3D acoustic characterization of barchan dunes in the Solimões River

Gabriela Nunes Turquetti[1], Marco Ianniruberto[1], Pedro Vencovsky Nogueira[1], Jonas Lion Pereira[1], Renato Paes de Almeida[2], Cristiano Padalino Galeazzi[2], Kayque Bergamaschi Carneiro[3], James Leonard Best[4]
[1]Instituto de Geociências – Universidade de Brasília (IGD/UnB)
[2]Instituto de Geociências – Universidade de São Paulo (IG/USP)
[3]Rural Tech – Serviços Topográficos e Hidrográficos
[4]University of Illinois at Urbana-Champaign

This paper was prepared for presentation during the 15th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 31 July to 3 August, 2017.

Abstract

During last decade, seismic and multibeam surveys have became quite common tools to study fluvial environments which lack in information due to the difficulty of direct studies and analysis, especially in large rivers. The Amazon region hosts some of the largest rivers, in terms of sediment load, planform width, course length and thalweg depth. The understanding of sedimentary processes in actual large rivers can help understanding past rock records. For this reason, a study area was selected area in Solimões river where acoustic survey revealed the presence of large barchanoid dunes with internal seismic horizons associated to sediment dynamics and dune migration.

Introduction

The study of the recent sedimentary environments is important for a better understanding of paleo-environments, whose records are registered in the sedimentary rocks. In the specific case of the large rivers defined by Potter (1978), according to the size of the river basin, course length, solid and liquid discharge, their recognition from the sedimentary facies observed in the rocks requires analogues to be observed in the current environments. Rivers are dynamic environments, their transport processes and sedimentary deposition are determined by factors such as flow velocity, type and quantity of suspended material and granulometry of the bottom material (Suguio, 2003). These factors can condition the occurrence of several bed forms, which will depend directly on current flow velocities (Bagnold, 1966; Allen, 1970). Therefore, sediment transport and deposition analysis makes it possible to characterize common river bed forms, such as ripples, two-dimensional and three-dimensional dunes, anti-dunes and under certain conditions, composite dunes.

Acoustic geophysical methods allow the quantitative and qualitative determination of several aspects that help in understanding fluvial dynamics, such as morphology, stratigraphy and liquid and solid discharge measurements. The high resolution acoustic methods that can be used to study the dunes include the combined use of multibeam bathymetry and high-frequency reflection seismic (Almeida et al., 2016; Poppe et al., 2006), which allow the visualization of the riverbed morphology and its underlying layers, respectively. The multibeam bathymetry allows a detailing of the bottom of the river with sub-metric resolution, being possible to observe features such as dunes, outcrops, among other structures. The high resolution seismic allows a profile visualization of the geometry of the layers in the bottom of the river and it is possible to correlate the observed patterns of the reflectors with the migration of the dunes and the variations in the hydrological and sedimentary regime.

Some studies (Almeida et al., 2005; Erstsen et al., 2005; Parsons et al., 2005; Abraham and Pratt, 2002) prove and discuss the applicability of acoustic geophysical methods in obtaining qualitative results, such as wavelength determination, height and angle of the dunes, as well as the development of a methodology capable of efficiently determining the morphology of the various bed forms.

The objective of this work is the characterization of a set of barchan dunes present in the lower course of the Solimões river with the use of multibeam bathymetry and high-resolution seismic, in order to obtain measurements of the wavelengths and height of the dunes, as well as description of the internal structure associated with dune formation and migration processes.

Study Area

The Amazon region has the greatest concentration of water resources in Brazil. It is the largest river basin in the world (approximately 7 million square kilometres), it is responsible for contributing with one-fifth of all fresh water discharge into the oceans (Smith, 2002). Its main river, the Amazon, has approximately 7000 affluents and 1100 tributary rivers, which we highlight the rivers Negro, Solimões, Purus and Madeira.

The study area is located on a portion of the Solimões River, upstream from the confluence with the Negro

River, which originates the Amazon River, popularly known as "Encontro das Águas", near the city of Manaus, Amazon (annex 1).

From the geological point of view, the study area is inserted in the central portion of the Amazon Sedimentary Basin, which is considered as intracratonic type and Phanerozoic age. The rocks that make up the study area are sandstones, kaolinized and locally conglomerate clay, containing, locally, discontinuous levels of silicified and ferruginous sandstones, with thickness between 1 and 2 meters, also called "Manaus Sandstone". These rocks belong to the Alter do Chão Formation, of Cretaceous age. Also sediments such as sand, silt, clay and gravel are found, all of which are unconsolidated and characterized as alluvial deposits of the Holocene (Albuquerque, 1922, Church, 1998, Franzinelli, 2011).

The Solimões River is of the anastomosed type (Mertes et al., 1996) originating in the Andes, being characterized by a high concentration of suspended sediments, mostly composed of clay and silt, responsible for its characteristic brown coloration (Franzinelli, 2011; Latrubesse, 2008). Sampling and sediment analysis performed by Mertes and Meade (1985) on the river bed, approximately 20 kilometers upstream of the confluence, showed that the granulometric distribution has more than 99% of grains finer than 0.5mm, so the sediments can be classified as fine to medium sands on the Wentworth scale.

Therefore, in order to try to understand the occurrence of the barchan dunes, as well as analyze their internal features and correlate them with those found by Almeida et al. 2016 on a stretch of the river downstream of the confluence, longitudinal and transverse lines were acquired with the multibeam bathymetry and the sub bottom profiler (Annex 1). From the obtained data, a three-dimensional view was developed with five lines of acquisition of high resolution seismic in order to analyze the continuity of the three main horizons found (figure 2).

Methods

For the characterization of dunes and bed forms, bathymetry and high resolution seismic were used. The use of bathymetry was established because of its feasibility in providing information on the bottom of rivers and other fluvial environments. As for high resolution seismic, the propagation and penetration of the seismic waves in depth allowed the characterization of the sedimentary layers, features of bed, rocky basement, thanks to their visualization in profile.

The bathymetric survey was carried out with a Teledyne Reson Seabat 7101, operating at a frequency of 240 kHz with 511 beams distributed at an angle of up to 210º. This equipment allows the acquisition in shallow water up to 200 meters deep and with a maximum resolution of 1.25 centimeters (RESON, 2008). For high-resolution seismic, the Edgetech 3100P sub bottom acoustic profiler was used with an operating frequency of 2 to 12 kHz. The maximum penetration obtained varied between 10-15 meters. The data collected by the equipments were georeferenced by the Hemisphere Vector VS330 AtlasLink system.

In order to aid in the navigation and acquisition of bathymetry data, the PDS2000 Control Center of Teledyne version 3.9.6.8 was used, which allows the visualization of the data in real time, allowing adjustment of the acquisition parameters in order to improve the data acquired. For the acquisition of high resolution seismic data, the software used was the one provided by the manufacturer (Discover 3100).

The bathymetric data processing was performed using the PDS2000 Teledyne Control Centre software version 3.9.1. For high resolution seismic data processing consisted of signal enhancement, with the application of gains and filters, in order to improve the visualization of the data. This processing was performed with the help of Geosuite AllWorks software version 2.6.5.

Results and Discussion

Ernstsen et al. (2005) suggest that barchan dunes are features formed when the availability and granulometry of sediments varies across the river channel, and evidence of this variability was proven by Strasser (2008), who analyzed the composition of samples along of transversal sections at several locations of the river Solimões and Amazonas.

The dune system observed in this study area (annex 1) is in shallower waters within the studied river, comprising depths between 8 and 12 meters, and dune heights varying from 2 to 3.4 meters, with an average wavelength of 57 meters. When compared to the results obtained by Almeida et al., (2016), who described a broad system of large compound barchan dunes in the Amazon river basin. Abraham and Pratt (2002), studied the migration of dunes and bed load on the Mississippi River. The results obtained by Abraham and Pratt (2002) and Almeida et al., (2016), comprising the characterization of barchan dunes in water streams are coherent with ours: the small barchan dunes characterized by Almeida et al., (2016) present a wavelength of approximately 60 meters, while the results obtained by Abraham and Pratt (2002) show heights that vary from 0.6 to 1.5 meters, with wavelengths in the order of 60 meters.

In addition to the description of the morphological characteristics of the dunes, a three-dimensional view of the high-frequency seismic profiles (annex 2) and sketches of the two-dimensional sections interpreted (figures 1 to 5) are presented.

The first step in understanding the behaviour of the dunes was the qualitative analysis of the longitudinal profiles (figures 1 and 5) and transversal profiles (figures 2, 3 and 4), which were used to analyze and validate the continuity of the internal structures. The maximum penetration reached by the sub-bottom profiler was 10 meters and in this interval it was possible to distinguish three patterns of different acoustic responses in the seismic records. In general, the presence of a reflector (horizon) should be related to acoustic impedance contrast between layers with different particle size distributions.

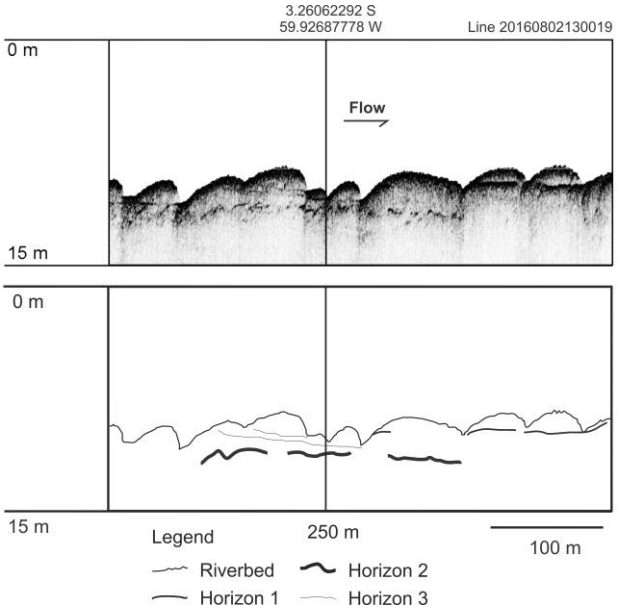


Figure 1 – 2D seismic profile of longitudinal survey line 20160802130019.

Based on the acoustic responses obtained, three horizons were identified. Horizon 1 (figures 1 to 5) is characterized by strong reflectors, which are located at the base of the dunes. Such behaviour suggests that the reflectors are the result of coarser grain size deposits at the base of the lee side. Its preservation occurs due to the burial caused by the migration of the dune itself. These reflectors have thickness of approximately 0.3 meters and consist in sub-horizontal surfaces (5º to 10º). The high reflectivity can be associated to different grain sorting, which can be explained by the deposition of coarser sediments due to grain fall and grain flow on the lee side.

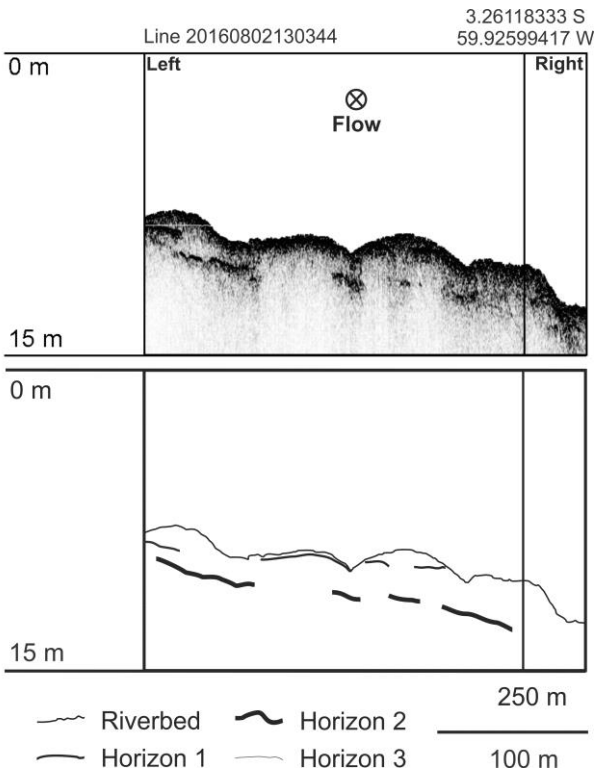


Figure 2 - 2D seismic profile of transverse survey line 20160802130344.

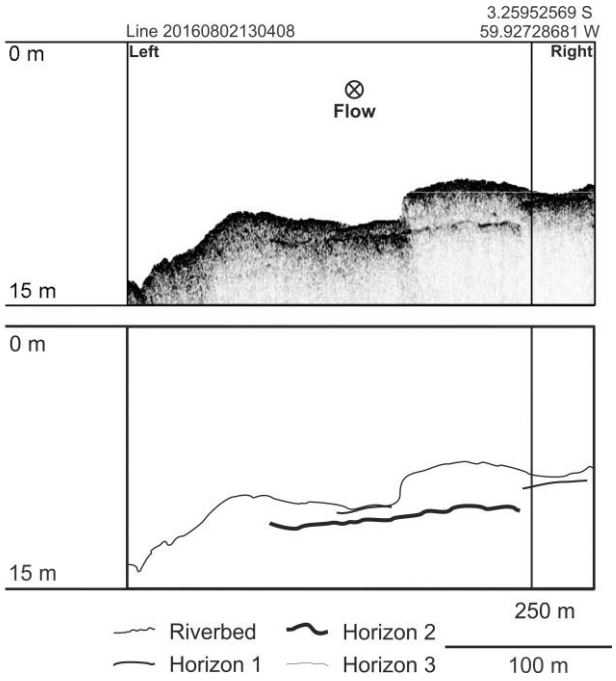


Figure 3 - 2D seismic profile of transversal survey line 20160802130408.

Horizon 2 (figures 1 to 5) is characterized by reflectors with sub-horizontal wavy pattern and may be related to set boundaries of older deposits, also associated to the

base of dunes, possibly resulting of a contrast in grain size. And lastly, Horizon 3 (figures 1 and 4) is characterized by weak low angle reflectors. Since the reflectors are attached to the base of dunes, their interpretation is the same as for Horizon 1, with lower intensity reflectivity due to less contrasting grain sorting.

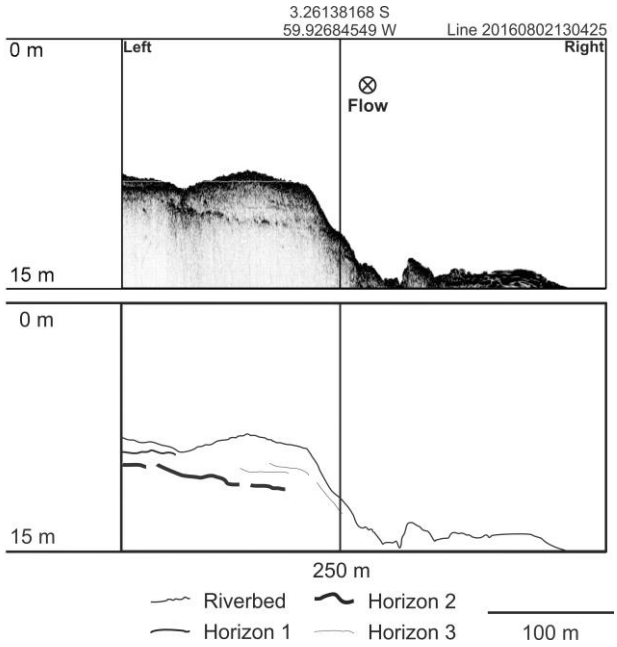


Figure 4 - 2D seismic profile of transversal survey line 20160802130425.

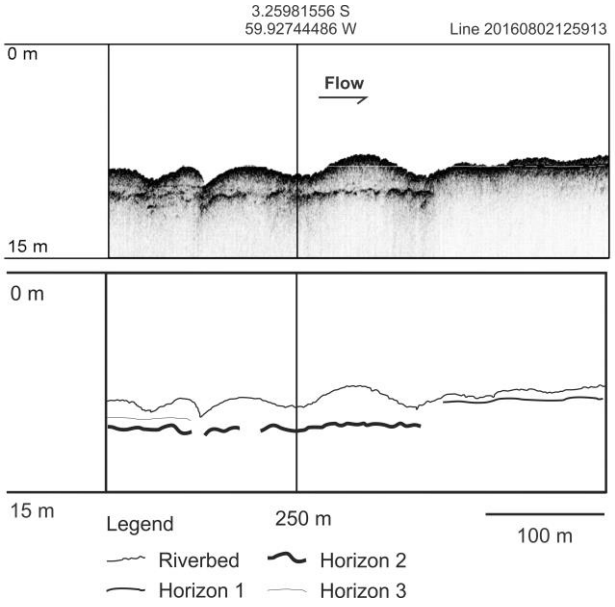


Figure 5 - 2D seismic profile of longitudinal survey line 20160802130913.

Conclusions

The results obtained with the bathymetry and high resolution seismic of the described portion of the Solimões River revealed the presence of compound barchan dunes with V-shaped ridges at depths between 8 and 11 meters, with wavelengths averaging 57 meters and heights ranging from 2 to 3.4 meters.
From a detailed analysis in the seismic records it was possible to classify three horizons according to their acoustic response. These horizons enabled the interpretation of some sedimentary processes that occurred in the Solimões River, such as a change in flow regime and dune migration records.

References

Abraham, D., Pratt, T. 2002. Quantification of the bed-load transport on the upper Misissipi River using multibeam survey data and traditional methods. US Army Engineer Research and Development Center (ERDC)/Costal and Hydraulics Laboratory (CHL), Coastal and Hydraulics Engineering Technical Note (CHETN), 9.

Albuquerque O.R. 1922. Reconhecimento no Vale do Amazonas. Bol. Serv. Geol. e Mineral. Rio de Janeiro, 3:1- 84.

Allen, J.R.L. 1970. Physical Processes of Sedimentation. Elsevier, New York, 433.

Almeida, R.P., Galeazzi, C.P., Freitas, B.T., Janikian, L., Ianniruberto, M., Marconato, A. 2016. Large barchanoid dunes in the Amazon River and the rock record: Implications for interpreting large river systems. Earth and Planetary Science Letters. 454, 92-102.

Bagnold, R.A. 1966. An approach to the sediment transport problem from general physics. U.S. Geol. Survey. 422-I, 11-137.

Best, J. (2005), The fluid dynamics of river dunes: A review and some future research directions, J. Geophys. Res., 110, F04S02, doi:10.1029/2004JF000218.

Caputo M.V., Rodriguez R., Vasconcelos D.N.N. 1972. Nomenclatura Estratigráfica da Bacia do Amazonas: histórico e atualização. In: SBG, Congr. Brasil. Geol., 26º, Belém, Anais, 3:35-46.

Cunha P.R.C., Gonzaga F.G., Coutinho L.F.C., Feijó F.J. 1994. Bacia do Amazonas. Bol. Geoc. Petrobr., 8(1):47-55.

Daemon R.F. 1975. Contribuição à datação da Formação Alter do Chão, Bacia do Amazonas. Rev. Bras. Geoc., 17:382-403.

Ernstsen, V.B., Noormet, R., Winter, C., Hebbeln, D., Bartholomã, A., Flemming, B. W., Barthody, J. 2005. Development of subaqueous barchanoid-shaped dunes due to lateral grain size variability in a tidal inlet channel of the Danish Wadden Sea. J. Geophys. Res. 110, F04S08, 13.

Franzinelli, E. (2011). "Características morfológicas da confluência dos rios Negro e Solimões (Amazonas, Brasil)". Revista Brasileira de Geociências. 41(4): 587-596.

Igreja, H. L. S. (1998). "Aspectos do modelo neotectônico da Placa sul-americana na Província estrutural amazônica, Brasil". Tese Concurso Prof. Titular, Universidade Federal do Amazonas, Manaus, 155.

Kleinhans, M. G. (2001), The key role of fluvial dunes in transport and deposition of sand-gravel mixtures, a preliminary note, Sedimentary Geology, 143, 7 – 13.

Latrubesse, E. (2008). "Patterns of anabranching channels: the ultimate end-member adjustments of mega-rivers. Geomorphology". 101(1-2), 130-145.

Mertes, L.A.K., Meade, R.H., 1985. Particle sizes of sands collected from the bed of the Amazon River and its tributaries in Brazil during 1982-84, Open-File Report 85-333, U.S. Geological Survey, Denver, Colorado.

Mertes, L. A. K., T. Dunne, and L. A. Martinelli, Channel-floodplain geomorphology along the Solimes–Amazon River, Brazil, *GSA Bull.*, 108(9), 1089–1107, 1996.

Parsons, D.R., Best, J.L., Orfeo, O., Hardy, R.J., Kostaschuk, R., Lane, S.N. 2005. Morphology and flow fields of three-dimensional dunes, rio Paraná, Argentina: results from simultaneous multibeam echo sounding and acoustic Doppler current profiling. J. Geophys. Res. 110, F04S03.

Poppe, L.J., DiGiacomo-Cohen, M.L., Smith, S.M. et al. 2006. Seafloor character and sedimentary processes in eastern Long Island Sound and western Block Island Sound. Geo-Marine Letters, 26: 59. doi:10.1007/s00367-006-0016-4.

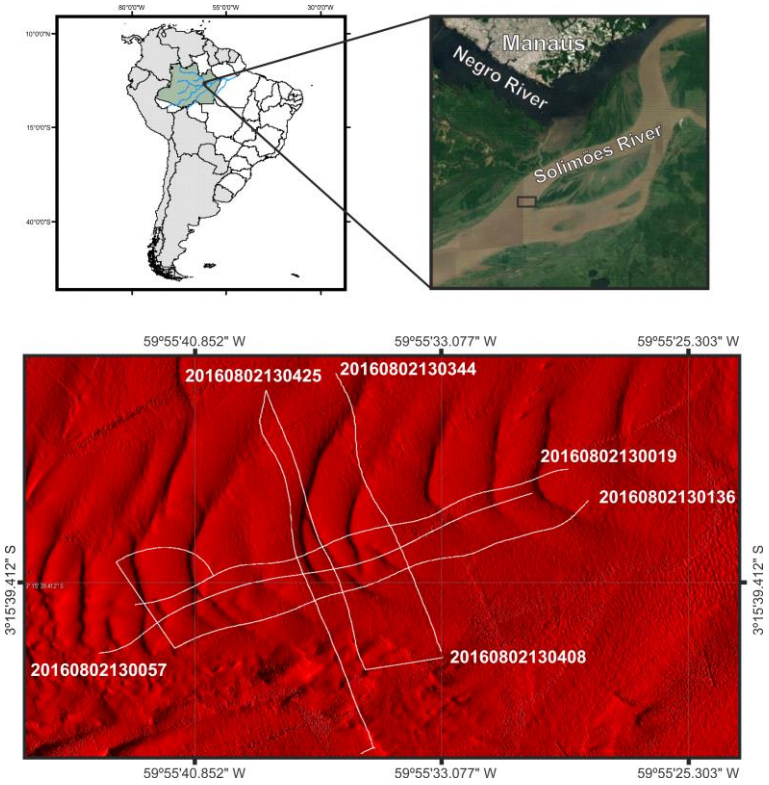
Potter, P.E., 1978. Significance and origin of big Rivers. The Journal of Geology, 86:1,13-33.

Smith, N. J. H. 2002. Amazon Sweet Sea: Land, Life and Water at the River's Mouth. University of Texas Press. 1-2.

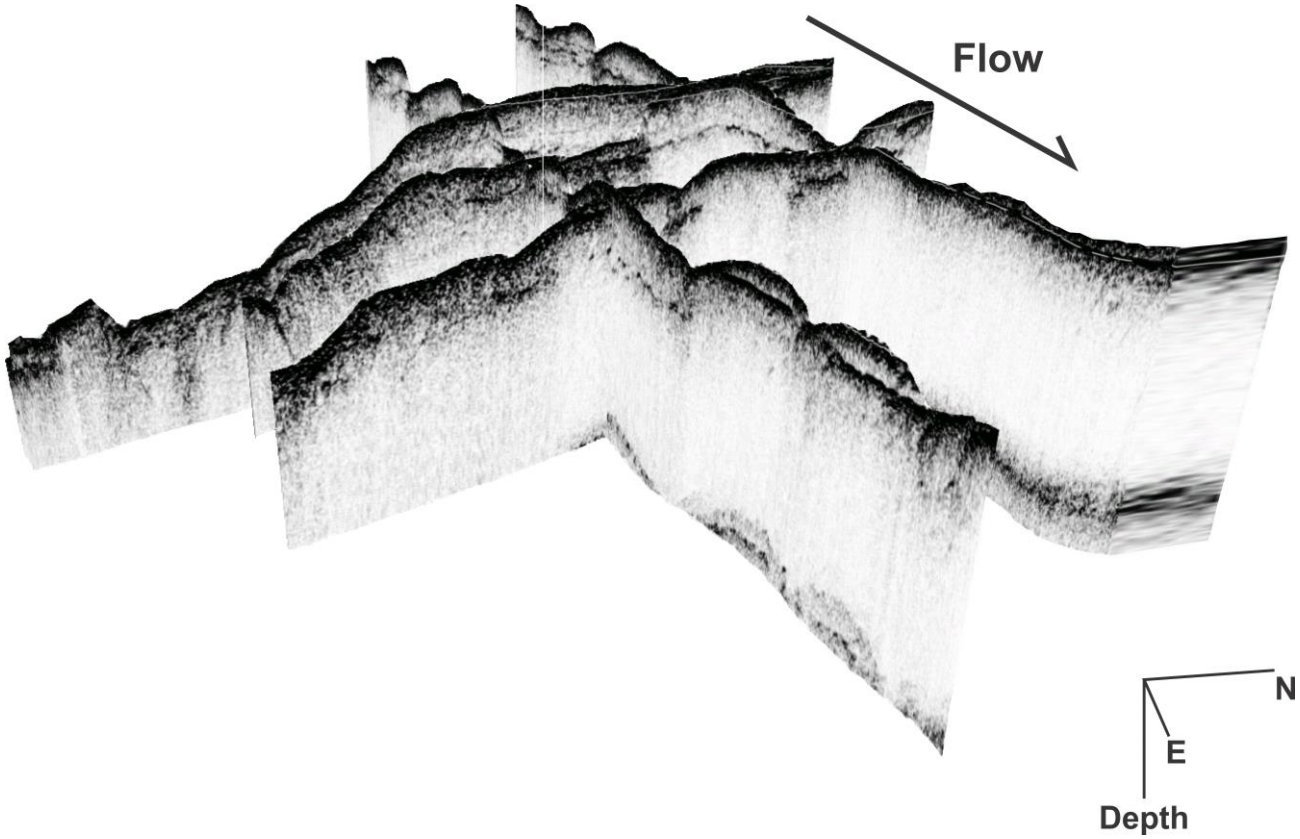
Sterling T. 1978. Der Amazonas. Time-Life Bücher, 8th German Printing, 19.

Suguio, K. 2003. Ambientes de sedimentação e fácies sedimentares. In: Geologia Sedimentar. São Paulo. 1ª ed. Ed. Blucher. 500.

Travassos W.A.S. & Barbosa Filho C.M. 1990. Tectonismo Terciário na área do Rio Tapajós, Bacia do Amazonas, Bol. Geoc. Petrobr., 4(3): 299-314.



Annex 1 – View of dune morphology with seismic tracks.



Annex 2 – 3D view of seismic profiles.