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# Mass-transport deposits controlling fault propagation, reactivation and structural decoupling on continental margins (Espírito Santo Basin, SE Brazil)

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ABSTRACT

This work uses high-quality 3D seismic data to assess the importance of mass-transport deposits (MTDs) as markers of fault propagation. We mapped three distinct MTDs and several fault families on the continental slope of Espírito Santo, SE Brazil. Fault mapping was based on seismic attributes such as seismic coherence and structural smoothing, and was further completed using ant tracking algorithms. Genetically related fault families were analysed in terms of their throw-depth (t-z) and throw-distance (t-x) gradient curves. A key result in this paper is that vertical fault propagation can be hindered by MTDs, as demonstrated for Eocene to Early Miocene faults in parts of the study area. Throw-depth variations in faults affected by MTDs are associated with: a) lithologic controls resulting from the presence of MTDs, b) local fault segmentation and c) reactivation by dip linkage. Based on their orientation and degree of interaction with MTDs, interpreted faults can be classified as decoupled and non-decoupled. Importantly, faults decoupled by MTDs have quasi-elliptical t-x profiles and show smaller cumulative throw values and fault propagation rates when compared to their non-decoupled counterparts. Recurrent MTDs can therefore be used as markers to estimate structural decoupling between distinct fault families.



## 1. Introduction

The contribution of mass-wasting processes to the geometry and architecture of sedimentary basins has been widely discussed in the literature (e.g. Hjelstuen et al., 2007; Hunerbach et al., 2004; Tailing et al., 2007). In particular, mass-transport deposits (MTDs) are important components of petroleum systems on continental margins (Gamboa et al., 2011; Ogiesoba and Hammes, 2012). They may comprise mud prone successions, homogeneous debris flows with good seal properties, or reservoir intervals composed of siliciclastic or volcaniclastic strata (Dykstra et al., 2011; Haughton et al., 2003; Jennette et al., 2000; Ogiesoba and Hammes, 2012; Posamentier and Kolla, 2003; Welbon et al., 2007). As shown in this work, MTDs can also be used as structural markers. In fact, erosional truncation of pre-existing fault scarps during mass-wasting events can help in constraining the timing of fault growth and movement in sedimentary basins (see also Alves et al., 2009; Gamboa et al., 2010; Omosanya and Alves, 2013).

The history of fault growth is commonly assessed through the collection of fault displacement data (Anette et al., 2013; Baudon and Cartwright, 2008a, 2008b; Cartwright and Mansfield, 1998; Mansfield and Cartwright, 2001; Morley, 2002; Peacock, 2002; Peacock and Sanderson, 1991; Stewart, 2001; Zhang et al., 2011). Throw-depth (t-z) and throw-distance (t-x) plots offer information on the nucleation, propagation, segmentation and linkage of individual faults, providing at the same time important data for fault seal prediction (Faulkner et al., 2010; Koledoye et al., 2003; Stewart, 2001). In addition, throw and displacement gradient plots have been used to assess the role of lithology and tectonic reactivation on the growth of faults (Baudon and Cartwright, 2008a; Cartwright and Mansfield, 1998), as discrepancies on throw/displacement gradients commonly result from mechanical heterogeneities, fault linkage or fault segmentation (Baudon and Cartwright, 2008b).

This paper aims to characterise the effect of MTDs on vertical fault propagation by providing a detailed history of fault families on the mid-continental slope of the Espírito Santo Basin, SE Brazil (Fig. 3). We apply throw-depth (t-z) plots in an area of recurrent MTDs to investigate the history of fault growth. Cumulative throw plots are introduced to distinguish fault families and assess their propagation history. Faults identified in the study area include those found in regions

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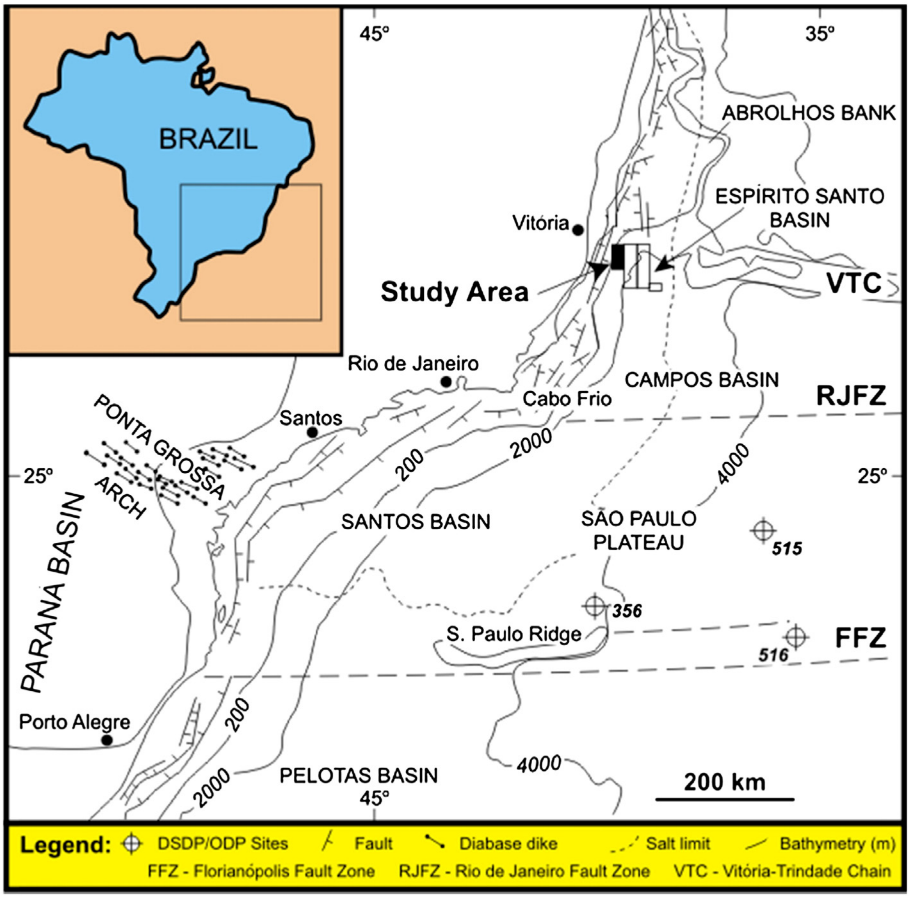


**Fig. 1.** Location map of the Espírito Santo Basin, offshore SE Brazil. The position of the seismic volume used in this study is shown in the figure. Also shown in the figure are major fault zones that affected the SE Brazilian margin since latest Jurassic–Early Cretaceous continental rifting.

where the MTDs are mapped and faults where no MTDs are observed. In essence, this paper aims to address the following questions:

a) Can MTDs impose lithological controls on the propagation of faults on continental margins?
b) Can MTDs be used as stratigraphic markers to assess fault propagation histories on structurally decoupled and non-decoupled fault families?
c) What methods can be used to distinguish different fault families in terms of their propagation histories?

To simplify the analysis in this paper, interpreted faults have been classified into Types A to D (see Fig. 2A for further information). Faults of types A and B are located in non-MTD regions, while Types C and D comprise faults mapped within the MTD interval. In addition, we defined decoupled faults as those faults whose tips are confined to the basal shear surfaces of the interpreted MTDs (Type D). Non-decoupled faults include Type A, B and C faults (Fig. 2B).

## 2. Data and methods

The 3D seismic volume used in this work covers ~1600 km$^2$ of the mid-continental slope, offshore Espírito Santo Basin, SE Brazil (Fig. 1). This interpreted zero-phased volume was acquired using a dual air gun array and six, 5700 m long streamers within a 12.5 m × 12.5 m grid at a vertical sampling interval of 2 ms. The volume has a dominant frequency of 40 Hz for a vertical resolution of ~15.6 m and 19.4 m, assuming velocities of 2100 m/s and 2500 m/s for shallow and deeper horizons in the study area, respectively (Barker et al., 1983; Fiduk et al., 2004). Horizontal resolution approaches 12.5 m.

Coherence slices were used to identify different fault families and pre-condition the seismic volume before using ant tracking algorithms (Fig. 2B). Seismic coherence is a measure of the waveform similarity, i.e. how a trace is similar to its neighbouring trace. Similar traces are mapped as high coherence coefficients while discontinuities have low coefficients (Bahorich and Farmer, 1995; Brown, 2004). Structural smoothing algorithms calculate changes in local dip by smoothing the input signal to increase the continuity of the seismic reflector (Randen et al., 2000). Structural smoothing attributes are useful for pre-conditioning the seismic for automatic fault extraction (see Basir et al., 2013).

Fault planes were manually mapped in Latest Cretaceous–Holocene strata showing three main MTDs (Figs. 4b and 5b). In densely faulted regions, we used ant tracking algorithms to extract fault patches (Randen et al., 2000). Faults automatically extracted by this method were manually checked to ensure that the automatic fault picks were valid. In order to achieve an effective automatic fault extraction, the volume was divided into four zones comprising both MTD and non-MTD areas (Fig. 2B). Two thousand two-hundred and eighty-two (2282) faults were automatically extracted and analysed in this work.

Fault propagation histories were analysed using throw-depth (t-z) techniques (Baudon and Cartwright, 2008a, 2008b; Cartwright and Mansfield, 1998; Dawers and Anders, 1995; Mouslopoulou et al., 2007; Peacock and Sanderson, 1991; Walsh and Watterson, 1989). In detail, throw values were estimated on faults using seismic profiles orthogonal to fault strikes at the inflection points closest to the hanging wall and footwall cut-offs (Mansfield and Cartwright, 1996). Throw values were contoured for twenty four (24) representative faults to further elucidate the styles of fault growth, linkage styles and