UNIVERSIDADE FEDERAL FLUMINENSE
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GEOMORFOMETRIA DA MARGEM CONTINENTAL DA FOZ DO AMAZONAS

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Dissertação apresentada ao Programa de Pós-Graduação em Dinâmica dos Oceanos e Terra, da Universidade Federal Fluminense, como requisito parcial para obtenção do grau de Mestre
Área de Concentração: Geologia e Geofísica Marinha

Orientador: Alex Cardoso Bastos

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Outubro de 2018

Ficha catalográfica automática - SDC/BIG
Gerada com informações fornecidas pelo autor

L392g Lavagnino, Ana Carolina Ribeiro Fieschi
Geomorfometria da margem continental da Foz do Amazonas / Ana Carolina Ribeiro Fieschi Lavagnino ; Alex Cardoso Bastos, orientador. Niterói, 2018.
72 p. : il.

Dissertação (mestrado)-Universidade Federal Fluminense, Niterói, 2018.

DOI: http://dx.doi.org/10.22409/PPGDOT .2018.m.12024931731

1. Benthic terrain modeler. 2. Dispersão da pluma do amazonas. 3. Recifes mesofóticos no amazonas. 4. Quebra da plataforma continental no amazonas. 5. Produção intelectual. I. Bastos, Alex Cardoso, orientador. II. Universidade Federal Fluminense. Instituto de Geociências. III. Título.

CDD -

Bibliotecário responsável: Debora do Nascimento - CRB7/6368

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Aprovada em 04/10/2018

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AGRADECIMENTOS

O caminho é muito mais valioso do que a chegada. É nele que nossa energia é mais demandada e que somos desafiados à grande chegada. Homenageio neste parágrafo pessoas que me foram importantes nessa trilha, principalmente nos dois últimos anos. Ao meu orientador que ensinou a fazer uma bela limonada quando só tínhamos limões azedos. Alex, obrigada por me guiar e fazer construir conceitos e muito aprendizado acreditando em mim mais do que eu mesma. Agradeço também a todos do LABOGEO que ao mesmo tempo em que me desafiaram com muita dedicação deixaram meus passos leves e com muito café sem açúcar! Agradeço ao Programa de Pós Graduação em Dinâmica dos Oceanos e da Terra e a CAPES pela bolsa concedida bem como ao Projeto Margem Equatorial financiado pela Brasoil. A Dalio Foundation e a Rede Abrolhos pelos dados coletados na Foz do Amazonas e cedidos para este trabalho bem como a Marinha do Brasil – DHN, Capitã Izabel King Jeck, pela ajuda na disponibilização dos dados regionais usados. Agradeço ao prêmio da Ron McDowell Student Support Award que me patrocinou a ida ao GEOHAB, congresso de mapeamento de habitas no qual pude fazer parte da comunidade internacional de “mapeadores”. Agradeço aos membros da banca por aceitarem me avaliar e contribuir para o desenvolvimento dessa pesquisa. Agradeço a minha família que sempre será meu porto seguro e homenageio meu avô Amilton que cumpriu seu papel neste mundo e me incentivou para além da vida. Aos meus pais que com seu amor incondicional me ensinaram a fazer o meu melhor e a valorizar a vida e os momentos em família e um coração sincero. A minha grande irmã Bibi e ao meu irmão JP que me sustentam com todo o seu carinho e apoio. Ao meu melhor amigo/parceiro/namorado Marcio, que me ensina a cada dia o que é amar. Por último, o que faz dar sentido a minha vida agradeço ao meu Pai, que me ensinou que a caminhada não faria sentido se não fosse para amar. Nunca ninguém viu a Deus; se amamos uns aos outros, Deus está em nós, e em nós é perfeito o Seu amor (1 João 4:12). Por isso, a minha homenagem e agradecimento irão para todas as pessoas maravilhosas que me foram colocadas no caminho para que este trabalho pudesse ter conclusão.

RESUMO

A Margem Equatorial Continental Brasileira em sua porção da Foz do Rio Amazonas foi analisada em termos de geomorfometria baseada em um grid batimétrico de 2,5 km de resolução utilizando o modelo BTM (Benthic Terrain Modeler), uma técnica de análise espacial que indica a possível ocorrência de habitats distintos em termos de heterogeneidade de relevo. Além disso, foram utilizados dados de multifeixe com um grid de 40 m de resolução para exemplificar a transição da plataforma e talude em alguns casos. Um desses grids foi interpolado para uma resolução de 5 m e foram usadas para caracterizar morfologicamente a feição mais notória da bacia atualmente, as estruturas recifais. A análise geomorfométrica da Margem Equatorial indica uma distribuição espacial distinta dos megahabitats, da plataforma interna ao mar profundo. O principal depocentro da pluma amazônica é ao longo da plataforma interna e média revelando a contínua influência da pluma na formação um depósito lamoso e suave (MFM - Mud Flat Shelf Megahabitat). A plataforma que não é continuamente influenciada pela pluma e acúmulo de sedimentos terrígenos provenientes do rio é caracterizada por um fundo carbonático dominado, principalmente por rodolitos e marcas de onda (CRM - Megahabitat de Estufa Rugosa de Areia / Carbonato). A diferença mais notável em termos da análise morfométrica e megahabitats pode ser observada ao longo da plataforma externa e a quebra da plataforma. O megahabitat da Transição plataforma-talude é muito distinto ao longo dos três setores mapeados. O primeiro setor localizado em frente a porção do Estado do Pará e Foz do Rio Pará, o segundo compreendendo a ilha de Marajó e a Foz do Rio Amazonas e o Terceiro a porção Norte do Estado do Amapá. Este megahabitat é marcado por duas classes geomorfométricas: cristas que definem a quebra de plataforma; e a maior inclinação da plataforma externa, definindo uma borda de quebra de plataforma externa, antes da quebra de plataforma. O setor que apresenta a borda da plataforma externa juntamente com as cristas é o S3 e foi onde o mapeamento acústico de alta resolução (5 m) apresentou recifes mesofóticos - entre 110 e 210 m de lâmina d'água atingindo altura máxima em torno de 20 m. Estas estruturas são recifes de borda da plataforma provavelmente formados durante o LGM (Último Máximo Glacial) que não foram enterradas devido à alta energia hidrodinâmica. O Setor 2 não apresenta quebra de plataforma definida, portanto não foram observadas cristas, apenas a classe de borda da plataforma externa. Isso está associado ao acúmulo de sedimentos em longo prazo e à formação do leque da Amazônia. O Setor 1 não apresenta a classe de borda da plataforma externa, apenas as cristas, apresentando canais incisos no vale na plataforma, isto é, é uma área muito erosiva com bypass de sedimentos e sedimentação de carbonato (dominada por rodolitos). Finalmente, os megahabitats de talude são muito diversos devido à ocorrência de depressões, isto é, cânion ou ravinas, enquanto que o megahabitat que não possui depressão é um habitat de bacias profundas.

Palavras-chave: Benthic Terrain Modeler, geomorfometria, habitats benticos, dispersão da Pluma do Amazonas, Recifes mesofóticos, recifes afogados, recifes de borda da plataforma.

ABSTRACT

The Brazilian Equatorial Continental Margin on its northeast portion – the Amazonas Mouth region - was analyzed in terms of geomorphometry based on a 2.5 km resolution bathymetric grid using BTM model (Benthic Terrain Modeler), a spatial analysis technique, which indicates the potential occurrence of distinct habitats in terms of relief heterogeneity. Also, 40 m grid resolution multibeam data were used to exemplify the transition from shelf to slope in some cases. One of these grids was interpolated for 5 m resolution and was used to characterize morphologically the current most notorious feature from the study region, reefs structures. The geomorphometric analysis indicates a distinct spatial distribution of megahabitats, from the inner shelf, to the deep sea. The main Amazon plume depocenter along the inner and mid shelf reveals the continuous influence of the plume forming a muddy and smooth deposit (MFM – Mud Flat Shelf Megahabitat). The shelf that is not continuously influenced by the plume and riverine terrigenous sediment accumulation is characterized by a carbonate dominated bed, mainly rhodoliths and sand waves (CRM - Sand/Carbonate Rugged Shelf Megahabitat). The most notable difference in terms of morphometric analysis and megahabitats can be observed along the outer shelf and shelf-break. The Shelf-Slope Transition megahabitat is very distinct along the three mapped sectors. First sector located in front of Pará State and Pará River Mouth, second sector in front of Marajó Island and third sector in front of Amapá State. This megahabitat is marked by two main seabed geomorphometric classes: ridges that define the shelf break; and the higher gradient of the outer shelf, defining an outer shelf edge, prior to the shelf-break. The sector that presents the outer shelf edge and the ridges together is the S3 and it was where the high resolution (5 m) acoustic mapping showed mesophotic reefs- between 110 and 210 m water depth reaching maximum height of around 20 m. These structures were probably formed as shelf-edge reefs during the LGM (Last Glacial Maximum) and were not buried due to the high energy hydrodynamics. Sector 2 presents no shelf-break, so ridges are not observed, only the shelf edge class. This is associated with long-term sediment accumulation and formation of the Amazon Fan. Sector 1, the southern-most sector does not present the outer shelf edge class, only the ridges, showing valley incised channels in the shelf, i.e., it is a very erosive area with main sediment bypass and carbonate sedimentation (rhodolith dominated). Finally, the slope megahabitat is very diverse because of the occurrence of depressions, i.e., canyons or ravines whereas Slope Depression Free Megahabitat is deep basin habitats.

Key-words: Benthic Terrain Modeler, geomorphometry, benthic habitats, Amazon Plume dispersion, mesophotic reefs, drowned reefs, shelf edge reefs.

SUMÁRIO

CAPÍTULO I

INTRODUÇÃO

Com o passar das décadas, houve um aumento da disponibilidade de dados digitais de batimetria em escalas global e regional que podem ser facilmente acessados e processados usando o Sistema de Informações Geográficas (GIS) e ferramentas de análise espacial. A análise espacial de terreno a partir de dados disponíveis se torna então uma ferramenta de grande utilização para a avaliação inicial de grandes áreas, padrões regionais e globais, propiciando assim uma primeira análise para investigação de áreas potenciais de levantamentos mais detalhados. Esta análise multi-escala vem então se tornando uma maneira de não só valorizar bancos de dados, mas também de possibilitar uma melhor abordagem detalhada em uma determinada área.

A margem equatorial brasileira representa uma região de grande apelo científico e exploratório devido ao grande aporte fluvial desempenhado pelo Rio Amazonas o que vem provocando não só o grande acúmulo de sedimentos ao longo do tempo geológico (Kuehl et al. 1986; Nittrouer and De Master 1996a, b) e gerando potencias reservatórios de hidrocarbonetos (Milani et al.200; Silva et al. 1999), como também toda a descarga de água doce no oceano Atlântico influenciando os diversos processos oceanográficos (Nittrouer et al. 1996; Geyer et al. 1996; Meade et al. 1979).

A Margem Equatorial da Foz do Amazonas é alvo de grande interesse na exploração de óleo e gás (Milani et al.2001), e recentemente se viu uma grande discussão de cunho ambiental em função da ocorrência de fundos recifais nas proximidades dos blocos aquisitados (Francini-Filho et al., 2018; Moura et al., 2016; Cordeiro et al., 2015). Desta maneira, algumas expedições foram realizadas, inclusive por organizações não governamentais como o Greenpeace e também por instituições de pesquisa como a parceria Woods Hole-UFRJ-Dalio Foundation a bordo do navio Alucia.

Uma das abordagens de base mais importantes em estudos para planejamento e uso do fundo marinho é o mapeamento de habitats bentônicos, que consiste no mapeamento geológico e biológico do fundo marinho (Greene et al. 2009). A integração e a análise de potenciais substitutos geofísicos e geológicos para o reconhecimento da ocorrência e distribuição de tipos de fundo ou de comunidades bentônicas é uma ferramenta amplamente usada e que pode ser aplicada como uma primeira análise da área a ser investigada. Sendo assim, a dispersão e deposição dos sedimentos da pluma do Rio Amazonas (Nittrouer and DeMaster 1996 a, b; Kuehl et al. 1986; Meade et al. 1979) atrelado ao alto dinamismo oceanográfico da região da borda da plataforma (Nittrouer and DeMaster 1996; Geyer et al. 1996; Lentz 1995b), bem como todo o processo geológico evolutivo da região, conferem a esta bacia a potencial ocorrência de megahabitats distintos. A lama se concentra na parte interna da plataforma (Nittrouer and DeMaster 1986; Milliman et al. 1975) enquanto que na zona externa ocorrem estruturas recifais de caráter único do mundo (Francini-Filho et al. 2018; Moura et al. 2016; Cordeiro et al. 2015). Sendo assim, é extremamente necessário o conhecimento abrangente do seu assoalho marinho bem como os padrões e tendências que caracterizariam um megahabitat na região. Estes padrões e tendências foram identificados em larga escala

Nesse contexto, esta dissertação tem como objetivo principal analisar padrões e tendências na distribuição de megahabitats ao longo da Bacia da Foz do Amazonas a partir do uso de um modelo geomorfométrico regional e discutir quais seriam os principais fatores que controlam esta distribuição em escalas temporais distintas. Além disso, foi conduzida uma análise morfológica em uma das feições mais discutidas e analisadas na região, as estruturas recifais. O presente trabalho de dissertação tem como formato dois capítulos, sendo o primeiro uma análise da geomorfometria e potenciais habitats do fundo marinho para a região da Bacia da Foz do Amazonas, enquanto que o segundo capítulo contempla um estudo morfológico das estruturas recifais. O estudo do primeiro capítulo utilizou-se de uma base de dados batimétrico da Marinha do Brasil livremente disponível para tratamento e análises. Já o segundo, contou com a disponibilidade de medição *in situ* através de sondagem acústica de multifeixe na borda da quebra da plataforma continental.

Para a elaboração da primeira parte deste trabalhou contou-se com o uso do grid batimétrico disponibilizado pela marinha do Brasil de 2,5 km de resolução (https://www.marinha.mil.br/dhn/?q=node/249). Esses dados foram tratados a partir do modelo de terreno bêntico – BTM, Benthic Terrain Modeler – desenvolvido pela ESRI que visa uma classificação supervisionada do fundo marinho através da execução de grid que derivam da batimetria tais como o de inclinação do fundo (slope) e o grid contendo o índice de posicionamento batimétrico de cada célula. Este índice batimétrico analisa espacialmente as posições georeferenciada do grid de batimetria e classifica cada célula de acordo com a média de elevação, estando acima, abaixo ou perto da média. Por fim, classes geomorfométricas foram agrupadas em potenciais habitats de acordo com a interpretação das feições e padrões encontrados.

Para a elaboração da segunda parte do trabalho, contou-se com o tratamento e o processamento de dados de multifeixe gerando um dado batimétrico de alta resolução (5 m) que possibilitou uma análise morfológica das estruturas recifais da região. Análises geomorfométricas também foram geradas com a finalidade de corroborar para o entendimento das estruturas.

CAPÍTULO II

GEOMORPHOMETRIC SEABED CLASSIFICATION OF THE BRAZILLIAN EQUATORIAL MARGIN AND POTENTIAL MEGAHABITAT DISTRIBUTION

SUMMARY

FIGURES

TABLES

1) INTRODUCTION

The Brazilian Equatorial Margin is the widest portion among Brazil Continental Margins and comprises the Foz do Amazonas Basin with approximately 360000 km² (Brandão and Feijó 1994; Silva et al. 1999). The modern set of this margin was stablished at 2.5 Ma (early-Pleistocene) and since then evolved based on the reshape of the Amazon river due to the Andean uplift event during Miocene (~10 Ma) (Gorini et al. 2014; Campbell et al. 2005; Figueiredo et al. 2009, Horn et al. 1995). This event changed the predominance of a carbonate platform to a siliciclastic-dominated shelf, contributing to the development of the Amazon Fan (Milliman et al. 1975; Gorini et al. 2014; Brandão& Feijó 1994). In addition, the low stand sea level during the Miocene was responsible to expose, karstify and erode carbonates that later on, from Mid-Pleistocene to Holocene progradation produced a steeper slope prone to failure and mass wasting events that transported slope sediments to the basin (Gorini et al. 2014).

During high stand sea level, the sedimentation along this margin is highly influenced by the Amazon River, one of the largest rivers in the world, responsible for around 20 % of the global riverine discharge (Coles et al. 2013). This River is responsible for a solid discharge of 10 billion tons of sediment per year (Meade et al. 1979) and is actively developing a fine-grained submergeddelta over an area of 3.3 x 10^5 km² (Kuehl et al. 1986; Nittrouer and DeMaster 1996a, b; Nittrouer and DeMaster 1996). The Amazon River plume is superficially (25 m maximum depth) driven by seasonal winds and currents that flows northwestward into the Caribbean by North Brazilian Current (Nittrouer and DeMaster 1996), while during September and October it retro-flexes eastward (Moura et al. 2016). This is a typical interglacial - high stand sea level - sediment dispersion configuration (Milliman et al. 1975; Milliman et al. 1982; Nittrouer and DeMaster 1986). During glacial – low stand sea level - sediment load bypasses the shelf break and is transported to the deep sea through various canyons and channels (Damuth and Fairbridge 1970; Milliman et al. 1975; Damuth and Kumar, 1975; Damuth and Flood 1984; Damuth et al. 1988), enabling, on the outer shelf, the occurrence of carbonate structures (Barreto et al. 1975; Milliman and Barretto 1975; Kumar et al. 1977; Moura et al. 2016).

Besides, this is a promising area with an enormous demand in terms of oil and gas exploration and production. It is part of the “Deep Water Golden Triangle” in the Atlantic Ocean, comprising Brazil, Gulf of Mexico and West Africa. These geologically similar margins comprise large accumulation of excellent quality and high commercial value oil (Milani et al. 2001). More than hundred exploration blocks were offered in auction in the past 5 years. Exploration in this area is still a matter of discussion and concern due to conservation issues related to the recently mapped reef system out of the Amazon mouth.

This background gives us a brief idea on how important this area is and its geological appeal worldwide. Since the 70’s there is a vast amount of survey effort to characterize sediment dynamics and stratigraphy of this margin continental shelf (Milliman et al. 1975; Nittrouer et al. 1996) as well as on continental slope (Gorini et al. 2014; Reis et al. 2010; Silva et al. 2000). In this context, a regional analysis of the shelf-slope-rise system geomorphology is relevant to understand the distribution of distinct seabed sedimentary features. Considering the recent discussion about carbonate sedimentation and the occurrence of mesophotic reefs along the shelf and shelf break (Francini-Filho et al. 2018; Moura et al. 2016; Cordeiro et al., 2015), a quantitatively terrain characterization can be a powerful tool to map potential benthic habitats based on their morphology (Lecours et al. 2016). Thus, the purpose of the current work is investigating if spatial changes in geomorphometric patterns along continental shelf and slope can be used as a proxy for habitats distribution. The work carried out along the Equatorial Margin was based on the use of the geomorphometric model, the BTM, Benthic Terrain Model (Waldbrige et al. 2018), which indicates the potential occurrence of distinct habitats in terms of relief heterogeneity.

2) METHODS

2.1) Bathymetric data set

A Digital Terrain Model (DTM) was produced by using a database obtained from the Diretoria de Hidrografia e Navegação – Marinha do Brasil (LEPLAC – Project). This bathymetric database is a compilation from seismic, single beam, multibeam and remote sensing data acquired from institutions as GEODAS (NOAA Geophysical Data System), GEBCO (General Bathymetric Chart of the Oceans from International Hydrographic Organization – IHO and the Intergovernmental Oceanographic Commission – IOC, UNESCO), PETROBRAS, ANP (Petroleum National Agency). Also, STRM30_Plus V7.0 (NASA Shuttle Radar Topography Mission) was used to fill further regions lacking *insitu* data. Data validation was carried out by a cross-check verification considering control lines as reference, using an Oasis Montaj tool, LevTie Line/Intersections and Rangrid GX/Geosoft. Minimum curvature and a cell size of 1500 m was adopted with Equatorial Mercator Projection and Datum (False N=0, False E=0, Latitude Origin=0, Longitude Origin=0 e Scale Factor Origin=1), WGS1984. The data was provided as a xyz file that was interpolated using ArcGIS IDW method, originating a 2.5 km grid. Slope longitudinal profiles along 3 sectors of the basin were delineated using ArcGIS 3D Analyst toolbox.

Concerning regional studies, GEBCO_2014 - 30 arc-second grids is the most used dataset worldwide. Even though is a 900 m resolution, for the area of interest the quality of data is better with LEPLAC, a 2, 5 km grid. GEBCO uses more altimetry rather than *in situ* data whereas in LEPLAC is a compilation of higher quality data being also altimetry only when it is further away.

Multibeam data available were also used to exemplify morphological features. The data set was acquired during the Alucia expedition on July 2017 using Reson 7160 multibeam echosounder operating at a nominal frequency of 44 kHz. The data was processed at CARIS

HIPS and SIPS software to remove any noise and adjust for sound velocity in the water column. Three multibeam mosaics were produced with 40 m cell size.

2.2) Seabed Classes

Bathymetric regional grid along with its derivate slope and Bathymetric Position Index (BPI) were used to produce morphometric analysis applying an ArcGIS toolbox, BTM – Benthic Terrain Modeler 3.0 (BTM), a combination of spatial analysis scripts aiming to classify seabed (Walbridge et al. 2018).

First, bathymetric values must be converted to negative and through a series of automatic mathematical algorithms, geomorphometric classification was accomplished. Slope values are the maximum rate of change for each cell and its neighbor, but the main concept behind BTM is BPI - a marine version of the terrestrial Topographic Positioning Index, TPI – (Weiss et al. 2001). This index evaluates elevation differences between focal point and mean elevation of its surrounding cells within a user defined area (Lundblad et al. 2006). The most used defined area to run BTM is via *annulus*, a donut shape area where from the focal point to each circle border a number of grid units is chosen for both inner and outer radius. The outer radius multiplied by data resolution defines the scale factor and the best way to identify the most suitable factor for the analysis is by trial-and-error (Erdey-Heydorn et al. 2008).

Intrinsically scale-dependent, BPI differ benthic features in both fine and broad scales. For example, at a small BPI neighborhood a large valley would appear as a flat plain whereas at a scale of several kilometers the same area will look like a deep canyon, which may be more significant for looking at overall processes. Combining BPI at fine and broad scale allows a variety of nested features to be distinguished. BPI positive cell value, greater than surrounding cells mean, defines high elevation areas (crests); negative cell value, lower than the surrounding cells mean, defines low elevation areas (depressions) and near or equal to zero cell value, close to the mean, defines flat areas (Weiss et al. 2001).

Once spatial data tends to be auto correlated, the raw BPI has to be standardized which allow classification of dataset at almost any scale (Lundblad et al. 2006). The fine scale grid was generated with a scale factor of 5000 and a broad scale grid was generated with a scale factor of 15000. Both BPIS' were used to classify the Amazon continental shelf and slope. These scale factors were chosen once, at the site, the small seascape features are, on average, about 5000 m across. This is based on thorough observation of the bathymetry prior to BPI calculation.

The final step to finalize BTM script is related to a dictionary. The dictionary is a table that categorizes the bathymetric BPI and slope grid into classes designated by the user (Tab.1). The categories work within a lower and upper bound. For BPI, the number 40 means that for this analysis 40 grid units were used. Negative values mean bellow the standard deviation while positive values mean above it. For example, in order to classify features such as depressions, the upper bound is set as negative values, whereas to classify positive features like crests, the lower bound is set as a positive value. For slope, we set the angle threshold as 0.1 (based on the majority part of the continental shelf exhibit values bellow that). This means that above the threshold the gradient is steep, while below it, the gradient is gentle. Finally, in terms of depth, the continental shelf was divided into three portions: up to 40 m water depth, inner shelf; from 40 to 60m, mid shelf; from 60 to 100 m water depth, outer shelf; and from 100 to 300 m outer shelf edge.

Twelve classes were defined based on depth (3 classes), slope (2 classes), depth and slope (1 class) and BPI (6 classes) (Tab.1). Regarding water depth, the classes are: (1) Inner Shelf (up to 40 m water depth), (2) Mid Shelf (40 to 60 m water depth), (3) Outer Shelf (60 to 100 m water depth), (4) Outer Shelf Edge (100 to 300 m water depth and lower than 0, 1° slope). Regarding only BPI, the classes are: (5) Ridge 1 – defined as crest on broad scale, representing a great plateau where gradient tends to become less gentle, (6) Ridge 2 –crest on both broad and fine scale, depicting the shelf break or depression edges where the gradient is about to get steeper, (7) Edges - crest on fine scale, associated with depression edges; (8) Thalweg 1- depression on both broad and fine scale, representing axial incision associated with the thalweg of broad scale depression, (9) Flanks - depression on broad scale, related to depression walls; (10) Thalweg 2 - depicting axial incision associated with the thalweg of fine scale depression. Regarding slope, the classes are: (11) Gentle Slope (values lower than 0.1°), (12) Steep Slope (values higher than 0.1°).

Apart from the BTM related grids, the Aspect analysis was also carried out. Aspect is another bathymetric derived grid that is used to analyze seabed direction. The aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors which is the slope dipping direction.

Table 1: BTM dictionary. Seabed classes were categorized into BPI on both broad and fine scale, slope and depth using a lower and upper bound. 40 grid units were used and missing value indicates that the bound is not applicable to the seabed class.

	Broad BPI		Fine BPI		Slope		Depth	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1) Inner Shelf	-40	40	-40	40			-40	
2) Mid Shelf	-40	40	-40	40			-60	-40
3) Outer Shelf	-40	40	-40	40			-100	-60
4) Outer Shelf Edge	-40	40	-40	40		0.1	-300	
5) Ridge 1	40		40					
6) Ridge 2	40		-40	40				
7) Edges	-40	40	40					
8) Thalweg 1		-40		-40				
9) Flank		-40						
10) Thalweg 2				-40				
11) Gentle Slope	-40	40	-40	40		0.1		
12) Steep Slope	-40	40	-40	40	0.1			

2.3) Slope Depressions

The DTM was used to map individual depressions on continental slope. The BTM results more specifically Thalweg 1 and 2 classes were distinctly used to set the beginning and the ending of depression features whereas the isobaths were used to track the axial incisions. Depressions metrics were measured using ArcMap 10.1 toolbox. The metrics are: length (m), sinuosity – length/straight length, area (km^2), minimum depth (m) - where canyons start, maximum depth (m) – where canyons end, slope mean (°) – gradient measurement at the canyon thalweg.

3) RESULTS

The Equatorial Margin can be divided into three sectors, based on their distinct characteristics of the shelf-slope transition region being them slope curvature (Figs.1 and 2) and shelf break depth, break zone differences (described after): sector 1 (S1), on the southeast side of the Amazon Fan, in front of Pará River and Marajó Island; sector 2 (S2), related to the Amazon Fan, in front of the Amazon River Mouth; sector 3 (S3), on northwest side of the Amazon Fan, in front of Amapá State.

The morphological profiles presented in Figure 2 show the distinct morphological characteristics among the sectors. Sectors 1 and 3 have an abrupt and well defined shelf breakpoint, while S2 show a smoother shelf – slope transition, with no clear break-point (Fig 2a). The notorious distinction between S1 and S3 is related to the depth of continental shelf break. Along S1, the shelf breaks around 100 m of water depth, while in S3 the shelf breaks around 300 m water depth (Fig 2a). Moreover, the shelf-slope transition in S3 is marked by a sort of outer shelf edge, similar to a plateau or terrace from 100 to 300 m water depth. The continental slope profiles also show distinct morphological curvatures being S1 convex, S2 concave and S3 sigmoidal (Fig 2a). S1 and S3 slope profiles are flatter on the continental shelf portion getting steeper on the shelf edge region, reaching their maximum magnitude at the shelf break zone (not higher than 6° for S1 yet higher than 7° for S3) whereas S2 is constantly smooth (values are not higher than 2°) (Fig 2b). In all three sectors, slope value gets lower than 1° magnitude at depth higher than 3000 water depth (Fig 2b).

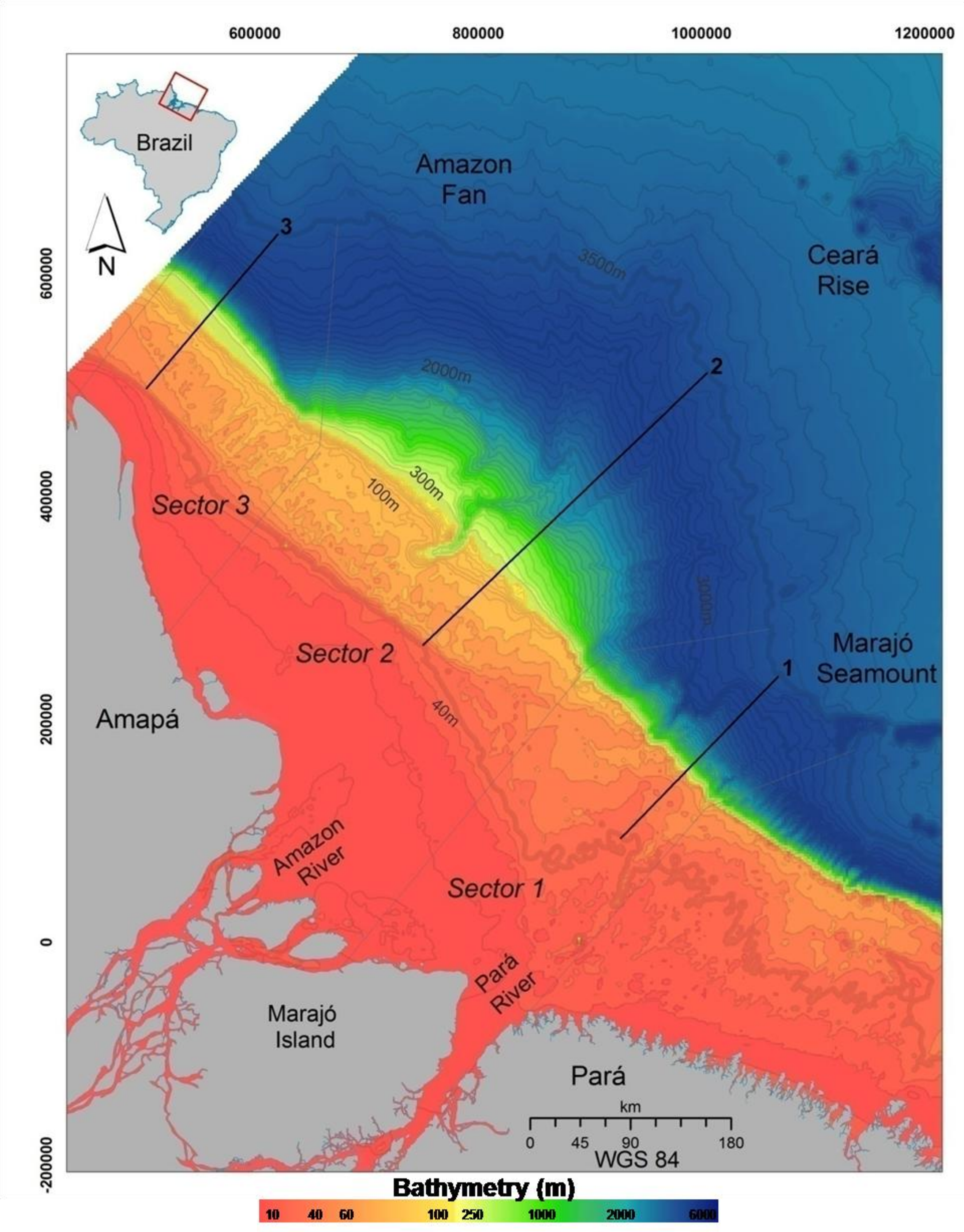

Figure 1: Study site delineated by sectors according to the shelf slope transition. Bathymetric grid available from Brazilian Navy, 2.5 km resolution. Grey dashed lines are sectors' border and black lines are geomorphological longitudinal profiles within each sector (from 40 m to 3500 m water depth – thicker isobaths). Isobaths are 10 m water depth spaced up to 300 m water depth and from then on 100 m water depth spaced.

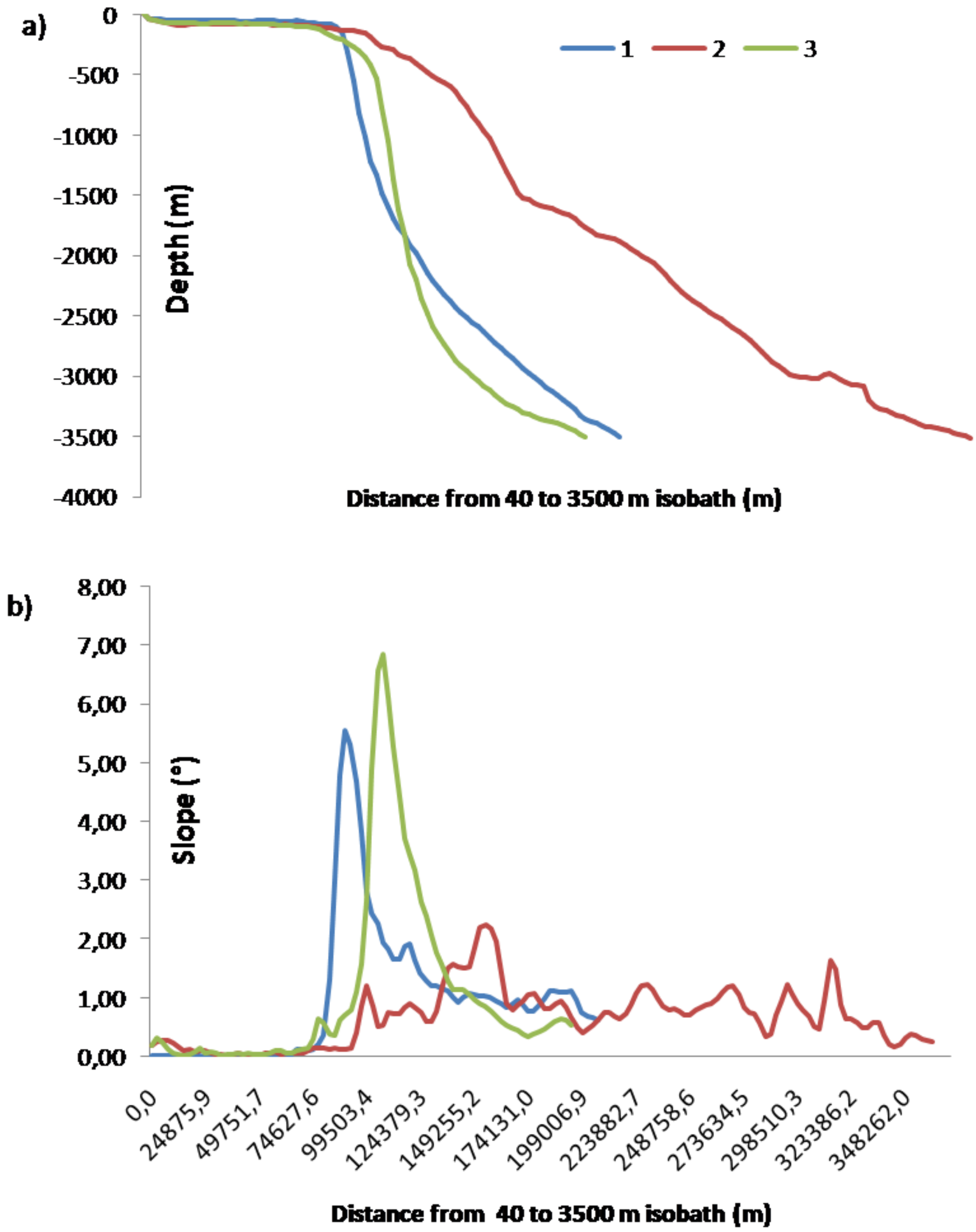

Figure 2: (a) Longitudinal geomorphological profiles from 40 to 3500 m water depth for each sector. Sector 1 breaks at around 100 m water depth depicting a concave curvature, sector 2 has no defined break with a convex curvature and sector 3 breaks at around 300 m water depth showing a sigmoidal curvature. (b) Longitudinal slope profiles for each sector: near 0° slope values are found at the inner shelf for all sectors while on the shelf edge region on sector 1 and 2, profiles are steeper. Sector 3 is smoother and values are no higher than 2°.

3.1) Seabed Classes

The seabed classes' description comprises the geomorphometric model results (Slope and BPI – Fig 3) as well as the Aspect analysis. Twelve seabed classes were modeled by BTM: Inner Shelf (1), Mid Shelf (2), Outer Shelf (3), Outer Shelf Edge (4), Ridge1 (5), Ridge 2 (6), Edges (7), Thalweg 1 (8), Flank (9), Thalweg 2 (10), Gentle Slope (11) and Steep Slope (12) (Fig. 4). All crest - related seabed classes are associated with above mean BPI, i.e, they are either related to the shelf break or depression edges depicting also steeper regions (seabed classes 5, 6, and 7). Depression-related seabed classes are associated with below mean BPI, depicting depression thalweg or lower regions (seabed classes 8, 9, and 10).

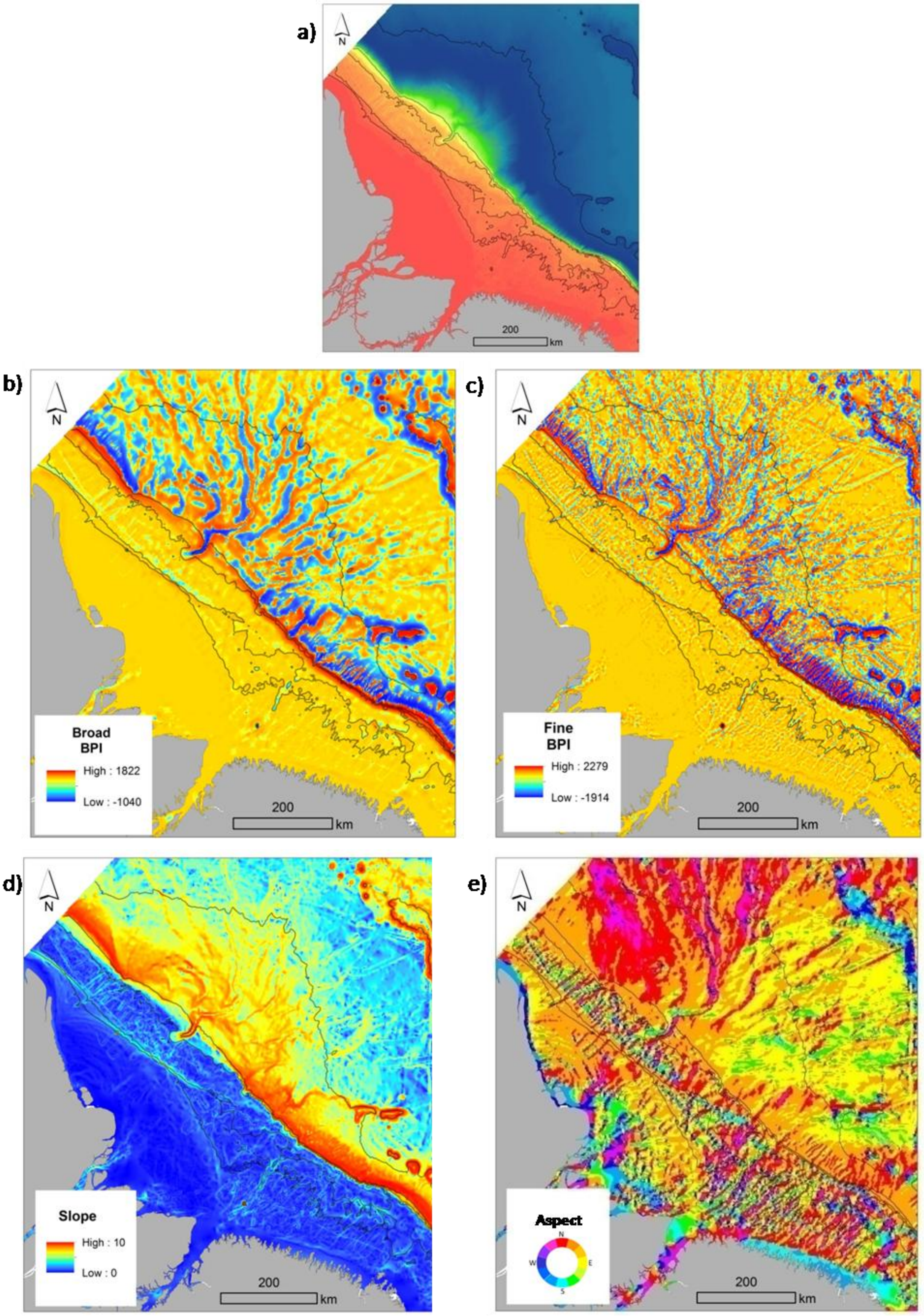

Figure 3: Benthic Terrain Modeler Fluxogram (a-d); (a) Bathymetric Grid, (b) Broad BPI standardized, (c) Fine BPI standardized, (d) Slope. (e) Aspect grid – not used for BTM analysis. Black lines referred respectively to 40, 60, 100 and 3500 m water depth isobaths.

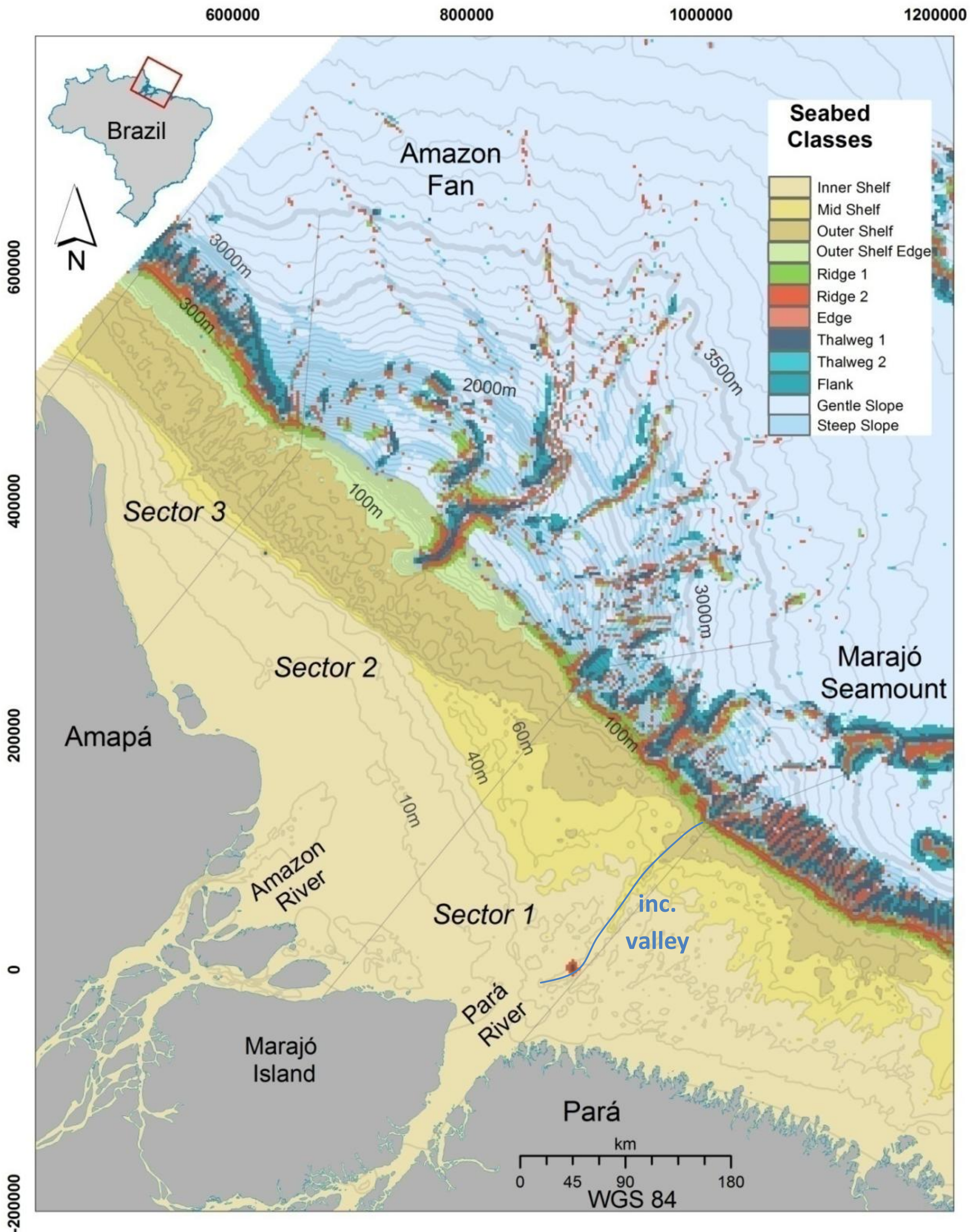

Figure 4: Seabed geomorphometric classes defined using the Benthic Terrain Modeler (BTM) according to DTM and its derivate BPI and slope as well as the dictionary (Tab. 1). Sectors were defined according to the shelf slope transition differences found in the region and grey dashed lines are delineating them. Isobaths are 10 m water depth spaced the shoreline up to 300 m water depth and from then on 100 m water depth spaced. The thicker isobath featured are 300 m water depth and the last one is limit, 3500 m water depth, that we will present in this work.

Table 2: Overall measurements of continental shelf and continental slope per sector.

	Sector 1	Sector 2	Sector 3
Continental Shelf			
Width	330 km	390 km	230 km
Inner	*170*	*200*	*115*
(~40 m wd)	*parallel/reentrant**	*parallel**	*parallel**
Mid	*80*	*10-70***	*4 – 20***
(40 – 60 m wd)	*reentrant**	*parallel/reentrant**	*parallel**
Outer	*80*	*90*	*80*
(60-100 m wd)	*reentrant**	*reentrant**	*reentrant**
Outer Edge	-	50	20
(100-300 m wd)	*parallel**	*parallel**	*parallel**
Slope Range	0-0,21°	0-0,47°	0-0,35º
Shelf Break	100 m	no break	300 m
Continental Slope			
Width	90 km	210 km	60 km
Slope Range	0,1-7,7°	6,14°	9,1°

wd= water depth
**Isobaths configuration within the seabed class*
***Mid Shelf range width, shown when the wide varies dramatically*

Table 3: Percentage of seabed classes per sector.

	Sector 1		Sector 2		Sector 3	
1) Inner Shelf	38		33		30	
2) Mid Shelf	18		3		4	
3) Outer Shelf	10		10		25	
4) Outer Shelf Edge	0,1	*66,01%**	3	*49%**	6	*65%**
5) Ridge 1	3		2		3	
6) Ridge 2	4		2		3	
7) Edges	2	*9%**	2	*6%**	1	*7%**
8) Thalweg 1	4		1		4	
9) Flank	2		1		2	
10) Thalweg 2	2	*8%**	1	*3%**	1	*7%**
11) Gentle Slope	10		30		14	
12) Steep Slope	7	*17 %**	12	*42%**	7	*21%**

**sum of above seabed classes*

Table 4: Division of Sector 2 continental slope gradient values, I from 100 to 1000 water depth, II (1000 – 2000 water depth), III (2000 – 3000 water depth), and IV (3000 – 3500 water depth). The slope values are shown according to maximum value (mean value).

	NW	SE
I	5,08° (0,93°)	6,14° (1,16°)
II	5,58° (1,41°)	4,80° (1,30°)
III	2,36° (0,86°)	3,08° (0,34°)
IV	1,02° (0,55°)	1,90° (0,55°)

Sector 1

The continental shelf has 330 km maximum width. It is manly flat, apart from valley edges where the slope is significantly steeper but not more than 0.21° (Fig. 3c, Tab. 2). One notorious feature from this sector continental shelf is an incise valley that goes from 30 to 60 m deep, on the SE most side (Fig.4 – inc. valley). Inner Shelf (1) is 170 km wide, representing 38% of the sector (Fig. 3, Tab. 2, and Tab. 3). A distinct diagonal geometry isobath –SE to NW oriented -ranging from 20 to 40 m water depth is observed. On its NW portion, the isobaths are regular, while on the SE are more irregular (Fig. 4, Tab.2). Mid (2) and Outer Shelf (3) are 80 km wide and the isobath geometry follows the same irregular pattern described above (Fig. 4, Tab. 2) representing, respectively, 18% and 10% of the sector (Tab. 3). Aspect (seabed dipping) on the Inner Shelf (1) (regular geometry) is N-NE preferably whereas on the Mid (2) and Outer Shelf (3) (irregular geometry) there is no preferred direction (Fig. 3 d).

On the shelf edge region, an almost 20 km wide feature, combining seabed classes Ridge 1 and Ridge 2,constitutes the shelf break zone at around 100 m water depth (Fig. 4). The same seabed classes, however, on deeper areas along with the Edges (7) compose depressions edges (Fig. 4). Ridge 1 (5), Ridge 2 (6) and Edges (7) represent, respectively, 3%, 4% and 2% of the sector (Tab. 3). The 90 km wide continental slope is steeper from 100 to 3500 m water depth reaching an angle of 7.7° and after that, the slope becomes gentler (less than 0.1°) apart from the Marajó Seamount area (Fig. 3c, Tab. 2). The continental slope is where most of the sectors' features are observed being defined by crests seabed classes (5, 6 and – representing 9% of the sectors area) and depressions classes (8, 9, 10 – representing 8% of the sectors area) (Fig. 4, Tab. 3). Steep Slope (12) is observed around the classes described above, representing 7% of S1 (Fig.4, Tab.3). This class marks where the sector shifts for deeper and smoother region (3000 m, 0,1°) where the sector is dominated by Gentle Slope (12), representing 10% of S1 area (Fig. 4, Tab. 3). In terms of aspect on continental slope, seabed dipping orientation is mostly N- NE (Fig. 3d).

Sector 2

The maximum continental shelf width in this sector is 390 km (Tab.2). Inner Shelf (1) and Outer Shelf (3) are flat, whereas the Mid Shelf (2) and Outer Shelf Edge (4) show higher slope values (Tab.2, Fig. 3c, Fig.4). The Inner Shelf (1) is 200 km wide, with regular isobath geometry and the same diagonal pattern described for S1 (from SE to NW) appear (Fig. 4, Tab.2). The Mid Shelf (2) shows a narrowing from 70 to 10 km wide in the same direction of the diagonal pattern described above (Fig. 4). The narrower part of this class has a regular geometry whereas the wider part has an irregular geometry (Fig. 4, Tab. 2). The Outer Shelf (3) is 90 km wide and depicts an irregular pattern (Fig. 4, Tab. 2).

The Outer Shelf Edge (4) is 50 km wide and shows a regular geometry isobath (Fig. 4, Tab. 2). The Inner Shelf (1) represents 33%, Mid Shelf (2) 3%, Outer Shelf (3) 10% and Outer Shelf Edge (4) 3% of S2 area (Tab 3). Seabed dipping on S2 follows the same pattern as S1 being on Inner Shelf (1) (regular geometry) preferably N-NE direction while on Mid (2) and Outer Shelf (3) (irregular geometry) no prevailing direction (Fig. 3 d). On Outer Shelf Edge (4) there is a prevailing dipping direction N –NE.

Following the Outer Shelf Edge (4), the continental slope comprises the notorious Amazon Fan System, measuring 210 km in width and ranging from 300 to 3500 m water depth. The shelf depicts no sharp break. The Amazon Canyon incises at 100 m water depth and its associated channels can be observed deeper than 3500 m water depth. The slope considerably varies in this portion of the sector, being steeper on the upper part of the Fan. Based on the seabed classes obtained herein, the Amazon Fan can be divided in four portions (I, II, III, IV) according to the water depth (up to 1000 m, up to 2000 m, up to 3000 m, and up to 3500 m; respectively), and also into two sections (NW and NE – being the Amazon Canyon the limiting feature) (Tab.4). SE-I has the relative highest slope value of 6° and all the other values are depicted at table 4. Once S2 depicts no clear shelf break, Ridge 1 (5) and Ridge 2 (6) classes act as depressions edges that combining with Edges (7) represents 6% of S2 area. Depressions shape classes such as Thalweg 1 (8), Flank (9) and Thalweg 2 (10) represent 3 % of S2 area (Tab. 3). Gentle Slope (11) is the most representative class of the sector, occupying 30% of S2 area, whereas Steep Slope (12) represents 12% of S2 area (Tab. 3). In terms of the aspect analysis, the continental slope seabed orientation is mostly N- NE on the NE side and N-NW on the NW side (Fig. 3d).

Sector 3

In S3, the continental shelf is 230 km wide (Tab. 2), manly flat. The Inner Shelf (3) is the most representative feature of the sector occupying 30% of the area (Tab. 2 and 3).The Mid Shelf (2) ranges from 4 to 20 km in width, representing only 4% of S3 area. Both seabed classes depict a senoidal parallel oriented isobaths that follow the same diagonal (from SE to NW) as described for the previous sectors (Tab. 2 and 3). The Outer Shelf (3) comprises 25% of S3 area (80 km wide) showing an irregular isobaths configuration (Tab. 2 and 3). The Outer Shelf Edge (4) is 20 km wide, regular geometry isobaths representing 6% of S3 area (Fig. 4, Tab. 2 and Tab. 3).

The slope values on S3 continental shelf reaches a maximum of 0.35° on the Mid Shelf (2) and also on valley edges on the Outer Shelf (3) (Fig. 3c and Tab. 2). In terms of aspect, the continental shelf seabed orientation is mainly N to NE where the configuration is regular and more chaotic oriented in the irregular isobaths area (Fig. 3).

The shelf edge is defined at around 300m water depth and is marked by a transition from the Outer Shelf Edge (4) to the seabed classes Ridge 1 and 2 (5, 6), which combined represents the shelf break region – the same representation found in S1. However, in S1 these classes also could be representing crests features at the border of depression, not herein in S3. Ridge 1 and 2 (5, 6) represent 6 % of S3 (Tab. 3). Confined at the continental slope are classes that define depressions Thalweg 1 (8), Flank (9) and Thalweg 2 (10) representing 7% of S3 (Tab.3). The Edge (7) is the only crest associated seabed class that is depicted in S3 continental slope representing 1% of S3 area (Tab. 3). The continental slope on S3 is the steepest among all other sectors an angle of 9.1º and is 60 km wide (Tab.2). Steep Slope (12) is the seabed classes that come after the ones described previously representing 7% of S3 area and is followed by Gentle Slope (11) representing 14% of S3 area (Tab. 3). In terms of continental slope seabed dipping orientation is mostly N- NE (Fig. 3).

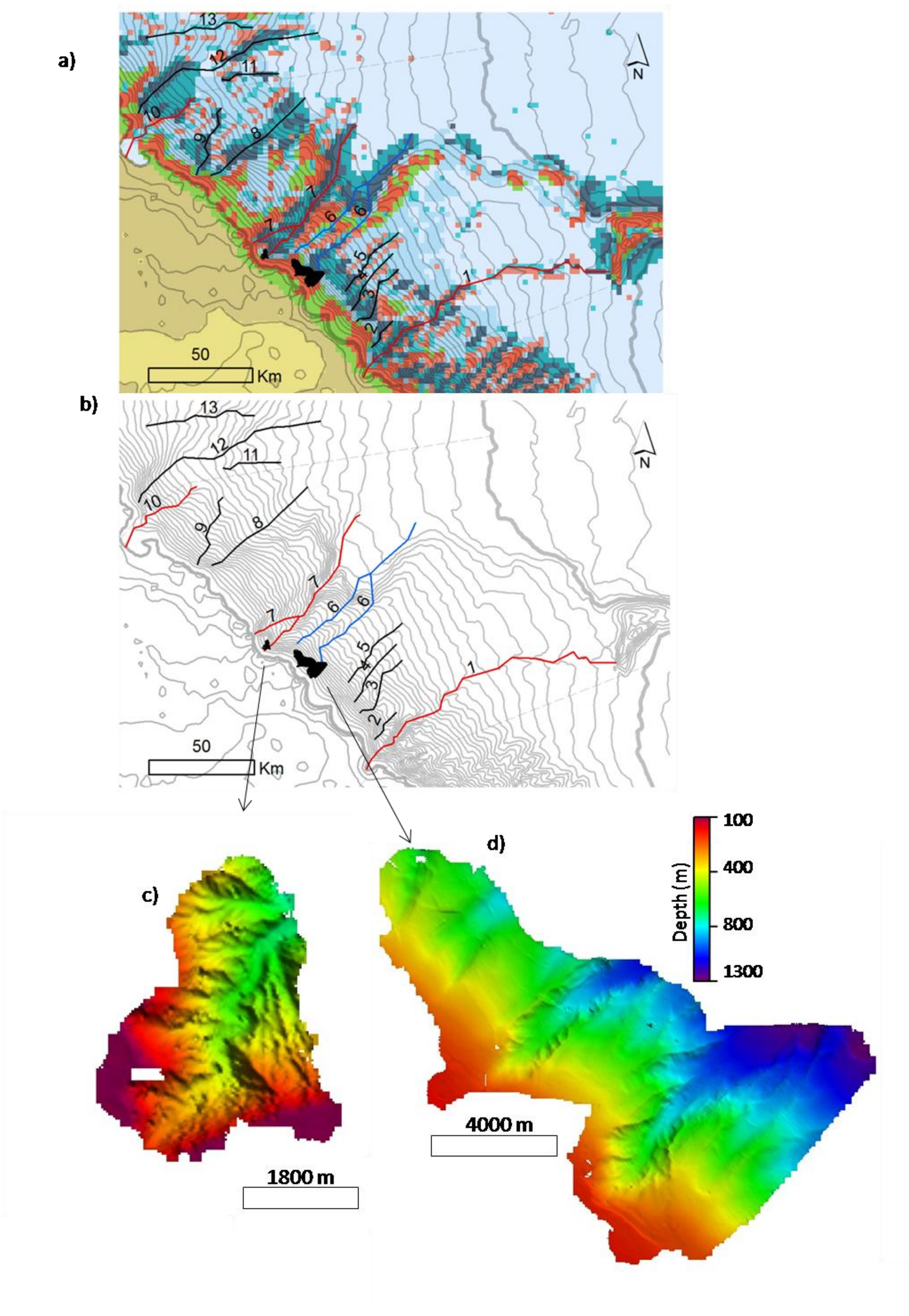

Figure 5: Sector 1 continental slope depression mapping. The mapping procedure followed the combined methods of delineation by BTM seabed classes Thalweg 1 and 2 (a) as well as the use of DTM with isobaths spacing 100 m water depth each (b). Types of depression are distinguished by colors: (1) depressions not classified as canyons and confined at the continental shelf (black lines), (2) canyons that are continental slope confined (blue lines) and (3) canyons that incise the continental shelf (red lines). Arrows from figure b to c show the location of a 40m resolution multibeam mapped area with examples of canyons incising on the continental shelf (c) and canyons confined at the slope (d). Vertical exaggeration 1.

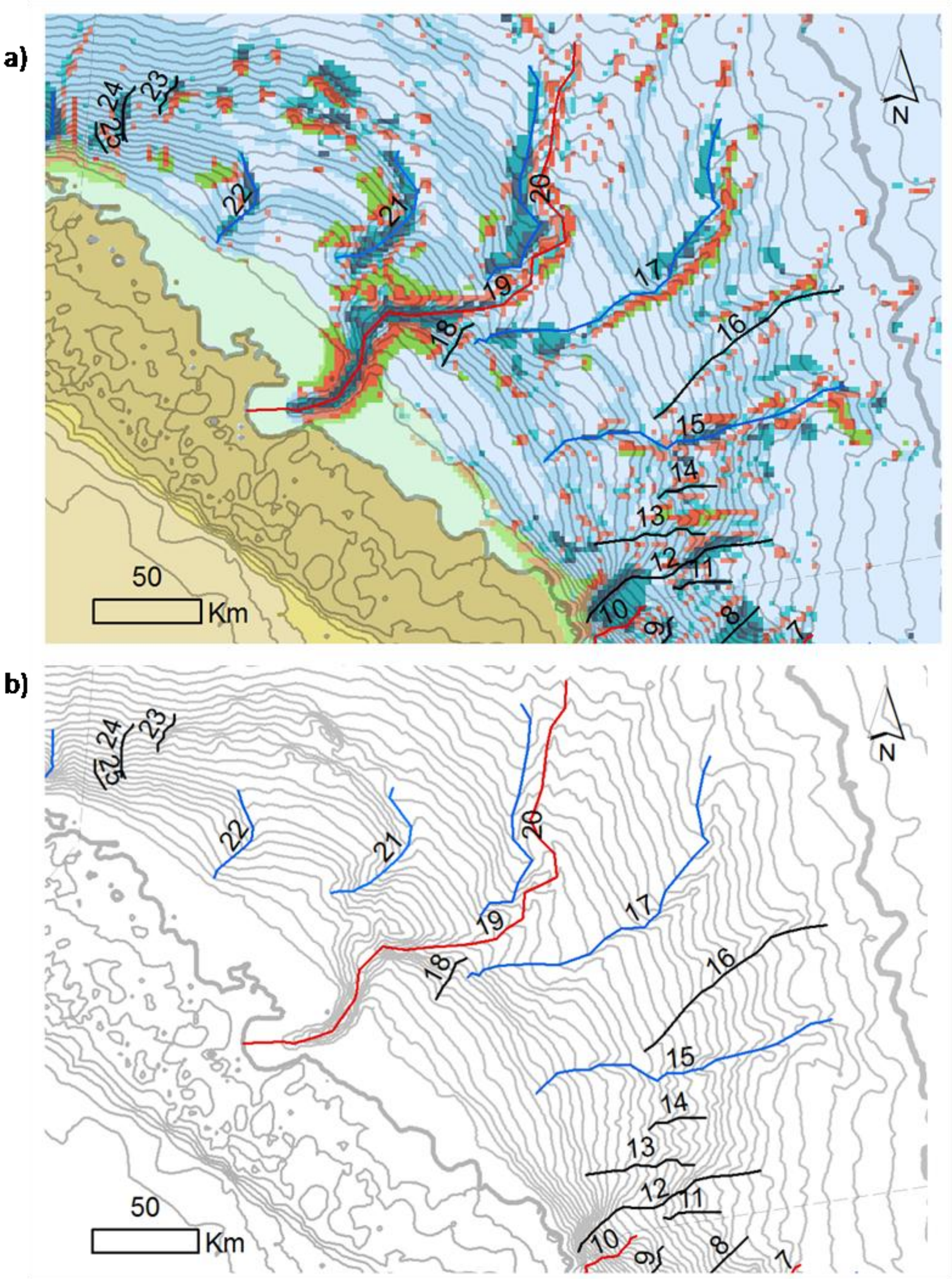

Figure 6: Sector 1 continental slope depression mapping. The mapping procedure followed the combined methods of delineation by BTM seabed classes Thalweg 1 and 2 (a) as well as the use of DTM with isobaths spacing 100 m water depth each (b). Types of depression are distinguished by colors: (1) depressions not classified as canyons and confined at the continental shelf (black lines), (2) canyons that are continental slope confined (blue lines) and (3) canyons that incise the continental shelf (red lines).

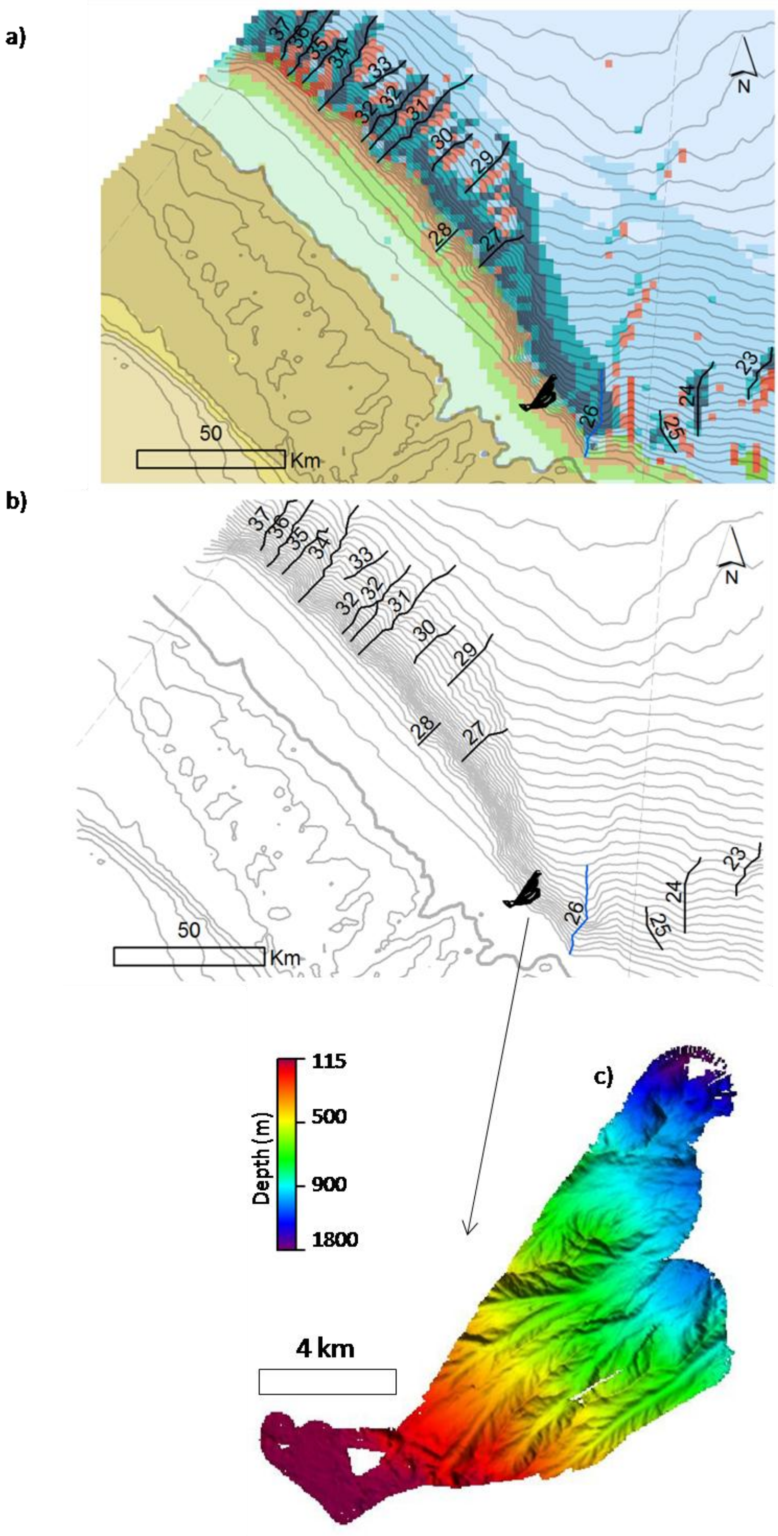

Figure 7: Sector 3 continental slope depression mapping. The mapping procedure followed the combined methods of delineation by BTM seabed classes Thalweg 1 and 2 (a) as well as the use of DTM with isobaths spacing 100 m water depth each (b). Types of depression are distinguished by colors: (1) depressions not classified as canyons and confined at the continental shelf (black lines), (2) canyons that are continental slope confined (blue lines) and (3) canyons that incise the continental shelf (red lines). Vertical exaggeration 5.

Table 5: Metric of mapped depressions for each sector. L (Length); SL (Straight Length); S(Sinuosity, L/SL); A (Area); MIND (Minimum Depth); MAXD (Maximum Depth); DR (Depth Range); SLM (Slope Mean); DNC (Distance to Nearest Canyon). Types of depressions were classified according to Harris and Whiteway (2011): (1) depressions not classified as canyons and confined at the continental shelf (black), (2) canyons that are continental slope confined (blue) and (3) canyons that incise the continental shelf (red). **Bold: maximum value**, **Bold and <u>Underlined: minimum value.</u>**

Sector1

	Type	L (km)	S	A (km^2)	MIND (m)	MAXD (m)	SLM (°)
1	3	***147,97***	***1,15***	*480,61*	**<u>100</u>**	***3300***	***<u>1,79</u>***
2	1	**<u>16,51</u>**	1,04	**<u>62,34</u>**	640	**<u>1560</u>**	3,65
3	1	35,55	1,11	168,56	700	2220	2,86
4	1	34,47	1,03	100,95	900	2240	2,40
5	1	37, 728	**1,02**	136,15	**1200**	2400	1,86
6	2	93,42	1,08	592,25	500	3270	2,60
7	3	83,54	1,06	555,75	**<u>100</u>**	3115	**3,93**
8	1	59,18	1,03	**696,57**	600	2800	2,46
9	1	37,25	1,07	266,70	300	1880	2,78
10	3	*47,80*	*1,08*	*170,96*	***<u>100</u>***	*1720*	*2,17*
Mean		55,95	1,07	293,58	520	2430	2,59
StdDev		36,73	0,04	223,33	350	640	0,65

Sector 2

	Type	L (km)	S	A (km^2)	MIND (m)	MAXD (m)	SLM (°)
11	1	30,08	1,05	86,39	**2090**	2630	1,16
12	1	101,13	1,07	804,10	400	2900	1,94
13	1	53,42	1,03	132,73	1200	2300	1,38
14	1	26,71	**<u>1,02</u>**	80,24	1800	2240	1,14
15	2	153,69	1,06	697,29	840	3220	1,15
16	1	108,62	1,03	546,62	1800	**3370**	0,91
17	2	182,14	1,17	1459,77	1035	3145	0,92
18	1	252,15	1,06	**<u>70,35</u>**	650	1210	1,36
19	3	***289,36***	*1,25*	***1840,01***	***<u>100</u>***	*2800*	*1,05*
20	2	119,20	1,17	1153,31	1500	2755	**<u>0,81</u>**
21	2	76,48	**1,32**	746,27	600	1750	1,17
22	2	50,69	1,15	256,20	300	1120	1,09
23	1	20,06	1,09	88,62	1400	1960	**2,15**
24	1	26,70	1,05	131,05	900	1740	1,93
25	<u>1</u>	**<u>15,08</u>**	1,03	89,53	600	**<u>1100</u>**	2,08
Mean		85, 238	1,10	545,50	1014,33	2282,67	1,35
StdDev		76,83	0,09	567,37	600,85	773,79	0,45

Sector 3

	Type	L (km)	S	A (km²)	MIND (m)	MAXD (m)	SLM (°)
26	2	*31,84*	*1,05*	*229,14*	***200***	*1600*	*2,78*
27	1	17,90	1,02	132,43	1100	2500	4,46
28	1	**10,75**	**1,00**	**51,54**	400	**1300**	**5,06**
29	1	17,43	1,01	82,07	**2100**	2800	**2,29**
30	1	19,07	1,03	65,72	1900	2730	2,76
31	1	**47,32**	1,07	224,05	640	**3065**	3,45
32	1	34,81	**1,08**	130,05	800	2850	3,44
33	1	18,45	1,03	54,78	1950	2770	2,70
34	1	41,37	**1,08**	**266,08**	500	2940	3,66
35	1	22,74	**1,00**	84,34	800	2600	4,54
36	1	31,11	1,02	114,48	700	2830	4,00
37	1	28,84	1,07	120,64	950	2790	3,94
Mean		26,01	1,04	124,08	984,62	2536,54	3,71
StdDev		10,85	0,03	72,24	615,03	530,47	0,93

3.2) Slope Depressions

A total of 37 depressions were mapped on the Amazon Equatorial Margin using BTM and the 2.5 km resolution bathymetric grid (Fig. 5-7). Their metrics (length, sinuosity – length/straight length, area, minimum depth, maximum depth and slope mean) are presented in Table 5. The Slope Depressions were classified according to Harris and Whiteway (2011) that assume canyons as depression minimum of 1000 m depth range, 100 m incision and with heads not deeper than 4000 m water depth. Canyons can also be described as shelf incises or slope confined canyons. If the feature does not fall within canyon metrics, it is described as slope confined depression.

Sector 1 (Fig. 5 and Tab. 5) presented 10 depressions being 3 of them shelf incised canyons, 1 slope confined canyon and 7 slope confined depression features. Depression 1, 7 and 10 are canyons incising the continental shelf at 100 m water depth.Canyon1 is the longest and most sinuous one reaching a depth range of more than 3000 m water depth. At the same time, canyon 10 is the only one among the entire shelf that seems to have an incising valley associated (Fig.4 – inc. valley). At the beginning of canyons 6 and 7, multibeam data were used to exemplify this shelf slope transition. Both BTM model and multibeam data reflect the same features: canyon confined at the slope (canyon 6) and canyon incising on the continental shelf (canyon 7), being the only difference the amount of details in each resolution.

Sector 2 (Fig. 6 and Tab. 5) presented 15 depressions and only 1 is considered shelf incising canyon (canyon 19). It is the so called Amazon Canyon that reaches an area of 1.840 km² and almost 300.000 km length and the only one that cut the continental shelf. This sector has 5 slope confined canyons located at the Amazon Canyon surroundings. The 9 rest of the depression features are slope confined.

Sector 3 (Fig. 7 and Tab. 5) has 12 depressions mapped and only one of them could be classified as slope confined canyons, the 26. This canyon reaches an area of 229 km² and almost 31.840 km length. The mapped area as an example depicts a non-canyon feature area that is full of gullies and ravines (Fig. 5c).

4) DISCUSSION

The geomorphometric analysis led to the classification of distinct seabed classes. Grouping some of the assigned seabed classes allowed the identification of potential benthic megahabitats. Megahabitats refer to large features that have dimensions from kilometers to tens of kilometers. Occasionally, this definition can lie within physiographic provinces such as continental shelf, slope and abyssal plain (Greene et al. 1999). The potential megahabitats are described as (4.1) Continental Shelf, (4.2) Shelf- Slope Transition and (4.3) Continental Slope. Processes in different time scale are responsible to explain the seabed heterogeneity among classes and the subsequent megahabitats in the Equatorial Margin, such as: mean sea level oscillation, gravity tectonics, and modern sedimentation. The benthic megahabitats of the Equatorial Margin and their related morphosedimentary processes are discussed below.

4.1) Continental Shelf Megahabitats

The Amazon Continental Shelf Megahabitat is strongly influenced by modern sedimentation processes connected to the Amazon River sediment input and its dispersion, the semidiurnal tidal processes and other physical processes associated with the North Brazilian Current, a western boundary geostrophic current that dominates this area (Nittrouer and DeMaster 1996; Lentz 1995b; Geyer et al. 1996). Continental shelf megahabitats can generally be determined by combing morphometric and sediment distribution variables. Here, we used a compiled sediment distribution dataset presented by Dutra (2018) with our morphometric results to classify the shelf megahabitats. Two megahabitats were identified: Mud Flat Continental Shelf Megahabitat (MFM) and Sand/Carbonate Rugged Continental Shelf Megahabitat (CRM) (Fig.8).

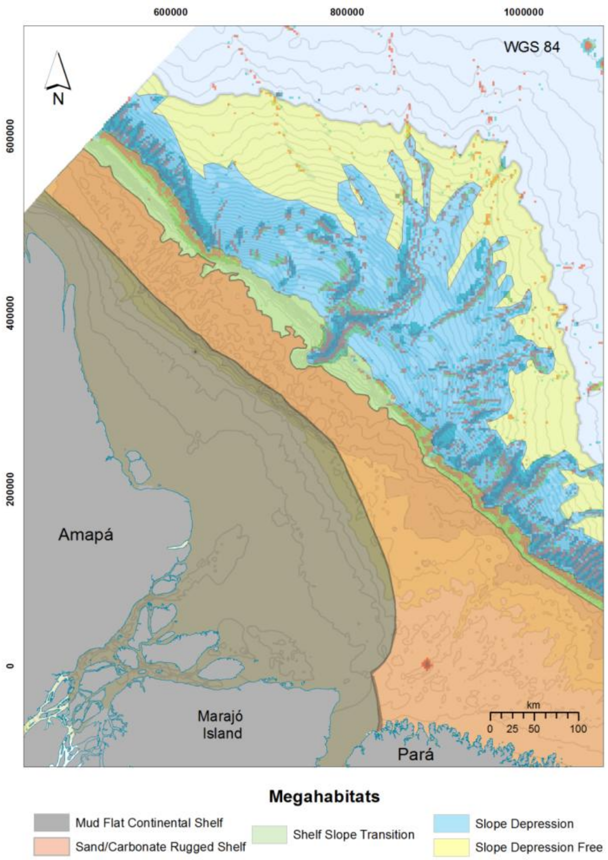

Figure 8: Megahabitat assigned on the Brazilian Equatorial Margin according to the seabed geomorphometric classes grouping.

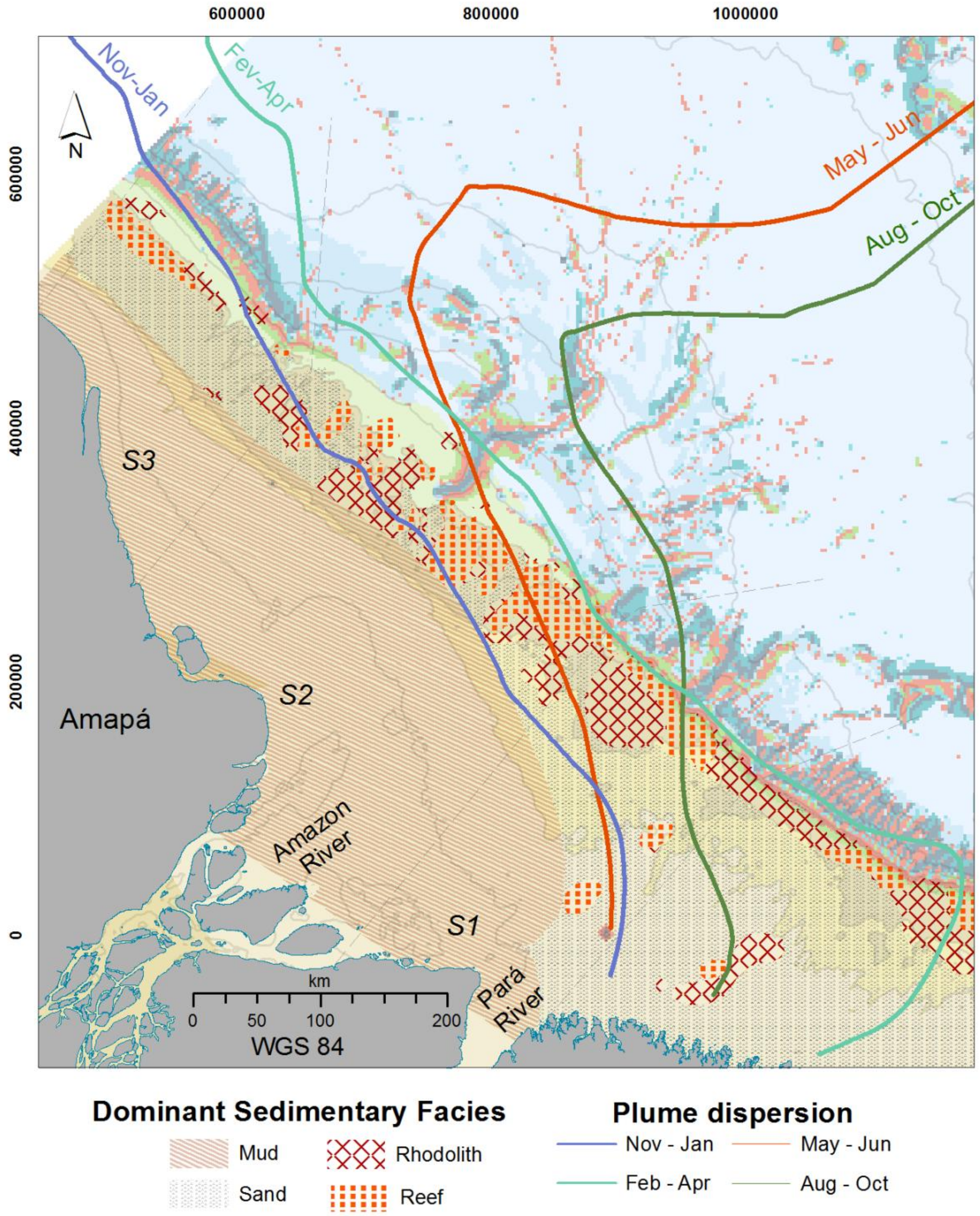

Figure 9: Combination of sedimentary facies and annual plume dispersion (adapted from Dutra et al. 2018 and Moura et al. 2016).

The MFM is composed mainly by the Inner and Mid Shelf Classes in which the maximum water depth reaches around 60 m, the isobath geometry is regular and the main sediment deposits are mud or sandy muds. The regular geometry of isobaths, the SE – NW predominance direction of deposition and the prevailing seabed dipping direction (N-NE) are observed at Inner Shelf Class. This habitat configuration is related to the ongoing development of the Amazon Submerged Delta and the main pattern of sediment dispersion and deposition. According to Nittrouer and DeMaster (1996) and our geomorphometric classes, the nearly flat Inner Shelf corresponds to the landward portion of the Amazon Delta (up to 40 m water depth - geomorphically referred as topset beds). The slightly steeper Mid Shelf on its northwest portion, precisely on S2 and S3 portions (from 40 m to 60 m water depths - regular geometry isobaths) are also part of the submerged delta, geomorphically referred as the delta foreset. The delta bottom set geomorphic feature could be identified in the Outer Shelf class from 60 to 70 m water depth on S2 and S3.

This entire megahabitat is mainly composed by muddy sediments (Fig. 9), dominated by a high energetic physical regime that enables an unstable benthic habitat with high bacterial biomass and low diversity and abundance of epifauna (Nittrouer and DeMaster 1996). Mass budgets indicate that about 6 x 10^6 tons per year of sediment accumulate on the inner shelf, primarily on the outer topset and foreset at rates exceeding 10 cm/y (Kuehl et al. 1986). These high rates and their spatial distribution lead to the typical clinoform shape of the sedimentary deposit forming the Amazon Delta (Nittrouer and DeMaster 1996).

The diagonal NW-NE pattern of the Amazon Delta is strongly influenced by the physical regime that dominates this megahabitat. A combination of strong tidal currents, large riverine outflow, persistent winds and meso-scale pressure gradients caused by the NBC originates the predominant northwestward flow (Nittrouer and DeMaster 1996; Lentz 1995b; Geyer et al. 1996).

The influence area of the Amazon Plume varies seasonally (Fig. 9). The MFM and part of the CRM along with the Shelf – Slope Megahabitat (both of them described below), more specifically in S2 and S3, are constantly dominated by the Amazon Plume dispersion. This makes S3 the sector that receive the greatest sediment input among the other sectors. The others sectors are seasonally influenced. From November to April, the northwestward predominant flow occurred due to the combination of strong trade winds and weak NBC transport (Geyer et al. 1996), while, from May to October the Amazon Plume retroflex via eddies due to less stress caused by trade winds from southeast and stronger NBC transport (Geyer et al. 1996) however 35 % of this flow still moves northwestward as NBC (Lentz 1995).

The CRM is composed by Inner, Mid and Outer Shelf Classes in which water depth ranges from 20 to 100 m, isobath patterns show a more irregular seabed, the slope parameter also indicates greater roughness and sediment distribution is dominated by sand deposits, rhodoliths and reefs. The irregular geometry of the isobaths shows no prevailing deposition direction neither shows seabed dipping direction. This megahabitat is observed at some areas of the continental shelf such as: part of inner shelf on S1 (eastward of Pará River), mid shelf on S1 and S2 and outer shelf for all sectors (part of mid shelf in S2 were included in the MFM because it is part of the Amazon Delta foreset). This megahabitat is dominated by coarse sediments and carbonates structures, more specifically on the outer part, such as large sand waves, erosive reefal structures and rhodoliths beds (Moura et al. 2016; Barreto et al. 1975).

The lower fluvial discharge dominance, together with the strong currents makes this habitat a suitable environment to carbonate occurrence. In addition, the Para River is a wide estuary that has a modest freshwater input relative to the Amazon (Geyer et al. 1996) and its correspondent continental shelf is probably dominated by tide currents.

S1 outer shelf has less influence of the plume and it is where younger carbonate were observed in comparison with S3 (permanent river sedimentation) (Vale et al. 2018; Moura et al. 2016). The existence of carbonate structures in a prevailing turbid environment can be explained by the role played by the NBC (Nittrouer and DeMaster 1996; Geyer et al. 1996) preventing terrigenous sedimentation to bury reefal structures resulting in the hard complex bottom topography (Moura et al. 2016). Such low sediment accumulation zone can also be related with permanent frontal along-shelf driven by the pressure gradient as well as Ekman transport associated with the advection of relatively cold and no turbid waters landward from the shelf break across the outer and mid shelf region (Nittrouer and DeMaster 1996; Geyer et al. 1996). Recently, a carbonate marginal reef system was mapped by Moura et al (2016). Samples collected from the reef structure located at S3 shelf edge area dated from 13,382 to 12,749 calibrated years BP, structures that ceased grow during the late stages of the last post glacial maximum transgression. In S1, structures are younger and dated from 4487 to 4846 calibrated years BP, being related to rhodolith beds. This shows the shutdown reef gradient from marginal conditions (S1) to structures that are beyond threshold for thousands of years (S3) but still support associated community and relevant ecosystem services (Moura et al. 2016).

A paleo valley is observed in S1 and is probably associated to canyon 1 (Fig. 4 – inc. valley, Fig. 5a and b). They were possibly connected in the last glacial period when sea level was about 120 m bellow today (Milliman et al. 1975). However, the paleo valley associated with the great Amazon Canyon (Fig. 4 and Fig. 5a and b – canyon 19) in S2 is not recognized within our dataset. One possible reason for that could be related to carbonate prevalence on S1 which led to the major preservation of paleo valleys. Also, the significant high sedimentation that subdue this portion of the continental shelf when sea level started to rise until current level (Sommerfield et al. 1995), which probably lead to the burial of the channel. In general, the stratigraphic record created on the Amazon shelf is punctuated by hiatuses caused by high-energy conditions and erosional processes occurring on many time scales (Sommerfield et al. 1995; Nittrouer et al. 1996).

4.2) Shelf – Slope Transition Megahabitat

The Shelf-Slope Transition Megahabitat is well defined at S1 and S3 by seabed geomorphometric classes that delineate the shelf break – Ridge 1 and 2. Also, the Outer Shelf Edge class plays an important role in this megahabitat definition, especially in S3. Even though S2 did not depict a notorious and sharp shelf to slope transition, the smoothness could be noticed due to the presence of the Outer Shelf Edge class. This megahabitat is defined by slightly increased slope values as well as regular isobath geometry and prevailing seabed dipping direction (N-NE).

The shelf break region varies significantly among all the sectors from around 100 m water depth at S1 (concave curvature) to 300 m water depth at S3 (sigmoidal curvature), whereas in S2 (convex curvature) there is no defined break. This variation can be explained by the preferred direction of the great load of sediments coming from the Amazon River. The extra load of sediment on S3, since the establishment of the current drainage system of this basin on 2.5 Ma BP (Gorini et al. 2014; Figueiredo et al. 2009), allowed this sector to extent its continental shelf at 300 m water depth.

This megahabitat is also dominated by carbonate sedimentation and structures, more developed on S1 (Outer Shelf and Shelf-Slope classes) because it is dominated mainly by tides and currents rather than fluvial dominance as it is seen in S2 and S3 (constant influence of Amazon Plume).

4.3) Continental Slope Megahabitat

The Continental slope was subdivided in terms of the presence/absence of depression features: Slope Depression Megahabitat and Slope Depression Free Megahabitat.

The Slope Depression Megahabitat is defined by classes that delineate depressions and crest on the slope. Ridge 1, Ridge 2 and Edge are the crest like classes; whereas Thalweg 1, Flank and Thalweg 2 are the depression like classes. Steep Slope is also part of this megahabitat since that occupies the surrounding areas of the depressions, where the slope is still higher than 0.1°. Sediment facies information, neither benthic data for this habitat was found available.

The type of depressions along the region varies among the sectors. Sectors 1 and 3 are erosive while sector 2 is non-erosive. Gravity tectonics was responsible to shape erosive and non-erosive continental slope over the time (Reis et al. 2016). The great amount of sediments that reach the shelf-slope transition thorough the geological time generate processes of mass movement leading to steep scarps and mega slides (Silva et al. 2010; Reis et al. 2016).

Sediment input is one explanation that makes the continental slope morphometry so different among the sectors. The slope transition curvature distinction described above reveals the convex shape in S2, where most of the sediment input occurs and where the Amazon Cone was formed. In the erosive part of the region, S1 depressions begin in shallower waters (around 100 m water depth). This is the sector that depicts more canyons incising in the continental shelf (canyons 1, 7 and 10). Comparing S1 and S3 depressions, S1 depicts longer, mores sinuous and lower slope values depressions. On the other hand, S3 depressions begin in deeper water depths, following the occurrence of a distinct shelf-edge area (shelf breaks around 300 m). Depressions in S3 are shorter, less sinuous and depict higher slope values when comparing to S1 depressions.

In the non-erosive part of the continental slope (S2), the Amazon Canyon is always active during low stand, when the immense amount of sediments caused turbidity current that were responsible to design the great canyon (Gorini et al. 2014; Figueiredo et al. 2009). In terms of depressions, S2 presents only the Amazon Canyon (canyon 19) that incises the shelf. 5 slope confined canyons are still observed in this sector. Depressions are the most sinuous and present lower slope values. On the NW portion of the Fan the canyons are fewer and shorter whereas on the SE portion canyons are longer. The abrupt distinction of NW and SE portion shows N-NW and N-NE seabed dipping orientation, respectively.

Thus, the Slope Depression Megahabitat could be also subdivided in meso and macrohabitats when considering the scale of the investigation. As pointed out, this megahabitat comprises a great number of morphometric classes that define the distinct morphological features associated with the occurrence of canyons. The detailed multibeam data presented in Figures 4 and 6 show the complex morphology of these features, and considering the important role played by the gravitational tectonics in the slope, rigid structures can be observed in deeper areas down to 300 m. This makes the Slope Depression a potential high diversity deep sea habitat, especially when combined with the Shelf-Slope Transition Megahabitat.

The deeper areas where no depressions are observed were classified as the Depression Free Megahabitat. This megahabitat is well defined exclusively by the Gentle Slope seabed geomorphometric class. This habitat is in > 2000 m water depth representing the base of the slope/continental rise and the beginning of abyssal plains. The slope values become gentler and there is no other features depicted being the start of sediment accumulation in deep basin (Harris et al. 2014).

The geomorphometric analysis of the Equatorial Margin indicates a significant spatial distribution of megahabitats, from the inner shelf, to the deep sea. It is important to note that these habitats are the product of short-mid and long-term geological and oceanographic processes. The ongoing discussion about the carbonate sedimentation over the area can be clearly depicted from the results presented herein. The main Amazon plume depocenter along the inner and mid shelf reveals the continuous influence of the plume forming a muddy and smooth deposit. The shelf that is not continuously influenced by the plume and riverine terrigenous sediment accumulation is characterized by a carbonate dominated bed, mainly rhodoliths (Moura et al. 2016; Vale et al. 2018). In the geomorphometric analysis, this shelf habitat is clearly marked by an irregular morphology, which is typical of carbonate sedimentation.

The most impressive difference in terms of morphometric analysis and megahabitats can be observed along the outer shelf and shelf-break. The Shelf-Slope Transition megahabitat is very distinct along the 3 mapped sectors. This megahabitat is marked by two main seabed geomorphometric classes: ridges that define the shelf break; and the higher gradient of the outer shelf, defining an outer shelf edge, prior to the shelf-break. The sector that presents the outer shelf edge and the ridges together is the S3, where Moura et al. (2016) have identified the erosive reef structures (also shown here in Fig. 7). S2 presents no shelf-break, so ridges are not observed, only the shelf edge class. This is associated with long-term sediment accumulation and formation of the Amazon Fan. S1, the southern-most sector does not present the outer shelf edge, only the ridges, showing valley incised channels in the shelf, i.e., it is a very erosive area with main sediment bypass and carbonate sedimentation (rhodolith dominated).

Finally, the slope megahabitats are very diverse because of the occurrence or not of depressions, i.e., canyons, ravines or gullies. Canyons, ravines and gullies can form macrohabitats as revealed by the number of seabed classes that form a depression: ridges/crests, edges, flanks/walls and thalwegs. In S1, the erosive characteristics of the Shelf-Slope transition, combined with the formation of canyons, ravines and gullies, have also the occurrence of erosive reef structures (Alucia Expedition Report – not published).

5) CONCLUSION

Potential megahabitats were defined by using spatial analysis geomorphometric technique in an available digital terrain model. Five megahabitats were defined grouping the 12 geomorphometric seabed classes: Mud Flat and Sand/Carbonate Rugged Shelves, the Shelf-Slope transition, as well as the Depression and Depression Free Slopes. Considering the greatness of the Amazon River-Margin system, this contribution showed that megahabitat distribution are related to distinct geological and oceanographic processes acting over different time scales.

The continental shelf megahabitats are basically controlled by the Amazon River discharge and sediment input (plume). A Mud Flat Shelf Megahabitat is currently the main depocenter of the basin. Sand and carbonate dominated shelf forms the second shelf megahabitat. This shelf habitat is seasonally influenced by the Amazon plume and, along the outer shelf, is influenced by the strong flow of the NBC. The strong flow of the NBC and the not continuous plume influence enable carbonate production, the formation of large sand waves and not burial of rigid structures.

The Shelf-Slope Transition Megahabitat is an interesting habitat because it combines the shelf-break points and a slightly increased in slope values along the outer shelf that was defined as the outer shelf edge. In a sense, the shelf-slope transition habitat varies significantly along the shelf-break due to long-term sediment accumulation and river incisions and potential gravitational tectonics. The shelf break depth region varies among all the sectors from around 100 m water depth at S1, where no outer shelf edge is observed and valley incision in the shelf is observed, down to 300 m water depth at S3 (sigmoidal curvature), where the outer shelf edge is very well defined and no incise valley is observed in the shelf. S2 (convex curvature), represents the transition to the Amazon fan, i.e., the most important long-term sediment path way to the slope and rise. In S2, there is no defined break, i.e., there is no Ridge class but an outer shelf edge.

Following the Shelf-Slope Transition, the Slope Depression Megahabitat is formed by long-term channel incisions (canyons, ravines or gullies) and gravitational tectonics forming mega-slides. Akin to the Shelf-Slope transition, S2 is very distinct from S1 and S3, as it comprises the Amazon Fan and the Amazon deep channel. S1 and S3 present similar habitats in terms of geomorphology; just S3 is deeper than S1, whereas S2 has the fan habitat type. The Slope Depression megahabitat is possibly the most diverse habitat when investigated in more detailed scales, as it comprises the greatest number of seabed classes defined by the terrain analysis. Slope Depression Free Megahabitat is deep basin habitats.

In conclusion, the geomorphometric analysis of the Equatorial Margin using a regional DTM has revealed the complexity of megahabitats in the region, and the potential for geomorphologically define more macrohabitats, mainly along the shelf-slope transition and the slope depression megahabitats.

CAPÍTULO III

UNVEILING THE MORPHOLOGY OF THE AMAZON REEFS

SUMMARY

FIGURES

TABLES

1) INTRODUCTION

Biogenic reefs are positive relief structures formed by benthic animals, algae and microorganisms that mineralize carbonate or siliceous skeletons (Birkeland 1997). Those structures are found under a much wider environmental conditions rather than optimal conditions for mineralization, being "marginal reefs" those deviating from the tropical coral reef common sense – shallow, warm and oligotrophic waters with higher saturation state of calcium carbonate (Moura et al. 2016). Even severely influencing salinity, pH, turbidity and nutrients, the Amazon River does not exclude reef associated assemblages to occur on the adjacent continental shelf (Moura et al. 2016). The occurrence of carbonate sedimentation and reefs along the Amazon shelf was suggested and proposed by authors in the 1970´s (Barreto et al. 1975; Milliman & Barreto 1975; Milliman et al. 1975; Collette & Rutzle 1977). In the last decade, Cordeiro et al. (2015) and Moura et al. (2016), consolidated the existence of a carbonate structures on continental shelf (from 50 to 150 m water depth) and shelf to slope transition (from 110 to 210 m water depth), respectively. Thus, a carbonate marginal reef system underneath the river plume that extends from the Brazil-French Guiana border to Maranhão State was delineated. This 9.500 km² area of complex topography is mainly composed by erosive structures, sponges and rhodolith beds located in the mesophotic zone (from 30 to 120-m depth).

The Foz do Amazonas Basin is a wide shelf evolved from carbonate to siliciclastic domain around 10- 8 Ma BP (Late Miocene) due to the reshape of the Amazon River catchment area caused by the Andean uplift (Gorini et al. 2014). This led to severe erosion and river incision, producing a great volume of sediment transport towards the Atlantic Ocean off the Amazon River (Figueiredo et al., 2009; Gorini et al. 2014). Sea level oscillations over the Quaternary and the great sediment input from the Amazon controlled the significant formation of sedimentary deposits along the Amazon margin. During lowstand periods, sediment passed over the shelf to deeper basin enabling carbonate sedimentation along the shelf break, while during highstand stages, sediments settled very rapidly in the inner and mid shelves turning off the continuous terrigenous supply to the Amazon Fan (Maslin et al., 2000) and forming a muddy benthic habitat (Moura et al. 2016).

Herein, we present for the first time a detailed morphological analysis of some of the reef structures located along the shelf edge of the Northern Amazon Shelf Sector. Our work aims to describe and discuss the morphology of these structures and the adjacent shelf break and continental slope, by using multibeam data and geomorphometric analysis.

2) METHODS

Multibeam data and ground truth images were acquired during the Amazon Reef expedition onboard the Alucia Vessel on July 2017. A Reson 7160 multibeam echosounder was used operating at the frequency of 44 kHz. The data were processed at CARIS HIPS and SIPS software to remove any noise and adjust for sound velocity in the water column. The mapped region occupies a 60 km² area within a depth range from 115 to 1500 m water depth, with 16 km length and 5 km maximum width (Fig. 1). Inside this mapped area in order to investigate the reef morphology, a higher resolution grid was setup. The mapped reef area comprises shallower depth from the entire mapped area. It occupies a 10 km² ranging from 110 to 225 m water depth, with maximum length of 3.5 km and less than 3 km width. Two multibeam mosaics were produced for the same area: a 40 m resolution cell size including shelf and slope; and a 5m resolution cell size highlighting the reefal area only (Fig. 2 a; b). The high resolution grid (5m) was imported in ArcGIS to accomplish the geomorphometric analysis such as slope and Bathymetric Positioning Index (BPI) – derivative inputs to the Benthic Terrain Modeler (BTM). This model - as thoroughly described in item 2.2 from the previous chapter - is a combination of spatial analysis scripts aiming to classify seabed (Walbridge et al. 2018) (Fig. 3). Slope values are the maximum rate of change for each cell and its neighbor. BPI is an index that evaluates the elevation differences between focal point and mean elevation of its surrounding cells within a user defined area (Lundblad et al. 2006).

Under water images were obtained using a man-operated Submersible. The images were recorded using a high resolution camera (Go Pro Hero 4) attached to the submersible acrylic screen. These images are used here as ground truth of the reef site only in order to show footages of the reef.

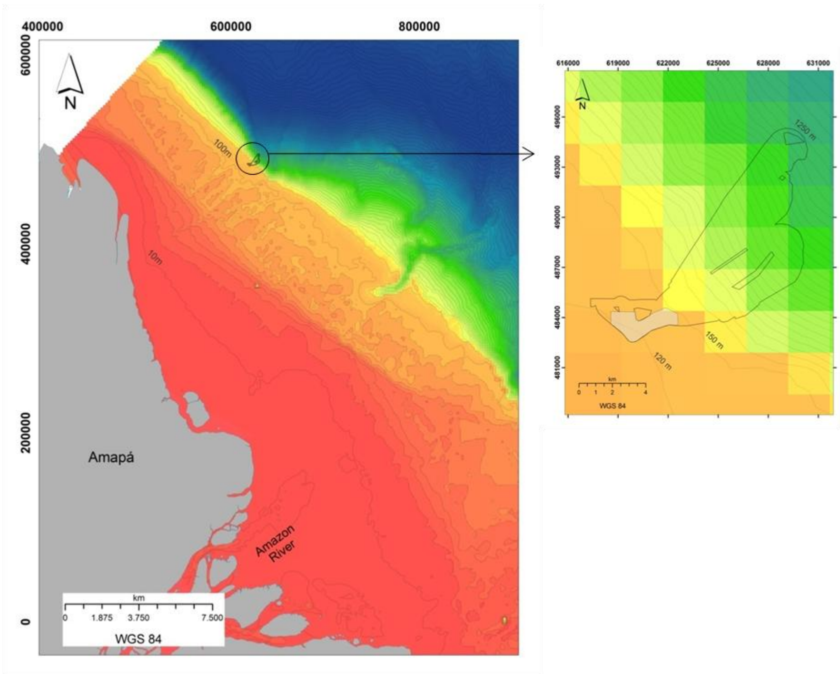

Figure 1: Study site in a regional setting and zoomed in. The black lines border corresponds to the mapped area and the 40 m grid generated and the grey polygon is the high resolution grid that depicts the reefal structures – 5 m grid.

Table 1: BTM dictionary. Seabed classes were categorized into BPI on both broad and fine scale, slope and depth using a lower and upper bound. 100 grid units were used and missing value indicates that the bound is not applicable to the seabed class.

	Broad BPI		Fine BPI		Slope		Depth	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1) Depression 1		-100		-100				
2) Depression 2				-100				
3) Reef Crest 1	100		100					
4) Reef Crest 2	-100	100	100			7.5		
5) Gentle Slope	-100	100	-100	100		7.5		
6) Steep Slope	-100	100	-100	100	7.5			

3) RESULTS

The mapped area represents the transition from the outer shelf to the continental slope (Fig.2a and b). The two-combined multibeam-derived grids show the transition from a gentle (degree) and irregular outer shelf to a steep (degree) continental slope with no major canyons, but gullies and ravines (Fig.2a). The irregular features on the outer shelf mark the reef structures that occur between 120 and 140m deep. It is interesting to note that between 140 to 200m deep, a group of joint reef structures occur in a quite steep shelf edge (degrees) (Fig. 2c). The shelf breaks only at 210m water depth, as a steep gradient is observed (Fig. 2b). The deeper part of the mapped area reached around 1300 m and is possibly a depositional area. The gradient magnitude for the entire area varies from 0.001 along the shelf, to 31.5^{o} along the continental slope.

Table 2: Percentage of each seabed classes.

	%
1) Depression 1	6.5
2) Depression 2	3.5
3) Reef Crest 1	10
4) Reef Crest 2	7.7
5) Gentle Slope	60
6) Steep Slope	12.3

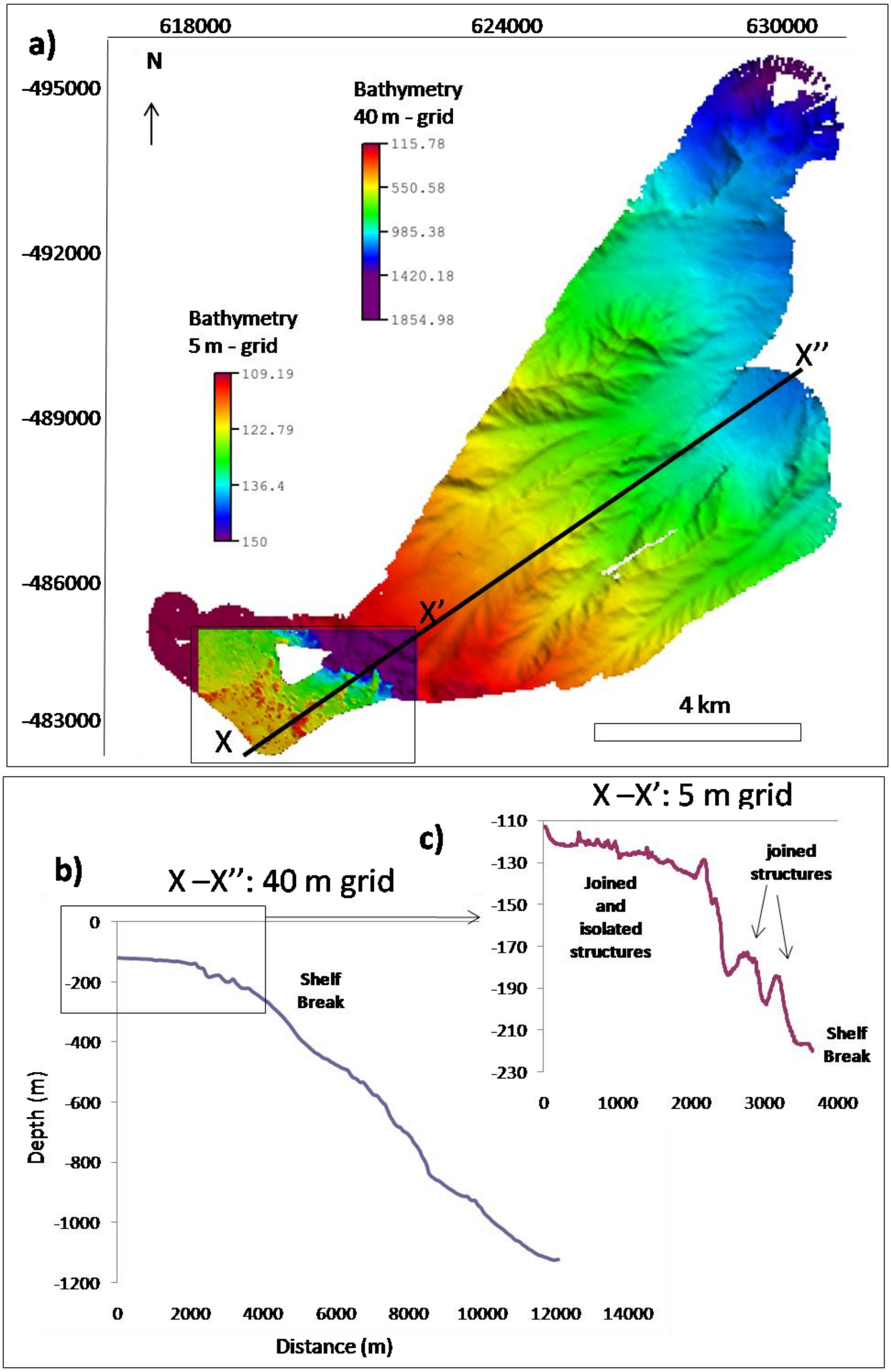

Figure 2: (a) Bathymetric grids from 40 and 5 m resolution, vertical exaggeration of 3; (b) Longitudinal profiles for the 40 m grid resolution, highlighting the black square – the 5 m grid (c) longitudinal profile showing isolated and joined reefal structures and the shelf break at around 250 – 300 m water depth.

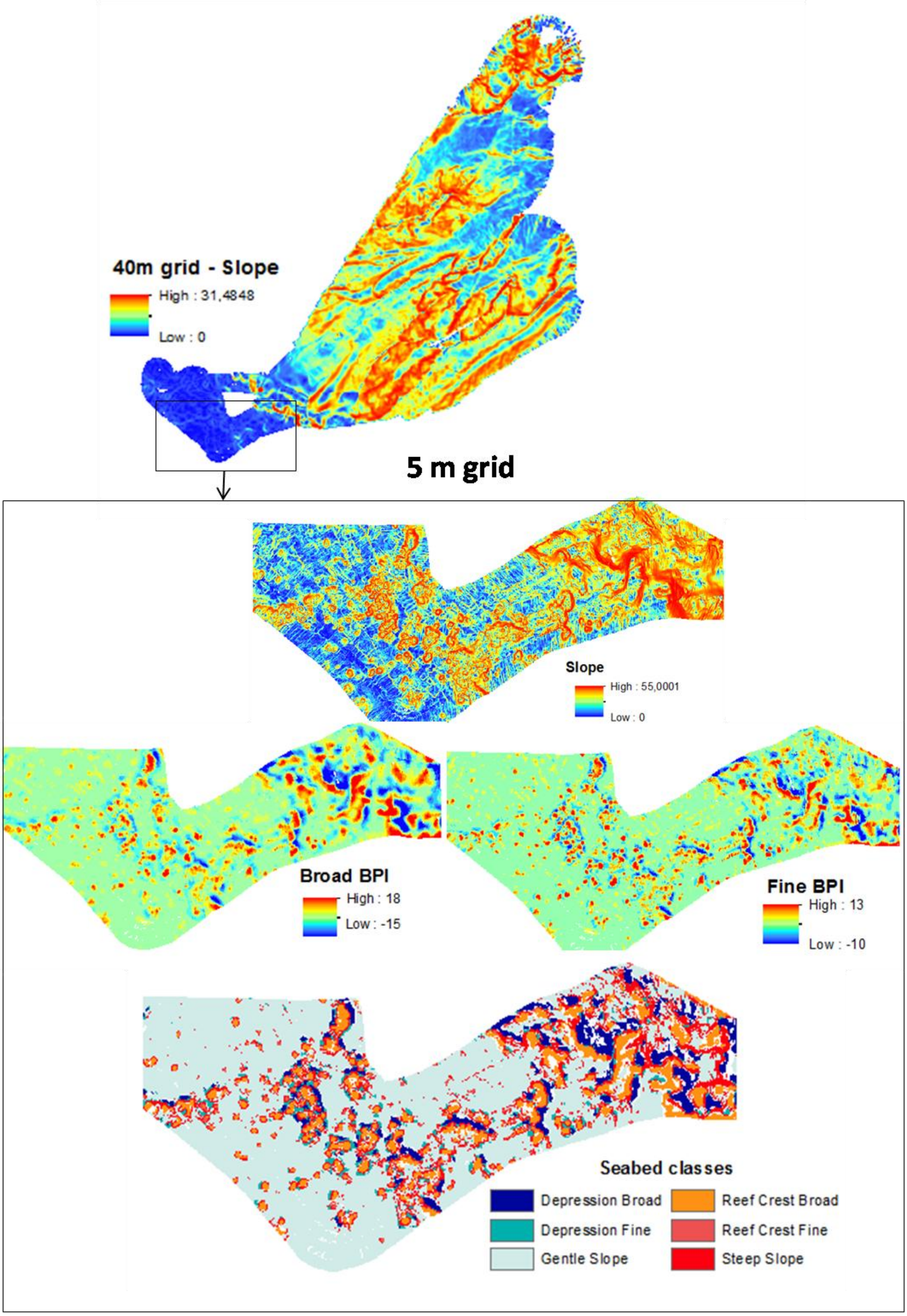

Figure 3: Slope, BPI and BTM.

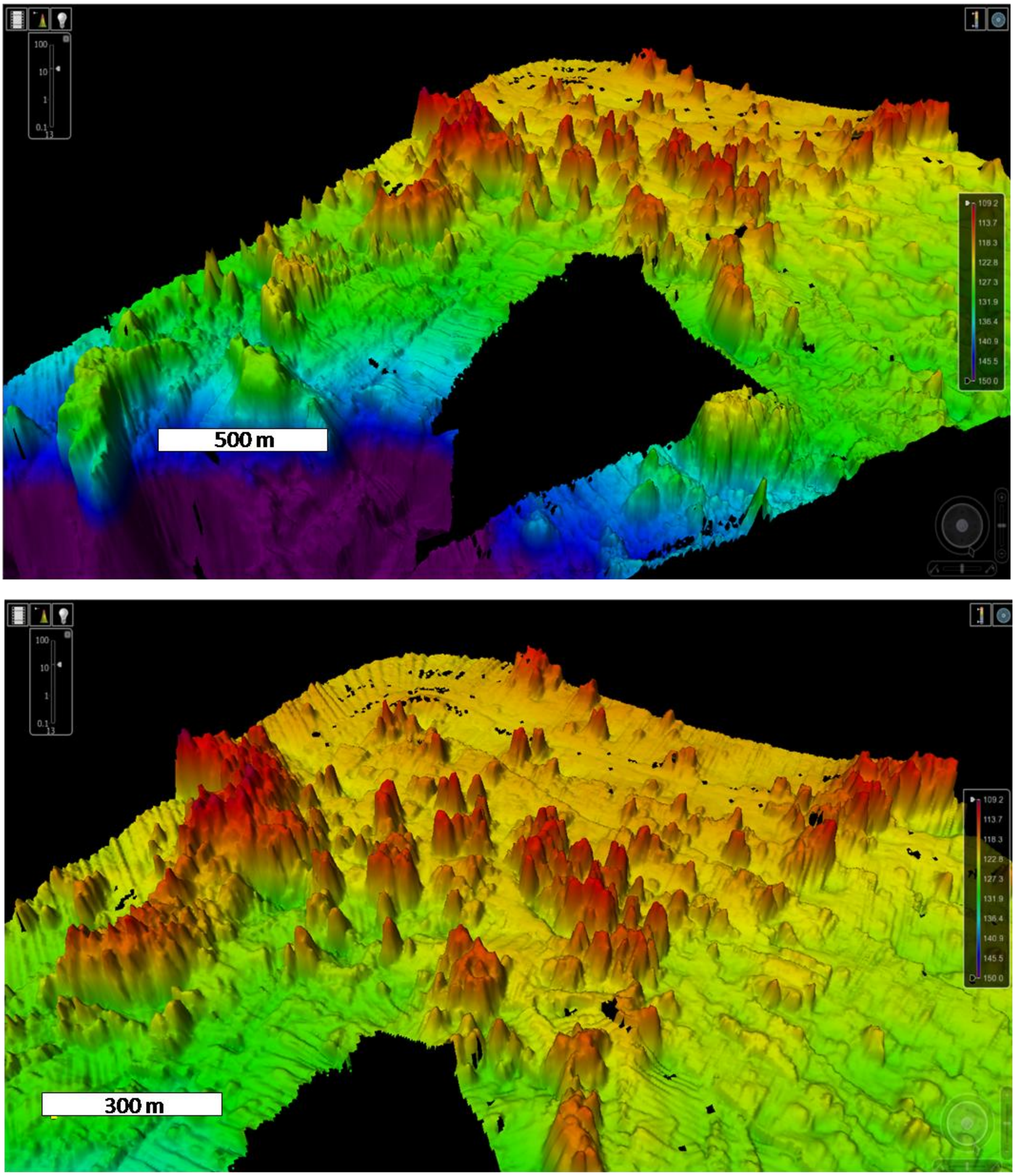

Figure 4: Tridimensional images from the reefs – 5m resolution. View towards southwest.

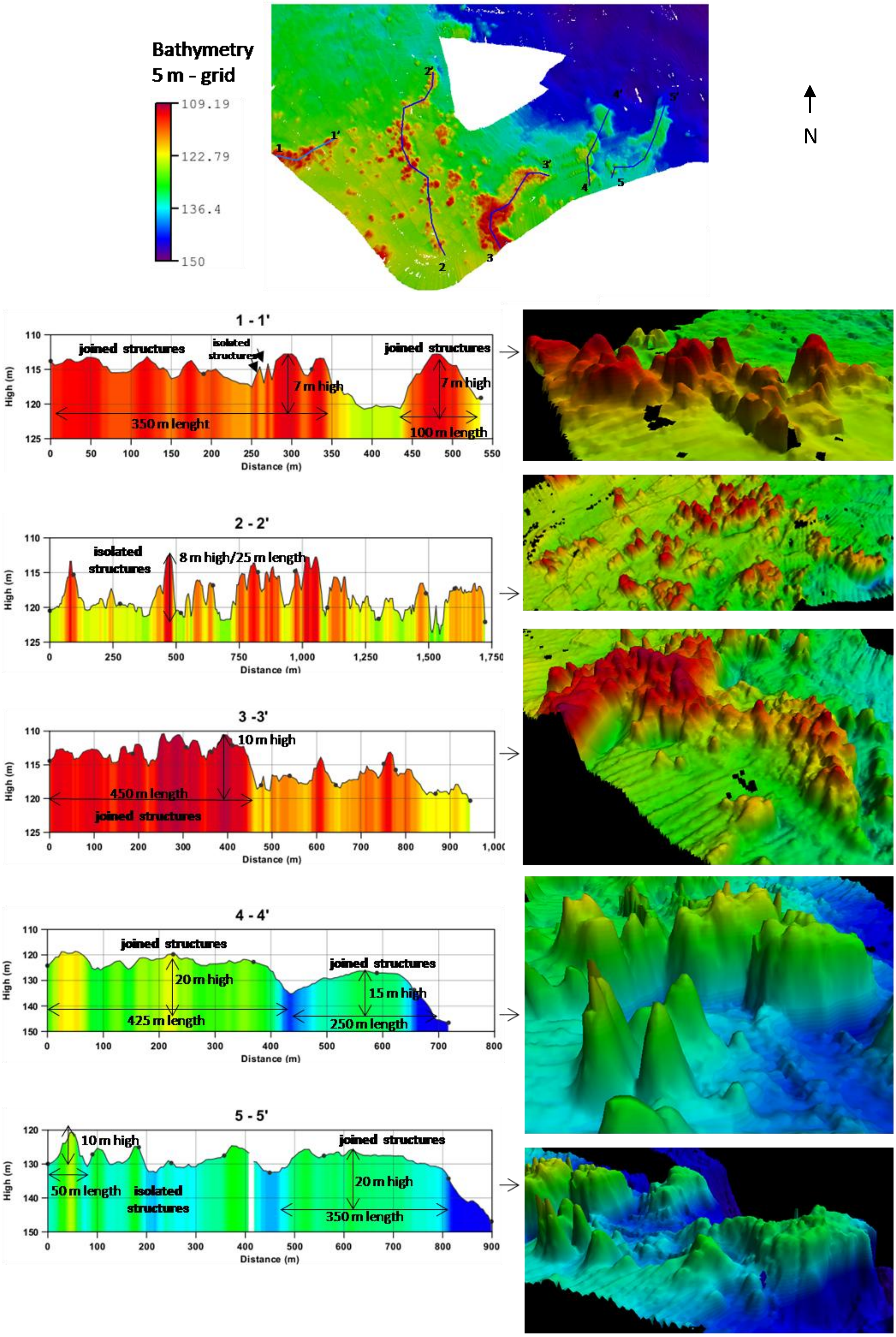

Figure 5: Longitudinal profiles along the 5 m grid (from 1-5).

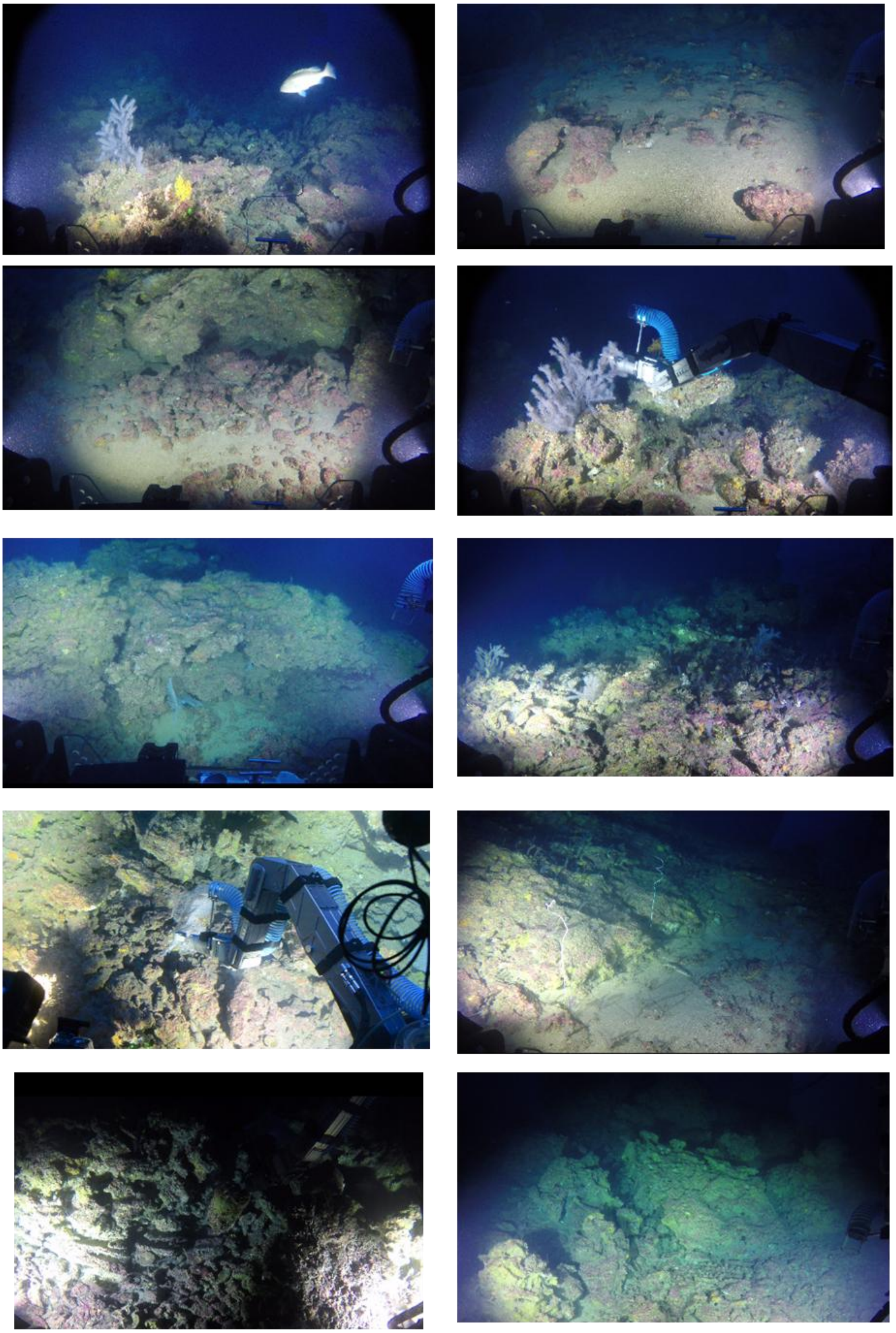

Figure 6: Images from the structures.

The reef morphology is shown in Figures 3 and 4 (3D grid). To better represent reef relief, five cross section profiles were extracted from the map and 3D images are also shown (profiles from 1 to 5 – Fig.3). The structures can be isolated or joined, forming reefal banks. Cross section 1presentsboth isolated and joined structures that reach up to 7 meters in height and 350 m in length. Cross section 2 is more representative of isolated structures. These structures can be up to 8 m high and 25 m long. Cross section 3 is the most notorious joined structure that reaches 450 m in length, 300 m in width and 10 m in height. Cross section 4 represents the deeper (deeper than 120 m) part of the outer shelf showing joined structures that reach 20 m in height and 425 m in length. Cross section 5 is also in the deeper part of the outer shelf (deeper than 130 m). The reef banks are, 20 m high and around 350 m long, while the isolated structures are10 m high and 50 m long.

To better describe and highlight the morphology of these reef structures, a geomorphometric analysis was carried out. Six seabed classes were recognized using BTM: four of them were depicted by the BPI and 2 by BPI and slope (Fig. 3). Regarding BPI: (1) Depression 1 – associated with seabed area in which upper bound is below the mean BPI on both broad and fine scale; (2) Depression 2 – associated with seabed area in which upper bound is below the mean BPI on fine scale; (3) Reef Crest 1 – associated with seabed area in which the lower bound BPI is above the mean (4); Reef Crest 2 – associated with seabed area in which while on broad BPI depicts a flat area or fine lower bound BPI is above the mean. Regarding slope, the classes are: (5) Gentle Slope – flatter areas, lower than 7.5°and (6) Steep Slope – steeper regions higher than 7.5°.

In general, the Gentle Slope class represents the main outer shelf substrate dip. The Reef Crest classes represent the top of the reef structures, while the Steep Slope class represents the reef walls. Depression classes are major inter-reefal areas, mainly in between the joined reefs. See table 2 for each class percentage.

The images depict reefal erosive structures with a benthic fauna associated (Fig. 6).

3) DISCUSSION

Submerged or drowned reefs constitute an important geological record of sea level variations. In the Last Glacial Maximum (LGM), about 21000 years BP, sea level has reached a depth of -120 m and evidence of colonization of shallow reefs at the edges of continental shelves is described throughout the world, e.g. in the South Pacific (Flamand et al. 2008), Hawaii (Webster et al. 2004), Caribbean (Blanchon et al. 2002), Australia (Woodroffe et al. 2010; Abbey et al. 2011b), among others (see review in Montagioni 2000). The rapid deglaciation process led to high rates of accommodation space creation and most of these shelf-edge reefs could not keep up with sea level rise, leaving behind a give-up reef (Neumann and Macintyre, 1985).

These reefs form the substrate for the colonization of modern mesophotic benthic communities, and are known as mesophotic reefs. In general, mesophotic reefs ranges from 30 to around 150/200m deep (Hinderstein et al. 2010; Khang et al. 2010, Abbey et al. 2011a). These reef zones provide structural habitats for a variety of organisms (Hinderstein et al. 2010), and thus are considered by many authors as extensions of shallow reefs, and may have biological, physical and chemical connectivity with the latter, thus having associated communities (Harris et al. 2011; Hinderstein et al. 2010). In the Great Barrier Reef, Bridge et al (2012) showed a depth gradient change in the dominated mesophotic community from photosynthetic organisms in shallower reefs (40 m) to filter-feeders dominated in deeper reefs (100 m deep). Abbey et al. (2013) present a first observation of how the coralgal community of mesophotic reefs responded to changes in the environment and variation of the sea level. The authors showed that for the Great Barrier Reef, two generations of mesophotic communities have developed on the shelf-edge reefs, with an initial 13,000 to 10,000 years BP and another from 8,000 year BP to the present.

Thus, the reef structures mapped herein at around 120 m deep can be interpreted as a relict shelf-edge reef with an associated mesophotic community. Moura et al. (2016) have already described these features as erosive relict reefs. A petrographic analysis carried out by the authors in a sample indicated a microfacies of an older grainstone (12,100 ± 30 thousand years BP) composed of filter feeders (polychaetes, foraminifera, barnacles, bryozoans, and molluscs) under a thin veener of coralline algae.

The video footage taken during the Alucia Cruise (Fig. 6) showed a living mesophotic reef community. The reef structure itself presented a very erosive characteristic, with seems to be falling blocks and sharp edges.

In terms of their distribution and morphology, the reefs appeared as patch reef structures reaching 20 m in height and 450 m length, occurring in a depth range of 110 m to 150 m. The structures were mapped as isolated or joined. Isolated structures reached a maximum of 10 m in height and are concentrated in areas shallower than 130 m water depth. The joined or bigger structures reached 20 m in height, and mostly occurred in areas deeper than 130 m water depth.

The hypothesis of reef growth of the Amazon mouth during the Last Glacial Maximum (LGM) is plausible. During this time, the active Amazon Submarine Canyon were bypassing sediments to the deep sea, turning off the muddy channels in the shelf (Gorini et al. 2014); therefore, enabling shallow water biogenic and oolitic carbonates accumulation off the Amazon River (Vale et al. 2018). As pointed out above, during the LGM and early deglaciation stages, coral reefs developed along the current shelf-edge of various places worldwide (Montagioni 2000) and now it is reported in the Equatorial Atlantic margin.

Biogenic reefs can develop under much wider range of conditions rather than warm, shallow and oligotrophic waters. These Amazon mesophotic reefs can be considered as a drowned reef system, where photosynthesis is less significant, macro organism is less diverse, grazing is reduced and microbial diversity is higher (Moura et al. 2016). Moreover, a stable near-bottom wedge of ocean water, combined with seasonal eastward retroflection of the plume also enables the endurance of this hard-bottom topography on the outer shelf (Moura et al. 2016). In this portion, the North Brazilian Current (NBC) reaches its maximum speed hardly enabling mud deposition and along with the permanent frontal zone and Ekman pumping prevents the burial of the reef structures by terrigenous sediments (Nittrouer and DeMaster 1996).

5) CONCLUSION

The drowned reef system of the Continental Shelf adjacent to the Amazon River was acoustically mapped and its geomorphology was described herein for the first time. The mesophotic reefs are observed between 110 and 210 m water depth as isolated or joined structures. Deeper reefs reach maximum height of around 20 m, while shallow reefs reach 10 m in height. These structures were probably formed as shelf-edge reefs during the LGM or early deglaciation stages. Through time, those reefs have been suffering erosion which shaped their relief. The physical setting of high energy hydrodynamics associated with the North Brazilian Current prevented reef burial.

CAPÍTULO IV

CONSIDERAÇÕES FINAIS

O principal objetivo deste trabalho foi investigar a distribuição de megahabitats na bacia da Foz do Amazonas a partir da análise geomorfométrica do relevo submarino e discutir as principais forçantes que condicionam a ocorrência destes habitats. Esta análise regional da bacia da Foz do Amazonas conferiu uma categorização de classes geomorfométricas que agrupadas definem os megahabitats ao longo da bacia, mas ainda indicam a ocorrência de macrohabitats. A distribuição das classes geomorfométricas mostra claramente uma variação morfo-sedimentar ao longo da bacia. A distribuição dos megahabitats está condicionada vários processos que atuam em escalas temporais distintas. A dispersão da Pluma bem como a atuação de intensas correntes são as variáveis ambientais que limitam os megahabitats associados à Plataforma Continental. A porção de transição entre a plataforma e talude é bem característica dos processos sedimentares ao longo do tempo, mostrando uma grande variação associada ao aporte e transferência de sedimento para o talude durante condições de nível de mar baixo e áreas onde efetivamente o processo erosivo é mais intenso e até mesmo a incisão fluvial levando a formação de cânions. Os megahabitats associados ao talude seriam os mais complexos porque as classes geomorfométricas indicam a ocorrência de depressões e cristas que foram efetivamente os cânions e ravinas. Ainda no talude, processos gravitacionais ao longo do tempo condicionam ainda a deposição de grandes mega deslizamentos e cicatrizes erosivas.

Ao mudarmos a escala de observação, a região de quebra da plataforma no setor norte nos mostra a ocorrência e distribuição de um complexo mosaico de estruturas rígidas, recifais e associadas a comunidades mesofóticas. Dados não publicados e confidenciais indicam que estas estruturas ainda se estendem em direção norte, ao longo da faixa de 100 a 200m de profundidade.

Desta forma, o propósito deste trabalho foi alcançado a partir da produção de um mapa que regionalmente distingue setores e regiões com potenciais habitats distintos e mostra que a análise geomorfométrica, combinada com uma análise faciológica é uma ferramenta importante e crucial em estudos pretéritos e que podem mostrar resultados relevantes que possam condicionar trabalhos de detalhe.

Sugerem-se para próximos passos uma maior cobertura de sondagem acústica de multifeixe, visando melhor caracterizar a morfologia da região além de refinar em níveis de escala os megahabitats. A aplicação de sísmica de alta resolução seria uma ferramenta importante para entender o papel estratigráfico das estruturas recifais do setor norte.

Vale destacar que este trabalho foi desenvolvido no contexto da Rede Abrolho e que os dados coletados durante a expedição Alucia estão sendo processados e analisados, principalmente no que diz respeito às imagens da comunidade bentônica e o processamento de amostras coletadas. Sendo assim, um passo importante será a integração dos resultados aqui apresentados com estas análises. Por exemplo, a combinação da análise morfológica das estruturas do recife com a da descrição comunidade bentônica e das amostras recifais acrescentaria um maior detalhe na caracterização da feição de grande apelo científico na Margem Equatorial atualmente.

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