X-ray microtomography characterization of carbonate microbialites from a hypersaline coastal lagoon in the Rio de Janeiro State – Brazil

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Abstract

The objective of the present study is to apply the micro-CT technique to assess recent microbialite samples from a hypersaline coastal lagoon in the Rio de Janeiro State. The study comprises structural assessment, mineralogical characterization and porosity distribution of each sample. Micro-CT is increasingly present in geological reservoir analyses, and has advantages over other laboratory techniques since it is non-invasive and allows 2D/3D visualization of inner structures without previous preparation method, such as slabbing, polishing, thinning or impregnation. This technique renders structural analyses which can be spatially resolved to a scale of micrometers. Results show that micro-CT technique is also adequate for the characterization of carbonate microbialites, providing excellent high resolution 3D images, that enabled to distinguish different mineralogies and porosity distribution beyond it is inner structure.

Introduction

X-ray Computed Microtomography (micro-CT) is a non-invasive technique that allows 2D/3D visualization of inner structures and does not need to be subjected to a preparation method such as impregnation, thinning or polishing (Remeysen and Swennen, 2008), what is an advantage. It is a highly reliable and established technique that inspired its use for geological research and industry (Landis and Keane, 2010). Some manufacturers developed desktop micro-CT systems according to the international demand for fast and accurate results in a laboratory environment. The 3D micro-CT allows full composition analyses, which can be spatially resolved to a scale of micrometers. Micro-CT physical principle is based on the attenuation of X-rays when they interact with the sample. The intensity of the photons crossing the object depends on the number of atoms by volume unit (density) and on the type of the atoms throughout the beam. In geological research it can be used in order to study rocks and their porosity network (Oliveira, 2012; Machado, 2013).

Microbialites are organosedimentary deposits formed by sediment trapping, binding and/or precipitation as a result of the growth and metabolic activity of micro-organisms, mainly cyanobacteria. The study of carbonate sediments formed by microbial induction, as well as of microbial carbonate rocks, is becoming very important in the Brazilian exploratory scenario of hydrocarbons, due to possible analogies with the Pre-salt reservoirs of the Eastern Brazilian margin sedimentary basins. In carbonate rocks, sedimentation and diagenesis produce a wide range of pore sizes, resulting in a complex spatial distribution of pores and pore connectivity (Arms, 2005).
The hypersaline coastal lagoons from the Rio de Janeiro State (Brazil) were chosen for this study because they present carbonate sediments formed by microbial induction and stromatolites with varied morphologies. Characterizing microbialite pore space is a great challenge for oil field development because of the high degree of its heterogeneity. In this context, the objective of the present study is to apply the micro-CT technique to assess four samples of recent microbialites from one of those hypersaline lagoons. The study comprises structural assessment, mineralogical characterization and porosity distribution of each sample.

Method

The lagoons are hypersaline water bodies that occur in the coastal area of the state of Rio de Janeiro. Together with other coastal lagoons, they form the Araruama Lake System, which represents a series of coastal lagoons, characterized by fresh to hypersaline waters, which enabled microbial mat development and carbonate precipitation (Vasconcelos, 2006). Microbialites used in the present study were collected by the authors in the interior of one of the hypersaline lagoons, in places which remain underwater most part of the year. Four different samples were analysed:

Sample I: Biscuit stromatolite – microfacies I. This microfacies is characterised by corrugated and very irregular carbonate laminae and the conspicuous presence of vuggy porosity.

Sample II: Biolaminite. Microbial mats composed of dark laminae (rich in organic matter) interbedded with light gray, carbonatic, stratiform to crenulated laminae, finely laminated.

Sample III: Biscuit stromatolites – microfacies II. This microfacies occur as carbonate plates composed by thin, irregular, discontinuous and distinct laminated carbonates, forming hardened crusts.

Sample IV: Organic matter. Formed by different stages of decomposition of microbial mats (organic matter), which also contains ostracods.

Micro-CT images were obtained in a high energy microtomography system – Skyscan / Bruker, model 1173 HE. Samples were placed in a polystyrene support. The system operated in an energy and current range of 60–100 kV and 100–133 μA, respectively. In order to reduce the contribution of low energy photons (beam hardening effect), a combination of two filters was used: copper (0.10 mm of thickness) and aluminum (1.0 mm of thickness). The pixel sizes were 14 μm, 22 μm, 24 μm and 25 μm. A flat panel detector was used (2240 x 2240) to register the cone X-ray beam transmission. The projection images were taken over 360º at each step of 0.30º rotation.

Results

High resolution microtomography analyses allowed to identify inner structures (ostracods, laminations, carbonate grains), different mineralogy (dolomite, calcite and quartz), as well as pore space distribution and quantification, providing a detailed description about microbialites sediments. Figures 1 and 2 show micro-CT results respective to the following samples:

Sample I – The different mineralogies (calcite and Mg-calcite) can be seen in Figure 1(I.b). The total porosity is 11% and the pore space distribution is shown in Figure 2(a).

Sample II – In this sample, compositional differences (presence of dolomite, calcite, organic matter and bright grains, possibly quartz) are shown in Figure 1 (II.c–II.f). It was possible to quantify about 0.01% dolomite plus quartz and 14% calcite. Pore distribution throughout the sample can be seen in Figure 2 (b); quantitative analyses showed a total porosity of 0.4%.

Sample III – Figure 1 (III.d and III.e) shows a diffuse mass of higher density carbonate material (dolomite?) in the biscuit stromatolite. This possibly occurs as a byproduct of dolomitisation associated with a distinct colony of cyanobacteria (0.97%). Sample's porosity is 0.35 % (Figure 2.c). Red arrow corresponds to the edge border effect in the image processing analysis when region of interest (ROI) is delineated. In this case, the last slice of the micro-CT dataset influences the porosity average value. This fact increases the sample porosity, which lead to a false conclusion of higher values. In this way, in order to avoid this kind of issue, the choice of the ROI must be investigated.

Sample IV – Lamination is seen by the concentration of carbonate grains (0.74%) inside the organic matter (microbial mat) as brighter lines in Figure 1(IV.e). In Figure 1(IV.f), ostracods (0.39%) are trapped in the microbial mats, some occurring with closed valves and some fragmented (transported by traction / suspension at low energy). The total porosity of this sample is 0.75%. The pore distribution graphic can be seen in Figure 2(d)

Conclusions

Micro-CT technique is adequate for the characterization of recent carbonate microbial sediments of microbialite with an advantage of non-destructive approach. It is possible to note an excellent 3D images with high resolutions, which permit distinguish different mineral phases and the porosity behavior, as well as the identification of bioclasts and sliciclastic components.

Acknowledgments

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References

Arms, C.H., et al., 2005. Pore scale characterization of carbonates using X-ray microtomography, SPE90368-MS, Society of Petroleum Engineers Journal, 146-157.

Landis, E.N. and Keane, D.T., 2010. X-ray Microtomography. Materials. Characterization 61, 1305–1316.

Machado, A. C., et al., 2013. Effect of 3d computed microtomography resolution on reservoir rocks. Radiation Physics and Chemistry.
http://dx.doi.org/10.1016/j.radphyschem.2012.12.029

Oliveira, M.S.F., et al., 2012. X-ray microtomography application in pore space reservoir rock. Applied Radiation and Isotopes 70, 1376-1978.

Remeysen, K. and Swennen, R., 2008. Application of Microfocus computed tomography in carbonate reservoir characterization: Possibilities and limitations. Marine and Petroleum Geology 25, 486-499.

Vasconcelos, C., et al., 2006. Lithifying microbial mats in Lagoa Vermelha, Brazil: modern Precambrian relics?. Sedimentary Geology 185, 175-183.

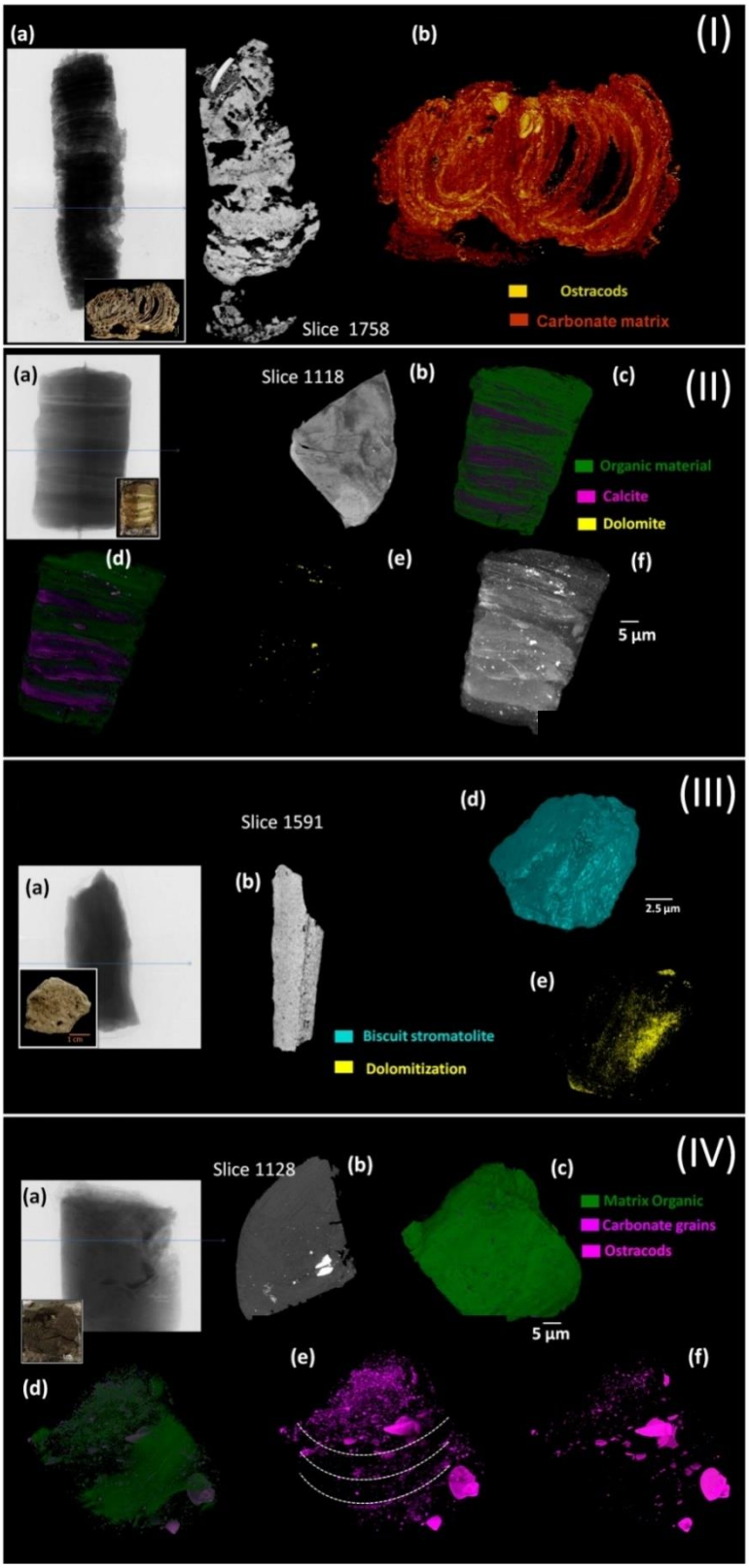

Figure 1: 3D micro-CT visualizations of all the analyzed samples. (I) Biscuit stromatolite/microfacies I, (II) Biolaminite (III) Biscuit stromatolites/microfacies II and (IV) Organic matter.

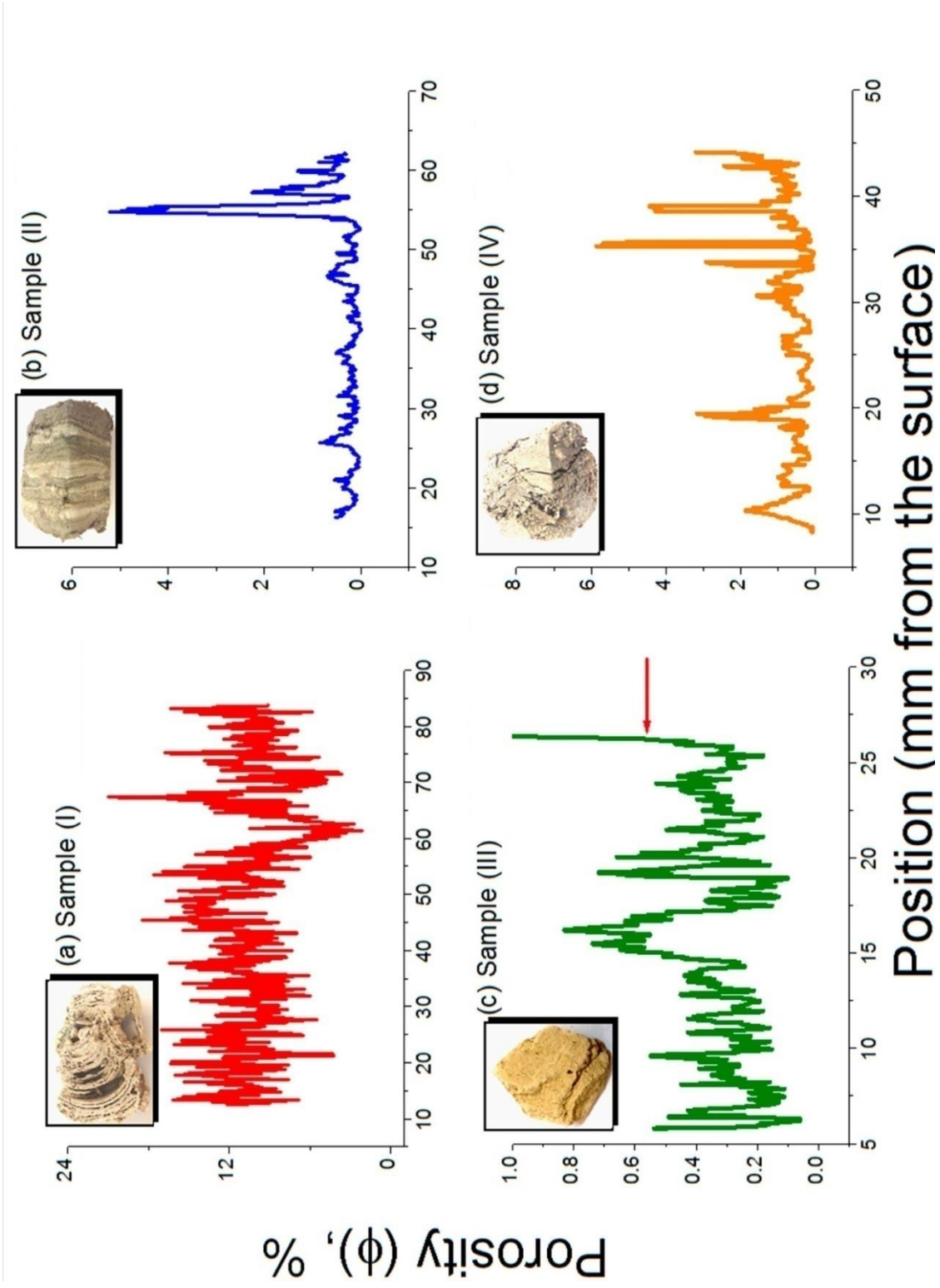

Figure 2: Pore distribution of all analyses samples (I, II, III and IV), the red arrow corresponds to edge border effect.