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RPPR Final Report
as of 21-Oct-2021

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Final Report for Period Beginning 01-Sep-2015 and Ending 30-Sep-2020

Title: Understanding the Geologic Causes of Variations in Natural Radiological Background - Research Area 2: Environmental Sciences, 2.1.1 Earth Surface Processes

Begin Performance Period: 01-Sep-2015 **End Performance Period:** 30-Sep-2020

Report Term: 0-Other

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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 7 **STEM Participants:** 10

Major Goals: Although the sources of natural background radiation are well understood, the geographic distribution has not been characterized at a resolution that is adequate for a variety of homeland security and disaster response purposes. The primary goal of this project is to improve our understanding of the geologic contribution to natural background radiation. This understanding will be useful for developing strategies to predict the distribution of natural background radiation using geologic maps and remote sensing imagery, combined with pre-existing geochemical data.

The geologic contribution to background radiation originates from both bedrock and regolith and is thus reflective of bedrock geochemistry as well as surficial processes. Thus the natural background at any particular point is governed by a number of disparate geological processes, including geochemistry at the time of a geologic unit's formation, subsequent alteration by geochemical processes such as hydrothermal and ground water circulation, and chemical modification caused by weathering and addition of material by eolian and fluvial processes.

This project has two major goals:

1) To examine the degree to which variations in exposure rate reflect variations in bed rock chemistry as compared to soil forming processes we proposed to examine variations in K, U and Th as measured by aerial gamma-ray surveys over volcanic units in southern Nevada and Utah for which we have high quality suites of geochemical data.

2) To examine the degree to which variations in exposure rate reflect variations in bed rock chemistry in sedimentary rocks we proposed to examine variations in K, U and Th as measured by the National Uranium Resource Evaluation survey over large outcrops of Paleozoic and Mesozoic sediments present in southern Utah and northern Arizona.

Accomplishments: Please see the uploaded document.

Training Opportunities: We have had four graduate students work on this project, Dan Haber, Alex Goya, Rebecca Gabriel and Genevieve Kidman. Both Alex and Becca realized, each in their own way, that they were not well positioned to complete a graduate education and left school. During their time in school they both learned ArcGIS skills. Dan Haber was involved at the very start of the project and was involved in training Alex Goya. He improved his teaching skills through this experience. Graduate student Genevieve Kidman worked on the project part time as her research focus was elsewhere. Her role was primarily in assisting undergraduates with learning GIS. She benefitted by extending her GIS skills as well as further developing her teaching skills. The project supported two post doctoral scholars, Racheal Johnsen and Joshua Sackett. Racheal improved her GIS skills as part of the project. Joshua learned GIS from scratch and improved his understanding of spatial statistics. The project supported undergraduates Jeremiah Smith, Audrey Rader, Ariel Wolfman, Lindsey Hanes, Rocio Castillo and Jordan Wachholtz. Jeremiah learned how to work with ENVI (geospatial software used for working with ASTER images). Audrey, Ariel, Rocio and Jordan obtained more experience with the use ArcGIS. Lindsey also learned how to use Microsoft access. All the trainees learned about gamma ray background radiation, where it originates and how it reflects the distribution of geologic materials and surficial processes. All of the trainees learned about unsupervised classification of geographic data and various aspects of working with geologic maps, remote sensing imagery and other spatial data sets.

Results Dissemination: We have published one paper and have a second manuscript in review with Mission Support & Test Services LLC, the DOE contractor who provided the radiological survey data. The PI has given a seminar about the work at UNLV.

Adcock, C.T. Haber, D.A. Burnley P.C., Malchow, R.L. and Hausrath E.M., 2019, Modeling Gamma Radiation Exposure Rates Using Geologic and Remote Sensing Data to Locate Radiogenic Anomalies, Journal of Environmental Radioactivity 208-209:106038. https://doi.org/10.1016/j.jenvrad.2019.106038

Sackett, J. C., Burnley, P.C. Johnsen, R., Malchow, R.L. and Hausrath, E.M. (in prep.) Modeling Background Radiation in the Ice Springs Volcanic Field, Black Rock Desert, Utah (26 manuscript pages plus supplement – currently under review with MSTS)

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

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Project Contribution:
National Academy Member: N

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Project Contribution:
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National Academy Member: N

RPPR Final Report
as of 21-Oct-2021

Partners

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I certify that the information in the report is complete and accurate:
Signature:
Signature Date:

Accomplishments under Goals

Goal 1: *To examine the degree to which variations in exposure rate reflect variations in bed rock chemistry as compared to soil forming processes we proposed to examine variations in K, U and Th as measured by aerial gamma-ray surveys over volcanic units in southern Nevada and Utah for which we have high quality suites of geochemical data.*

For this goal we decided to focus our efforts initially on two areas, the Black Rock Desert in Utah and the northwest corner of the Nevada National Security Site ('the Site', formerly the Nevada Test Site) and was able to add a third area near Las Vegas called Mormon Mesa.

Ice Springs, Black Rock Desert

The first area is a young volcanic field in the Black Rock Desert in Utah, for which we already had recent aerial gamma-ray surveys conducted by NSTec Aerial Measuring Systems (AMS). In the first year post doc Racheal Johnsen conducted additional field work and collected samples of soil, and volcanic units that needed further geochemical analysis. These samples were prepared and analyzed by XRF and ICP-MS and Johnsen began writing manuscripts describing this work. Johnsen suffered serious medical problems that limited her ability to work steadily on the project so progress was very slow. Johnsen could no longer work on the project the PI hired a part time post doc (Joshua Sackett) to continue working on the data set. Joshua completed the remote sensing and statistical analysis of the aerial gamma-ray data over the Ice Springs Volcanic field in the Black Rock Desert and wrote a manuscript describing the work.

The project focused on testing which geographic properties could best predict the observed gamma ray background radiation. Therefore, various test predictions were created by subdividing the mapped area of interest according to geologic unit boundaries, lava flow boundaries, remote sensing data (image classification of satellite imagery) Figure 1, and all possible combinations therein. None of the single-component models were successful in modeling these data; however, three of the seven models generated were successful in binning exposure rates into meaningful categories while also constraining variation in exposure rates. Further, all successful models required geologic data as a component of the model, highlighting the relationship between geology and background radiation. Rock geochemistry data and data from the low spatial resolution National Uranium Resource Evaluation (NURE) aerial gamma-ray survey, were used to develop an *a priori* predictive understanding of the relationship between geology and exposure rate measurements. The use of geochemical analysis of bed rock units was used to successfully forward modeled exposure rates when the mapped area was subdivided according to geologic unit and only aa (bare surfaces of broken lava) was considered (corresponding to pure rock, inferred from image classification analysis of satellite imagery in AMS survey modeling). Chi-Square goodness of fit tests identified no significant difference in mean exposure rates between NURE and the AMS survey for each of the seven models. Finally, we endeavored to develop a model to predict alluvium depth over lava flows from aerial gamma-ray surveys using an existing model derived from Monte-Carlo simulations.

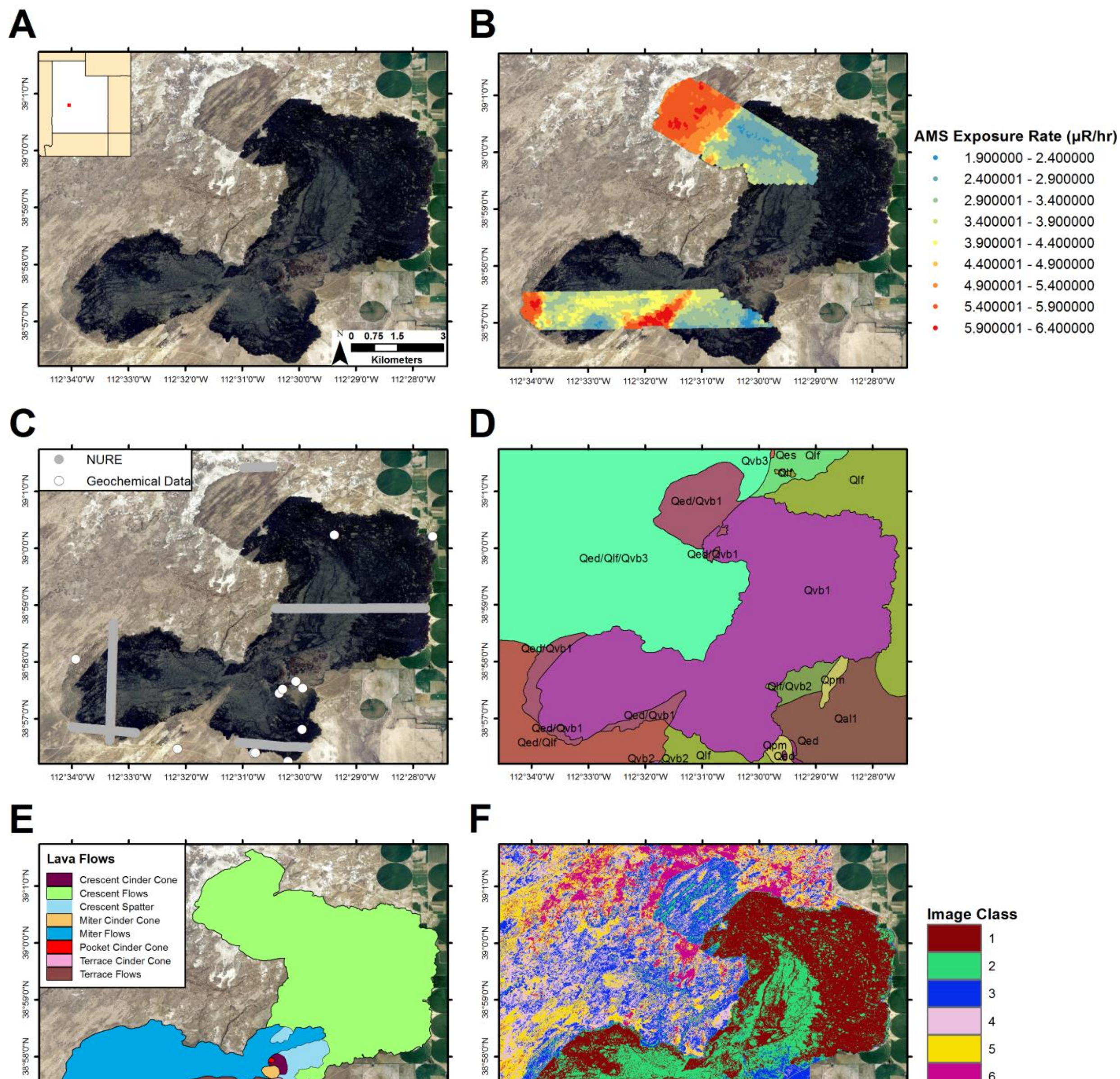


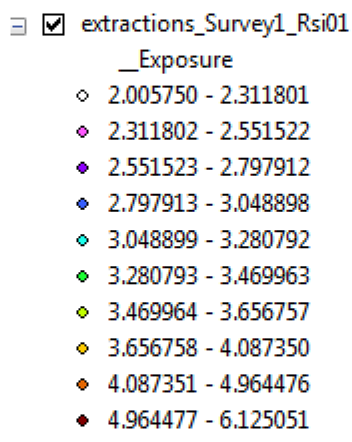
Figure 1 Maps of Ice Springs study area. ***A)*** *Satellite imagery map of the Ice Springs study area. Imagery basemap source: USDA National Agriculture Imagery Program (2009).* ***B)*** *AMS survey map showing location and measured exposure rate (µR/hr).* ***D)*** *Map showing location of NURE survey data and geochemical data.* ***E)*** *Geologic map of the Ice Springs study area. Modified from: Hintze and Davis 2002, Hintze et al. 2003.* ***F)*** *Map showing the generalized distribution of cinder, lava, and spatter at Ice Springs. Unit boundaries have been interpolated from Lynch and Nash 1980.* ***G)*** *Classified image (six classes) generated from Iso Cluster Unsupervised Classification of satellite imagery RGB bands. Note: Crop land to the North and East of the Ice Springs lava flow were clipped and excluded from the image classification. Figure from Sackett et al. (in prep).*

Area 20 Nevada National Security Site

The second area is in the northwest corner of the Nevada National Security Site ('the Site', formerly the Nevada Test Site) that contains a variety of volcanic tuffs that are several million years old. The advantage of this study location is that it provides us with a variety of locations where we can examine the natural weathering, transport and soil forming process that have occurred since the volcanic units were deposited millions of years ago and also allows us to look at the transport of anthropogenic nuclides over time. During the first year we were offered the opportunity to work with an extremely high resolution aerial gamma-ray survey over the Site and we also learned about an extensive body of 'grey data' from boreholes and soil samples taken on the Site that is available to the public, but has not been cataloged or published on-line. We decided to take advantage of this pre-existing data to compare the geochemical variability of various wide spread volcanic unit as measured across the surface, with the geochemical variability of the same units as measured by gamma spectroscopy in the boreholes. During the second year of the project we went through the process of having the 1994 aerial survey of the Site released to us (a 5 month process), and developed the procedures for analyzing digital data files and spectra, which were in a different format from previous aerial data that we had worked with. During the third year, we discovered that critical calibration information for this legacy data set had been lost so PI devised a strategy for normalizing the raw spectra by the reported exposure rate values in order to determine raw K, U and Th counts which can them be processed by the traditional techniques. Our collaborators at MSTS AMS agree that the procedure is valid and the PI has now written the codes to process the raw data files. We researched the geology of the Site, travelled to the Site to meet with geologists there and to become acquainted with the USGS core library and its resources. We researched and examined a number of possible study areas and settled on one at the northwest end of the Site (Area 20). This area includes one of the widespread volcanic units mentioned above, and also contains the location of the Palanquin nuclear test which vented and produced a well-defined and well-documented contaminant plume. We completed the flight planning process for the area with NSTec (now Mission Support and Test Services (MSTS)) during the second year of the project. During the third year of the project MSTS AMS flew the region in Area 20 over Palanquin and delivered the data to us. Although we have GIS shape files for a large geologic map of the site, we found that the accuracy of the shapes were poor when compared to the 1:24,000 quadrangle maps. Therefore we had an undergraduate students (Rocio Castillo) work on digitizing the geologic quadrangles needed to compare the flight data with the bedrock distribution. When Rocio graduated, undergraduate Jordan Wachholtz took over with the digitizing. Jordan graduated before the shape files were completely finished but, left us in a good position to finish the work. Our efforts to find gamma-ray data from bore holes and acquire soil geochemical data has run into a variety of road blocks related to multiple levels of security restriction on any transfer digital information belonging to the Test Site and its contractors. We invested substantial amounts of time meeting with MSTS and Navarro personal both at the Test Site and at their headquarters in Las Vegas, but despite assurances to the contrary, have decided acquiring the data is not a realistic expectation thus we will focus on just bedrock surficial geology. Due to the COVID crisis and closure of the University we were not able to finish this aspect of the project. However, a new PhD student (Dan Haber) is likely to take up the analysis of this large and promising data set in the future.

Mormon Mesa

The third area is a portion of the desert north of Las Vegas called Mormon Mesa. The Mesa is a highland that sits between the Virgin and Colorado Rivers just to the north of their confluence. The surface of Mormon Mesa is host to some of the most ancient soils in Nevada; thought to be at least several million years old. The area was called to our attention by our collaborators at MSTS who have noticed anomalously 'hot' areas as they fly over the area on their way to and from making radiological surveys elsewhere. We reached out to a group of soil scientists who have been working in the area (Dr. Brenda Buck and Dr. Amy Brock-Hon) and found that they were very interested in



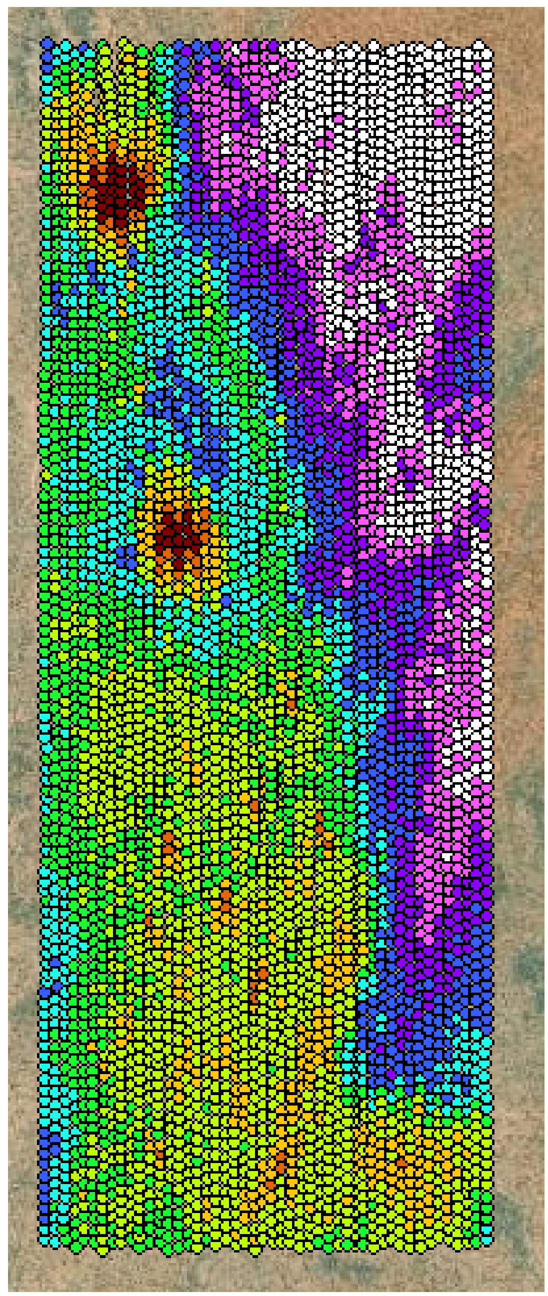


Figure 2 Aerial gamma-ray survey over a portion of Mormon Mesa. Exposure rates are shown in colored cirlces. Low exposure rates to the north east are associated with eaolian dune deposits. High exposure rates are assoicated with small seasonal ponds.

learning more about what the radiation signals might be telling us. We commissioned a high resolution aerial gamma ray survey and the PI conducted field work with Brock-Hon in the area where the survey was conducted. We were able to document that the distribution of gamma-ray radiation on the surface was reflecting the formation small temporary ponds (Figure 2). The ponds host deep deposits of silicate sediments in contrast to surrounding regions dominated by caliche (carbonate deposits that form in desert soils) at or very close to the surface. Continued progress on this project has been delayed by the shutdown of activity due to the COVID crisis. However, we are optimistic that this very nice data set will be incorporated into a larger study of the formation of the ponds in the not too distant future.

Goal 2 *To examine the degree to which variations in exposure rate reflect variations in bed rock chemistry in sedimentary rocks we proposed to examine variations in K, U and Th as measured by the National Uranium Resource Evaluation survey over large outcrops of Paleozoic and Mesozoic sediments present in southern Utah and northern Arizona.*

Navajo Sandstone

The sedimentary unit that we decided to examine is the Navajo Sandstone and its correlative units the Nugget and Aztec Sandstones. These eolian dune sands originate from rivers carrying sediment eroded from the Appalachian orogeny. To start with undergraduate student Jeremiah Smith created shape files for all exposures of the Navajo/Aztec/Nugget in Utah, Nevada and Arizona and joined it with the NURE data set. Working with post doc Chris Adcock, Jeremiah subdivided selected areas of the Navajo/Aztec/Nugget into classes using ASTER imagery based on these color differences and soil cover and showed that there was no statistical correlation between the diagenetic color and K, U or Th contents as measured by the NURE spectra. He also showed that soil cover did not explain the regional geochemical variations in the unit. After Jeremiah graduated, undergraduate Lindsey Hanes worked on testing the idea that regional variations in clay content as measured using band math on Landsat images could be significant. Since the Landsat images were not originally normalized, Lindsey developed a procedure to do this and then tested various hypothesis about which Landsat band combinations would yield the most promising results. Lyndsey graduated and handed the project over to Genevieve Kidman, who further advanced the data analysis. Recently we received a small aerial data set from MSTS taken over the Aztec sandstone in Nevada. Undergraduate Jordan Wachholtz did preliminary work on this data set before he graduated. A challenge with this data set has been a somewhat inconsistent mapping of lithologic boundaries in the easternmost section of the Navajo sandstone where the sandstone interfingers with fine grained sediments. Some field work on the Navajo reservation may be required to bring this project to a close.

To the south of the area where we have been struggling with lithological changes in the Navajo sandstone, is a region around Cameron Arizona where our group has worked before. Chris Adcock saw an opportunity to improve our remote sensing strategies for ASTER images and reanalyzed the imagery that we had used in a prior study. Chris was able to improve our ability to predict gamma-ray background using classified ASTER imagery in combination with geologic maps in this region

(Figure 3). Chris also developed a method to highlight anomalous regions that were correlated with uranium mines as well as identifying regions that had anomalously low background level which correlated to uranium mines which had been remediated (as identified by reworking of the surface in satellite photos). This work led to the publication of Adcock et al 2019 in the Journal of Environmental Radioactivity.

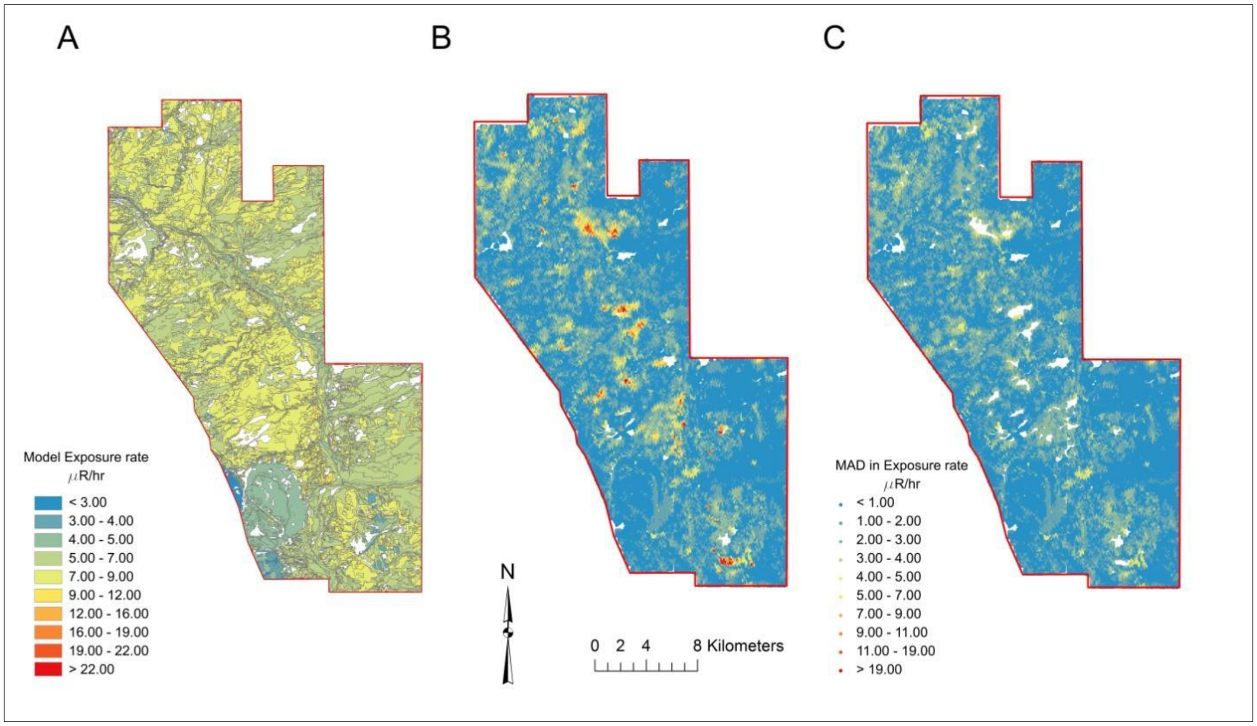


Figure 3 Model 3, ASTER and Geologic map based model. A) The modeled exposure rates. B) Map of the absolute differences between the model and the AMS measured data. C) Map the absolute differences between the model and AMS measured data with the highest 5% of the AMS measurements removed to mitigate obvious radiogenic anomalies (associated with uranium mines).

References

Adcock, C.T. Haber, D.A. Burnley P.C., Malchow, R.L. and Hausrath E.M., 2019, Modeling Gamma Radiation Exposure Rates Using Geologic and Remote Sensing Data to Locate Radiogenic Anomalies, *Journal of Environmental Radioactivity* 208-209:106038. https://doi.org/10.1016/j.jenvrad.2019.106038

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