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Seismic Geomorphology, Lithology, and Evolution of the Late Pleistocene Mars-Ursa Turbidite Region, Mississippi Canyon Area, Northern Gulf of Mexico

A Thesis in

Geosciences

by

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Abstract

The interplay between sedimentation and erosion during the late Pleistocene in the Mars-Ursa region, northern Gulf of Mexico, resulted in a complex compartmentalized reservoir. Rapid deposition, directly down-dip of the Mississippi River beginning about 70 ka, quickly filled antecedent topography in the Mars-Ursa region with a thick accumulation of sand and mud called the Blue Unit. This permeable reservoir was rapidly and asymmetrically buried by thick mud-rich levees of two channel-levee systems. Both systems plunged from north to south with a steeper gradient than the underlying Blue Unit. Rotated channel-margin slides present in both channel-levee systems, rotated low-permeability mud-rich levee deposits beneath the sand-rich channel fill. As a result of the channel-levee systems, the east-west hydraulic connectivity of the Blue Unit decreases progressively from north to south until its eastern and western halves become completely separated.

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Acknowledgements

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CHAPTER 1:

Seismic Geomorphology, Lithology, and Evolution of the Late Pleistocene Mars-Ursa Turbidite Region, Mississippi Canyon Area, Northern Gulf of Mexico

1.1 INTRODUCTION

Seismic, well log, and core data acquired in the near-surface sedimentary section while targeting the deeper section provide a great opportunity to study deep-water stratigraphy and depositional processes. The high resolution of seismic data in the near-surface sedimentary section provide a three dimensional visualization that is not possible in deeper reservoirs.

This approach has been applied in various settings around the world. Deptuck et al. (2003) examined 2-D and 3-D seismic data to investigate the architecture and evolution of shallowly buried deep-water channel systems offshore Africa and in the Arabian Sea. Saller et al. (2004) used 3-D seismic data from offshore Indonesia to link a Pleistocene delta with a correlative basin-floor fan. Dean et al. (2000) used 3-D seismic and core data of the seafloor in the shallow sedimentary section in the deep-water Gulf of Mexico to understand the distribution of sheet sands, channel deposits, and debris flows. Fonnesu (2003) discussed seismic and lithologic attributes of two Pleistocene channel-levee systems in a slope setting from offshore West Africa. Posamentier and Kolla (2003) presented a comprehensive review of deep-water depositional elements. Pirmez and Imran, (2003) integrated seismic data, sedimentological data, and numerical flow models to reconstruct turbidity flows in the Amazon Channel.

Late Pleistocene strata in the Mars-Ursa region have received attention since the 1990's when overpressured and unconsolidated sands in the shallow section plagued drilling operations (Eaton, 1999; Ostermeier et al., 2000; Winker and Shipp, 2002). This drove the acquisition of both high-resolution 3-D seismic data and several geotechnical cores to study the geological and geotechnical framework in the region (Winker and Shipp, 2002).

We examine 3-D seismic strata and well logs to describe the geomorphology and lithology of the main depositional elements in the Mars-Ursa region. We interpret the geological evolution in the Mars-Ursa region for the past 70 ka, and illuminate the underlying processes that built and reshaped these strata.

1.2 GEOLOGIC SETTING

The Mars-Ursa salt-withdrawal mini-basin is located 210 kilometers (130 miles) south-southeast of New Orleans, Louisiana, on the northeastern Gulf of Mexico continental slope in 800-1400 meters (2600-4600 feet) of water (Figure 1 and Figure 2). It is at the center of late Pleistocene deposition derived from the Mississippi River drainage system. Rapid sedimentation is recorded by the large topographic wedge of deposits that disguise the otherwise hummocky nature of the seafloor in the northern Gulf of Mexico (Figure 2A). The study area is bounded to the west by the Mars Ridge, a prominent north-south trending bathymetric high that is the bathymetric expression of a buried channel-levee system. Eastward from the Mars Ridge, the seafloor slopes down to a zone of

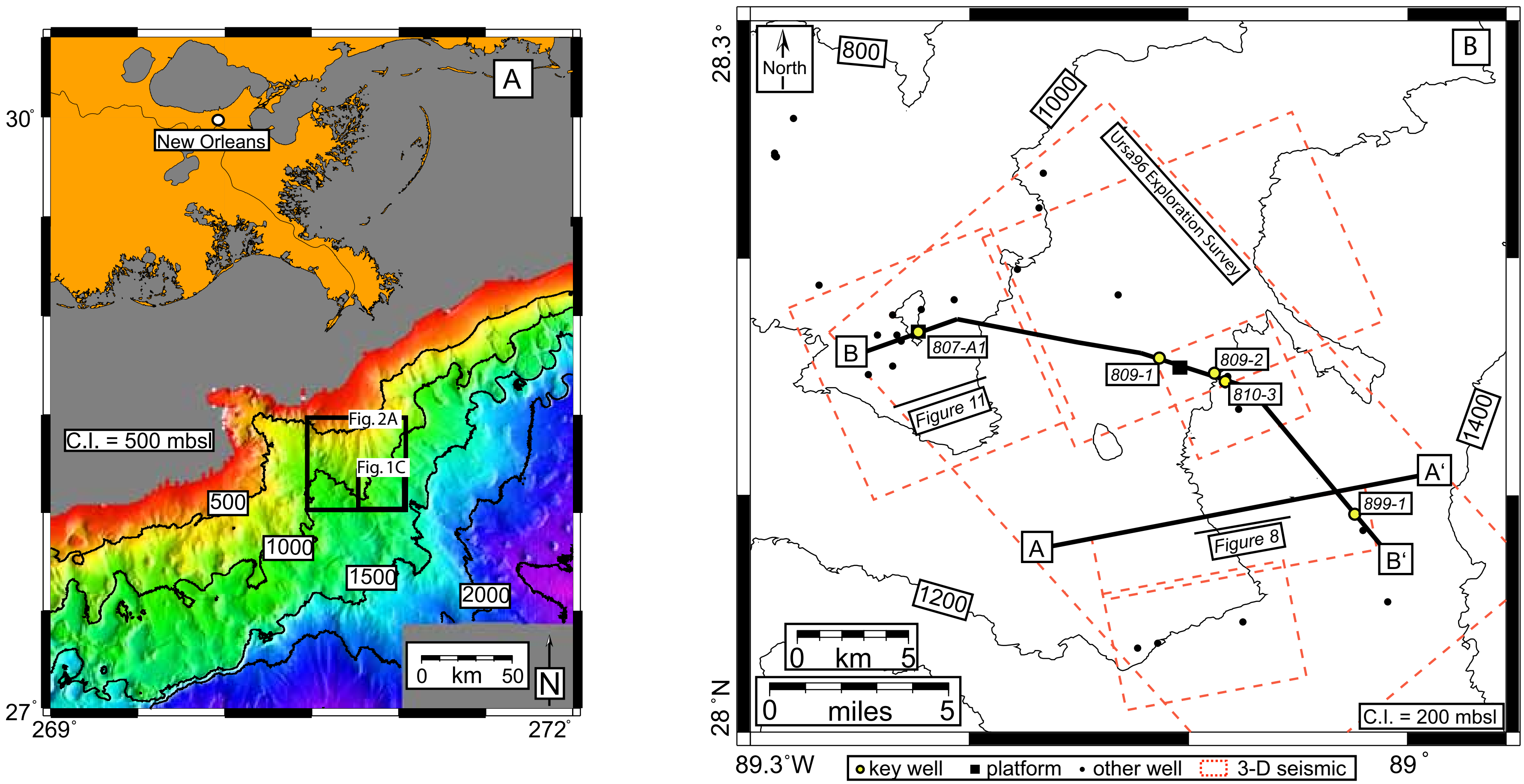


Figure 1. (A) The Mars-Ursa region is located 95 km (60 miles) down-dip of the Mississippi River on the continental slope (NGDC, 1998). (B) Base map of the Mars-Ursa study area with location of3-D seismic datasets (red dashed rectangles), Mars and Ursa tension-leg platforms (black rectangles), key wells used in this study (yellow circles with black outline) other industry wells (black dots), bathymetry contours, location of well log cross sections and other figures.

mass transport deposits, including one failure described as one of the largest submarine mass transport deposits in the world (Figure 2A) (McAdoo et al., 2000).

Late Pleistocene shelf, shelf-margin, and mini-basin turbidite deposits that were sourced from the Mississippi River in the north-central Gulf of Mexico are termed the Eastern Depositional Complex (Winker and Booth, 2000). Shelf and shelf-margin deposits have been described by Coleman and Roberts (1988), and McFarlan and LeRoy (1988). The deep-water strata we studied are one component of this system that were deposited outboard of the shelf break on the continental slope (Figure 2B). These strata accumulated during Marine Isotope Stages (MIS) 2-4 in response to North American continental glaciation (Late Wisconsinan) (Winker and Booth, 2000; Winker and Shipp, 2002). They overlie the MIS 5 condensed section which contains the extinction events of the planktonic foraminifera *Globorotalia flexuosa* (70 ka) and the calcareous nannofossil *Pontosphaera 1* (~70 ka) (Styzen, 1996; Winker and Booth, 2000). This regional datum has been identified on the Mississippi Fan and in other academic and industry holes in the Gulf of Mexico (Joyce, et al., 1990; Martin, et al., 1990).

Most of the deposits are associated with four channel-levee systems which filled and bypassed the region with thick deposits. From oldest to youngest and from east to west, they are the Ursa, Southwest Pass, Old Timbalier, and Young Timbalier systems (Figure 2B). Each of these channel-levee systems transported material from the continental margin to the Mississippi Fan

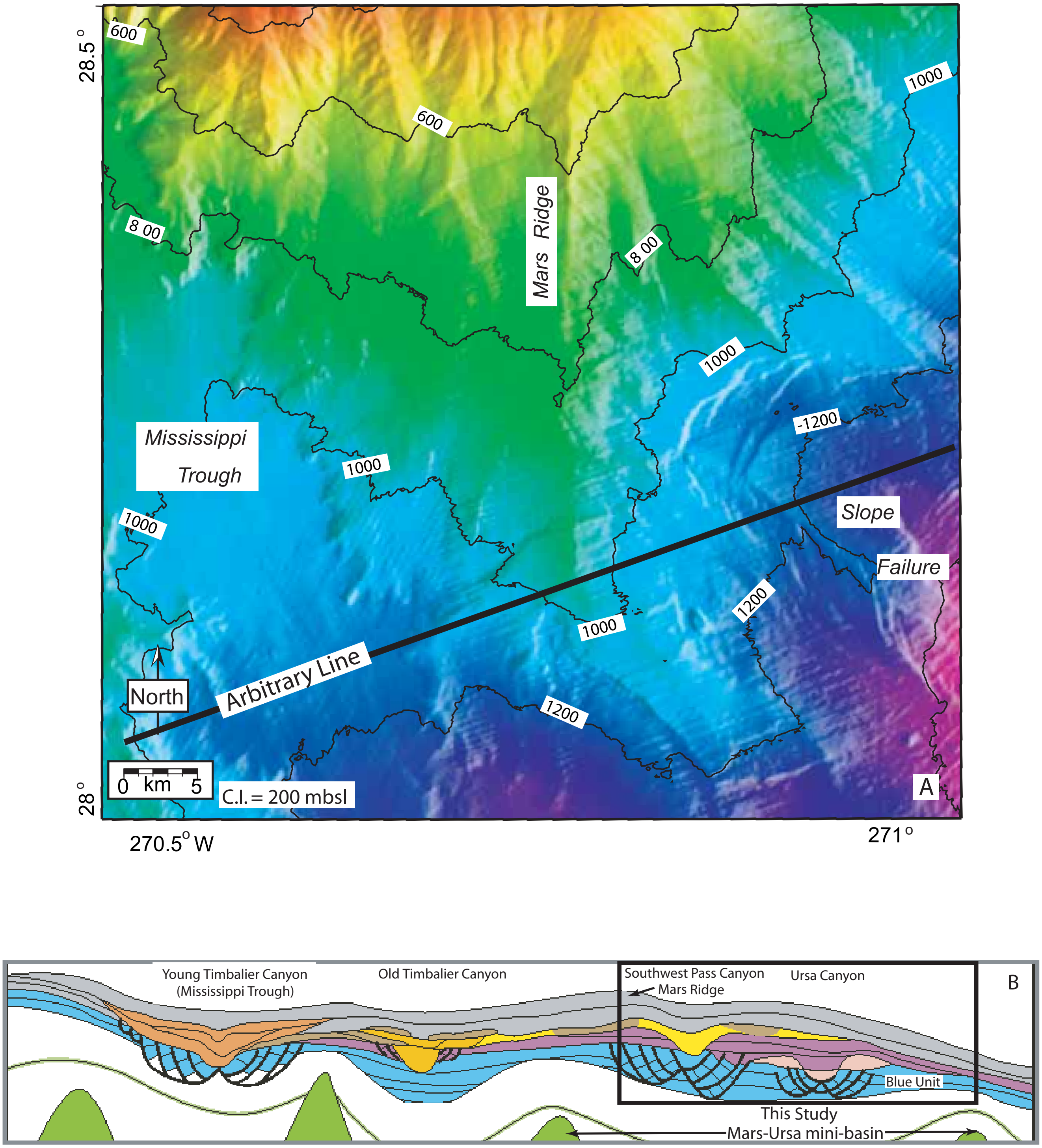


Figure 2. (A) Mars-Ursa region bathymetry is produced by the thick wedge of late Pleistocene sediments from the Mississippi River, fed by four canyon-channel-levee systems shown in B. (B) This study encompasses the deposits of the Blue Unit and the Ursa and Southwest Pass Canyon systems.

throughout the late Pleistocene. All were back-filled and buried except for the Young Timbalier system, which is still seen on bathymetric charts and referred to as the Mississippi Trough. This study is within the Ursa and Southwest Pass channel-levee systems (Figure 2B).

1.3 DEPOSITIONAL ELEMENTS

The depositional elements that have built the stratigraphic succession in the Mars-Ursa region in the last ~70 ka are, from oldest to youngest, the Blue Unit, the Ursa Canyon channel-levee system, the Southwest Pass Canyon channel-levee system, and mass transport deposits (Figure 3). We adopted the naming convention of Winker and Shipp (2002) yet established our own criteria for identifying and mapping key stratigraphic surfaces. For each depositional element, we define mapping criteria, present our observations of seismic and lithological character, and present our interpretation. We close by describing the overall evolution of this system.

The Blue Unit

The Blue Unit is composed of interbedded sand and mud (Figure 4 and 5). The base of the Blue Unit is the base of the deepest sand that ties to a weak negative amplitude within the shallow sedimentary section (within the exploration survey, 90-degree phase data) (Figure 4). However, we mapped the positive seismic amplitude associated with the top of this sand because it was more regionally mappable than its base. The top of the Blue Unit ties to a positive seismic amplitude that marks an increase in impedance with depth at the top of

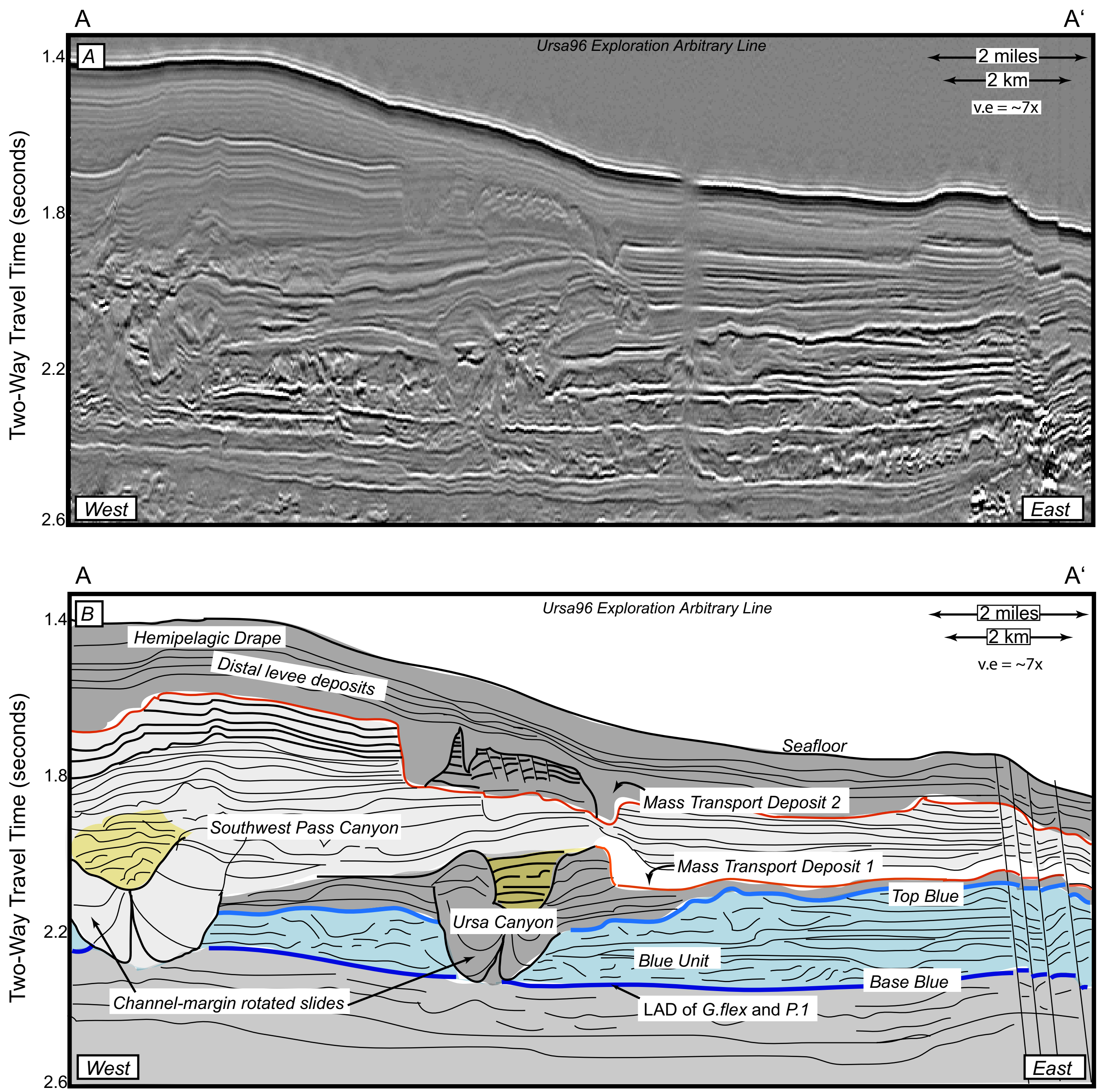


Figure 3. (A) Seismic cross section A-A' (located in Figure 1B). (B) Interpreted cross section A-A' showing depositional elements and key surfaces. Light and dark gray represent mud-rich levee, rotated channel-margin slides, hemipelagic drape, and yellow represents sand-rich channel fill. The Blue Unit (light blue) is composed of sand and mud. Mass transport deposits have occurred in the mud-rich levee deposits above the Blue Unit. Detachment surfaces are colored red.

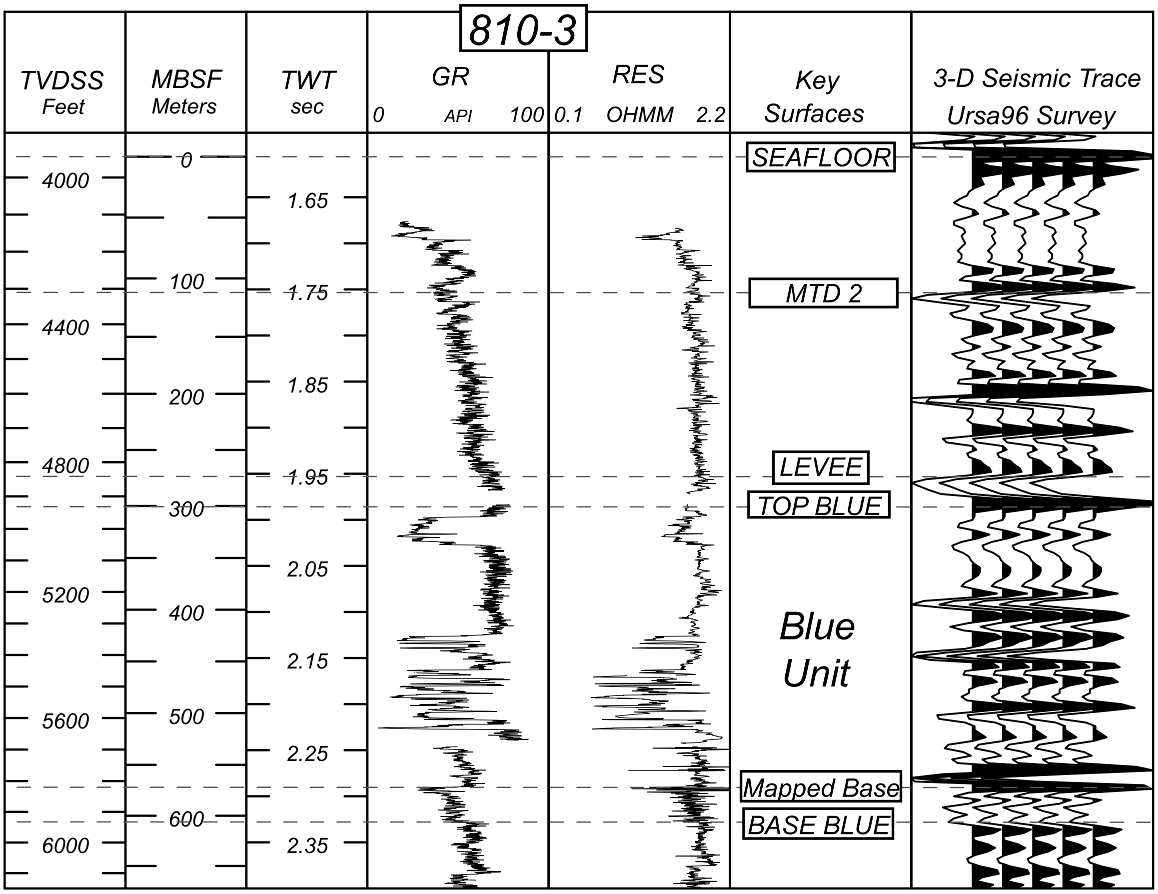


Figure 4. Type well log, 810-3, showing gamma ray (GR), resistivity (RES) on a logarithmic scale, key surfaces, and extracted 3-D seismic trace from the exploration survey (located in Figure 1C). The Blue Unit is composed of interbedded sand and mud. Depth scales are true vertical depth below sea surface (TVDSS), meters below seafloor (MBSF), and two-way travel time below sea surface (TWT). MTD 2 = mass transport deposit 2 (see text for details).

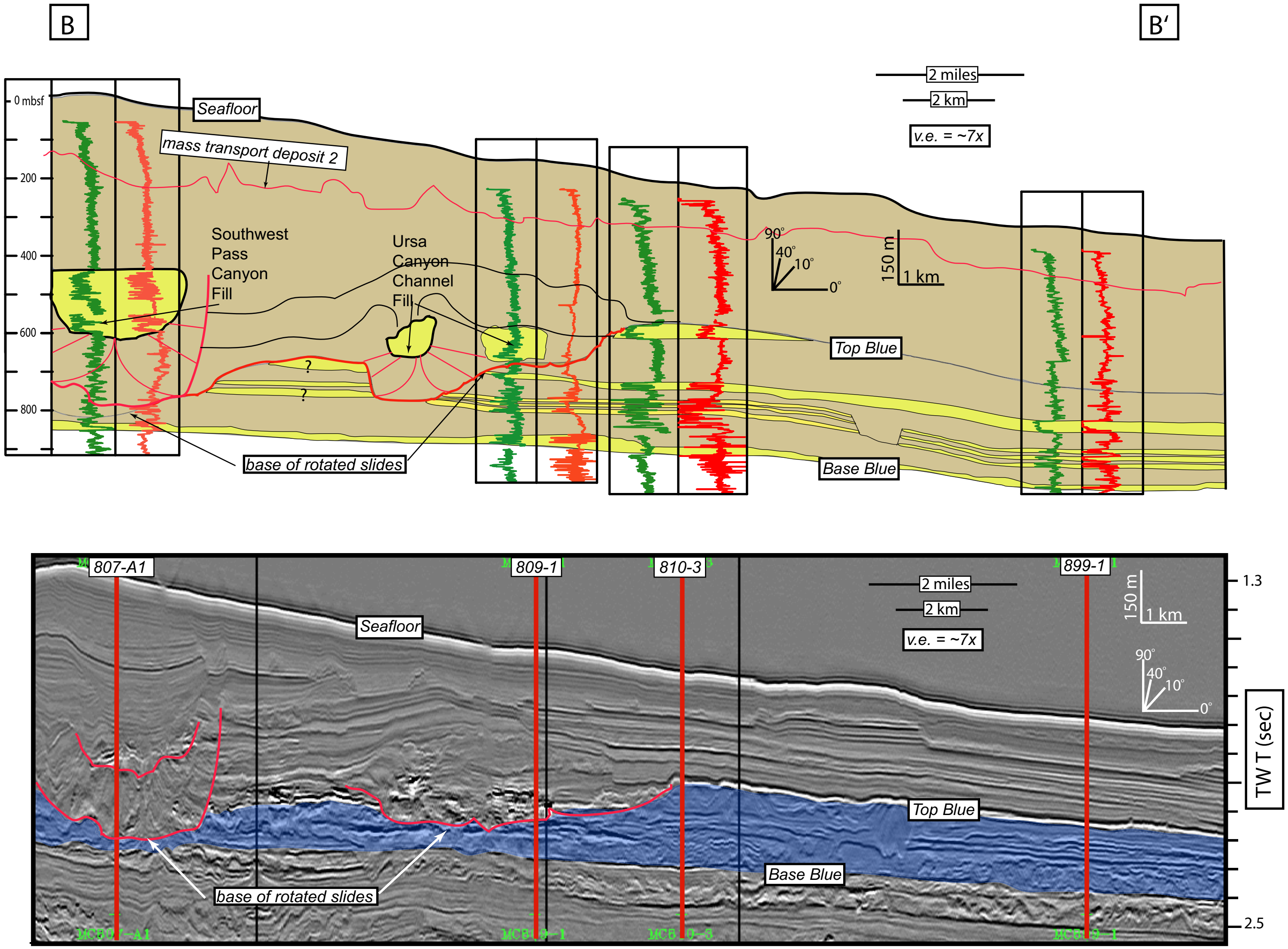


Figure 5. Well and seismic log cross section B-B' illustrating the Blue Unit and other depositional elements (location in Figure 1C). Sands are colored yellow, and shales are colored brown based on interpreted lithology from gamma ray (green) and resistivity (red) logs. Much of the Blue Unit, is deformed by two channel-levee systems in the western part of the study area.

sands within the Blue Unit (Figure 4). However, where this surface has been eroded by channel-levee systems, we mapped the base of the channel levee systems as the top of the Blue Unit.

The base of the Blue Unit was correlated in all well logs and was mapped throughout the exploration seismic data (Figure 6). It is generally planar and dips to the south at a gradient of ~0.23˚. In the western and southern parts of the study area, it is truncated by a deformation zone associated with two channel-levee systems.

Reflections within the Blue Unit are associated with interbedded sand and mud (Figure 4). Sand bed thicknesses range from a few meters to several tens of meters and mud layers have similar thicknesses (Figure 4). In some areas, individual sand-rich members within the Blue Unit could be correlated between wells (Figure 5). In other cases, correlation was difficult due to chaotic, discontinuous intervals. This chaotic seismic character within the Blue Unit represents mass transport deposits within the Blue Unit.

The top of the Blue Unit is difficult to correlate away from the 810-3 well because of the complex seismic character and significant post-depositional erosion (Figures 5 and 7). The true top sand of the Blue Unit is truncated by channel-margin slides associated with two channel-levee systems in the western half of the study area (Figure 7).

The Blue Unit is thickest in the eastern part of the study and has a maximum thickness of ~250-300 ms two-way travel time (Figure 8). It pinches out in the eastern part of the study area and where the Southwest Pass and Ursa

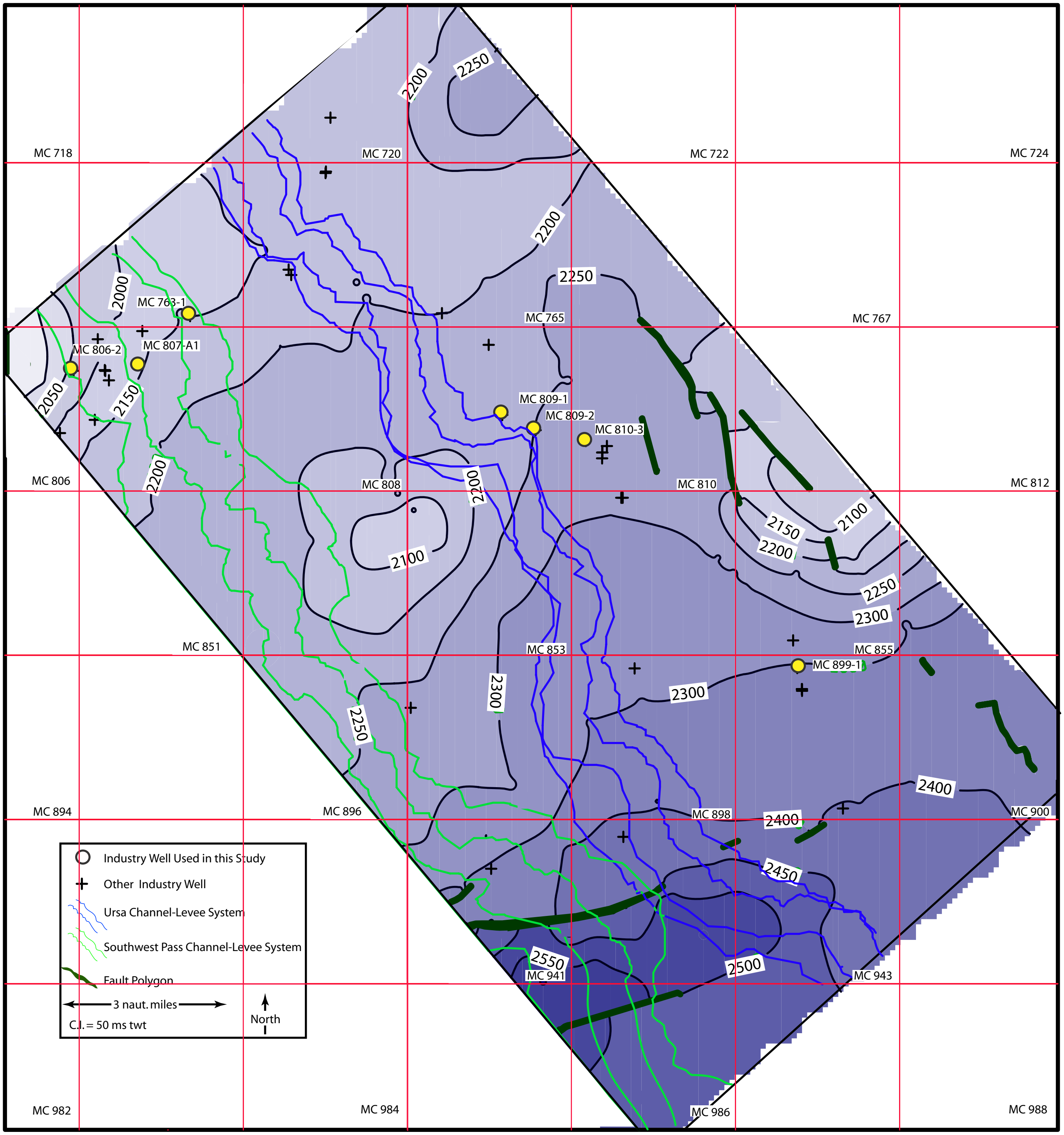


Figure 6. Structure map of the base of the Blue Unit within the Ursa96 exploration survey (location in Figure 1). Contours are two-way travel time in milliseconds. Outlines of the Ursa and Southwest Pass Canyon channel-levee systems are overlain.

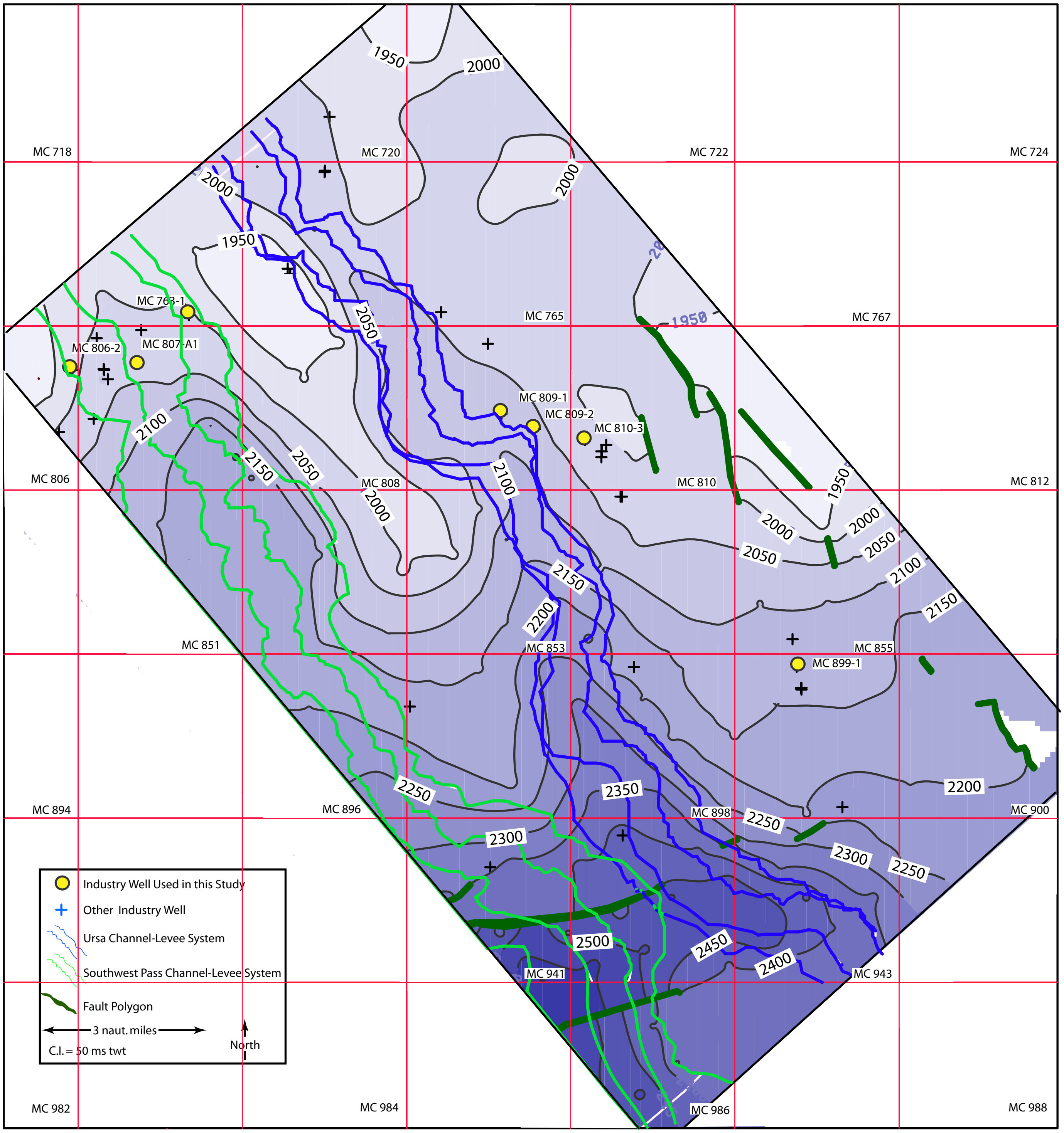


Figure 7. Structure map of the top of the Blue Unit contoured in two-way travel time within the Ursa96 exploration survey (location in Figure 1). Outlines of the Ursa and Southwest Pass Canyon channel-levee systems are overlain. Where truncated by the Ursa nd Southwest Pass Canyon channel-levee systems, the base of the channel systems was mapped as the top of the Blue Unit.

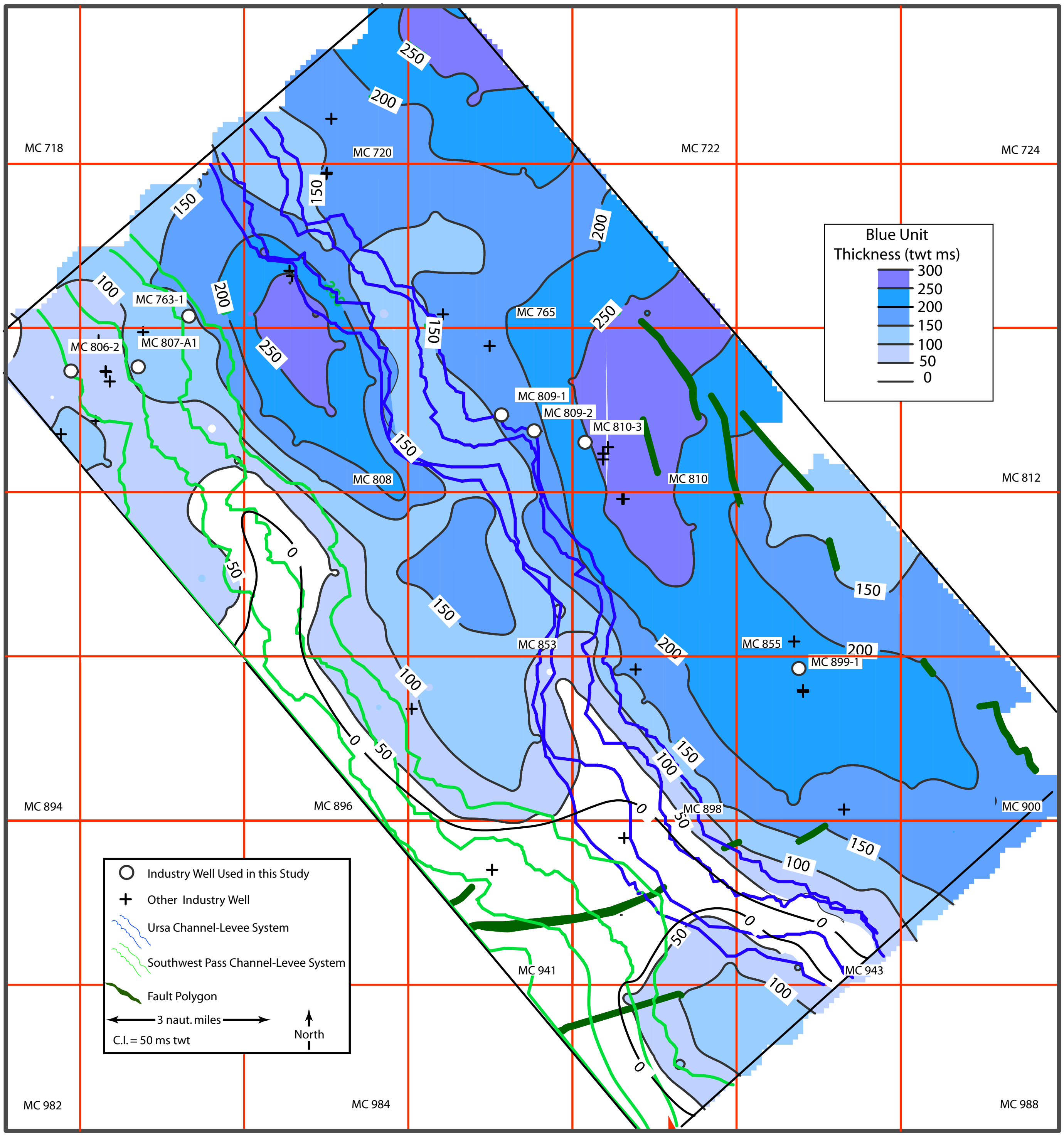


Figure 8. Isochron map of the Blue Unit contoured in two-way travel time (milliseconds) within the Ursa96 Exploration survey (location in Figure 1). The thickest deposits are in the eastern half where it experienced relatively little post-depositional erosion and is more indicative of original thickness. In the southern part of the area, the Blue Unit has no thickness (white areas) that correspond to complete deformation by the channel-levee systems.

channel-levee systems impinge upon it. In the southern part of the study area beneath the two channel-levee systems, the Blue Unit is completely removed by channel-margin slides.

Origin of the Blue Unit

We interpret that the Blue Unit was deposited by unconfined-flow turbidity currents that filled a depression in the Mars-Ursa mini-basin. It could have been sourced from turbidity currents funneled by channel-levee systems that were present up-dip on the shelf margin. Multiple sand beds within the Blue Unit imply multiple stages of turbidite deposition interspersed with quiescent periods of hemipelagic deposition. The Blue Unit has been referred to as a basin-floor fan (Winker and Booth, 2000; and Winker and Shipp, 2002). These deposits are typical in other deep-water fans and have been termed sheet sands, frontal-splay complexes, depositional lobes, channel termination lobes, and high-amplitude reflection packages (HARPs) (Mahaffie, 1994; Posamentier and Kolla, 2003; Fonnesu, 2003; and Deptuck et al., 2003). They often underlie channel-levee systems (Pirmez et al., 1997).

This Blue Unit was most likely deposited during the MIS Stage 4 eustatic sea level fall and with the corresponding eastward shift in the drainage pattern of the Mississippi River that focused deposition up-dip of the Mars-Ursa region (Pulham, 1993; Winker and Booth, 2000). It was most likely deposited with a relatively uniform thickness considering outcrop and seismic studies of other basin-floor fans (King, et al., 1994; Dean et al., 2000). The thickness variations shown in the isochron map are not indicative of original depositional thickness because of significant post-depositional erosion.

The Ursa Canyon Channel-Levee System

The Ursa Canyon channel-levee system is composed of a channel fill, channel-margin slides, and levees (Figure 9 and 10). The channel fill has high-amplitude, chaotic seismic reflections. A zone of channel-margin rotated slides surrounds the fill. Levees are intervals of thin, sub-parallel reflectors that thin away from the channel fill. It is difficult to reconstruct the original thickness and lateral extent of the Ursa Canyon levees because the younger Southwest Pass Canyon channel-levee system eroded much of the western levee, and because the eastern levee was truncated by mass transport deposits (Figure 10).

Wells MC 809-1 and MC 809-2 penetrated the Ursa Canyon channel-system (Figure 11A). The 809-1 well penetrated the channel fill, which contains 40 meters (~120 ft) of sand with upward-decreasing sand content (Figure 11). The channel-margin rotated slides beneath the channel fill correlate to about 40 meters (~120 ft) of sandy mud. The 809-2 well penetrated the levee reflectors, which correlate to ~80 meters (~240 ft) of thin bedded sand and mud.

Over the ~28-kilometer (~17 miles) stretch covered by the study area, the Ursa Canyon channel-levee system width ranges from 1.7 - 3.5 km (1.1 - 2.2 miles) including the channel-margin rotated slides (Figure 9). The channel fill is 1.0 - 1.5 km wide (~0.6 - 0.9 miles). The Ursa Canyon channel-levee system has an average gradient of 0.77˚, more than 3 times the slope of the underlying Blue

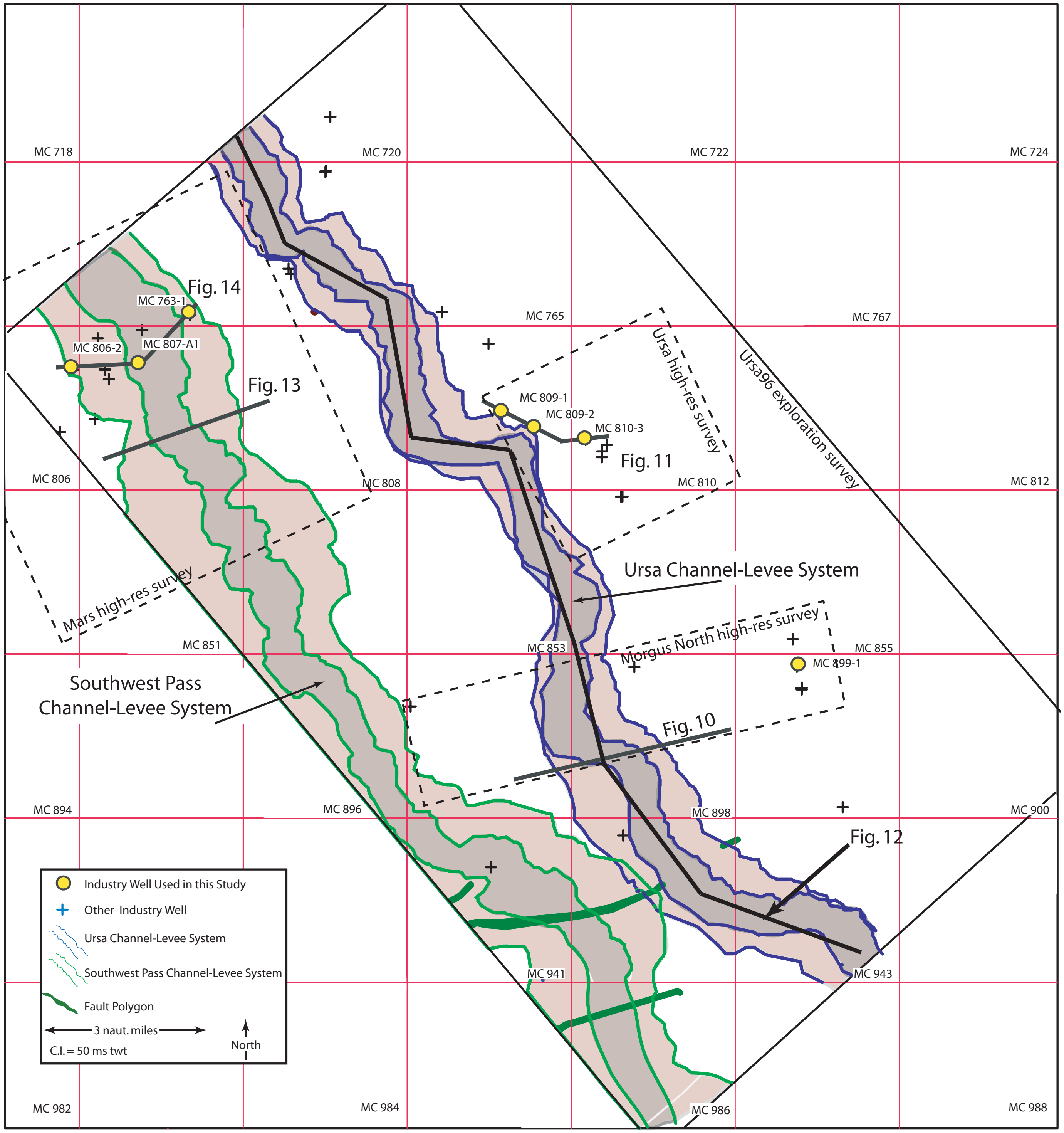


Figure 9. Base map of the Southwest Pass and Ursa channel-levee systems within the Ursa96 exploration survey. Gray zone indicates channel fill and light brown margins indicate zone of channel-margin rotated slides.

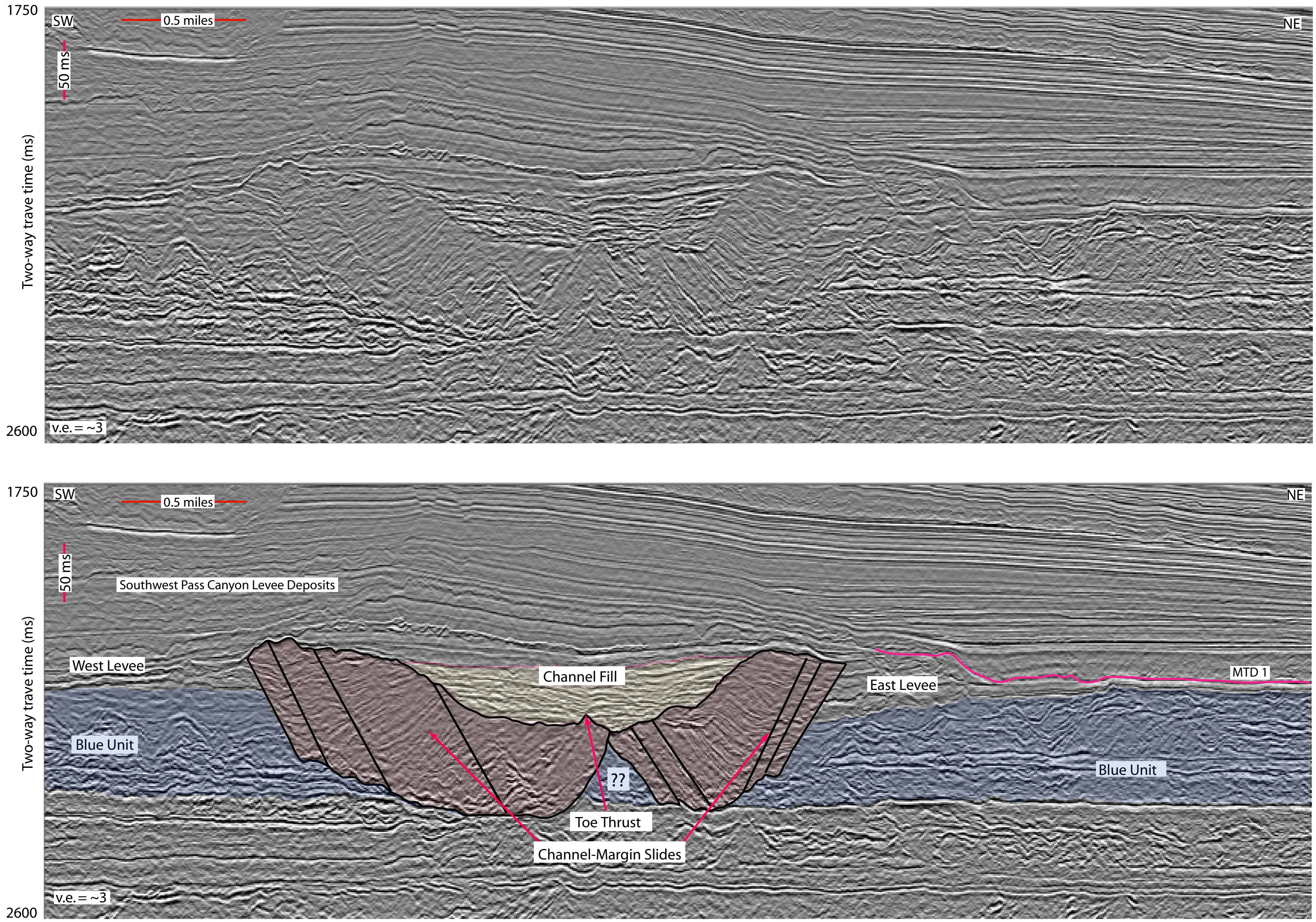


Figure 10. (A) Uninterpreted seismic cross section through Ursa Canyon within the Morgus north high-res survey (Located in Figure 9). High-amplitude reflectors define the channel fill, parallel reflectors characterize the eastern levee, and a broad seismically transparent zone surrounds the fill. (B) Interpreted seismic section showing elements of the Ursa Canyon. The top of this system is partially eroded by the adjacent Southwest Pass Canyon. A wide deformation zone of channel-margin slides that sole out in the base of the Blue Unit surrounds the channel fill.

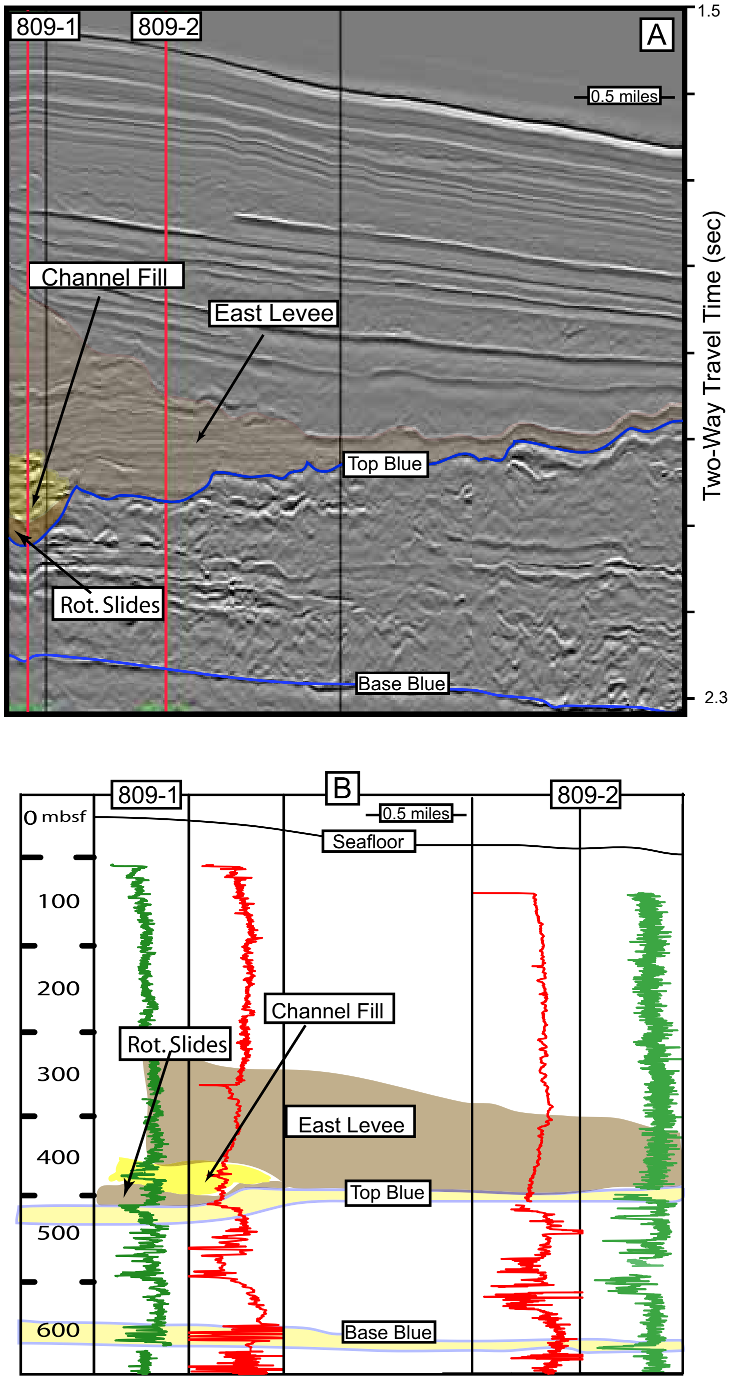


Figure 11. (A) Seismic cross section through wells 809-1 and 809-2 (location in Figure 9). 809-1 penetrated the Ursa Channel fill and the 809-2 well penetrated the eastern levee. (B) Correlated gamma ray profiles of the 809-1 and 809-2 wells colored according to lithology (brown is mud and yellow is sand). Rot. Slides = rotational slides.

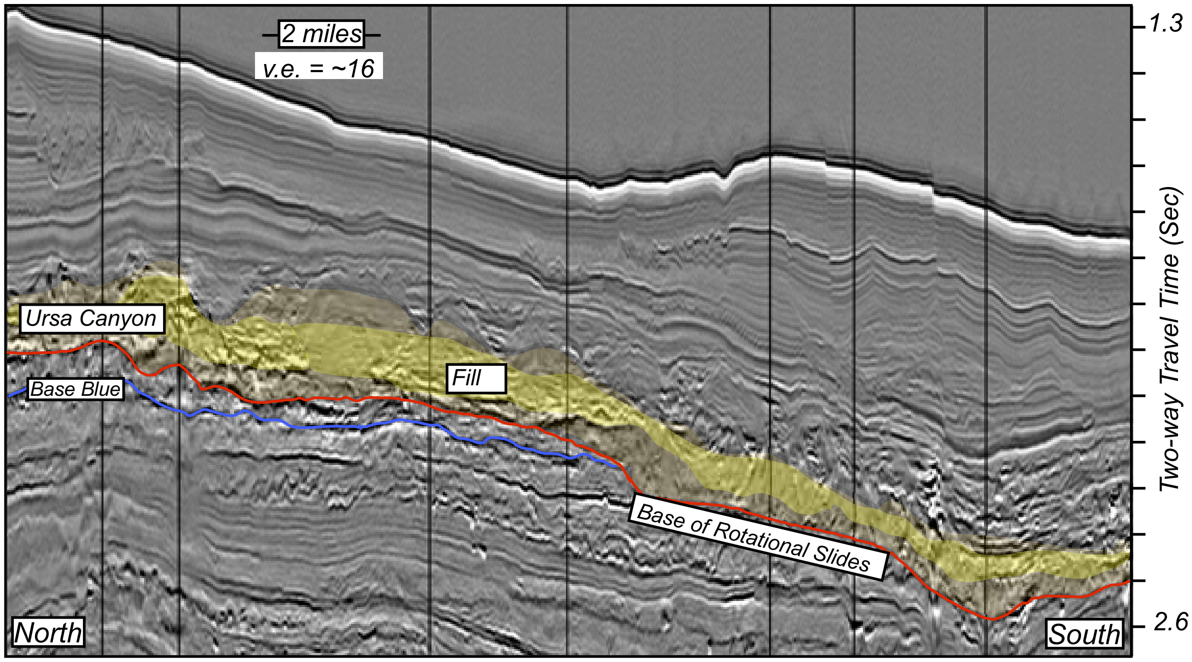
Unit. Because of its steeper gradient, the Ursa Canyon channel-levee system progressively incises more of the Blue Unit from north to south (Figure 12).

The Southwest Pass Canyon Channel-Levee System

The Southwest Pass Canyon channel-levee system is younger and lies to the west of the Ursa Canyon channel-levee system (Figure 9). It eroded much of the western levee of the Ursa channel and completely buried the Ursa channel fill and its eastern levee. It has similar characteristics as the Ursa Canyon channel-levee system but is larger (Figure 13).

The Southwest Pass Canyon channel-levee system also contains a belt of rotated channel-margin slides, but it is wider than the Ursa system. It has a maximum width of 5.5 km (3.4 miles), accounting for the width of the channel-margin slides (Figure 9). The channel fill itself is approximately 1.3 – 1.6 km wide (0.8 – 1.0 mile).

The Southwest Pass Canyon channel fill contains several sands 1-7 meters thick (3 – 22 feet), each separated by approximately 5 meters of mud. This is capped by a 49 meter-thick sand (161 feet) with very thin (<2.5 meters) beds of mud. The levees of the Southwest Pass Canyon are predominantly composed of mud, as inferred from the gamma ray profiles of wells 806-1 and 763-1 (Figure 13). The channel-margin rotated slides were penetrated by well 807-A1 below the channel fill and is composed predominantly of mud.



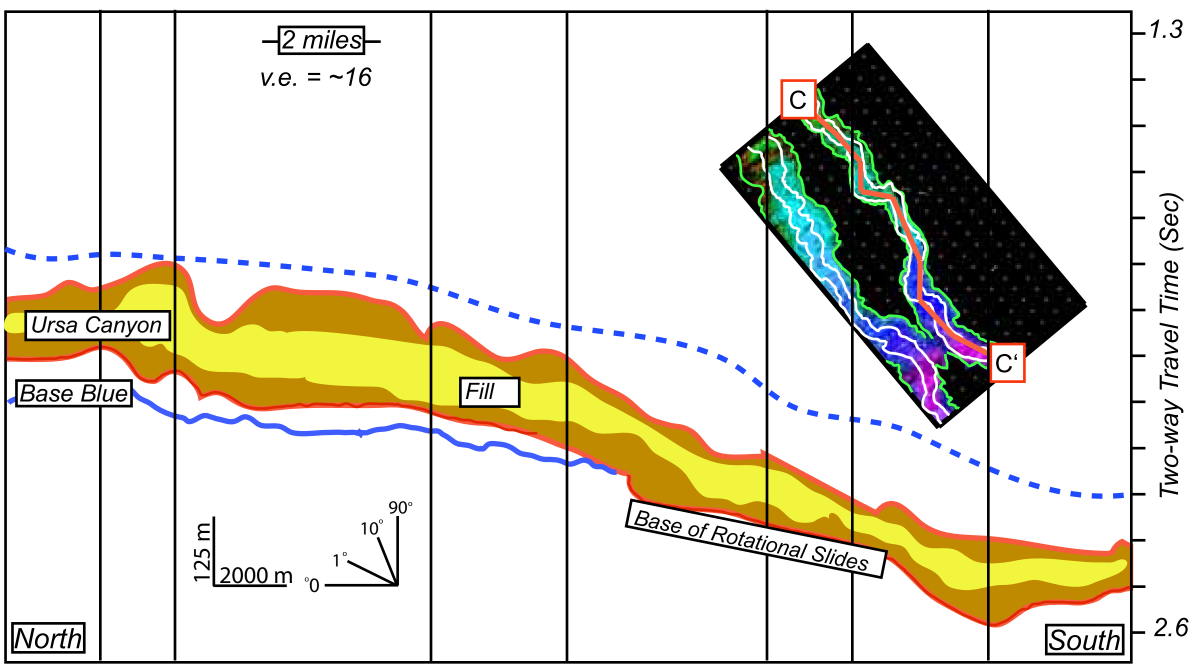


Figure 12. Dip seismic section C-C' through the Ursa Canyon channel system in the Ursa96 exploration survey (location in Figure 9). The channel has a steeper gradient than the Blue Unit and completely deformed it to below the base of the Blue Unit in the southern part of the study area. We assume that the original top of the Blue Unit was parallel with the base and was approximately the seafloor (dashed blue line) when the initial Ursa Canyon channel impinged on the region.

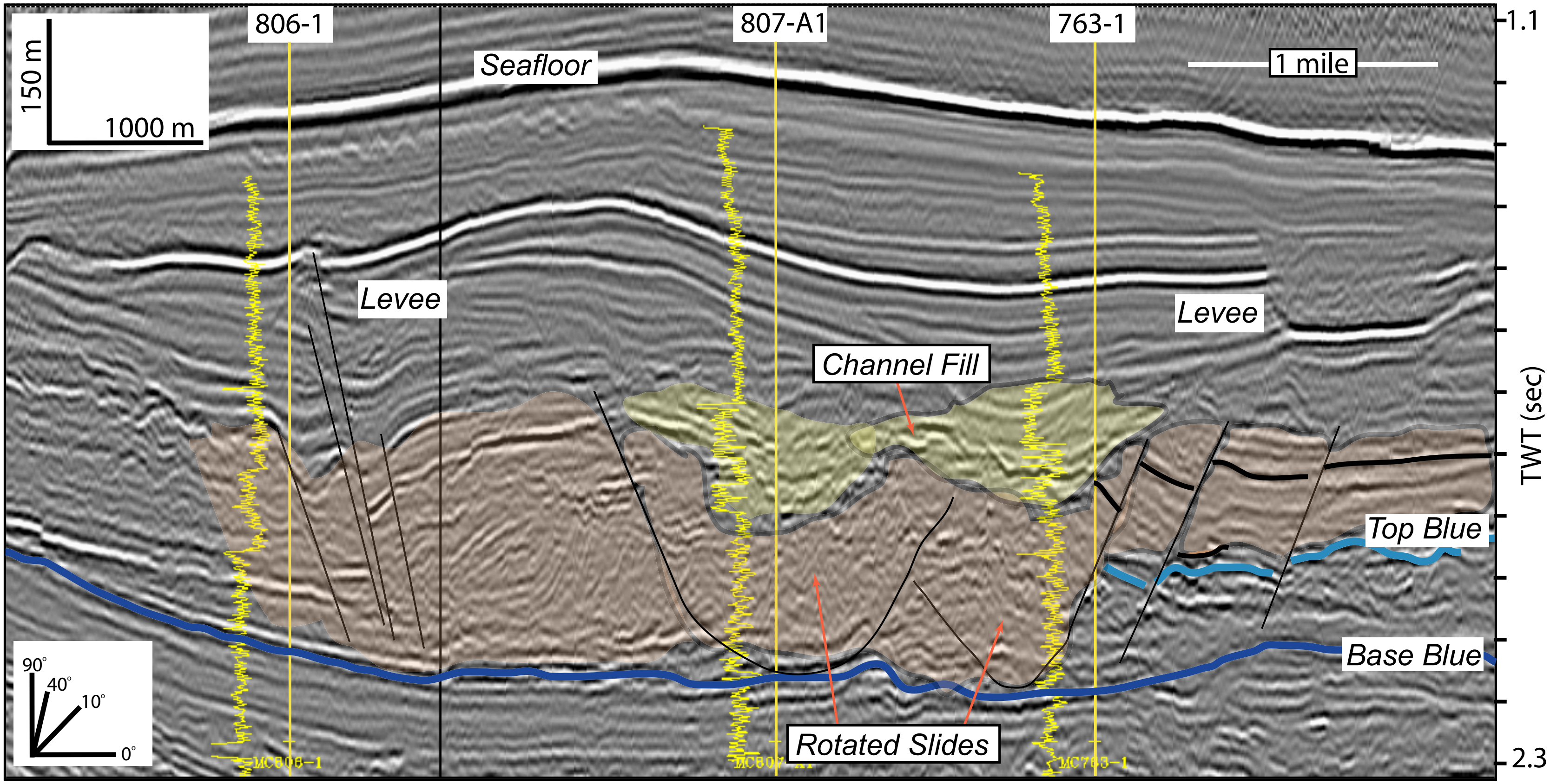


Figure 13. Seismic cross-section through the Southwest Pass Canyon channel-levee system (Location in Figure 9). Wells are posted with gamma ray logs (yellow). The top and base of the Blue Unit are also shown. The channel fill is predominantly sand and the deformation zone is predominantly shale. Reflectors (Top Blue and black line) can be tracked through the zone of channel-margin rotated slides where they are faulted down and rotated clockwise.

Evolution of Channel-Levee Systems

A two-dimensional model of the origin the channel-levee systems in the Mars-Ursa region involves four phases (Figure 14). In Phase 1, initial incision and erosion of the seafloor and the shallow subsurface was accomplished by turbidity currents (Figure 14A). This established a pathway for subsequent turbidity currents. In the case of the Ursa Canyon channel-levee system, it directly incised into the Blue Unit but the Southwest Pass Canyon system incised and eroded into the western Ursa Canyon levee.

In Phase 2, turbidity currents eroded more Blue Unit material, and the channel deepened (Figure 14B). Overspill of fine-grained material in the upper parts of turbidity flows periodically deposited on each side of the channel and formed levees. During this phase the height (H) of the channel floor to the crest of the adjacent levees increased.

Rotated channel-margin slides formed in Phase 3 when a critical height (Hc) of the channel floor to the levee crest was reached (Figure 14C). The weight of the levees and the lack of lateral support adjacent to the channel triggered these slides. On each side of the channel, a fault plane formed at the levee crest, extended into the subsurface below the depth of the channel floor, and then surfaced as toe thrusts in the channel floor from below (Figure 14C). Each failure plane defined a slide block that was composed of both levee and underlying material. Each slide block rotated down and deposited a toe thrust into the adjacent channel axis. Turbidity currents then entrained this material and transported it down-channel. The erosion of this material, coupled with continued

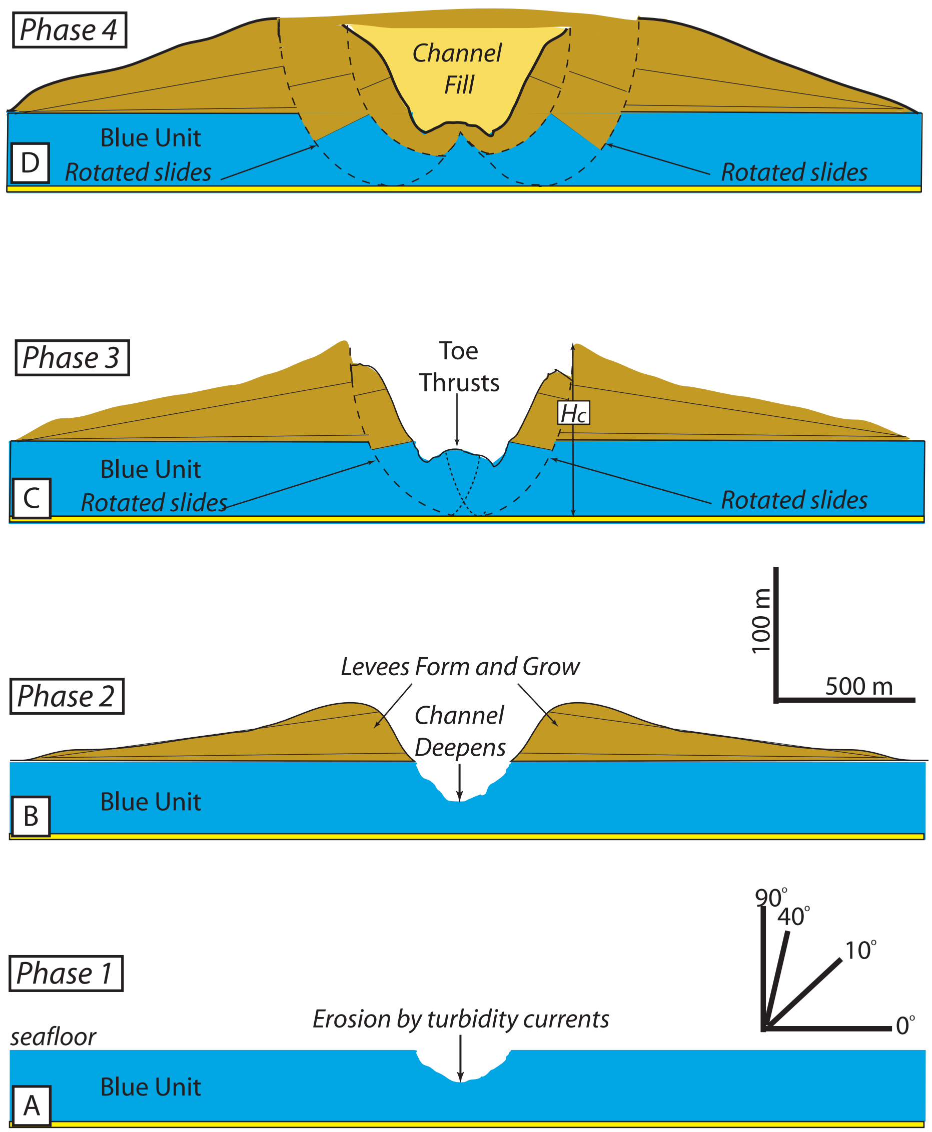


Figure 14. Evolution of channel-levee systems in the Mars-Ursa region. (A) Turbidity currents incised the Blue Unit in Phase 1. (B) Channel deepened and levees were deposited in Phase 2. (C) Rotational channel-margin slides formed by base failure and forced Blue Unit and levee material to slide down on circular failure planes, and force toe thrust up through the channel floor. (D) Levee growth, rotational sliding, and channel excavation continued synchronously to maintain a conveyor belt process in Phase 4.

levee growth, promoted a conveyor belt-like process in which turbidity currents flushed the channel axis while levee growth induced further channel-margin sliding.

This form of slope failure occurs when the weight of the soil adjoining an inclined bank is greater than the bearing capacity of the soil (Terzaghi, 1943). The soil sinks into the subsurface and yields toward the open space. Examples of deep-seated failures such as those that surround the Ursa and Southwest Pass channel-levee systems in submarine channel literature are unknown to the authors. However, similar deep-seated failures occurred during the excavation of the Panama Canal (Binger, 1948; McCullough, 1978; and Lutton et al., 1979). Historical accounts after slide events in the Culebra Cut included railroad tracks being pushed up tens of feet from below by the toe thrusts of the deep-seated failures.

Shallow-seated channel-margin slides with failure planes that sole out near the actual floor of the channel are a much more common feature of both subaerial and submarine channels. Examples have been observed in Paleozoic outcrops of alluvial channels in central Pennsylvania, in the modern day Red River in Canada, and in subsurface deep-water channels (Williams, et al., 1965; Williams et al., 1985; Beaubouef and Friedmann, 2000; Brooks, 2003; Deptuck et al., 2003).

During Phase 4, the channel was back-filled and terminated channel-margin sliding (Figure 14D). Channel backfilling occurs in response to changes in base level, which exert a strong control on submarine channel equilibrium, including headward migration of knickpoints, which can lead to channel backfilling (Beaubouef and Friedmann, 2000; Pirmez et al., 2000). Once the channel backfilled, subsequent turbidity currents were eventually forced to breach the confinement of the channel and spillover, thereby establishing new turbidite pathways and the start of a new channel-levee system.

Mass Transport Deposits

Numerous mass transport deposits exist within the mud-rich levee deposits above the Blue Unit (Figure 3, 5, and 15). They are characterized by a high-amplitude reflector at the base of a semi-transparent seismic interval with steeply dipping sidewall scarps that truncate otherwise sub-parallel reflectors (Figure 15). The high-amplitude reflector at the base of mass transport deposits is the detachment surface along which the failure event slipped. In some cases the detachment surface is irregular and cross-cuts stratigraphy, in other cases it is flat (Figures 3, 4, and 15). Mass Transport Deposit 1 (MTD1) occurred on the eastern levee of the Ursa Canyon channel-levee system and Mass Transport Deposit 2 (MTD2) occurred within the eastern levee of the Southwest Pass Canyon channel-levee system. MTD2 is a prominent feature but is much larger than the size of the study area here and will not be discussed further.

MTD 1 truncated the sub-parallel, continuous reflectors on the eastern levee of the Ursa Canyon channel-levee system (Figure 10 and 15). There were actually two failures: MTD 1A and MTD1B (Figure 15). MTD1B lies entirely within MTD1A. In map view, both events widen to the southeast, revealing the failure direction. The headwall scarp of MTD1B, which is the up-dip limit of the paleo-

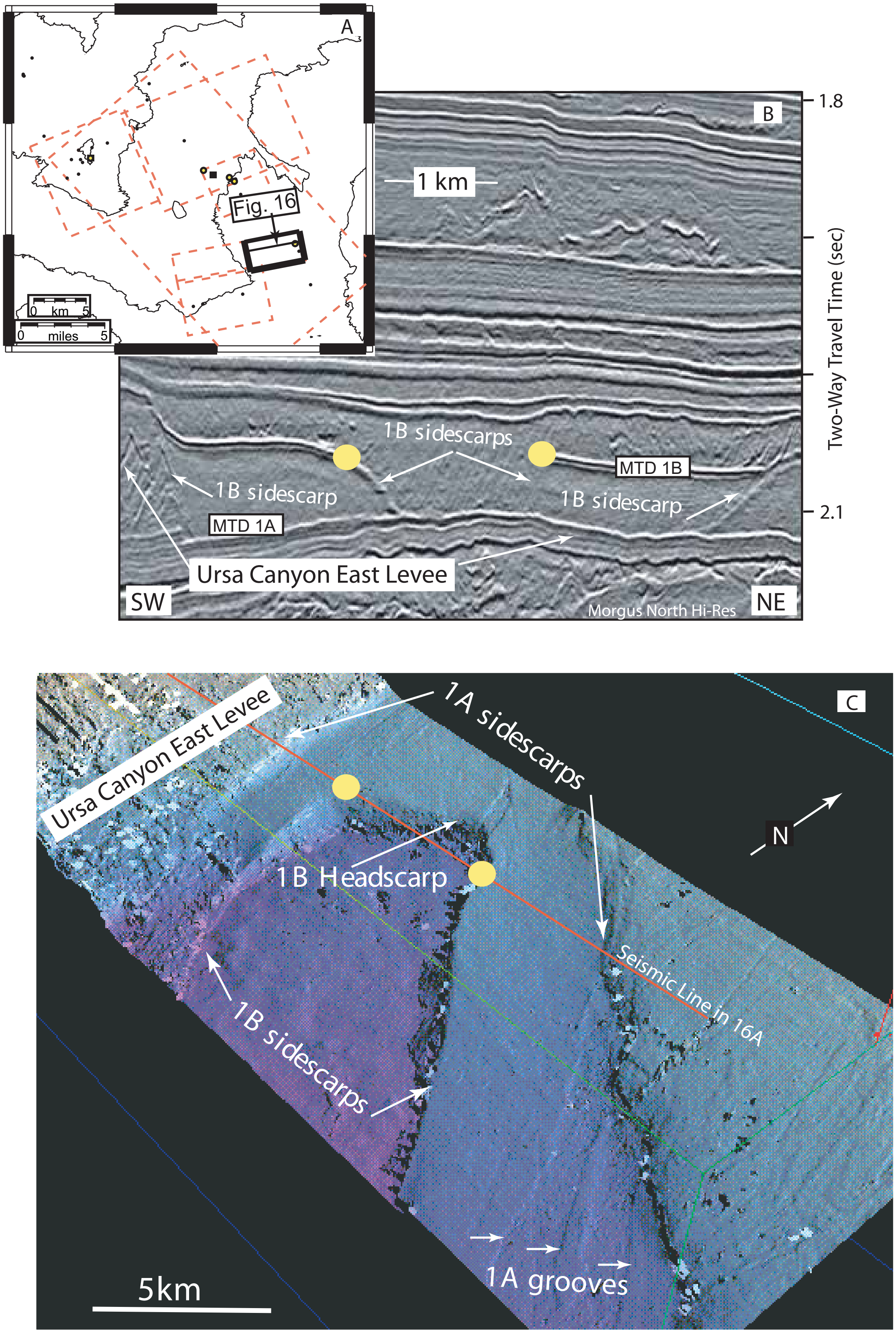


Figure 15. (A) Location map for (B) and (C). (B) Seismic line showing mass transport deposits 1B and 1A. Mass transport deposit 1A occurred on the flank of the east levee of the Ursa channel-levee system and before 1B. Mass transport deposit 1B occurred within the deposits associated with 1A. (C) Map of the detachment surfaces of mass transport deposit 1B and 1A. The headwall scarp and sidewall scarps mark the edges of the failure events.

failure, and the sidewall scarps of MTD1B can both be seen in map view (Figure 15B). However, only the sidewall scarps of MTD1A are visible, the headscarp is farther north. Linear grooves in the detachment surface of MTD1A trend to the southeast, and also indicate the failure direction to be to the southeast.

Origin and Evolution of Mass Transport Deposits

Mass transport deposits have been observed in recent subsurface seismic studies, (Brami et al., 2000; Deptuck et al., 2003; Posamentier and Kolla, 2003; Gee et al., 2005). The seismic character of deposits above detachment surfaces range from low-amplitude chaotic to transparent and it is often assumed that they are the remobilized material that originally failed (Brami et al., 2000; Posamentier and Kolla, 2003, Gee et al., 2005). Linear scours (>10 km long (>6 miles)) on the detachment surfaces of mass transport deposits have been interpreted to originate from slide blocks lodged at the base of mass transport deposits (Brami et al., 2000; Posamentier and Kolla, 2003, Gee et al., 2005).

Mass transport deposits occur because shear strength is exceeded by the shear stress, and this can occur for a number of reasons. In environments where sediments are rapidly deposited, overpressures can develop, which decreases the strength of the sediment. Geotechnical studies, including in-situ pore pressure measurements, established the presence of pore pressures significantly above hydrostatic within the shallow strata of this study area (Ostermeier et al., 2000). Dugan and Flemings (2000) (2002), and Flemings et al., (2002) describe how rapid, asymmetric loading of an underlying permeable unit results in low effective stresses where the overburden is thin. The concentration of mass transport deposits where the overburden is thin at Ursa suggests that this process may be occurring.

1.4 DISCUSSION

We summarize the paleogeographic evolution of the last 70 ka in the Mars-Ursa region (Figure 16). The Blue Unit ponded within topographic depressions on the continental slope and formed a regionally connected sand-rich body extending as much as 150 km (~90 miles) east-west and 75 km (~45 miles) north-south (Winker and Booth, 2000). At the scale of our study area, the Blue Unit is envisioned as several sand bodies 10s of meters thick interbedded with mud 10s of meters thick.

After the Blue Unit ponded the paleo-depression with sand-rich turbidites, the Ursa Canyon channel-levee system developed and funneled sandy turbidites down-dip. During this period of bypass, the Ursa Canyon channel-levee system incised some depth into the Blue Unit and developed thick mud-rich levees. Enough channel relief formed by channel incision and levee construction to cause base failure on the eastern and western channel margins (Figure 16B). Rotated channel-margin slides on the levee flanks penetrated deeper than the channel floor itself.

The Southwest Pass Canyon channel-levee system formed to the west of the Ursa Canyon system. It is much larger than the Ursa Canyon channel–levee system and its eastern levee is responsible for the significant west-to-east

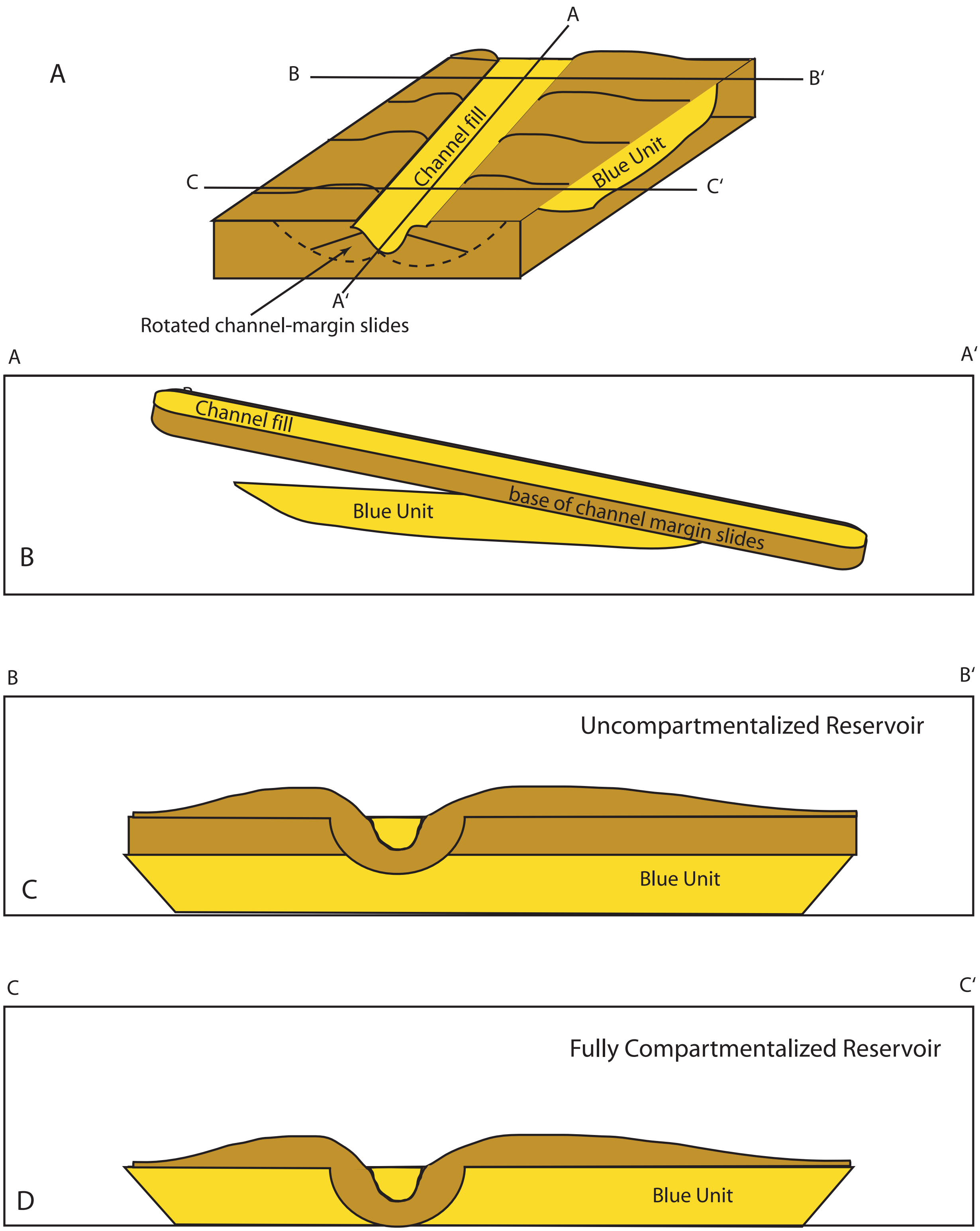


Figure 16. Late Pleistocene deposition in the Mars-Ursa mini-basin. (A) Unconfined flow deposition of the Blue Unit ponded the minibasin with thick turbidite beds of sands and mud. (B) Ursa Canyon channel-levee system incised and buried the Blue Unit. The Southwest Pass Canyon formed to the west of the Ursa system (not shown). (C) The channel systems, with a low-permeability zone of mud surrounding the sandy and permeable channel fill, progressively erode into the Blue Unit.

thinning overburden above the Blue Unit. Weimer (1990) describes how this channel-levee system branches into 8 subsidiary channels farther down slope on the Mississippi Fan.

The superposition of leveed channel turbidite deposits above sheet-sand turbidite deposits has long been proposed as a characteristic record of the eustatic cycle. These models argue that a change in the flux of sediment to the shelf margin may drive this shift in depositional processes. (Vail et al., 1977; Posamentier and Vail, 1988). Alternatively, others have argued that the evolution from ponded sheet sands, to levee-channel sands, to bypass, is a natural result of the decrease in accommodation that results as sediment fills accommodation during prolonged base level fall (Prather, 1998; Winker and Booth, 2000).

This seismic resolution possible with this study provides important clues to understand reservoir compartmentalization. As a result of the difference in slope between the nearly flat Blue Unit and the overlying, southward-dipping, channel-levee systems, these components are separated in the north, yet amalgamated in the south (Figures 12 and 16C). To the south, where the channels completely deform the underlying Blue Unit, a broad, mud-rich zone of channel-margin rotated slides surrounds the sandy and permeable channel fill. As a result, the channel-levee systems act as permeability barriers. The hydraulic connectivity of the Blue Unit is compromised by this phenomenon, especially in the southern part of the study area where the Blue Unit is completely deformed (Figure 8).

Rotated channel-margin slides in the channel-levee systems results in an intriguing stratigraphic paradox. During the bypass phase, significant erosion at the channel base may continually occur, yet the channel floors themselves do not move downward because material is continually replaced by the toe thrusts of the rotating slide blocks. Thus a channel may be at grade (neither moving upward nor downward), yet continually eroding its base.

1.5 CONCLUSIONS

We have presented the seismic geomorphology and lithology of the main depositional elements deposited in the Mars-Ursa region in the last 70 ka. The Blue Unit is a basin-floor fan that ponded a topographic depression in the Mars-Ursa Region with interbedded sand and mud. Two channel-levee systems plunged from north to south into the Blue Unit. Each of the channel-levee systems deposited a package of eastward thinning mud-rich levee sediments that asymmetrically buried the Blue Unit. Spectacular, rotated channel-margin slides formed around the channel fill of each channel-levee system. This resulted in a zone of mud-rich sediments that surrounded the sandy channel fill, which created a permeability barrier within the Blue Unit.

This study provides insight into the architectural building blocks of a deep-water turbidite systems and it can be used to design well plans in the shallow section. The steeper gradient of the levee-channel systems relative to the underlying sheet sands results in a system where, within a few tens of kilometers, these components transition from being detached to amalgamated. The channels themselves are surrounded by low permeable mud even when they incise sands of the Blue Unit. At the broadest level, the integration of high resolution 3-D seismic data with well data in the shallow subsurface provides an extraordinary opportunity to examine the distribution, lithology, and connectivity of deep-water turbidite sands.

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