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Modification of mudstone fabric and pore structure as a result of slope failure: Ursa Basin, Gulf of Mexico

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ABSTRACT

Mud-rich mass transport deposits (MTDs) have a microfabric that is significantly different from bounding non-deformed mudstones at similar depths in the first 200 m of burial. Core samples from the Integrated Ocean Drilling Program Expedition 308, Ursa Basin, Gulf of Mexico sample many well identified MTDs. These MTD mudstones have higher clay mineral fabric intensities than compositional equivalent mudstones either at a given porosity or a given depth. Clay mineral fabric intensity was quantified using high resolution X-ray texture goniometry and confirmed by visual inspection on backscattered electron micrographs imaged on argon-ion milled surfaces. Enhanced clay-mineral fabric intensities in MTD mudstones are interpreted to result from remolding and shearing after mass movement, where the initially deposited clay mineral flocs have been mechanically disaggregated and physio-chemical forces of attraction overcome. Recognition of enhanced microfabrics has important implications for seismic anisotropy as well as for shallow fluid flow.

1. Introduction

Mass transport deposits (MTDs) may comprise 50% of the rock record in deep marine continental margins (McMurtry et al., 2004; Garziglia et al., 2008). MTDs are sedimentary deposits that result from slides, slumps and debris flows (Stow, 1986; Weimer and Shipp, 2004); and do not result from turbidite flows (Moscardelli et al., 2006 and references therein). MTDs record slope failure and they can occur in association with tsunamis (Tappin et al., 2001; Fryer et al., 2004; Dan et al., 2007). MTDs are a shallow drilling hazards in hydrocarbon exploration (e.g. Piper et al., 1997; Shipp et al., 2004 and references therein) as shallow overpressures may result and cause sediment flow near to a rig caisson.

Mud-rich MTDs are commonly identified by their strong basal seismic reflector (e.g. Moscardelli and Wood, 2008; Sawyer et al., 2009; Dugan, 2012), with the MTD itself being a low-amplitude zone and the underlying unit a high-amplitude zone. Outcrop studies (Pickering and Corregidor, 2005) and core-based research (Jenner et al., 2007; Sawyer et al., 2009) have begun to tie MTD lithological and petrophysical behavior to the seismic response (Moscardelli and Wood, 2008; Tripsanas et al., 2008) with Shipp et al. (2004) describing how MTDs have lower porosity than surrounding, non-deformed sediments. More recently, Integrated Ocean Drilling Program (IODP) Expedition 308 documented a sediment density increase in repeated MTDs in the Ursa Basin (Sawyer et al., 2009; Dugan, 2012) and Meissl et al. (2010) described the reduction in permeability and decrease in compressibility.

Shipp et al. (2004) and Sawyer et al. (2009) proposed that the sediment density increase observed is due to a process called remolding: a shearing process at constant void ratio that results in breakdown of the original soil structure (Mitchell and Soga, 2005) as a result of slumping and sediment movement rather than initial depositional processes. This breakdown in original structure occurred during a slope failure. The precursor clay-rich sediment presumably had a random orientation of clay particles (O'Brien, 1970, 1971) but during slope failure mechanical remolding took place, altering the sediment microfabric. Laboratory uniaxial consolidation at equivalent vertical effect stress on intact and remolded samples (Skempton, 1970; Burland, 1990) found lower porosity in remolded samples.

We further explore the sediment density increase observed within MTDs through an analysis of the microfabric and pore modification of MTDs. We quantify how sediment mass movement modifies the microfabric by shear and aligns clay mineral in a manner similar to how clay minerals are aligned in fault gouge (Solum et al., 2003; Solum et al., 2005; Haines et al., 2009). Cores from IODP Expedition 308 provide an excellent opportunity to explore the microfabric of mud-rich MTDs. We first characterize the mineralogy and grain size distributions of MTD mudstone and mudstones from the Ursa Basin. We show that clay minerals are more aligned in MTD mudstone than in bounding intact sediment using high resolution X-ray texture

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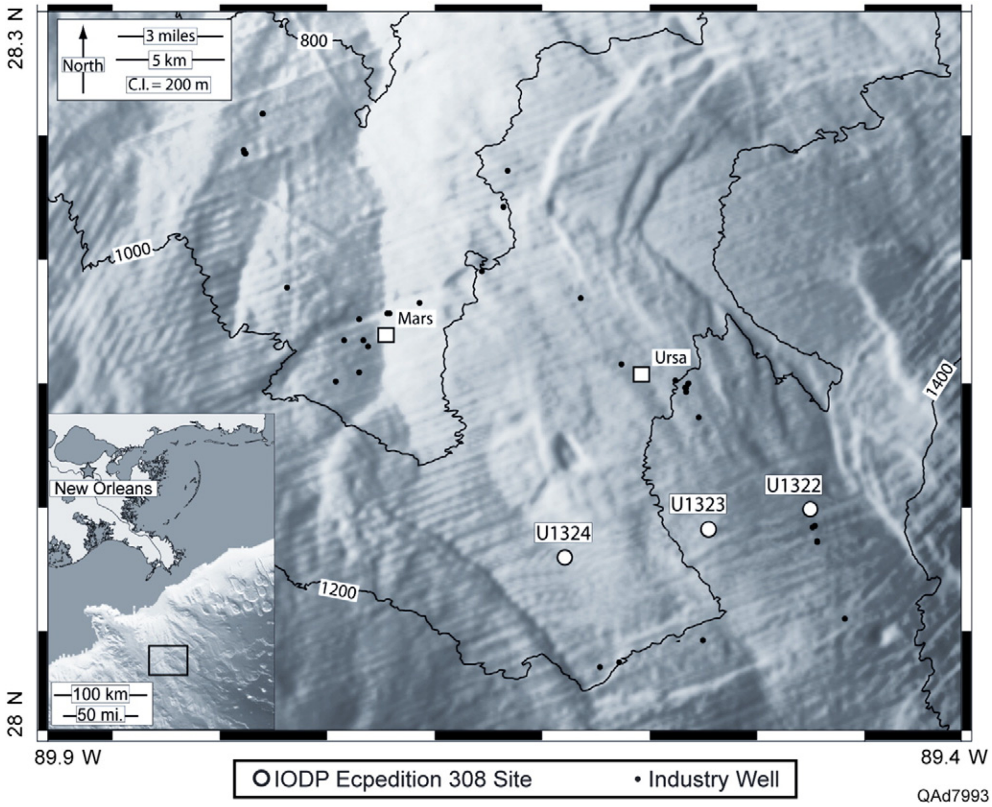

Fig. 1. The location of the Ursa Basin on the continental slope in water depths of ~1000 m. The Ursa Basin in the Gulf of Mexico and the locations of IODP Expedition Leg 308 drill Sites U1234, U1323 and U1322 relative to oil and gas drilling platforms Mars and Ursa, black dots are industry wells.

goniometry (van der Pluijm et al., 1994). We then show these fabrics in backscattered electron images using argon-ion milled sample surfaces. With the aid of these images and mercury injection capillary pressure (MICP) data we find that MTD mudstones have distinct pore throat size distributions relative to mudstones consolidated by only a change in vertical effective stress. Through this analysis we can describe how MTD mudstones could have enhanced sealing qualities, low permeabilities and potentially enhance permeability anisotropy.

2. Materials and methods

2.1. Ursa region samples

Whole cores from IODP Expedition 308 Site 1324 and Site 1322 (Fig. 1) provide the samples for this study. Mass transport deposits (MTDs) are abundant at Ursa and their presence and identification are well defined (Sawyer et al., 2009). Samples range from depths

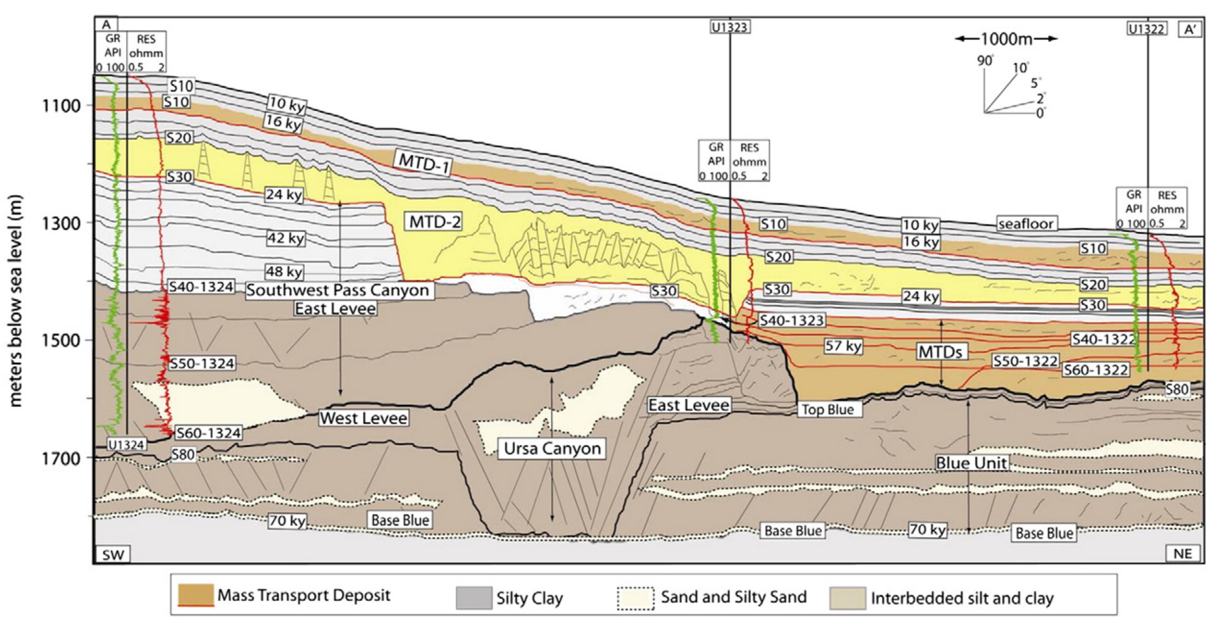

Fig. 2. Interpreted seismic line showing locations of Mass Transport Deposits (MTDs) through Sites U1324, U1323 and U1322. Major MTDs (1 and 2) are marked. Modified from interpretation by Sawyer et al. (2009).