

Radiometric Analyses of Beach Sands from the Southeast of Brazil

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Abstract. Natural gamma radiation measurements of coastal sand deposits were used to determine the provenance of the sandy sediments and to obtain information about paleo-sea-levels along the coast of three Brazilian States: São Paulo (SP), Rio de Janeiro (RJ) and Espírito Santo (ES). Th/U and Th/K ratios suggest a considerable positive correlation with the geological evolution of the Quaternary coastal deposits of the Brazilian Southeast.

Keywords: Quaternary deposits; heavy minerals; sediment transport

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1. Introduction

The southeastern Brazilian coast is mainly formed by pre-Cambrian rocks and Quaternary deposits. Quaternary sediments can either be found in an extensive area as in the State of Espírito Santo or can represent just a narrow strip of coast surrounded by granitic formations, as in the division of São Paulo and Rio de Janeiro States.

As weathering resistant remains of rocks, sediments do retain memory of its original formation and can give information about the environmental conditions of the deposition site. From the very first igneous rock, crystallized from the magma, the differentiation process will depend upon chemical composition and physical conditions, leading to different concentrations of each constituent element. Among many others, thorium, uranium and potassium are available in the magma and so do enter the minerals crystalline structure. Potassium is abundant in rock-forming minerals, especially in potash feldspar, like microcline and orthoclase, but is also present in accessory minerals. As part of the chemical structure of the minerals it is not expected any loss of potassium during the transition from rock to sediment, so

sands having originated from the same parent rock should have the same gamma-activity from K. Thorium content increases with differentiation process, making the ratio of Th/K diagnostic of mineral species [1,2].

Thorium and uranium are usually bound to heavy minerals, having its transport affected by gravitational separation. Similar in size and weight this effect should affect both elements in the same way. On the other hand, they can behave differently under oxidizing conditions. While thorium exists only in its quite insoluble state, uranium can be oxidized and assume a more soluble form, being leached from the mineral. The relative concentration of thorium to uranium will reflect this behavior: the Th/U will remain unchanged under reducing conditions indicating uranium fixation, and will increase under oxidizing conditions due to uranium leaching. Moreover, oxidizing conditions are generally associated to terrestrial environments while reducing conditions are more commonly marine [1,2]. For this reason the Th/U can be used to study the sea-level changes along the Brazilian coast, which characterize the Quaternary period, and can be considered easier to measure than the classical heavy mineral analysis method [3].

With the aim to contribute to the present knowledge on the structure and functioning of the Brazilian Coastal Systems it was performed a radiometric analysis of several beaches from São Paulo to Espírito Santo.

2. Material and Methods

Superficial beach sand samples of 35 different coastal sites were collected, covering 1500 km along three Brazilian States: São Paulo (SP), Rio de Janeiro (RJ) and Espírito Santo (ES). Figure 1 shows the main geological features of the southeastern Brazilian coast and the locations where the sand samples were collected. Sample sets of about four samples were collected from lower to upper beach from several sites within the same beach. A few sand profiles of 120 cm depth were also sampled.

Since the Th, U and K correlations are usually given in equivalent ground concentrations, the ^{238}U and ^{232}Th content was expressed in parts per million and ^{40}K in percents. Technical details of measurements performed and calculations of the K, eU and eTh concentrations can be obtained in references [3,4].

3. Results

The analysis of the mean values of potassium content obtained from superficial beach sand samples of 35 different sites, leads to interesting results concerning the formation of its sedimentary strata. The coastal plain involving the north of São Paulo State and south of Rio de Janeiro State presents enrichment of potassium content (with mean value of $\approx 2.6\%$), whereas there is an extensive zone along the southeastern Brazilian coast where the potassium content is depleted by one order of magnitude. In these localities, K contents vary between 0.2 and 0.4 %. On the other hand, some sites along this coastal zone where potassium contents show some

enrichment: $\approx 1.9\%$ in Arraial do Cabo (site 22 in Figure 1); $\approx 1.0\%$ in Búzios (site 24); $\approx 0.7\%$ in Marataízes (site 27); and $\approx 1.3\%$ in Itapemirim (site 28). Similar results were found for the potassium distributions as a function of depth for the sand profile samples analyzed.

The enrichment in the radioactive potassium ^{40}K spread throughout the main rock-forming minerals, such as K-feldspar, present on the pre-Cambrian basement rocks (granites, ortho-gneisses and migmatites), can explain the high value of about 2.6% for the K-activity along the sites on the north São Paulo State and south Rio de Janeiro State. The same interpretation can be used to explain the K enrichment in Arraial do Cabo, Búzios, Marataízes and Itapemirim. Finally, the low K-activity in the other coastal zones shows that its sediments do not retain memory of pre-Cambrian formations.

However, the sole analysis of potassium content is not enough to draw more conclusive information about the mineral composition of the sedimentary strata of beach sands. The thorium-to-potassium ratio can be used in the recognition of clay mineral associations and the discrimination of micas and feldspars in granitic rocks [1,2]. Also, the thorium-to-uranium ratio has proved to be useful in the determination of "geochemical facies", since this ratio can be an indicator of relatively oxidizing or reducing conditions, varying from 0 - 2 in anoxic environments and greater than 7 in a strongly oxidizing environment [2].

The cross plot of eTh/eU and eTh/K ratios presented in Figure 2 summarizes the compositional changes related to potassium (sites are grouped by its potassium content and diverse geological provenance) as well as implications concerning redox potential [3]. The horizontal divisions indicate the different mineral associations present in the beach sand samples. The vertical bars represent the values of eTh/eU equal to 2 and 7. Based on eTh/eU ratios, an oxidizing environment is suggested for most beach sands from the North Rio de Janeiro and Espírito Santo States (sites 26, 27 and 31 to 35), where the ratios vary from 7 to 43. In this area, the geological and oceanographic evolution of the continental shelf and coastal plains during the Quaternary have created conditions for the formation of large economic heavy mineral deposits, represented by the highest values of eTh/K in Figure 2. Such deposits are consistent with its supposed origin as Quaternary sedimentation, associated with depositional systems of continental origin and transitional/marine. Medium eTh/eU ratios (varying from 2 to 7) characterize the strandplain of Santos (site 1), Arraial do Cabo (site 22), Búzios (site 24), Marataízes (site 28) and Itapemirim (site 29), including Maricá (site 21), Cabo Frio (site 23), Rio da Ostras (25) and Piúma (site 30). Their sandy facies could be explained as from shallow marine or lagoonal origin covered by eolian sands.

Stacked repetitions of high and medium eTh/eU ratios characterize the Niterói formation (sites 17 to 20) and low, medium and high eTh/eU ratio values are observed in the south of Rio de Janeiro State (points 3 to 16). This behavior probably reflects high lateral variability in sandy facies and interplay between mostly brackish and freshwater regimes of distribution channels, bays and marginal marine deposits. The long-term cyclic pattern of the eTh/eU ratio mean values of different beaches

in the marine sequence of Southern Rio de Janeiro State is an excellent indicator of a broad transgression/regression couplet on an open marine shelf.

Sand profile measurements show that the ratio of eTh/eU is constant in depth independently of the distribution of eTh or eU.

Additionally, from eTh/K ratio one can derive an evaluation of the mineral concentration in heavy mineral deposits. Results from South Espírito Santo State, Guarapari (site 33), show the highest values of eTh/K ratio ($\approx 10^5$), compared with Buena zone (site 27), Anchieta zone (site 31), Meaípe (site 32), North Espírito Santo State (sites 34 and 35), which show values of eTh/K ratios $\approx 10^3$ or Mambucaba (site 3) with eTh/K ratios $\approx 10^2$. Such results indicate that Guarapari beaches have higher monazite enrichment than Buena, Mambucaba, Serra (site 34) or São Mateus (site 35), which could have higher concentration of zircon, rutile and ilmenite than Guarapari. For Mambucaba, the low value of eTh/eU ratio (≈ 7) shows that although this costal plain has been covered by eolian sands, its source of heavy mineral deposits could be shallow marine or due to a delta complex.

4. Conclusions

Radiometric analysis of Quaternary deposits from the southeastern Brazilian coast showed that coastal plains of North Rio de Janeiro and Espírito Santo States have heavy mineral deposits, each one with specific features for their heavy-mineral concentrations. For instance, Guarapari deposits have monazite enrichment above Buena, Serra or São Mateus deposits. Particularly, it was discovered the existence of a deposit in Mambucaba, which source of heavy minerals is possibly on alluvial deposits. The results obtained in this work also confirm the main features of the geological mapping of Quaternary coastal deposits, showing that the gamma-ray technique can be used as a tool in the understanding of the origin and transport of sediments.

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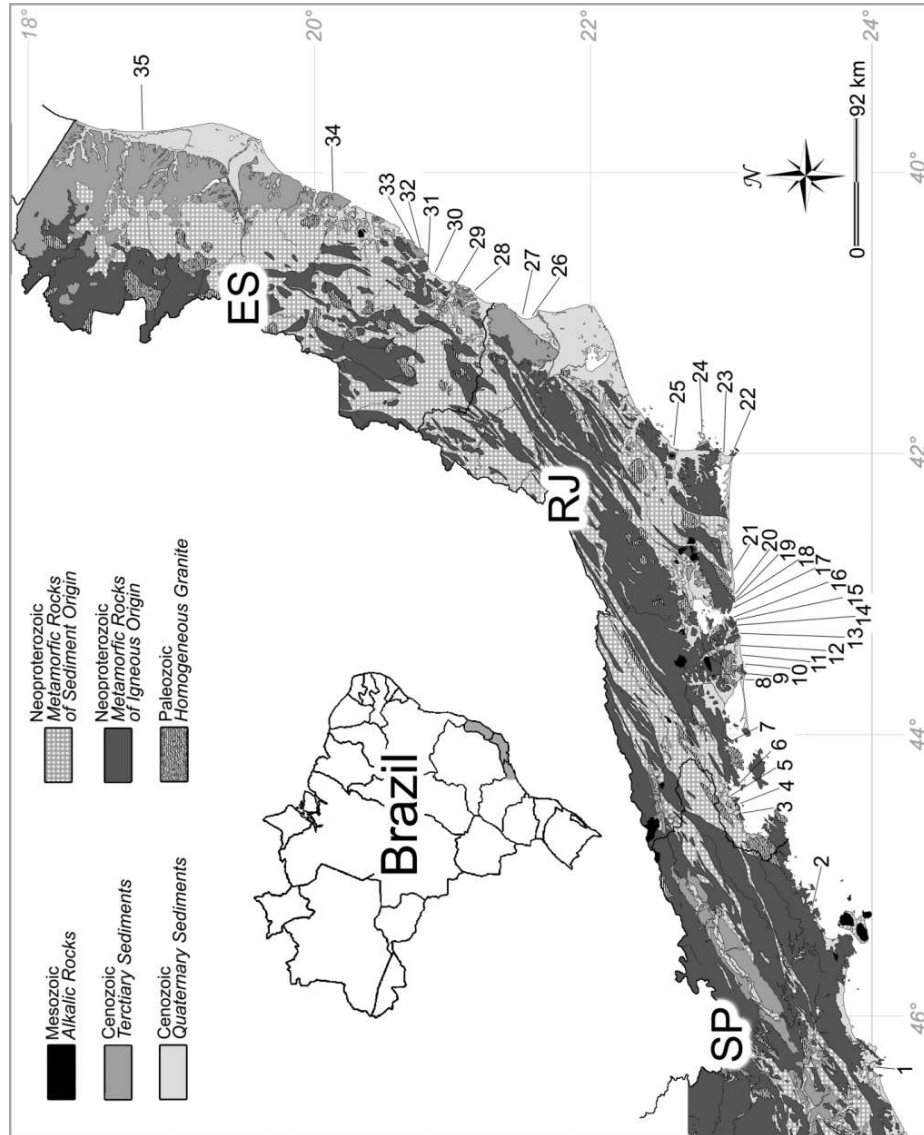


Fig. 1. Geological Map of the Brazilian Southeast [3].

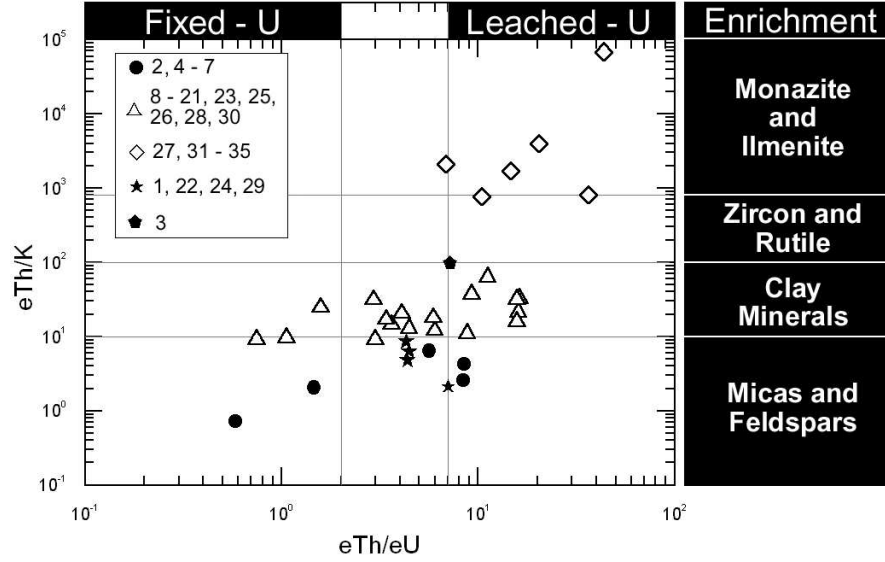


Fig. 2. Cross plot of thorium-potassium and thorium-uranium ratios in 35 different sites of the southeastern Brazilian coast. The vertical bars represent the values of eTh/eU equal to 2 or 7. The horizontal lines show that the data can be arranged in zones with different values of eTh/K ratio or mineral compositions [3].