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Modeling background radiation in Southern Nevada

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ABSTRACT

Aerial gamma ray surveys are an important tool for national security, scientific, and industrial interests in determining locations of both anthropogenic and natural sources of radioactivity. There is a relationship between radioactivity and geology and in the past this relationship has been used to predict geology from an aerial survey. The purpose of this project is to develop a method to predict the radiologic exposure rate of the geologic materials by creating a high resolution background model. The intention is for this method to be used in an emergency response scenario where the background radiation environment is unknown. Two study areas in Southern Nevada have been modeled using geologic data, images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), geochemical data, and pre-existing low resolution aerial surveys from the National Uranium Resource Evaluation (NURE) Survey. Using these data, geospatial areas that are homogenous in terms of K, U, and Th, referred to as background radiation units, are defined and the gamma ray exposure rate is predicted. The prediction is compared to data collected via detailed aerial survey by the Department of Energy's Remote Sensing Lab - Nellis, allowing for the refinement of the technique. By using geologic units to define radiation background units of exposed bedrock and ASTER visualizations to subdivide and define radiation background units within alluvium, successful models have been produced for Government Wash, north of Lake Mead, and for the western shore of Lake Mohave, east of Searchlight, NV.

1. Introduction

The Aerial Measuring System (AMS) section of the Department of Energy's Remote Sensing Lab at Nellis (RSL-N) Air Force Base, performs high resolution aerial gamma ray surveys for national security and scientific purposes. These surveys are performed by low-flying aircraft equipped with scintillation radiation detectors. When AMS performs an aerial gamma ray survey they are typically looking for anomalies related to anthropogenic sources of gamma rays. There are robust techniques to correct for background radiation from sources such as atmospheric radon, cosmic rays, and equipment related sources of gamma rays (IAEA, 2003). Typically, these sources of gamma rays are corrected for by flying over an open body of water, flying high in the atmosphere above the influence of ground based sources, or by flying over previously measured territory (IAEA, 2003). However, currently there is no accepted way of correcting for the signal from geologic sources when the purpose is to measure anthropogenic sources.

In natural materials, there are three radioelements that are responsible for gamma rays: Potassium (K), Uranium (U), and Thorium (Th). These three elements either generate detectable gamma rays directly when they decay (e.g., ^{40}K) or they decay to daughter isotopes that subsequently decay and generate detectable gamma rays. Because U and Th do not directly emit easily detectable gamma rays when they decay, their concentrations are determined by measuring the concentrations of their daughter isotopes. Therefore, concentrations derived from gamma spectra are referred to as equivalent uranium (eU) and equivalent thorium (eTh). There is a direct relationship between the concentration of the primary radioelements and gamma ray exposure rate (Beck et al., 1972; Grasty et al., 1984; Løvborg and Kirkegaard, 1974). This study focuses on three of the primary isotopes of these

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elements: potassium-40 (^{40}K), uranium-238 (^{238}U) and thorium-232 (^{232}Th).

The link between the gamma ray exposure rate and geology is well known (Books, 1962; Ford et al., 2008; Grasty et al., 1984; Griscom and Peterson, 1961; Moxham, 1963; Pitkin et al., 1964; Wilford et al., 1997). Many of the early studies were performed around nuclear power plants to serve as a baseline so that future surveys could assess any change in background levels of radioactivity. During these surveys, a consistent change in counts as the geology changed across the surface was observed (Books, 1962; Griscom and Peterson, 1961; Moxham, 1963; Pitkin et al., 1964). It was also determined that some geologic structures, such as faults, could be detected due to high levels of radon emanation from the fractured rock (Pitkin et al., 1964). The purpose of our project is to produce a means of predicting the gamma ray exposure rate of geologic sources in an area so that the geologic signal may be understood in the results of an aerial gamma ray survey.

Exposure rate is a measure of the number of ionizations produced in a quantity of air by photon radiation per unit time. There is a linear relationship between radioelement concentration and exposure rate given by the following equation:

$$\dot{X} = 1.32*K + 0.548*eU + 0.272*eTh \quad (1)$$

(Beck et al., 1972; Duval et al., 2005; Løvborg and Kirkegaard, 1974).

Where K is the concentration of K in weight percent, eU is equivalent U in parts per million, eTh is equivalent Th in parts per million and $\dot{X}$ is the exposure rate in μR(Roentgen)/h. This equation was first derived by Beck et al., in 1972 using NaI measurements of activity of K, and U and Th daughter isotopes in a soil and comparing that to available branching ratios assuming a homogenous distribution of nuclides in the soil. In 1974, Løvborg et al. also derived similar coefficients by theoretical calculation, using computer code they designed and branching ratios determined by a statistically weighted average of twelve previously published studies. Grasty et al. (1984) averaged the coefficients from Beck and Løvborg for use in a national scale aerial gamma ray survey of Canada. Grasty's coefficients were updated by Duval in 2005 to reflect units of dose and used here assuming a factor of 0.1 between nGy/h and μR/h. This factor is assumed because the conversion from roentgen to rad is about 1 and 1 Gy is equal to 100 rad (Cember and Johnson, 2009).

In this study, models of the distribution of K, U, Th, and exposure rate for two field areas in Southern Nevada, Government Wash and Lake Mohave, were created as a test of our strategy for predicting the results of an aerial survey. Government Wash is located north of Lake Mead, and east of Las Vegas, while Lake Mohave is located east of Searchlight, Nevada (Fig. 1). These areas were chosen primarily because AMS has surveyed these areas numerous times making aerial gamma ray data readily available for comparison (Fig. 2). RSL-N is primarily an emergency response organization and finding a reliable method to quickly assess the background in an area was the primary motivation of this work. This study was done in parallel with a study by Marsac et al. (2016) in an area around Cameron, AZ.

The most challenging task associated with forward modeling an aerial gamma ray survey is defining geospatial areas that are homogenous in terms of their radiogenic properties so that they may be assigned a single K, U, Th, and exposure rate value. These geospatial areas are referred to as background radiation units. This study used two primary means of defining background radiation units. The first is to use geologic units defined by published geologic maps. The second method uses multispectral imaging data from spacecraft to define background radiation units consisting of similar spectral features. Once these regions are defined, K, U, and Th values can be assigned to them and an exposure rate can be calculated.

The arid climate of our study areas simplifies attenuation problems related to soil moisture and vegetation. However, arid environments present their own unique set of challenges including eolian dust deposition and alluvial processes. Eolian dust occurs on regional and global transport scales and has little to no connection with local bedrock (Reheis et al., 2009). In addition, alluvial material is composed of eroded rock from the surrounding environment and may not represent the bedrock it overlies.

2. Background

2.1. Geologic context of Government Wash

Government Wash lies within the Las Vegas Valley Shear Zone; a right lateral fault system that experienced significant tectonic activity during the Cenozoic with displacement between 23 and 69 km (Langenheim et al., 1997). The area of interest (AOI) contains modern alluvial fans as well as sedimentary and volcanic units. The two primary formations that occur in the AOI are the Muddy Creek Formation and the Horse Spring Formation, both of which were deposited after the cessation of displacement during the Miocene (Fig. 1) (Duebendorfer, 2003). An alluvial fan dominates the AOI and is expected to be radiologically mixed due to multiple upstream source materials feeding the fan. On the other hand, the Muddy Creek and Horse Spring Formations are composed of multiple subunits that are internally homogenous and composed of materials that should be radiologically cool. The volcanic units in the area tend to be mafic and are therefore expected to be radiologically cool.

The Muddy Creek Formation is middle to late Miocene in age and is composed of clastic sedimentary rocks ranging from claystone to conglomerate. There are three primary members of this formation within the AOI. Tmcl is the lower member of the formation and is composed of claystone, siltstone, and gypsiferous siltstone that ranges in color from tan to red-brown with an angular unconformity that separates Tmcl from the member that lies above Tmcg (Duebendorfer, 2003). Tmcg is the middle member of the Muddy Creek Formation and is composed of white to grey or pale yellow gypsum. There are variable amounts of silt and clay intermixed with the gypsum deposits. Tmcg is weakly resistant to erosion but more resistant than the lower member, Tmcl, and therefore forms ledges on top of Tmcl (Duebendorfer, 2003). Tmcu is the upper member of the Muddy Creek Formation and is composed of a poorly sorted boulder conglomerate with minor sandstone and siltstone that are tan to light brown in color. Conglomerate clasts are composed of a heterogeneous mix of Paleozoic, Mesozoic and Miocene age rocks sourced from surrounding units (Duebendorfer, 2003).

The Horse Spring Formation is early Miocene in age and consists primarily of an ancient alluvial fan that was fed by a wide variety of rock types. The Thl/Thlv member consists of clasts of white limestone, calcareous and tuffaceous sandstone and siltstone. Thlv also contains basalt and basaltic andesite from interbedded volcanic flows and sills (Duebendorfer, 2003). The Tht/Thtb member consists of conglomerate, megabreccia, sandstone, siltstone, limestone, calcareous sandstone, tuff, and tuffaceous sandstone. The Thtb sub-member consists of megabreccia debris flows and avalanche deposits that are composed of a variety of rock types including: leucogranite, megacrystic granite, garnet-biotite gneiss and schist, hornblende schist, amphibolite, and gabbro (Duebendorfer, 2003).