Mobility of radionuclides during weathering and erosion in Saquarema (RJ): Implications for submerged Monazite deposits in adjacent offshore areas.

Justo J.[1,2], Hamza V.M.[1] and Lamego Simões Filho F.F.[3]
[1] National Observatory – ON/MCTI – Department of Geophysics
[2] University of Rio de Janeiro – UERJ – Department of Geology
[3] Nuclear Energy Institute – IEN/CNEN

Abstract

Analysis of the results of ground and airborne radiometric measurements in the Saquarema region (Rio de Janeiro) has allowed new insights into the breakdown and transport of mineral aggregates containing monazites, under sub-tropical weathering conditions. The breakdown process, accompanied by loss of low-density clay fractions in weathered materials is considered as responsible for the observed patterns in relative enrichment of thorium and uranium along the migration paths of radionuclides. The characteristic features of these patterns provide clues as to the time and distance scales associated with processes of weathering and erosion. It is also possible to determine approximate locations of concentrations of accessory minerals. In this context, we advance the hypothesis that large under-water monazite deposits may be present along the offshore sand banks, in the coastal region of the state of Rio de Janeiro.

Introduction

Knowledge of the distribution of radioactive elements in soil layers is of considerable interest in studies of the dynamics of a variety of physico-chemical processes occurring in near surface layers. Gamma ray spectrometric techniques are commonly used for measurements of concentrations of natural radioactive elements (Uranium, Thorium and Potassium) in terrestrial environments (Winkelmann, et al., 2001; Dickson,1997 and 2004). Weathering is associated with the chemical and mechanical processes having a direct relationship with the time needed for break down or alteration of rocks in response to environmental conditions near the earth's surface (Wilford, John, 2012). Mobility of such weathered material depends primarily on the physic-chemical characteristics of the mineral aggregates undergoing the weathering. But other factors such as local precipitation, topography and the nature of fluvial systems are also known to play important roles.

In the present work, we report progress obtained in analysis of the mobility of natural radioactive elements in the municipality of Saquarema, in the state of Rio de Janeiro. There are indications that the source region of radioactive elements is the uplifted crustal blocks in the adjacent Serra do Mar continental escarpment. We examine the weathering and erosional processes responsible for transport of these radionuclides and consider the implications of the results for occurrence of eventual ore-grade deposits of Monazites in the adjacent offshore regions.

Geologic Context of the study area

The basement rocks in the coastal region southeast Brazil belongs to the Mantiqueira Province. According to geologic studies, the terrain has a number of NE – SW structures composed of thrusts and folds generated during the Brasiliano Orogeny. The units that constitute the basement rocks are orthogneisses and orthoamphibolites of the Ribeira fold belt of Paleoproterozoic age (Viana, et al., 2008). Extensive sedimentary layers, of Tertiary to Quaternary age, cover the down-faulted blocks. The geologic context of the study area is illustrated in the map of Figure (1).

Outcrops of basement rocks are rare as intense weathering processes have lead to the formation of thick soil cover. According to the classification system of Embrapa (1999) Argi soil is the predominant type, characterized by low clay activity and argilic horizon B. Other types present in the area include Pod soil, Glei soil, Neo soil, Organo soil. A number of lagoons and backwaters also occur along the coastal region.

The climate is sub-tropical with annual median temperatures of 22.5°C and annual median precipitation of 1700 mm and has a long dry season.

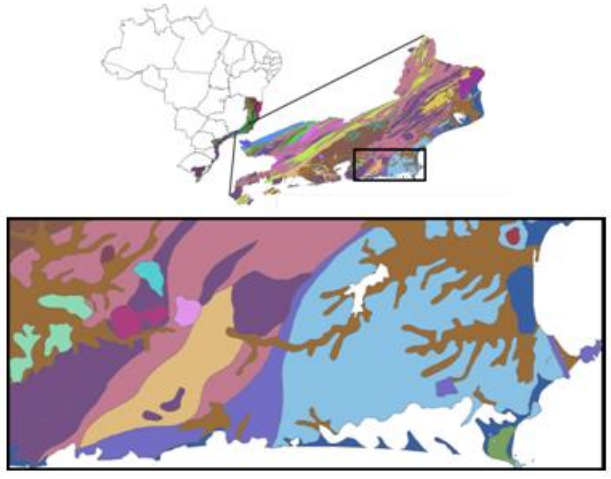

Figure 1. Geologic context of Saquarema region.

An understanding of the topographic characteristics is important in evaluating terrain attributes related to geomorphologic processes and soil/regolith properties in the study area. According to the digital elevation map of

the study area (see Figure 2) the escarpments of the highlands along the western border of the study area have altitudes reaching over 400 meters. It drops rapidly to sea-level over distances of approximately 30km.

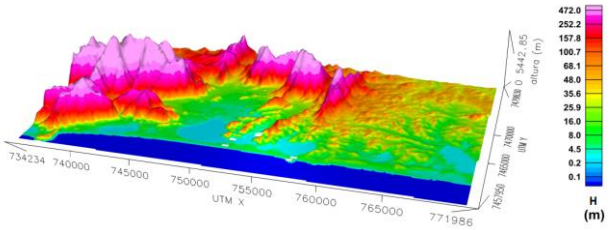

Figure (2). Digital Elevation Model of the study area.

Database

The database employed in the present work includes results of airborne and ground surveys. The airborne radiometric survey was carried out in 1978, within the framework of the São Paulo – Rio de Janeiro Project. The data sets acquired also include measurements of geomagnetic field. These are recorded in separate channels, along with information on flight altitude and atmospheric conditions. The flight lines were set in north – south direction, has a spacing of 1000m and altitude of 150m. Quality control tests were carried out not only prior to data acquisition, but also during and after the surveys. The total investigated area is 654.67km^2, where lakes and lagoons occupy an area of 21.2km^2.

Most of the data processing in the present work has been carried out using the computational package GEOSOFT, Oasis Montaj. Initially the raw data were corrected for the perturbing effects of technical survey operations (LAG and Heading effects and altitude variations). In addition, procedures were adopted for filtering, levelling and micro levelling operations, as per standard data processing techniques.

The original data, recorded in units of counts per second (cps), were transformed into values of relative abundances using conversion factors specific to each flight path (BARMP, 1997). These factors depend on the sensitivity and geometry of detectors used and the survey altitude. Finally the values were corrected using calibration data for the particular survey operations (Minty, 1997).

Results of Airborne Surveys

In illustrating the results of airborne surveys we have used the technique of draping the maps of radioelement distributions over the topographic features of the study area. This technique allows easy visualizations of the relations between regional distributions radionuclides and changes in elevations. Consider for example the distribution of uranium, illustrated in the map of Figure (3). The abundance values are greater than 3ppm in areas in the western parts, where altitudes are higher than 100 meters. Similar high values also occur in the central parts of the study area. Belts of low concentrations of uranium (less than 2ppm) occur in the southern parts of the study area, which have altitudes of less than 10 meters. Lakes and coastal water bodies are present in most such areas. Similar trends can also be seen in the regional distributions of thorium and potassium, illustrated in the maps of figures (4) and (5) respectively.

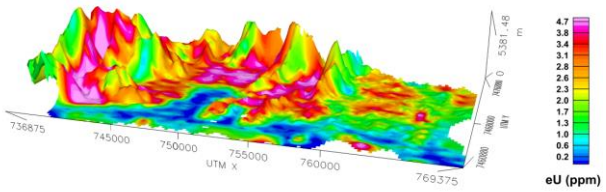

Figure (3). Regional distribution of equivalent uranium.

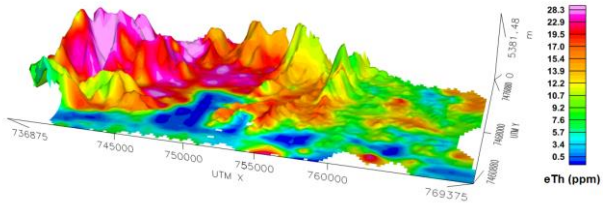

Figure (4). Regional distribution of equivalent thorium.

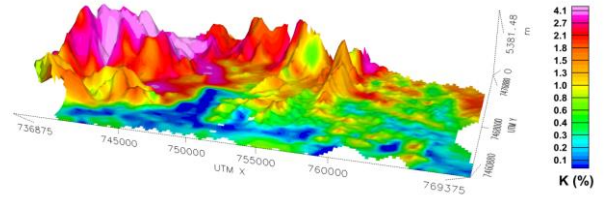

Figure (5). Regional distribution of potassium.

Relative Movements of Radionuclides

The regional distributions of uranium, thorium and potassium, illustrated in the maps of figures (3), (4) and (5), provide clues as to the action of weathering and erosion. Note that the occurrences of relatively high concentrations of radionuclides are associated with topographic features of Serra do Mar continental escarpment, situated at the northwestern border of the study area, which is the source region. The systematic decrease in abundances of radionuclides away from this source region may be considered as arising from the action of erosion.

In the present work, our interest is in examining the relative movements of these radionuclides within the study area. Some insights into the general trends in the mobility can be obtained by considering the geographic distributions of the ratios Th/K, U/K and U/Th. These are illustrated in the maps of Figures (6), (7) and (8) respectively. In all cases, high values of the ratios are found in the areas with altitudes of less than 10 meters, while regions with altitudes higher than 100 meters are characterized by relatively low values. These trends are contrary to those of the absolute abundances, illustrated in figures (3), (4) and (5).

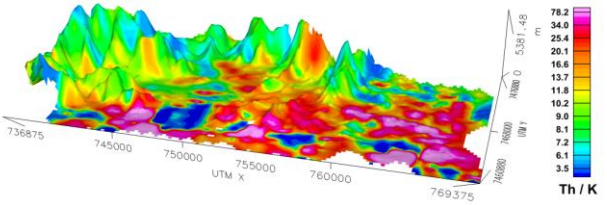

Figure (6). Regional distribution of Th/K ratio.

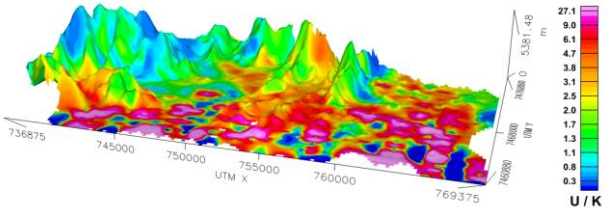

Figure (7). Regional distribution of U/K ratio.

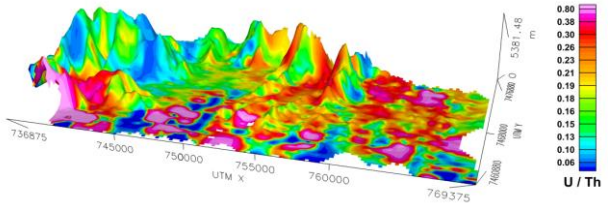

Figure (8). Regional distribution of U/Th ratio.

Since potassium is usually associated with the clay fractions, the observed trends of decrease in Th/K and U/K ratios are clear indications that weathering processes have led to gradual retention of clay fractions in soil layers. Consequently, there have been steady enrichments of thorium and uranium along the migration paths. Thus, even though the absolute values of the abundances of uranium and thorium decrease with distance from the source region the enrichment process with respect to potassium prevails and seems to be a characteristic feature of the weathering process.

Formation of Ore-grade Deposits

We now consider the implications of the observation that steady enrichment, along the migration paths, of thorium and uranium relative to potassium in the formation of ore-grade deposits of monazites. It seems reasonable to argue that removal of light fractions from mineral aggregates lead to reduction in mobility of accessory minerals. Obviously, this process will continue only as long as the lighter clay fractions remain attached to the mineral aggregates. Complete removal of lighter clay fractions leads to aggregates that contain only the heavier accessory minerals, which remain as relatively immobile residue of the erosion process. Continued action of erosion brings in additional residues into this zone, which contributes to enrichment of accessory minerals and eventual formation of ore grade deposits.

It is possible to obtain approximate estimates of the time and distance scales of the ore-forming environment, from an analysis of the characteristics of the enrichment process illustrated in figures (6) and (7). For example, samplings along selected profiles allow us to examine nature of variations in the values of Th/K ratios as a function of distance from the source region. Examples of such trends of the Th/K ratios are illustrated in Figure (9) for Saquarema and Gurapari regions.

Extrapolations of the trends illustrated in figure (9) should allow estimates of the distance at which ore-grade deposits are located. This procedure requires choice of a representative value of Th/K for the ore deposits. In the present case, the value Th-232/K-40 ratio reported by Anjos et al (2006), for the monazite deposits in the adjacent region of Guarapari (ES), has been adopted. Consequently, the dashed vertical line in green colour in Figure (9) may be considered as indicative of the distance between the source region and the monazite deposits in Guarapari area. The geographic association between the source region and Monazite deposits in Guarapari coastal area is illustrated in Figure (10).

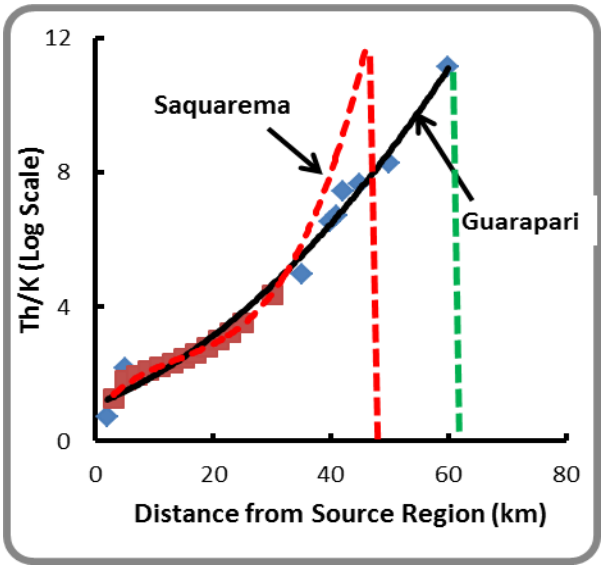

Figure (9) Variation of Th/K ratio with distance from the source regions of Saquarema and Guarapari.

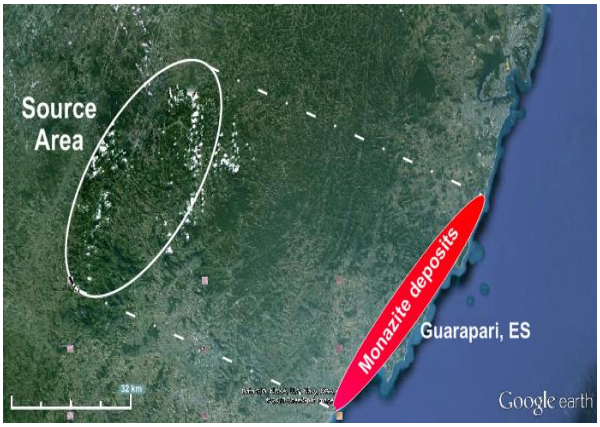

Figure (10). Locations of the source region and the monazite deposits in the Guarapari area.

Similar arguments may also be extended in evaluation of eventual occurrence of monazite deposits in the study area of the present work. In this case, however, the proposed deposits are located at distances of about 40 to 50 km from the source region in Saquarema. The relative locations of the source region and hypothesized monazite deposits are illustrated in Figure (11). The occurrence of such deposits in the submerged portions of the sand banks in the continental platform area may be considered a consequence of the sea-level variations of the last 20000 years.

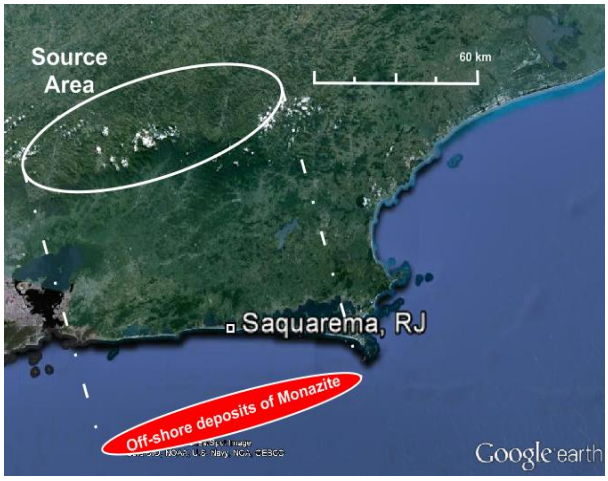

Figure (11). Locations of the source region and the hypothesized monazite deposits in the offshore area of Saquarema.

Discussion and Conclusions

Analysis of the results of ground and airborne radiometric measurements has provided new insights into the distribution of radionuclides in the Saquarema region (Rio de Janeiro). There are indications that sub-tropical weathering and erosion processes contribute to mobility of mineral aggregates containing low-density clay fractions and accessory minerals. Steady loss of low-density components in the regolith have been considered responsible for the observed patterns in relative enrichment of Th and K along the migration paths of radionuclides.

The time-scale for the weathering process, estimated by Price et al (2005) is about a few million years. Blackenberg (2006) have quoted estimates of denudation rates of few mm/kyr for a variety of geologic environments. Such values imply times of the order of several tens of millions of years for the denudation process to attain current topographic pattern.

Estimates have been made of the distance and time scales for transportation of radionuclides, based on the characteristic features in the occurrence of Monazite deposits along the coastal belt of Espirito Santo. Assuming that such features are representative of the weathering and accumulation processes, we may expect similar situations for the Saquarema region as well. Since the coast line in this area is only about 35km away from the source region monazite deposits of Saquarema region would be at a distance of about 10 to 20 km from the present coastline.

In this context, we advance the hypothesis that large under-water monazite deposits may be present along the offshore sand banks, in the coastal region of the state of Rio de Janeiro. The submerged Monazite deposits may have formed during periods of low-stands of sea-level. This hypothesis can be tested by carrying out drag operations of sand banks in the platform area.

Acknowledgments

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