, 48*(2), 1-36. https://doi.org/10.18637/jss.v048.i02

Roszak, T. (1995). Where psyche meets Gaia. In M. E. Gomes, A. D. Kanner, T. Roszak (eds.), *Ecopsychology: Restoring the earth, healing the mind* (pp.1-20). Sierra Club

Schultz, P. W. (2002). Inclusion with nature: The psychology of human-nature relations. In P. Schmuck, & W. P. Schultz (Eds.), *Psychology of Sustainable Development* (pp. 61-78). Springer. https://doi.org/10.1007/978-1-4615-0995-0_4

Schultz, P. W., Shriver, C., Tabanico, J. J., & Khazian, A. M. (2004). Implicit connections with nature. *Journal of Environmental Psychology, 24*(1), 31-42. https://doi.org/10.1016/S072-4944(03)00022-7

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. In M. Zanna (Ed.), *Advances in experimental social psychology* (vol. 25, pp. 1-65). Academic Press. https://doi.org/10.1016/S0065-2601(08)60281-6

Schwartz, S. H. (1994). Are there universal aspects in the structure and contents of human values? *Journal of Social Issues, 50*, 19-45. https://doi.org/10.1111/j.1540-4560.1994.tb01196.x

Shank, D. B. (2016). Using crowdsourcing websites for sociological research: The case of Amazon Mechanical Turk. *The American Sociologist*, *47*(1), 47-55. https://doi.org/10.1007/s12108-015-9266-9

Slimak, M. W., & Dietz, T. (2006). Personal values, beliefs, and ecological risk perception. *Risk Analysis, 26*(6), 1689-1705. https://doi.org/10.1111/j.1539-6924.2006.00832.x

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2007). The affect heuristic. *European Journal of Operational Research, 177*(3), 1333-1352. https://doi.org/10.1016/j.ejor.2005.04.0006

Steg, L., de Groot, J. I. M., Dreijerink, L., Abrahamse, W., & Siero, F. (2011). General antecedents of personal norms, policy acceptability, and intentions: The role of values, worldviews, and environmental concern. *Society & Natural Resources, 24*(4), 349-367. https://doi.org/10.1080/08941920903214116

Steg. L., Perlaviciute, G., van der Werff, E., & Lurvink, J. (2012). The significance of hedonic values for environmentally relevant attitudes, preferences, and actions. *Environment and Behavior, 46*(2), 163-192. https://doi.org/10.1177/0013916512454730

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29*(3), 309-317. https://doi.org/10.1016/j.jenvp.2008.10.004

Stern, P. C., & Dietz, T. (1994). The value basis of environmental concern. *Journal of Social Issues, 50*(3), 65-84. https://doi.org/10.1111/j.1540-4560.1994.tb02420.x

The jamovi project (2022). *jamovi*. (Version 2.3) [Computer Software]. Retrieved from https://www.jamovi.org.

Urien, B., & Kilbourne, W. (2011). Generativity and self-enhancement values in eco-friendly behavioral intentions and environmentally responsible consumption behavior. *Psychology & Marketing, 28*(1), 69-90. https://doi.org/10.1002/mar.20381

Wang, X., Van der Werff, E., Bouman, T., Harder, M. K., & Steg, L. (2021). I am vs. we are: How biospheric values and environmental identity of individuals and groups can influence pro-environmental behaviour. *Frontiers in Psychology, 12*, 618956. https://doi.org/10.3389/fpsyg.2021.618956

Weber, J. M., Hair, Jr., J. F., & Fowler, C. R. (2000). Developing a measure of perceived environmental risk. *The Journal of Environmental Education, 32*(1), 28-35. https://doi.org/10.1080.00958960009598669

Whitburn, J., Linklater W., & Abrahamse, W. (2019). Meta-analysis of human connection to nature and proenvironmental behavior. *Conservation Biology, 34*(1), 180-193. https://doi.org/10.1111/cobi.13381

Wilson, E. O. (1984). The human bond with other species. *Cambridge, MA, USA: Harvard.*

Yapici, G., Ögenler, O., Kurt, A. Ö., Koçaş, F., & Şaşmaz, T. (2017). Assessment of environmental attitudes and risk perceptions among university students in Mersin, Turkey. *Journal of Environmental & Public Health, 2017.* https://doi.org/10.1155/2017/5650926

Zylstra, M. J., Knight, A. T., Esler, K. J., & Le Grange, L. L. L. (2014). Connectedness as a core conservation concern: An interdisciplinary review of theory and a call for practice. *Springer Science Reviews, 2,* 119-143. https://doi.org/10.1007/s40362-014-0021-3

CHAPTER 3: Assessing motivations, benefits, and barriers of implementing virtual field experiences in geoscience-related disciplines

Note: Published in *Journal of Geoscience Education* (2023)
https://doi.org/10.1080/10899995.2023.2258760

Abstract

Outdoor field experiences have long been part of the traditional curriculum in geoscience-related disciplines and are considered a key aspect of professional development in these areas. When the COVID-19 pandemic forced the cancellation of many field excursions around the world, geoscience departments were forced to make abrupt changes to the ways students would be introduced to field study. Virtual field experiences, which were often utilized prior to COVID-19 in a variety of ways, including preparation for in-person fieldwork, increasing student interest, and increasing student accessibility, were developed and employed as alternative options to in-person field experiences. This embedded mixed-methods study used open, hierarchical coding schemes with referential category structure to code open-ended survey responses from 89 department heads and 27 instructors in geoscience-related departments across the U.S. The study was aimed at better understanding acceptance and familiarity with VFEs, motivations for use, and the benefits and barriers encountered during development and implementation. Binary quantitative data was collected to identify institution type, familiarity with, and motivation for the use of VFEs. Opportunities for student diversity, inclusion, and access for students from historically underrepresented groups (BIPOC, disabled students, women, and LGBTQ+ students) were the most immediate benefits recognized. The most often cited barriers were time, skills, and resources needed to create VFEs and put them to use. As VFEs have been utilized in a variety of ways before and during COVID-19, it has become

increasingly necessary to discuss the roles they will play going forward in academic and professional geoscience-related spaces.

Background

Outdoor field experiences, including single-day or short overnight trips outside the classroom setting and standalone courses such as geology field camps, have been a part of the required curriculum in geosciences and related disciplines for well over a century. They are considered by many to be a vital part of student success in these subjects (Bacon & Peacock, 2021; Kent et al., 1997; Peace et al., 2021; Whitmeyer & Mogk, 2009) by directly applying conceptual ideas learned in the classroom to the natural world. In fact, the adage, "The best geologist is the one who has seen the most rocks," from an address by H. H. Read (1940), has been passed down by geologists for decades, suggesting that success is driven by firsthand experience in the field rather than dissemination of knowledge in the classroom. Past research has substantiated this notion by showing that field excursions may lead to an increase in advanced cognitive skills (Petcovic et al., 2014) such as the ability to think in three dimensions spatially, understand deep geologic time, and solve complex problems (Hannula, 2019; Mogk & Goodwin, 2012), all while helping to prepare students with the scientific and professional skills needed to succeed in the workforce after graduation (Buckley et al., 2022; Streule & Craig, 2016). Previous literature suggests that students participating in field activities may also develop deeper social connections (Fuller et al., 2006; Kempa & Orion, 1996) which may lead to higher overall enjoyment of fieldwork as a learning style (Boyle et al., 2007). Building relationships with instructors and other students can help to promote learning through enculturation (Brown et al., 1989; Fedesco et al., 2020) by allowing students to observe expert behavior in the field and to begin learning the necessary problem-solving skills *in situ* (Mogk & Goodwin, 2012).

With the onset of the global COVID-19 pandemic in March 2020, there was a momentous change in the way people interacted with one another and went about their daily lives. The academic sector was not immune to this shift (García-Morales et al., 2021; Sahu, 2020). Restrictions on gathering in common spaces meant that many classes normally held in person were forced to switch to an online format. As colleges and universities shut down worldwide in response to the crisis, instructors were forced to rethink class organization and instructional methods, including unexpectedly reexamining and implementing online modalities (Agasisti & Soncin, 2021; García-Morales et al., 2021; Pokhrel & Chhetri, 2021; Stukalo & Simakhova, 2020). Because field excursions are so common in, and arguably one of the defining aspects of, geosciences-related disciplines (Bursztyn et al., 2022) these impacts were felt in unique ways. In addition to changes in class dynamics, class field trips, and scheduled summer field courses were largely canceled, redesigned as self-guided or independent study options, or adapted to include a virtual component (Bacon & Peacock 2021; de Paz-Álvarez et al., 2022; Peace et al., 2021). However, it has not yet been determined how many geoscience-related departments in the U.S. temporarily or permanently altered their field course offerings to virtual field experiences (VFEs).

VFEs are not new learning approaches in the earth sciences and have often been used as supplements to traditional fieldwork (Buckley et al., 2022; Hurst, 1998; Stainfield et al., 2000). They do not offer the same physical experiences as an in-person field trip, especially from a sensory perspective (Çalişkan, 2011; Evelpidou et al., 2021; McCauley, 2017; Stumpf et al., 2008). They have long been considered useful for preparing students for coursework or data collection in the field (Arrowsmith et al., 2005; Falk et al., 1978; Orion & Hofstein, 1994; Shepherd, 1985; Warburton & Higgitt, 1997), increasing efficiency and productivity of field excursions (Senger et al., 2021b; Stainfield et al., 2000), and allowing for post-fieldwork exercises and review (Bentley, 2014; Stainfield et al., 2000; Whitmeyer & Dordevic, 2021).

Aside from these ancillary benefits, VFEs offer a variety of other advantages over their traditional counterparts. Budget constraints leading to reductions in field-based activities (Buckley et al., 2022; Bursztyn et al., 2017; Cho & Clary, 2020; Mullens et al., 2012), weather uncertainties and extreme conditions (Klippel et al., 2020; Senger et al., 2021a), concerns over safety issues (Buckley et al., 2022; Clancy et al., 2014; Giles et al., 2020), large introductory class sizes (Dolphin et al., 2019), and even sudden, widespread disease outbreak (Fuller et al., 2003; Peace et al., 2021) are all examples of barriers that may be wholly or partially overcome by using VFEs. Some students who may have previously been unable to join geoscience programs due to the often-exclusive nature of field study may now have the opportunity to participate through the use of VFEs. Those who may benefit from the implementation of VFEs and the access they provide, while not an exhaustive list, include students with health problems, physical or mental disabilities (Arrowsmith et al., 2005; Atchison & Martinez-Frias, 2012; John & Khan, 2018), historically underrepresented racial and ethnic communities (Haynes & Jacobson, 2015), and those with family, work, or other personal obligations (Birlenbach, 2019; Ruberto, 2018).

As part of this work, we seek to answer the following research questions:

i) What is the level of familiarity among department faculty and leadership of virtual field experiences?

ii) What were some of the motivating factors for implementing VFEs before and during the COVID-19 pandemic?

iii) What were some noticeable benefits and barriers that were encountered by administrators and instructors while attempting to employ VFEs?

Theoretical Framework

Our research goals for this project are to assess the awareness level of VFEs by geoscience-related departments across the U.S., the primary motivations for implementation, and the ways they are being used as alternatives to in-person field trips and field courses, especially as related to the COVID-19 pandemic. We look at awareness, acceptance, and implementation of VFEs from both departmental and instructor perspectives through the framework of the Technology Acceptance Model (TAM). TAM was first introduced by Davis (1986, 1989) as an adaptation of the Theory of Reasoned Action (Fishbein & Ajzen, 1975) and theorizes that the acceptance of technology is based on two primary factors—perceived usefulness and perceived ease of use—and that these two factors can predict attitudes toward technology and intent to use technology (Masrom, 2007). It has seen additional development and enhancement since its introduction (Venkatesh & Davis, 2000) and has been used across a variety of sectors including tourism (Khalil et al., 2023), online retail (Lui & Forsythe, 2010; ur Rahman et al., 2018), telehealth (Hu et al., 1999), and education (Boese et al., 2009; Inocencio et al., 2022; Masrom, 2007; Villena-Taranilla et al., 2023). Here, we use the perceived usefulness element of the TAM framework to better understand the primary motivations for VFE implementation, and the perceived ease of use element to understand the benefits and barriers that have been encountered while attempting to employ VFEs.

Positionality

It is important to acknowledge the lead author's identity as an able-bodied, white man in shaping perspectives on in-person fieldwork in geoscience-related disciplines. Having participated in fieldwork in the environmental consulting industry and having served as a teaching assistant for several weekend and summer field trips to geologically noteworthy parts of the U.S. as a geology undergraduate and graduate student, a unique understanding of, and appreciation for, the value and importance of "being there" in geoscience-related field study was developed. These experiences, and the interactions with co-workers and fellow students involved, also brought to light many of the obstacles faced by those who expressed interest in wanting to be part of the geoscience community but felt held back or excluded in some way.

This work was born out of a semester project in a qualitative research methods class attended online by the lead author as a first-year Ph.D. student during the summer of 2020. The uncertainty surrounding the COVID-19 pandemic at the time of the project raised significant questions regarding the future of traditional field excursions and inspired conversations between the authors about the applicability of alternative techniques (i.e., VFEs) as supplements or replacements for traditional field study. Further discussion focused on how VFEs might be utilized beyond the scope of a global pandemic as a resource to increase involvement in the geosciences.

Both authors feel strongly that traditional, in-person field experiences are important to the education and success of students in geoscience-related fields, but that VFEs are a valuable tool that may be used to help ease logistical or financial challenges related to in-person fieldwork, increase interest and participation in these disciplines through the development of a more inclusive community, and continue to support the growth of the geosciences workforce.

Methods

This embedded mixed-methods study includes quantitative and qualitative data collected simultaneously from our participants using binary survey and open-ended questions (Bastable et al., 2019; Creswell & Clark, 2010; Edmonds & Kennedy, 2017). We prioritized qualitative data with an emphasis on analysis of personal text from open-ended survey questions but still collected both datasets from our participants.

We realize there is often some overlap among department administration and field faculty. Our goal for this project was to better understand the experiences of using VFEs by department heads from a more generalized, department-level perspective, and more specifically by those faculty who are directly involved in the instruction of class field trips and field courses, especially in response to the sudden and monumental "disruption" brought on by COVID-19 (García-Morales et al., 2021). Additionally, because many departments do not offer traditional geology field camps or other related standalone field courses but do include course-specific field trips in their curriculum, we felt it was necessary to provide separate questions regarding these modalities to allow for a greater variety of responses. Because there is no existing theory for how faculty and department leadership might respond to the impacts of a global pandemic, we utilized the embedded mixed methods approach to holistically explore the phenomenon of how this population made instructional decisions regarding VFEs during a global pandemic and the perceived benefits and barriers of VFEs.

Creation of Mailing List

The American Geoscience Institute's (AGI) Directory of Geoscience Departments (Wilson & Keane, 2019) and The University of South Dakota's Geoscience Departments WWW Directory of U.S. and Canada (Ansfield & Heaton, 2017) were used to create a list of heads of 1,015 geoscience-related departments at 2- and 4-year colleges and universities across the United States that included names, email addresses, and department names. The list was then used as the basis for the dissemination of the surveys described below.

Two surveys were created, one aimed at department heads and lead decision-makers of geoscience-related curriculum (hereafter referred to as *department heads*), and one targeting instructors of geoscience-related curriculum that included field trips either as part of the class structure or who were involved in the instruction of field-based courses, including geology field camps. Both surveys were reviewed for content, question phrasing, spelling, and grammar by members of the Geocognition Lab at Auburn University prior to distribution. The Auburn Geocognition Lab is led by Dr. Karen McNeal (co-author), a subject matter expert in the field of geoscience education research, and is made up of six doctoral students, including the lead author. The instructor-focused survey was reviewed by two members of the Auburn University Department of Geosciences faculty who had recently instructed the department's field camp. Unfortunately, multiple requests outside the Geocognition Lab group for review of the department head-focused survey went unanswered. Comments and revisions made for each survey were largely grammatical. One question was added to each survey regarding respondents' institutional status as a Minority Serving Institution (MSI) or Historically Black College or University (HBCU). Each survey is available by contacting the corresponding author.

Recruitment

Approval was received by Auburn University's Institutional Review Board (Protocol #22-117 EX 2203). Respondent demographic data was not collected as part of either survey. No incentives were offered or provided for participation in either survey.

The first 27-question survey was sent to the list of 1,015 department heads via email using Qualtrics cloud-based software. The survey included questions regarding the effects of the COVID-19 pandemic on class field trips and field courses, the use of VFEs as a supplement to, or replacement for, field trips and field courses in the past and in the future, benefits, and barriers to using VFEs, and any benefits specifically related to diversity, equity, and inclusion (DEI). The survey contained 11 'yes-or-no' questions and 16 short-answer or open-ended questions. Additionally, this initial survey asked for names and email addresses of instructors in those departments who include field trips as part of class curriculum, and/or those who are instructors of field courses.

After receiving the results of this department head survey, a second 26-question survey was sent, also using Qualtrics cloud-based software, to 193 instructors who were identified in responses to the department head survey. Department heads were asked to provide names and contact information of instructors in their department who included field trips as part of class curriculum or were instructors of field courses. These questions were similar to those in the initial survey sent to department heads, but some questions more specifically differentiated between class field trips and field courses. This survey contained 7 'yes-or-no' questions and 19 short answer or open-ended questions.

Data Cleaning

Of the 1,015 survey requests sent to department heads and lead curriculum decision-makers, a total of 98 responses were received. The responses were downloaded from Qualtrics into a Microsoft Excel file and the data were cleaned to remove any potential identifying information. Of these, 89 (8.8% of the total distributed) were over 30% complete and included useful responses for analysis. Those that were not included in the analysis were below 5% complete and no survey information was gathered. The remaining respondents did not consent to participate in the survey.

A total of 29 responses were received from the survey to instructors of class field trips and field courses. The responses were downloaded from Qualtrics into a Microsoft Excel file and the data were cleaned to remove any potential identifying information. Of the total responses, 27 were over 40% complete (14% of the total 193 distributed) and included useful responses for analysis. The remaining two responses were below 5% complete and no survey information was gathered.

Quantitative Data Analysis

We used Microsoft Excel to calculate the percentage of responses from 2- and 4-year institutions, as well as those that were considered MSIs or HBCUs. Excel was also used to quantify percentages of answers to several 'yes' or 'no' questions.

Qualitative Data Analysis

Open-ended responses were copied by the lead author to a Microsoft Word document and uploaded to Delve, a cloud-based coding software, to begin initial qualitative analysis using a thematic analysis structure with open, hierarchical coding schemes using a referential category structure as described by Richards & Richards (1995). The initial round of coding used a combination of deductive and inductive approaches (Proudfoot, 2022), each as described by Bingham & Witkowsky (2022) and Burnard et al. (2008). Responses were first grouped into specific categories based on the main topic of the survey question (a deductive, or top-down approach), then additional codes were created based on response excerpts (an inductive, or bottom-up approach). Following this initial coding step, the responses were uploaded to the web-based coding software Dedoose for additional code refinement and inter-rater analysis. Excerpts were largely coded into single categories; however, some response excerpts could fit into more than one code category. For example, the department head survey comment "T*he idea is to be able to offer a greater number of field experiences in a more standardized way*" falls under both ***Student Experience/Opportunity*** and ***Inclusion/Accessibility*** categories, while the instructor survey comment "*Didn't have to manage physical abilities or weather issues which meant students could focus on the content instead of just surviving*" falls under both ***Student Skills/Success/Professional Development*** and ***Inclusion/Accessibility*** categories. A total of 63 codes were created from the 89 department head respondents and a total of 74 codes were created from the 27 instructor respondents. Once coding was completed, co-coding was completed using approximately 15% of excerpts from each question category (McNeal et al., 2014; Park 2005) to establish interrater reliability (further details in Co-Coding and Inter-rater Reliability section). The external coder was a doctoral student in the Auburn Geocognition Lab who completed qualitative research and analysis coursework. Example excerpts and codes from each survey may be viewed in the supplemental material.

Co-Coding and Inter-rater Reliability

One round of co-coding was completed for each survey using approximately 15% of the total excerpts from each question section (McNeal et al, 2014; Park, 2005). This resulted in a pooled Cohen's kappa score of 0.80 for the department head survey (individual code scores ranged from 0.43 to 0.97) and a pooled Cohen's kappa score of 0.66 for the instructor survey (individual code scores ranged from 0.19 to 0.88). The pooled kappa value for each survey represents substantial strength of agreement between codings (Landis & Koch, 1977).

Results

Data collected from each survey was meant to determine the awareness level of VFEs by leadership and faculty in geoscience-related departments across the U.S., to understand if and how VFEs are being used as alternatives to in-person class field trips and field courses, and to recognize the barriers and benefits faced when developing and employing VFEs.

Of the 89 responses to the department head survey used in this study, approximately 73% came from 4-year institutions and 27% from 2-year institutions. Of these, 31.5% are considered MSIs or HBCUs. This can be broken down more specifically with 18.5% of 4-year institutions being considered MSIs or HBCUs, while roughly 66.7% of the responding 2-year institutions fall into this category. Additional analysis of responses to yes/no questions in this survey may be seen in Table 3-1.

Table 3-1. Binary results from the survey of dept. heads regarding institution classification, field-related curriculum requirements and offerings, and familiarity with, benefits of, and past or future use of VFEs.

	Survey Responses (%)	
2-Year and 4-year Institutions	2-year	4-year
Is your institution primarily a 2-year or 4-year college or university?	27.0	73.0
Yes/No Survey Questions	Yes	No
Is your institution considered a Minority Serving Institution or a Historically Black College or University?	31.5	68.5
Do classes in your department include in-person, field-based excursions as part of the curriculum?	94.4	5.6
Does your undergraduate curriculum **require** a field camp or other field-based course?	32.6	67.4
Does your department **offer** an in-person field course or field camp?	34.2	65.8
Are you familiar with VFEs (field excursions taught using digital or virtual programs)?	80.2	19.8
Have there been attempts made in your department to use VFEs in the past?	73.9	26.1
Was professional development credit offered for developing or training to use VFEs?	8.3	91.7
Was professional development credit a motivating factor for VFE development or training?	50.0	50.0
Were there any recognized benefits of using VFEs that were related to diversity, equity, & inclusion of students?	52.1	47.9
Are there plans by faculty in your department to further investigate or use VFEs in the future?	59.0	41.0

Nearly 81% of the responses to the instructor survey came from those at 4-year institutions, with just over 19% from 2-year institutions. A total of 26.9% are considered MSIs or HBCUs. This can be broken down more specifically with three 4-year institutions being considered MSIs or HBCUs (14.3%), while 4 out of 5 (80%) of the responding 2-year institutions fall into this category. Additional analysis of responses to yes/no questions in this survey may be seen in Table 3-2.

Table 3-2. Binary results from the survey of instructors regarding institution classification and familiarity with, benefits of, and past or future use of VFEs.

	Survey Responses (%)	
2-Year and 4-Year Institutions	2-year	4-year
Is your institution primarily a 2-year or 4-year college or university?	22.2	77.8
Yes/No Survey Questions	Yes	No
Is your institution considered a Minority Serving Institution or a Historically Black College or University?	29.6	70.4
Are you familiar with VFEs (field excursions taught using digital or virtual programs)?	96.3	3.7
Have you attempted to use VFEs in the past as part of a class curriculum?	65.4	34.6
Were there any recognized benefits of using VFEs that were related to diversity, equity, and inclusion of students?	50.0	50.0
Do you plan to further investigate or use VFEs for class field trips in the future?	76.9	23.1
Do you plan to further investigate or use VFEs for field courses in the future?	26.9	73.1

Open-ended questions from each survey comprised individual, broad-level themes with more specific codes given to excerpts within question responses. Responses were first grouped into specific, predetermined categories based on the main topic of the survey question, then additional codes were created within those categories based on response excerpts.

Overall, the coded response excerpts between the two groups were not noticeably different. The most notable difference between the respondent groups was in the length of their responses. While many of the department head responses included short sentences or brief comments, several of the instructors offered more lengthy opinions for some of the open-ended questions, especially regarding why they would or would not use VFEs in the future (department head average = 27.2 words, instructor average = 50.6 words).

Department Heads

COVID-related modifications to field trips and field courses largely included cancellations and/or the use of some remote or virtual options. Those who continued to run field excursions implemented shorter, more localized field trips, and employed COVID-19 safety protocols such as masking, social distancing, and enhanced cleaning practices. COVID-related restrictions and shutdowns were the most frequently mentioned motivations for using VFEs followed by opportunities to provide a universal student experience and increase inclusion and accessibility.

The advantages of VFE use identified in this study varied across individual responses, but student inclusion and accessibility was the most common benefit listed. This was followed by student engagement and performance, and the ability to "visit" geologically interesting regions of the world that may have previously been difficult to access.

Aside from the perceived inadequacy of VFEs as substitutes for in-person field excursions, lack of access to materials, software, and technology, as well as a perceived lack of time and skills necessary for VFE development appear to be the most glaring obstacle to future VFE employment. These issues, along with a preference for in-person fieldwork, were also mentioned as reasons why respondents were unlikely to employ VFEs in the future.

Instructors

Like the survey of department heads, those who responded to the instructor-focused survey cited cancellation and postponement of fieldwork and the use of remote or virtual options as the most common modification made to field courses and class field trips, followed by the implementation of COVID safety protocols.

COVID-related restrictions and shutdowns were among the most common motivations for using VFEs, with inclusion and accessibility, student success and professional development, financial considerations, and access to new and distant locales were also prominent motivations. Inclusion and accessibility and student success were also mentioned most often as benefits for both field courses and class trips.

Noted barriers to successful VFE implementation in the survey of instructors were similar to those listed in the department heads survey. A lack of access to proper materials and technology along with a need for additional faculty time and skills were mentioned as obstacles to be addressed for consideration of future VFE use.

Table 3-3. Deductive coding themes with inductive subcodes and the number of excerpts included from the survey of department heads (n=89).

COVID Modifications - 126	
5	Few to None/N.A.
50	Field Trips/Courses Cancelled/Postponed
3	Independent Field Study
3	Instructional/Academic Changes
18	Masks/Distancing/Other COVID Requirements
40	Remote/VFEs/Other Option Developed/Used
7	Shorter/Localized Trips
VFE Motivations - 70	
2	Meeting Academic Requirements
4	Access to New/Distant Places
26	COVID Restrictions/Shutdowns
1	Environmental Factors (e.g., weather)
1	Funding/Financial Factors
10	Inclusion/Accessibility
13	Student Experience/Opportunity
6	Student Skills/Success/Professional Development
4	Supplementary to Field Work
3	Transportation/Logistics
DEI-Related Outcomes - 42	
9	Allows for Broader Participation
7	Family/Work/Other Previous Obligation
5	Health Issues/COVID
3	Income/Cost/Expense
5	Marginalized/Underrepresented/Cultural
10	Physical Disability/Mobility
3	Universal Student Experience
VFE Barriers - 60	
12	Faculty Time/Skills
3	Funding/Administrative Support
16	Materials/Software/Technology
2	Scheduling/Faculty Support
8	Student Engagement/Performance
12	Not a Good Substitute
7	Few to None Encountered/N.A.
VFE Benefits - 72	
12	Access to New/Distant Places
2	Better than Nothing
2	COVID Restrictions/Shutdowns
2	Environmental Factors (e.g., weather, poor air quality)
21	Inclusion/Accessibility
1	Materials/Software/Technology
13	Student Engagement/Performance
6	Student Skills/Success/Professional Development
5	Supplementary to Field Work
1	Time/Resource Flexibility
6	Transportation Costs/Logistics
1	Few to None/N.A.
Future Use: Yes - 69	
7	Access to New/Distant Places
2	COVID Restrictions/Shutdowns
17	Currently In Use/In Development
2	Environmental Factors
12	Inclusion/Accessibility
3	Resources/Costs
5	Student Engagement/Performance
12	Supplementary to Field Work
9	Worth Attempting for Various Reasons (e.g., "depends on circumstances")
Future Use: No - 42	
5	Faculty Time/Skills
10	In-Person Is Preferred
8	Lack of Administrative/Faculty Support
18	Not a Good Substitute
1	Lack of Student Interest/Enrollment
Future Use: Undecided/Unsure - 2	
Future Needs - 61	
16	Faculty Time/Skills
6	Funding/Administrative Support
1	Inclusion/Accessibility (e.g., lower student cost)
31	Materials/Software/Technology
7	None/Not Sure/N.A.

Table 3-4. Deductive coding themes with inductive subcodes and the number of excerpts included from the survey of instructors (n=27).

COVID Modifications - 38

1	Official COVID Safety Plan Required
14	Field Trips/Courses Cancelled/Postponed
1	Independent Field Study
5	Masks/Distancing/Other COVID Requirements
14	Remote/VFEs/Other Option Developed/Used
2	Shorter/Localized Trips
1	Few to None/N.A.

Class Trip Motivations for VFE Use - 22

4	Access to New/Distant Places
1	Better Than Nothing
4	COVID Restrictions/Shutdowns
4	Inclusion/Accessibility
4	Student Skills/Success/Professional Development
4	Transportation Cost/Logistics
1	Did Not Use/N.A.

Field Course Motivations for VFE Use - 27

1	Better Than Nothing
6	COVID Restrictions/Shutdowns
2	Inclusion/Accessibility
1	Student Skills/Success/Professional Development
17	Did Not Use/N.A.

Class Trip VFE Benefits - 21

3	Access to New/Distant Places
4	Inclusion/Accessibility
3	Offered Mixed Instructional Methods
3	Student Skills/Success/Professional Development
2	Supplementary to Field Work
2	Transportation Cost/Logistics
4	Few to None/N.A.

Field Course VFE Benefits - 23

1	Access to New/Distant Places
1	Course Completion
7	Inclusion/Accessibility
5	Student Skills/Success/Professional Development
1	Supplementary to Field Work
1	Transportation Cost/Logistics
7	Few to None/N.A.

DEI-Related Outcomes - 15

3	Allows for Broader Participation
2	Family/Work/Other Previous Obligation
2	Health Issues/COVID
2	Income/Cost/Expense
1	Marginalized/Underrepresented/Cultural

Class Trip VFE Barriers - 27

2	Faculty Time/Skills
1	Inclusion/Accessibility (e.g., closed captioning)
5	Materials/Software/Technology
8	Not a Good Substitute
6	Student Engagement/Performance
4	Student Skills/Success/Professional Development
1	Few to None/N.A.

Field Course VFE Barriers - 25

5	Faculty Time/Skills
1	Inclusion/Accessibility (e.g., closed captioning)
2	Materials/Software/Technology
4	Not a Good Substitute
1	Student Engagement/Performance
6	Student Skills/Success/Professional Development
6	Few to None/N.A.

Future Needs - 33

8	Faculty Time/Skills
4	Funding/Administrative Support
1	Inclusion/Accessibility (e.g., closed captioning)
16	Materials/Software/Technology
2	Student Interest/Enrollment
2	None/Not Sure/N.A.

Future Use: Yes - 30

2	Access to New/Distant Places
1	COVID Restrictions/Shutdowns
6	Currently In Use/In Development
1	Student Skills/Success/Professional Development
8	Inclusion/Accessibility
2	Resources/Costs
1	Student Engagement/Performance
5	Supplementary to Field Work
4	Worth Attempting for Various Reasons (e.g., "depends on circumstances")

Future Use: No - 19

4	Faculty Time/Skills
5	In-Person Is Preferred
4	Resources/Costs
4	Not a Good Substitute
2	Lack of Student Interest/Enrollment

Codes and subcodes, plus the number of mentions for each category are available in Table 3-3 for department heads and in Table 3-4 for instructors. Example response excerpts are available as supplemental material.

Discussion

VFEs have seen an increase in popularity over the past several years (Buckley et al., 2022; Dolphin et al., 2019), and our results indicate significant familiarity with, and acceptance of, VFEs among both survey groups as resources that may be useful as supplements or replacements for in-person field excursions going forward. While the most common motivations noted for VFE use in this study were tied to the onset of the COVID-19 pandemic and its timing and uncertain nature, especially during the first few months, several respondents had already taken note of the advantages and benefits VFEs offered as compared to in-person field experiences. Many of these were related to student inclusion and academic success, but finances and logistics were also prominently noted. At the same time, our respondents mentioned several drawbacks and barriers to using VFEs that had been encountered while attempting to develop or use existing programs. These most often included the quality of the student learning experience and the availability of time and resources. Broader acceptance of VFEs in the future will likely be tied to overcoming the barriers noted here, as well as others that were not mentioned in response to our surveys.

Motivations

While many noted the inability of VFEs to provide the same depth of knowledge and experience as in-person field trips, cancellation of these outings in the wake of COVID-19 and the need to fill the resulting instructional gap were the reasons most often given as motivating factors in the development and use of VFEs. Due to the timing and uncertain nature of the early stages of the pandemic, geosciences and related departments were forced to quickly make decisions regarding the future of field outings. Many of those surveyed as part of this work opted to cancel or postpone all field study, shorten the travel time and distance of field excursions, implement COVID safety precautions (i.e., masks and distancing), or employ virtual alternatives.

The use of digital or virtual technologies is not new in the field of education, but the COVID-19 pandemic forced the rapid, widespread adoption of tools such as video conferencing and online examinations, as well as a reassessment of instructional methodologies to match the shift in pedagogical framework (García-Morales et al., 2021; Gerard et al., 2022; Jensen, 2019). VFEs are just one part of the technological wave that swept across the worldwide educational landscape as a result of COVID-19, but one that may be somewhat unique to the geosciences and related fields. Many of these departments rely on field experiences in courses and/or as standalone capstone experiences. These activities require travel and often close in-person contact which can make implementation of pandemic safety precautions difficult, and as such, were greatly impacted by the pandemic.

Motivations mentioned for VFE use that were unrelated to COVID-19 included increasing inclusion and access for students who may have felt excluded or unable to participate previously, and offering the ability to explore areas of the world that can be difficult to access due to time, money, or logistics.

Benefits

The benefits of VFE use can be recognized from a variety of perspectives and are well-documented in previous literature (Arrowsmith, 2005; Buckley et al., 2022; Peace et al., 2021; Klippel et al., 2020; Stainfield et al., 2000). One such documented benefit of VFEs includes being able to prepare students for a later in-person field trip (Senger et al., 2021b). Our work showed that preparation for field outings was a perceived benefit, but our results also showed that student skill development, such as experience with remote sensing and other geospatial data, as well as increased student engagement and participation, were also commonly mentioned benefits to employment of VFEs.

The benefits most frequently noted, however, were related to diversity, equity, inclusion, and accessibility. Many survey respondents saw the added benefit of being able to include students from a wider array of backgrounds who may have previously felt excluded from participation in outdoor field excursions or geoscience-related programs in general. Overall, in the U.S., scientific disciplines have been less than representative of the nation's population in terms of diversity of race, gender (Beede et al., 2011; Huntoon et al., 2015; National Center for Science and Engineering Statistics, 2021), and disability status (National Center for Science and Engineering Statistics, 2019), and the geosciences are even further behind (Huntoon et al., 2015; Sidder, 2017). Students from historically underrepresented communities (e.g., BIPOC, women, LGBTQ+, disabled students) may feel uncomfortable or unsafe and may face challenges participating in traditional field activities (Atchison & Martinez-Frias, 2012; Clancy et al., 2014; John & Khan, 2018; Pickrell, 2020). Inclusion of these students who might otherwise be interested in pursuing a geoscience-related education, if not for the exclusive nature of field study, may be an important reason for departments to invest time and resources into VFE development (Birlenbach, 2019; Dolphin et al., 2019; Haynes & Jacobson, 2015).

Barriers

While the benefits of using VFEs seem to be clear to department faculty and leadership, obstacles to their sustained use still remain. When asked about the barriers to implementation and what would be needed to make VFEs a more attractive option in the future, aside from not being an acceptable substitute for in-person fieldwork, respondents cited lack of access to proper materials and technology (e.g., audio/visual equipment, software) along with time and skills (e.g., website development, adoption of new technology) needed to successfully develop VFEs that meet their own instructional goals as primary reasons why they have not, and are unlikely to use these programs in the future. Development of VFEs is no small task (Rotzien et al., 2021; Stott et al., 2009), requiring a great deal of planning and data collection (Fleming, 2022; Pugsley et al., 2022). It is evident from responses to these surveys that if VFEs are to become more widely accepted by faculty in geoscience-related fields, even in a supplementary role, future administrative support in the form of time and training will be a key factor (Ramasundaram et al., 2005).

Limitations

Some limitations exist in both the survey design and distribution. More specific respondent demographic data, such as faculty rank and length of tenure, which may have been useful in comparing quantitative data with qualitative responses were not collected. Additionally, both surveys received lower-than-expected response rates (8.8% from the survey of department heads; 14% from the survey of instructors) which may adversely affect the applicability of the results of the study to the larger geoscience community. A variety of factors may have played a role in the low rate of survey responses, including the corresponding author being an unknown identity to many email recipients. A 2016 survey by the National Association of Geoscience Teachers (NAGT), a well-known entity within the geoscience community, sent to U.S. geoscience faculty members achieved a response rate between 24% and 27.3%, depending on necessary exclusions (Egger et al., 2019; Beane et al., 2019). Some recipients of the department head survey may have forwarded it on to faculty members in their departments not understanding that there would be a follow-up instructor survey or dismissed the instructor-focused follow-up survey as a repeat instead of a separate survey for the instructors. The timing of distribution for each survey may have played a role in the lowered number of responses and may be reflected in the results. This was especially noticeable in the circulation of the instructor-focused survey and its release near the end of the Spring 2022 semester and the beginning of the summer field season for many institutions in the U.S., especially 4-year institutions, where instructors may have been unable to respond due to their teaching in remote field locations.

A brief mention should be made of the possibility that respondents' answers to an open-ended question about DEI-related benefits may have been influenced by an earlier binary question asking whether a benefit had been realized as part of VFE use. However, because at least 50% of both groups indicated a noticeable benefit, we believe this shows that it was an important factor in the use of VFEs.

Implications

Traditional field outings and VFEs, while each having its own set of advantages and disadvantages, should not be considered mutually exclusive from one another. Both virtual and in-person modalities share common goals and benefits including learning to enjoy and appreciate the scientific process and all its complexities, development and enhancement of reasoning skills, and learning to work within a team (Dolphin et al., 2019; National Research Council, 2006; Streule and Craig, 2016). The rapid, COVID-driven shift to online instruction has exposed many of the advantages, opportunities, and challenges of online learning (Abu Talib et al., 2021; Garcia-Morales, 2021), similar to those mentioned in these survey responses for VFEs. Digital and virtual tools, including VFEs, have been pushed to the forefront of discussions regarding the use of technology in education and appear set to remain an important aspect of geoscience-related field education, especially as technology continues to evolve (Cliffe, 2017) and bring the field into the classroom.

Looking beyond academia and to employment after graduation, increased participation in geoscience-related departments has the potential to lead to workforce growth in these disciplines and to increased representation in the workforce (Bennett & Lamb, 2016). The U.S. Bureau of Labor Statistics (2021) projects a total national employment growth rate of 7.7% from 2020-2030, including growth related to recovery from the COVID-19 pandemic (approximately 6%). Growth in the geosciences and many (though not all) related fields is expected to roughly match the total projection (Bureau of Labor Statistics, 2022). If the demand in these employment fields continues as projected, there will be opportunities to include groups that are historically underrepresented in geoscience-related fields and promote their perspectives in the workforce (Locke, 2005).

Though virtual field tools have been slowly gaining acceptance in geoscience-related fields and other similar fields, it took the rapid onset of a global pandemic to bring them solidly into the conversation. Our aim in exploring this phenomenon with department chairs and instructors is to provide a starting point for discussions about how and why future resources, professional development, and classroom implementation may or may not be needed for future consideration of VFEs as an optional tool.

Recommendations and Considerations

Decisions to make use of VFEs should be made with the curricular objectives of individual degree programs in mind, and the role that field outings play in meeting those objectives. Should departmental goals align with many of the stated benefits that VFEs offer, the adoption of VFEs as pedagogical tools, along with a commitment to include time for instructors to devote to the development of the programs and associated modules may be worthwhile.

An additional matter that was not mentioned by survey respondents, but should be considered, is the ability of students to meet the requirements for licensure as professional geologists, which may include a requisite amount of field-based coursework. The National Association of State Boards of Geology (ASBOG) oversees the standardization of testing for its member states in the U.S., however, individual state boards are responsible for setting requirements that applicants must meet to be considered for licensure (ASBOG, 2021). ASBOG representatives reached out to the authors to discuss this matter and noted that some member states had specifically decided against the acceptance of virtual field courses as a satisfactory fulfillment of their standards (J. Patton & D. Sneyd, personal communication, May 26, 2022). Departments may need to consider these constraints if their goal is to graduate geologists who qualify for licensure. However, some departments may determine that the job sectors that their graduates target may not require licensure, and thus, virtual field experiences are acceptable. Once again, we recommend that each department carefully weighs its desired curriculum and aligns student learning outcomes with the affordances and disadvantages of VFEs as they make decisions about their use.

Future Work

Questions remain that can provide opportunities for future study on this topic within the geoscience education community. Follow-up specific to this work may include: i) uncovering whether the amount of time and resources afforded to faculty for the development of virtual field courses have changed post-pandemic; ii) whether VFE development has significantly increased or decreased with the relaxation of COVID-19 protocols and restrictions; and iii) whether learning environments have returned to ‘business as usual’ with no additional consideration given to the use of VFEs as supplementary or replacement tools for in-person class field trips or field courses.

Opportunities exist for further exploration of a hybrid model that allows students to: i) choose whether to participate through traditional field outings or through VFEs (Indiana University, 2023), ii) participate in a simultaneous hybrid model where some students are in the field, others are in the virtual environment, and they are able to interact with one another (a model for this exists at the GeoSPACE Geoscience Field Program at the University of Florida (Marshall et al., 2022)), or iii) be exposed in an intentional sequence first to the virtual environment where scaffolding to develop skills is emphasized and then followed by an in-person field experience (Rotzien et al., 2021; Schlosser et al., 2022). In this case, the VFE was also utilized as a way for students to continue their learning if they needed to be removed from the field environment due to COVID exposure or diagnosis.

There is also room to examine the effect VFEs have had from a student-centered perspective. To offer examples: investigating how participation in these programs impacted students' interest, engagement, or retention in the geosciences and related fields, and the effects VFEs might have had on student achievement as compared to traditional fieldwork in light of COVID-19. It is also important to consider the social implications of taking students out of the field and putting them in front of a computer. Streule and Craig (2016) discussed the importance of students developing the ability to communicate and collaborate with peers during in-person fieldwork, and consideration should be given to the effects VFEs have on the development of those and other social skills.

Finally, after a brief conversation with ASBOG representatives regarding limitations to obtaining professional licensure, we believe the expansion of this topic to include industry professionals and their perceptions of VFEs are of great interest to the entire geoscience community. Collaboration between members of the geoscience-focused private and academic sectors may lay the foundation for more widescale acceptance of VFEs as alternatives to traditional field courses and open the door for additional discussion surrounding licensure requirements in the future.

Acknowledgements

The authors would like to thank all of those who took the time to respond and offer input for each of these surveys. Thanks to Haylie Mikulak for serving as co-coder on the qualitative data, and to the Auburn Geocognition Lab, Dr. Laura Bilenker, and Dr. David Brink-Roby for their review and input on both surveys.

Funding

This work was supported by the Southeastern section of the Geological Society of America under Grant 13454-22.

Disclosure Statement

The authors report there are no competing interests to declare.

Ch. 3 References

Abu Talib, M., Bettayeb, A. M., & Omer, R. I. (2021). Analytical study on the impact of technology in higher education during the age of COVID-19: Systematic literature review. *Education and Information Technologies, 26*, 1-28. https://doi.org/10.1007/s10639-021-10507-1

Agasisti, T., & Soncin, M. (2021). Higher education in troubled times: On the impact of COVID-19 in Italy. *Studies in Higher Education, 46*(1), 86-95. https://doi.org/10.1080/03075079.2020.1859689

Ansfield, V. J., & Heaton, T. H. (2017). *Geoscience Departments WWW Directory – US & Canada*. Geoscience Departments WWW Directory – U.S. & Canada. Retrieved April 20, 2022, from http://apps.usd.edu/esci/geodepts.html

Arrowsmith, C., Counihan, A., & McGreevy, D. (2005). Development of a multi-scaled virtual field trip for the teaching and learning of geospatial science. *International Journal of Education and Development using ICT, 1*(3), 42-56. http://ijedict.dec.uwi.edu//viewarticle.php?id=29&layout=html

ASBOG (The National Association of State Boards of Geology). (2021). *A cross sectional view – 4th edition*. https://www.asbog.org/crosssection/CrossSection_Nov_2021_web.pdf

Atchison, C., & Martinez-Frias, J. (2012). Inclusive geoscience instruction. *Nature Geoscience, 5*(6), 366. https://doi.org/10.1038/ngeo1487

Bacon, K. L., & Peacock, J. (2021). Student challenges in teaching ecology and aligned disciplines during a global pandemic: Reflections on the rapid move online and perspectives on moving forward. *Ecology and Evolution, 11*(8), 3551-3558. https://doi.org/10.1002/ece3.7090

Bastable, E., Meng, P., Falcon, S. F., McIntosh, K. (2019). Using an embedded mixed methods design to assess and improve intervention acceptability of an equity-focused intervention: A methodological demonstration. *Behavioral Disorders, 00*(0). https://doi.org/10.1177/0198742919880486

Beane R., McNeal, K. S., Macdonald, R. H. (2019). Probing the National Geoscience Faculty Survey for reported use of practices that support inclusive learning environments in undergraduate courses. *Journal of Geoscience Education, 67*(4), 427-445. https://doi.org/10.1080/10899995.2019.1621717

Beede, D. N., Julian, T. A., Langdon, D., McKittrick, G., Khan, B., & Doms, M. E. (2011). Women in STEM: A gender gap to innovation. *Economics and Statistics Administration Issue Brief, 04-11.*

Bennett, R. A., & Lamb, D. A. (2016). Accessibility and innovation. *Nature Geoscience, 9*(4), 263-263. https://doi.org/10.1038/ngeo2685

Bentley, C. (2014, Oct. 20). *Telling the story of the Canadian Rockies via Google Earth and Gigapan* [Conference presentation]. Geological Society of America Annual Meeting, Vancouver, British Columbia. https://gsa.confex.com/gsa/2014AM/webprogram/Paper248315.html

Bingham, A.J., & Witkowsky, P. (2022). Deductive and inductive approaches to qualitative data analysis. In C. Vanover, P. Mihas, & J. Saldaña (Eds.), *Analyzing and interpreting qualitative data: After the interview*, (pp. 133-146). SAGE Publications.

Birlenbach, D. M. (2019). Flyover country: Creating flexible field experiences using a mobile geoscience app. *In The Trenches, 9*(3).

Boese, M. J., Sheng, P. D., & Salam, M. A. (2009). Evaluating the use of 3D visualization technology in geology education. *AMCIS 2009 Proceedings,* 7.

Boyle, A., Maguire, S., Martin, A., Milsom, C., Nash, R., Rawlinson, S., Turner, A., Wurthmann, S., & Conchie, S. (2007). Fieldwork is good: The student perception and the affective domain. *Journal of Geography in Higher Education, 31*(2), 299-317. https://doi.org/10.1080/03098260601063628

Brown, J. S., Collins, A., & Duguid, P. (1989) Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42. https://doi.org/10.3102/0013189X018001032

Buckley, S. J., Howell, J. A., Naumann, N., Pugsley, J., Vanbiervliet, J., Ringdal, K., Lewis, C., Tong, B., & Chmielewska, M. (2022, Apr. 27). *Virtual field trips: Experience from a global pandemic and beyond* [Conference presentation]. Society of Petroleum Engineers Norway Subsurface Conference, Bergen, Norway. https://doi.org/10.2118/209560-MS

Bureau of Labor Statistics, U.S. Department of Labor. (2022, Apr. 18). Life, Physical, and Social Science Occupations. In *Occupational Outlook Handbook*. Retrieved August 13, 2022, from https://www.bls.gov/ooh/life-physical-and-social-science/geoscientists.htm

Bureau of Labor Statistics, U.S. Department of Labor. (2021, Sept. 23). Employment to grow 7.7 percent from 2020 to 2030; 1.7 percent excluding COVID-19 recovery. In *The Economics Daily*. https://www.bls.gov/opub/ted/2021/employment-to-grow-7-7-percent-from-2020-to-2030-1-7-percent-excluding-covid-19-recovery.htm

Burnard P., Gill, P., Stewart, K., Treasure, E., & Chadwick, B. (2008). Analysing and presenting qualitative data. *British Dental Journal, 204*(8), 429-432. https://doi.org/10.1038/sj.bdj.2008.292

Bursztyn, N., Sajjadi, P., Riegel, H., Huang, J., Wallgrün, J. O., Zhao, J., Masters, B., & Klippel, A. (2022). Virtual strike and dip – advancing inclusive and accessible field geology. *Geoscience Communication, 5*(1), 29-53. https://doi.org/10.5194/gc-5-29-2022

Bursztyn, N., Shelton, B., Walker, A., Pederson, J. (2017). Increasing undergraduate interest to learn geoscience with GPS-based augmented reality field trips on students' own smartphones. *GSA Today, 27*(6), 4-10. https://doi.org/10.1130/GSATG304A.1

Çalişkan, O. (2011) Virtual field trips in education of earth and environmental sciences. *Procedia-Social and Behavioral Sciences, 15,* 3239-3243.

Cho, Y., & Clary, R. M. (2020). Challenges and opportunities for virtual learning in college geology. In J. J. Mintzes & E. M. Walter (Eds.), *Active Learning in College Science* (pp. 713-728). Springer International Publishing. https://doi.org/10.1007/978-3-030-33600-4_44

Clancy, K. B. H., Nelson, R. G., Rutherford, J. N., & Hinde, K. (2014) Survey of academic field experiences (SAFE): Trainees report harassment and assault. *PloS one, 9*(7), e102172. https://doi.org/10.1371/journal.pone.0102172

Cliffe, A. D. (2017). A review of the benefits and drawbacks to virtual field guides in today's geoscience higher education environment. *International Journal of Educational Technology in Higher Education, (14)*1, 1-14. https://doi.org/10.1186/s41239-017-0066-x

Creswell, J. W., & Clark, V. L. P. (2010). *Designing and conducting mixed methods research* (2nd ed.). SAGE Publications, Inc.

Davis, F. (1986). *A technology acceptance model for empirically testing new end-user information systems: Theory and results* [Unpublished doctoral dissertation]. Massachusetts Institute of Technology. Accessed July 2023. https://dspace.mit.edu/handle/1721.1/15192

Davis, F. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340. https://doi.org/10.2307/249008

de Paz-Álvarez, M. I., Blenkinsop, T. G., Buchs, D. M., Gibbons, G. E., & Cherns, L. (2022). Virtual field trip to the Esla Nappe (Cantabrian Zone, NW Spain): Delivering traditional geological mapping skills remotely using real data. *Solid Earth, 13,* 1-14. https://doi.org/10.5194/se-13-1-2022

Dolphin, G., Dutchak, A., Karchewski, B., & Cooper, J. (2019). Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one. *Journal of Geoscience Education, 67*(2), 114-130. https://doi.org/10.1080/10899995.2018.1547034

Edmonds, A. W., & Kennedy, T. D. (2017). Embedded approach. In *An Applied Guide to Research Designs: Quantitative, Qualitative, and Mixed Methods* (2nd ed.) (pp. 189-195). SAGE Publications, Inc. https://dx.doi.org/10.4135/9781071802779

Egger, A. E., Viskupic, K., & Iverson, E. R. (2019). Results of the National Geoscience Faculty Survey (2004-2016). *National Association of Geoscience Teachers*, Northfield, MN. 82 p.

Evelpidou, N., Karkani, A., Saitis, G., Spyrou, E. (2021). Virtual field trips as a tool for indirect geomorphological experience: A case study from the southeastern part of the Gulf of Corinth, Greece. *Geoscience Communication, 4*(3), 351-360. https://doi.org/10.5194/gc-4-351-2021

Falk, J. H., Martin, W. W., & Balling, J. D. (1978). The novel field-trip phenomenon: Adjustment to novel settings interferes with task learning. *Journal of Research in Science Teaching, 15*(2), 127-134.

Fedesco, H. N., Cavin, D., & Henares, R. (2020). Field-based learning in higher education: Exploring the benefits and possibilities. *Journal of the Scholarship of Teaching and Learning, 20*(1), 65-84. https://doi.org/10.14434/josotl.v20i1.24877

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behavior.* Reading, MA: Addison-Wesley.

Fleming, Z. (2022). Using virtual outcrop models and Google Earth to teach structural geology concepts. *Journal of Structural Geology, 156*, 104537. https://doi.org/10.1016/j.jsg.2022.104537

Fuller, I., Edmonson, S., France, D., Higgitt, D., & Ratinen, I. (2006). International perspectives on the effectiveness of geography fieldwork for learning. *Journal of Geography in Higher Education, 30*(1), 89-101. https://doi.org/10.1080/03098260500499667

Fuller, I., Gaskin, S., Scott, I. (2003). Student perceptions of geography and environmental science fieldwork in the light of restricted access to the field, caused by foot and mouth disease in the UK in 2001. *Journal of Geography in Higher Education, 27*(1), 79-102. https://doi.org/10.1080.0309826032000062487

García-Morales, V. J., Garrido-Moreno, A., & Martín-Rojas, R. (2021). The transformation of higher education after the COVID disruption: Emerging challenges in an online learning scenario. *Frontiers in Psychology, 12*, 616059.

Gerard, L., Wiley, K., Debarger, A. H., Bichler, S., Bradford, A., Linn, M. C. (2022). Self-directed science learning during COVID-19 and beyond. *Journal of Science Education and Technology, 31*, 258-271. https://doi.org/10.1007/s10956-021-09953-w

Giles, S., Jackson, C., & Stephen, N. (2020) Barriers to fieldwork in undergraduate geoscience degrees. *Nature Reviews Earth & Environment, 1*(2), 77-78. https://doi.org/10.1038/s43017-020-0022-5

Hannula, K. A. (2019). Do geology field courses improve penetrative thinking? *Journal of Geoscience Education, 67*(2), 143-160. https://doi.org/10.1080/10899995.2018.1548004

Haynes, N. A., & Jacobson, S. (2015). Barriers and perceptions of natural resource careers by minority students. *The Journal of Environmental Education, 46*(3), 166-182. https://doi.org/10.1080/00958964.2015.1011595

Hu, P. J., Chau, P. Y. K., Sheng, O. R. L., Tam, K. Y. (1999). Examining the technology acceptance model using physician acceptance of telemedicine technology. *Journal of Management Information Systems, 16*(2), 91-112. https://doi.org/10.1080/07421222.1999.11518247

Huntoon, J. E., Tanenbaum, C., & Hodges, J. (2015). Increasing diversity in the geosciences. *Eos, 96.* https://doi.org/10.1029/2015EO025897

Hurst, S. D. (1998). Use of "virtual" field trips in teaching introductory geology. *Computers & Geosciences, 24*(7), 653-658.

Indiana University. (2023). *Judson Mead geologic field station: 2023 course offerings*. https://iugfs.indiana.edu/courses/eas-x429/index.html

Inocencio, L. C., Veronez, M. R., da Silveira, Jr., L. G., Tognoli, F. M. W., de Souza, L. V., Bonato, J., & Diniz, J. L. (2022). 3-D reconstruction of rock samples via structure-from-motion for virtual reality applications: A methodological proposal. *Geosciences, 13*(1), 5. https://doi.org/10.3390/geosciences13010005

Jensen, T. (2019). Higher education in the digital era: The current state of transformation around the world. *International Association of Universities, 2019*, 28-42. https://www.iau-aiu.net/IMG/pdf/technology_report_2019.pdf

John, C. M., & Khan, S. B. (2018). Mental health in the field. *Nature Geoscience, 11*(9), 618-620. https://doi.org/10.1038/s41561-018-0219-0

Kempa, R. F., & Orion, N. (1996). Students' perception of co-operative learning in earth science fieldwork. *Research in Science and Technological Education, 14*(1), 33-41. https://doi.org/10.1080/0263514960140103

Kent, M., Gilbertson, D. D., & Hunt, C. O. (1997). Fieldwork geography teaching: A critical review of the literature and approaches. *Journal of Geography in Higher Education, 21*(3), 313-332. https://doi.org/10.1080/03098269708725439

Khalil, S., Kallmuenzer, A., & Kraus, S. (2023). Visiting museums via augmented reality: An experience fast-tracking the digital transformation of the tourism industry. *European Journal of Innovation Management, 26*, 17p. https://doi.org/10.1108/EJIM-09-2022-0479

Klippel, A., Zhao, J., Oprean, D., Wallgrün, J. O., Stubbs, C., La Femina, P., & Jackson, K. L. (2020). The value of being there: Toward a science of immersive virtual field trips. *Virtual Reality, 24*(4), 753-770. https://doi.org/10.1007/s10055-019-00418-5

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*, 159-174. https://doi.org/10.2307/2529310

Liu, C., & Forsythe, S. (2010). Sustaining online shopping: Moderating role of online shopping motives. *Journal of Internet Commerce, 9*(2), 83-103. https://doi.org/10.1080/15332861.2010.503848

Locke, S. (2005, Oct.). *The status of persons with disabilities in the geosciences* [Conference presentation] Regional Alliance for Science, Engineering, and Mathematics Squared (RASEM2) Symposium, Las Cruces, New Mexico. https://www.researchgate.net/publication/333670646_The_Status_of_Persons_with_Disabilities_in_the_Geosciences

Marshall, A., Piatek, J. L., Williams, D. A., Gallant, E. Thatcher, S., Elardo, S., Williams, A. J., Collins, T., & Arroyo, Y. (2022) Flexible fieldwork. *Nature Reviews Earth & Environment, 3*(12), 811-811. https://doi.org/10.1038/s43017-022-00375-9

Masrom, M. (2007). Technology acceptance model and e-learning. *Technology, 21*(24), 81.

McCauley, D. J. (2017). Digital nature: Are field trips a thing of the past? *Science, 358*(6361), 298-300. https://doi.org/10.1126/science.aao1919

McNeal, K. S., Libarkin, J. C., Ledley, T. S., Bardar, E., Haddad, N., Ellins, K., & Dutta, S. (2014). The role of research in online curriculum development: The case of *Earthlabs* climate change and earth system modules. *Journal of Geoscience Education, 62*(4), 560-577. https://doi.org/10.5408/13-060.1

Mogk, D. W., & Goodwin, C. (2012). Learning in the field: Synthesis of research on thinking and learning in the geosciences. In K. A. Kastens, & C. A. Manduca (Eds.), *Earth and Mind II: A synthesis of research on thinking and learning in the geosciences* (Vol. 486, pp. 131-165). Boulder, CO: Geological Society of America. https://doi.org/10.1130/2012.2486(24)

Mullens, J. B., Bristow, R. S., & Cuper, P. (2012). Examining trends in international study: A survey of faculty-led field courses within American departments of geography. *Journal of Geography in Higher Education, 36*(2), 223-237. https://doi.org/10.1080/03098265.2011.619521

National Center for Science and Engineering Statistics (NCSES). (2021, Apr. 29). *Women, minorities, and persons with disabilities in science and engineering: 2021, Special Report. NSF 21-321*, National Science Foundation, Arlington, VA. https://ncses.nsf.gov/pubs/nsf21321/report

National Center for Science and Engineering Statistics (NCSES). (2019, Mar. 8). *Women, minorities, and persons with disabilities in science and engineering: 2019, Special Report. NSF 19-304*, National Science Foundation, Arlington, VA. https://ncses.nsf.gov/pubs/nsf19304/digest

National Research Council. (2006). *America's lab report: Investigations in high school science.* Retrieved from https://www.nap.edu/catalog/11311/americas-lab-report-investigations-in-high-school-science

Orion, N., & Hofstein, A. (1994). Factors that influence learning during a scientific field trip in a natural environment. *Journal of Research in Science Teaching, 31*(10), 1097-1119. https://doi.org/10.1002/tea.3660311005

Park, D-Y. (2005). Differences between a standards-based curriculum and traditional textbooks in high school earth sciences. *Journal of Geoscience Education, 53*(5), 540-547. https://doi.org/10.5408/1089-9995-53.5.540

Peace, A. L., Gabriel, J. J., & Eyles, C. (2021). Geoscience field work in the age of COVID-19 and beyond: Commentary on the development of a virtual geological field trip to Whitefish Falls, Ontario, Canada. *Geosciences, 11*(12), 489-497. https://doi.org/10.3390/geosciences11120489

Petcovic, H. L., Stokes, A., & Caulkins, J. L. (2014). Geoscientists' perceptions of the value of undergraduate field education. *GSA Today, 24*(7), 4-10. https://doi.org/10.1130/GSATG196A.1

Pickrell, J. (2020). Scientists push against barriers to diversity in the field sciences. *Science, 374*(375), 10-1126. https://doi.org/10.1126/science.caredit.abb6887

Pokhrel, S., & Chhetri, R. (2021). A literature review on impact of COVID-19 pandemic on teaching and learning. *Higher Education for the Future, 8*(1), 133-141. https://doi.org/10.1177/2347631120983481

Proudfoot, K. (2022) Inductive/deductive hybrid thematic analysis in mixed methods research. *Journal of Mixed Methods Research, 0*(0). https://doi.org/10.1177/15586898221126816

Pugsley, J. H., Howell, J. A., Hartley, A., Buckley, S. J., Brackenridge, R., Schofield, N., Maxwell, G., Chmielewska, M., Ringdal, K., Naumann, N., Vanbiervliet, J. (2022). Virtual field trips utilizing virtual outcrop: Construction, delivery and implications for the future. *Geoscience Communication 5*(3), 227-249. https://doi.org/10.5194/gc-5-227-2022

Ramasundaram, V., Grunwald, S., Mangeot, A., Comerford, N. B., & Bliss, C. M. (2005). Development of an environmental virtual field laboratory. *Computers & Education, 45*(1), 21-34. https://doi.org/10.1016/j.compedu.2004.03.002

Read, H.H. (1940). Metamorphism and Igneous Action (Address to Section C, Geology), *The Advancement of Science*, *1*(2), 223-250.

Richards, T., & Richards, L. (1995). Using hierarchical categories in qualitative data analysis. In U. Kelle (Ed.), *Computer-aided qualitative data analysis: Theory, method, and practice*, (pp. 80-95). SAGE Publications.

Rotzien, J. R., Sincavage, R., Pellowski, C., Gavillot, Y., Filkhorn, H., Cooper, S., Shannon, J., Yildiz, U., Sawyer, F., & Uzunlar, N. (2021). Field-based geoscience education during the COVID-19 pandemic: Planning, execution, outcomes, and forecasts. *GSA Today, 31*(3-4), 4-10. https://doi.org/10.1160/GSATG483A.1

Ruberto, T. J. (2018). *Implications of learning outcomes of in-person and virtual field-based geoscience instruction at Grand Canyon National Park* (Publication No. 10845563) [Master's thesis, Arizona State University]. ProQuest Dissertations Publishing.

Sahu, P. (2020). Closure of universities due to coronavirus disease 2019 (COVID-19): Impact on education and mental health of students and academic staff. *Cureus, 12*(4). https://doi.org/10.7759/cureus.7541

Schlosser, W. E., Aumell, A. J., & Kilkenny, M. M. (2022). Hybrid classroom approach: Virtual & live field data integration. *Natural Sciences Education*, e20094. https://doi.org/10.1002/nse2.20094

Senger, K., Betlem, P., Birchall, T., Buckley, S. J., Coakley, B., Eide, C. H., Flaig, P. P., Forien, M., Galland, O., Gonzaga, Jr., L., Jensen, M., Kurz, T., Lecomte, I., Mair, K., Malm, R. H., Mulrooney, M., Naumann, N., Normodo, I., Nolde, N., … Smyrak-Sikora, A. (2021a). Using digital outcrops to make the high Arctic more accessible through the Svalbox database. *Journal of Geoscience Education, 69*(2), 123-137. https://doi.org/10.1080/10899995.2020.1813865

Senger, K., Betlem, P., Grundvåg, S-A., Horota, R. K., Buckley, S. J., Smyrak-Sikora, A., Jochmann, M. M., Birchall, T., Janocha, J., Ogata, K., Kuckero, L., Johannessen, R. M., Lecomte, I., Cohen, S. M., & Olaussen, S. (2021b). Teaching with digital geology in the high Arctic: Opportunities and challenges. *Geoscience Communication, 4*(3), 399-420. https://doi.org/10.5194/gc-4-399-2021

Shepherd, I. D. H. (1985). Teaching geography with the computer: Possibilities and problems. *Journal of Geography in Higher Education, 9*(1), 3-23. https://doi.org/10.1080/03098268508708921

Sidder, A. (2017). Geosciences make modest gains but still struggle with diversity. *Eos, 98*(7). https://doi.org/10.1029/2017EO071093

Stainfield, J., Fisher, P., Ford, B., & Solem, M. (2000). International virtual field trips: A new direction? *Journal of Geography in Higher Education, 24*(2), 255-262. https://doi.org/10.1080/713677387

Stott, T., Nuttall, A.-M., McCloskey, J. (2009). Design, development, and student evaluation of a virtual Alps field guide. *Planet, 22*(1), 64-71. https://doi.org/10.11120/plan.2009.00220064

Streule, M. J., & Craig, L. E. (2016). Social learning theories—An important design consideration for geoscience fieldwork. *Journal of Geoscience Education, 64*(2), 101-107. https://doi.org/10.5408/15-119.1

Stukalo, N., & Simakhova, A. (2020). COVID-19 impact on Ukrainian higher education. *Universal Journal of Educational Research, 8*(8), 3673-3678. https://doi.org/10.13189/ujer.2020.080846

Stumpf, II, R. J., Douglass, J., & Dorn, R. I. (2008). Learning desert geomorphology virtually versus in the field. *Journal of Geography in Higher Education, 32*(3), 387-399. https://doi.org/10.1080/03098260802221140

ur Rahman, S., Khan, M. A., & Iqbal, N. (2018). Motivations and barriers to purchasing online: Understanding consumer responses. *South Asian Journal of Business Studies, 7*(1), 111-128. https://doi.org/10.1108/SAJBS-11-2016-0088

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46*(2), 186-204.

Villena-Taranilla, R., Cózar-Gutiérrez, R., González-Calero, J. A., & Diago, P. D. (2023). An extended technology acceptance model on immersive virtual reality use with primary school students. *Technology, Pedagogy, and Education, 32*(3), 367-388. https://doi.org/10.1080/1475939X.2023.2196281

Warburton, J., & Higgitt, M. (1997). Improving the preparation for fieldwork with 'IT': Two examples from physical geography. *Journal of Geography in Higher Education, 21*(3), 333-347. https://doi.org/10.1080/03098269708725440

Whitmeyer, S. J., & Dordevic, M. (2021). Creating virtual geologic mapping exercises in a changing world. *Geosphere, 17*(), 226-243. https://doi.org/10.1130/GES02308.1

Whitmeyer, S. J., & Mogk, D. W. (2009). Geoscience field education: A recent resurgence. *EOS Transactions, 90*(43), 385-386. https://doi.org/10.1029/2009EO430001

Wilson, C. E., & Keane, C. M. (Eds.) (2019). *Directory of Geoscience Departments, U.S. Section.* Directory of geoscience departments and other geoscience organizations (54th ed., pp. 1–172). American Geosciences Institute.

CHAPTER 4: Assessing the source, distribution, and attenuation of radon contamination in fractured groundwater aquifers

Abstract

Many residents in rural parts of Alabama rely on private groundwater wells to access potable water for drinking and other household tasks. In the mid-2010s, an unusual number of leukemia and lymphoma cases were reported in the small communities of Fruithurst and Muscadine in Cleburne County, Alabama. A previous investigation (Cain, 2020) found radon levels higher than the U.S. EPA advisory level of 4,000 pCi/L in about 16% of private wells tested in the area. Wells in the area draw from aquifers located in metamorphic rocks of the Talladega Metamorphic Belt and are subject to potential natural and anthropogenic contaminants (e.g., trace elements, radioactive elements, and PFAs) present in the underlying formations. Building on the previous investigation, this project sought to explore potential geological sources of uranium and thorium—potential radioactive parents of radon—through LA-ICP-MS analysis of outcrop and core samples collected throughout Cleburne County and to continue examination of the long-term efficacy of residential scale 5-stage reverse osmosis and 2-stage activated carbon water filtration systems in attenuating radon in groundwater supplies. and adds a 24-hour stress test for the 5-stage system. LA-ICP-MS results showed levels of uranium and thorium in the areas around Fruithurst and Muscadine are higher than average crustal concentrations (U_{med} = 2.93 ppm; Th_{med} = 8.8 ppm). Continued filter testing results suggest that the filters can effectively capture radon at early, fresh stages, but the capacity gradually decreases over time or quickly reduces during high water use.

Background

In many rural Alabama communities, residents still rely on private groundwater wells as a source of potable water for drinking and other household tasks (Alabama Department of Public Health, 2023; Liu, Ming, and Ankumah, 2005). Because these wells are drilled into aquifers located within natural geological formations, the water produced is subject to contaminants that may be present within the surrounding rock, including dissolved metals and metalloids, and some natural radioactive elements (Banks & Robins, 2002). Privately owned groundwater wells are not subject to the same quality or safety standards that federal and state laws require for municipal water sources and often contain higher levels of radon than their regulated counterparts (National Resource Council, 1999).

Over four years in the mid-2010s, a total of eight individuals in the communities of Fruithurst and Muscadine, Alabama, located in Cleburne County (Figure 4-1), received diagnoses of leukemia or lymphoma (Ashwood et al., 2023). In small rural communities like these, with a combined population of approximately 1,600 residents, such a high rate of occurrence (0.5%) is higher than the national average of 0.4% (Leukemia and Lymphoma Society, 2023). The active cases, along with reports of past diagnoses of leukemia, lymphoma, stomach, and lung cancers, and the widespread use of groundwater wells as potable water sources, raised questions regarding potential environmental impacts on human health in the area.

Previous research conducted in Fruithurst (Cain, 2020) sought to better understand the geochemistry of groundwater in the area and primarily focused on the level and distribution of radon-222 (^{222}Rn), a naturally occurring byproduct of the uranium-238-to-lead-206 (^{238}U-^{206}Pb) decay series. During the initial investigation of well water in the county, high levels of radon (up to 8,000 pCi/L) were detected in groundwater samples collected from private wells. The study intended to investigate spatial relationships between leukemia and lymphoma cases in the community and potential groundwater contamination, as well as test the efficacy of residential-scale reverse osmosis (RO) and activated charcoal filter systems in reducing radon levels in well water prior to residential use.

Here, the goal is to build upon the previous work done by Cain (2020) in two ways. First, by identifying the distribution and potential geological source of radon in the area through geochemical analysis of outcrop and drill core rock samples, and second by continuing to examine the efficacy of the previously mentioned water filtration systems.

Geology

Cleburne County, Alabama, lies almost entirely within the Talladega Metamorphic Belt (also called Talladega Slate Belt), located between the Valley and Ridge and the Piedmont physiographic provinces of the southeastern United States (Bearce, 1973; Tull, 1977) (Figure 4-1). The Talladega belt is comprised of four main geologic formations (in ascending order): Kahatchee Mountain Group, Sylacauga Marble Group, Talladega Group, and Hillabee Greenstone (Tull & Barineau, 2012). Earlier work by Bearce (1973) separated the Talladega Group into three main lithologic sections (ascending): Heflin Phyllite, Abel Gap Formation (quartzite/phyllite), and Chulafinnee Schist. Tull (1982) redefined the Heflin Phyllite as a lower member of the larger Lay Dam Formation, which can be thousands of feet thick and consists of tan to greenish gray metapelites interbedded with tan to off-white quartzite lenses (Spurgeon, 2022; Tull et al., 1988) (Figure 4-2). Locally, the Heflin Phyllite/Lay Dam Formation and quartzites are exposed at the surface. The fractured unit serves as the groundwater source for many of the residential wells in the area.

Figure 4-1. Fruithurst, Cleburne County, AL, located in the Talladega Metamorphic Belt (Cain, 2020).

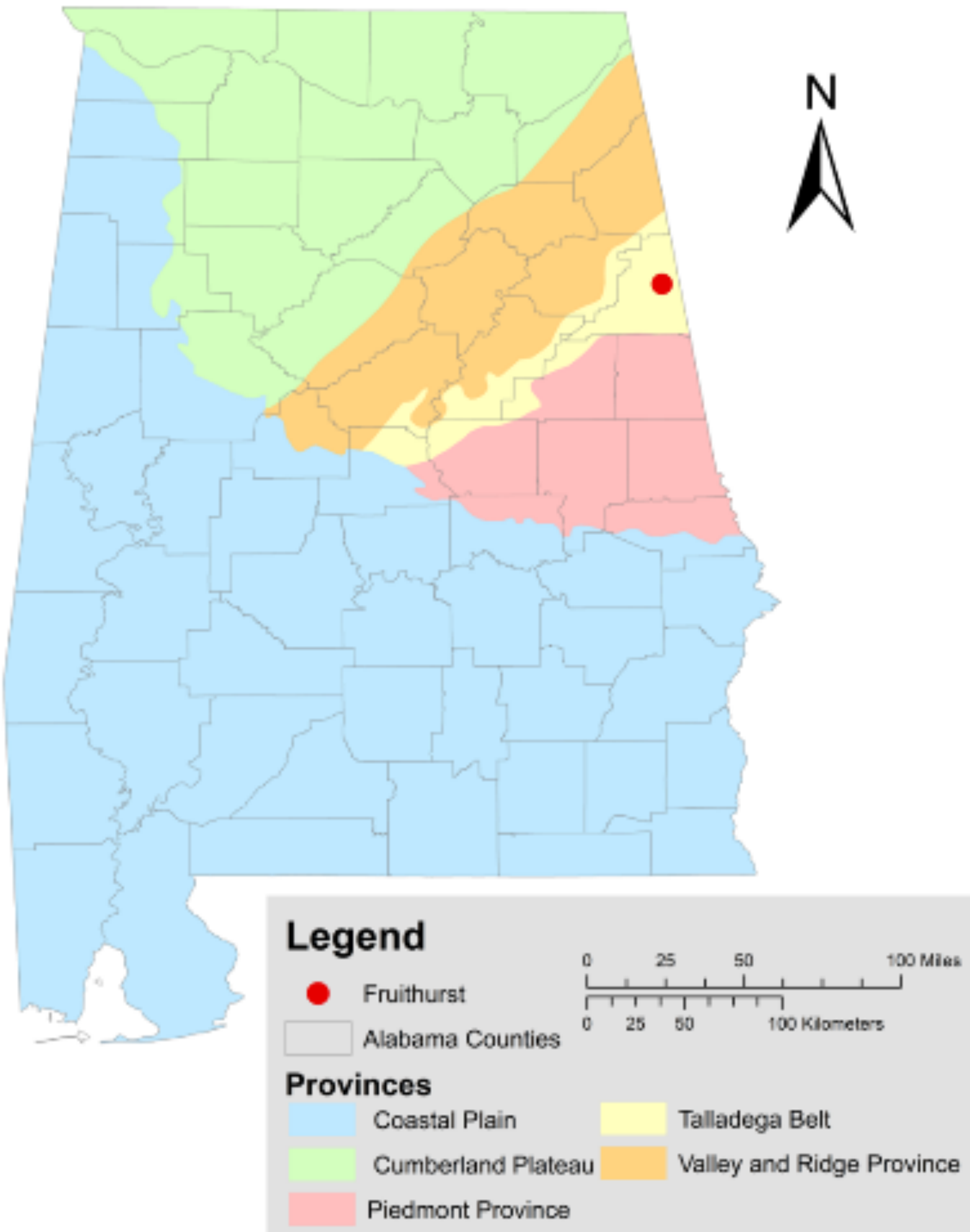
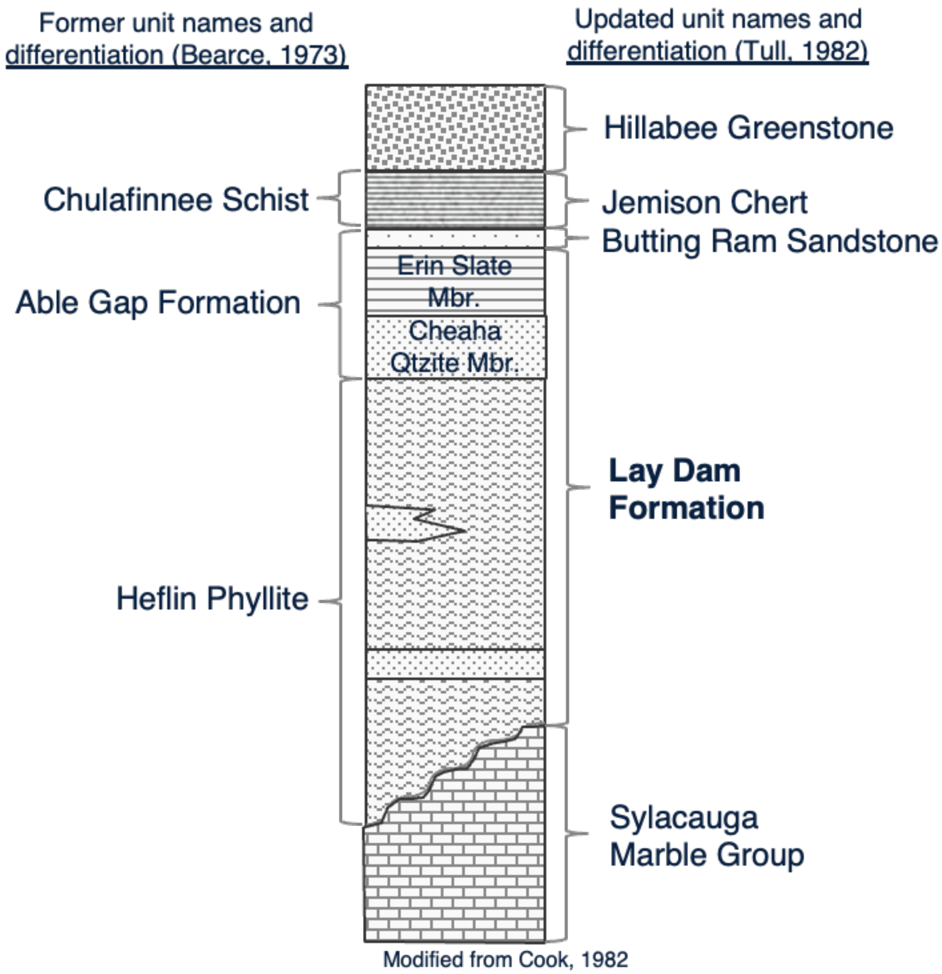


Figure 4-2. Generalized stratigraphic column of the geology of the Talladega Metamorphic Belt (modified from Cook, 1982).

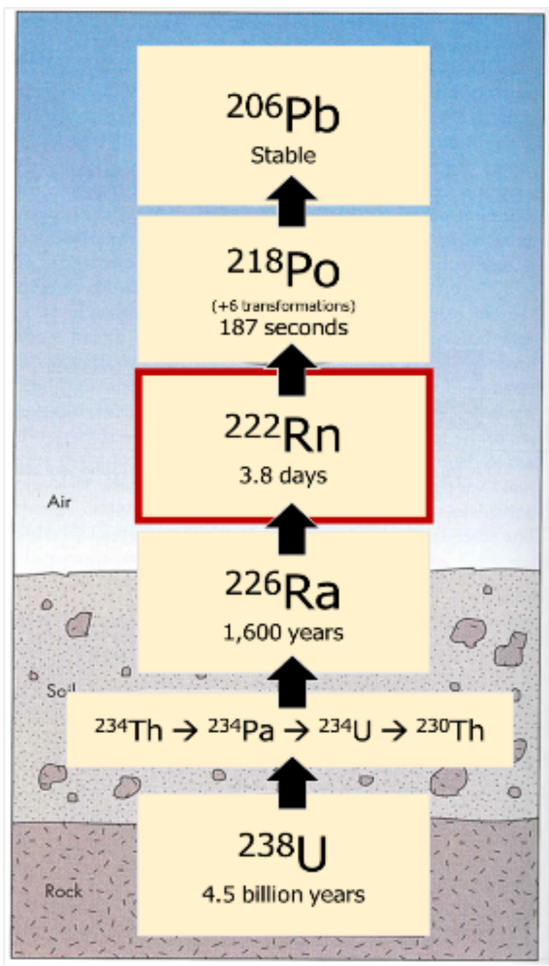


Radon

Radon is the heaviest of the noble gases and its most common isotope, ^{222}Rn, occurs as a product of the decay series of ^{238}U to ^{206}Pb (Figure 4-3), itself decaying to polonium-218 (^{218}Po) through alpha particle emission with a half-life of approximately 3.82 days. Other isotopes, such as ^{220}Rn (thoron) and ^{219}Rn (actinon), occur as part of the ^{232}Th-^{206}Pb and ^{235}U-^{207}Pb decay chains, respectively (Pulinets et al., 2024). Radon is commonly found as a colorless, odorless, and tasteless gas near the Earth's surface and is known to be the second leading cause of lung cancer in the United States, behind cigarette smoking (Cothern et al., 1986; U.S. EPA, 2016;

Zeeb & Shannoun, 2009). Radon is soluble in water (Ball et al., 1991) and may occur as a contaminant in groundwater aquifers that are formed in fractured openings of crystalline metamorphic or igneous rock (Smith et al., 1961; Sukanya, 2021), potentially leading to forms of cancer other than of the lungs when ingested (Collman et al., 1988; Collman et al., 1991). The United States Environmental Protection Agency's (U.S. EPA) action level for airborne radon has been set at 4 pCi/L (U.S. EPA, 2012). There is no official limit for levels of radon in drinking water, although the U.S. EPA and many states have recommended standards between 300 and 10,000 pCi/L (Swistock, 2015; U.S. EPA, 2000).

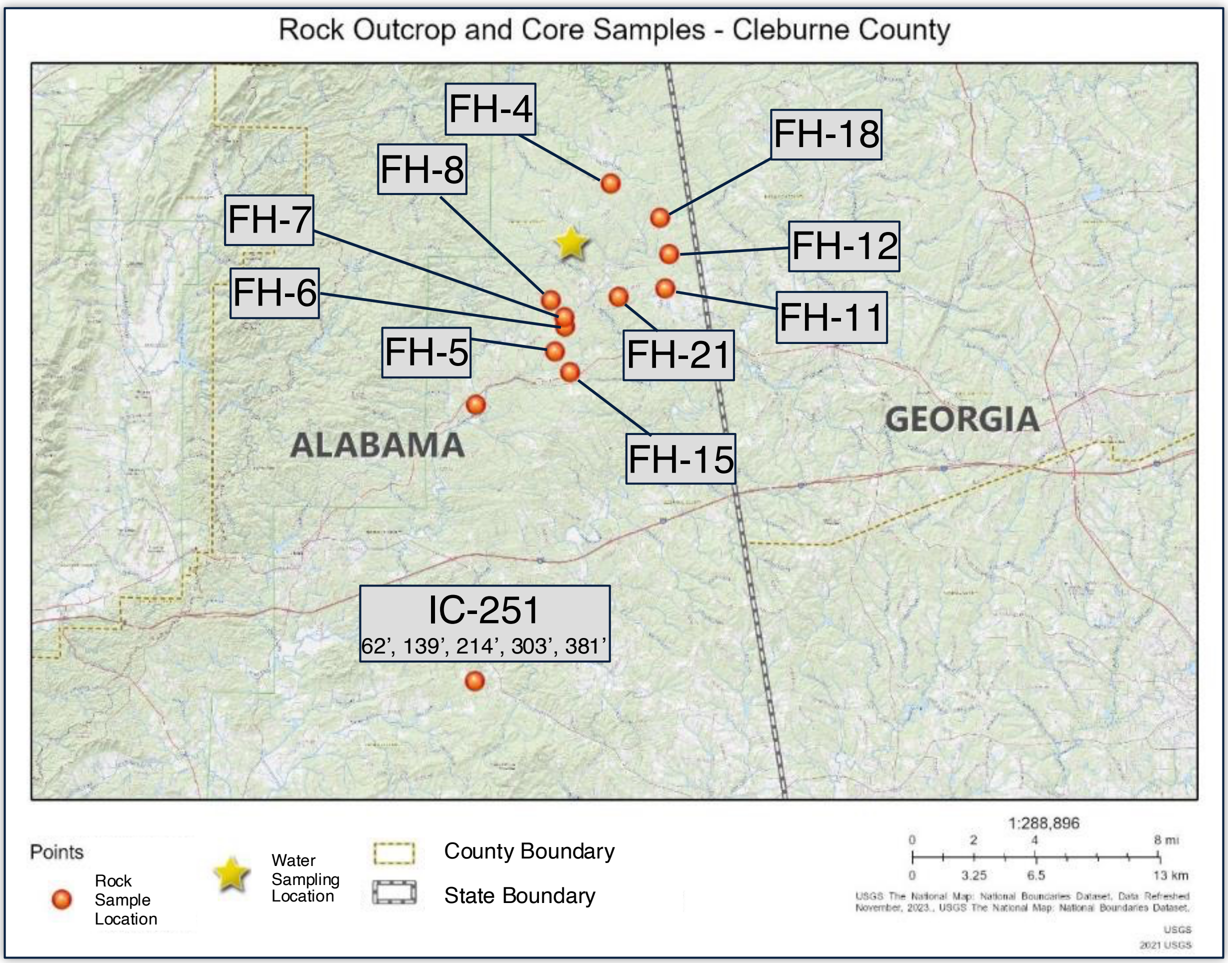
Figure 4-3. Decay path of ^{238}U to ^{206}Pb with approximate half-life values (modified from Kelly, 2000).



Methods and Materials

This work included analysis of radon levels in groundwater collected from three sources—filtered and unfiltered—on a residential property north of Fruithurst, AL, as well as mineralogical and geochemical analyses of rock samples collected from outcrops around Cleburne County, AL, in the vicinities of Fruithurst and Muscadine, and one drill core from the southern part of the county (Figure 4-4). These methods are discussed in more detail below.

Figure 4-4. Location map of outcrop and drill core (IC-252) samples collected in Cleburne County, AL. The locations of FH-13 and FH-14 are unknown.

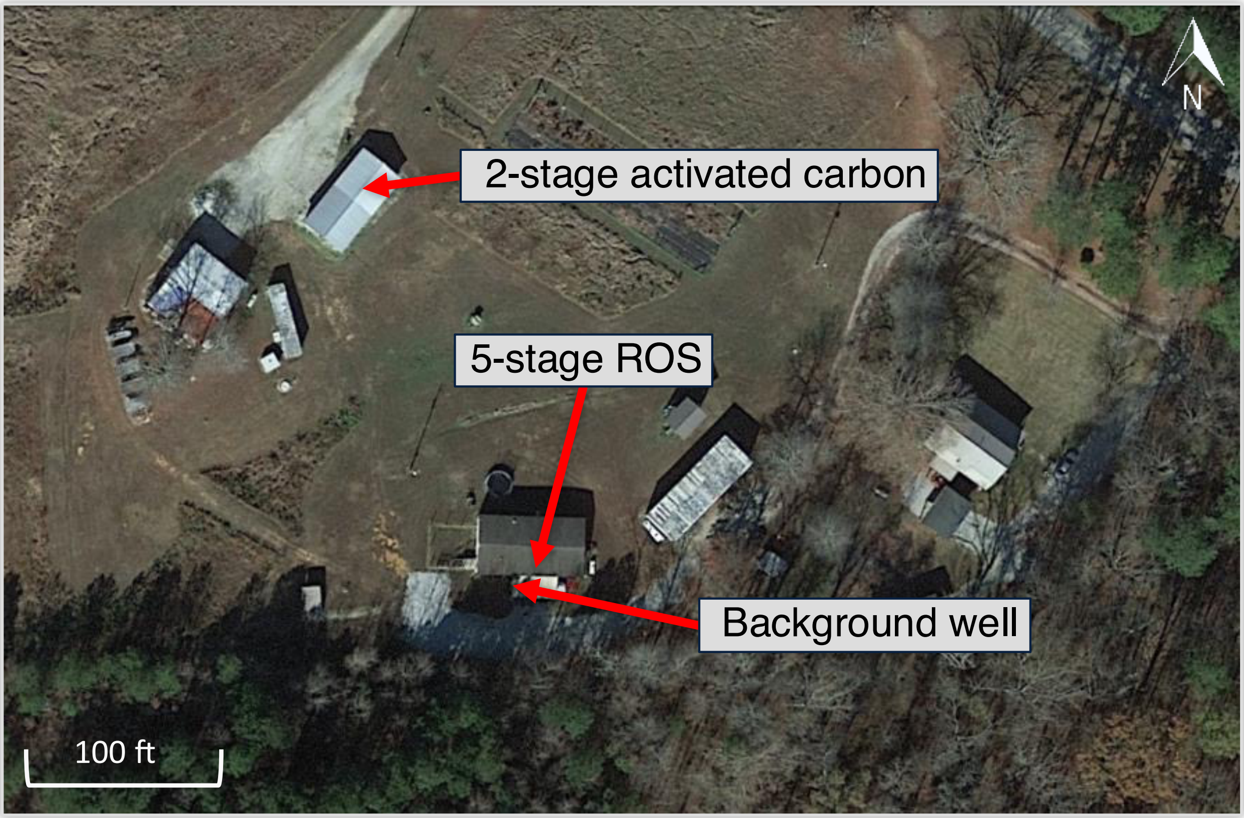


Long-Term Water Analysis

Radon has been analyzed in groundwater through a variety of methods in the past (Dimova et al., 2009; Dixon, 1988; Freyer et al., 1997, Harris et al., 2006). As part of this project, and continuing the methods used by Cain (2020), periodic water samples were collected from three sources on a residential property located approximately 4.3 miles north of the town of Fruithurst. Samples were collected by Cain (2020) for October 2019 through March 2020 and for July 2020. This study continued the sampling and radon measurement and added a new 24-hour filtering stress test in September 2022. The three water sources (Figure 4-5) were:

1. A five-stage ROES-50 reverse osmosis filtration system, manufactured by APEC Water Systems (APEC), that is installed beneath the kitchen sink inside a home on the property. This system consisted of a sediment filter, two activated carbon filters, a reverse osmosis membrane, and a final refining carbon filter (APEC Water Systems, n.d.). APEC claims a capacity of up to 50 gallons per day for this system.
2. A two-stage filtration system that used only the first two activated carbon filters of the ROES-50. This filtration system was installed beneath a sink in an outbuilding on the property.
3. An outdoor faucet just outside the residence, that draws directly from a 532-foot groundwater well with no filtration system. This well provides water to the entire property, including the previously listed filtration systems.

Figure 4-5. Locations of groundwater well, with 5-stage reverse osmosis, and 2-stage activated carbon systems installed on residential property north of Fruithurst, AL.



The samples were collected in 2.5-liter glass amber bottles and, due to the short half-life of ^{222}Rn, transported back to the Hydrogeology Lab in the Auburn University Department of Geosciences the same day for analysis. Once back in the lab, the samples were analyzed with the RAD7 radon detector "Big Bottle System" manufactured by Durridge Radon Capture & Analytics (Durridge, n.d.) to determine radon levels (Figure 4-6). The RAD7 is a sniffer detector that monitors aerated water in cycles to measure alpha particle emissions resulting from the radioactive decay of ^{222}Rn to ^{218}Po and converting those alpha emissions into an electrical signal (Durridge). For this study, the RAD7 was set to a cycle time of three minutes with thirty recycles for a total analysis time of 90 minutes per collected sample. The system was purged for 10 minutes between each sample. The results were downloaded from the detector using the included

CAPTURE software and added to an existing database in Microsoft Excel. Each filtration system included an in-line flow meter to track the volume of water passing through the filter between each sampling. This data was collected and added to the Excel database, as well.

Figure 4-6. The Durridge RAD7 “Big Bottle System” (Durridge.com).

Full ROS "Stress Test"

In the fall of 2022, the two-stage activated carbon filtration system in the property's outbuilding was replaced by a full ROES-50 five-stage system to evaluate the system's ability to remove radon when stressed over 24 hours. An unfiltered background sample was collected from the well outside the residence to compare with radon levels from filtered water samples and evaluate the efficacy of the full RO system. The unfiltered sink faucet ran continuously starting at midnight to allow new formation water to flow into the well and plumbing system. Samples were collected every two hours from the filtered faucet followed by a 90-minute sample analysis and 10-minute system purge. Lack of pressure and low flow rate prevented the filtered faucet from running continuously for the test. In total, eight gallons of water were collected and analyzed in 12 samples between midnight and 11:45 pm. After returning to Auburn, the results were downloaded from the detector using the CAPTURE software and added to the Microsoft Excel database.

Mineralogical Analyses

Twelve outcrop and five drill core samples collected in the area (Figure 4-4) were powdered using a planetary ball mill fitted with agate milling jars and balls. Powder X-ray diffraction (XRD) analysis was completed for the samples using a Bruker D2 X-ray Diffractometer at the Auburn University XRD laboratory. The spectral data collected were analyzed using Bruker's DIFFRAC.EVA software to evaluate the mineralogical makeup of the samples.

Geochemical Analyses

Outcrop and drill core samples previously collected from the area (Figure 4-4), along with a U.S. Geological Survey mica schist reference standard, SDC-1, underwent lithium-borate flux fusion in preparation for bulk chemical analysis using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to better understand the source and distribution of uranium and thorium—potential radioactive parents of radon—in the vicinity of Fruithurst and Muscadine. Flux fusion was completed at the geochemistry laboratory in the Department of Geosciences at Middle Tennessee State University (MTSU). A mixture of 3.61 g lithium tetraborate ($Li_2B_4O_7$), 8.17 g lithium metaborate ($LiBO_2$), and 1.52 g sample was weighed into platinum-gold crucibles and stirred, followed by six drops of LiBr (as a wetting agent). The mixture was placed in one of two Claisse LeNeo fusion instruments for 22 minutes at 1065 °C. The molten material was poured into a platinum-gold mold and fan-cooled, forming 40-mm glass disks. The disks were broken into fragments, with pieces approximately 5 mm wide collected for epoxy mounting. Eight one-inch mounts were made (3 samples per mount), ground flat using progressively finer wet polishing disks, and finally polished to a scratch-free finish using 1 μm alumina powder on a felt lap.

The fused glass samples were analyzed in the Auburn University ICP-MS Lab using an Elemental Scientific Lasers NWR193 193 nm excimer laser ablation system coupled to an Agilent 7900 quadrupole inductively coupled plasma mass spectrometer (ICP-MS). Synthetic glasses from the National Institute of Standards and Technology (NIST 610 and NIST 612) and a natural basalt glass from the United States Geological Survey (BCR-2ga) were used as reference materials and analyzed at the beginning, middle, and end of the run. Sample mounts and reference materials were loaded into the ablation chamber, and ablation line scan locations were defined using ActiveView2 software. A pre-ablation pass was completed for all samples and reference materials prior to analysis to remove any impurities from the surface of the glass. Pre-ablation conditions were set at a beam width of 120 μm, scan speed at 20 μm/s, and 2% energy

(1.48 J/cm^2) with a repetition rate of 2 Hz. The 75-µm analysis line scans were ablated at a velocity of 10 µm/s and 20% energy (2.65 J/cm^2) with a repetition rate of 16Hz. Data reduction was completed with iolite v4 software (Paton et al., 2011). NIST 610 was set as the primary standard and BCR-2ga was used as the secondary standard. ^{44}Ca was used as the internal standard for reference materials, while ^{29}Si and ^{24}Mg (FH-18) concentrations from x-ray fluorescence (XRF) data collected at MTSU were used as internal standards for samples. Laser ablation parameters are summarized in Table 4-1.

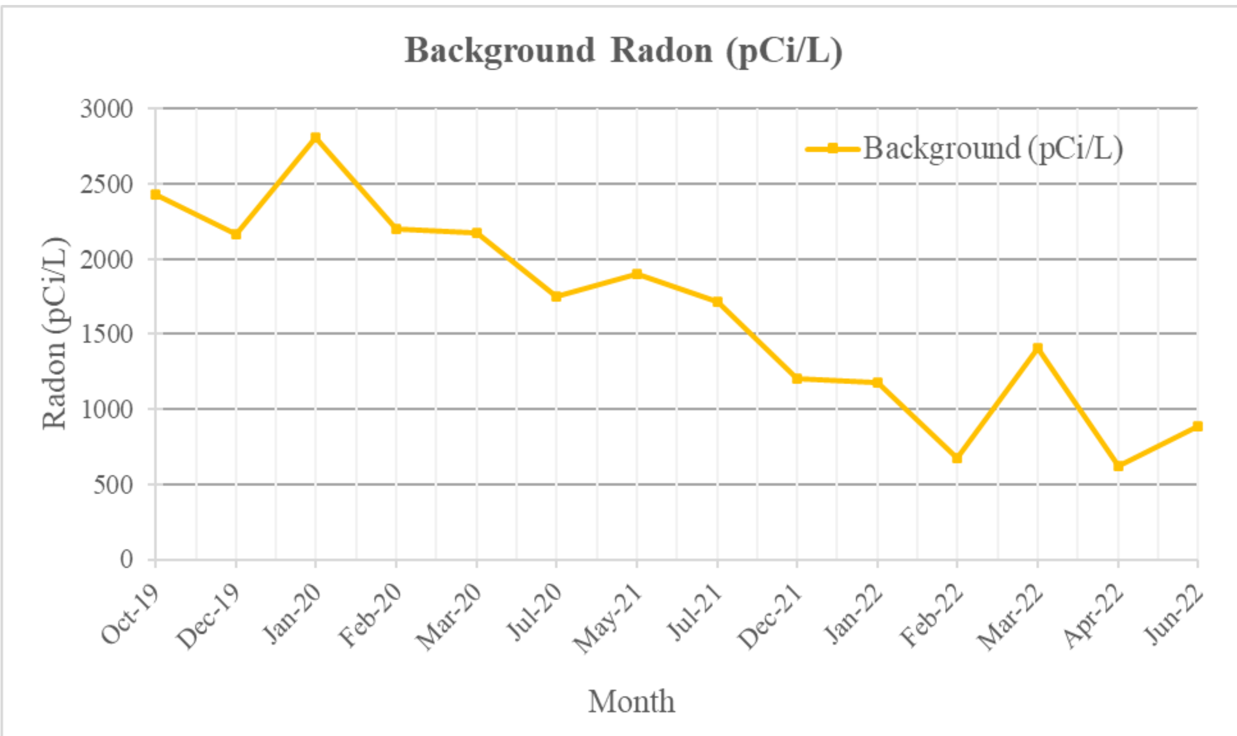
Table 4-1. LA-ICP-MS conditions at Auburn University.

Laser Ablation System	Elemental Scientific Lasers NWR193 193 nm excimer laser
ICP-MS	Agilent 7900 ICP-MS
Analyzed Isotopes	^{23}Na, ^{24}Mg, ^{27}Al, ^{29}Si, ^{39}K, ^{43}Ca, ^{44}Ca, ^{47}Ti, ^{51}V, ^{52}Cr, ^{55}Mn, ^{56}Fe, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{75}As, ^{78}Se, ^{88}Sr, ^{95}Mo, ^{111}Cd, ^{118}Sn, ^{121}Sb, ^{208}Pb, ^{232}Th, ^{238}U
Line Scan Conditions	Beam Width: 75 µm Scan Speed: 10 µm/s Energy: 20% (2.65 J/cm^2) Frequency: 16 Hz
Pre-ablation Conditions	Beam Width: 120 µm Scan Speed: 20 µm/s Energy: 2% (1.48 J/cm^2) Frequency: 2 Hz
Reference Materials	NIST 610 (synthetic glass) BCR-2ga (natural basalt glass)
Internal Standards (values from XRF)	Reference Glasses: 44Ca Sample Glasses: 29Si, 24Mg (FH-18)
Data Processing	iolite v.4

Water Filtration Results

Initial results indicated that the five-stage and two-stage filtration system setups effectively removed high radon levels in groundwater drawn from the control well. Still, there are volume thresholds at which the filter systems became less effective. Long-term filter testing and 24-hour filter stress test results are presented here.

Figure 4-7. Average background radon levels (pCi/L) in unfiltered well water during long-term filter testing.



Long-Term Filter Testing

Average background radon levels in water collected directly from the well outside the residence ranged from 622.23 to 2809.13 pCi/L over the course of the study (Figure 4-7). Radon solubility, concentration, and mobility in groundwater are also subject to several additional factors including time spent in residence, dilution, barometric pressure, and temperature, therefore, it is difficult to identify one primary cause for the downward trend of this data over time (Figures 4-8 and 4-9). The radon level in groundwater tends to be higher in months with higher precipitation (Figure 4-9). If the groundwater table is open to the atmosphere locally, lower barometric pressure during rainfall may allow more radon to rise from deeper storage zones. The relationship between radon level and precipitation requires further investigation as it may reflect a potential connection between the atmosphere and fractured aquifers.

Figure 4-8. Average precipitation (in.) for each water sampling month.

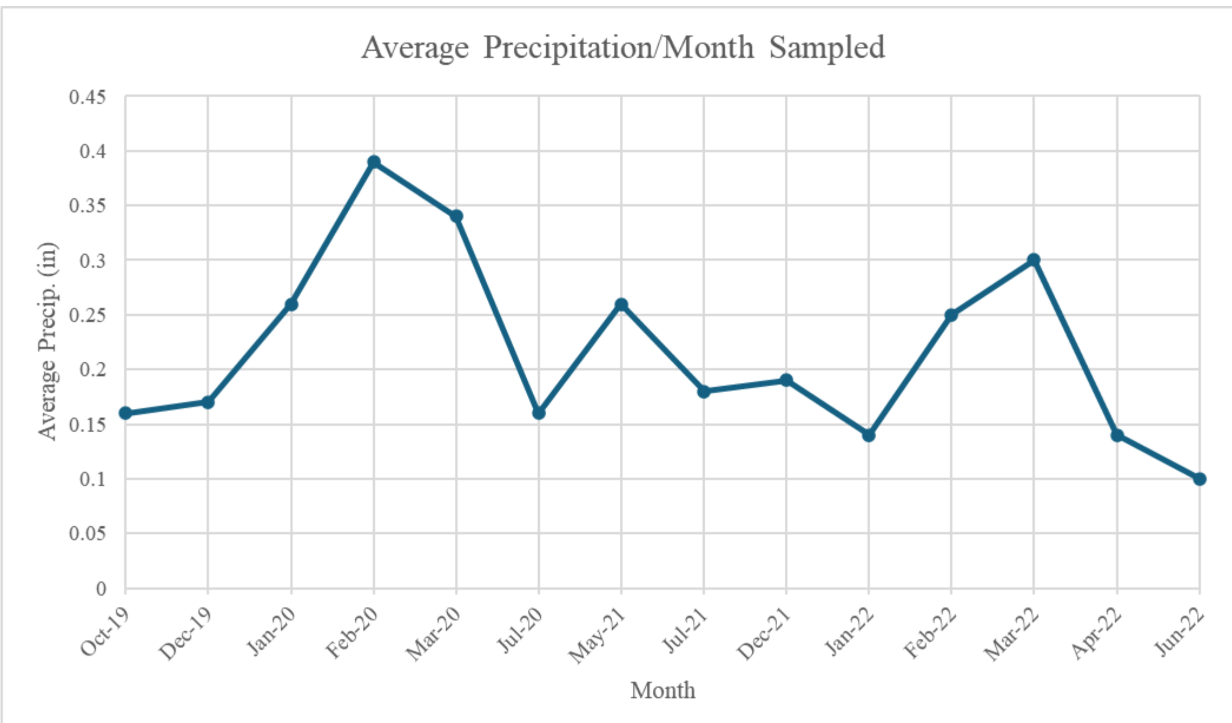
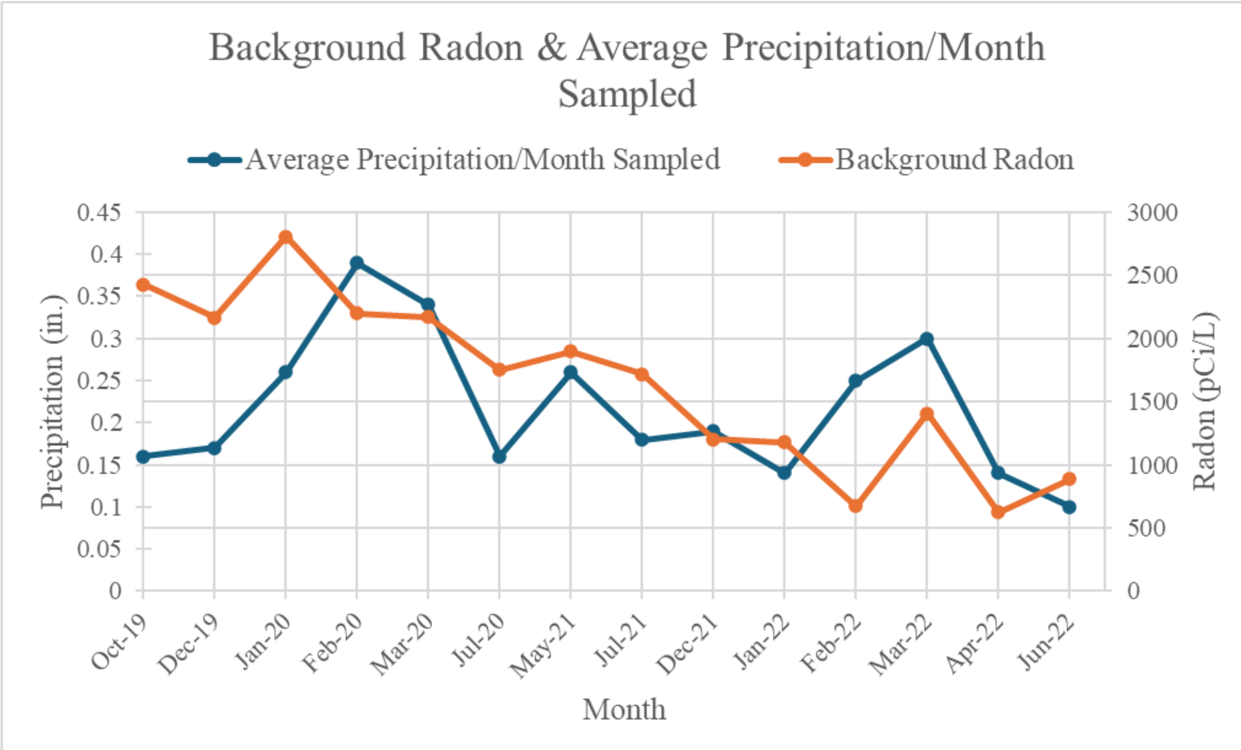


Figure 4-9. Background radon (pCi/L) and average precipitation (in.) for each water sampling month.



Each of the first eight sampling events showed a significant decrease in radon from the full five-stage ROS and two-stage activated carbon filtration systems (Figures 4-10 and 4-11, respectively). A decline in average monthly water usage was noted for the May and July 2021 events. The homeowner indicated that the filtration system was not being used as often as it was earlier in the study. They were asked to begin leaving the filtered faucets running throughout the night before a sampling event beginning in December 2021 and going forward (the faucets were not run overnight in January 2022). This increase in flow through the filtration systems, coupled with increased radon levels in sampled water, indicates an apparent limitation of the filters to effectively filter radon during times of high water use.

Figure 4-10. Radon levels (pCi/L) and average water use (L) for each sampling event from the full 5-stage ROS.

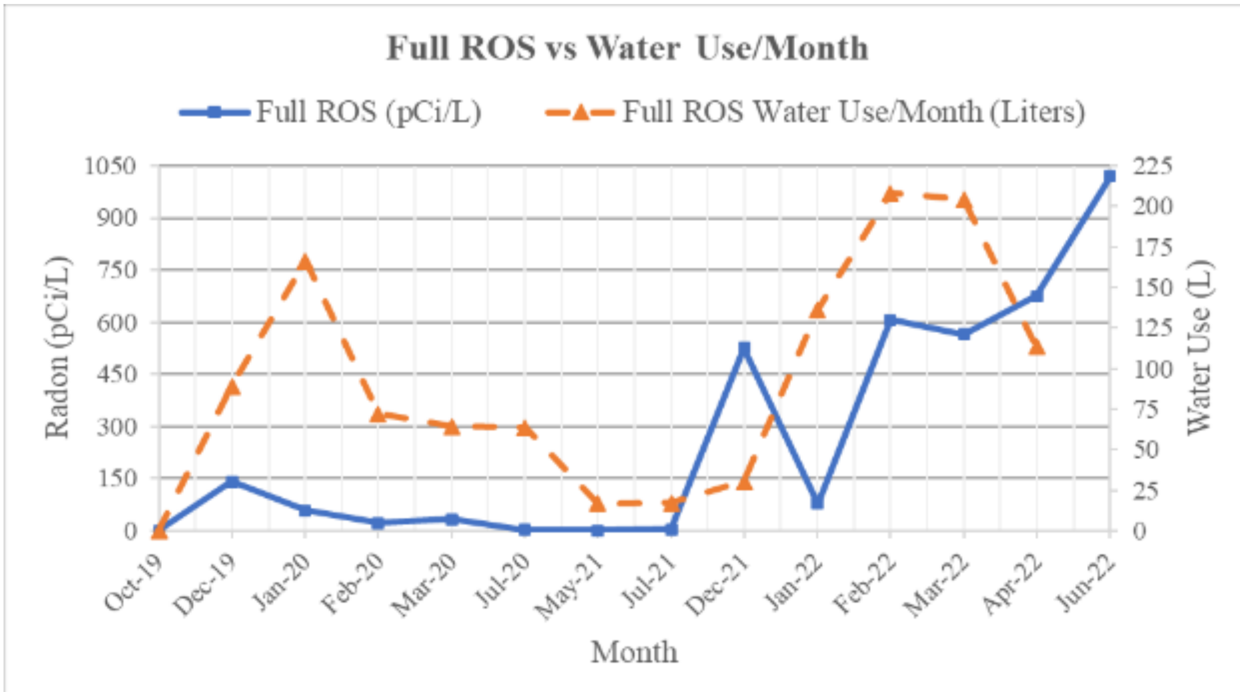
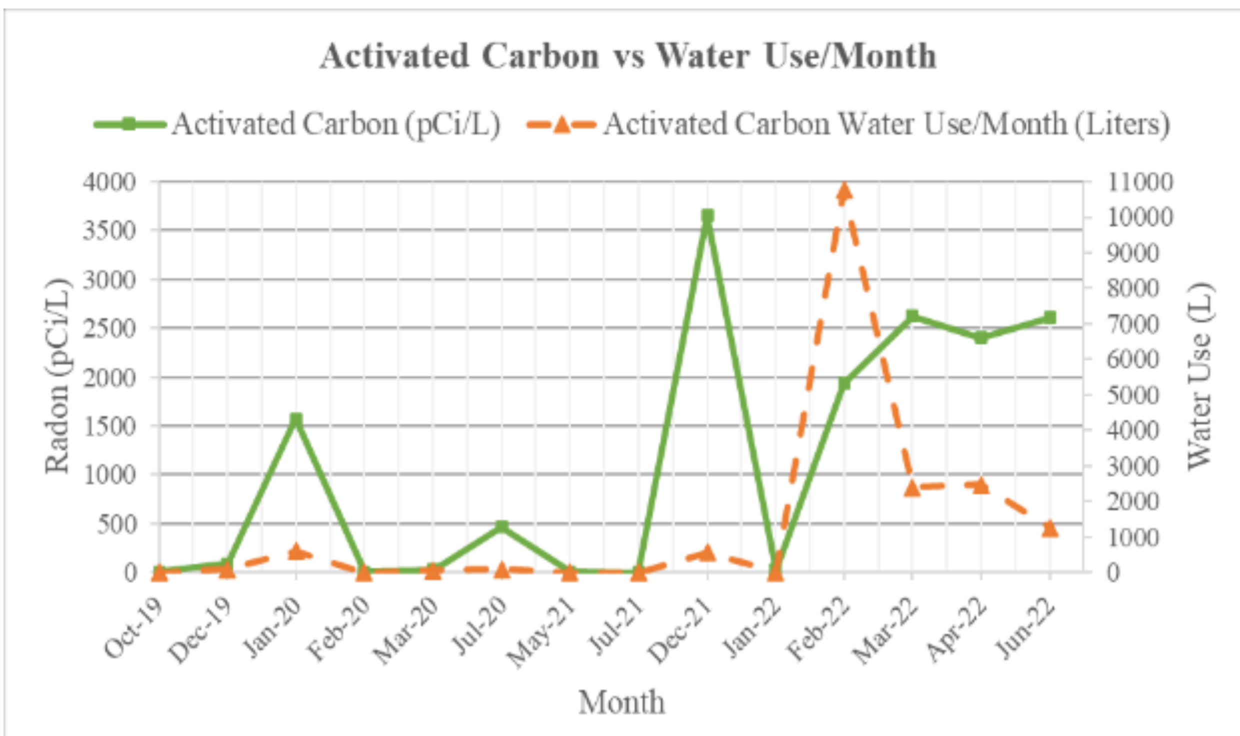


Figure 4-11. Radon levels (pCi/L) and average water use (L) for each sampling event from the 2-stage activated carbon system.



Full ROS "Stress" Test

Background radon levels in water collected before the filter stress test ranged from a low of 42.22 pCi/L (3rd minute) to a maximum reading of 1264.76 pCi/L (84th minute) and averaged 1020.39 pCi/L over the entire 90-minute test (Figure 4-12). Lower concentrations in the first few minutes reflect low radon levels associated with aged water residing inside the well or tubing. After approximately 20 minutes, the higher, stable concentrations represent actual radon levels in more representative groundwater. By contrast, radon levels for all 12 filtered water samples stayed below 180 pCi/L for the entirety of the test runs (Figure 4-13). Like the background sample, radon levels in all filtered samples began low and steadily rose over the first 12-18 minutes before appearing to settle into a steadier range of values. Average radon levels from filtered water (Figure 4-14) rose from 33.05 pCi/L in the first test (0:00) to 131.46 pCi/L in the final test (22:00). Had the test continued beyond 24 hours, it is reasonable to expect this upward trend to have continued before eventually reaching a plateau representative of the background radon level. These results suggest that the ROS filters can continue to capture radon with gradually decreasing filtering capacity over time until all available pores and surface areas become fully occupied by the gas. Beyond this threshold, the RO system can no longer attenuate radon dissolved in the well water effectively.

Figure 4-12. Full ROS radon levels (pCi/L) over a 90-minute test period for 12 samples compared to background radon.

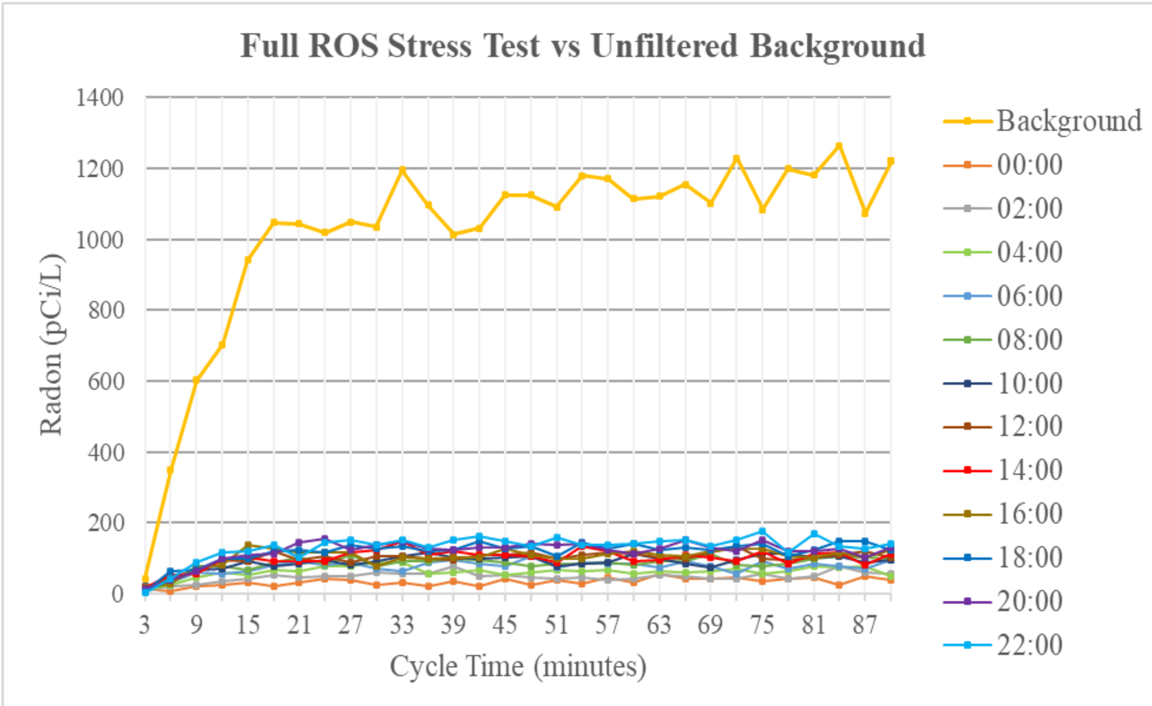


Figure 4-13. Full ROS radon levels (pCi/L) over a 90-minute test period for 12 samples (zoomed in to show detail from Figure 4-12).

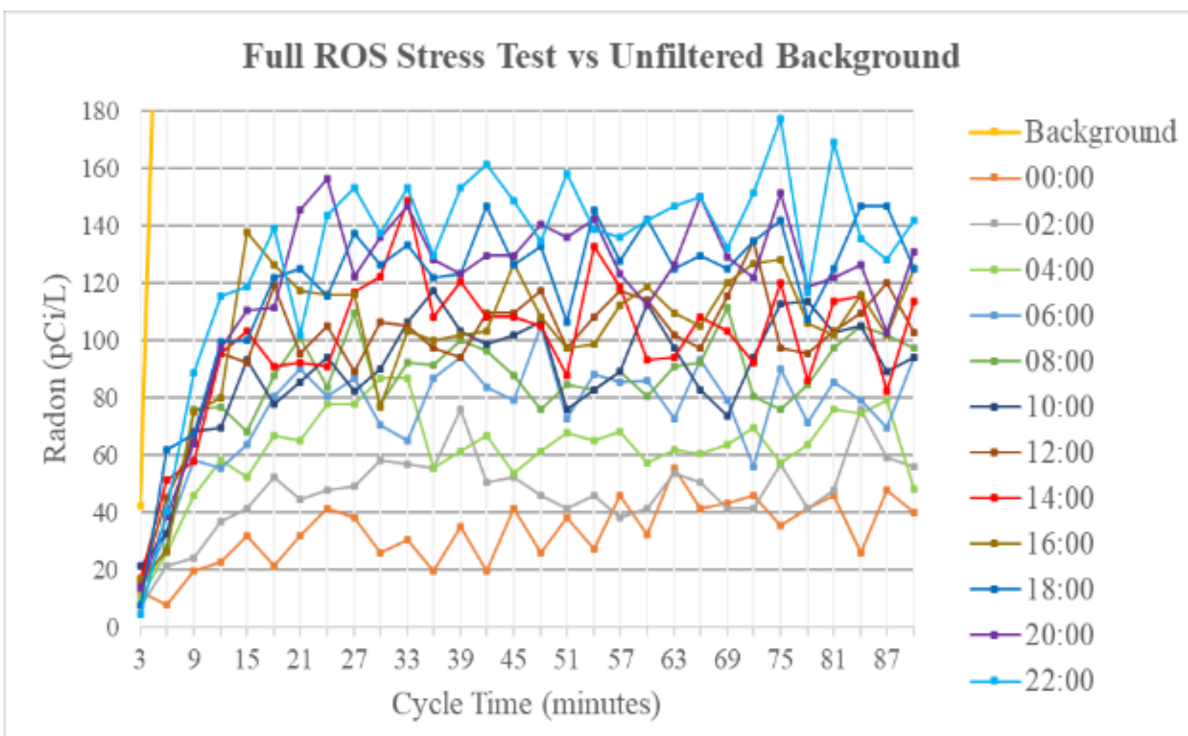
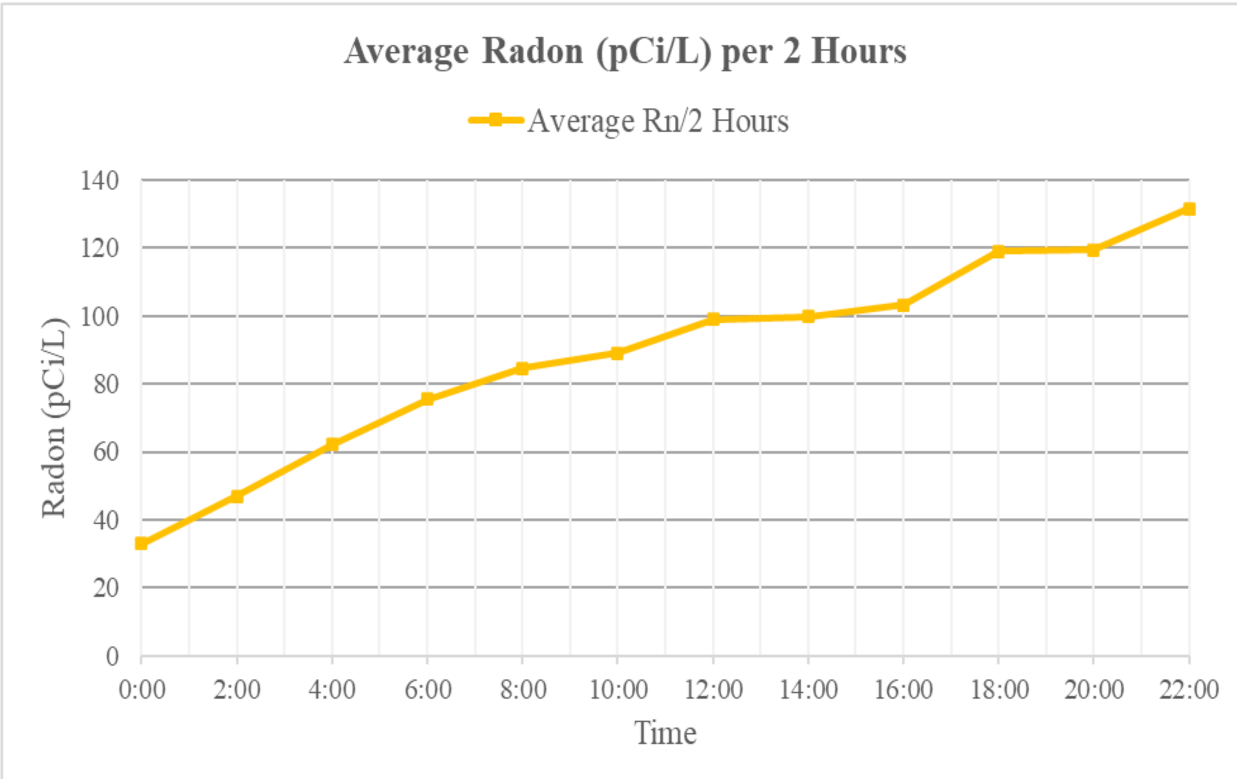


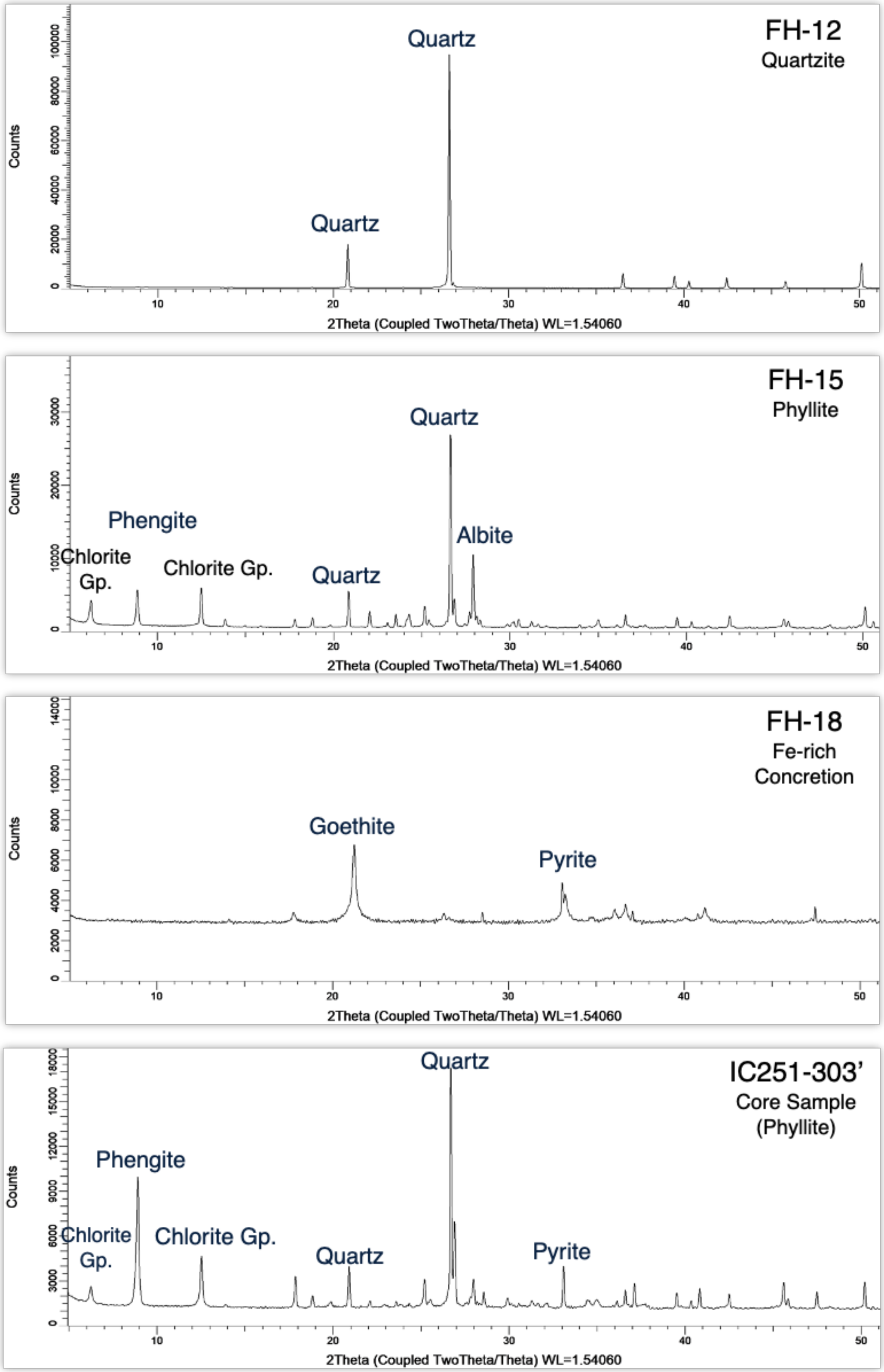
Figure 4-14. Average radon levels (pCi/L) for each of 12 samples over one day.



XRD and LA-ICP-MS Analysis Results

Outcrop and drill core samples collected in the area included phyllites and quartzites with one iron-rich concretion (sample FH-18). XRD analysis of outcrop and drill core phyllites showed the presence of iron- and magnesium-rich minerals such as phengite, pyrite, and chlorite group minerals chamosite and clinochlore. Outcrop quartzite samples showed the presence of quartz. Sample FH-18, an iron-rich concretion, showed primarily pyrite, an iron sulfide mineral, and goethite, an iron (III) oxyhydroxide that forms via weathering and oxidation of iron (II) minerals. Representative XRD spectra are found in Figure 4-15. XRD spectra for all samples may be found in Appendix 3C.

Figure 4-15. Representative XRD spectra for outcrop quartzites (FH-12), outcrop phyllites (FH-15), core sample phyllites (IC251-303'), and iron-rich concretion (FH-18).



Major and trace element data from XRF and LA-ICP-MS analyses are presented in Appendix 3A and 3B, respectively, while specific LA-ICP-MS data for uranium, thorium, and iron may be found in Table 4-2. Phyllite samples FH-4, FH-5, FH-6, FH-7, FH-8, FH-11, FH-15, and FH-21 all contained uranium concentrations above the average upper crust concentration of 2.5 ppm (Wedepohl, 1995), as did samples from the IC-251 drill core, also phyllites, at depths of 139 feet, 303 feet, and 381 feet. Of the three quartzite samples analyzed, only one, FH-12, contained concentrations of uranium higher than the average crustal concentration at 6.19 ppm (±0.0621). A sample of iron-rich concretion, FH-18, was also well over the average crustal concentration at 169 ppm (±5.06).

Phyllite samples FH-4, FH-5, FH-6, FH-8, FH-15, and FH-21 were above the average thorium crustal concentration of 10.3 ppm (Wedepohl, 1995). Only FH-12 of the quartzite samples was above the average crustal concentration (46.1 ppm ±0.0507). FH-18, the iron-rich concretion, was also above the average crustal concentration for thorium (98.6 ppm ±3.73). None of the IC-251 drill core samples were above the average crustal value.

$$\text{ANEF} = \frac{U_{sample}/Al_{sample}}{U_{crust}/Al_{crust}}$$

Concentrations of uranium and thorium were normalized by calculating the aluminum-normalized enrichment factor (ANEF). This provides a measure of the enrichment of these elements in the study area in relation to the upper crust. In this equation, U_{sample} is the concentration of a trace element (uranium), U_{crust} is the average crustal concentration for the element, and Al (aluminum) is the reference metal.

Outcrop samples showed varying levels of uranium enrichment, ranging from 97% (FH-5) to 6,640% (FH-18). In comparison, four of the five drill core samples show enrichment between 81% (214 feet) and 109% (381 feet), with the 62-foot sample showing the lowest enrichment at 18%. Thorium enrichment varied among the outcrop samples from 68% (FH-7) to 742% (FH-18). Drill core sample thorium enrichment was lowest at the shallowest depth (62 feet, 1% enrichment) and became higher with depth (70%, 381 feet). The average uranium enrichment in the area is 640% when accounting for the measured levels of FH-18 but is reduced to 265% when this sample is removed from the equation. Similarly, without FH-18, thorium enrichment is 93%, a value that increases to 132% when FH-18 is factored in.

In addition to uranium and thorium, we consider iron concentrations and enrichment in the area as part of this study. Outcrop phyllite samples FH-4, FH-5, FH-6, FH-7, FH-8, FH-9, FH-11, and FH-21 all contained iron concentrations above the average upper crustal value of 30,890 ppm. These values ranged from 34,816 ppm (FH-7) to 56,189 ppm (FH-8) with ANEF values between 99.3% (FH-6) and 1800% (FH-11). Outcrop quartzite sample FH-12 was the only sample of its kind above the threshold at 75,015 ppm and 101% enrichment. All core phyllites except the 214' sample were above the average upper crustal concentration, ranging from 56,735 ppm at the deepest level (381 feet) to 116,897 ppm at the shallowest depth, 62'. The lowest enrichment value for core phyllites was 138% at 214', while the highest was the 62' sample at 334%. Sample FH-18, an iron-rich concretion showed concentrations of 6,700,000 ppm and enrichment of 222000%. The mean iron enrichment in the area is 12600% when accounting for the measured levels of FH-18 but drops to 254% when this sample is not calculated as part of the average.

Table 4-2. Mean (n=2) ^{238}U, ^{232}Th, and ^{57}Fe concentrations and aluminum-normalized enrichment factor (ANEF), for outcrop and drill core samples in Cleburne County, AL, by LA-ICP-MS **line** analysis.

Sample	Rock Type	^{238}U (ppm ±2SE)*	ANEF	^{232}Th (ppm ±2SE)*	ANEF	^{57}Fe (ppm ±2SE)*	ANEF
Avg. Upper Crust Conc.		2.5 ppm		10.3 ppm		30890 ppm	
FH-4	Phyllite	**4.94 ±0.0999**	1.40	**20.3 ±0.0147**	1.11	**45529 ±76.8**	1.04
FH-5	Phyllite	**3.24 ±0.0396**	0.969	**20.7 ±0.166**	1.19	**49397 ±694**	1.20
FH-6	Phyllite	**3.75 ±0.116**	1.04	**28.1 ±1.11**	1.50	**44159 ±337**	0.993
FH-7	Phyllite	**2.73 ±0.0238**	1.03	9.31 ±0.285	0.679	**34816 ±126**	1.07
FH-8	Phyllite	**4.38 ±0.0260**	1.01	**27.7 ±0.0820**	1.23	**56189 ±58.4**	1.05
FH-11	Phyllite	**5.32 ±0.743**	26.1	1.34 ±0.150	1.27	**45343 ±9550**	18.0
FH-12	Quartzite	**6.19 ±0.0621**	1.03	**46.1 ±0.0507**	1.48	**75015 ±701**	1.01
FH-13	Quartzite	0.285 ±0.000857	1.42	1.64 ±0.0403	1.57	3996 ±98.4	1.61
FH-14	Quartzite	1.21 ±0.0431	1.80	4.32 ±0.116	1.24	12715 ±827	1.53
FH-15	Phyllite	**2.89 ±0.0421**	1.20	**12.5 ±0.520**	0.995	26605 ±111	0.893
FH-18	Fe-rich concretion	**169 ±5.06**	66.4	**98.6 ±3.73**	7.42	**$6.7x10^7$ $±4.25x10^6$**	2220
FH-21	Phyllite	**5.11 ±0.0155**	1.19	**24.9 ±0.678**	1.12	**52841 ±85.3**	0.999
IC-251: 62’	Phyllite	0.523 ±0.0115	0.184	0.166 ±0.0119	0.0113	**116897 ±1634**	3.34
IC-251: 139’	Phyllite	**2.97 ±0.0256**	1.08	0.722 ±0.00282	0.0506	**82584 ±976**	2.44
IC-251: 214’	Phyllite	1.25 ±0.00934	0.814	2.72 ±0.0198	0.341	26263 ±320	1.38
IC-251: 303’	Phyllite	**2.59 ±0.0342**	1.07	5.82 ±0.0954	0.464	**75338 ±2905**	2.53
IC-251: 381’	Phyllite	2.49 ±0.0098	1.09	8.29 ±0.681	0.696	**56735 ±476**	2.10
IC-251: 381’ (Duplicate)	Phyllite	**2.53 ±0.104**	1.09	8.26 ±0.391	0.682d	**58335 ±2429**	2.03
Avg. Enrichment (with FH-18)			2.65 (6.40)		0.93 (1.32)		2.54 (126)
Reference Materials		**^{238}U (ppm ±2SE)**		**^{232}Th (ppm ±2SE)**		**^{57}Fe (ppm ±2SE)**	
SDC-1C		2.85 ±0.0746		11.3 ±0.213		36247 ±1816	
Certified Values		3.14 ±0.2		12.1 ±0.9		46739 ±1757	
BCR-2ga		1.65 ±0.0133		6.09 ±0.0784		75034 ±4385	
Certified Values		1.69 ±0.12		5.9 ±0.3		96385 ±0	
NIST 610		462 ±1.13		457 ±3.67		458 ±1.75	
Certified Values		461.5 ±1		457.2 ±1		458 ±9	

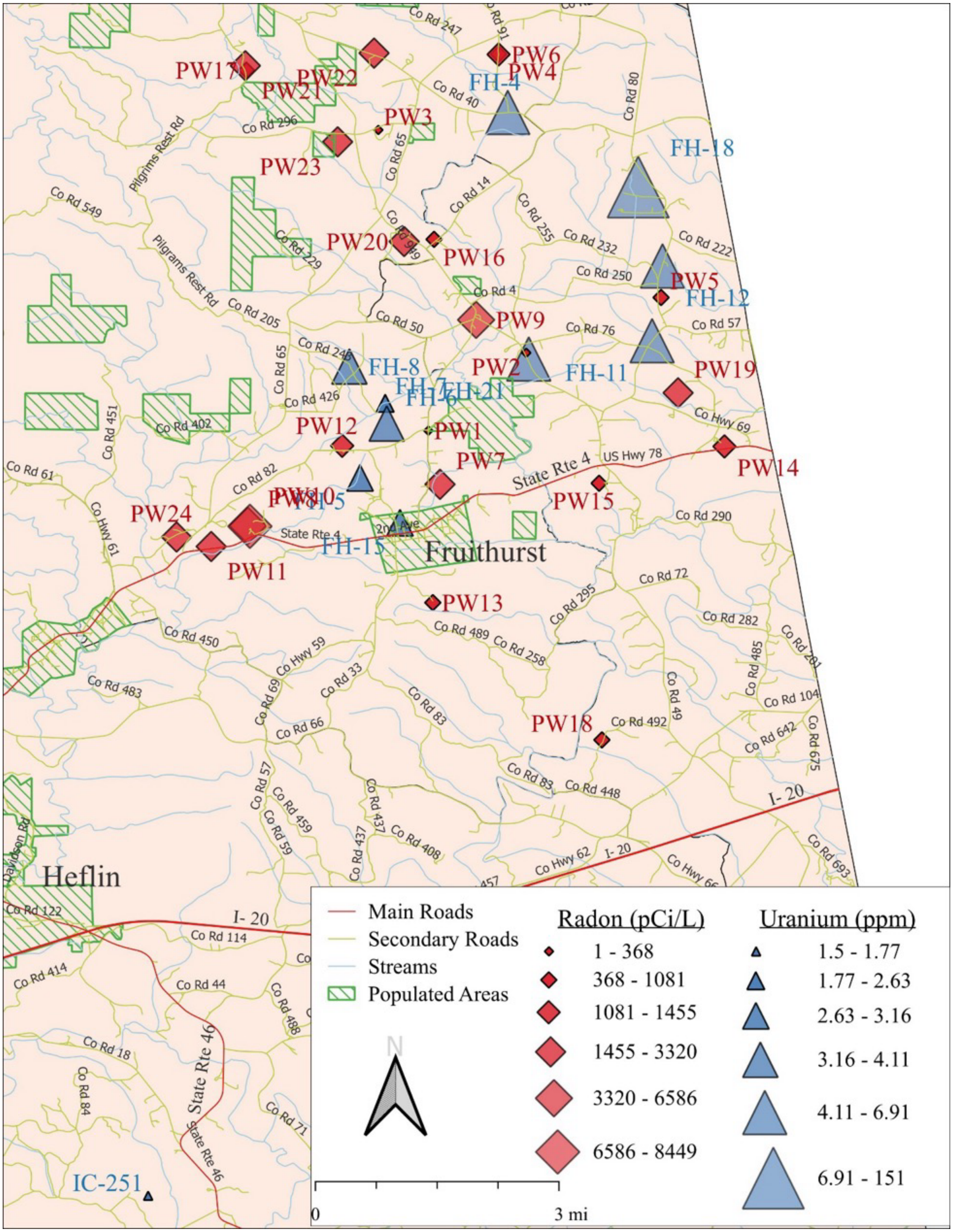
**Measures above average upper crust concentration are in bold.*

Discussion

Understanding the geochemistry of an area is an important part of contextualizing environmentally related health effects that may come from living there. Because radon is part of the radioactive decay process for uranium and thorium, and concentrations of both elements are relatively high in the vicinity of Fruithurst and Muscadine, Alabama, as well as farther reaches of Cleburne County, we can infer that this is likely associated with high levels of radon in private groundwater wells as measured by Cain (2020) and in this study. However, because measured radon levels are representative of a single point in time and overall concentrations fluctuate frequently based on a variety of factors, and because there were no geographically correlated samplings, no direct spatial link between radon and uranium measurements in their respective sample matrices was discovered as part of this work. A map showing radon levels measured by Cain (2020) and uranium concentrations in outcrop and core samples from this study can be found in Figure 4-16.

Previous studies have suggested a connection between uranium concentrations and the presence of iron-rich minerals in geologic materials (Descostes et al., 2010; Duff et al., 2002; Peng et al., 2022). Strong adsorption of uranium on the surface of iron oxyhydroxides could occur under oxidized/weathered conditions (Bruno et al., 1995). Iron was highly enriched in the study area with an average aluminum-normalized enrichment of 13466% in the samples analyzed by LA-ICP-MS. This opens the door for additional general study into the potential for uranium incorporation in minerals rich in iron or other major elements.

Figure 4-16. Locations of private well samples (Cain, 2020) and outcrop and core samples in Cleburne County, AL. Smaller shapes indicate lower ^{222}Rn and ^{238}U values.



Water Filtration

Overall, each filtration system proved to be effective at removing radon from drinking water at the point of use. The full, 5-stage system, which pairs reverse osmosis with activated carbon, lowered radon levels more substantially than activated carbon alone, but the upfront cost and regular filter replacement for a complex filtration system may not be feasible for all interested homeowners. Activated carbon is, by itself, highly effective, with some sources claiming a removal efficiency rate over 95% (DWI, n.d.; Turtiainen et al., 2000). However, this raises additional questions about the radioactive and environmental effects of discarded filters as the half-lives of many of the remaining radionuclides are on the order of a few seconds to just over 20 years (Lewis and Houle, 2008). Alternative methods of radon removal include aeration and microbial remediation (Ghernaout, 2019; Nayak et al, 2022).

As a gas, radon's primary pathway into the body is through inhalation, therefore it is important to consider the myriad alternative paths that radon enters a residence and work to mitigate those, as well. This study focused on the efficacy of small filtration systems that remediate dissolved radon and other contaminants in drinking water. Showers are another significant means of access into homes and a point-of-entry, or whole-home filtration system should be considered when deciding on a mitigation strategy.

Limitations

Part of this work relied on regular testing of water from a groundwater well and two filtered water faucets on a residential property. Sampling frequency was limited primarily by the ability to access the areas where the faucets were located. Often, infrequent email communication between the property owner and the researchers prevented regular scheduling of sample collection. Additionally, the onset of the COVID-19 pandemic beginning in the spring of

2020, led to the cancellation of several sampling trips due to health concerns by the property owner as well as the researchers.

As water sample collection continued, it became apparent that the homeowners had all but discontinued regular use of filtered drinking water. This leading to irregular testing results and a request by the researchers to allow the faucets to run continuously overnight before a sampling event, allowing fresh water to flow into the holding tank and resulting in more accurate sampling data.

Ch. 4 References

Alabama Department of Public Health, Bureau of Environmental Services. (2023, January 25). *Well water.* https://www.alabamapublichealth.gov/environmental/well-water.html

APEC Water Systems (n.d.). *ROES-50 – Essence 5-stage 50 GPD reverse osmosis water system for drinking water, WQA Certified.* https://www.freedrinkingwater.com/roes-50.htm

Ashwood, L., Vick, K. C., Hiett, C. Lee, M-K., & Dimova, N. (2023). Rural and community-based cancer cluster research. *Environmental Justice, 16*(4), 272-285. https://doi.org/10.1089/env.2021.0118

Ball, T. K., Cameron, D. G., Colman, T. B., & Roberts, P. D. (1991). Behaviour of radon in the geological environment: a review. *Quarterly Journal of Engineering Geology, 24*(2), 169-182. https://doi.org/10.1144/GSL.QJEG.1991.024.02.01

Banks, D., & Robins, N. (2002). *An introduction to groundwater in crystalline bedrock*. Norges Geologiske Undersokelse, 64 pp.

Bearce, D. N. (1973). Geology of the Talladega Metamorphic Belt in Cleburne and Calhoun counties, Alabama. *American Journal of Science, 273*(8), 742-754. https://doi.org/10.2475/ajs.273.8.742

Bruno, J., de Pablo, J., Duro, L., & Figuerola, E. (1995). Experimental study and modeling of the U(VI)-$Fe(OH)_3$ surface precipitation/coprecipitation equilibria. *Geochimica et Cosmochimica Acta, 59*(20), 4113-4123.

Cain, C. J. (2020). Natural and anthropogenic contaminants in groundwater and cancer cases in Fruithurst, Alabama [Unpublished master's thesis]. Auburn University.

Collman, G. W., Loomis, D. P., & Sandler, & D. P. (1991). Childhood cancer mortality and radon concentration in drinking water in North Carolina. *British Journal of Cancer, 63*(4), 626-629. https://doi.org/10.1038/bjc.1991.143

Collman, G. W., Loomis, D. P., & Sandler, D. P. (1988). Radon-222 concentration in groundwater and cancer mortality in North Carolina. *International Archives of Occupational and Environmental Health, 61*, 13-18. https://doi.org/10.1007/BF00381602

Cook, T. A. (1982), Stratigraphy and structure of the central Talladega slate belt, Alabama Appalachians. In Bearce, D. N., Black, W. W., Kish, S. A., and Tull, J. F. (Eds.), *Geological Society of America Special Papers, 191,* 47-60, https://doi.org/10.1130/SPE191-p47

Cothern, C. R., Lappenbusch, W. L., & Michel, J. (1986). Drinking-water contribution to natural background radiation. *Health Physics, 50*(1), 33-47.

Descostes, M., Schlegel, M. L., Eglizaud, N., Descamps, F., Miserque, F., & Simoni, E. (2010). Uptake of uranium and trace elements in pyrite (FeS_2) suspensions. *Geochimica et Cosmochimica Acta, 74*(5), 1551-1562. https://doi.org/10.1016/j.gca.2009.12.004

Dimova, N., Burnett, W. C., & Lane-Smith, D. (2009). Improved automated analysis of radon (222Rn) and thoron (220Rn) in natural waters. *Environmental Science and Technology, v. 43*(22), 8599–8603. https://doi.org/10.1021/es902045c.

Dixon, K. L., & Lee, R. G. (1988). Occurrence of radon in well supplies. *Journal of the American Water Works Association, 80*(7), 65-70. https://doi.org/10.1002/j.1551-8833.1988.tb03069.x

Drinking Water Inspectorate (DWI). (n.d.). *Treatment for radon and uranium*. https://www.dwi.gov.uk/private-water-supplies/pws-installations/treatment-for-radon-and-uranium/

Duff, M. C., Coughlin, J. U., & Hunter, D. B. (2002). Uranium co-precipitation with Fe oxide minerals. *Geochimica et Cosmochimica Acta, 66*(20), 3533-3547. https://doi.org/10.1016/S0016-7037(02)00953-5

Durridge Radon Capture & Analytics. (n.d.). *RAD7 radon detector: Real-time continuous radon monitor with spectral analysis.* https://durridge.com/products/rad7-radon-detector/

Freyer, K., Treutler, H. C., Dehnert, J., & Nestle, W. (1997). Sampling and measurement of radon-222 in water. *Journal of Environmental Radioactivity, 37*(3), 327-337. https://doi.org/10.1016/S0265-931X(96)00102-6

Ghernaout, D. (2019). Aeration process for removing radon from drinking water – A review. *Applied Engineering, 3*(1), 32-45. https://doi.org/10.11648/j.ae.20190301.15

Harris, S. A., Billmeyer, E. R., and Robinson, M. A. (2006). Evaluation of repeated measurements of radon-222 concentrations in well water sampled from bedrock aquifers of the Piedmont near Richmond, Virginia, USA: Effects of lithology and well characteristics. *Environmental Research, 101*(3), 323–333, https://doi.org/10.1016/j.envres.2006.02.002

Leukemia & Lymphoma Society. (2023). *Facts 2022-2023. Updated data on blood cancers.* lls.org. https://www.lls.org/booklet/facts-updated-data-blood-cancers

Lewis, R. K., & Houle, P. (2008). Disposal of granular activated charcoal used for the treatment of radon-222 in well water. *Proceedings of the American Association of Radon Scientists and Technologists, 2008 International Symposium*

Liu, A., Ming, J., & Ankumah, R. O. (2005). Nitrate contamination in private wells in rural Alabama, United States. *Science of the Total Environment, 346*(1-3), 112-120. https://doi.org/10.1016/j.scitotenv.2004.11.019

National Research Council, Commission on Life Sciences, Board on Radiation Effects Research, Committee on Risk Assessment of Exposure to Radon in Drinking Water. (1999). *Baseline information on indoor radon in water in the United States* in Risk Assessment of Radon in Drinking Water. National Academies Press. https://nap.nationalacademies.org/read/6287/chapter/5

Nayak, T., Basak, S., Deb, A., & Dhal, P. K. (2022). A systematic review on groundwater radon distribution with human health consequences and probable mitigation strategy. *Journal of Environmental Radioactivity, 247,* 106852. https://doi.org/10.1016/j.jenvrad.2022.106852

Paton, C., Hellstrom, J., Paul, B.,Woodhead, J. & Hergt, J. (2011). Iolite: Freeware for the visualisation and processing of mass spectrometric data. *Journal of Analytical Atomic Spectrometry, 26*(12), 2508-2518. https://doi.org/10.1039/c1ja10172b.

Peng, H., Jiao, Y., Dong, F., & Guo, X. (2022). Relationships between uranium occurrence, pyrite and carbonaceous debris in Fuxin Formation in the Songliao Basin: Evidenced by mineralogy and sulfur isotopes. *Ore Geology Reviews, 140,* 104580. https://doi.org/10.1016/j.oregeorev.2021.104580

Pulinets, S., Mironova, I., Miklyaev, P., Petrova, T., Shitov, A., & Karagodin, A. (2024). Radon variability as a result of interaction with the environment. *Atmosphere, 15*(2), 167. https://doi.org/10.3390/atmos15020167

Smith, B. M., Grune, W. N., Higgins, Jr. F. B., Terrill, Jr., J. G. (1961). Natural radioactivity in ground water supplies in Maine and New Hampshire. *Journal of the American Water Works Association, 53*(1), 75-88. https://doi.org/10.1002/j.1551-8833.1961.tb00637.x

Spurgeon, D. L. (2022). *Geology of the Jacksonville 7.5-minute quadrangle and U-Pb and (U-th)/HE reveal sediment routing and uplift in the southern Appalachian Valley and Ridge province* (Publication No. 3747)[Master's thesis, Missouri State University]. BearWorks. https://bearworks.missouristate.edu/theses/3747

Sukanya, S., Noble, J., & Joseph, S. (2021). Factors controlling the distribution of radon (^{222}Rn) in groundwater of a tropical mountainous river basin in southwest India. *Chemosphere, 263*, 128096. https://doi.org/10.1016/j.chemosphere.2020.128096

Swistock, B. (2022, August 26). *Reducing radon in drinking water.* Penn State Extension. https://extension.psu.edu/reducing-radon-in-drinking-water

Tull, J. F. (1982). Stratigraphic framework of the Talladega slate belt, Alabama Appalachians. In D. N. Bearce et al. (Eds.), *Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen* (pp. 3-18). Geological Society of America Special Paper 191.

Tull, J. F., Harris, A. G., Repetski, J. E., McKinney, F. K., Garrett, C. B., & Bearce, D. N. (1988). New paleontological evidence constraining the age and paleotectonic setting of the Talladega slate belt, southern Appalachians. *Geological Society of America Bulletin, 100*, 1291-1299.

Turtiainen, T., Kokkonen, P. & Salonen, L. (2000). *Removal of radon and other natural radionuclides from household water with domestic style granular activated carbon filters.* STUK—Radiation and Nuclear Safety Authority, 82 pp.

Ullah, F., Muhammed, S., & Ali, W. (2022). Radon concentration and potential risks assessment through hot springs water consumption in the Gilgit and Chitral, northern Pakistan. *Chemosphere, 287*(3).

US Environmental Protection Agency. (2000). *Technical Fact Sheet: Proposed Radon in Drinking Water Rule.* EPA Archive. https://archive.epa.gov/water/archive/web/pdf/radon-proposed-technical-fact-sheet.pdf

US Environmental Protection Agency. (2012, May) *A citizen's guide to radon: The guide to protecting yourself and your family from radon.* Radon. https://www.epa.gov/sites/production/files/2016-02/documents/2012_a_citizens_guide_to_radon.pdf

Wedepohl, K. H. (1995). The composition of the continental crust. *Geochimica et Cosmochimica Acta, 59*(7), 1217-1232.

Zeeb, H., Shannoun, F. (Eds.). (2009). *WHO handbook on indoor radon: a public health perspective.* World Health Organization.

<u>CHAPTER 5</u>: Conclusion

This work represents the interdisciplinary nature of the Earth System Science Ph.D. program at Auburn University. The projects within this dissertation include topics from the fields of environmental psychology, geoscience education, and environmental geology. Collectively, they investigate interactions between humans and the natural world in the ways we think about, learn about, and are affected by nature. It reinforces ideas about the role of societal values and worldviews in thinking about environmental risks, offers insight into ideas about developing methodologies in geoscience field education, and provides a better understanding of the potential source of a groundwater contaminant while providing a possible approach to attenuating that contaminant.

Study 1: Thinking About

Quantitative analyses were used to examine how U.S. outdoor activity levels changed due to employment changes resulting from early COVID-19 shutdown orders and how these changes, along with societal values, political leanings, and demographics, predicted environmental risk perceptions. The results of this study indicated that, compared to before the pandemic, self-reported outdoor activity levels dropped among our study group during the early stages of COVID-19. They also suggested, congruent with previous literature, that societal values and worldviews, as well as political orientation, played a more significant role in predicting perceptions of environmental risk and environmental awareness than outdoor activity.

Study 2: Learning About

When the pandemic caused a rapid shift in course delivery, geosciences and other field-centric departments were uniquely affected by the sudden cancellation or restructuring of field trips and field courses, cornerstone pieces of many of these disciplines. This project used an embedded mixed methods approach to identify some of the motivations for employing virtual field experiences before and during COVID-19, benefits that were realized during the use of these programs, and barriers that were faced while attempting to implement them.

The results of this work suggested a slow-growing acceptance of virtual field experiences as useful tools in field-based education before the pandemic. The sudden onset of COVID-19 forced many field-focused faculty to consider these programs, perhaps reluctantly, as alternatives. Supplementary preparation for later field excursions, geospatial skill development, and accessibility were benefits cited by survey respondents. Noted barriers to use during the pandemic and in the future included lack of necessary resources (e.g., equipment and software), time, and skills needed to develop these programs to acceptable standards.

The COVID-19 pandemic created an opportunity to more closely examine the role of virtual field experiences in geoscience-related spaces and to better understand how they can be used to recruit, engage, and retain students who are interested in these areas of study.

Study 3: Being Affected By

Building upon previous work surrounding the relationship between high levels of radon in well water and elevated cancer rates in the small, rural communities of Fruithurst and Muscadine, Alabama, this work investigated a potential geogenic source of radon by examining levels of uranium and thorium in the area using laser ablation inductively coupled plasma mass spectrometry. To test a possible method for attenuating radon levels in drinking water, the efficacy of two filtration systems was tested over several months along with a short-term "stress test" of the full reverse osmosis system.

Geochemical analysis of rock samples collected in the area showed elevated levels of uranium and thorium, as compared to the average crustal concentration. This suggested a relationship between these elements and the occurrence of dissolved radon in sampled groundwater. Results of filtered water testing showed the ability of each system to successfully remove radon from supplied groundwater with regular maintenance and filter replacement.

There are opportunities to expand this research to test for the presence and sources of airborne radon in homes and to better understand the effectiveness of larger filtration systems in its removal from groundwater before entry.

Conclusion

These three projects are singular examples of the myriad ways humans interact with nature and the world around them. They highlight the importance of looking at problems from a variety of scales and the viewpoints of different disciplines.

APPENDIX 1 - Environmental Risk Perception Survey

Environmental Risk Perception – Full

As a registered worker for Amazon Mechanical Turk (MTurk) who is of legal adult age, you are invited to participate in a research study to evaluate change in environmental risk perception during the global COVID-19 pandemic. If you decide to take part you will be asked to complete the following 20–25-minute online survey consisting of multiple-choice questions related to climate, outdoor activity, and environmental risk.
Your participation in this study is completely voluntary. If you change your mind about participating, you can withdraw at any time by closing your browser window.

Please review the Electronic Information Letter below for additional information. If you decide to participate in this project, please proceed by clicking 'Next Question'.

Smith 20 359 ex 2007 elec info

What is your general level of interest in environmental topics (e.g., water quality, air quality, climate, recycling, etc.)?
Extremely interested (5)
Very interested (4)
Moderately interested (3)
Slightly interested (2)
Not interested at all (1)

How concerned are you about the same environmental topics you considered in the previous question (e.g., water quality, air quality, climate, recycling, etc.)?
Extremely concerned (5)
Very concerned (4)
Moderately concerned (3)
Slightly concerned (2)
Not concerned (1)

Are you a member of an environmental organization (e.g., Greenpeace, The Nature Conservancy, National Audubon Society, etc.)?
Yes (1) / No (0)

How often do you participate in environmentally related activities (e.g., roadside trash pickup, tree planting, recycling, etc.)?
Weekly or more often (5)
About once a month (4)
A few times a year (3)
Rarely (2)
Never (1)

Environmental risk is defined as the actual or potential threat of adverse effects on living organisms and environment by effluents, emissions, wastes, resource depletion, etc. Please answer the following questions with the above definition of environmental risk in mind:

Indicate the level of risk you perceive each of the following items poses to the environment:
No risk Very low risk Somewhat low risk Somewhat high risk Very high risk

- Storage of chemicals in tanks or barrels that may leak
- Worldwide human population growth
- Wastewater discharge into lakes, rivers, and other bodies of water from business or industrial plants
- Commercial fishing
- Pollution from rainwater that is washing off pesticides, dirt, and nutrients into lakes, rivers and other bodies of water
- Sport and recreational hunting
- Wastewater discharged from home septic tanks into ditches, rivers, and other bodies of water
- Overgrazing of range and pasture lands due to excessive numbers of livestock for a specific area
- Disposal of hazardous waste by burning it
- Wastewater discharged from a city sewage treatment plant into lakes, rivers, and other bodies of water
- Destruction and loss of wetlands by residential, commercial, industrial, agricultural, or recreational development
- Disposal of hazardous waste into a landfill
- The damming of rivers for electric power generation, flood control, navigation, and recreation
- Storage of hazardous waste in a pond or lagoon
- Destruction and fragmentation of wildlife habitat due to urbanization and suburban sprawl
- Trash along highways, in rivers, and in other bodies of water
- Invasive species that are not native to a specific location and have a tendency to spread, causing damage to the local ecosystem
- Moving hazardous waste by boat, train, or truck through towns and cities
- Contaminated drinking water
- Eutrophication: the over-enrichment of waters due to nitrogen fertilizer runoff and nitrogen oxide deposition in watersheds. This may lead to algal blooms and depletion of dissolved oxygen in rivers and coastal waters
- Clear-cut logging of large tracts of forests for pulp, paper, and wood products
- Pesticides: insecticides used to treat insect pests, herbicides used to treat weeds, and rodenticides used to kill animal pests
- Pumping of liquid waste or hazardous materials hundreds of feet down into the earth for disposal (injection wells).
- Heavy metals like lead, zinc, and cadmium released into surface waters from mining operations, and mercury released from the burning of coal
- Fumes from automobiles, trucks, businesses, and industry causing smog
- Persistent and toxic organic pollutants (e.g., PCBs, DDT, dioxin, toluene, and benzene) that are discharged into surface streams or into the air from chemical manufacturing plants

- Storage or disposal of hazardous waste, in a facility in your neighborhood, that comes from another city, county (parish) or state
- Disposal of wastewater and drilling fluid from the oil and gas industry
- Drilling for oil from offshore drilling platforms along the coasts and the transportation of oil and petroleum products (e.g., pipelines, tank trucks, and supertankers) that may result in spills
- Lead poisoning of children from drinking water
- The ozone hole caused by ozone-depleting substances like refrigerants (e.g., Freon) that reduce the protective ozone layer and lead to an increase in ultraviolet radiation from the sun
- Open burning of trash and garbage
- Global warming caused by excessive amounts of greenhouse gases like carbon dioxide and methane that may lead to weather extremes, such as temperature increases and flooding
- Disposal of used motor oil
- Acid rain caused by the deposition of acid-producing sulfur dioxide into streams and on forests, usually from the burning of coal
- Disposal of trash and garbage in a landfill
- Lead poisoning of children from contaminated soil
- Disposal of medical waste from a doctor's office or hospital into a landfill
- Billboards and businesses along scenic highways
- Radiation: release of radioactive materials associated with nuclear power generation
- The growing of genetically engineered crops (e.g., corn), also known as genetically modified organisms or GMOs
- Surface runoff (also known as non-point pollution) contaminated with agricultural chemicals and sediment

On a scale of 1 (no risk) to 10 (extreme risk), what is your assessment of the risk for air pollution?

No Risk Extreme Risk
1 2 3 4 5 6 7 8 9 10

On a scale of 1 (no risk) to 10 (extreme risk), what is your assessment of the risk for water pollution?

No Risk Extreme Risk
1 2 3 4 5 6 7 8 9 10

On a scale of 1 (no risk) to 10 (extreme risk), what is your assessment of the risk for substances commonly used in agriculture (e.g., fertilizers, pesticides, etc.)?

No Risk Extreme Risk
1 2 3 4 5 6 7 8 9 10

On a scale of 1 (no risk) to 10 (extreme risk), what is your assessment of the risk associated with nuclear power?

No Risk Extreme Risk
1 2 3 4 5 6 7 8 9 10

On a scale of 1 (no risk) to 10 (extreme risk), what is your assessment of the risk for climate change?

No Risk								Extreme Risk	
1	2	3	4	5	6	7	8	9	10

What is 2 + 2?
4 (1)
78 (0)
-18 (0)
196 (0)
60 (0)

The following questions are regarding the effects of the COVID-19 pandemic on your life. Please answer the questions as accurately as you can.

Did you, or someone you know, receive a positive COVID-19 test result or suffer symptoms of the COVID-19 virus?
Yes (1) / No (0)

What is your perception of the risk of COVID-19 to the health and well-being of you or your family?
Very high risk (5)
Somewhat high risk (4)
Somewhat low risk (3)
Very low risk (2)
No risk (1)

Did the COVID-19 pandemic affect your job or employment status?
Yes (1) / No (0)

Were you considered an "essential worker" during any state or local "Safer-At-Home" or "Shelter-In-Place" order?
Yes (1) / No (0)

Did you experience a layoff, furlough, or other loss/change of employment during the COVID-19 pandemic?
Yes (1) / No (0)

Were you able/required to "work from home" using digital methods such as email, video meeting software, conference calls, or other online or telecommunication methods?
Yes (1) / No (0)

The following questions are about the activities you may have participated in during the COVID-19 pandemic. Please answer the questions as accurately as you can.

Do you enjoy spending time outdoors?
A great deal (5)
A lot (4)
A moderate amount (3)
A little (2)
Not at all (1)

Do you enjoy gardening or other yard work?
A great deal (5)
A lot (4)
A moderate amount (3)
A little (2)
Not at all (1)

Were state and/or local parks closed during "Safer-At-Home" or "Shelter-In-Place" orders where you live?
State and local parks were open (5)
State parks were closed, but local parks were open (4)
State parks were open, but local parks were closed (3)
State and local parks were closed (2)
I don't know (1)

How frequently did you participate in the following activities BEFORE *state or local "Safer-At-Home" or "Shelter-In-Place" orders?*
Daily (5) - Once to a few times a week (4) - Once to a few times a month (3) - Once to a few times a year (2) - Never (1)
- Hiking (in a natural area or on an unpaved trail/path)
- Walking (in a neighborhood or on a track/paved path)
- Running (in a neighborhood or on a track/paved path)
- Trail running (in a natural area or on an unpaved trail/path)
- Gardening or yard work
- Backyard sports (badminton, bag toss, horseshoes, etc.)
- Outdoor home projects
- Camping or RVing
- Kayaking/Canoeing/Paddleboarding
- Fishing
- Hunting or other shooting sports
- Boating, sailing, or other water sports
- Tennis
- Golf or driving range
- Mountain biking (in a natural area or on an unpaved trail/path)
- Bike riding (in a neighborhood or on a paved road)

How often did you participate in the following activities DURING *state or local "Safer-At-Home" or "Shelter-In-Place" orders?*
Daily (5) - Once to a few times a week (4) - Once to a few times a month (3) - Once to a few times a year (2) - Never (1)

- Hiking (in a natural area or on an unpaved trail/path)
- Walking (in a neighborhood or on a track/paved path)
- Running (in a neighborhood or on a track/paved path)
- Trail running (in a natural area or on an unpaved trail/path)
- Gardening or yard work
- Backyard sports (badminton, bag toss, horseshoes, etc.)
- Outdoor home projects
- Camping or RVing
- Kayaking/Canoeing/Paddleboarding
- Fishing
- Hunting or other shooting sports
- Boating, sailing, or other water sports
- Tennis
- Golf or driving range
- Mountain biking (in a natural area or on an unpaved trail/path)
- Bike riding (in a neighborhood or on a paved road)

Has the global COVID-19 pandemic changed the way you think about nature and the environment?
Please explain: ____

As a result of the COVID-19 pandemic, how has your perception of environmental risk changed?
I see much greater risk to the environment than before. (5)
I see somewhat greater risk to the environment than before. (4)
I see risk to the environment the same as before. (3)
I see somewhat less risk to the environment than before. (2)
I see much less risk to the environment than before. (1)

The following questions are about Earth's climate. Please answer the questions to the best of your ability.

What do greenhouse gases do as part of the greenhouse effect?
A. - Greenhouse gases absorb energy emitted by Earth. (1)
B. - Greenhouse gases reflect energy emitted by Earth. (0)
C. - Greenhouse gases reflect energy reflected by Earth. (0)
D. - Greenhouse gases absorb energy reflected by Earth. (0)
E. - I do not know. (0)

Which of the following can be caused by climate change? CHOOSE ALL THAT APPLY.
A. - Climate change can cause food shortages. (1)
B. - Climate change can cause changes in temperature. (2)
C. - Climate change can cause water shortages. (3)
D. - Climate change can cause changes in weather. (4)
E. - I do not know. (5)

Which is the best definition of a positive feedback loop in the climate system?
A. - A change in the climate system leads to a response that benefits climate change. (0)
B. - A change in the climate system leads to a response that slows down climate change. (0)
C. - A change in the climate system leads to a response that speeds up climate change. (1)
D. - A change in the climate system leads to a response that harms climate change. (0)
E. - I do not know. (0)

Which of the following best describes how plants take in carbon dioxide?
A. - Plants take in carbon dioxide from rain. (0)
B. - Plants take in carbon dioxide from sunlight. (0)
C. - Plants take in carbon dioxide from air. (1)
D. - Plants take in carbon dioxide from soil. (0)
E. - I do not know. (0)

How does sunlight affect temperature on Earth?
A. - Sunlight warms the air directly, but the air does not warm the land. (0)
B. - Sunlight warms the land directly, but the land does not warm the air. (0)
C. - Sunlight warms the air directly, and the air warms the land. (0)
D. - Sunlight warms the land directly, and the land warms the air. (1)
E. - I do not know. (0)

Which is the best description of the differences between climate and weather?
A. - Climate does not change over time, and weather does change over time. (0)
B. - Climate changes over time, weather does not change over time. (0)
C. - Climate changes over long periods of time, weather changes over short periods of time. (1)
D. - Climate changes over short periods of time, weather changes over long periods of time. (0)
E. - I do not know. (0)

Which statement comes closest to your view of the degree to which consensus exists surrounding climate change?
Most scientists think climate change is happening (4)
Scientists generally disagree about whether or not climate change is happening (3)
Most scientists think climate change is NOT happening (2)
I do not know (1)

How sure are you that global climate change is happening?
Extremely sure (4)
Very sure (3)
Somewhat sure (2)
Not at all sure (1)

Have you come across any information about reduced environmental impacts as a result of COVID-19 shutdown measures taken by different world governments (e.g., greenhouse gas emissions, air pollution/smog, etc.)?
Yes (1) / No (0)

The following questions relate to societal values. Please respond to the following statements with your level of agreement.
Strongly agree (5) - Somewhat agree (4) - Neither agree nor disagree (3) - Somewhat disagree (2) - Strongly disagree (1)

- Sometimes government needs to make laws that keep people from hurting themselves.
- It's not the government's business to try to protect people from themselves.
- The government should stop telling people how to live their lives.
- The government should do more to advance society's goals, even if that means limiting the freedom and choices of individuals.
- We have gone too far in pushing equal rights in this country.
- Our society would be better off if the distribution of wealth was more equal.
- We need to dramatically reduce inequalities between the rich and the poor, whites and people of color, and men and women.
- Discrimination against minorities is still a very serious problem in our society.
- It seems like many minority groups don't want equal rights, they want special rights just for them.
- Society as a whole has become too soft and feminine.
- The government interferes too much in our everyday lives.
- Government should put limits on the choices individuals can make so they don't get in the way of what is good for society.

On a scale of 1 (not at all important) to 10 (extremely important), please describe the level of importance of each of the following:
Not at all important Moderately important Extremely important
1 2 3 4 5 6 7 8 9 10

- WEALTH (material possessions, money)
- EQUALITY (equal opportunity for all)
- AUTHORITY (the right to lead or command)
- SOCIAL POWER (control or dominance over others)
- FAME (public recognition)
- RESPECT FOR EARTH (harmony with other living things)
- PLEASURE (joy or gratification of desires)
- UNITY WITH NATURE (fitting into nature)
- WORLD PEACE (freedom from war or conflict)
- SOCIAL JUSTICE (correcting injustices and caring for the weak)
- ENJOYMENT OF LIFE (enjoying food, sex, leisure, etc.)
- ENVIRONMENTAL PROTECTION (preservation of nature)
- INFLUENCE (having an impact on people and events)
- HELPFULNESS (working for the welfare of others)
- POLLUTION PREVENTION (protecting natural resources)
- SELF-INDULGENCE (doing pleasant things)
- AMBITION (aspiration and hard work)

We use this question to discard the survey of people who are not reading the statements. Please select DISAGREE to preserve your answers.
AGREE (0) / DISAGREE (1)

Please enter your AGE: ____

Please indicate your GENDER:
Man (1)
Woman (0)
Non-binary (2)
(3) ____

Please enter your U.S. 5-digit ZIP CODE: ____

Your RACE or ETHNICITY:
Black or African American (6)
American Indian or Alaska Native (2)
Hispanic or Latinx (3)
Middle Eastern or North African (4)
Asian, Native Hawaiian, or Pacific Islander (5)
White (1)
(7) ____
Prefer not to answer (8)

Your highest level of EDUCATION:
Less than high school (1)
High school graduate (2)
Some college (3)
2-year degree (4)
4-year degree (5)
Master's or Professional degree 6)
Doctoral or Medical degree (7)

Do you currently work in a STEM (Science, Technology, Engineering, Math) field?
Yes (1) / No (0) / Not Sure (2)

What is your current job field? Please choose from the drop-down menus:
(Dropdown Menu) ▼ Agriculture and Forestry (1) ... This does not apply to me ~ NA (149)

How often do you attend religious services?
Weekly or more often (5)
About one time per month (4)
A few times a year (3)
Rarely (2)
Never (1)

How would you describe your political orientation?
Very conservative (5)
Somewhat conservative (4)
Moderate / middle of the road 3)

Somewhat liberal / progressive (2)
Very liberal / progressive (1)

Would you like to include any additional information about yourself? ____________________

PLEASE READ CAREFULLY: TO FINISH THIS SURVEY, YOU MUST FIRST COPY AND PASTE your Amazon Mechanical Turk Worker ID into the box below. YOU MUST ALSO return to the Amazon Mechanical Turk HIT, and enter your Worker ID in the blank box at the bottom of the window. If you do not enter your Worker ID in these two boxes before you submit both the survey and the HIT, you will NOT be paid for your participation in this survey.

____

APPENDIX 2 – Virtual Field Experience Surveys

2-A – Department Heads Survey

VFEs - Dept. Heads

Informed Consent

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS IRB APPROVAL INFORMATION WITH CURRENT DATES HAS BEEN ADDED TO THIS DOCUMENT.)

INFORMATION LETTER for a Research Study entitled:

"Using Virtual Field Experiences to Increase Accessibility and Inclusion in the Geosciences"

You are invited to participate in a research study to evaluate the use of virtual field experiences in geoscience-related departments in the United States as a supplement or replacement to in-person field trips or field courses. The study is being conducted by Tyler G. Smith, Graduate Student, under the direction of Dr. Karen S. McNeal, Professor, in the Auburn University Department of Geosciences. You are invited to participate because you are the head of and/or faculty in a geoscience-related department and are of legal adult age.

What will be involved if you participate?
Your participation is completely voluntary. If you decide to participate in this research study, you will be asked to complete an online survey consisting of multiple-choice and text answer questions related to in-person class field trips and field courses. Your total time commitment will be approximately 15 minutes.

Are there any risks or discomforts?
There are no foreseeable risks or discomforts associated with participating in this study. The survey is solely meant to evaluate any change in class field trips or field courses from in-person to virtual options.

Are there any benefits to yourself or others?
There are no anticipated direct benefits to you as a participant of this study. General benefits of this study will be the addition of knowledge and information to the field regarding the use of virtual field experiences and the benefits of using these programs as potential recruitment tools for geoscience-related departments.

Will you receive compensation for participating?
There are no current plans for compensation for participation in this study.

Are there any costs?
There are no costs associated with participating in this study.

If you change your mind about participating, you can withdraw at any time by closing your browser window. Your participation is completely voluntary, and any decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Geosciences or Tyler G. Smith.

Any data obtained in connection with this study will remain confidential.
We will protect your privacy and the data you provide by keeping your responses completely confidential; names and email addresses will be collected during this study. Information collected through your participation may be presented at professional meetings or published in professional journals. These data will be reported at the study level and no individual data will be reported.

If you have questions about this study, please contact Tyler G. Smith at tgs0023@auburn.edu or Dr. Karen S. McNeal at ksm0041@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334) 844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION ABOVE, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, PLEASE CLICK ON THE LINK BELOW. YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

The Auburn University Institutional Review Board has approved this document for use from 4/18/2022 to ---------. Protocol #22-117 EX 2203

Click “I consent, begin the study” to start the survey.
- I consent, begin the study
- I do not consent, I do not wish to participate

This survey focuses primarily on the use of virtual field experiences (VFEs) as a supplement to, or in place of, in-person field trips and field courses as related to undergraduate geoscience-related education. Please answer these questions to the best of your knowledge as head/chair of your department. Your participation in this study is greatly appreciated!

College or University Name: ______________________________

Is your institution primarily 2-year or 4-year college or university?
2-year / 4-year / Other

Is your college or university considered a Minority-Serving Institution or Historically Black College or University?
Yes / No

Department Name: ______________________________

What is the approximate number of undergraduate majors in your department? ______________

Do classes in your department include in-person class field trips or other field-based excursions outside of the classroom as part of the curriculum?
Yes / No
Does your undergraduate department curriculum require a field camp or other summer field course (separate from class-related field trips)?
Yes / No

Does your department offer an in-person summer field course or a traditional geology field camp?
Yes / No

Of the faculty in your department, approximately what percentage lead in-person class field trips and/or field courses/field camps during the year? ______________________________________

Approximately what percentage of in-person class field trips or field courses/camps in your department were, or still are, affected by the COVID-19 pandemic? ______________________

Generally, please describe any modifications that were made to in-person class field trips and/or field courses/camps as a result of the COVID-19 pandemic. ______________________________

Are you familiar with virtual field experiences (field trips/courses/camps taught using online or other digital programs)?
Yes / No

Have you or other faculty members in your department attempted to use virtual field experiences in the past?
Yes / No

Approximately what percentage of faculty in your department employ some form of virtual field experience, either currently or in the past, in place of, or in addition to, in-person class field trips and/or field courses/camps? ____

Regarding past use of virtual field experiences in your department, please name and describe the type(s) of software or virtual system(s) that you employed, if known.
Name of Program or System
1) ____________________; 2) ____________________; 3) ____________________

Approximately how many students have participated in these past courses that include a virtual field experience? ____

Have faculty members in your department been offered any kind of professional development credit connected to taking on virtual field experiences or training in any associated programs?
Yes / No

Was the potential for earning professional development credit a motivating factor for faculty in your department to take on these virtual field experiences or trainings?
Yes / No

What were the motivations for using these tools in place of, or in addition to, in-person class field trips or field courses/camps? ____

If your department has attempted to use virtual field experiences in place of, or in addition to, in-person class field trips and/or field courses/camps, please describe, in detail, any barriers or difficulties that were encountered with regard to implementation. ________________________

Please describe, in detail, any benefits you feel have/may come with implementation of virtual field experiences in place of, or in addition to, in-person class field trips or field courses/camps.
____

Did you notice any benefits using virtual field experiences that were related to diversity, equity, and inclusion of participating students?
Yes / No

Please describe any benefits related to diversity, equity, and inclusion that you noticed through the use of virtual field experiences. ____

Does your department have plans to further investigate or employ virtual field experiences in place of, or in addition to, in-person class field trips and/or field courses/camps in the future?
Yes / No

Please elaborate below on your decision whether or not to employ virtual field experiences in the future. ____

What, if any, additional resources do you feel might be needed to implement and use virtual field experiences in the future? ____

As part of this research, we would like to better understand instructor curriculum decision making in regard to virtual/in-person field experiences in geoscience classes.

If possible, please share names and email contact information for all instructors in your department (including yourself) responsible for teaching in-person or virtual field experiences to your undergraduate students. We plan to follow up with them with an additional survey. Thank you very much for your time.

First Name Last Name Email Address
1) ____________________; 2) ____________________

2-B – Instructors Survey

VFEs – Instructors

Informed Consent

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS IRB APPROVAL INFORMATION WITH CURRENT DATES HAS BEEN ADDED TO THIS DOCUMENT.)

INFORMATION LETTER for a Research Study entitled:

"Using Virtual Field Experiences to Increase Accessibility and Inclusion in the Geosciences"

You are invited to participate in a research study to evaluate the use of virtual field experiences in geoscience-related departments in the United States as a supplement or replacement to in-person field trips or field courses. The study is being conducted by Tyler G. Smith, Graduate Student, under the direction of Dr. Karen S. McNeal, Professor, in the Auburn University Department of Geosciences. You are invited to participate because you are the head of and/or faculty in a geoscience-related department and are of legal adult age.

What will be involved if you participate?
Your participation is completely voluntary. If you decide to participate in this research study, you will be asked to complete an online survey consisting of multiple-choice and text answer questions related to in-person class field trips and field courses. Your total time commitment will be approximately 15 minutes.

Are there any risks or discomforts?
There are no foreseeable risks or discomforts associated with participating in this study. The survey is solely meant to evaluate any change in class field trips or field courses from in-person to virtual options.

Are there any benefits to yourself or others?
There are no anticipated direct benefits to you as a participant of this study. General benefits of this study will be the addition of knowledge and information to the field regarding the use of virtual field experiences and the benefits of using these programs as potential recruitment tools for geoscience-related departments.

Will you receive compensation for participating?
There are no current plans for compensation for participation in this study.

Are there any costs?
There are no costs associated with participating in this study.

If you change your mind about participating, you can withdraw at any time by closing your browser window. Your participation is completely voluntary, and any decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Geosciences or Tyler G. Smith.

Any data obtained in connection with this study will remain confidential.

We will protect your privacy and the data you provide by keeping your responses completely confidential; names and email addresses will be collected during this study. Information collected through your participation may be presented at professional meetings or published in professional journals. These data will be reported at the study level and no individual data will be reported.

If you have questions about this study, please contact Tyler G. Smith at tgs0023@auburn.edu or Dr. Karen S. McNeal at ksm0041@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334) 844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION ABOVE, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, PLEASE CLICK ON THE LINK BELOW. YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

The Auburn University Institutional Review Board has approved this document for use from 4/18/2022 to ----------. Protocol #22-117 EX 2203

Click “I consent, begin the study” to start the survey.
- I consent, begin the study
- I do not consent, I do not wish to participate

This survey focuses primarily on the use of virtual field experiences (VFEs) as a supplement to, or in place of, in-person field trips and field courses as related to undergraduate geoscience-related education. Please answer these questions to the best of your knowledge. Your participation in this study is greatly appreciated!

College or university name: ____

Department name: ____

Is your college or university primarily a 2-year or 4-year institution?
2-year / 4-year / Other

Is your college or university considered a Minority-Serving Institution or Historically Black College or University?

Yes / No

How many different classes do you teach? ____

Please list any classes that you are or have been involved in that include some sort of field component.

Class Name

Class 1) __________; Class 2) __________; Class 3) __________; Class 4) __________

Approximately what percentage of in-person class field trips that you lead were, or still are being affected by the COVID-19 pandemic? ____

Approximately what percentage of in-person field courses/camps that you teach were, or still are being affected by the COVID-19 pandemic? ____

Please describe any modifications that were made to in-person class field trips and/or field courses/camps as a result of the COVID-19 pandemic. __________________________________

Are you familiar with virtual field experiences (field trips/courses/camps taught using online or other digital programs)?

Yes / No

Have you attempted to use virtual field experiences in the past as part of a class curriculum?

Yes / No

If you have used virtual field experiences in the past, approximately how many students participated in these courses? ____

Regarding past use of virtual field experiences, please name and describe the type of software or virtual system that you employed, if known.

Name of Program/System

1) ____________________; 2) ____________________; 3) ____________________

What were the motivations for using these tools in place of, or in addition to, in-person class field trips? ____

What were the motivations for using these tools in place of, or in addition to, in-person field courses/camps? ____

If you have attempted to use virtual field experiences in place of, or in addition to, in-person class field trips, please describe, in detail, any barriers or difficulties you encountered with regard to implementation. ____

If you have attempted to use virtual field experiences in place of, or in addition to, in-person field courses/camps, please describe, in detail, any barriers or difficulties you encountered with regard to implementation. ____

Please describe, in detail, any benefits you feel have/may come with implementation of virtual field experiences in place of, or in addition to, in-person class field trips. ___________________

Please describe, in detail, any benefits you feel have/may come with implementation of virtual field experiences in place of, or in addition to, in-person field courses/field camps. ___________

Did you notice any benefits using virtual field experiences that were related to diversity, equity, and inclusion of participating students?
Yes / No

Please describe any benefits related to diversity, equity, and inclusion that you noticed through the use of virtual field experiences. ____

Do you have plans to further investigate or use virtual field experiences in place of, or in addition to, in-person class field trips in the future?
Yes / No

Do you have plans to further investigate or use virtual field experiences in place of, or in addition to, in-person field courses/camps in the future?
Yes / No

Please elaborate below on your decision whether or not to employ virtual field experiences in the future. ____

What, if any, additional resources do you feel might be needed to implement and use virtual field experiences in the future? ____

Is there anyone else in your department that we should speak to regarding the use of virtual field experiences? Please list their names and email addresses below.
First Name Last Name Email Address
1) _______________; 2) _______________; 3) _______________; 4) _______________

APPENDIX 3 – Major and Trace Element Data and XRD Results

3-A – XRF Results (values in wt% oxide)

Sample	TiO_2	MnO	Fe_2O_3	Al_2O_3	SiO_2	Na_2O	MgO	P_2O_5	K_2O	CaO
FH-4	0.77	0.03	9.07	18.97	54.08	< 0.00	1.28	0.11	5.38	0.03
FH-5	0.85	0.04	9.49	18.19	51.89	0.16	4.38	0.17	4.83	0.01
FH-6	0.83	0.07	8.41	19.12	53.45	0.06	2.56	0.14	6.38	4.34E-05
FH-7	0.67	0.08	6.26	15.76	62.90	2.69	2.24	0.19	2.65	1.01
FH-8	0.95	< 0.00	10.83	19.14	48.18	0.13	1.61	0.18	7.90	< 0.00
FH-11	< 0.00	0.30	8.67	5.10	82.05	< 0.00	0.14	0.13	0.25	0.17
FH-12	< 0.00	0.21	< 0.00	7.19	87.60	< 0.00	< 0.00	0.01	0.03	0.21
FH-13	0.02	0.22	< 0.00	7.76	86.19	< 0.00	< 0.00	0.01	0.33	0.21
FH-14	0.26	0.04	1.63	10.03	81.13	< 0.00	< 0.00	0.04	0.81	0.18
FH-15	0.77	0.14	4.33	15.15	66.73	3.61	1.21	0.24	1.43	0.20
FH-18	0.23	< 0.00	81.46	< 0.00	< 0.00	< 0.00	4.06	0.17	0.02	< 0.00
FH-21	1.11	< 0.00	10.28	22.95	41.22	0.18	1.82	0.15	8.30	< 0.00
IC-251: 62'	1.40	0.25	19.73	13.17	46.14	4.21	3.66	0.12	0.37	4.74
IC-251: 139'	1.70	0.20	14.37	17.99	42.38	0.43	3.50	0.12	3.36	7.57
IC-251: 214'	0.35	0.14	4.43	15.57	64.27	3.33	1.42	0.06	0.31	4.60
IC-251: 303'	0.52	0.47	13.84	16.16	48.96	0.93	3.14	0.10	3.31	1.10
IC-251: 381'	0.37	0.22	9.86	13.93	59.16	1.78	2.39	0.08	1.46	3.23
IC-251: 381' (Duplicate)	0.37	0.22	9.84	14.12	58.74	1.79	2.44	0.08	1.48	3.20
SDC-1C	0.97	0.12	6.63	16.01	62.71	1.73	1.65	0.14	3.14	1.39
Certified Values	1.01 ±0.04	-	2.62 ±0.15	15.75 ±0.34	65.85 ±0.43	2.05 ±0.09	1.69 ±0.10	0.158 ±0.025	3.28 ±0.10	1.40 ±0.07

3-B – LA-ICP-MS Results (values in ppm)
(IS = Internal Standard; nd = not detected)

Sample	^{23}Na	^{24}Mg	^{27}Al	^{29}Si	^{39}K
FH-4	740.86 ± 0.5522	5602.4 ± 12.931	113594 ± 407.9	IS ± IS	41170 ± 716.29
FH-5	772.67 ± 13.051	22014 ± 303.08	107631 ± 266.81	IS ± IS	37768 ± 561.76
FH-6	1416.5 ± 12.537	12342 ± 6.2005	115940 ± 979.83	IS ± IS	50362 ± 101.53
FH-7	20062 ± 412.92	12054 ± 40.058	84971 ± 886.08	IS ± IS	21316 ± 73.981
FH-8	1799.8 ± 25.9	8660.6 ± 18.672	139160 ± 149.79	IS ± IS	62078 ± 127.37
FH-11	143.9 ± 49.308	298.47 ± 83.751	6550 ± 1006.3	IS ± IS	1716.1 ± 503.17
FH-12	2350.7 ± 9.2044	20497 ± 64.238	193485 ± 61.346	IS ± IS	84054 ± 1169.5
FH-13	317.49 ± 49.34	329.15 ± 6.9131	6467.1 ± 26.11	IS ± IS	2494.4 ± 93.609
FH-14	443.79 ± 30.494	790.74 ± 64.23	21611 ± 1193.9	IS ± IS	6158.5 ± 425.31
FH-15	27003 ± 399.96	7184.6 ± 83.473	77620 ± 2133.8	IS ± IS	11169 ± 37.244
FH-18	7568.9 ± 671.39	IS ± IS	82219 ± 13236	1801735 ± 73398.47	13308 ± 970.55
FH-21	1287.5 ± 2.6658	7816.9 ± 23.085	137852 ± 2876.9	IS ± IS	63111 ± 608.29
IC-251: 62'	34288 ± 655.66	16775 ± 31.005	91337 ± 605.39	IS ± IS	3082.2 ± 21.944
IC-251: 139'	3434.7 ± 40.776	16958 ± 222.84	88336 ± 276.73	IS ± IS	27527 ± 346.88
IC-251: 214'	24044 ± 167.03	7418.7 ± 2.1216	49484 ± 814.39	IS ± IS	2418.6 ± 6.8179
IC-251: 303'	6924.3 ± 169.37	13182 ± 178.45	77573 ± 132.59	IS ± IS	25681 ± 522.1
IC-251: 381'	14821 ± 198.25	12560 ± 135.97	70414 ± 2772.7	IS ± IS	11972 ± 42.66
IC-251: 381' (Duplicate)	15329 ± 684.53	13040 ± 335.3	74922 ± 2950	IS ± IS	12556 ± 295.09
BCR-2ga	21736 ± 455.52	18262 ± 98.863	76579 ± 1394.9	244706 ± 938.85	14436 ± 108.65
Certified Values	23962 ± 0	21467 ± 0	70913 ± 0	254270 ± 0	14900 ± 150
NIST 610	99420 ± 177.39	432.13 ± 1.5075	10793 ± 38.227	327308 ± 1300.8	463.81 ± 2.4299
Certified Values	99415 ± 0	432 ± 29	10797 ± 0	327180 ± 0	464 ± 21
SDC-1C	13640 ± 190.03	8070.6 ± 40.802	85522 ± 1983.4	IS ± IS	24323 ± 173.03
Certified Values	15199 ± 215.15	10141 ± 236.39	84205 ± 717.92	IS ± IS	26952 ± 309.13

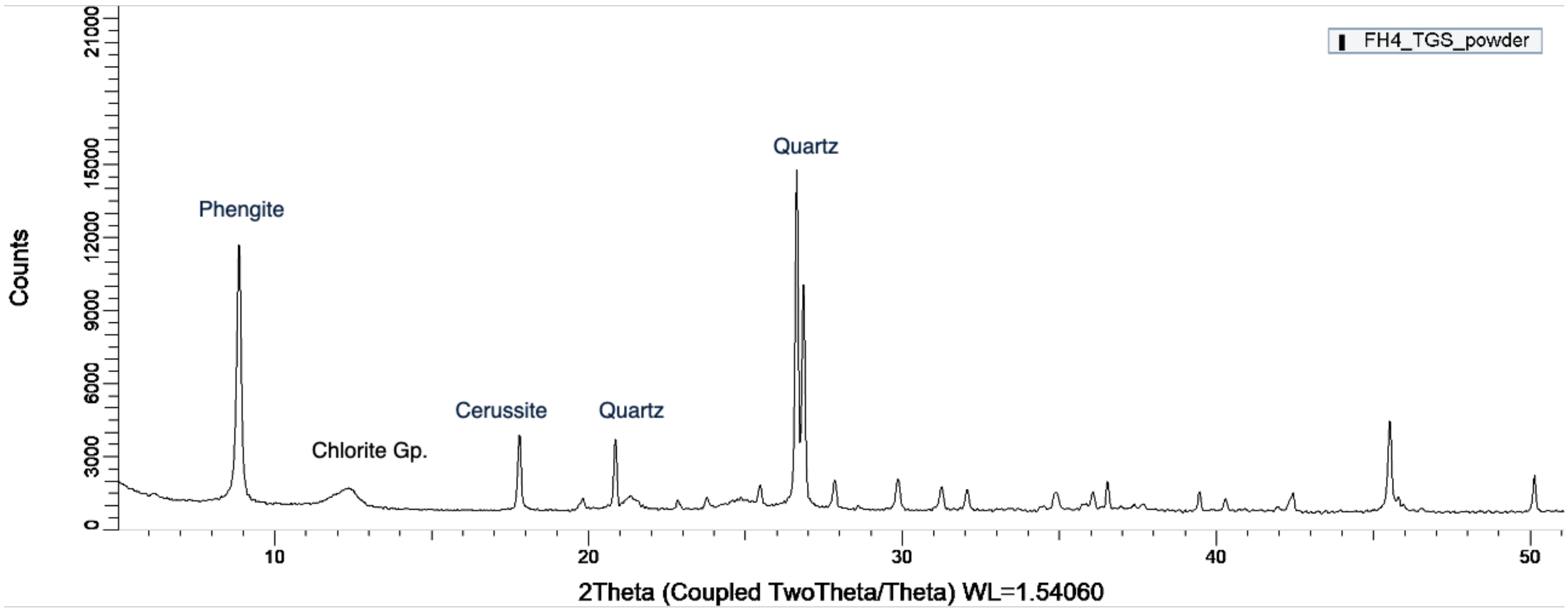
Sample	^{43}Ca	^{44}Ca	^{47}Ti	^{51}V	^{52}Cr
FH-4	4608.9 ± 484.66	1215.3 ± 77.424	4657.4 ± 102.57	83.517 ± 1.0865	77.771 ± 3.2602
FH-5	3712.1 ± 20.406	1005.7 ± 44.566	5084.7 ± 52.256	72.206 ± 0.9546	73.276 ± 0.0619
FH-6	3342.5 ± 389.52	914.11 ± 39.086	5124.4 ± 8.1962	79.969 ± 0.264	63.838 ± 1.0283
FH-7	9440.2 ± 90.751	7999.3 ± 154.84	4027.5 ± 15.618	46.178 ± 0.5472	38.557 ± 0.2418
FH-8	2468.4 ± 178.37	714.47 ± 63.008	5937.4 ± 8.1986	80.824 ± 0.7252	78.023 ± 1.4191
FH-11	1085.1 ± 433.35	342.63 ± 108.39	322.41 ± 84.113	10.309 ± 2.8652	8.3964 ± 2.9566
FH-12	2944.4 ± 922.62	716.81 ± 126.06	8528.5 ± 108.84	132.05 ± 0.1084	107.3 ± 1.4085
FH-13	1337.8 ± 52.151	573.62 ± 32.482	382.88 ± 9.5852	10.455 ± 0.4045	9.682 ± 0.0643
FH-14	1602.2 ± 3.6375	612.01 ± 37.638	1683.1 ± 125.83	26.255 ± 1.2829	20.24 ± 1.2693
FH-15	2628.1 ± 109.02	1297.5 ± 41.152	4699.5 ± 22.816	49.759 ± 0.2641	39.513 ± 0.8763
FH-18	1000000 ± 297844	307213 ± 79648	51846 ± 1993	684.19 ± 0.5634	24080 ± 1213.3
FH-21	5897.6 ± 575.24	1650.6 ± 61.514	6611.4 ± 31.26	106.11 ± 2.1497	70.73 ± 0.0395
IC-251: 62'	40772 ± 570.04	38768 ± 788.76	8300.3 ± 48.54	439.71 ± 4.2452	34.612 ± 0.9818
IC-251: 139'	60806 ± 373.5	60541 ± 277.24	10354 ± 243.95	543.17 ± 4.3038	56.857 ± 0.0422
IC-251: 214'	35168 ± 488.67	34890 ± 306.61	2016.8 ± 18.369	72.945 ± 1.7559	6.5613 ± 0.0128
IC-251: 303'	9853.9 ± 390.02	8706.5 ± 50.704	2840.5 ± 8.2038	102.71 ± 0.0162	13.091 ± 0.3071
IC-251: 381'	25540 ± 229.82	24953 ± 110.45	2173.8 ± 9.1474	118.32 ± 2.5002	14.678 ± 0.1711
IC-251: 381' (Duplicate)	25328 ± 1629.8	25606 ± 1345.8	2316.6 ± 67.783	123.97 ± 5.2731	14.98 ± 0.6346
BCR-2ga	50599 ± 35.94	IS ± IS	13099 ± 315.49	419.67 ± 2.2783	14.328 ± 0.0639
Certified Values	50429 ± 0	50429 ± 0	14100 ± 1000	425 ± 18	17 ± 2
NIST 610	82112 ± 118.92	IS ± IS	451.8 ± 1.4182	449.91 ± 2.2517	407.95 ± 0.9461
Certified Values	82144 ± 0	82144 ± 0	452 ± 10	450 ± 9	408 ± 10
SDC-1C	14993 ± 913.23	11396 ± 320.85	5692.7 ± 96.819	94.21 ± 0.1925	61.027 ± 0.166
Certified Values	10149 ± 110.72	10149 ± 110.72	5993.5 ± 75.812	102 ± 12	64 ± 7

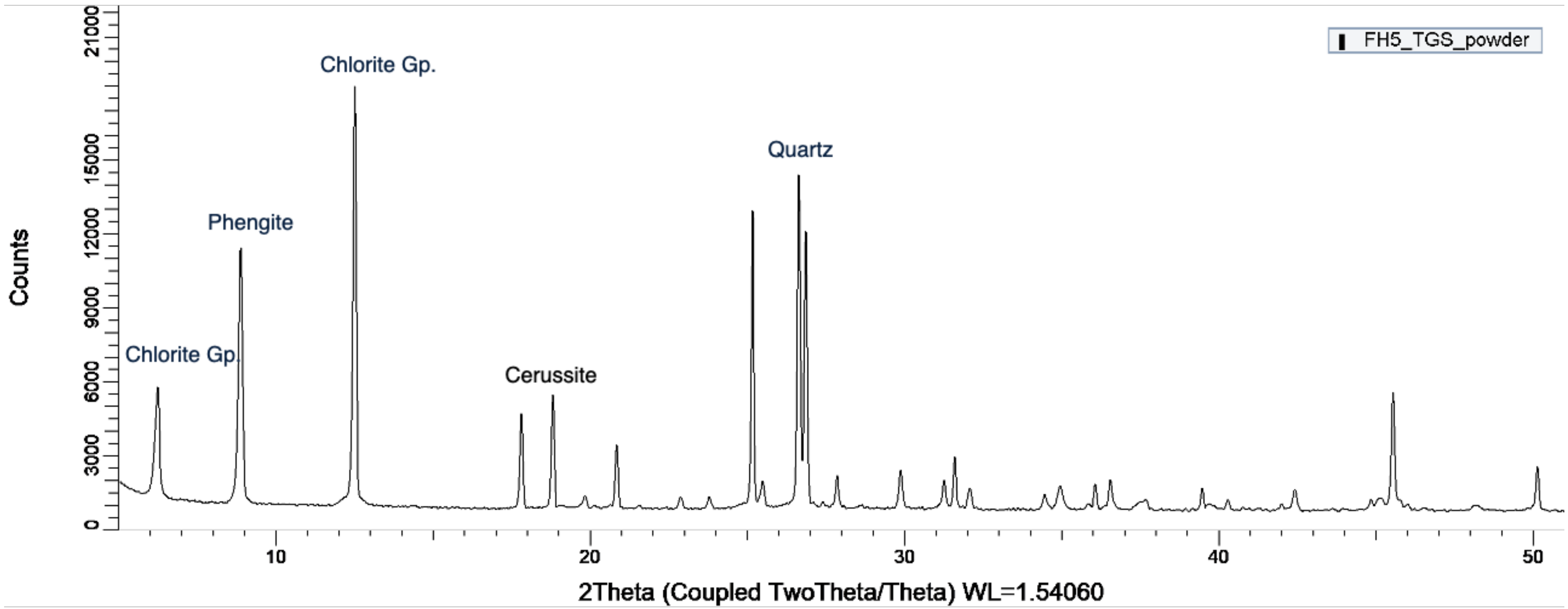
Sample	^{55}Mn	^{56}Fe	^{57}Fe	^{59}Co	^{60}Ni
FH-4	350.66 ± 2.2378	54993 ± 151.84	45529 ± 76.815	17.478 ± 0.0298	29.641 ± 0.2719
FH-5	435.24 ± 9.5113	59001 ± 1100.3	49397 ± 693.88	18.112 ± 0.2976	41.515 ± 0.0808
FH-6	511.34 ± 3.5821	52775 ± 359.32	44159 ± 337	16.224 ± 0.0543	35.516 ± 0.3098
FH-7	528.29 ± 3.1567	41141 ± 489.89	34816 ± 126.02	15.911 ± 0.0443	27.788 ± 0.4734
FH-8	79.954 ± 0.8532	66307 ± 554.8	56189 ± 58.412	11.525 ± 0.3252	33.63 ± 0.3087
FH-11	1619.7 ± 497.55	52543 ± 10604	45343 ± 9551.5	7.9937 ± 2.4588	10.112 ± 3.9701
FH-12	851.44 ± 5.5015	86868 ± 488.91	75015 ± 700.65	27.656 ± 0.1398	60.174 ± 1.5635
FH-13	1075 ± 32.319	4669.8 ± 32.361	3996.1 ± 98.387	54.265 ± 1.4027	18.436 ± 0.5686
FH-14	269.3 ± 17.235	14472 ± 1149.1	12715 ± 826.97	16.664 ± 1.6403	10.239 ± 1.0803
FH-15	855.47 ± 8.35	30838 ± 690.41	26605 ± 111.37	19.62 ± 0.142	30.455 ± 1.4088
FH-18	10143 ± 559.2	80000000 ± 4000000	70000000 ± 4000000	641423 ± 40129	99412 ± 5078.3
FH-21	110.21 ± 0.2898	60141 ± 106.81	52841 ± 85.301	7.4771 ± 0.1279	21.349 ± 0.4698
IC-251: 62'	1902.5 ± 28.676	135571 ± 661.68	116897 ± 1634.3	43.191 ± 0.5054	20.559 ± 0.2531
IC-251: 139'	1456.8 ± 13.418	95375 ± 24.264	82584 ± 975.72	23.291 ± 0.8497	18.338 ± 0.1194
IC-251: 214'	838.74 ± 3.6668	29613 ± 160.27	26263 ± 320.13	9.134 ± 0.2243	2.9696 ± 0.0799
IC-251: 303'	2867.1 ± 31.289	86258 ± 925.31	75338 ± 2904.9	74.265 ± 1.5155	5.6793 ± 0.3789
IC-251: 381'	1433.9 ± 18.814	63949 ± 678.47	56735 ± 476.36	17.332 ± 0.2685	11.323 ± 0.9258
IC-251: 381' (Duplicate)	1463.2 ± 30.344	66105 ± 1476.6	58335 ± 2428.9	17.303 ± 0.0607	11.66 ± 0.4906
BCR-2ga	1461.1 ± 13.112	88481 ± 699.71	75034 ± 4384.5	35.748 ± 0.2642	11.461 ± 0.1617
Certified Values	1550 ± 70	96385 ± 0	96385 ± 0	38 ± 2	13 ± 2
NIST 610	443.98 ± 0.9529	457.87 ± 1.6767	458.21 ± 1.7503	409.93 ± 0.5406	458.46 ± 1.9155
Certified Values	444 ± 13	458 ± 9	458 ± 9	410 ± 10	458.7 ± 4
SDC-1C	787.8 ± 5.9383	42080 ± 547.75	36247 ± 1816.3	17.166 ± 0.491	35.781 ± 0.4768
Certified Values	851.91 ± 47.741	46739 ± 1756.8	46739 ± 1756.8	17.9 ± 1.2	33.192 ± 7.469

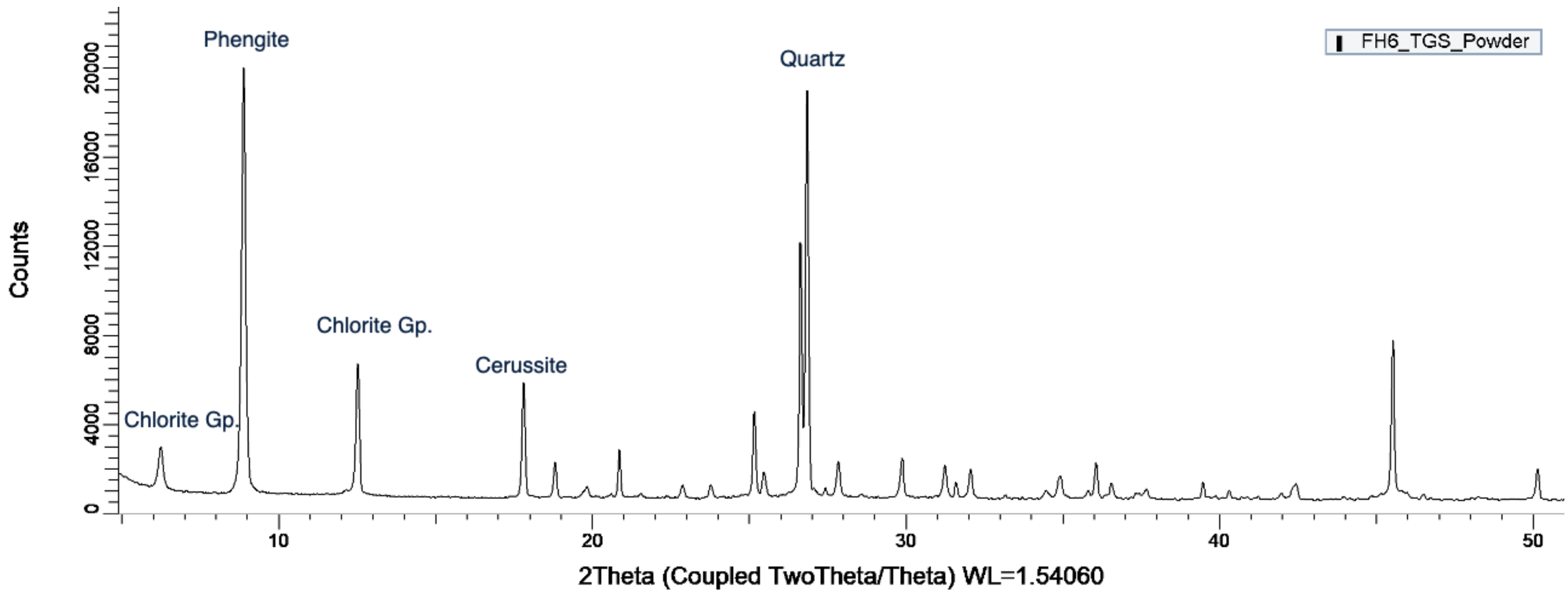
Sample	^{63}Cu	^{66}Zn	^{75}As	^{78}Se	^{88}Sr
FH-4	17.399 ± 0.1229	66.79 ± 2.1582	1.402 ± 0.2746	*nd*	25.396 ± 0.3063
FH-5	30.749 ± 0.3064	122.93 ± 0.0029	3.0792 ± 0.1843	7.1519 ± 51.123	42.52 ± 0.299
FH-6	11.188 ± 0.0683	122.77 ± 1.8726	3.2098 ± 0.1742	*nd*	50.654 ± 0.2115
FH-7	7.7333 ± 0.9594	127.5 ± 3.9206	1.4443 ± 0.2741	*nd*	131.91 ± 0.6866
FH-8	25.999 ± 0.2828	106.49 ± 0.4981	4.1625 ± 0.37	18.951 ± 24.149	86.574 ± 0.2418
FH-11	98.544 ± 26.226	54.969 ± 17.681	11.143 ± 2.4219	*nd*	8.0502 ± 2.3786
FH-12	21.27 ± 0.0524	200.17 ± 2.6553	5.4965 ± 0.6061	6.4865 ± 11.467	83.604 ± 0.1297
FH-13	7.2194 ± 0.2199	46.873 ± 4.6564	2.6853 ± 0.5434	*nd*	4.7271 ± 0.3302
FH-14	51.749 ± 4.4894	13.953 ± 1.1712	2.1683 ± 0.1705	*nd*	9.8317 ± 0.4089
FH-15	41.768 ± 0.5509	116.8 ± 5.5515	2.4731 ± 0.8918	*nd*	62.897 ± 1.9842
FH-18	18143 ± 1031.9	1606.9 ± 130.84	7163.6 ± 379.36	853.71 ± 3767.9	141.64 ± 5.1587
FH-21	21.142 ± 0.3946	59.486 ± 0.1831	1.4147 ± 0.1397	21.582 ± 17.518	41.105 ± 1.7107
IC-251: 62'	6.2588 ± 0.0297	134.63 ± 10.491	2.3111 ± 0.1917	*nd*	231.97 ± 0.0348
IC-251: 139'	5.811 ± 0.3017	151.56 ± 1.9887	1.5699 ± 0.0777	*nd*	156.99 ± 0.5924
IC-251: 214'	10.607 ± 0.5998	21.814 ± 0.1963	1.6243 ± 0.6093	16.442 ± 70.016	85.909 ± 0.7316
IC-251: 303'	82.907 ± 2.6185	615.99 ± 29.376	46.079 ± 1.5928	*nd*	39.796 ± 0.0109
IC-251: 381'	107.38 ± 2.9374	245.05 ± 7.2479	2.5712 ± 0.1571	*nd*	128.19 ± 0.6378
IC-251: 381' (Duplicate)	102.17 ± 1.1314	240.69 ± 2.9092	3.1922 ± 0.4256	18.9 ± 44.723	131.89 ± 4.4556
BCR-2ga	16.242 ± 0.3999	153.95 ± 3.9837	0.9871 ± 0.0541	*nd*	334.49 ± 1.2165
Certified Values	21 ± 5	125 ± 5	- ± -	- ± -	342 ± 4
NIST 610	440.91 ± 1.1022	459.78 ± 0.9931	324.86 ± 0.7051	138.06 ± 1.0989	515.27 ± 0.9821
Certified Values	441 ± 15	460 ± 18	325 ± 18	138 ± 42	515.5 ± 1
SDC-1C	29.622 ± 1.1119	92.87 ± 3.0764	0.6882 ± 0.1695	0.614 ± 23.513	169.28 ± 2.8141
Certified Values	30 ± 3	103 ± 8	0.218 ± 0.012	0.14675 ± 0.2355	183 ± 9

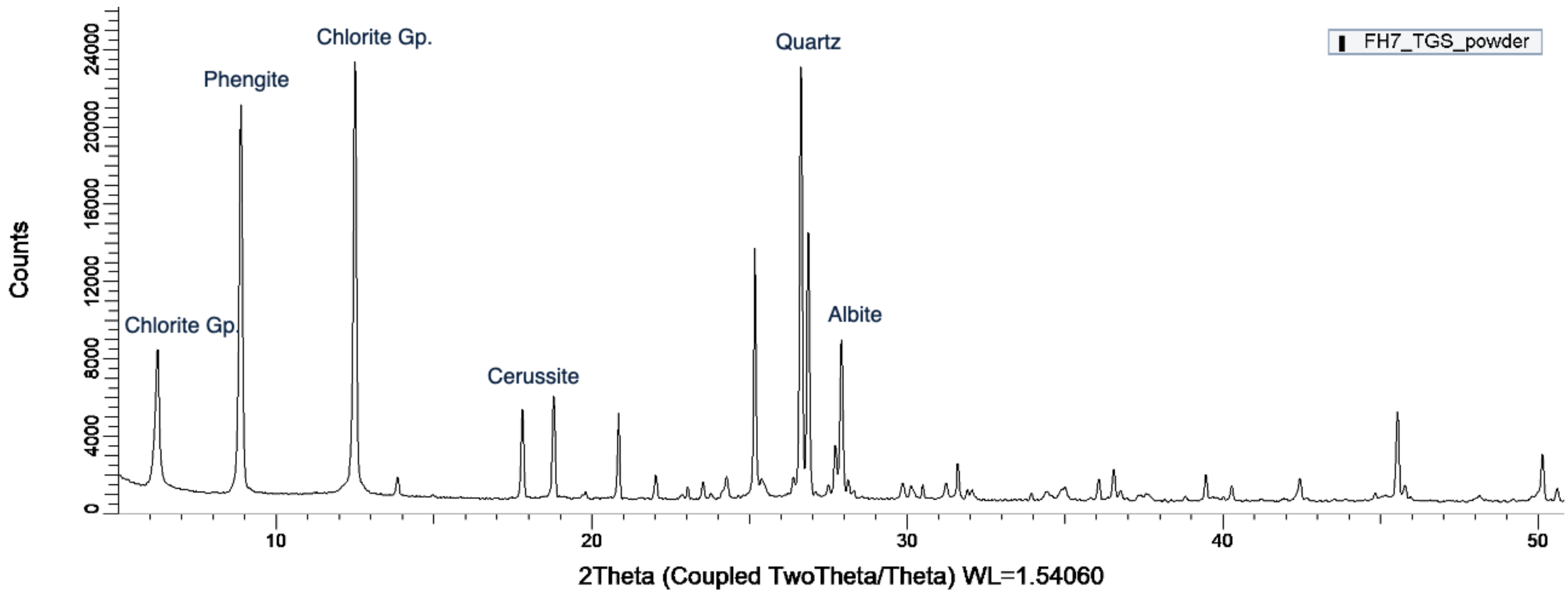
Sample	^{95}Mo	^{111}Cd	^{118}Sn	^{121}Sb	^{208}Pb
FH-4	9.0066 ± 0.0366	-0.021 ± 0.132	5.2053 ± 0.0427	1.7218 ± 0.0987	20.738 ± 0.0148
FH-5	9.9998 ± 0.2611	*nd*	4.6817 ± 0.0994	1.8285 ± 0.3175	5.1866 ± 0.2699
FH-6	9.6816 ± 0.171	0.0141 ± 0.0259	5.5423 ± 0.0781	2.5692 ± 0.1271	14.572 ± 0.4276
FH-7	9.822 ± 0.1861	0.151 ± 0.0536	3.4577 ± 0.1403	1.8452 ± 0.0174	4.3493 ± 0.074
FH-8	0.1257 ± 0.0192	0.1263 ± 0.2744	6.6081 ± 0.165	1.7035 ± 0.0707	16.001 ± 0.0867
FH-11	9.1672 ± 3.9263	*nd*	2.913 ± 0.5964	1.5864 ± 0.6126	158.01 ± 45.628
FH-12	16.879 ± 0.6228	*nd*	9.257 ± 0.1337	4.2079 ± 0.0663	23.467 ± 0.1371
FH-13	9.416 ± 0.0601	0.5418 ± 0.4055	0.9989 ± 0.0125	1.6751 ± 0.2165	6.7557 ± 0.7064
FH-14	9.2457 ± 1.3454	0.1066 ± 0.1816	11.314 ± 0.2993	1.8256 ± 0.1207	12.273 ± 0.7368
FH-15	9.077 ± 0.583	0.1843 ± 0.2023	3.5433 ± 0.156	2.5007 ± 0.0232	9.0574 ± 0.2564
FH-18	1346.6 ± 37.979	9.0035 ± 0.4047	105.95 ± 11.924	209.3 ± 6.1895	4943.4 ± 395.92
FH-21	9.4022 ± 0.4766	*nd*	5.9851 ± 0.1427	2.0403 ± 0.0508	11.987 ± 0.383
IC-251: 62'	9.8803 ± 0.0998	0.1943 ± 0.0892	1.8594 ± 0.1083	2.4393 ± 0.2577	14.223 ± 0.1798
IC-251: 139'	10.183 ± 0.593	0.2988 ± 0.3287	6.5094 ± 0.1939	3.0744 ± 0.0747	12.625 ± 0.0672
IC-251: 214'	9.3869 ± 0.6437	0.1536 ± 0.142	1.6048 ± 0.039	1.709 ± 0.0519	3.6495 ± 0.1462
IC-251: 303'	10.184 ± 0.1145	1.2218 ± 0.1784	19.256 ± 0.6467	2.0222 ± 0.1322	297.4 ± 13.807
IC-251: 381'	11.923 ± 0.186	0.2183 ± 0.0022	10.766 ± 0.5594	1.7465 ± 0.109	450.06 ± 6.3905
IC-251: 381' (Duplicate)	12.847 ± 0.2399	0.3349 ± 0.2089	11.392 ± 0.9021	1.9098 ± 0.1904	427.23 ± 2.1595
BCR-2ga	247.48 ± 0.6806	0.2576 ± 0.013	1.9884 ± 0.0569	0.3103 ± 0.0131	10.53 ± 0.0951
Certified Values	270 ± 30	0.2 ± 0	2.6 ± 0.4	0.35 ± 0.08	11 ± 1
NIST 610	417.05 ± 0.6395	270.14 ± 0.9691	429.94 ± 1.0395	395.56 ± 1.9326	425.87 ± 1.9657
Certified Values	417 ± 21	270 ± 16	430 ± 29	396 ± 19	426 ± 1
SDC-1C	9.3886 ± 0.0868	0.0321 ± 0.1138	3.2272 ± 0.1429	2.0659 ± 0.1537	21.507 ± 0.4275
Certified Values	0.18667 ± 0.07767	0.08 ± 0	2.98 ± 0.18	0.54 ± 0.05	25 ± 2

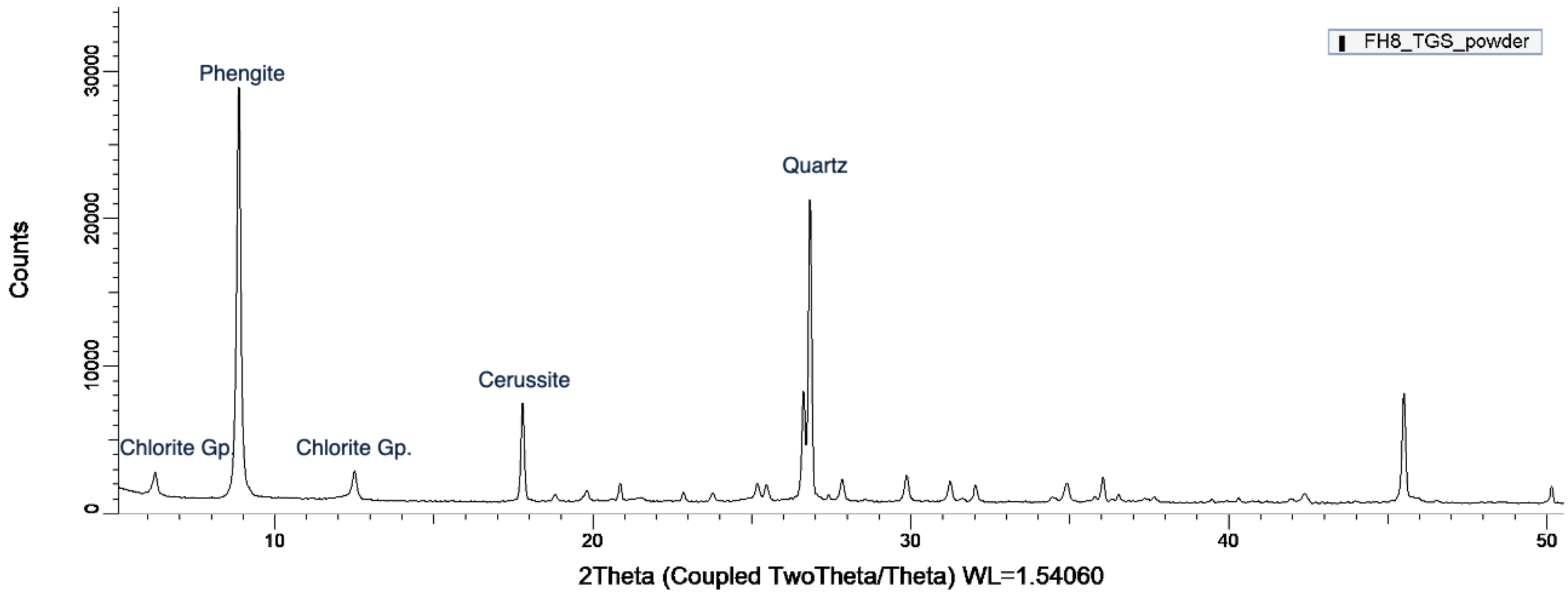
3-C – XRD Spectra for outcrop phyllites & quartzites, core phyllites, & iron-rich concretion

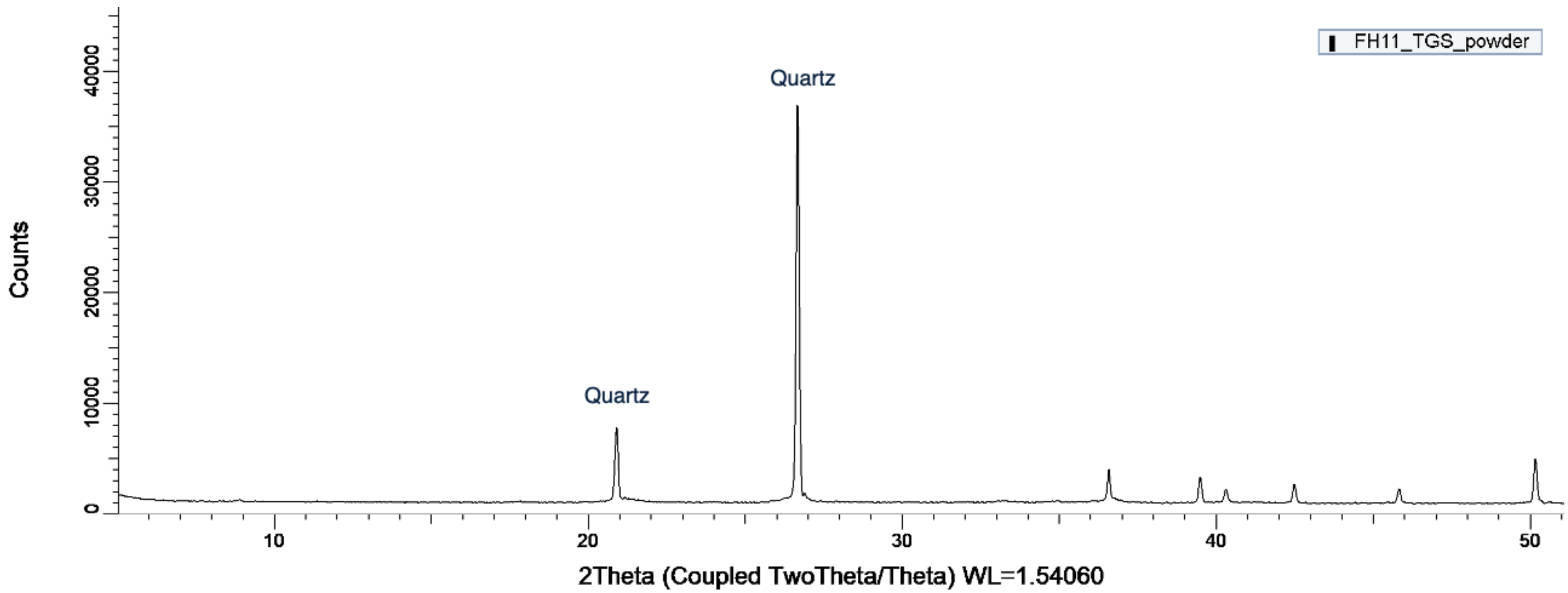


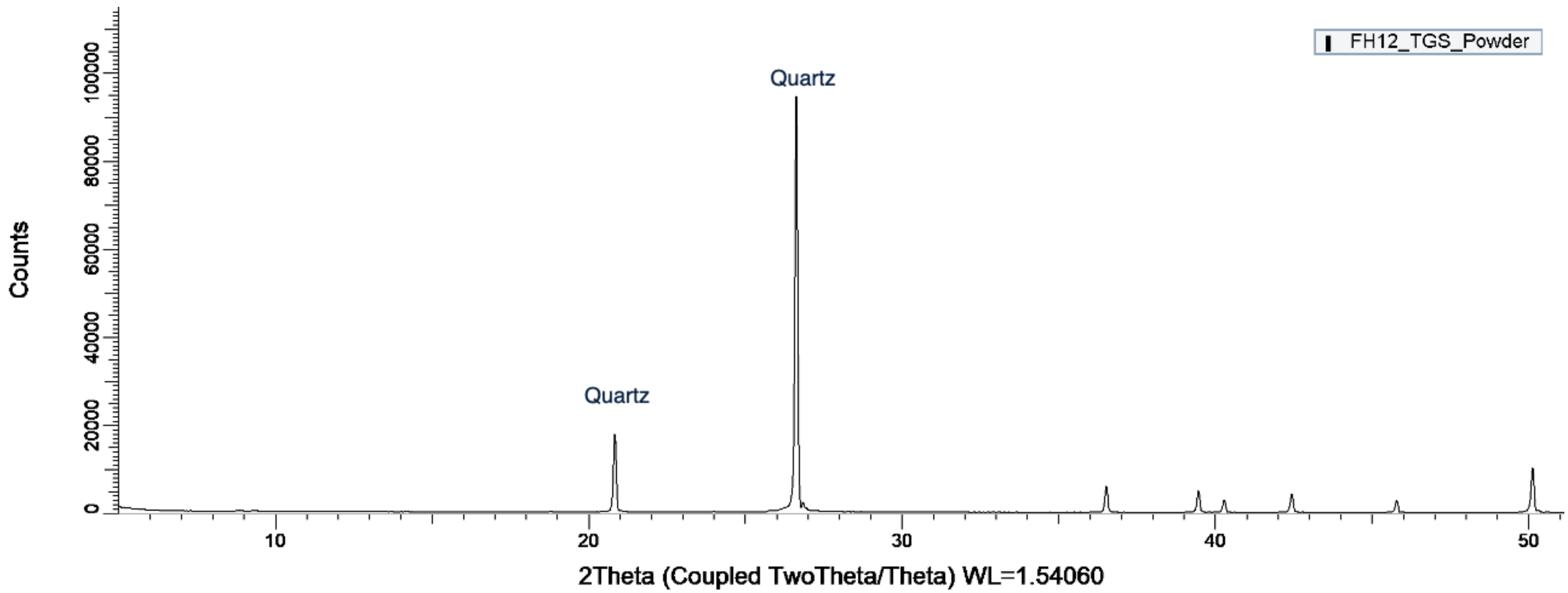

FH5_TGS_powder
Chlorite Gp.
Phengite
Chlorite Gp.
Cerussite
Quartz
Counts
0
3000
6000
9000
12000
15000
21000
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

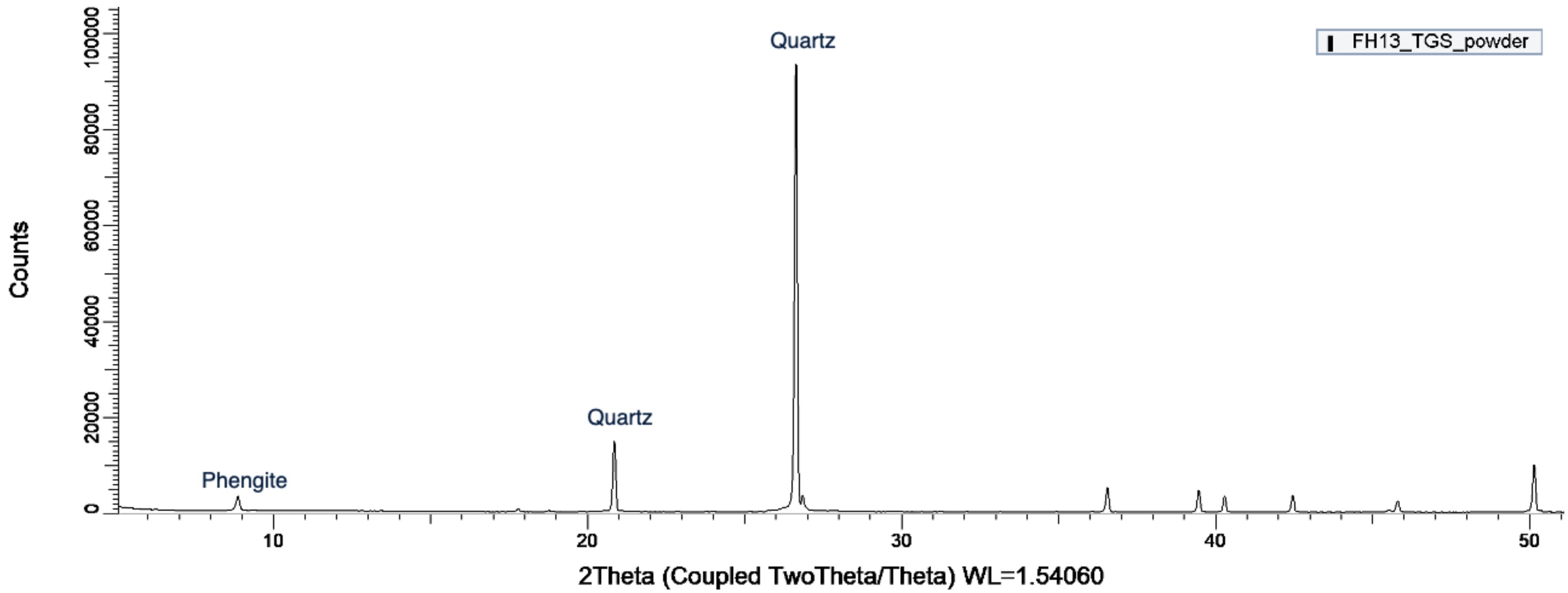

Counts
0
4000
8000
12000
16000
20000
Phengite
Quartz
FH6_TGS_Powder
Chlorite Gp.
Cerussite
Chlorite Gp.
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

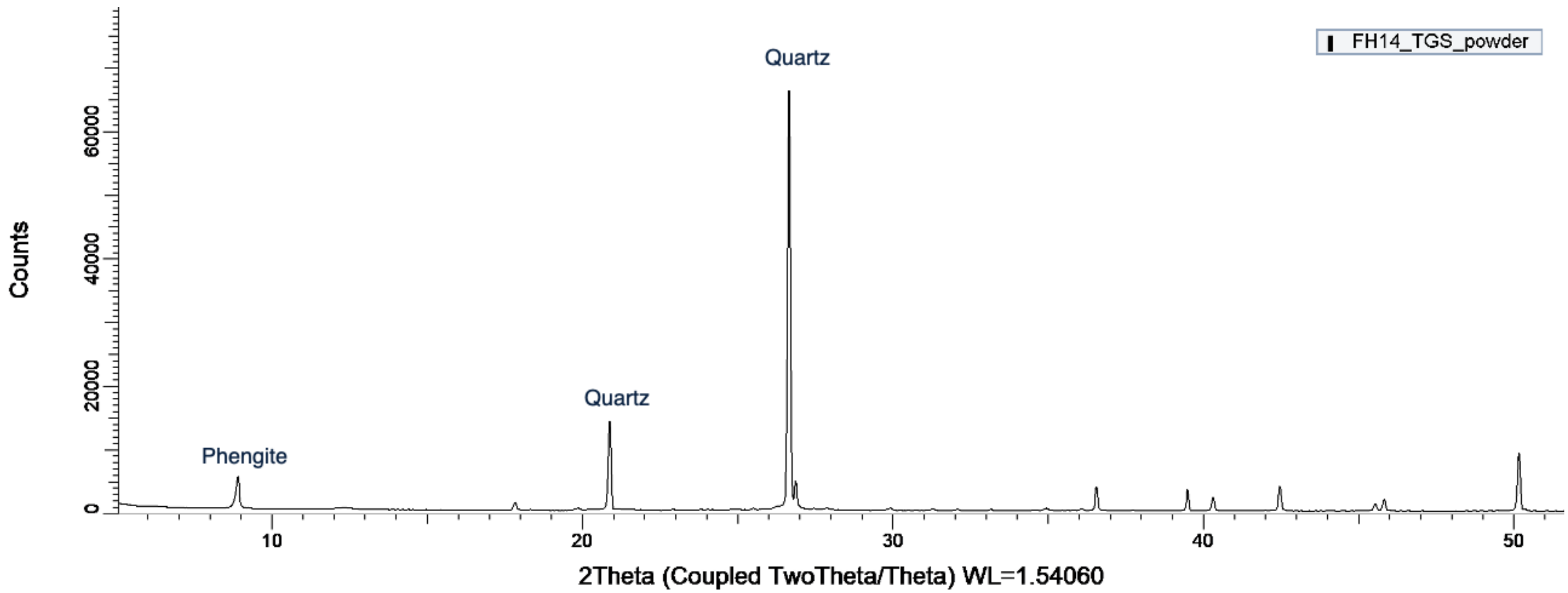

FH7_TGS_powder
Chlorite Gp.
Phengite
Chlorite Gp.
Cerussite
Quartz
Albite
Counts
0
4000
8000
12000
16000
20000
24000
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

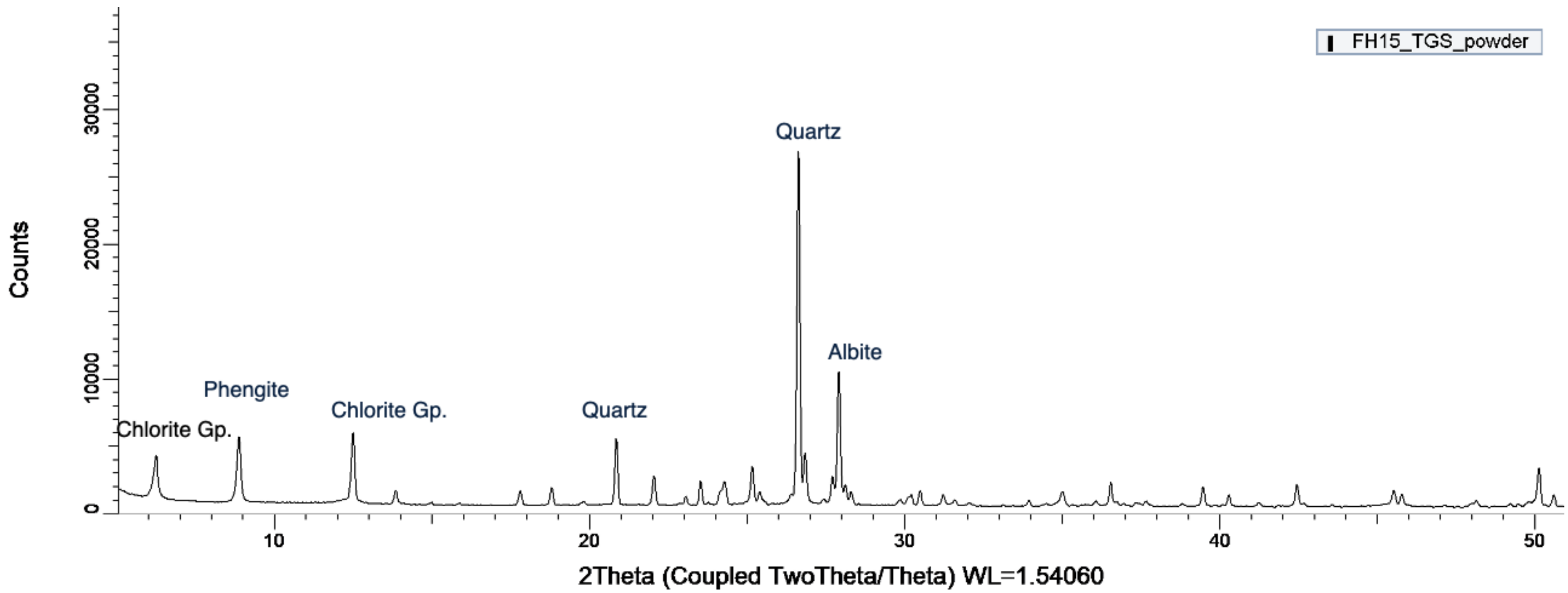

FH8_TGS_powder
Counts
30000
20000
10000
0
Phengite
Quartz
Cerussite
Chlorite Gp.
Chlorite Gp.
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

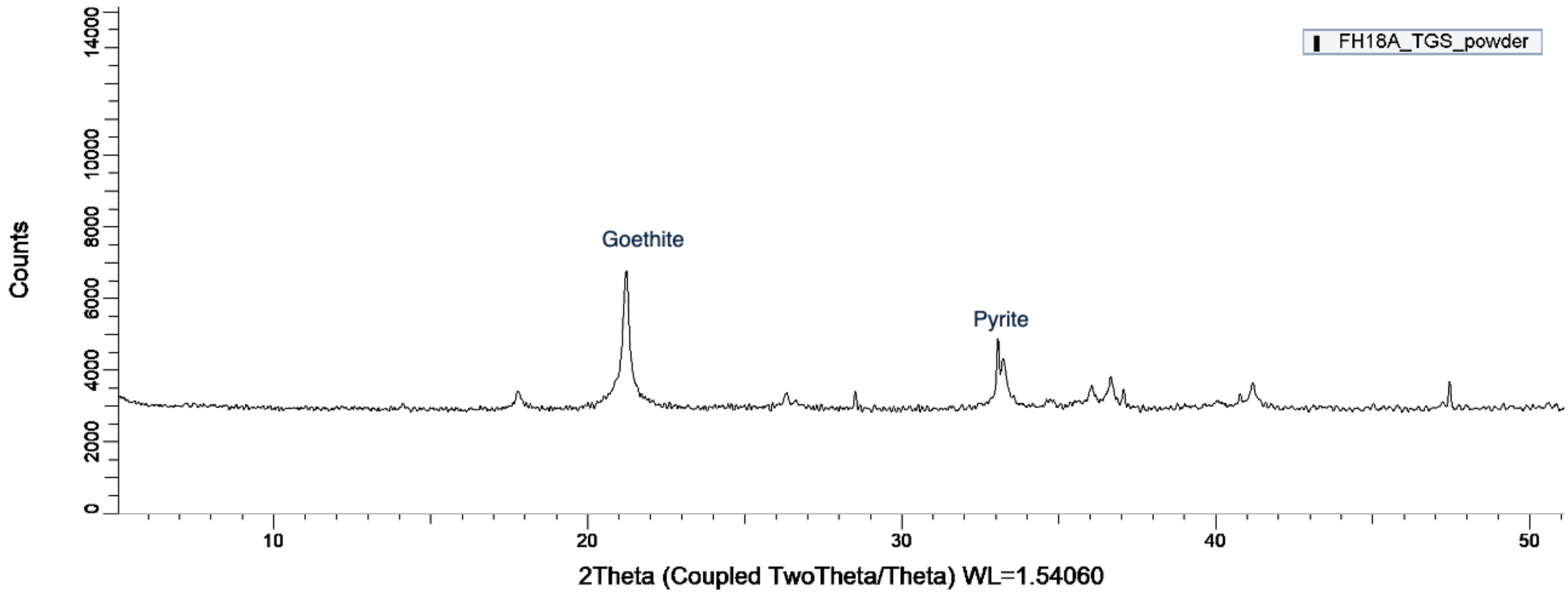

FH11_TGS_powder
Quartz
Quartz
Counts
0
10000
20000
30000
40000
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

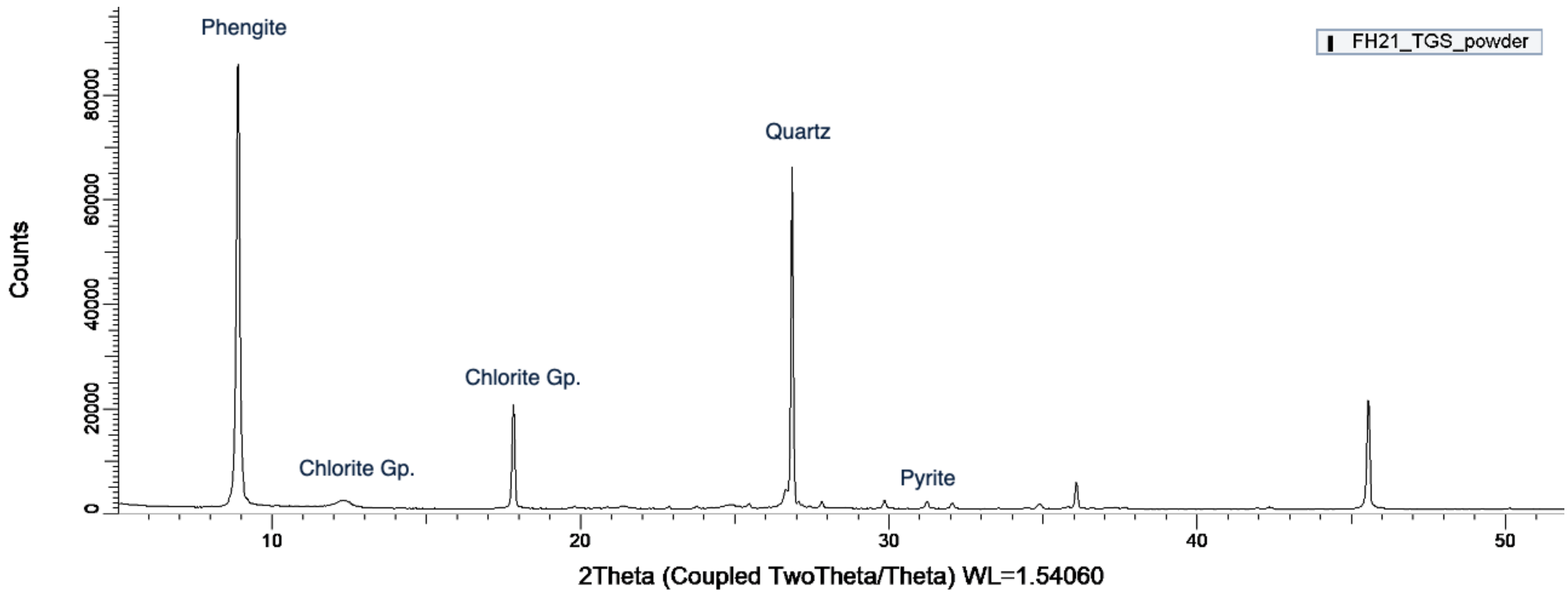

FH12_TGS_Powder
Quartz
Quartz
Counts
100000
80000
60000
40000
20000
0
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

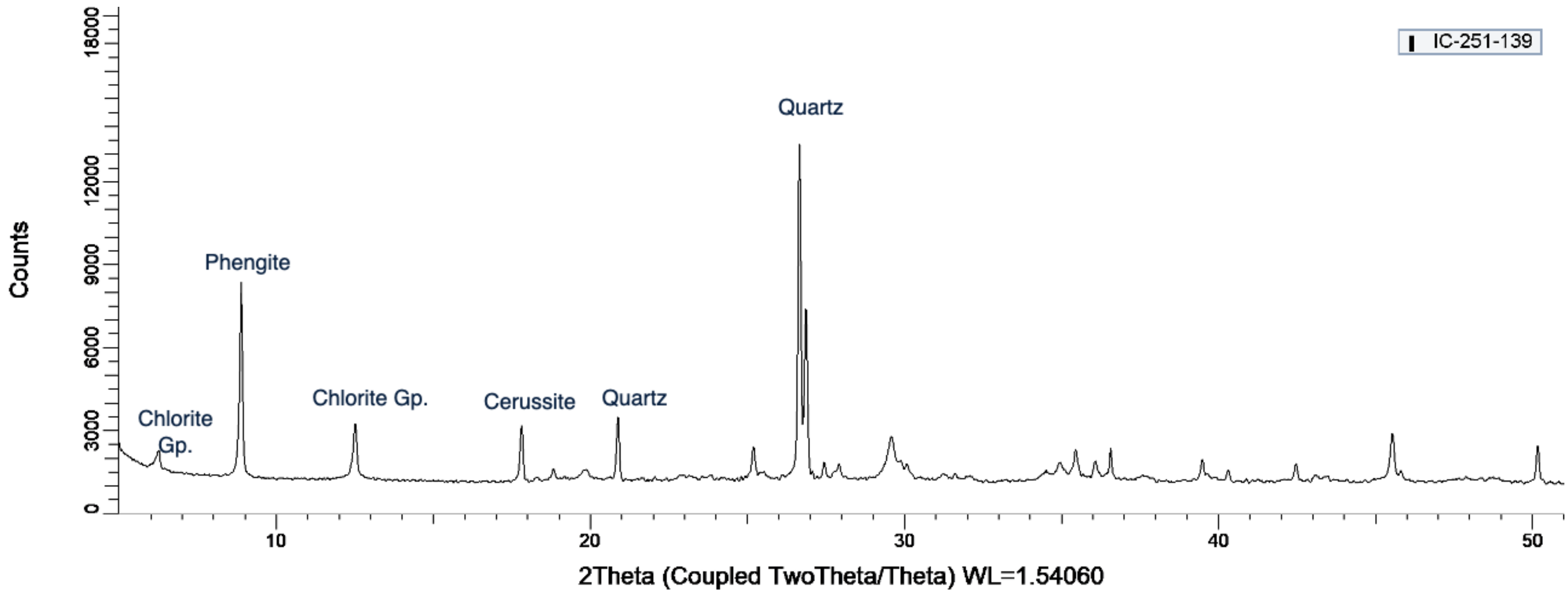

Counts
100000
80000
60000
40000
20000
0
Quartz
Quartz
Phengite
FH13_TGS_powder
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060


FH14_TGS_powder
Quartz
Quartz
Phengite
Counts
60000
40000
20000
0
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

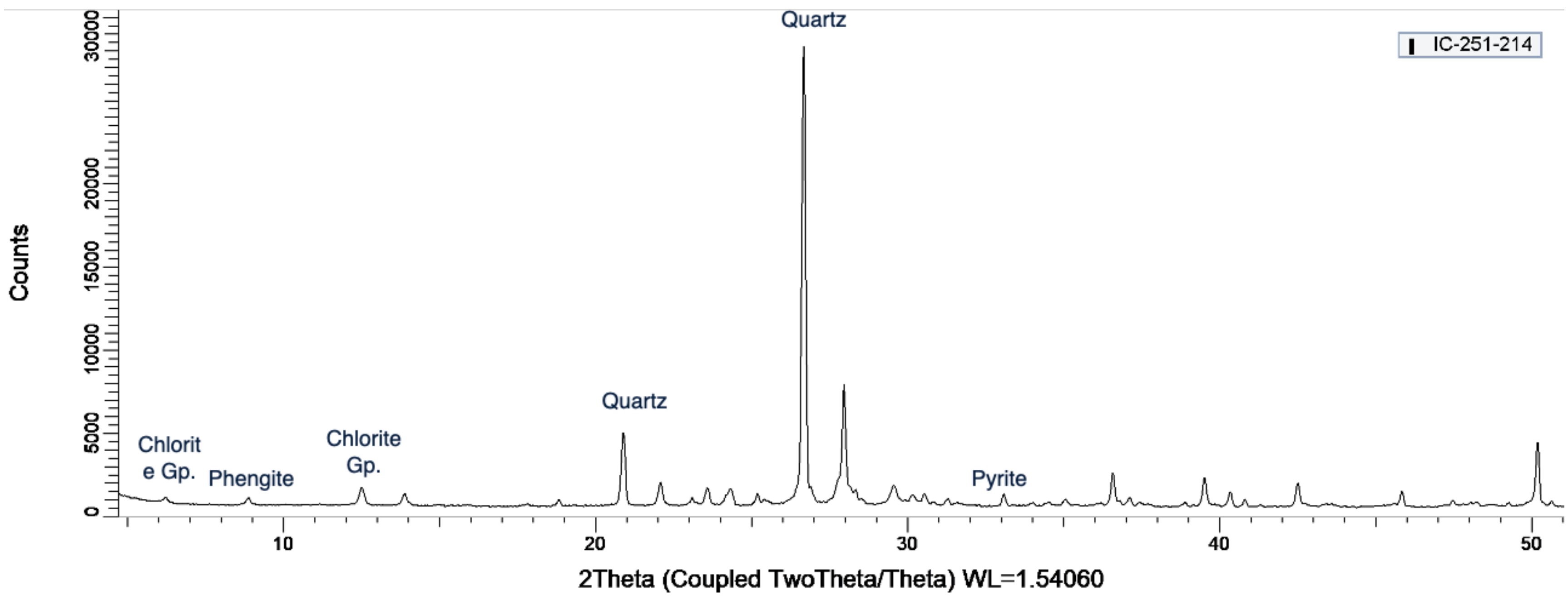

FH15_TGS_powder
Counts
30000
20000
10000
0
Quartz
Albite
Phengite
Chlorite Gp.
Chlorite Gp.
Quartz
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

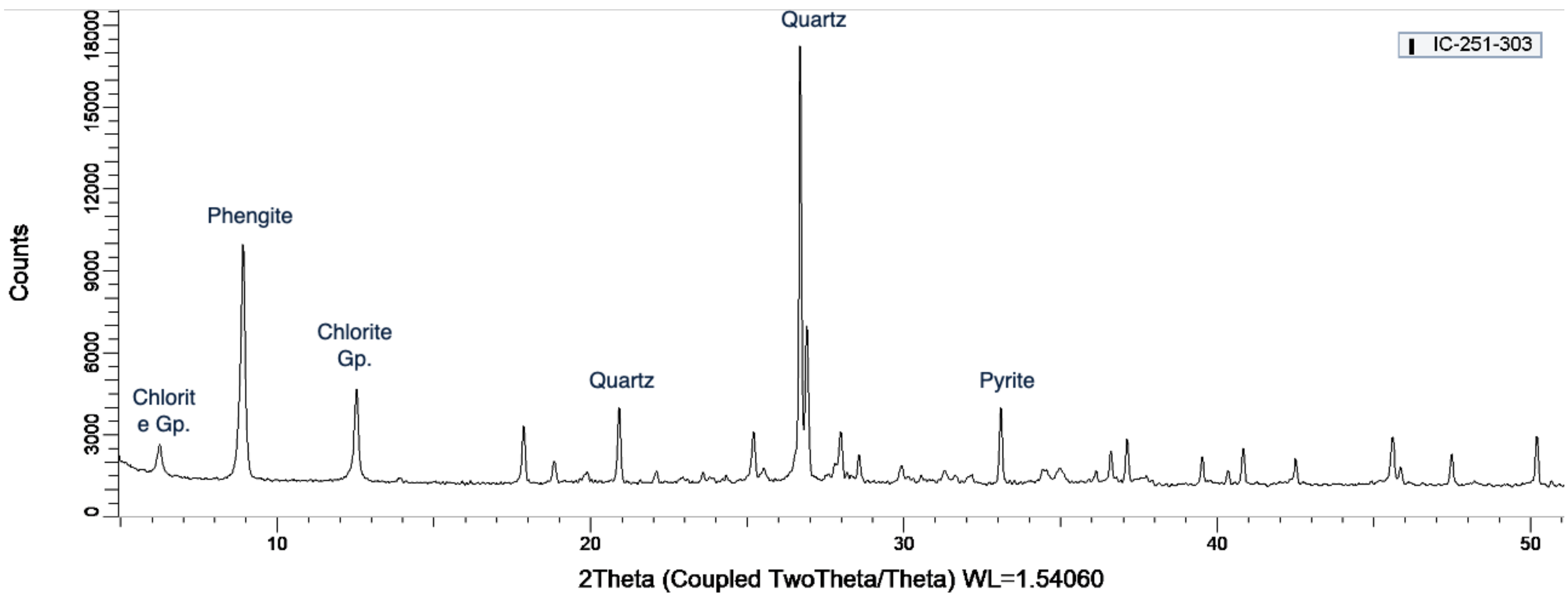

FH18A_TGS_powder
Goethite
Pyrite
Counts
0
2000
4000
6000
8000
10000
14000
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060

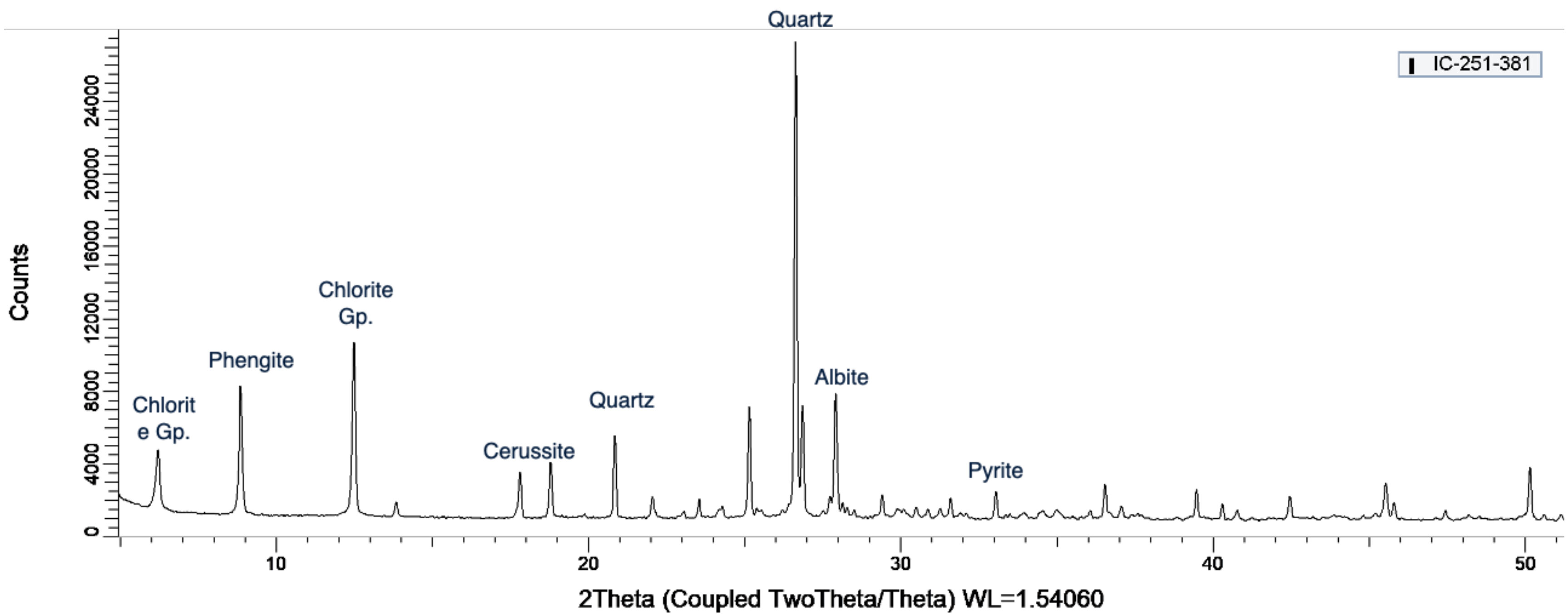

Phengite
FH21_TGS_powder
Quartz
Chlorite Gp.
Chlorite Gp.
Pyrite
Counts
80000
60000
40000
20000
0
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060



IC-251-139
Quartz
Phengite
Chlorite Gp.
Cerussite
Quartz
Chlorite
Gp.
Counts
0
3000
6000
9000
12000
18000
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060


Quartz
IC-251-214
Counts
30000
20000
15000
10000
5000
0
Quartz
Chlorit
e Gp.
Phengite
Chlorite
Gp.
Pyrite
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060


Counts
0
3000
6000
9000
12000
15000
18000
Chlorit
e Gp.
Phengite
Chlorite
Gp.
Quartz
Quartz
Pyrite
IC-251-303
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060


Quartz
IC-251-381
Counts
24000
20000
16000
12000
8000
4000
0
Chlorite Gp.
Phengite
Chlorite Gp.
Cerussite
Quartz
Albite
Pyrite
10
20
30
40
50
2Theta (Coupled TwoTheta/Theta) WL=1.54060