Internal architectural analysis of mass transport deposits to unravel deepwater dispersal fairways; a novel approach to an old challenge

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SUMMARY

High resolution borehole images were used to study the internal architecture of mass transport deposits (MTD units) in a well drilled in offshore deepwater Borneo. The main objective was to utilize information from bedding orientations within MTDs to infer the direction of sediment transport which can in turn imply the distribution of reservoir facies. In this work, we first subdivided the deepwater package into turbidite and MTD deposits. Then, we utilized the dip attributes of bedding features in the deposits interpreted as moderately deformed slumps to identify the folding within the MTD packages. We utilized the geometry of these folds to infer the paleoslope trend which is NE-SW with overall MTD transport direction almost perpendicular to that, i.e. northeast. This trend direction corresponds to fairways along which reservoir facies sands have been transported and deposited in deepwater depocenters. Therefore, using this approach, we can provide vital clues to one of the most persistent exploration challenges in the energy industry, which is to identify main sediment transport directions in deepwater environments.

Key words: mass transport deposit, borehole image, dispersal fairways.

INTRODUCTION

Determining the main sediment dispersal fairways that control reservoir geometry and distribution has always been a challenge in deepwater prospects. This is mainly because of scarcity of well data and lack of high angle cross beds as conclusive paleocurrent direction indicators.

In this study we analysed the internal architecture of mass transport deposits (henceforth called MTD) to extract information on the transport direction of deepwater sands. MTDs are generally the product of slope instability and are interpreted as the fore-runners which open the conduits for the ensuing reservoir sand transport (Armitage et al., 2009).

MTDs are predominantly regarded as the ugly facies in deep water exploration as they do not typically have reservoir potential, while posing several drilling hazards (Weimer and Shipp 2004). However, in this work, we used a relatively novel approach based on borehole image interpretation results to demonstrate that when studied properly these sediments form a critical element to understand distribution of the associated reservoir units i.e. thin bed turbidites. Basically, emplacement of significant thickness of MTDs usually controls the basin floor topography which governs the dispersal fairways of subsequent thin bedded turbidite reservoirs.

BACKGROUND

Deepwater Sabah is part of the NW Borneo basin in East Malaysia, where the main reservoirs consist of turbidite sands. These turbidite packages were deposited in basin floor fan systems. These reservoirs are usually underlain by MTDs which often constitute large portions of the stratigraphic column, sometimes up to 150 m.

These MTD units have significant influence on the distribution of associated turbidite reservoirs in two principal ways. Firstly, by the topography of the MTD top surface which governs the geometry of overlying turbidites and secondly, by creating conduits favourable for focusing turbidity-current flow and deposition (Hackbarth and Shew, 1994). Therefore, any clue about movement path of these MTDs can provide valuable insights into depocenter locations of associated turbidite deposits.

METHOD AND RESULTS

We used high-resolution borehole images in conjunction with other conventional logs (gamma ray, density and neutron logs) acquired in a deepwater well drilled within a deepwater prospect in offshore Sabah. This borehole image was processed and interpreted as per a standard scheme. Then we used the results to classify the sedimentary packages based on the rock texture on images and dip orientations. In general, two sedimentary elements were discriminated as follows; turbidites and MTDs. We then analysed dips of the bedding contacts within MTD units to identify slump folds. We used structural analysis methods to extract the axis and vergence of the folds which in turn indicate the approximate orientation of paleoslope and direction of movement of the corresponding MTD packages.

Turbidite vs. MTD Packages

Turbidite intervals are discriminated from MTD units based on log response and internal architecture revealed by borehole images. We identify turbidite zones by a typical funnel shape on gamma ray corresponding to the fining up sequence. These units show a characteristic thinly bedded texture with an occasional thicker sand bed on the borehole image. Dip attributes of the bedding are systematic with minimum variations. This is in accordance with the classical Bouma sequence (Figure 1).

MTD units on the other hand, show a blocky gamma ray trend and heterogenous texture with bedding contacts of varying

orientations on borehole images. However, the MTD units which are of the interest in this study are those slump folds with characteristic dip trends.

Internal Architecture of Slump Folds

Slump deposits are very well-known in all environments from subaerial to deepwater settings. They are products of mass wasting which occurs when a coherent mass of loosely consolidated material or rock layers moves down a slope (Figure 2). During this sediment transport, non-tectonic folds are generated in such a way that their fold axis is almost parallel to the slope and their vergence implies the direction of movement (Bradley and Hanson, 1998). Although the mechanism and products of such sediment transport can be much more complex than what was described here, we take this simple approach for practical purposes. We demonstrate this concept in Figure 2.

Slump Folds on Borehole Images

Figure 3 depicts the results of the slump fold analysis using borehole images in this study. We used a stereographic approach to analyse the slump fold bedding planes. In this approach the best fitting plane of the bedding poles represents the fold profile. The pole of this plane is the fold axis which has a plunge of 5 degrees towards the azimuth of 232 degrees. We also derived the vergence orientation towards the azimuth of 324 degrees. This can be considered as the possible direction of the sediment transport/dispersal fairway as described above. This orientation shows a very good match with results from 3D seismic interpretations in the same area (Figure 4).

CONCLUSIONS AND DISCUSSION

This study demonstrates an attempt towards utilizing borehole image data for obtaining clues on sediment dispersal fairways controlling the distribution of reservoir facies within deepwater settings. We came to the idea of such analysis after observing the challenge of placing exploration wells in very high cost (~US$20M each well) deepwater environments. We precisely investigated several borehole images in deepwater wells to ensure the feasibility of this approach. Here, we presented the results of one of these wells. This work does not and cannot claim a conclusive procedure for the challenging problem of dispersal fairways in deepwater prospects. However, it provides a reliable approach based on easily accessible high-resolution borehole images to add one more piece to complete the puzzle.

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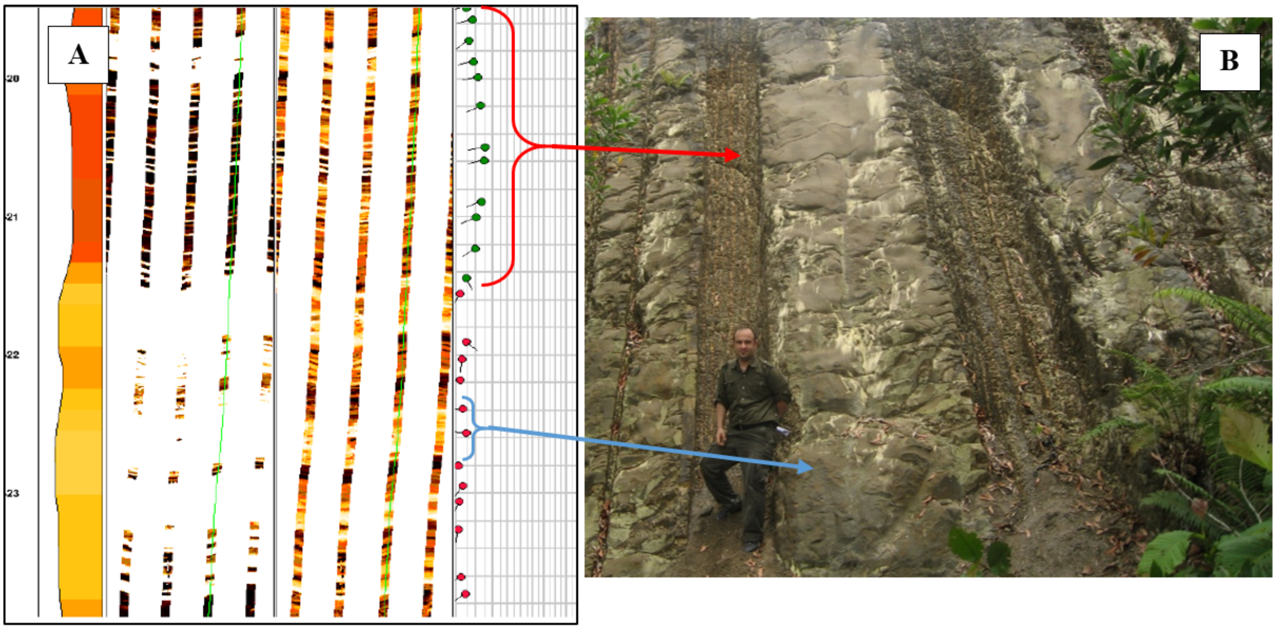

Figure 1. (A) composite image showing typical sequence of a turbidite package. The tracks are (from left to right) depth index (meter), Gamma ray log shading (increasing toward right), statically normalized oil-base mud image, dynamically normalized oil-base mud image and dip tadpole track (0 deg left-90 deg right). The composite depicts a fining upward sequence changing from thickly bedded sands to finely laminated heterolithics at top. Sand-rich areas are represented by bright colors. Such packages are interpreted to represent typical Bouma sequences. (B) an outcrop analogue of tectonically tilted multiple turbidite sequences. Arrows indicate each equivalent sediment unit.

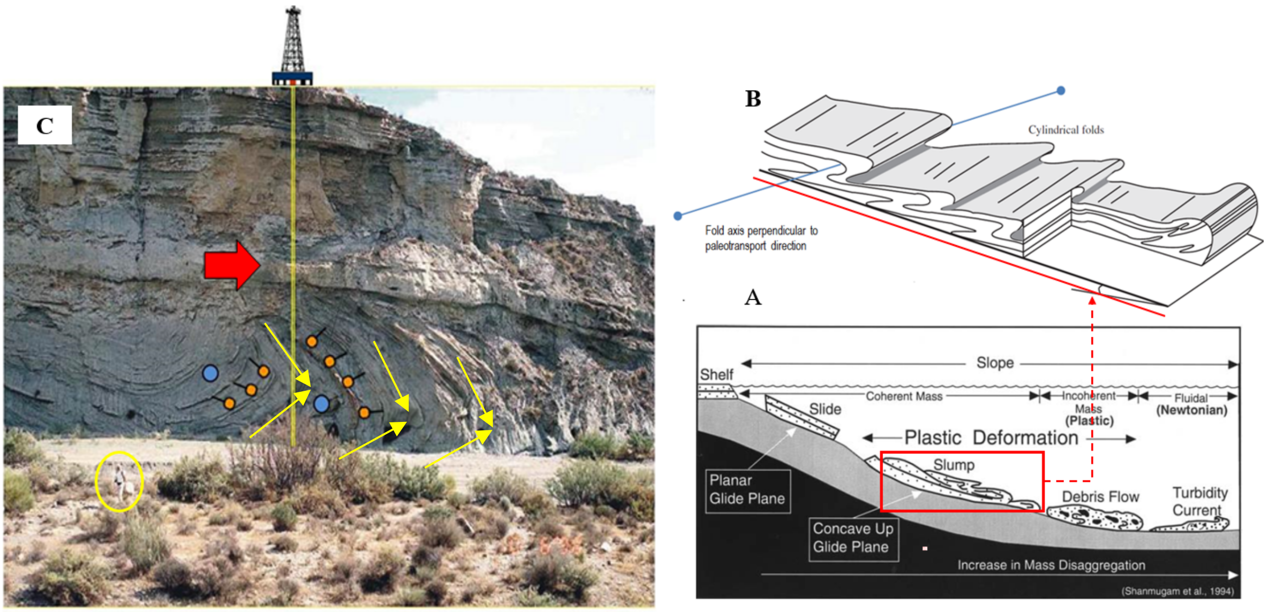

Figure 2. (A) Schematic diagram showing four common types of gravity driven process that transport sediments into deepwater environments (Shanmugam 1994). (B) Illustration of cylindrical slump fold with fold axis parallel to paleoslope (modified from Strachan, 2006). (C) A series of slump folds in deepwater settings overlain by gently dipping turbidite deposits (Weimer and Slatt, 2006). A schematic vertical well displayed to visualize the expected dip orientations of the slump bedding planes represented by orange circle tadpoles. Blue circles represent axis of the respective folds. As it can be seen, the fold axes are expected be aligned strike-parallel with paleoslope direction and perpendicular to the direction of the transport (red arrow). Also, vergence directions (intersections between each pair of yellow arrows) are in fact aligned with the transport direction.

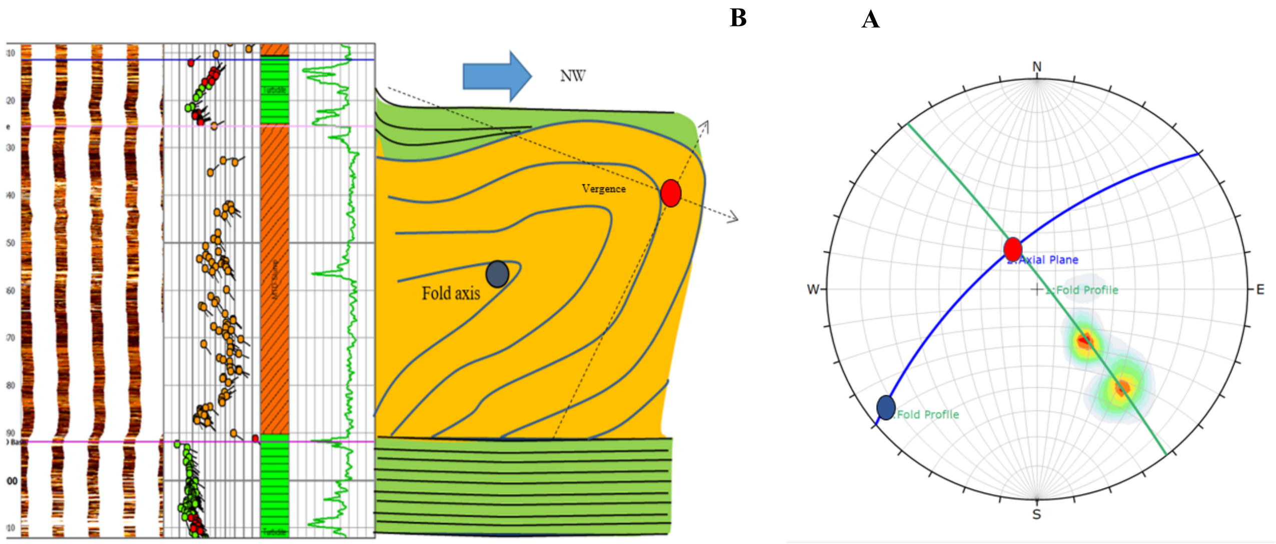

Figure 3. (A) Stereographic analysis (upper hemisphere) of the slump fold dip set as identified on the image log. Blue circle reresents the fold while the red circle is the vergence. (B) The schematic interpretation of the slump fold interpreted based on the stereographic analysis results.

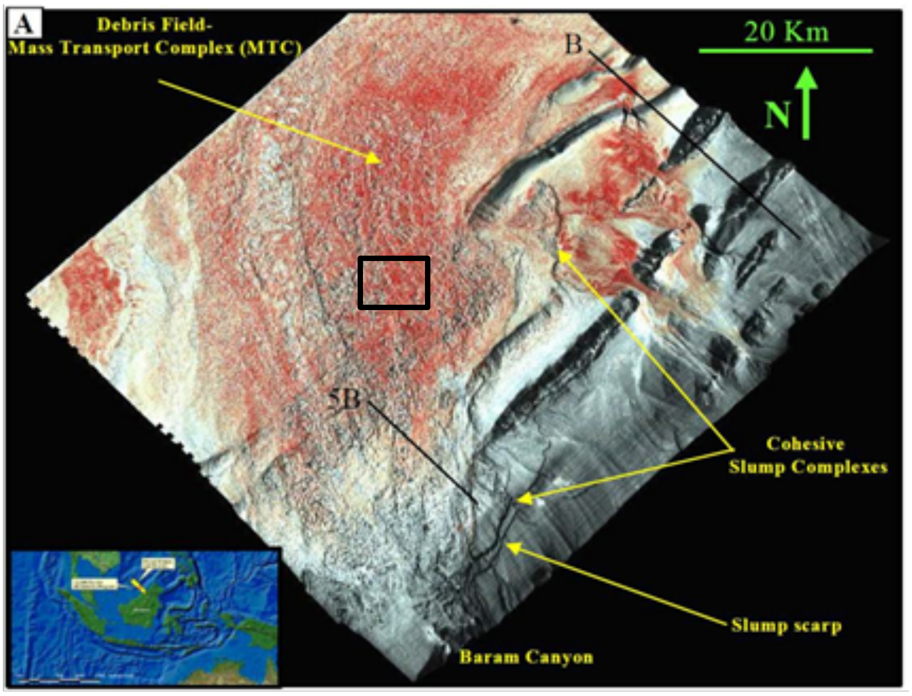

Figure 4. 3D perspective view from above- seafloor structure with max-positive amplitude overlay illustrating the general bathymetry and transport direction of MTD in offshore Brunei. The approximate location of the study is shown by a black box.