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OSL-SAR dating of sediments from Brazilian aeolian system: Dama Branca, Rio de Janeiro, morphodynamic study

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ABSTRACT

It has been reported that the formation and stabilization of coastal dune fields in Brazil have a dependence on the climatic changes, Relative Sea Level (RSL) variations, etc. In this work, a dune field known as "Dama Branca", located in the city of Cabo Frio, Rio de Janeiro, has been studied to understand its mobility. Dating by trapped charge dating techniques as Optically Stimulated Luminescence (OSL) using the Single Aliquot Regenerative protocol (SAR), helps us to understand the formation and dynamics of aeolian systems in Brazil. Samples from two positions; DB and 2DB, were collected from different heights and points for dating. The results obtained by OSL-SAR showed that ages decrease as the height from the dune base increases and older samples are found in deeper horizontal positions. The ages from the base of the studied dunes indicated that its stabilization occurred during the recess of the sea level and that erosion caused by the wind action is revealing an old generation of this dune filed.

Keywords: OSL-SAR dating, dune mobility, climatic changes

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1. INTRODUCTION

Aeolian systems have been extensively studied by many authors [1, 2, 3]. It has been reported that morphodynamics of those systems are influenced by geological factors as the Relative Sea Level variations (RSL) and the Relative Sedimentary Balance, *i.e.*, the ratio between absolute sediment balance (influx-efflux) and accumulation space [4]. Climatic factors as the rain, the wind strength and direction are mainly responsible for the sediment transport [5]. Mendes & Giannini [6] correlate the evolution of aeolian systems in Brazil with climatic changes, they conclude that coastal dune fields are recorders of those variations.

Here, we are engaged in geochronological work of sediments collected from coastal plains in the state of Rio de Janeiro. More specifically, there are dune barrier formations along the coast from Cabo Frio to Arraial do Cabo. We expect to find evidences of vertical and horizontal dynamic of the dune field, for this purpose, in this work, the dune field known as "Dama Branca" was studied. In this location, there have been found large sand mounds, enabling to collect samples from different heights and depths, allowing to study its dynamics and sand movement vertically and horizontally and to try understanding the Dama Branca formation.

The Optically Stimulated Luminescence (OSL) using Single Aliquot Regenerative Protocol (SAR) developed by Wintle & Murray [7] was applied to estimate the accumulated dose, also known as Equivalent Dose; D_E (given in mGy), which is the total amount of natural radiation absorbed by the sediment. D_E divided by the Natural Dose Rate, also known as Annual Dose; D_{AN} (given in mGy/year), yields the sample's age [8].

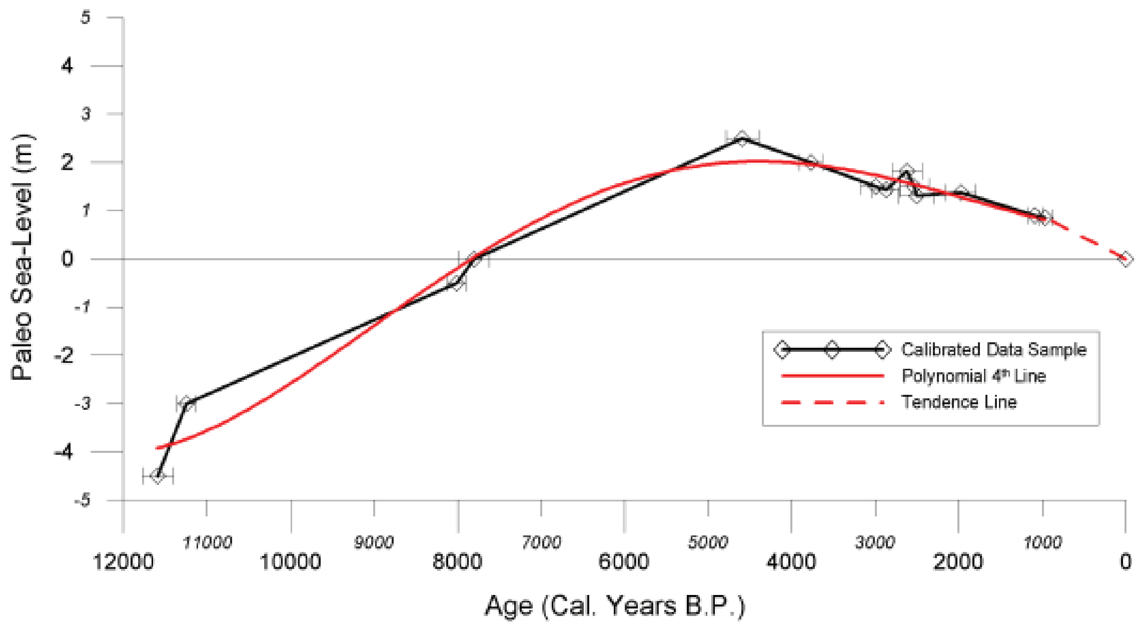
The calculation of D_E and D_{AN} must consider some correction factors. The most critical ones are the grain size fraction, water content and depth of sample collection. These factors are responsible to modify the natural dose rate (D_{AN}). They are discussed in the literature [8], however, those correction factors have been modeled in a single computer program; DRAC (Dose Rate and Age Calculator) distributed online for free by Aberystwyth University [9].

1.2. Dune Field Dynamics.

1.2.1. Relative Sea Level (RSL)

Termed as the most polemic factors controlling the aeolic sedimentation, the RSL basically controls the amount of sediment that can be worked out by the wind to create a dune field [5]. Castro et. al. [10] constructed a RSL curve during the Holocene in the Rio de Janeiro coastline based on ^{14}C dating of mollusk shells, vermitides and other biological and geological evidences (Fig. 1). As we can infer, almost 5000 years back, the Relative Sea Level reached its maximum during Holocene (+2.5 m above the current level), since then, it is observed a trend towards to recess of the sea level. [10].

Figure 1: *Relative sea-level variation curve for the coast of the state of Rio de Janeiro [10].*



1.2.1. Relative Sea Level (RSL)

The wind action and amount of precipitation can be decisive to the formation and stabilization of a dune field. Cabo Frio region weather is considered semi-arid, with negative balance of precipitation/evaporation [11], the rainfall at Arraial do Cabo (a few km far from Cabo Frio) is about 800 mm/year, rather low value compared to São Paulo annual precipitation of 1621.9 mm/year. The wind power is used to calculate an important parameter; The Drift Potential (DP), which is an indicator of how strong the wind in a certain region is and if it’s enough to promote a significant sand transportation. It is calculated by the following equation:

$$\mathrm{DP} = \sum \frac{U^2(U-Ut)}{100}.t \tag{1}$$

Where U is the wind speed 10 m above the surface, Ut is the threshold for sand transport and t is the amount of time when U is higher than Ut [6].

2. MATERIALS AND METHODS

Sediments age measurements using OSL-SAR protocol are based on the radiation energy deposition during the burial time of quartz grains. In this method, the quartz grains found in the sediments are considered radiation dosimeters, the relation between Equivalent Dose, which is the absorbed dose by buried quartz grains (mGy), and the dose rate of natural radiation delivered to the sample (mGy/year) will result in the sediment age (years) (equation 2) [7].

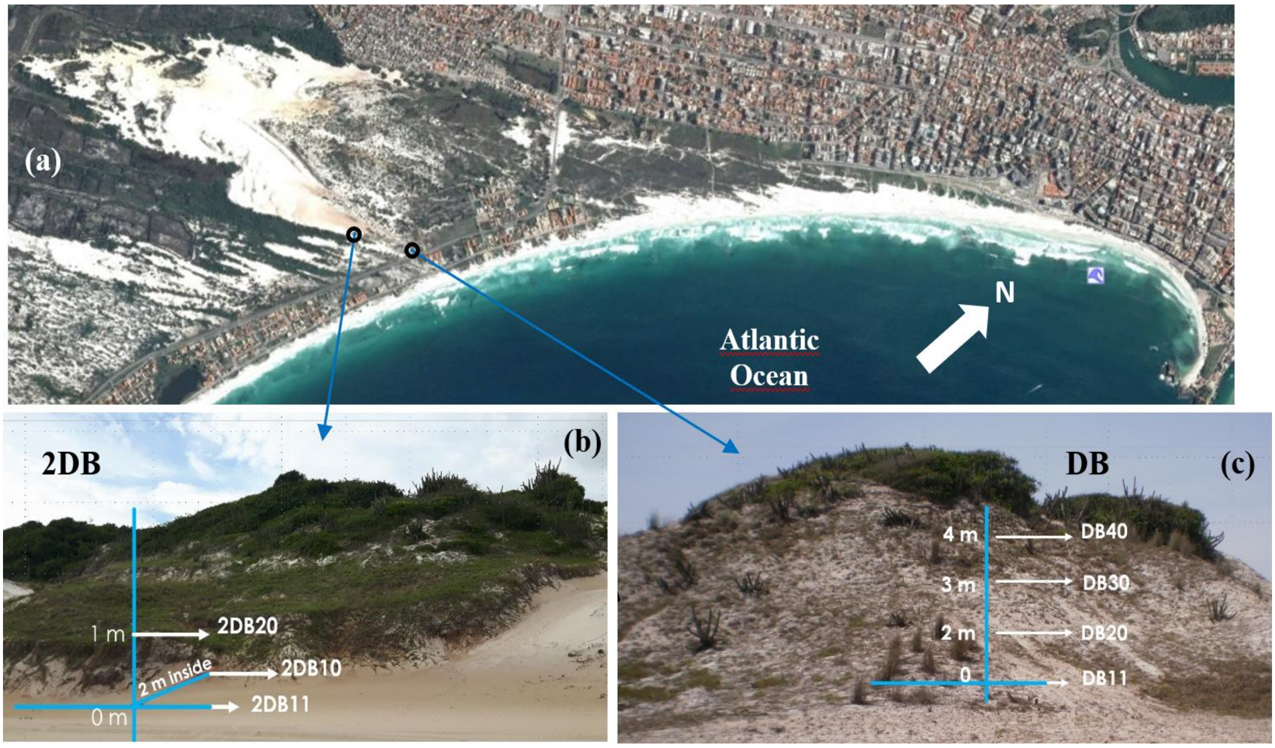
Equivalent Dose is the dose retained by the sample since its last signal resetting. The sunlight is responsible for “bleaching” the OSL signal [7]. When quartz grains are exposed for a few seconds to sunlight, its OSL response is zero (an exposition period of 100 s is enough to eliminate the OSL signal). The “sample’s birth” is its last sunlight exposition.

In this work, while grains are being transported, they are exposed to UV sunlight. They will reach a certain point where transportation is no longer possible, and a burial process will take place. At this moment, the sediment is covered by sand dragged by the wind action and, consequently, the sunlight stops illuminating it. The natural radiation, provided by the radioactive decay of Uranium and Thorium series and ^{40}K isotope and Cosmic Rays, interacting with quartz crystals yields D_E which can be measured by OSL if the sediment was kept covered until its collection. Taking this observation into account, dating dune fields by OSL-SAR can be useful to understand sand mobility, which in turn reveals its activity, formation and stabilization. Crossing those ages with other data, i.e. rainfall, wind power, relative sea level curves, aerial photographs, models can be constructed to describe the relation of sand mobility and environment aspects, as consequence the dune field becomes a recorder of climatic changes [1,4,5,6].

$$\textbf{Age} = \frac{\textbf{Equivalent Dose (mGy)}}{\textbf{Annual Dose Rate (mGy/year)}} \tag{2}$$

Fig. 2 (a), (b) and (c) show the points of sample collection used in this work. Samples were collected from two different positions; DB and 2DB. These positions consist of two sand mounds with vegetation covering them. Vegetation prevent sand mobility which in turn makes dating possible, a non-vegetated mound exhibits great age variation (even zero ages are found) due to the frequent sunlight exposition of sediments.

Figure 2: *a) Dama Branca dunefield extension, b) DB position and c) 2DB position.*



Sample gathering was done using PVC tubes of 3 m long and 3 cm in diameter to take sediments from sand mound's base: DB11, 2DB10 and 2DB11. The sample 2DB10 was collected 1 m deeper compared with 2DB11, then, this sample is from a more internal position. The reason to collect this sample is to evaluate whether there is or not horizontal age distribution.

Samples were also taken from 2 m (2DB20 and DB 20), 3 m (DB 30) and 4 m (DB 40) above the base using a 1 m long and 3 cm diameter PVC tube. These samples will reveal whether there is or not a vertical age distribution. Table 1 shows the samples used in this work.

Table 1: Depth and Height of sampling

Sample name	Horizontal depth (m)	Height
2DB10	2	Dune base (0m)
2DB11	1	Dune base (0m)
DB11	1	Dune base (0m)
2DB20	1	1 m (from dune base)
DB20	1	2 m (from dune base)
DB30	1	3 m (from dune base)
DB40	1	4 m (from dune base)

The hypothesis is that samples from the base must older than the ones above it, the underneath volume of sand might be immobilized by the volume over it. The age should decrease with increasing height, the difference among then could reveal how many years it took to form a sand mound in vertical direction.

Regarding horizontal direction, the idea is that the more central a certain sediment volume is placed, the oldest age will be found for this volume compared with an external one. It's true if deposition starts from a point and sediment dragged by wind action was placed and uniformly distributed around it.

In all cases, tubes containing samples were emptied in red light environment to prevent bleaching of the samples [7,12]. The sand amount within ten centimeters of each tube edge was discarded to prevent contamination by bleached grains. Only the sediments in the last 30 cm of each tube were taken for measurement.

Samples have been wet sieved to retain grains from 212 to 150 μm (2DB20 and DB20) and from 150 to 90 μm (DB11, DB30, DB40, 2DB10 and 2DB11). Then, samples were chemically washed in the following sequence to separate quartz grains from other minerals:

- Hydrochloric acid (10%) followed by hydrogen peroxide (27%) and hydrofluoric acid (48%) for 40 min to remove carbonates, organic materials, feldspars grains as well as the outer layer of the quartz grains to exclude the α-radiation contribution, respectively. A repeated treatment with Hydrochloric acid (10%) was done at the end to wash off residual compounds created by HF attack.
- Density separation using sodium polytungstate ($Na_6[H_2W_{12}O_{40}]$) solutions at densities of 2.75 g/cm³ and 2.65 g/cm³ to remove heavy minerals and remaining feldspars, respectively.

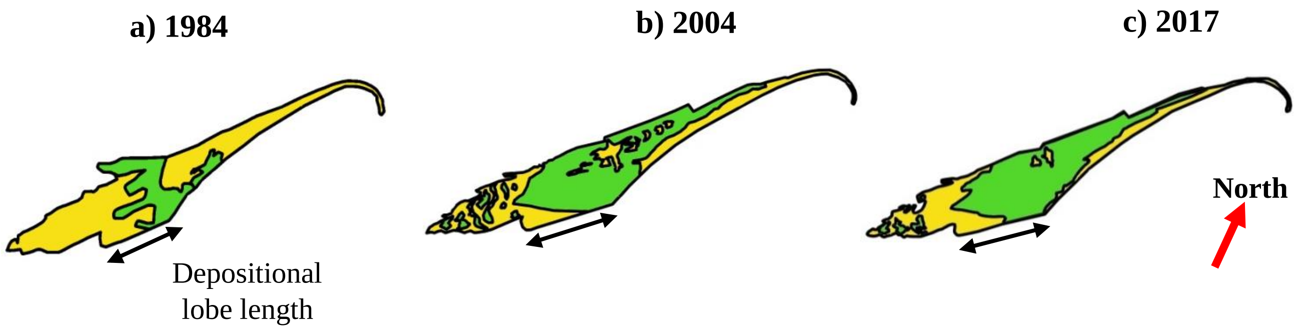
OSL measurements of quartz grains were carried out using a Risø TL/OSL DA-20 at the ECU Luminescence Laboratory. The reader is equipped with a $^{90}Sr/^{90}Y$ beta radiation source and blue LEDs (470 nm) and IR LEDs (870 nm) for stimulation. A Hoya U-340 filter (290-370 nm) was used to separate the OSL signal from the stimulation blue light. Equivalent Dose (De) estimation of each sample was determined by the Common Age Model and Central Age Model developed by Galbraith, et. al. [12] using at least 16 aliquots.

A Canberra Ge-Li gamma ray spectrometer at LACIFID, Physics Institute of the University of São Paulo was used to determine the ^{40}K, thorium and uranium concentrations to estimate the Annual Dose Rate using DRAC (Dose Rate and Age Calculator) available online at www.aber.ac.uk/alrl/drac [9].

3. RESULTS AND DISCUSSION

Fig.3 shows the morphology of Dama Branca dunefiled in 1984, 2004 and 2017 using the images available in Google Earth®. The photograph was processed using Gimp 2® to illustrate sand covered and vegetated areas and their values in km² as well the migration rate was obtained using Global Mapper®.

Figure 3: *Morphological changes in Dama Branca dunefield during the years a) 1984, b) 2004 and c) 2017*



The migration rate is related to maximum distance reached by the fastest depositional lobe divided by the elapsed time from the older to the newest aerial photograph [6]. The migration rate between 1984 and 2004 was 2.54 m/years and between 2004 and 2017 was 5.74 m/years.

The sand covered area (yellow) was drastically reduced, being 2.839 km² in 1984, 1.944 km² in 2004 and 1.215 km² in 2017.

From 2004 to 2017 there was an acceleration in the migration rate, this acceleration is related to the increase in the ratio wind power and aeolian supply [6], which indicates the wind activity over the aeolian supply and sand movement in the direction of the depositional lobe growth.

The Equivalent Dose was determined by constructing a linear dose-response curve for at least 24 aliquots of each sample using the SAR protocol (Table 2).

Table 2: OSL-SAR sequence used in this work (protocol summary)

Step	Treatment	Observed
1	Dose D_i	--
2	Preheat	--
3	Stimulation for 100 s at 125 °C	L_i
4	Dose test D_t	--
5	Cut heat at 160 °C	--
6	Stimulation for 100 s at 125 °C	T_i
7	Return to 1	--

OSL signal of a specific sample is taken after preheat (D_i; i = 0 mGy if natural sample), a test dose is given and the OSL signal is taken again. A corrected signal is obtained by the ratio Li/Ti. [7].

Fig. 4 and 5 show the histograms of the calculated D_e for at least 16 aliquots, which bin sizes have been calculated using the Freedman-Diaconi's formula [13]. The temperature of 220 °C has been set as preheat temperature by using plateau test [7]. For DB20, DB30 and 2DB20 the preheat temperature was change to 200 °C due to a high recuperated signal (signal obtained when no dose is given)

Two mathematical models have been employed to generate a single D_E value

- Central Age Model used for 2DB20, DB20, DB30 and DB40 [12].
- Common Age Model 2DB10, 2DB11 and DB11 [12].

Figure 4: *Histograms of Equivalent Dose for a) 2DB10, b) 2DB11 and c) 2DB20*

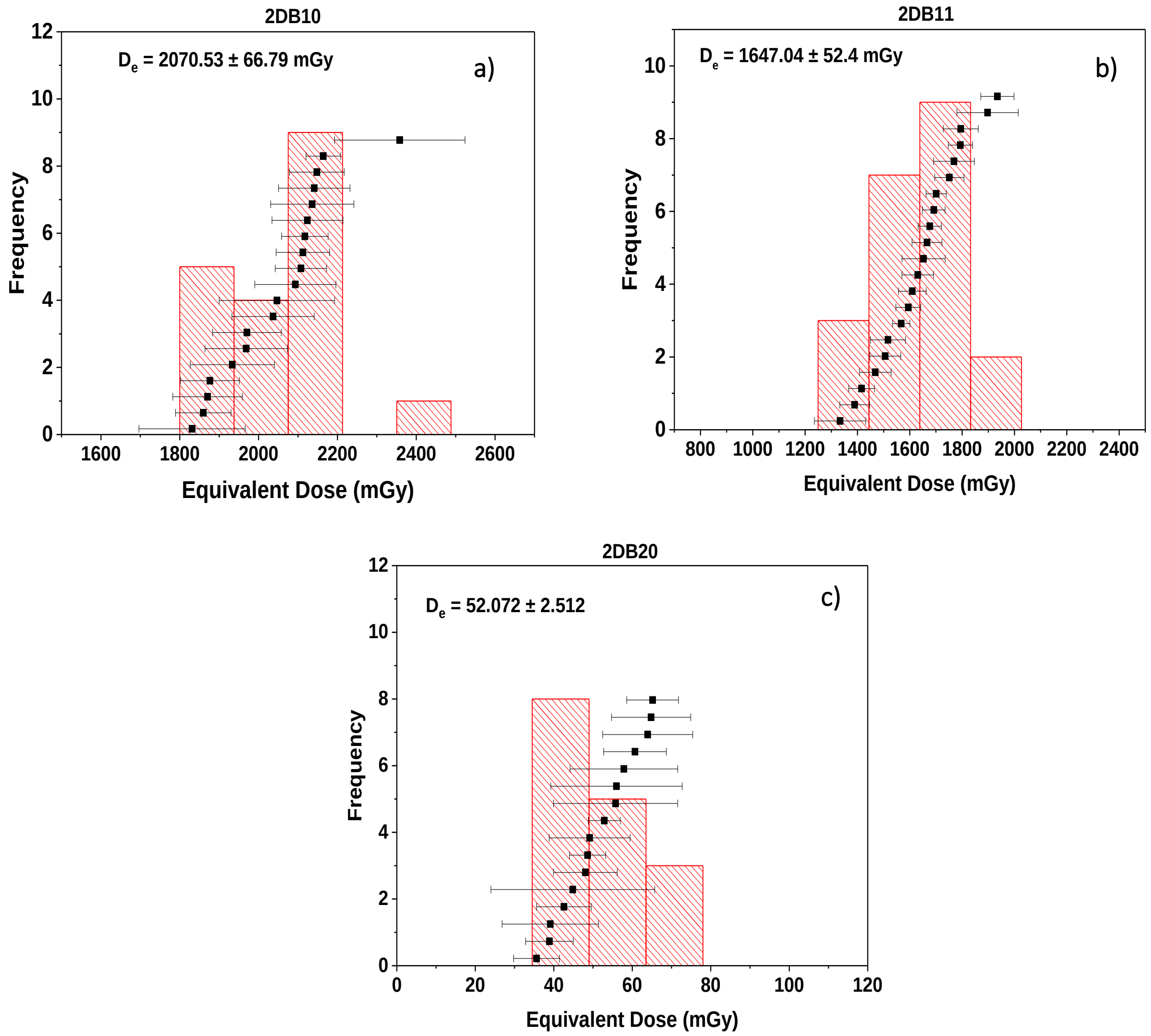


Figure 5: *Histograms of Equivalent Dose for a) DB11, b) DB30, c) DB20 and d) DB40*

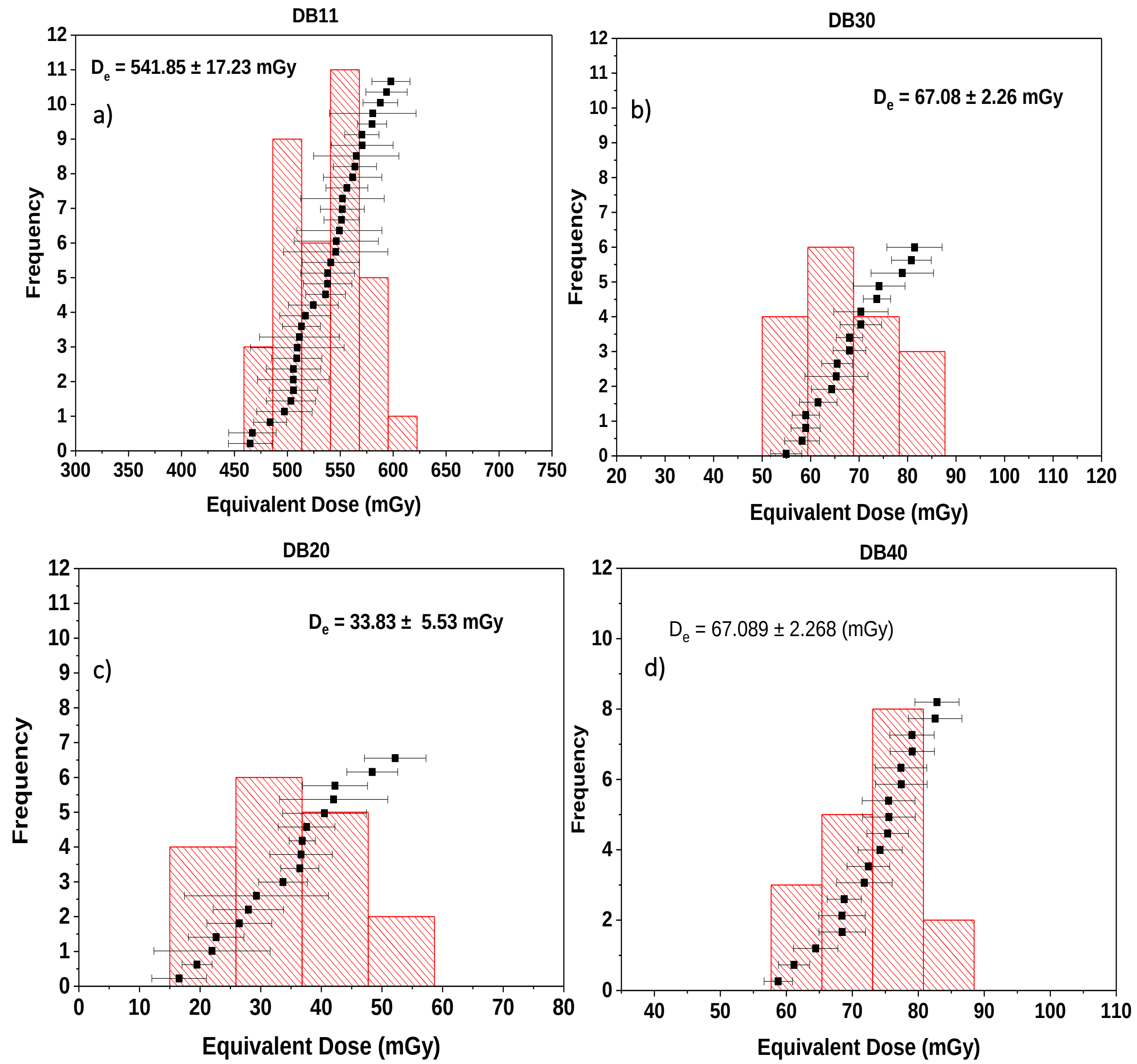


Table 3 shows the Equivalent Dose, Annual Dose Rate and the Age calculated for all samples studied in this work.

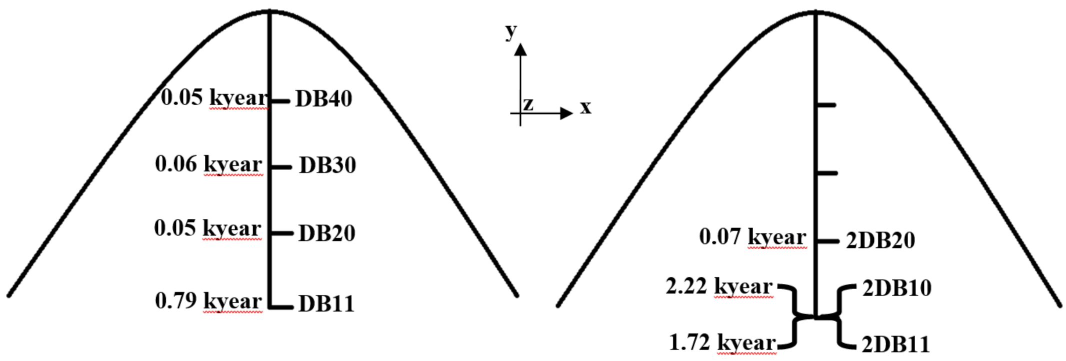
Table 3 – Ages obtained using OSL-SAR protocol.

Equivalent Dose (mGy)	Sample	Annual Dose Rate (mGy/year)	Age (k years)
2,071 ± 67	**2DB10**	0.932 ± 0.04	2.22 ± 0,12
1,647 ± 52	**2DB11**	0.958 ± 0.03	1.72± 0.08
542 ± 17	**DB11**	0.69 ± 0.03	0.79 ± 0.04
52.1 ± 2.5	**2DB20**	0.731 ± 0.03	0.07 ± 0.01
34.8 ± 5.5	**DB20**	0.66 ± 0.03	0.05 ± 0.01
67.8 ± 2.3	**DB30**	1.051 ± 0.03	0.06 ± 0.01
67.1 ± 2.1	**DB40**	1.456 ± 0.05	0.05 ± 0.01

As the height increases, the younger is the sediment. Regarding DB position, the ages indicate a mean difference of 735 years between DB11 (base) and all positions over it (DB20, DB30 and DB40).

In the case of 2DB positions, the difference between 2DB11 and 2DB20 (1 m higher) is 1,650 years. 2DB11 is 500 years younger than 2DB10 (1 m deeper). This result showed that a more internal position can be older than an external one. (Fig. 6)

Figure 6: *Age variation with the height collection: a) In DB position, DB11 located at the base is older than samples collected above it, b) at 2DB position, 2DB11 and 2DB10 located at the base are older than 2DB20, located above them. 2DB10 is 1 m deeper (z axis) and older than 2DB11.*



The studied positions; DB and 2DB, accordingly to the presented results, are formed by stable sediment at the base with young sediment mounted above, which indicate that the mounds are relative active, stable only due to vegetation action. This result implies that samples from the base of both positions (DB11, 2DB10 and 2DB11) can be an old generation that now is emerging by erosion, while samples placed over can represent the amount of time that vegetation has been present and holding the mound preventing its mobility; a mean of 57.5 years.

From figure 2 is possible to see that DB position comes before in the migration line than 2DB. DB11 is almost 500 years younger than 2DB11 and 1430 years younger than 2DB10. Of course, they are from different generations, which means that the process of stabilization of those parts were different.

In figure 1 is seen that the ages belong to the recess of the Relative Sea Level [5, 13]. During the recess of the RSL, accordingly to [5], it is more difficult the formation of dune fields due to growth of vegetation which prevent the sediment to be moved by wind action, so that the sediment influx is reduced. As presented in figure 3, the vegetated area has been grown during the years which leads to a stabilization process. With less sediment influx, the wind starts an erosion and reveals antique parts of the studied dune field.

4. CONCLUSION

OSL-SAR protocol is a suitable technique for measuring the equivalent dose of sedimentary quartz grains. Seven samples were measured, and ages from 2.22 ± 0,12 to 0.05 ± 0.01 were determined. The sand covered area was drastically reduced from the past 33 years, evidencing a possible stabilization process. An acceleration in the migration rate from 2004 to 2017 was identified, evidencing the sand mobility influenced by the wind action.

The ages showed that this dune field is formed by well-stablished sediments at the base and young sediments mounted above it, evidencing a higher surface activity. Comparing the ages for the base and the RSL curve presented before, the values are coincident with descending Sea Level [13].
The samples from the base of both studied positions (DB and 2DB), showed that antique generations have been exposed by the wind action and that those parts are from different epochs of stabilization to be studied in the future.

5. ACKNOWLEDGMENT

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6. REFERENCES

1. P.C.F. Giannini, A.O. Sawakuchi, R. DeWitt, D.R. Nascimento Jr., V.A.P. Aguiar, M.G. Rossi, Determination of controls on Holocene barrier progradation through application of OSL dating: The Ilha Comprida Barrier example, Southeastern Brazil, **Marine Geology**, 285, pp. 1-16, 2011

2. K. Zen Ķeizars, Beth M. Forrest, W. Jack Rink, Natural Residual Thermoluminescence as a Met hod of Analysis of Sand Transport along the Coast of the St. Joseph Peninsula, Florida, **Journal of Coastal Research**, Vol. 24, pp. 500-507, 2008

3. A.M. Cunha, J.W.A. Castro, F.M.B. Pereira, M.A. Carvalho, K. Suguio, Variações do Nível Rel ativo do Mar Durante o Holoceno na Bacia do Rio Una, Cabo Frio - Rio De Janeiro: Aspectos S edimentológicos, Faciológicos e Geocronológicos, **Revista Brasileira de Geomorfologia**, Vol 1 8, pp.143-154, 2017

4. P. C. F. Giannini, A. O. Sawakuchi, V. R. Mendes; A. Zular, H. A. A. Andrade, C. T. Martinho, C. C. F. Guedes, D. R. Nascimento Jr., A. P. B. Tanaka, M. Fornari, Morfodinâmica de sistemas eólicos costeiros: um modelo baseado em exemplos do Holocénico brasileiro e seu potencial inte rpretativo**, Comunicações Geológicas**, 101, Especial II**,** pp. 681-685, 2014

5. P.C.F Giannini, **Sistemas Deposicionais Eólicos no Quaternário Costeiro do Brasil**, (Tese de Livre-Docência), Universidade de São Paulo, São Paulo, Brazil, 2007

6. V.R. Mendes, P.C.F. Giannini, "Coastal dunefields of south Brazil as a record of climatic chang es in the South American Monsoon System", **Geomorphology**, 206, pp 22-34, 2015

7. A.G. Wintle, A.S Murray, "A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols", **Radiation Measurements**, Issue 4, pp. 369-391, 2006

8. M.J. Aitken, **Thermoluminescence Dating**, Academic Press, London, 1985

9. J.A. Durcan, G.E. King, G.A.T. Duller, DRAC: Dose Rate and Age Calculator for trapped charg e dating, **Quaternary Geochronology**, 28**,** pp. 54-61, 2015

10. J.W.A. Castro, K. Suguio, J.C.S. Seoane, A.M. Cunha, F.F. Dias, Sea-level fluctuations and co astal evolution in the state of Rio de Janeiro, southeastern Brazil, **Anais da Academia Brasileir a de Ciências**, 86(2), pp. 671-683, 2014

11. H.A.A. Andrade, **Evolução Sedimentar e Cronologia da Barreira Costeira Quaternária de Maçambaba: A Influência de Ventos de Rumos Opostos e seu Possível Significado Paleocli mático** *(Dissertação de Mestrado),* Universidade de São Paulo, São Paulo, 2015

12. R. F. Galbraith, R. G. Roberts, G. M. Laslett, H. Yoshida, J. M. Olley, Optical Dating of Single a nd Multiple Grains of Quartz from Jinmium Rock Shelter, Northern Australia: Part I, Experimen tal Design and Statistical Model, **Archaeometry**, 41, pp. 339-364, 1999.

13. D. Freedman, P. Diaconis, On the histogram as a density estimator: l_2 theory, **Zeitschrift fur Wahrscheinlichkeitstheorie verw**, 57, pp. 453–476, 1981.

14. R.J. Ângulo, G.C. Lessa, The Brazilian sea-level curves: a critical review with emphasis on the c urves from the Paranaguá and Cananéia regions, **Marine Geology**, 140, pp.141-166, 1997