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Influence of growth faults on coastal fluvial systems: Examples from the late Miocene to Recent Mississippi River Delta

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ABSTRACT

The details of how fluvial systems respond to spatial changes in land-surface subsidence produced by active faulting remain incompletely understood. Here, we examine the degree to which the positioning of individual channels and channel-belts is affected by local maxima in subsidence associated with the hanging walls of growth faults. The channel forms and faults are imaged using a seismic volume covering 1400 km^2 of Breton Sound and Barataria Bay in southern Louisiana, USA. We look at the consequences of interactions between channels, channel-belts, and faults in late Miocene to Recent strata. More than fifty individual channels that crossed the traces of active growth faults were examined. Of these channels, only three appear to have been redirected by the faults. There also appeared to be no systematic change in the cross-sectional geometries of channels or channel-belts associated with crossing a fault, though the orientation of the channel-belts appears to be more influenced by faulting than the orientation of individual channels. Seven out of ten mapped channel-belts appear to have been steered by growth faults. We propose that channel belts are more likely to be influenced by faults than individual channels because channel-belts are longer lived features, unlikely to shift their overall position before experiencing a discrete faulting event. In addition, the style of influence in the few cases where an individual channel is affected by a fault is different from that of larger systems. While downstream of a fault channel-belts generally become oriented perpendicular to fault strike, the individual channels are directed along the hanging wall of the fault, running parallel to the fault trace. We relate this to the ratio of the length-scale of fault rollover relative to the channel or channel-belt width. Fluvial-fault interactions with higher values for this ratio are more likely to be carried parallel to the fault trace than systems with lower ratio values.

1. Introduction

A basic principle in the study of interactions between fluvial systems and spatially varying subsidence is that rivers can be preferentially attracted to areas of higher subsidence (Alexander and Leeder, 1987). The potential for variations in subsidence to affect fluvial stratigraphy has been documented in numerous field studies (e.g., DeCelles, 1986; Mack and Seager, 1990; Peakall, 1998; Mack and Leeder, 1999; Peakall et al., 2000). Fluvial sensitivity to subsidence is, however, dependent on the interplay of a number of different factors. In a simulation model of alluvial stratigraphy, Bridge and Leeder (1979) found a strong clustering trend in areas of high tectonic tilting due to a fault-created, transverse floodplain slope. In their model, this only occurred when tilting was maintained for a prolonged period of time. Mackey and Bridge (1995) found that tectonic tilting caused channel-belts to shift away from zones of uplift and towards zones of maximum subsidence. However, in their model, if the aggradation rate is high enough to keep pace with subsidence, no fault effect was seen. This numerical result for the case of high sediment supply was confirmed experimentally by Hickson et al. (2005). Kim et al. (2010) demonstrated the importance of the relative magnitudes of the tectonic timescale versus channel-avulsion frequency when determining the likelihood that a channel will be redirected by subsidence. In their associated physical experiment, channels were most influenced by variations in subsidence if channel mobility was low relative to the accumulation of significant surface relief via spatially varying subsidence rates.

The majority of previous studies have focused on the effects of large, basin-scale extensional tilting on fluvial systems. Only a few workers have looked at the extent to which local faulting can influence stratigraphy. Maynard (2006) used high resolution 3D seismic data to document fluvial response to the development of a growth fault related rollover anticline. A series of seismic time slices imaged the evolution of a system of narrow (100's of meters wide) channels on the hanging wall side of a growth fault. The fluvial system underwent an increase in sinuosity and avulsion frequency in response to the increase in slope created by faulting. Taha and Anderson (2008) studied channel avulsion frequency within the Brazos River incised valley, Texas, USA. Using

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core, radiocarbon, aerial photo, and digital elevation-model data, they examined the effect of tilting due to a growth fault on avulsion history within the valley. Their results showed that a late Pleistocene nodal avulsion point was co-located at a site of active movement on a prominent growth fault.

The present study uses an industry-grade 3D seismic volume to examine the effect of local growth faults on fluvial stratigraphy of the late Miocene to Pliocene deposits of the Mississippi River Delta, as well as the modern channel of the Mississippi River. The seismic volume imaged in this study contains dozens of examples of paleo-channels, channel-belts, and valleys that cross growth faults. Most of these growth faults were active for the entire Miocene to Pliocene interval and continue to be active today (George, 2008) so the fluvial systems crossing these faults may have been subject to significant spatial variations in subsidence.

The interplay between cross stream versus downstream surface gradients has been proposed as a primary control on whether or not fluvial stratigraphy is influenced by lateral differences in subsidence (Peakall et al., 2000; Kim et al., 2010). If the cross-stream slope created by growth faulting is much lower than the downstream slope, then growth faults would not be expected to influence channel behavior. Downstream slopes in this coastal study area are low (around $\frac{1}{10{,}000}$). Field data (Gagliano et al., 2003) show that short term, localized fault displacement rates can be on the order of 10^2 mm/year. As a result, local cross-stream gradients are likely to be more than one order of magnitude greater than the downstream slope, yet small channels appear relatively insensitive to faulting. As demonstrated by Kim et al. (2010), channel mobility is also an important factor in fluvial sensitivity to growth fault-created subsidence. If the timescale for channel avulsion is short relative to the frequency of faulting events, then an individual channel may avulse before feeling the effect of a fault. The relative timescales of faulting and channel avulsion appear to be an important control for small channels in this dataset.

In addition to the many small channels, the seismic volume imaged in this study shows ten individual channel-belt systems (with widths ranging from 1.5 km to 4 km) that cross growth faults. The relationship between these larger systems and faults has not been previously addressed. While exact avulsion frequencies cannot be constrained from this dataset, channel-belts are relatively long lived features with avulsion frequencies that are likely lower than those of smaller channels. It follows that for channel-belt systems, the ratio of the timescale of avulsion to faulting is higher than for small channels. This allows the relative importance of timescales on the potential for fault influence on fluvial stratigraphy to be examined.

2. Geological setting of the study area

The 1375 km^2 3D seismic survey is located under Breton Sound and Barataria Bay, Louisiana, USA, approximately 50 km southeast of the city of New Orleans and 50 km northwest of the leading edge of the modern Mississippi River Delta (Fig. 1). The seismic survey clearly images channelized features within deltaic sandstone and mudstone over subsurface depths ranging between 500 m and 2000 m. Paleo-Data, Inc. provided us with biostratigraphic data from five wells within the study area that places the base of this 1500 m depth interval in the latest Miocene and its top in the latest Pliocene (Straub et al., 2009).

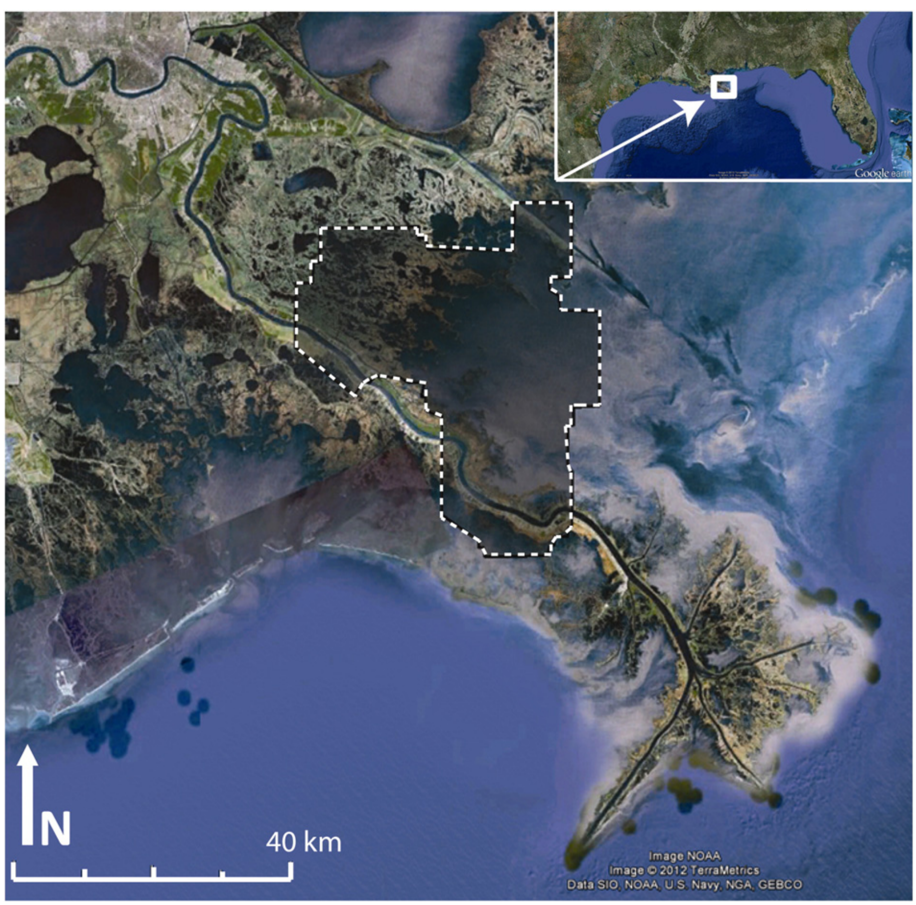

Fig. 1. Aerial extent of the Breton Sound 3D seismic survey outlined on the modern Mississippi River Delta surface (white dashed lines) and regional map showing approximate survey location (white box) along the Gulf Coast. The approximate center of the 3D seismic survey is at latitude 29.468408°, longitude −89.518501° (WGS84 coordinate system). Access to this seismic volume was provided by WesternGeco®; images are satellite photos from Google Earth®.