Quantifying methods for analyzing submarine slope-gullies in the North Carnarvon Basin, Offshore NW Australia.
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Summary
Analysis of 3D seismic data in Cenozoic strata, located in the offshore North Carnarvon Basin (NCB), Australia, reveals a network of channel-like features that migrate the Rankin platform, into the Exmouth plateau. These observed features, identified as submarine gullies, are characterized as being a system of geometrically closely, dense sub-linear channels confined within the upper to lower slope regions. The occurrence and geometries of these submarine features along the shelf to slope area is a function of the morphology of the slope, and the equilibrium between accommodation space, sediment supply, and sea level changes. We focus on applying methods that not only include qualitative analyses but quantifying our observations in order to improve our understanding of the factors that drive the depositional system. We compute and utilize the curvature, variance, and sweetness seismic attributes to enhance our interpretation and characterize the different sedimentary features present within the submarine gullies in the Paleogene sequence of the study area.

Introduction
We use a 3D seismic reflection from offshore Northwest Australia to study submarine slope-gullies that developed in mixed carbonate-clastic clinothems of Eocene-Miocene time. Previous studies conducted in the NCB have explored the connection between the evolution of sub-marine gullies and shelf-margin cliniform development and associated architectural elements (Prelat et al., 2015; Tellez-Rodriguez, 2015). Submarine slope-gullies (i.e. gullies restricted to the slope, between the shelf edge and the toe-of-slope) are common on many clastic and carbonate-dominated continental margins (Mulder et al., 2012). Gullies are usually oriented normal to the slope and form conduits for sediment transport from the shelf edge toward the deep basin. In cross section they are “U” or “V” shaped and are typically narrower, shorter and of lower relief than submarine channels or canyons (Prelat et al., 2015). In depositional settings, the progradation of cliniforms can experience increases in slope gradient which can result in the formation of gullies that incise into the underlying lithology and expand in width and depth. It is thought that submarine gullies initiate and evolve in response to erosion by shelf-derived turbidity currents and/or retrogressive slope failure (Gardner et al., 1999). Since the sub-marine gullies are not the only potential channel-like features identified, we aim to gain a wider scope of the depositional setting by expanding our area of interest, across the NCB using several neighboring seismic volumes. As a result, there is the potential to observe the evolution of the channel networks along shelf-to-slope, to deeper water basinal settings (Nugraha et al., 2018). For now, we use one time-migrated 3D seismic reflection dataset.

Northern Carnarvon Basin
Geologic Setting
The North Carnarvon Basin (NCB) is located at the southern margin of the North West Shelf of Australia with an area of 535,000 square kilometers. The basin is composed of the Rankin Platform, the Exmouth Plateau, and sub-basins such as, Barrow, Beagle, Dampier, and Exmouth. The basin was developed during the Late Paleozoic. Its formation is linked to regional extension during late Permian to early Mesozoic. It has a geologic history of multiple stages of extension, subsidence, and minor inversion (Tellez Rodriguez, 2015). The North Carnarvon Basin was affected by a rifting stage in Early Jurassic followed by syn-rifting stages that are subdivided into three phases, the early, main, and final late rifting (Alrefaee et al., 2018). The area of study lies on the Rankin Platform (Figure 1). This is a Northeast trending structural high that is separated from the Dampier and Barrow sub-basins by a major fault system. The entire platform plunges to the North (Stein, 1994). The structure of the platform consists of a series of en echelon fault blocks bounded by NE and NS faults. We focus on shelf-margin cliniforms that are composed mainly of transported carbonate grains (e.g. calcisiltite, calcilutite and calcarenite), and unconsolidated fine-grained carbonate (e.g. marl). Additionally, our time interval of interest is of Post Jurassic age, where post rift thermal subsidence was disturbed by a minor phase of inversion during Late Cretaceous.

Seismic Data
This study utilizes for now one time-migrated, 3D seismic reflection dataset situated on the Rankin Platform, (See Figure 1). The Rosie-3D seismic survey consists of 41,713 kilometers of data covering an area of 1109 km². It was
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acquired in 1996 by Geco Praka and processed between 1996 and 1997 by Western Geophysics. Dominant frequencies of seismic data in the interest interval are 45-55 Hz (Tellez Rodriguez, 2015). The reflection data is of zero-phase processed with negative polarity.

Methods

We incorporate multiple measurements such as channel intensity, channel density, average channel width, and channel sinuosity within our time-interval of interest by creating referenced scan lines and a sliding window throughout the seismic volume. This will allow us to set the parameter in which channel density, intensity, width, and sinuosity will be measured.

This study comprises of a workflow that would encompass 4 stages (Figure 2). Stage one is the inspection of the three seismic volumes and selection of the time interval of interest. In the following stages, we compute meaningful attributes. Subsequently, we performed horizon picking and analysis to finally employ the quantifying methods proposed for this time interval.

Attributes

A subset of attributes was selected for our methods of parametric calculation based on their ability to aid in channel architecture identification and interpretation. They include geometric attributes such variance, sweetness, and curvature (k1, k2) (Marfurt et al., 1998). Most positive curvature, k1, and most negative curvature, k2, assist in identifying anticlinal (k1) and synclinal (k2) features (Marfurt et al., 2007). In addition to the geometric attributes that we used to detect channel architectural elements, attributes such as sweetness was also used. Sweetness is a reliable lithological attribute.

Stage #1: Volume Inspection
- Load Data
- Select Interval
- Map age markers
- Map key horizons
- Create static slices

Stage #2: Attributes computation, co-rendering, and interpretation
- Variance
- Sweetness
- Dip magnitude and Azimuth
- Coherence (polar slice)
- Curvature (k1,k2)

Stage #3: Horizon interpretation and analysis
- Identify, interpret horizons
- Extract surface attributes
- 3D tracking or manual picking

Stage #4: Quantifying Methods
- Channeled density
- Channel intensity
- Channel sinuosity
- Channel width

Quantifying Methods

On Rosie-3D seismic survey, we placed three scan lines and a sliding window that runs along the Rosie-3D volume. This moving window is used as a parameter that helps us to accurately observe and quantify key characteristics of slope-confined gullies. We calculated channel density, intensity, channel sinuosity, and average channel width within the same time interval.

The parameters used for channel density were the number of channels inside the moving window divided by the area of the window. For channel intensity, the total length of channels within the window is divided by the area of the window as well. For channel sinuosity, we used stream length (L) divided by the meander length (Λ). Lastly, for average channel width, we selected three random channels anywhere inside the window to obtain an average width and use it as a constant (Figure 3). The reason behind this is that we might encounter multiple windows falling in the same channel. As a result, we use a constant channel width.

Subsequently, we made scatter plots using distance in kilometers and the variables of channel density, intensity sinuosity, and average channel width. Thus, we observe trends in the different incisional geometries and evolution of slope-gullies from SW-NE and downslope. These methods will be expanded across several seismic surveys in the NCB and within the same time interval.

Figure 2: Workflow implemented.
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Figure 3: Methodology diagram used to describe different components of channels and equations employed to quantify slope-dominated gullies.

Results

Rosie-3D seismic volume interpreted strike-oriented (SW-NE) seismic section is marked by gullies that have a range of seismic characters such as subtle brightening or dimming of amplitude. Deeper incisions with chaotic fill, typically of low amplitude (Figure 4-b). We can also notice the dominant direction of gully stacking which is NE. The margins of the bigger gullies are marked by truncation of gully fill against surrounding strata or by brighter reflectors that appear to continuously drape the gully axis. Furthermore, map view of time slice -1304 ms co-rendering of k1 and k2 curvature displays red linear anomalies that correspond to channel edges or levees (convex-upward features) and blue linear anomalies that correspond to the base of the channel (convex-down features) (Figure 5-c) (Posamentier, 2003). We can also visualize the flow migration and small meander-loop migration of gullies with well-developed levees in map view variance seismic attribute (Figure 5-a). Proximal gullies range from 260 m to 285 m in width and distal gullies range from 450 m to 470 m in width.

Figure 4: a) Uninterpreted strike-oriented (SW-NE) seismic section through Rosie-3D. b) Interpreted strike-oriented cross section showing black dashed lines indicating the direction of lateral migration and aggradational stacking pattern of gullies towards NE. Black arrows indicating smaller gullies and blue arrows indicating larger gullies. Note possible levee geometry on the northeast margin of channel highlighted in yellow.

Figure 5: A) Map view of variance seismic attribute time slice at -1304 ms TWT generated to enhance channel visualization and interpretation. High values of variance depict in yellow/red color and low values show in white. B) Co-rendering of sweetness and variance both visualized on time slice at -1304 ms TWT. Sweetness used as a lithological aid indicator co-rendered with variance to define channel geometry. C) Co-rendering of k1 and k2 curvature at time slice -1304 ms TWT. Note green arrow indicating north, red arrows indicating red anomalies, levees, and blue arrow indicating blue anomalies, channels. Also, note flow direction down slope indicated by yellow arrow.
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Discussion

On map view of Rosie-3D we notice the increment of natural migration as we go down slope. We also expect to see an increase of channel width, intensity, and sinuosity down slope and a decrease of channel density (Posamentier, 2003). Several mechanisms may have been involved in the initiation of these slope-confined gullies on continental margins. For instance, erosion at the base of sediment-poor waters, mass-wasting via retrogressive failure, and erosional scour at the base of turbidity current (Prelat et al., 2015). Because no data is available on oceanic current circulation or tide-generated currents during the Eocene-Miocene of NW Australia we assume these processes can be driven by an increase in sediment supply caused by increasing proximity to a shelf delta and/or by sea level variations caused by climatic changes. Even though, we do not which process may have created these gullies. We know that it is not tectonically induced because this is a passive continental margin.

Future Work

At this moment, results indicate that the geometric parameters reveal an important relationship between the initiation of the gullies closer to the shelf-margin as compared to the lower slope-to-basin region. As aforementioned, further steps in the study will include the merging of neighboring 3D seismic volumes (Figure 6). Here we aim to identify the potential differences in channel network, intensity, sinuosity, and density influenced not only by internal, but external factors, and how this has influenced the depositional system into the surrounding sub-basins. We aim to accomplish this by creating several surfaces within our time interval of interest throughout several neighboring seismic volumes to visualize the evolution of gullies as slope gradient changes.

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Figure 6: Merge of three time-migrated, 3D seismic reflection datasets that cover ~ 2500 km² on the NBC, Australia. Variance seismic attribute time slice at -1304ms TWT. Note that the figure shows the merging of the three datasets that will be used for further study. We use this as a regional representation of the seismic and not a final interpreted figure. The time slice does not indicate events occurring simultaneously.
REFERENCES


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