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Introduction

Sedimentary basins developed along the eastern margin of North America in the early Mesozoic and Cenozoic following extensional rifting and the breakup of Pangea. Grabens and half grabens in and adjacent to Nova Scotia and New England were the sites of deposition for continental clastics, evaporites and volcanics predominantly of Triassic age overlying Paleozoic basement rocks. This was followed in the Early Jurassic by the separation of North America from Africa and eventually the development of an ocean basin. The thick sedimentary wedge on the continental margin of Nova Scotia, the Scotian Basin of Jansa and Wade (1975), has been mapped, from hundreds of thousands of kilometres of petroleum industry 2D and 3D seismic data and some 200 hydrocarbon exploratory and development wells, and described by numerous authors over the last half-century. However, much less is known of the stratigraphy and structure of the distal extremities of this basin, which occur beneath the Sohm Abyssal Plain.

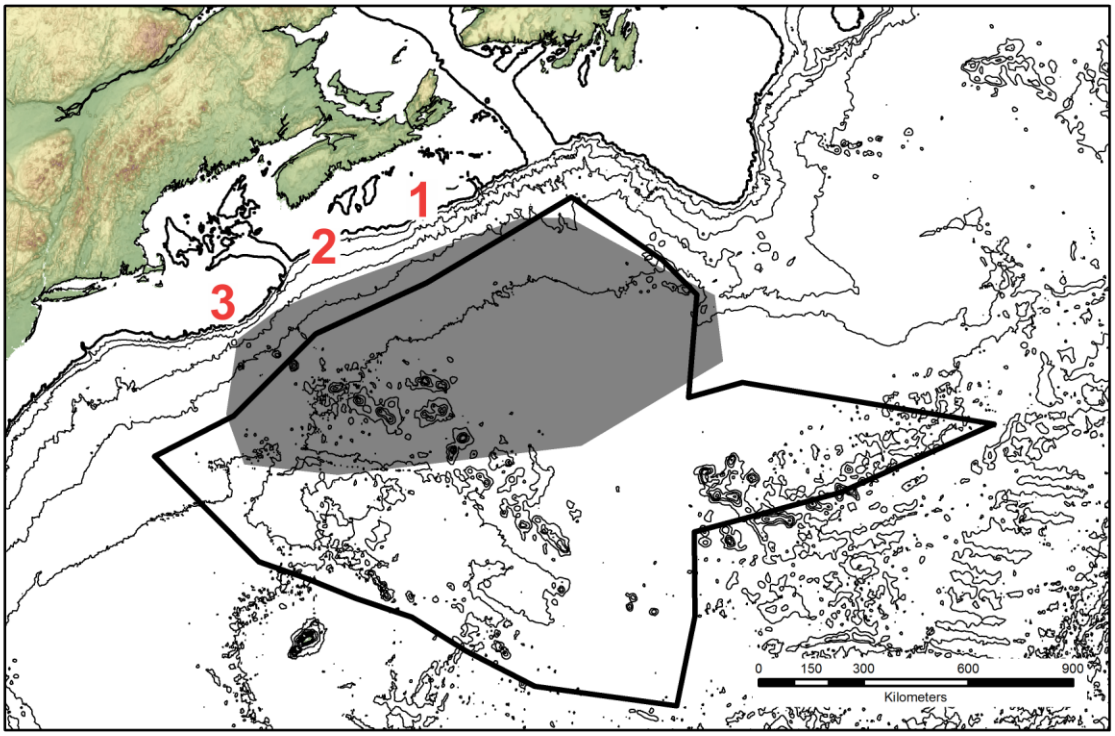

Figure 1*: Location of the Sohm Abyssal Plain. The 200 m bathymetric contour is darker and indicates the approximate shelf edge. Other contours are at 1000 m intervals. The Sohm Abyssal Plain, simplified from Fig. 5 of Horne et al. (1971) is outlined in black and the area of focus for this study highlighted in grey tint. The locations of subbasins referred to in the text are also identified: (1) Sable Subbasin, (2) Shelburne Subbasin, and (3) Georges Bank Basin.*

The Sohm Abyssal Plain (SAP) is the largest of the three named abyssal plains off eastern North America. It was defined by Horne et al (1971) as including the sedimentary apron extending from the flank of the Grand Banks to Hudson Canyon and Bermuda Rise and from approximately the 4500 m depth contour to where sediments sourced from the eastern North American seaboard deposit onto the western flank of the Mid-Atlantic Ridge. This area is shown as the black-outlined polygon in Figure 1. According to Stanley et al. (1981), it has an area of about 660,000 km^2. This study focuses on the area nearest the Nova Scotia margin, extending out as far as the J-Anomaly Ridge (JAR).

The deep-water stratigraphy of the southern U. S. margin has been developed through numerous seismic transects and DSDP boreholes in the Blake-Bahama and Cat Gap regions off Florida and the Bermuda Rise. It includes six formations and two members ranging in age from late Middle Jurassic to Quaternary and represents regionally mappable facies separated by widely recognized unconformities (Jansa et al 1979) (Fig. 5). Although correlating these facies across the New England Seamounts is difficult, stratigraphic equivalents of these formations occur beneath the Sohm Abyssal plain (Swift et al., 1986 and Ebinger and Tucholke, 1988).

Data

The Scotian shelf and slope, Georges Banks, and the Grand Banks have been exploration targets owing to their hydrocarbon potential for years. However, aside from a handful of shallow reflection seismic surveys over the Laurentian Fan (Parsons, 1975, Uchupi and Austin, 1979, Piper and Normark, 1988, Piper et al. 1984, Piper et al., 2007, and others) and a single deep multichannel survey (Ebinger and Tucholke, 1988), relatively little seismic reflection data has been acquired in the deeper water over the greater Sohm Abyssal Plain.

Pioneering aeromagnetic work by the United States Naval Oceanographic Office led to the discovery of the East Coast Magnetic Anomaly (Taylor et al., 1968) (Fig. 2). It is a linear magnetic anomaly running roughly parallel to the margin along the lower slope from the southeast US margin until midway along the Scotian margin, where it diminishes in intensity, bifurcates, and eventually blends into the background magnetic signal (Sibuet et al., 2012 and Dehler, 2012). Keen and Potter (1995) noticed that the location on the margin at which the ECMA disappears is coincident with the disappearance of seaward-dipping reflectors (SDR) in deep seismic reflection data along the margin. Since SDRs are considered characteristics of volcanic-rich margins (Mutter, 1984), they proposed that the margin changes nature offshore Nova Scotia from a magma-rich style in the southwest to a magma-poor margin toward the Grand Banks Transform Margin.

To explore the nature of the crust on either side of the termination of the ECMA in detail, a series of seismic refraction profiles was conducted in 2001. The program, called the Scotian MARgin Transect (SMART), consists of three refraction profiles running seaward from the Scotian Shelf to the slope and beyond the continent-ocean transition. SMART Line 01 was shot over what Keen and Potter, 1995 suggested would be unambiguously volcanic-poor crust (Funck et al., 2004), Line 03, over crust that displayed seaward-dipping reflectors and therefore should be volcanic-rich crust (Dehler and Welford, 2013), and Line 02 was an intermediate line (Wu et al., 2006) (Fig. 2). The program largely confirmed the hypothesis that the ECMA terminus marked the transition in margin character from a magma-rich one to the southwest to magma-poor to the northeast.

Swift et al., 1986 carried seismic horizons interpreted in the North Atlantic Basin across the New England Seamount chain into the SAP along the Scotian slope. Ebinger and Tucholke, 1988, using multichannel seismic data released to the public domain and used in this survey (see Fig. 3, RC2111_1979) extended these horizons further into the SAP.

Relatively few cores have been drilled in the study area, however there is one of note. In 1975, Leg 43 of the Deep Sea Drilling Program drilled on top of the J-Anomaly Ridge at Site 384 (reported by The Shipboard Scientific Party, 1979). From these data, Tucholke and Ludwig (1982) determined that the ridge formed as a volcanic ridge at or near sea-level in the mid-Cretaceous as rifting began between Iberia and the Grand Banks.

The principle dataset used in this study is a 320-channel seismic reflection survey collected in 2007 for the Geological Survey of Canada (Atlantic). The survey was commissioned by the Canadian government as part of its commitment to the United Nations Convention on the Law of the Sea (UNCLOS). It consists of 6900 km of high-resolution reflection seismic data over the Sohm Abyssal Plain. The survey provides a network of 16 lines tied to existing seismic data from the Scotian Slope with the few existing available lines from the Sohm. The 2007 data set consists of two long ENE-trending strike lines 80 to 100 km apart intersected by 14 dip lines shot in a zig-zag pattern and are shown in red in Figure 4.

Processing of the survey was performed in-house using GLOBE-Claritas software from GNS-New Zealand. After pre-processing shot and trace data, a Weiner predictive deconvolution was applied and the data was stacked. The data was migrated after stacking using a finite difference migration model.

In addition to this dataset, several other multichannel seismic reflection surveys have been conducted over the SAP and are included in this study. Data made available to this survey include freely distributed data acquired in 1978 by the Lamont-Doherty Geological Observatory and in 2004 by Woods Hole Oceanographic Institute (for the Integrated Ocean Discovery Program), and unpublished data used with permission from the German Federal Institute for Geosciences and Natural Resources (BGR) and the United States Geological Survey. Details for all multichannel data used here are summarized in Tabel 1.

Most lines mentioned in the text are from the GSC2007 survey and will be referred to simply as “Line 01”, “Line 02”. When lines from any of the other surveys are directly referenced in the text, the line number will be appended to the survey name, for example, “BGR1989-12”.

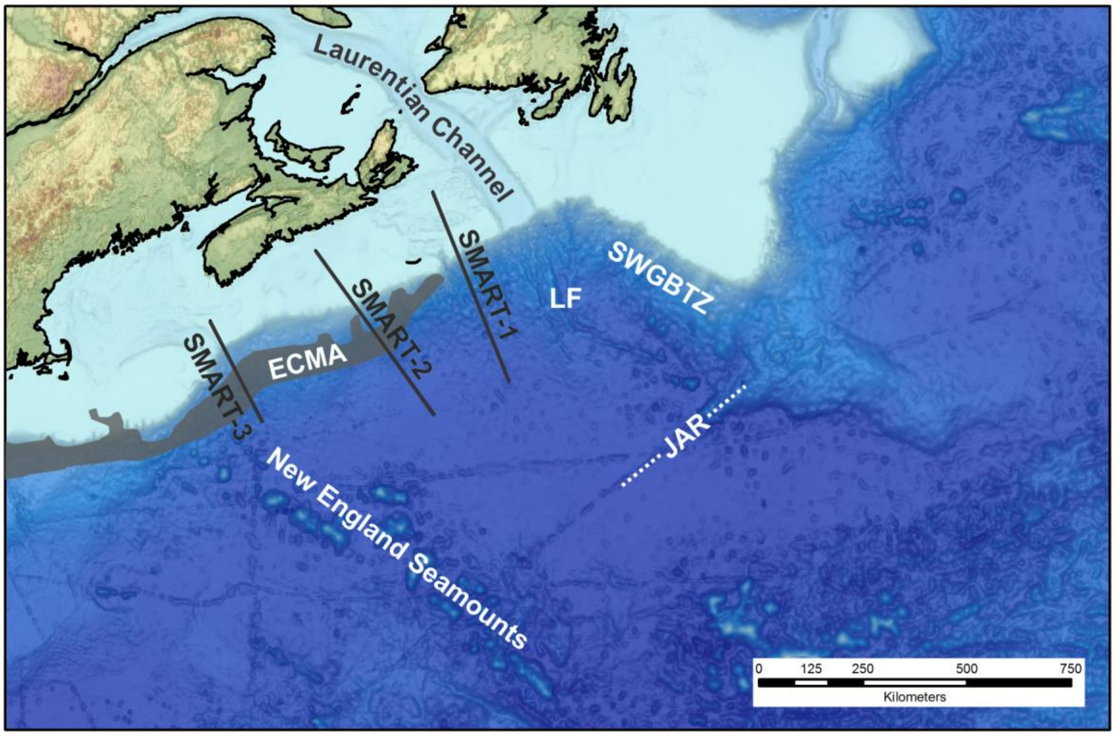

Figure 2*: Tectonic elements around the Sohm Abyssal Plain. The bathymetric background image was generated from the GEBCO 2014 30-second grid. Acronyms used in the figure are: SMART = Scotian MARgin Transect, LF = Laurentian Fan, ECMA = East Coast Magnetic Anomaly, SWGBTZ = Southwest Grand Banks Transform Zone.*

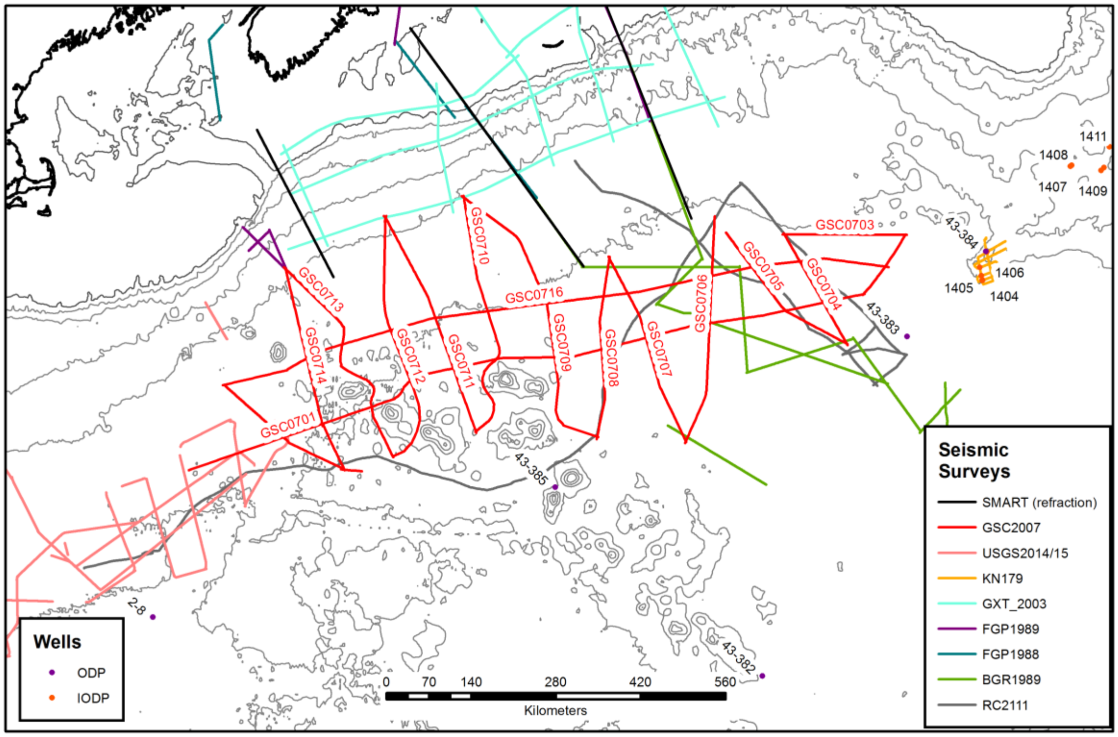

***Figure 3**: Location of multichannel seismic reflection data used in this study.*

Stratigraphy

Several of the Sohm Basin formations and unconformities, established from the U.S. margin, are present in the combined seismic data set and provided a basis for subdividing the sedimentary section into meaningful mapable stratigraphic units.

Table 1: Multichannel seismic reflection data referenced in this study.

Name used in this report	**Collecting Agency**	**Year**	**Number of Channels**	**Reference**
GSC2007	Geological Survey of Canada	2007	320	This publication
GXT_2003	GX Technology	2003		
RC2111	Lamont-Doherty Geological Observatory	1978	24	Ebinger and Tucholke (1979)
BGR1989	Federal Institute for Geosciences and Natural Resources (BGR)	1989	64	Unpublished
KN179	Woods Hole Oceanographic	2004	48	Expedition 342 Scientists (2012)

	Observatory (for Integrated Ocean Discovery Program)			
USGS2014/15	United States Geological Survey (projects MGL1407 and MGL1506)	2014/ 2015	Varying, up to 636	Hutchinson et al. (2015)
FGP1988	Geological Survey of Canada	1988	180	Keen et al. (1991)
FGP1989	Geological Survey of Canada	1989	120	Wade et al. (1995)

Eight regional to semi-regional seismic horizons were picked and mapped. Numerous other unconformities occur within the sedimentary succession of the Sohm Basin resulting from sea level fluctuations and scouring by turbidity flows and deep bottom currents. These eight horizons have been selected to provide a broad understanding of the stratigraphy. Detailed description of the regional stratigraphy and biostratigraphy of the nearby Scotian Basin can be found in papers such as Wade and Maclean (1990), Weston et al. (2012) and Williams et al. (1990). Horizons picked in this study are put into a regional context in Figure 5. Campbell et al (2015) describe and illustrate the complex depositional facies which occur across the Scotian Slope north of the Sohm Basin.

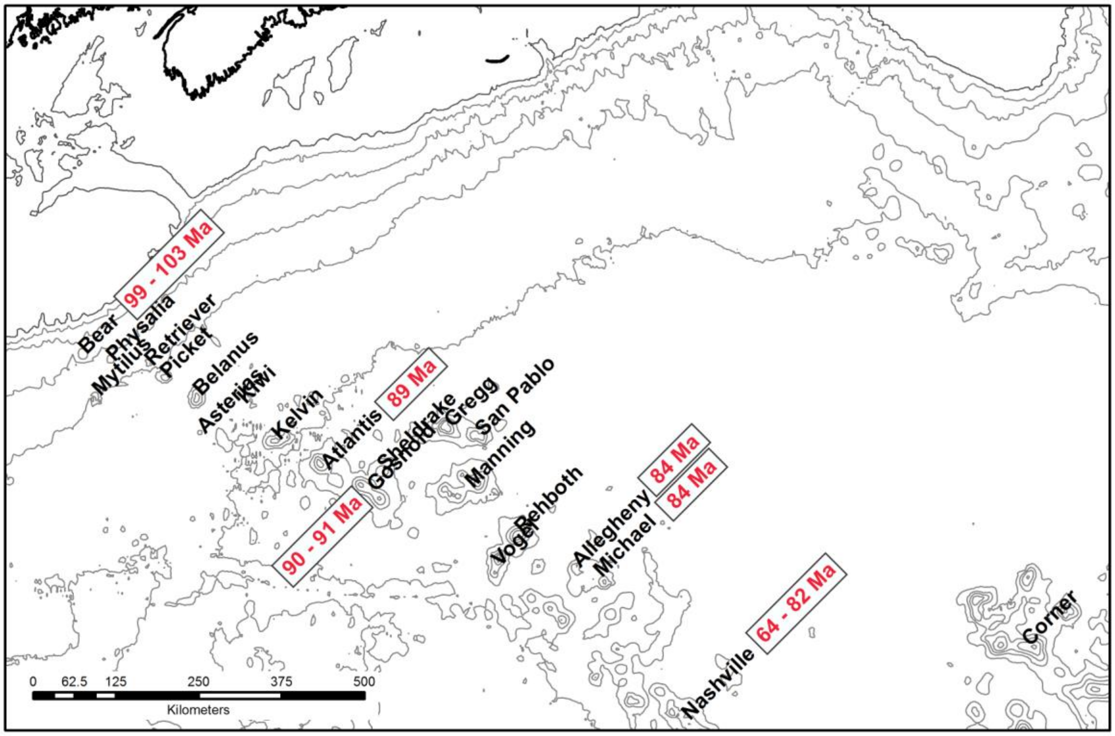

***Figure 4**: The New England Seamounts in and around the Sohm Abyssal Plain. The dates in red are 40Ar-39Ar dates from dredged samples published by Duncan (1984).*

Base of sediments or Base Event

The Base Event is the interpreted interface between continental or oceanic crystalline basement rocks and the overlying Mesozoic-Cenozoic sedimentary strata. Over most of the area it is an irregular surface sometimes broken by faulting into horst and graben complexes interspersed with undulating highs/ridges and depositional lows (see Figure 6 – Figure 9). Seismic coverage is too sparse to allow detailed mapping of the structures seen on this horizon between lines. It is mappable everywhere in the survey area except where penetrated by seamounts (Figure 8) or obscured by overlying salt (Figure 6).

The character of the Base Event changes at the eastern end of the 2007 survey area and becomes smoother and devoid of the ridges and lows that typify it elsewhere (Figure 9). This character change may result from flows associated with the development of the nearby J Anomaly Ridge, which formed around 125-130 Ma (Ogg, 2012), or it may be interbedded volcanic flows and volcaniclastics similar to those encountered in wells on the Scotian Shelf and SW Grand Banks, which have a common age of about 125-130 Ma (Tucholke and Ludwig, 1982, Jansa and Pe-Piper, 1988).

J1

This horizon approximates the Cretaceous-Jurassic boundary from the Scotian and Georges Bank basins, e.g. ~145 Ma, and is identified intermittently on both of the GSC2007 strike lines (lines 01 and 16) plus dip lines 07 through 14 as well as various industry and research lines within the study area. It manifests itself as a strong, conformable reflector in areas between localized basement highs. It downlaps largely on crust older than ocean anomaly M25, but in some areas downlaps on crust older than M21 (Figure 10). This places the J1 horizon near the top Jurassic.

Mid-Cretaceous Red (MidK)

The Mid-Cretaceous (MidK) marker is a bright horizon within a prominent reflective package that is slightly older than, but closely approximates, oceanic horizon ß which has been dated as Barremian/Hauterivian (~131 Ma) (Ebinger and Tucholke, 1988). Its lithology is probably limestone or marl dominated. The MidK horizon is traced well beneath the volcanoclastic aprons of the New England Seamounts as seen on lines 01, 12 and 13 and hence predates the volcanism (Figure 8 shows this). The MidK horizon occurs on all lines except Line 2. Distally it downlaps on oceanic basement.

A*

A* is a mid-Campanian unconformity, e.g. ~80 Ma that is found on all lines. It onlaps the volcanic debris cones of Kelvin, Atlantis and Gosnold seamounts supporting a Late Cretaceous age for the volcanism at these locations. This is consistent with radiometric dating from two of the seamounts at 80 to 90 Ma (Duncan, 1984). However, where Line 01 crosses the north flank of Gregg Seamount at the tie with Line 10, horizon A* underlies interpreted volcanic apron debris suggesting either a slightly younger age for the undated Gregg Seamount or a younger pulse of volcanism (Figure 8).

A^C

A^C is an early Eocene unconformity, e.g. ~50 Ma, found on all lines. Where drilled, Horizon A^C correlates with late early Eocene to early middle Eocene cherts (Tucholke, 1979). It also correlates with the T50 event of Deptuck and Campbell (2012).

A^U

A^U is an intra-Oligocene unconformity, e.g. ~30 Ma (Weston et al, 2012, Figure 2, Figure 6 and others). A^U is found on all lines and is probably associated with a major Oligocene lowstand of sea level that affected the Scotian Margin. A^U is identified as an erosional unconformity on the US margin (Mountain and Tucholke, 1985).

LM

This is an early Miocene unconformity which is ~18 Ma. LM has limited occurrence on lines 13 to 15 but is widespread on Line 12 and all lines to the east. LM was originally identified by Ebinger and Tucholke (1988), who tentatively correlated it with the R2 horizon in the North Atlantic Basin of Tucholke and Mountain, 1986.

L

L is a Plio-Pleistocene unconformity, probably less than 5 Ma, found on all lines. It was originally defined by Uchupi and Austin (1979) in the Laurentian Fan area and traced further around the SAP by Ebinger and Tucholke (1988).

Seafloor

The seafloor horizon represents the sediment-water interface, i.e. the top of the geological section in the Sohm Basin.

New England Seamounts

One disrupting factor to the regional mapping was the occurrence of a series of some 30 extinct volcanoes comprising the Late Cretaceous New England Seamount Chain, which crosses the southwestern part of the Sohm Abyssal Plain (Figure 2 and Figure 4). Several of the 2007 seismic lines passed near enough to seamounts to have their lower sedimentary section disrupted.

Duncan (1984) suggested the seamounts developed progressively as the North American Plate moved northeastward over the active New England Hot Spot for a period of about 20 million years. Other researchers find no evidence of a hot spot across the margin and attribute the seamount development to episodic extrusions controlled by renewed movement along fracture zones (e.g. Holbrook and Kelemen, 1993, Jansa and PePiper, 1988, McHone and Butler, 1984.)

Regardless of the origin of the seamounts, those that formed in the area of the Sohm are dated to between 84 and 90 Ma by Duncan (1984) and within the stratigraphic resolution possible in this study, are considered to have formed effectively simultaneously (Figure 4).

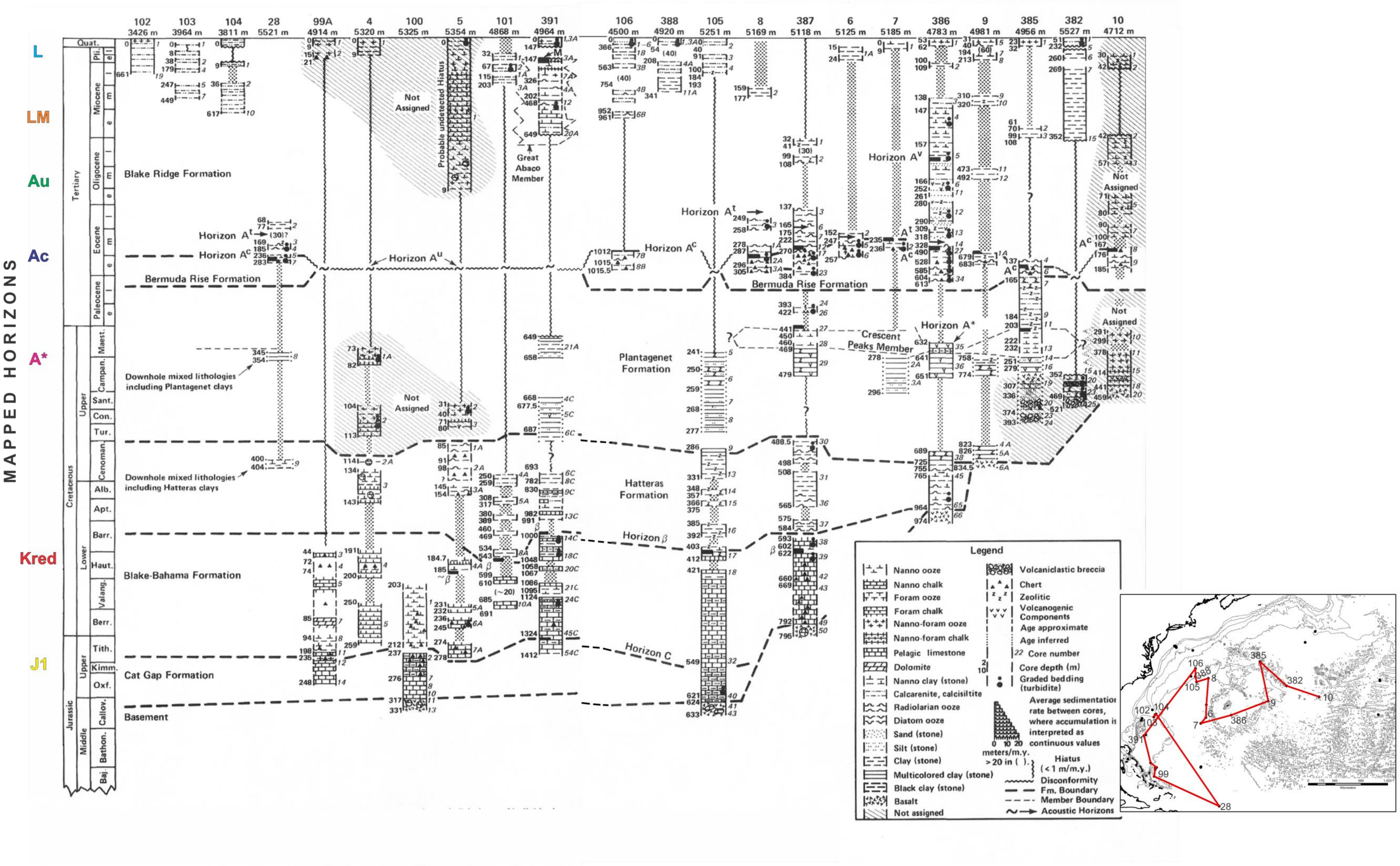

Figure 5: *Correlation chart of DSDP sites in the North Atlantic Basin. This chart schematically links lithology of individual cores, sub-bottom depth, age, formation names and boundaries, and stratigraphic position of regionally important seismic markers. Quaternary nannofossil-foraminiferal oozes are not assigned to any formation (Adapted from Jansa et al., 1979). If accumulation rate is greater than 20 m/my, the rate is shown in parentheses. Horizons mapped in this study are indicated on the left. Inset map in lower right shows location of wells in correlation.*

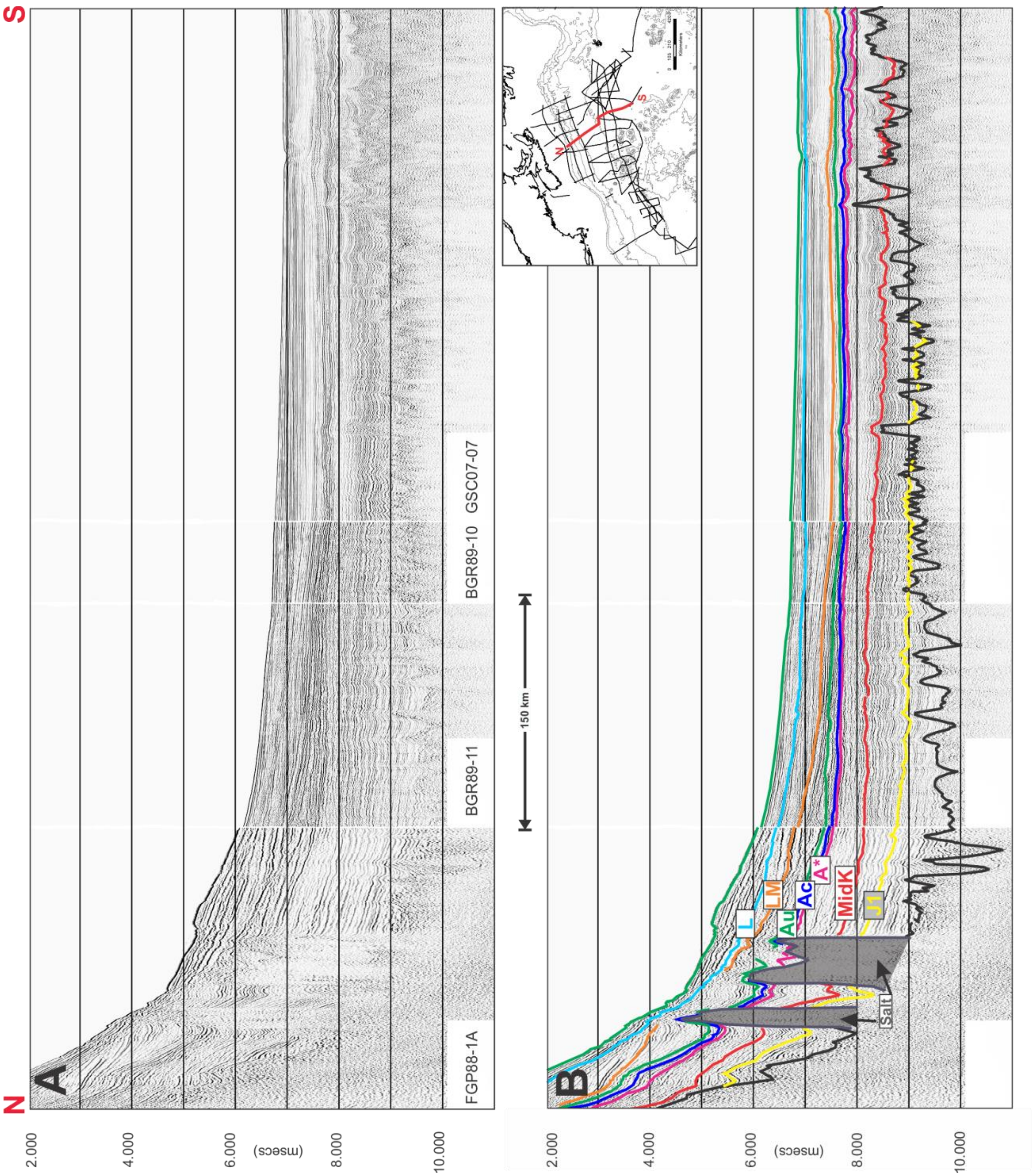

***Figure 6**: Uninterpreted (A) and interpreted (B) composite dip-profile across the Sohm Abyssal Plain (location in inset). The interpreted profile shows all horizons discussed in the text.*

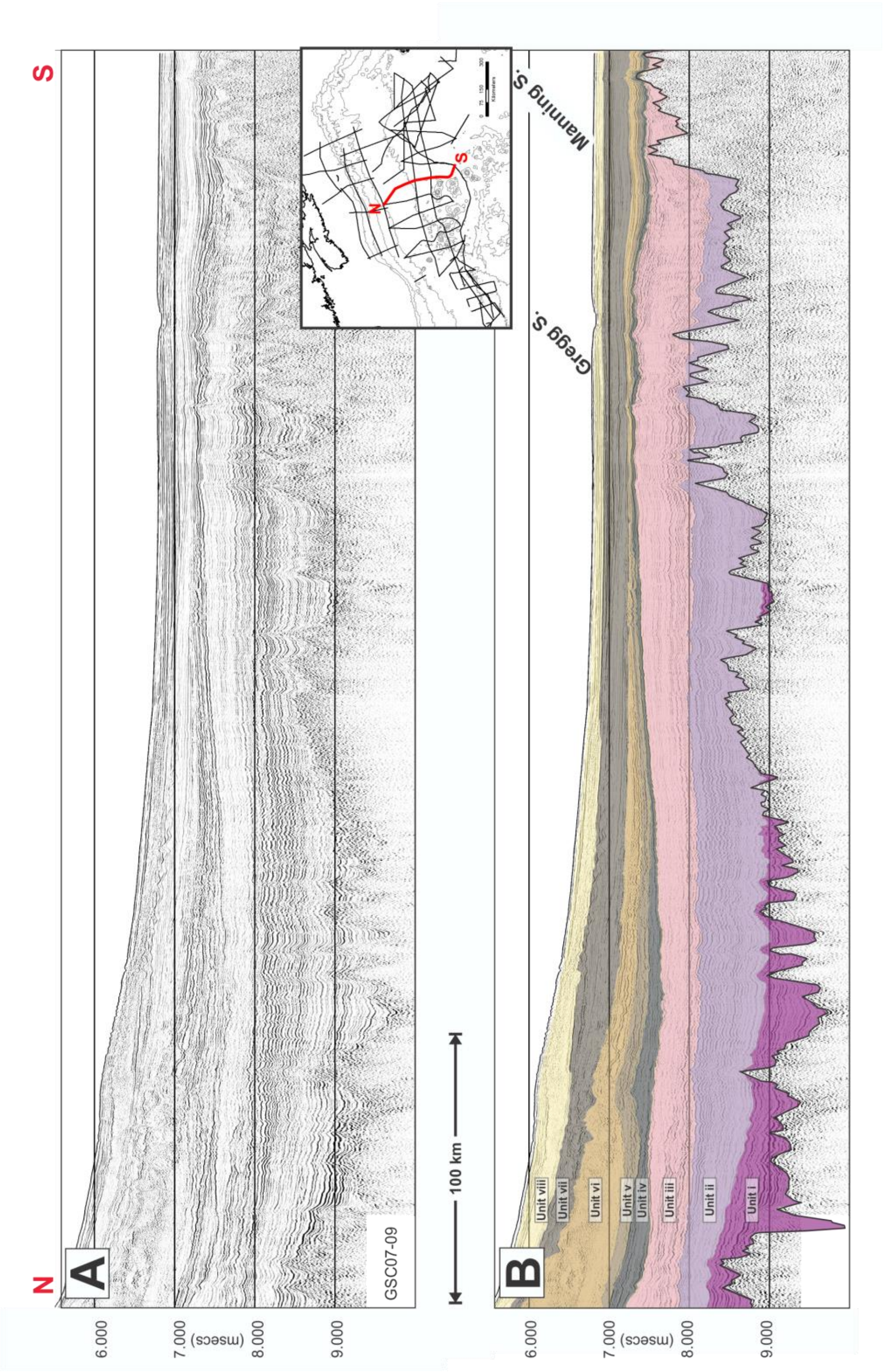

Figure 7: *Uninterpreted (A) and interpreted (B) cross-sections of Line 09 showing seismic stratigraphic units defined in this study. The location of the line is shown in the map inset. The profile crosses the eastern flank of the Gregg and Manning seamounts.*

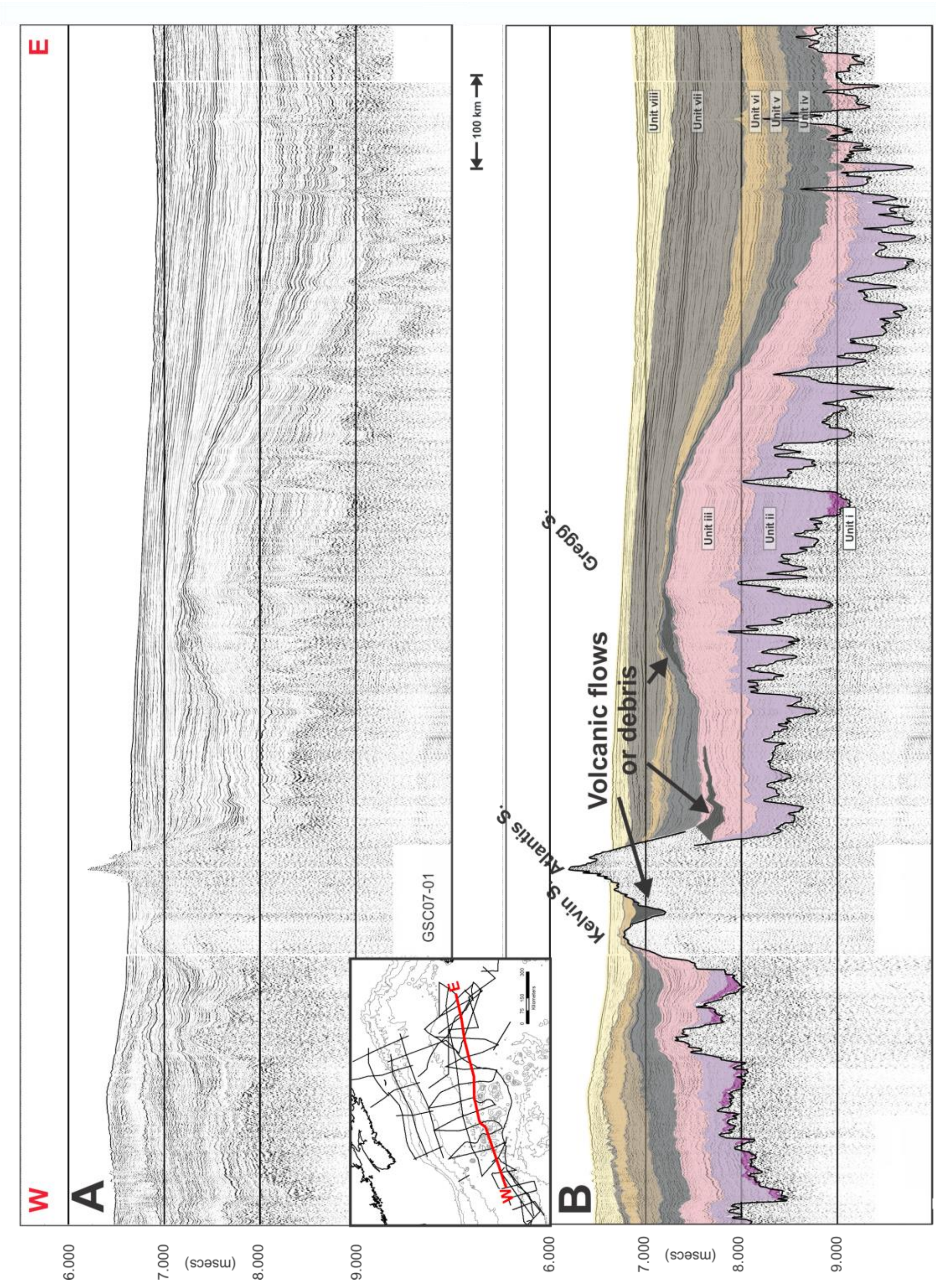

***Figure 8**: Uninterpreted (A) and interpreted (B) cross-section of the long strike line, Line 01, showing the seismic stratigraphic units defined in this study. The location of the line is shown in the map inset. The location of seamounts are identified in (B). The profile crosses the southern flank of the Kelvin and Gregg seamounts, and the northern flank of the Atlantis. Their nearest points to the profile are identified in (B). Note also the volcanic flows or volcaniclastic debris on the flanks of the Atlantis and Gregg seamounts identified in (B).*

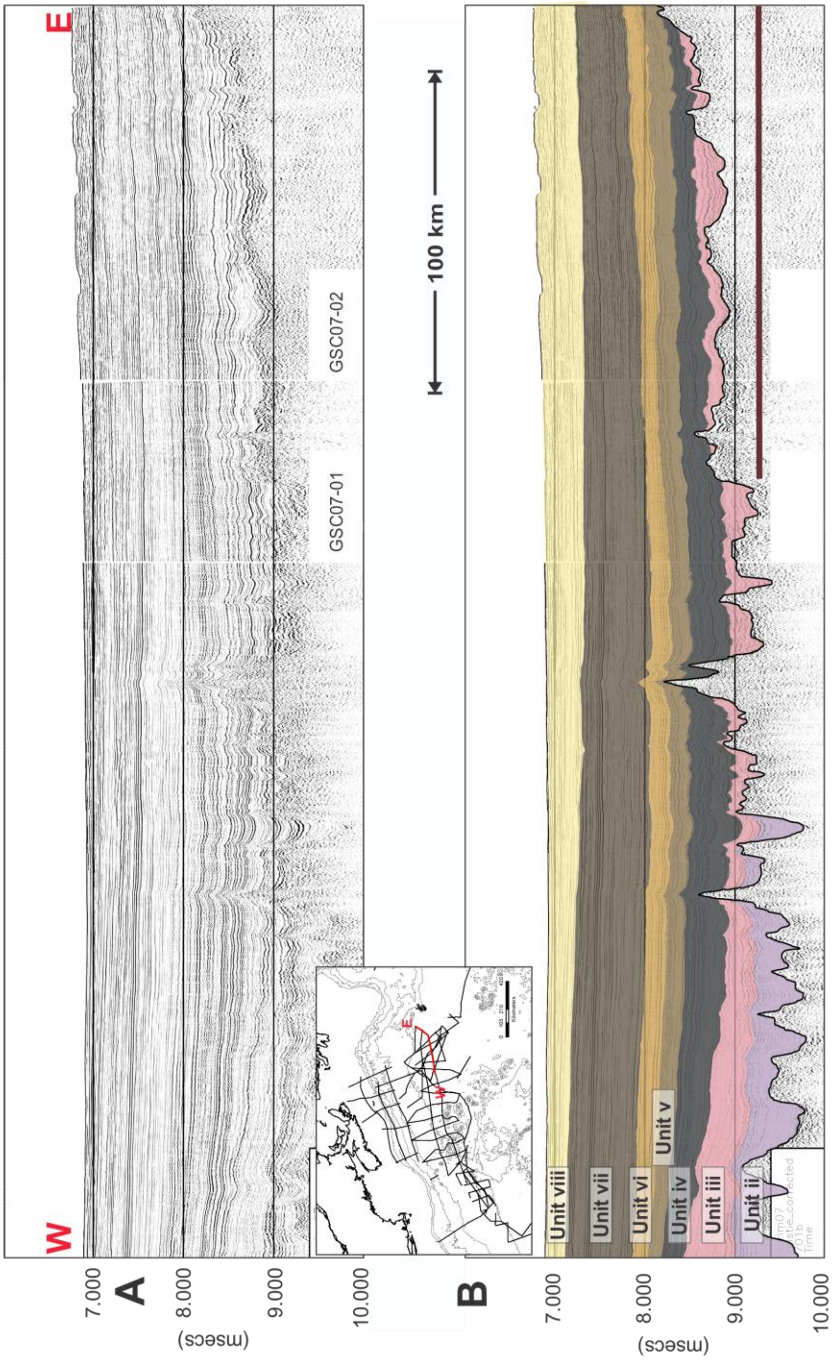

***Figure 9**: Uninterpreted (A) and interpreted (B) cross-section (parts of Line 01 and 02) at the eastern end of the SAP. Here the large peaks and troughs common in much of the deeper SAP disappear and the basement becomes more rounded. This area is marked by the heavy brown bar beneath the cross-section at the eastern end of the interpretation (B).*

Stratigraphic Units

Using the seismic horizons described above, the stratigraphy of the Sohm Abyssal Plain has been divided into eight units designated **i** to **viii**.

Unit **i**

Unit **i** includes all strata between the Base Event and the near-top Jurassic (J1) marker. Jurassic or older strata are widespread beneath the Scotian Shelf and Georges Bank and their adjacent slopes as well as in grabens or depositional lows between basement highs/ridges in the Sohm Basin. The isochron map of Unit **i** (Figure 10) shows that the greatest thickness occurs beneath the lower continental slope and rise in front of the Sable and Shelburne Subbasins and the Georges Bank Basin of Wade and Maclean, 1990 (Figure 1). The coloured grid shows the thickness (in milliseconds) between the J1 and base event markers. As some occurrences of the package were too small for the gridding algorithm to pick up, every appearance of the J1 horizon in the survey area appears in heavier black stipple. Unit **i** appears as a southward thinning wedge in N-S transects (Figure 6 and Figure 7), eventually becoming a discontinuous horizon found between local highs at the seaward end of the lines. The great distance between seismic lines in the regional survey make it impossible to prove, but many of these separated occurrences are likely interconnected. The presence of interpreted Unit **i** south of the seamount chain is supported by the magnetic data which indicates crustal ages of between 147-154 ma (M21-M25 isochrons) in transform slices in this area suggesting a mid-Tithonian age.

In spite of the numerous basement features which control Unit **i** strata, they are generally well-bedded and correlate in character from one occurrence to the next indicating they were not likely formed in isolation. Thicknesses in excess of 1.0 sec TWTT occur in the northeast as part of the Sable Subbasin. Given its top Jurassic age, the seaward limit of Unit **i** should approximate the limit of Jurassic age oceanic crust, ~M21 Chron. The presence of J1 near the M21 Chron in the vicinity of the New England Seamounts implies an original extent of J1 close to M21 crust in that area. Lack of seismic coverage beyond M21 in this area precludes determining whether J1 actually reaches it, but it is possible that it does. However, J1 is rarely found beyond Chron M25 in the eastern and central areas of the survey area. Further to the east however, the lack of Unit **i** between Chrons M25 and M21 under what is now the distal Laurentian Fan, may be the result of a lack of sediment supply.

That J1 does not reach M21 in the east and central SAP can mean one of three things. First, the horizon itself might be incorrectly identified. It is supported by the fact that it closely matches the horizon identified by Swift et al., 1986, Ebinger and Tucholke, 1988, and Keen and Potter, 1995, however with the lack of wells penetrating into the deeper strata, all of these studies required correlating horizons into the SAP from outside, which invariably requires correlating across the New England Seamounts or through the Slope Diapiric Province. Each of these impediments require great care and offer a source of potential error. Secondly, however remote, there is a chance that the isochron itself has been mis-identified. Finally, and it is the contention of this study, if the horizon and the isochron are correctly picked, there was insufficient, identifiable sediment supply at the end of the Jurassic in the central and eastern Sohm to reach fully out to the Late Jurassic ocean crust.

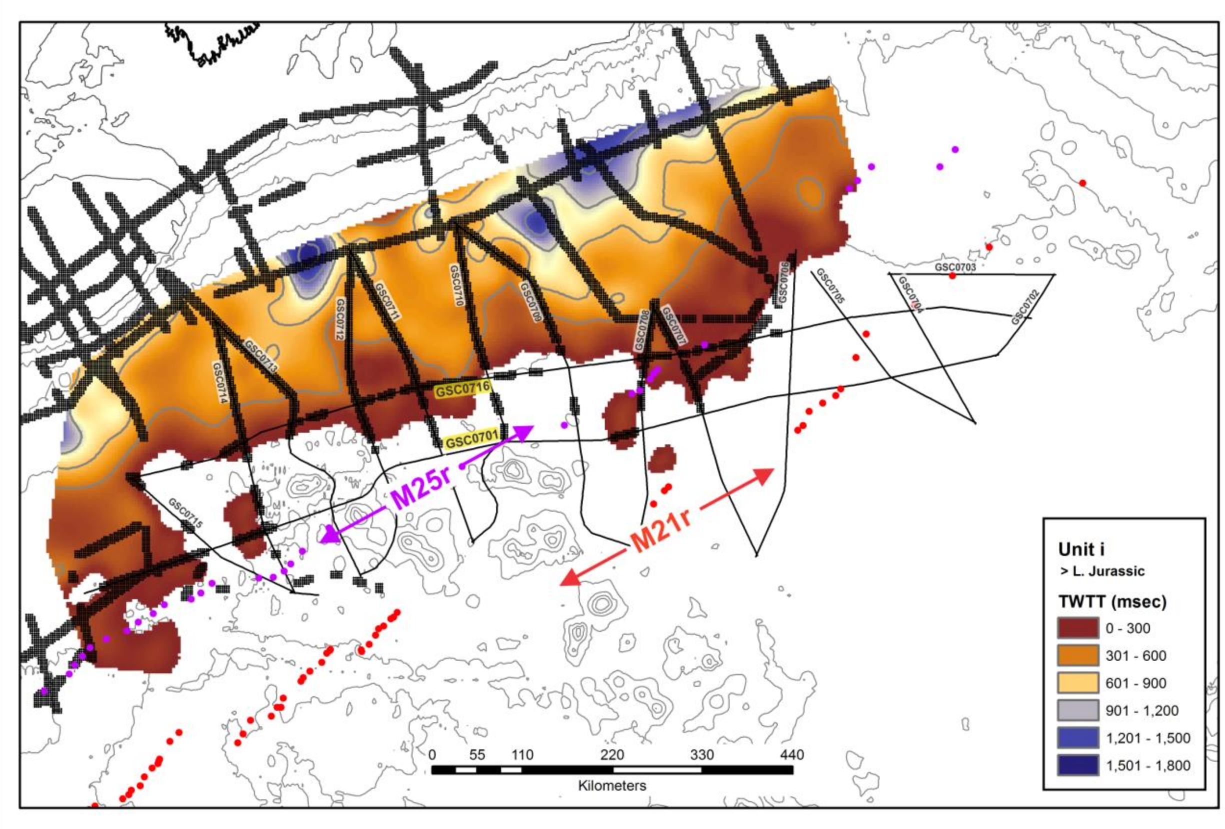

***Figure 10**: Isochron showing the thickness of Unit i and the extent of the occurrences of the J1 horizon. Unit I consists of sediment older than the J1 horizon (L. Jurassic). Isochron contours are grey lines. The contour interval is 300 msec. Seismic line tracks for the GSC2007 survey are shown as black lines. The dark black stipple represents occurrences of the J1 horizon. Much of the horizon downlaps on crust older than the M25r magnetic anomaly, but the horizon occurs on crust as young as M21r. (Anomalies from Klitgord and Shouten, 1986.)*

Unit **ii**

The section from J1, or Base Event where J1 is absent, to the MidK marker, is designated Unit **ii**. It occurs on all of the lines in the 2007 survey, except in the easternmost end of the SAP, unless it is penetrated by a seamount or basement high, or until it downlaps distally on oceanic crust (Figure 11). Unit **ii** is thickest (>1.0 sec TWTT) in front of the Sable Subbasin and is distributed downslope into a broad, east-west trending trough, the axis of which lies just north of Line 16.

Unit **ii** equates to the deep, distal basinal facies of the Cretaceous portion of the Verrill Canyon Formation calcareous shales and siltstones on the Scotian Margin and to the predominantly Berriasian to Barremian Blake-Bahama Formation on the U. S. Margin. In DSDP hole 105, the Blake-Bahamas Fm was 146 m thick and was a hard, light-coloured, chalky limestone (Hollister et al., 1972). The regional thickness of these formations on the U. S. margin is not known.

Maximum thickness of the combined units **i** and **ii** was encountered on Line 09, at about 1.7 sec TWTT, (est. ~2.5-3.0 Km), but much greater thicknesses occur landward beneath the lower slope. Across the study area, the thickness of these two units varies widely because of the highly irregular nature of the Base Event. Both units **i** and **ii** have several lobes running to the south suggesting possible distal distributaries.

The reflection data indicate the strata within units **i** and **ii** are well bedded with several high amplitude sequences probably indicative of carbonate-enriched facies. The units thin to zero distally and to the east, both through onlap onto the base event and non-deposition or erosion on its top. They thin in a similar manner to the west but their limits are not seen on the seismic lines used in this study (Figure and Figure). Extensional faulting is prevalent throughout both of these units, particularly east of Line 12 (Figure).

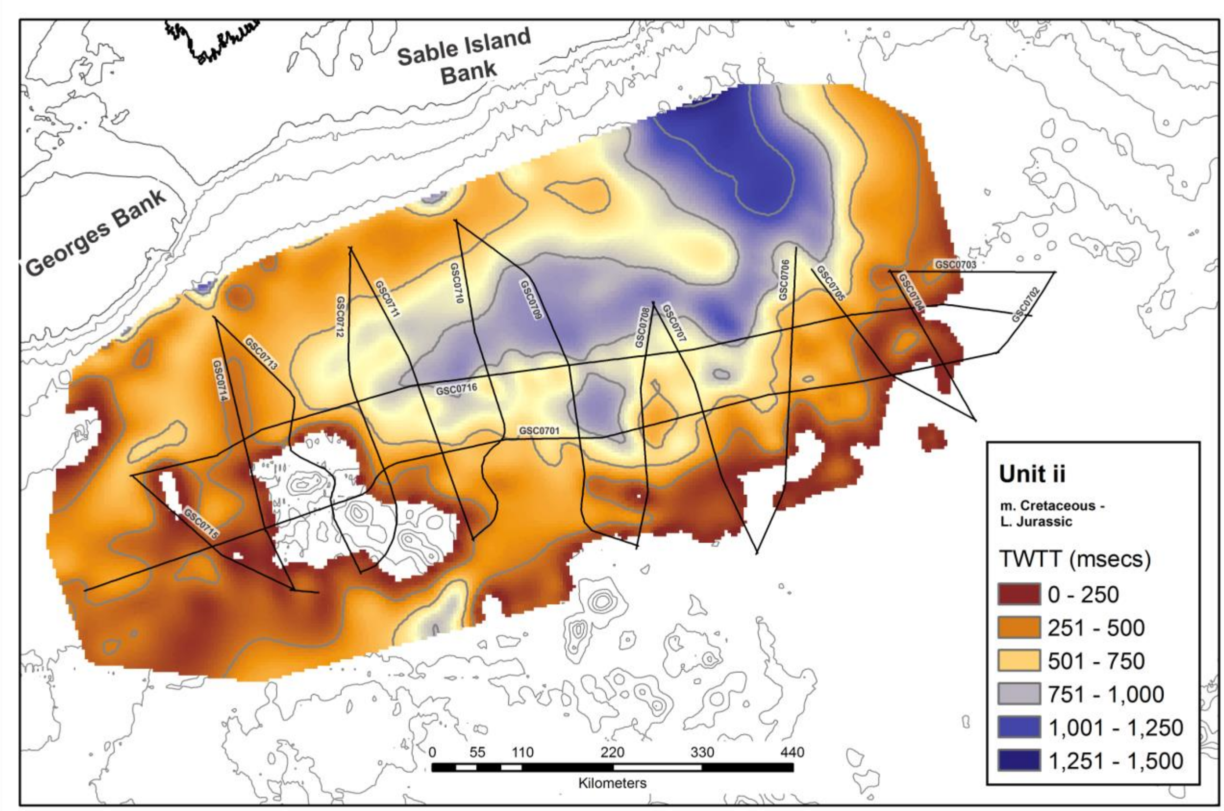

***Figure 11**: Extent of Unit ii in the study area. Isochron contours are grey lines. Unit ii is bounded by the Kred marker (mid Cretaceous) and J1 (L. Jurassic). The contour interval is 250 msec. Seismic line tracks for the GSC2007 survey are shown in black lines. The gap in the isochron over the New England Seamounts would likely have been filled with a continuous blanket of sediment of this age. Uplift, erosion, and intrusion in and around the seamounts have removed this interval.*

Unit **iii**

Unit **iii** is defined as the interval between the mid-Cretaceous MidK marker and the mid-Campanian A* horizon. As such, it roughly represents the Upper Cretaceous sedimentary section in the Sohm. It occurs on all of the lines in the study area and consists of sediment sourced primarily from the Scotian Basin and Georges Bank and is deposited across the slope, rise, and into the Sohm Basin (Figure 13). The unit reaches its maximum thickness off Sable Island Bank in the north and off Georges Bank in the northwest. It is thinnest in the Laurentian Fan area and over the New England Seamounts. In the western Sohm, Unit **iii** forms two areas that exceed 1.0 second in thickness. Another depositional thick occurs, distally, southeast of the Gregg and San Pablo seamounts. The latter depocentre indicates a southerly shift in sediment accumulation from the underlying Unit **ii**, which was at its thickest further north (compare Figure 11 and Figure 13 and see Line 09 in Figure 14(B)).

The thickest part of Unit **ii** lies north of the tie with line 16 and the thickest part of Unit **iii** lies south of Line 1. Line 09 also shows erosion at the A* level north of the tie with Line 16 and Line 01 shows significant erosion at A* west of the tie with Line 09 (Figure).

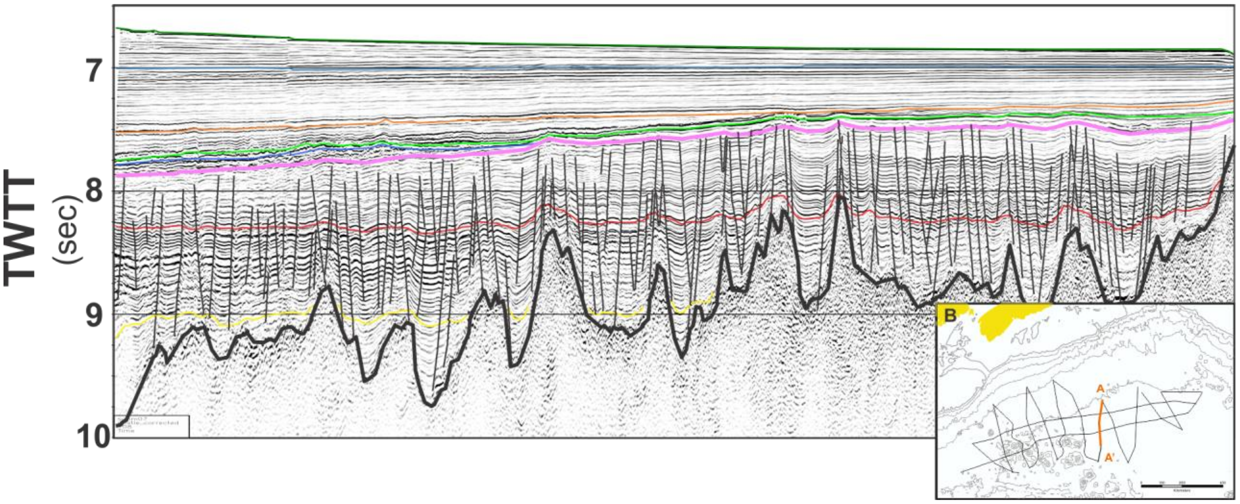

Figure 12: A segment of Line 08 showing the pervasive faulting in units ii and iii, ending abruptly at the A horizon. The line location is shown in the inset map.*

To the southeast, Unit **iii** thins out against shallowing basement and it disappears adjacent to the seamount chain. Over much of the centre of the basin, Unit **iii** is more uniform in thickness than Unit **ii** and is approximately 0.8-0.9 sec TWTT on Line 07 and Line 09 south of Line 01 suggesting a thickness >700-800 m. The high basement feature at the south end of Line 09 is the northeast flank of Manning Seamount (Figure 14). Igneous sills or dikes are interpreted in Unit **iii** sediments adjacent to seamounts in Lines 09 and 01. Extensional faulting is also common in this well bedded package throughout the centre of the Sohm.

In the Sohm Basin, Unit **iii** equates to the abyssal equivalents of the upper part of the Verrill Canyon Formation, the Shortland Shale and Dawson Canyon formations as well as a portion of the Wyandot Formation. On the U. S. Margin, the stratigraphic equivalents are the Barremian to Cenomanian Hatteras Fm and the Turonian to Campanian part of the Plantagenet Fm, including the Crescent Peaks Member, all of which have deep water, mixed lithologies of claystone, siltstone, radiolarian ooze and nanno-foram ooze. Black shales are common in this interval in some of the U.S. wells including Hole 386 on the Bermuda Rise. However, the equivalent interval in DSDP Hole 384, drilled just west of the crest of the then emergent J Anomaly Ridge, recovered 125 m of *shallow water* bioclastic limestones with minor interbedded calcareous clays of late Barremian to early Albian age (Tucholke, Vogt, et al., 1979). These limestones are underlain by a highly vesicular, weathered basalt interpreted as a *subaerial* or *shallow water* flow at the time of formation. The biostratigraphic data from DSDP 384 are consistent with the M0-M4 (126-130 MA) age of the JAR and its interpretation as a locally, shallow water feature (Tucholke and Ludwig, 1982). Other seismic data (Figure 3) indicate that, south of Lines 04 and 05, the northerly flank of the ridge is onlapped by Upper Cretaceous strata.

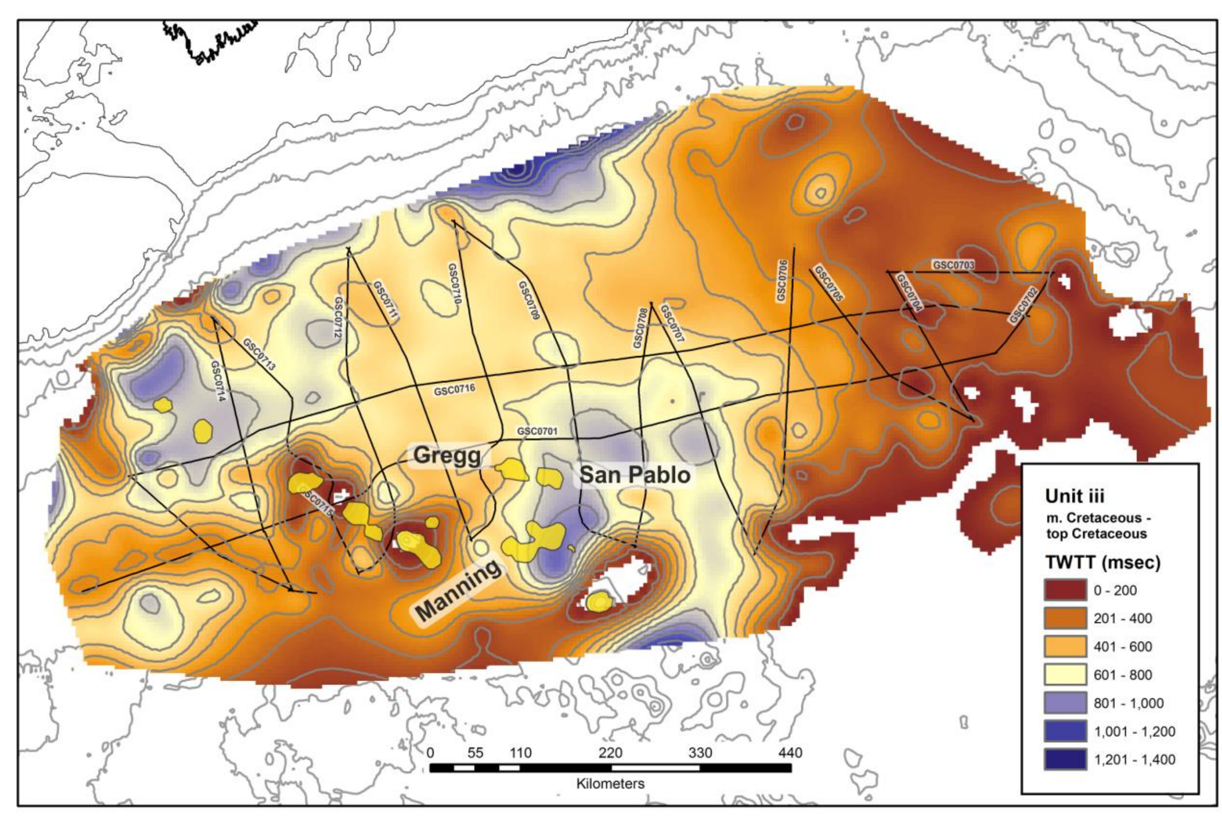

***Figure 13**: Isochron showing thickness of Unit iii, between the A* and MidK horizons, in the Sohm Abyssal Plain. Unit iii is bounded on the top by A* horizon (top Cretaceous) and Kred horizon (middle Cretaceous). Contour interval 100 msec. The location of the New England seamounts are approximated by infilling the 4000 m isobath in pale yellow.*

The 2012 Integrated Ocean Drilling Program (IODP) Expedition 342 drilled nine core holes on the J Anomaly and Southeast Newfoundland ridges. The holes were based on a network of seismic lines collected in 2004. The drilling objectives were to reconstruct the Paleogene carbonate compensation depth in the North Atlantic and also to recover sedimentary sequences with unusually high rates of accumulation as compared to normal deep pelagic sites (Expedition 342 Scientists, 2012). Four core holes were completed ascending the east flank of the J-Anomaly Ridge in water depths ranging from 4946 m at site U1403 to 3813 m at site U1406 which was very close to the DSDP 384 hole and some 150 km east of our 2007 seismic data. Well locations are shown in Figure.

Although not penetrated by the U1406 hole, the seismic indicates a probable Cretaceous reefal carbonate sequence overlain by, interpreted, thin Late Cretaceous/early Tertiary deposits and capped by some 200 m of nannofossil chalk and nanno ooze of Oligocene to Plio-Pleistocene age. The Unit **iii** reef facies grades down dip into an interpreted deep water carbonate prone facies. The 342 IODP Program identified similar shallow and deep water carbonate facies on the adjacent Southeast Newfoundland Ridge sites (Expedition 342 Scientists, 2012).

Late in the deposition of Unit **iii**, the region to the northeast of the Gregg and San Pablo Seamounts began to rise and form a large structural high. Figure 14 (B) shows the extent of the uplift, which we refer to as the "Great Sohm Dome" (GSD). It is discussed in greater detail below.

Unit **iv**

Unit **iv** is defined as the interval between the upper Cretaceous A* horizon and the early Eocene A^C horizon. The isochron map of Unit **iv** shows a different depositional pattern. In the central part of the SAP, from Line 10 to Line 06, a north – south trending thin effectively splits the basin in two (Figure). The western depocentre continues west of Line 10. In the northwest, beneath the lower slope and rise this package consists of mass transport sequences from the Shelburne Subbasin and Georges Bank Basin, which thin and become well bedded near the intersect with Line 16 and then thins to the southeast and the southwest. East of Line 7 and north of the J-Anomaly Ridge is a depositional thick, which is probably related to deposition adjacent to the rapidly subsiding ridge sourced off the southwestern Grand Banks.

Between these two thicks, due to continued inversion, Unit **iv** rarely exceeds 0.400 sec TWTT in thickness and has been subjected to some erosion. A^C is missing on the upper flanks of the seamounts and, locally, over the crest of the saddle where it is cut by A^U. Unit **iv** is thickest on Line 05 in the east and Line 14 in the west (see Figure A-5 and figure A-14). There is little faulting in this package. Some Unit **iv** sediments were recovered in IODP holes U1403 and U1406 (Expedition 342 Scientists, 2012). The main facies found was nannofossil ooze with an average sedimentation rate of less than 1 cm/ky (Norris et al., 2014).

Unit **iv** equates to the upper part of the Plantagenet Formation and lower part of the Bermuda Rise Formation. Plantagenet facies, in DSDP wells to the south, is multicoloured, sometimes zeolitic, claystone and marly ooze and the Bermuda Rise Fm consists of greenish-grey silicified claystone, mudstone and porcelanite and greenish-grey zeolitic claystone (Jansa et al., 1979). In the DSDP site 384, U1403 and U1406 locations the equivalent facies is a nannofossil chalk and a marly, nanno ooze dated Maastrichtian/Paleocene. Off the Scotian Margin, the A* to A^C unit is the abyssal equivalent of the uppermost Wyandot chalk and distal equivalents of the Banquereau Formation.

Unit **v**

Unit **v** is defined as the interval between the early Eocene A^C horizon and the overlying Oligocene A^U horizon. Unit **v** has similar depositional patterns as Unit **iv** with a central thin over the GSD flanked by areas of thicker deposition to the east and northwest (Figure 16). The package is missing around the seamounts crossed by Lines 01, 12, and 13, and is missing on all of the seamounts that penetrate the seafloor. It is also missing, through non-deposition, over the crest of the GSD on Line 01 between lines 09 and 10.

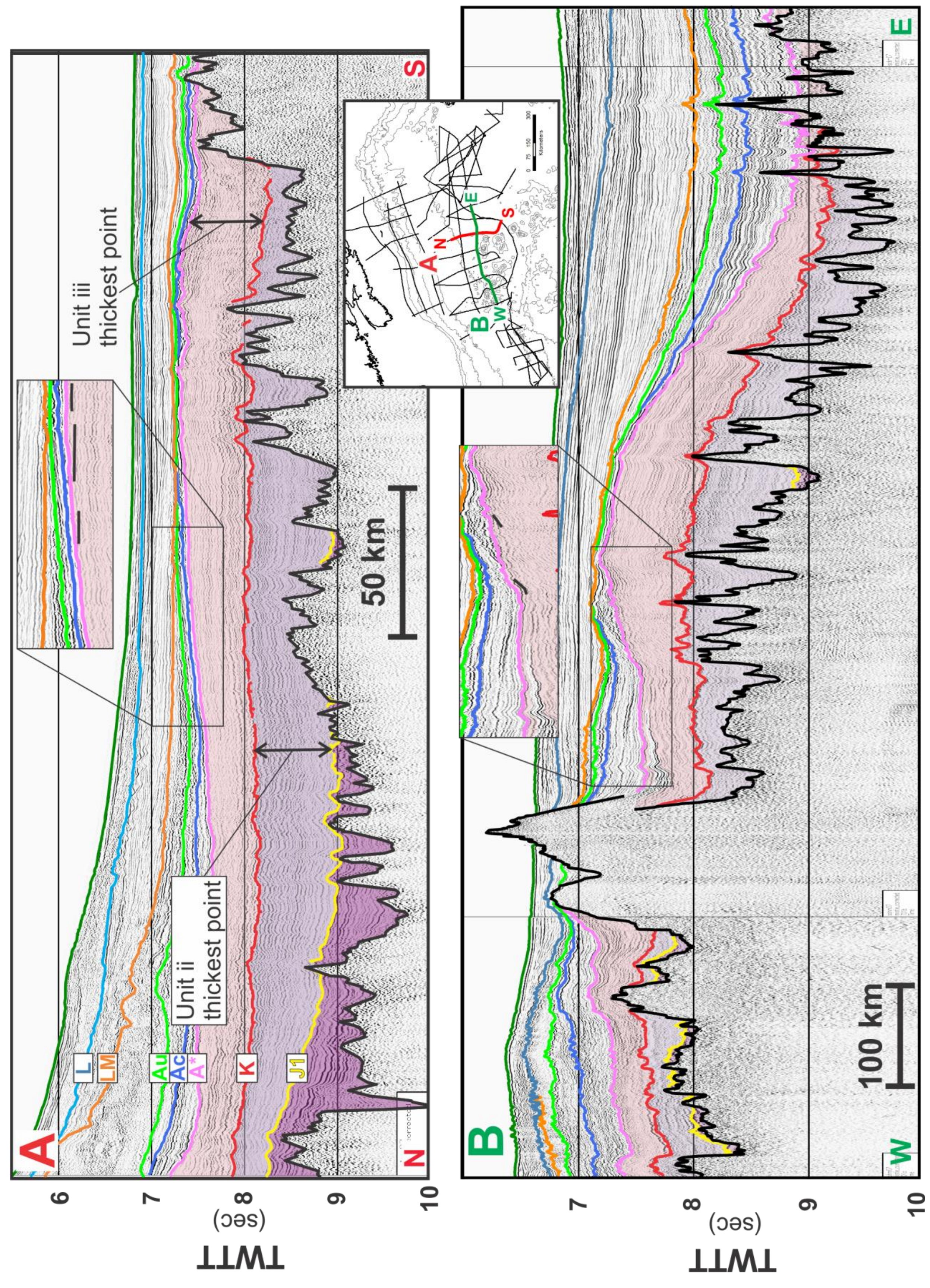
A
B
N
S
W
E
L
LM
Au
Ac
A*
K
J1
Unit ii thickest point
Unit iii thickest point
50 km
100 km
TWTT (sec)
6
7
8
9
10

Figure 14 *(previous page): Detail of GSC2007 lines (A) 09 and (B) 01. Insets show evidence of erosion at horizon A*. The mound formed by the thick, inverted Unit iii in (B) forms the core of the Great Sohm Dome (GSD).*

The A^C to A^U package is poorly sampled in the Sohm Basin but Hole 384 cored about 66 m at its base which was described as marly, nannofossil ooze, deposited in a quiet water environment at 2000 to 3000 m depth (Tucholke, Vogt, et al., 1979). Chert fragments and thin cherty limestones found in the bottom few metres are characteristic of the Ac horizon. Unit **v** sediments were recovered in IODP sites U1403, U1404 and U1406. In the first two holes the facies was predominately clay while U1406 was nannofossil ooze (Expedition 342 Scientists, 2012). In the U.S. basins this package equates to the Bermuda Rise Formation and the lower part of the Blake Ridge Formation. In some DSDP wells at or just south of the seamounts, two additional Eocene-Oligocene seismic horizons, A^T and A^V, have been picked (Jansa et al., 1979). Neither of these have been identified on the 2007 data although Uchupi and Austin (1979) identified a horizon A^T which they felt was coeval with Horizon A with an extrapolated age of late Eocene to early Oligocene and therefore within Unit **v**.

Unit **v** is the deep water equivalent of the Eocene to early Oligocene shales and chalks of the middle portion of the Banquereau Formation of the Scotian Basin.

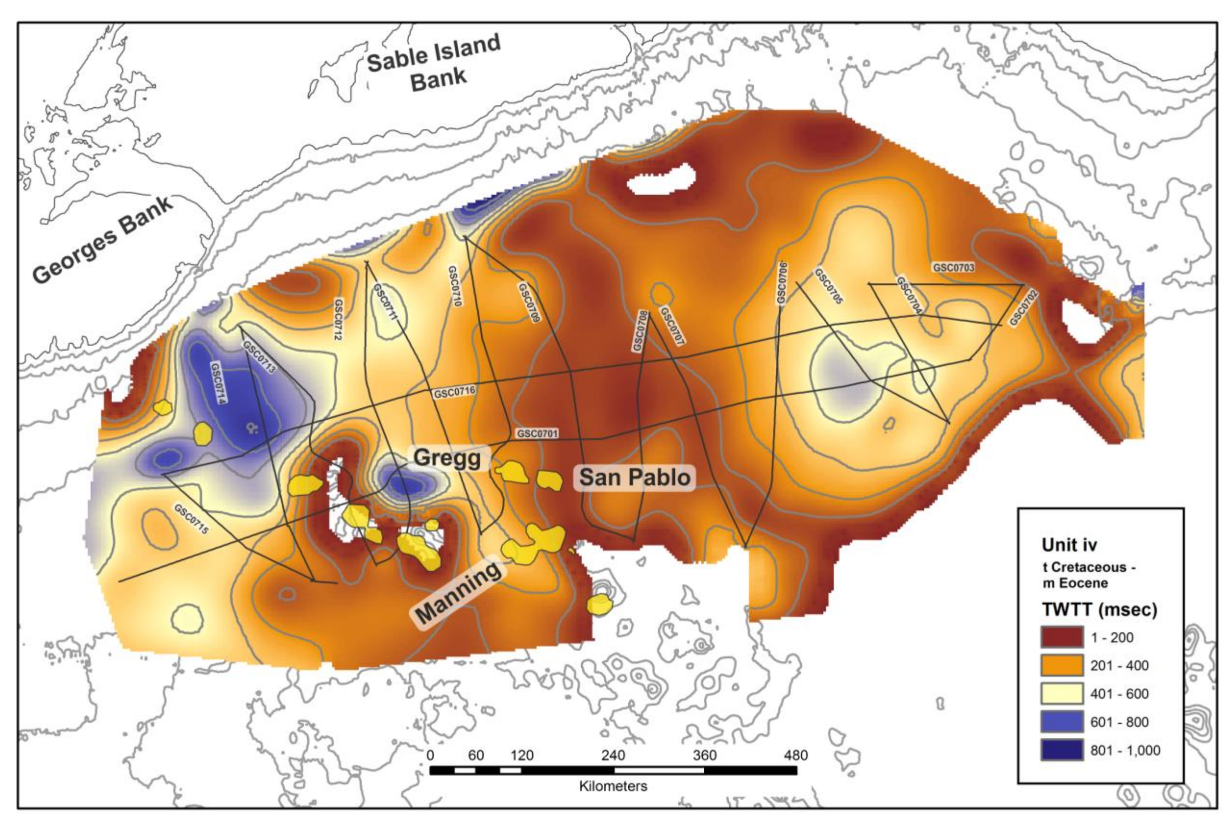

Figure 15*: Isochron of Unit iv, the seismo-stratigraphic interval bounded by horizons A^C on the top and A* at its base. Unit iv is bounded on the top by the A^C horizon (Eocene) on top and A* (top Cretaceous) on bottom. Isochron contours at an interval of 100 msec are displayed in grey. The location of the New England seamounts are approximated by infilling the 4000 m isobath in pale yellow.*

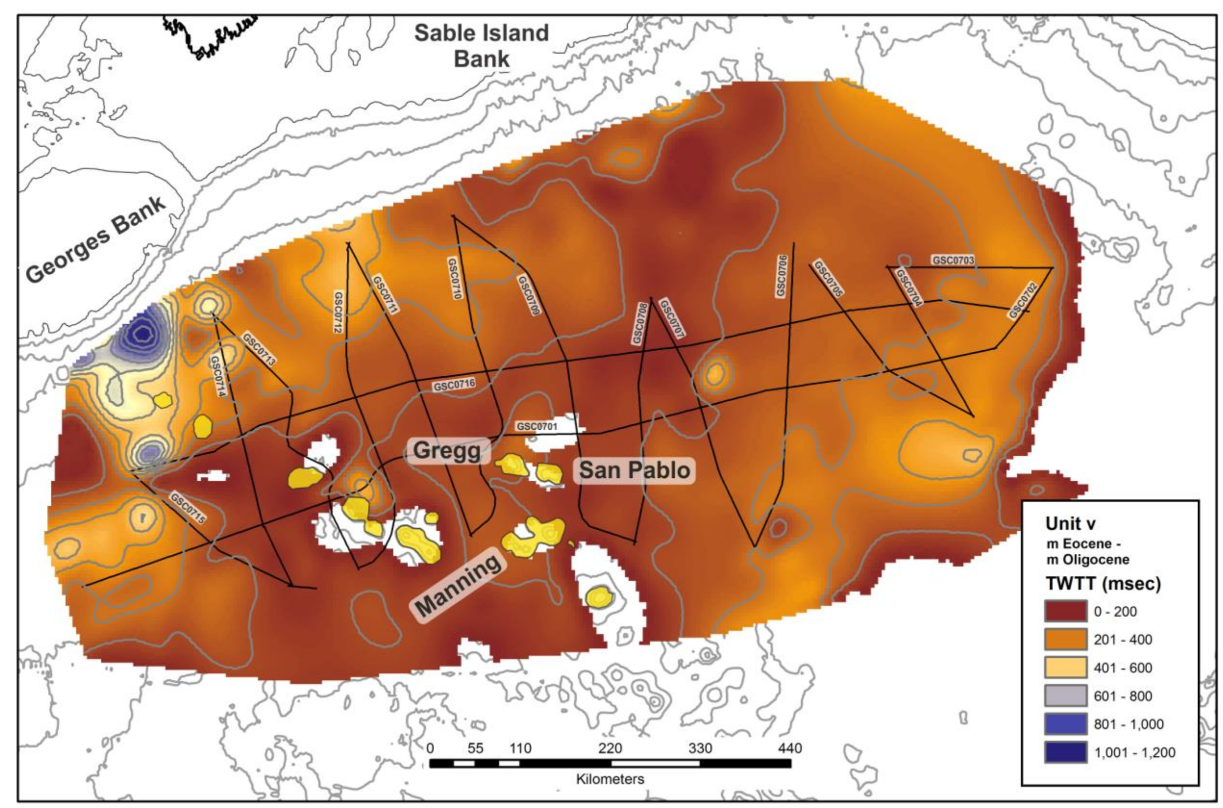

Figure 16*: Isochron of Unit v, the seismo-stratigraphic interval bounded by horizons A^U (Oligocene) on the top and A^C (Eocene) at its base. Isochron contours at an interval of 100 msec are displayed in grey. The location of the New England seamounts are approximated by infilling the 4000 m isobath in pale yellow.*

Unit **vi**

Unit **vi** extends from A^U, a major Oligocene lowstand of sea level on the Scotian Margin to LM, a Lower Miocene unconformity. Both horizons were correlated throughout the seismic data set. During this period there was a refocusing of sediment distribution systems on the Nova Scotia and adjacent margins. Thick sequences of mass transport and slump deposits occur in the north across the lower slope and rise in front of the Shelburne Subbasin, whereas to the south Unit **vi** is thin with regular bedded turbidite deposits across a broad arch, including over the GSD. The dome is still prominent with at least two areas where A^U is cut out by LM (Figure 17). The larger of these areas, northeast of the Gregg and San Pablo seamounts, measures approximately 15,000 km^2 in area.

Sediments dated as equivalent to Unit **vi** occur on the J Ridge in the IODP holes U1404 (130 m), U1405 (220+ m) and U1406 (145 m) as part of the thick Oligocene/Miocene or Eocene/Oligocene drift (Expedition 342 Scientists, 2012).

Unit **vi** equates to a portion of the upper Banquereau Formation on the Scotian Margin and to the lower part of the Blake Ridge Formation on the U.S. margin. One of the better DSDP holes testing the Bermuda Rise Formation was Hole 386, on the Bermuda Rise, which cored approximately 100 m of lower Miocene to 'middle' Oligocene turbidites. The lower part was a sequence of volcaniclastic turbidites grading upward into calcareous turbidites. DSDP hole 385 on the flank of Vogel Seamount, about 150 km SE of the end of Line 11, recovered 19 m of firm homogeneous olive to light grey nannofossil/foraminiferal ooze from a 100m interval of this formation. No sediments of this age were sampled in the 384 hole. IODP sites U1404, U1405 and U1406 cored 200-300 m thick sections of Oligocene and early Miocene age. The lithology grades from predominately biosiliceous clays in the U1404 hole to nannofossil ooze updip in hole U1406.

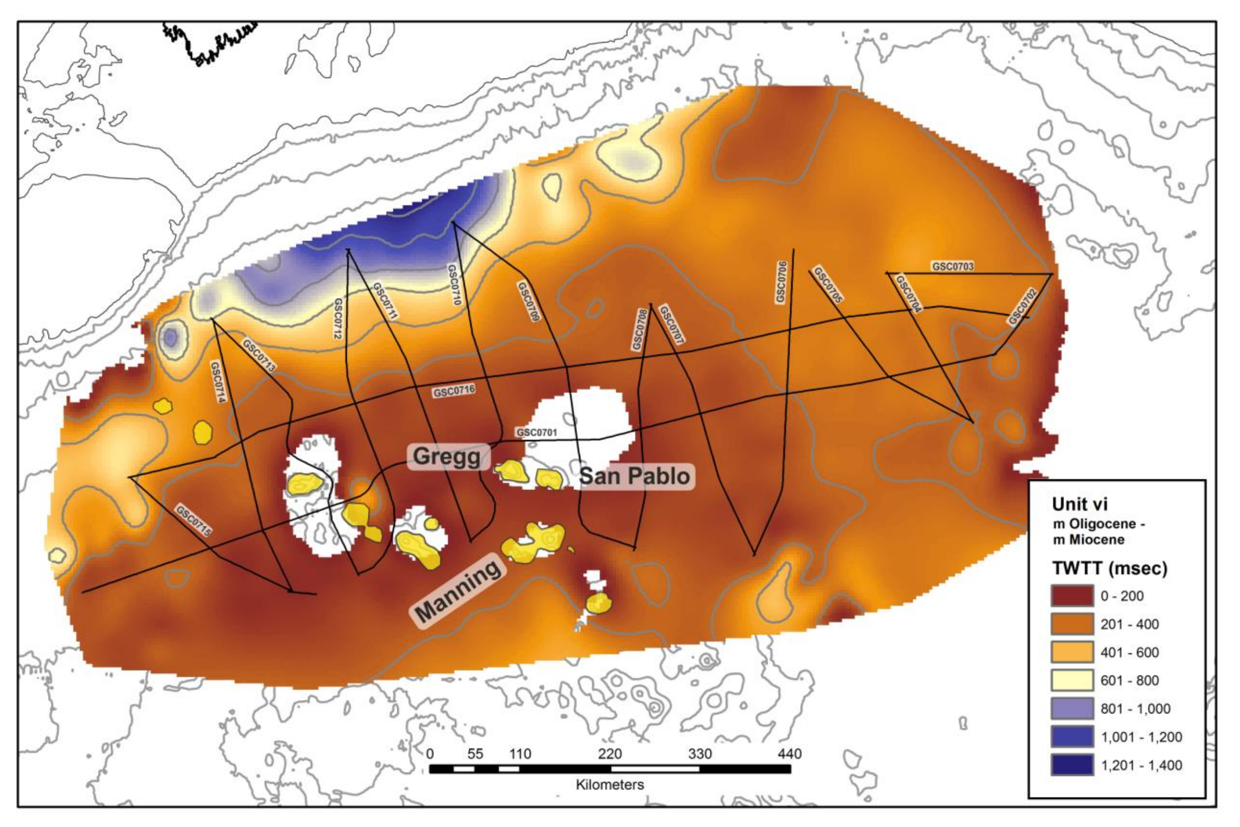

Figure 17: *Isochron of Unit vi, the seismo-stratigraphic interval bounded by horizons LM (lower Miocene) on the top and A^U (Oligocene) at its base. Isochron contours at an interval of 200 msec are displayed in grey. The location of the New England seamounts are approximated by infilling the 4000 m isobath in pale yellow.*

Unit **vii**

Unit **vii** is bounded on the bottom by the lower Miocene LM horizon and the top by the Pliocene L horizon, initially identified by Uchupi and Austin (1979) in the Laurentian Fan area and extended by Ebinger and Tucholke (1988) into the greater Sohm Abyssal Plain. There are many unconformities within Package **vii** resulting from sea level fluctuations, numerous mass transport flows, current scouring, sediment redistribution, etc.

The isochron map of Unit **vii** (Figure 18) shows a unit that is very thick in the eastern SAP, thinning abruptly westward, as an ancestral Laurentian Channel drained a large portion of eastern Canada, discharging huge volumes of sediment from across the eastern Scotian Shelf and the western Grand Banks into the rapidly subsiding area in the eastern Sohm basin. In the western end of the survey area, Unit **vii** is very thin, particularly around the New England Seamounts. A tongue of thicker sedimentation extends westward from the very thick Laurentian Fan deposit across Lines 09 and 10 (Figure 18), thinning over the GSD.

The distal ends of lines 06 and 07, show fields of large sediment waves within Unit **vii**, which would have developed in very deep water (Figure 19). On Line 06 the field is up to 700 msec TWTT in thickness and extends for more than 130 kms along the line. Other sediment waves occur on Line 09 north of Line 16, (see Appendix Figure A-19). Sediment waves only occur in the Neogene and Quaternary, units **vii** and **viii**.

Unit **vii** equates to the upper part of the Blake Ridge Formation, which consists predominantly of hemipelagic grey-green muds and mass flow deposits.

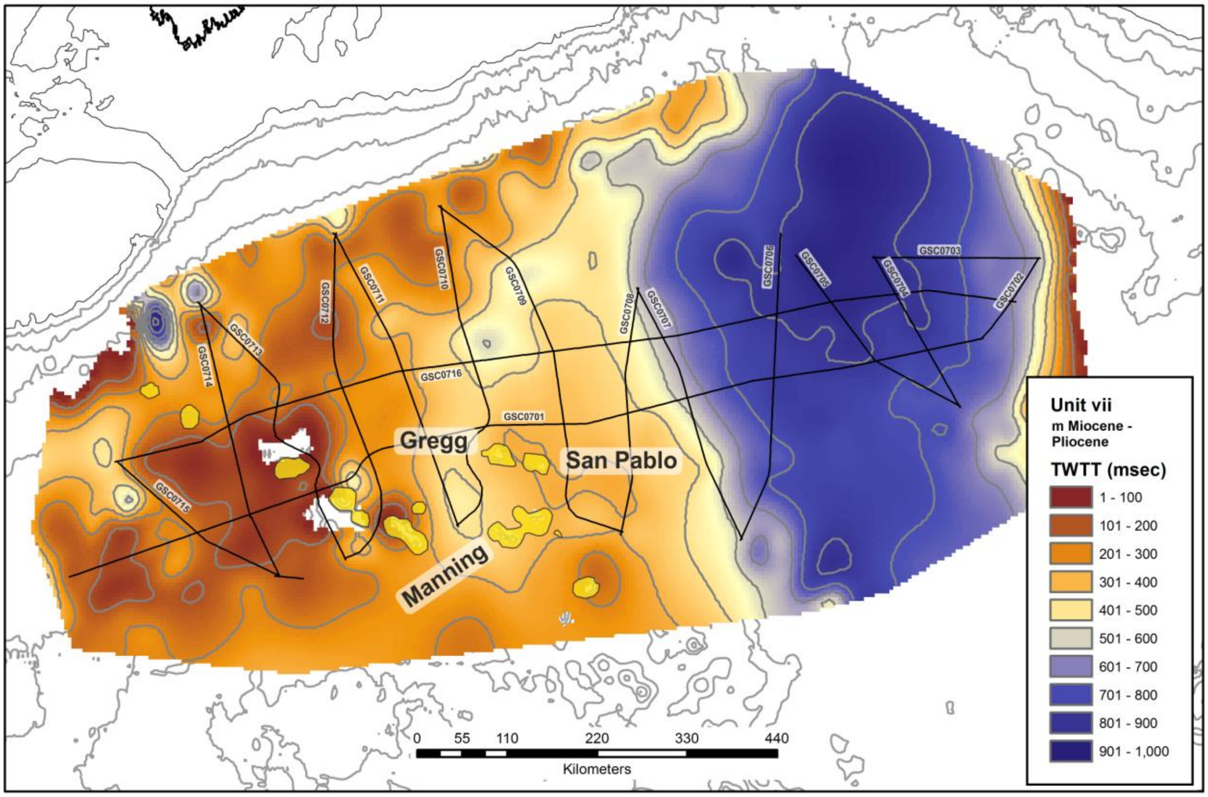

Figure 18*: Isochron of Unit vii, the seismo-stratigraphic interval bounded by horizons L Pliocene) on the top and LM (lower Miocene) at its base. Isochron contours at an interval of 100 msec are displayed in grey. The location of the New England seamounts are approximated by infilling the 4000 m isobath in yellow.*

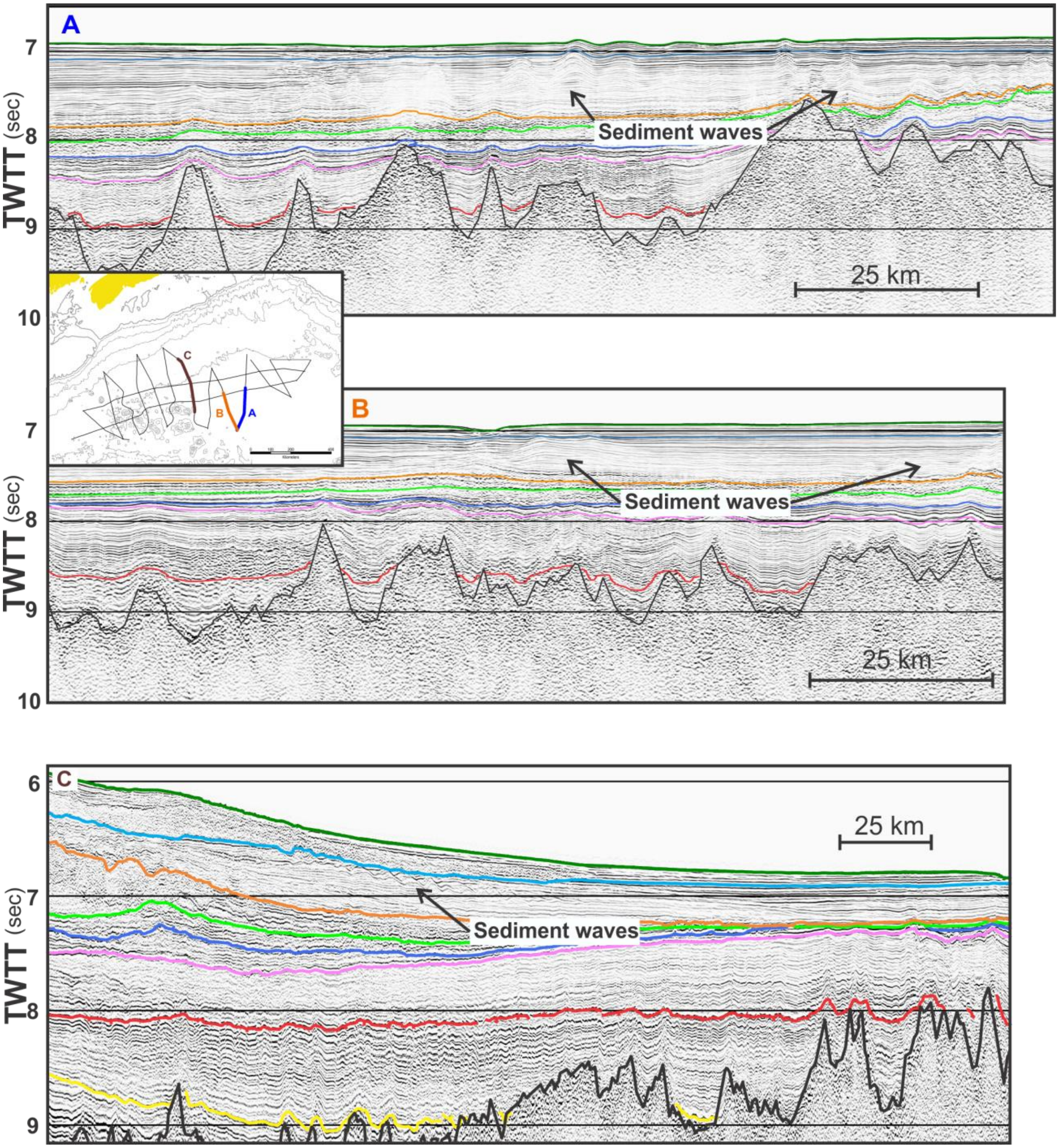

***Figure 19**: The seaward end of lines 06 (A), 07 (B), and 09 (C), showing sediment waves in the Neogene and Quaternary. Line locations are shown in the inset map, and each line is presented from north (left) to south.*

Unit **viii**

The shallowest unit is bounded by horizon L below and the seafloor reflector at the top. It shows the influence of the Plio-Pleistocene lowstands. In the Sohm Basin this package is thickest in the northwest, off of Georges Bank, and in the northeast, in front of the Laurentian Channel, with more than 1.0 sec TWTT (Figure 20). Across the central Sohm, the package is generally < 200 msec in thickness. The thickest section occurs north of Line 03 reflecting the late stage development of the

Laurentian Cone (Uchupi and Austin, 1979). The GSD was still a slightly positive feature at L time, with post-L sediments onlapping its eastern flank and thinning over its crest. DSDP Hole 383, drilled just east of the crest of the J Anomaly Ridge, recovered 4.9 m of 19.1 m cored of unconsolidated Pleistocene turbiditic sand. Caving sand forced abandonment of this hole.

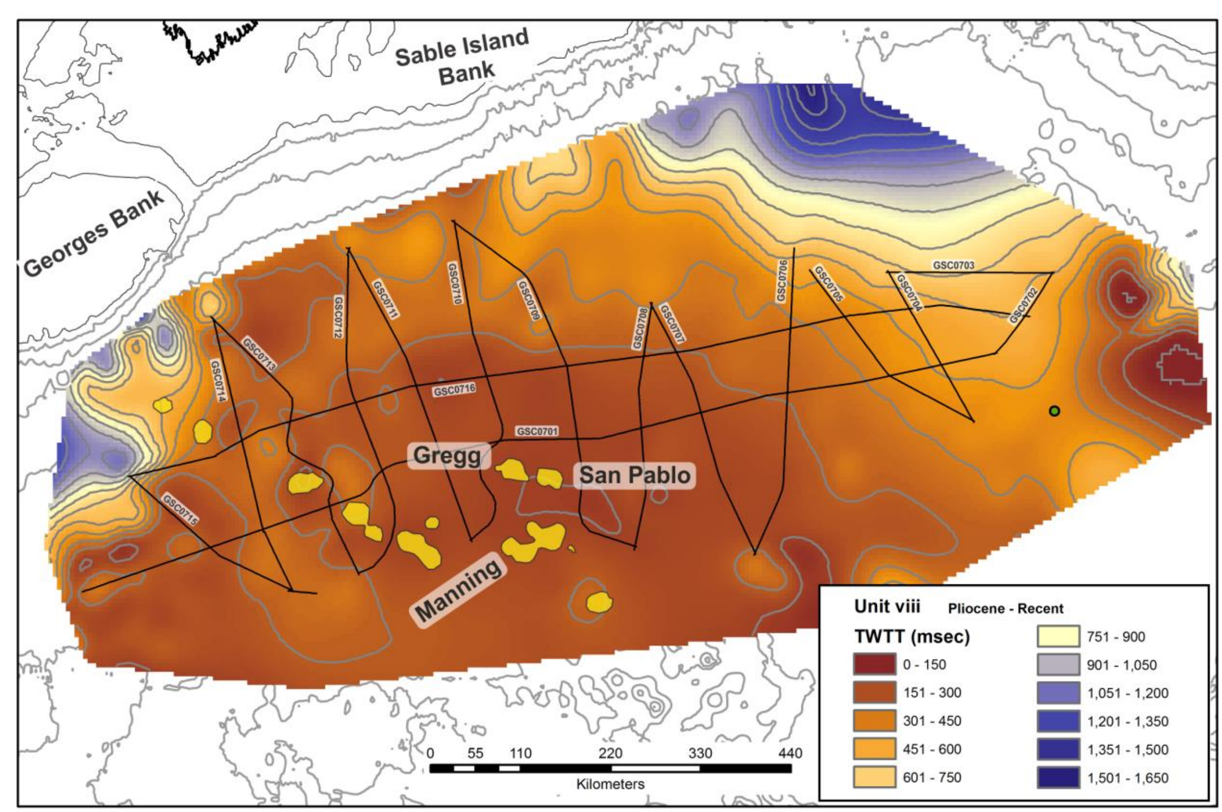

__Figure 20__: Isochron of Unit viii, the seismo-stratigraphic interval bounded by the seafloor on the top and L at the bottom. Isochron contours at an interval of 150 ms are displayed in grey. The location of the New England seamounts are approximated by infilling the 4000 m isobath in yellow. The location of DSDP hole 383 is indicated in green.

Discussion

Marine sedimentation in the Sohm Abyssal Plain began in the Jurassic over thinned continental and oceanic crust (Unit **i**). Early deposition was thickest offshore of the modern Sable and Brown's banks and thinned quickly outward from these local depocentres (Figure 10). Early Cretaceous deposition (Unit **ii**) is thickest from Sable Island Bank and seaward into what appears to have been a large margin-parallel trough at the base of the ancient slope (Figure 11). During the later Cretaceous, deposition was concentrated in two depocentres, one off Georges Bank and the other adjacent to the then newly-formed Gregg, San Pablo, and Manning seamounts, where Unit **iii** is up to 800 msec thick (Figure 13). The latter area forms the core of the Great Sohm Dome (GSD) (Figure 21). Isochrons of Paleogene deposition (units **iv** and **v**, Figure 15 and Figure 16) show the thickest accumulations in the slope area off Shelburne subbasin and Georges Bank, increased deposition in the eastern Sohm, and very thin deposits in the central basin. After the Late Cretaceous, much of the deposition in the eastern Sohm is concentrated in the Laurentian Fan.

During the Cretaceous, the intrusion of the New England Seamounts (Duncan, 1984) disrupted older sediments and modified existing and future depositional patterns. Also during this period, as shown in Figure 8 and Figure 14, a large dome formed in the central Sohm adjacent to the Gregg, San Pablo, and Manning seamounts. The scale of the feature can be seen more clearly by looking at a composite isochron of the overlying seismic units **iv** – **viii** (Figure 21). The dome is part of a larger structural high that extends to the west across the New England Seamounts, however as can be seen in the profile provided by Line 01 (Figure 8(B)), the inversion of the Late Cretaceous depocentre seems to form a distinct mound on top of the larger feature. The dome, which we refer to as the "Great Sohm Dome" (GSD) is very large – the area encompassed by the 750 msec contour in Figure 21 is roughly 50,000 km^2. Figure 21 shows where the dome is at its thickest point, which coincides with the region in which Unit **vi** is absent in the section (Figure 17). This indicates that the GSD was a bathymetric obstacle to deposition throughout the Paleogene and possibly into the Neogene.

The origin of the GSD is undetermined; however, the timing indicated by the stratigraphy suggests a possible mechanism. In the Early Cretaceous, Unit **ii** deposited into a large margin-parallel trough in an area that overlaps the location of the dome (compare Figure 11 and Figure 21). During the Late Cretaceous, the basement began to rise in the central region resulting in the local inversion of the thick Jurassic-Cretaceous sedimentary units of Units **i**, **ii**, and **iii**. Uplift continued at least through the Oligocene as on lines 01, 08, and 16 beds of Unit **iii** are overlain by beds as young as Unit vii (Figure 8, Appendix Figures A-3, A-8, and A-17). Additionally, pre-A* sediments over the region of the GSD are cut by numerous extensional faults indicating uplift occurred following lithification of these beds, Figure 12.

The proximity of the New England Seamount chain and the timing of its intrusion/emplacement, suggests a possible relationship with the uplift. It is worth noting that there is still some discussion as to whether the New England Seamounts were created as the crust drifted across a mantle plume or hot spot (Duncan, 1984) or formed as a result of episodic extrusions controlled by movement along fracture zones (Holbrook and Kelemen, 1993, Jansa and Pe-Piper, 1988, McHone and Butler, 1984). This study does not speak to either of these scenarios, as the seamounts age-dated in the study by Duncan (1984), the only study so far to age date the seamounts, all occur during the deposition of Unit **iii** and are therefore beyond the temporal resolution possible with this data. While the uplift associated with the formation of the GSD may have begun with the intrusion of the New England Seamounts, specifically the Gregg and San Pablo seamounts, erosion of Late Cretaceous sediments near its top suggests that the GSD remained a positive bathymetric feature well beyond the end of the Cretaceous.

As a final note on the nature of the Great Sohm Dome, it is interesting that there appears to be little total field evidence for it. Figure 22 and Figure 23 show the magnetic anomaly and gravity data for the study area and it is readily apparent that if there is any passive field fingerprint for the dome, it is very subtle. If the dome was formed by thermal uplift related to the intrusion the New England Seamounts, it might be reasonable to expect a magnetic anomaly at or near its core, and given the existing data, none is present.

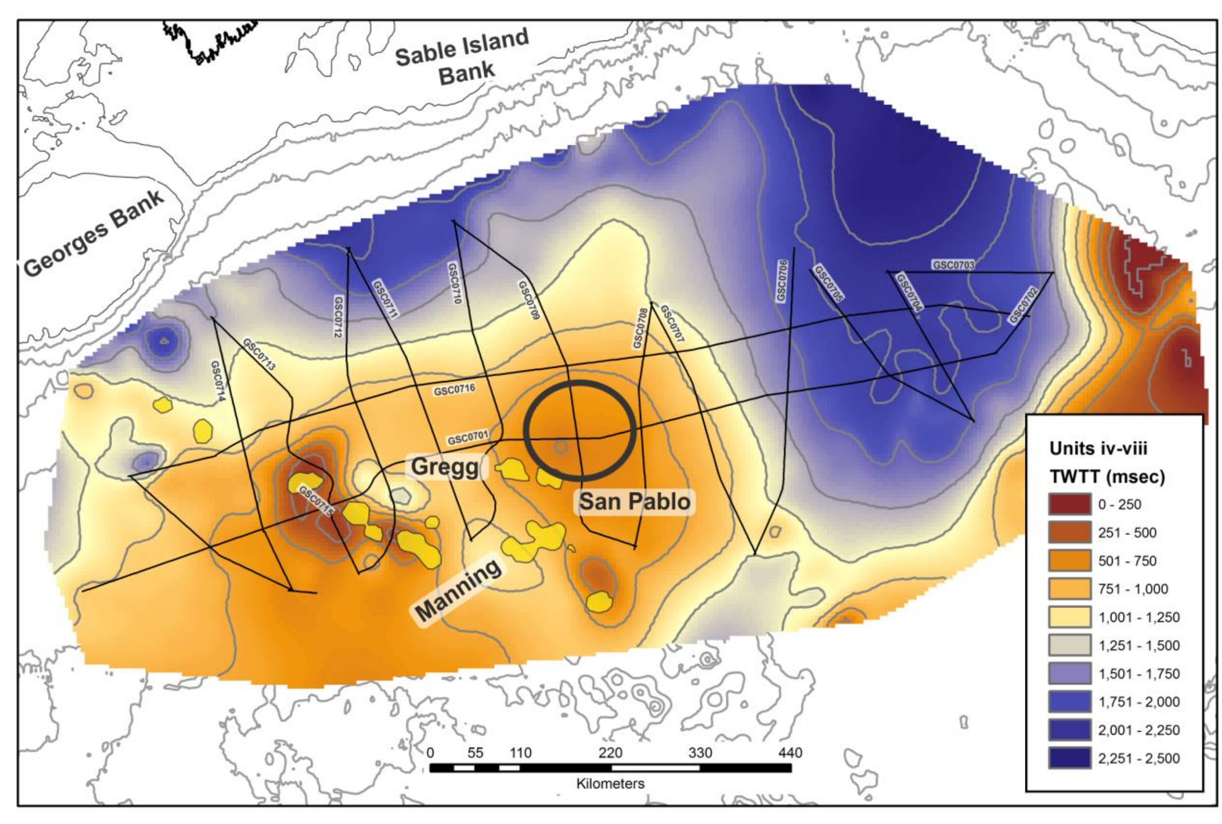

Figure 21*: Composite isochron of units iv – viii (from horizon A* to seafloor, the entire Cenozoic section in the SAP). The location of the New England seamounts are approximated by infilling the 4000 m isobath in yellow. This composite shows the location and extent of the GSD relative to the Gregg, Manning, and San Pablo seamounts. The black circle indicates where the dome is at its thickest. This area is also roughly where unit vi is not present in the section.*

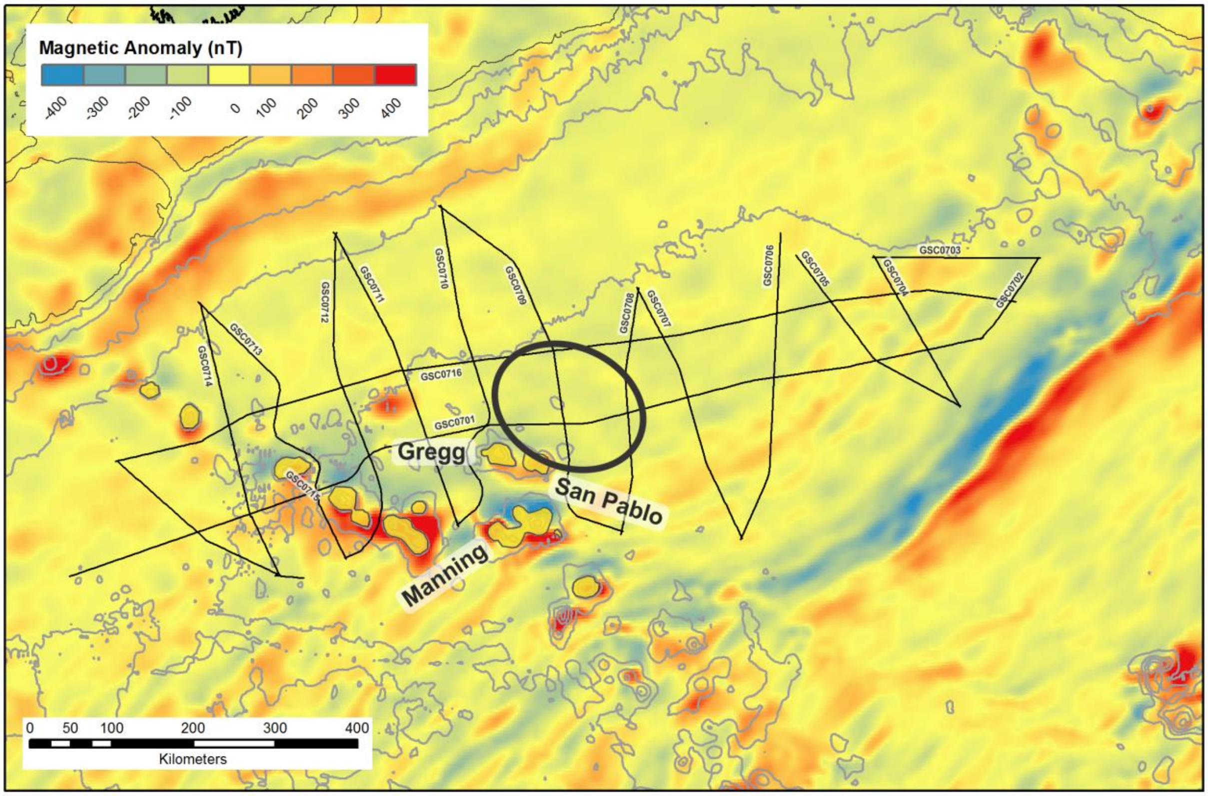

Figure 22*: Magnetic anomaly map with the approximate centre of the Great Sohm Dome indicated in the black circle. The location of the New England seamounts are approximated by infilling the 4000 m isobath in yellow.*

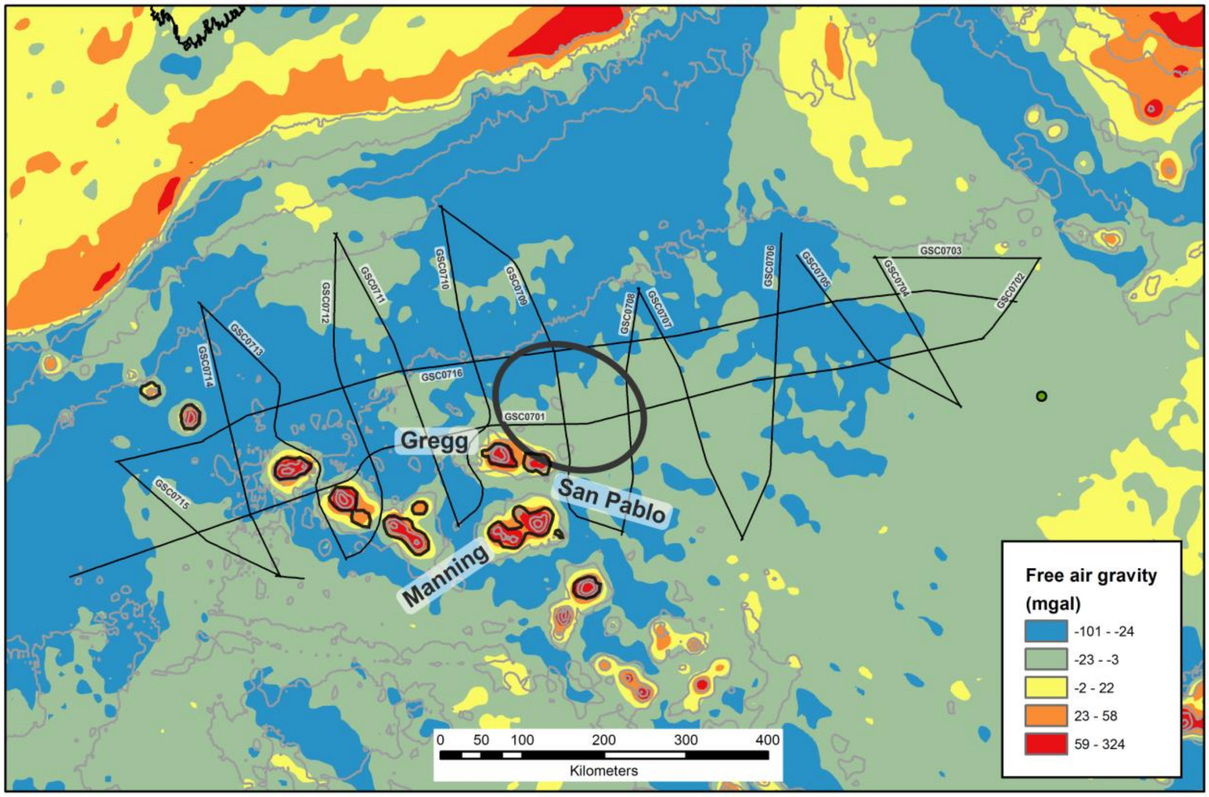

***Figure 23**: Free-air gravity map of the study area (Bonvalot et al., 2012). The approximate centre of the Great Sohm dome is indicated with a black circle. The location of the New England seamounts are outlined in black.*

Conclusion

The collection of multichannel seismic reflection data for the Canadian UNCLOS program in 2007 provides an opportunity to explore the structure and depositional history of the deep-water Sohm Abyssal Plain. The SAP formed during the rifting and separation of North Africa and North America in the Early Jurassic. Jurassic deposition (Unit **i**) was thickest immediately off the Sable and Shelburne subbasins. Thin deposits of this unit extend out to nearly magnetic chron M21 in the west of the study area, however in the central and eastern regions, it does not extend this far, implying a lack of sediment source. Early Cretaceous deposition (Unit **ii**) appears to be largely sourced from the Sable Island Bank area and forms a long, margin-parallel trough. Unit **iii** is also at its thickest near the shelf edge, but it also formed a thick deposit further offshore, near the present-day Gregg, San Pablo, and Manning seamounts, which developed during the Late Cretaceous. Together, these three features flank a large structural dome called the Great Sohm Dome. It is likely, though not proven, that the dome formed as a result of local crustal uplift during the Late Cretaceous, probably associated with the emplacement of the New England Seamounts. There is stratigraphic evidence that the GSD was a major bathymetric feature through much of the Paleogene. The deposition of units **iv**, **v**, and **vi** act as fill around this high. From the mid-Miocene on, deposition shifts dramatically to the eastern SAP, as the Laurentian Channel becomes the main sedimentation source for much of the region, however the dome remained slightly positive until late in the Neogene.

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Appendix

As an addendum to this document, images of the lines from the GSC 2007 survey are presented here. Each line is presented uninterpreted and interpreted, showing both the seismic horizons and the seismic units described in the main text.

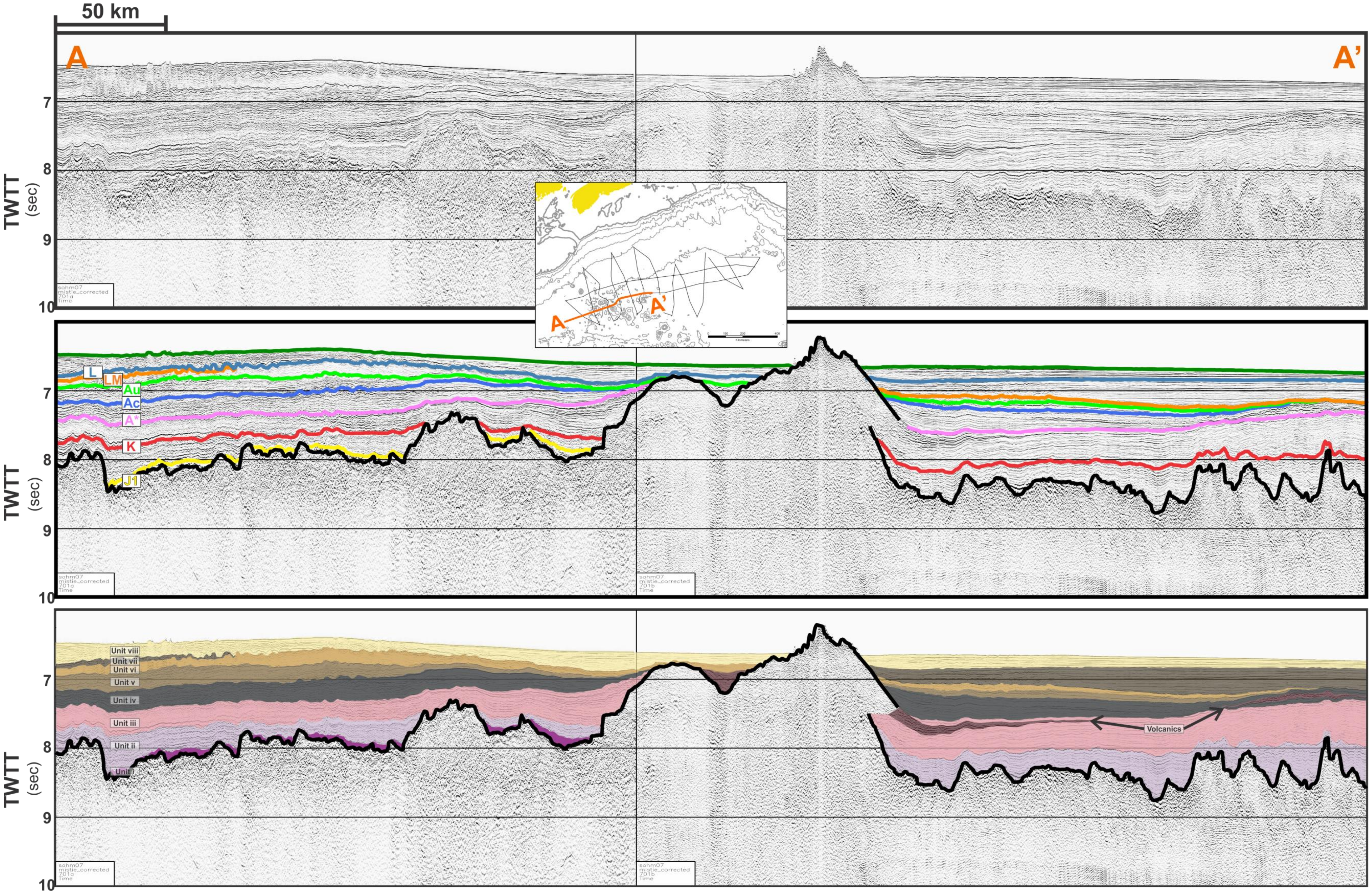

Fig. A - 1: The western portion of GSC07 Line 01 (location of profile shown in inset map).

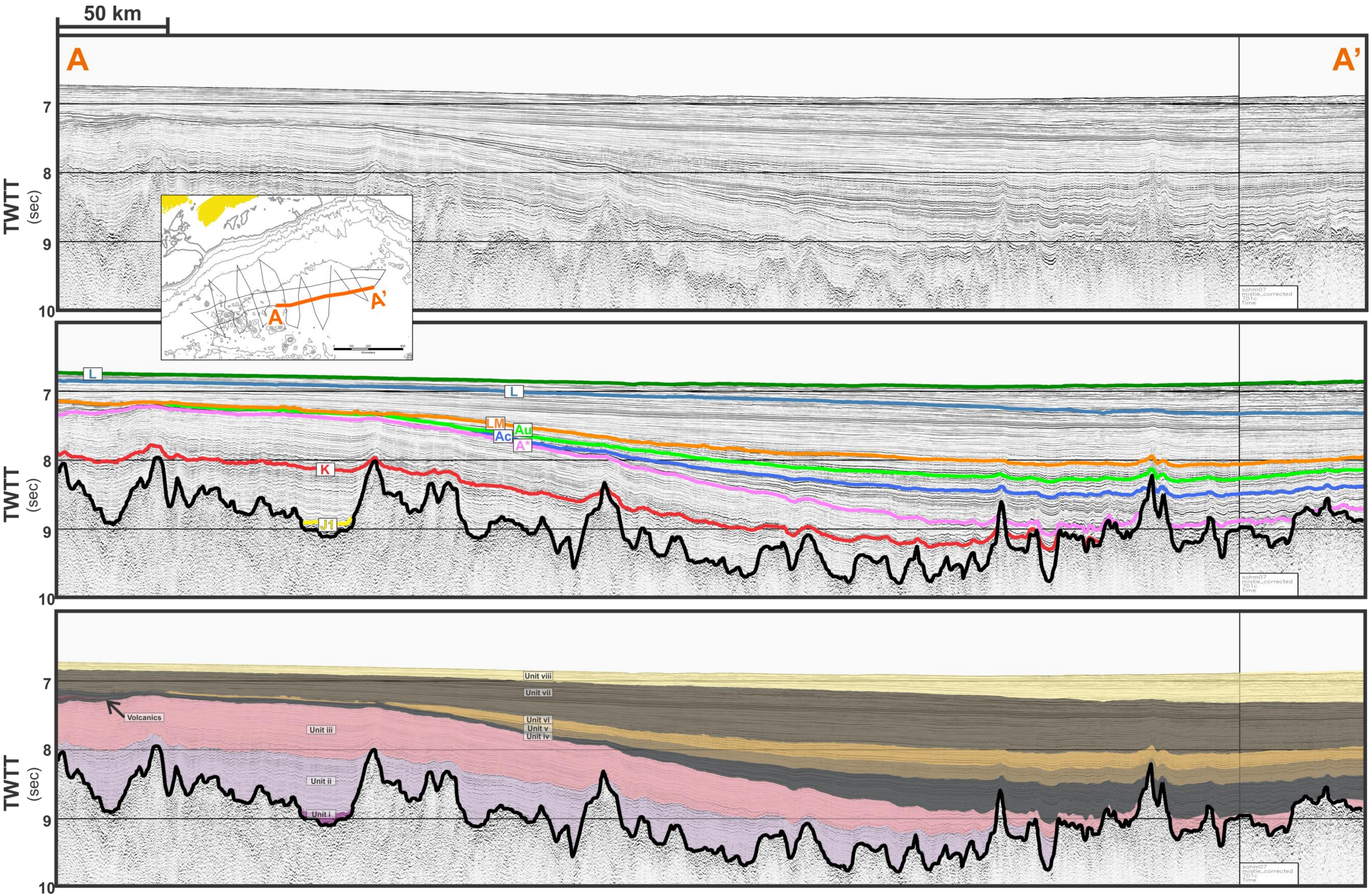

Fig. A - 2: The eastern portion of GSC07 Line 01 (location of profile shown in inset map).

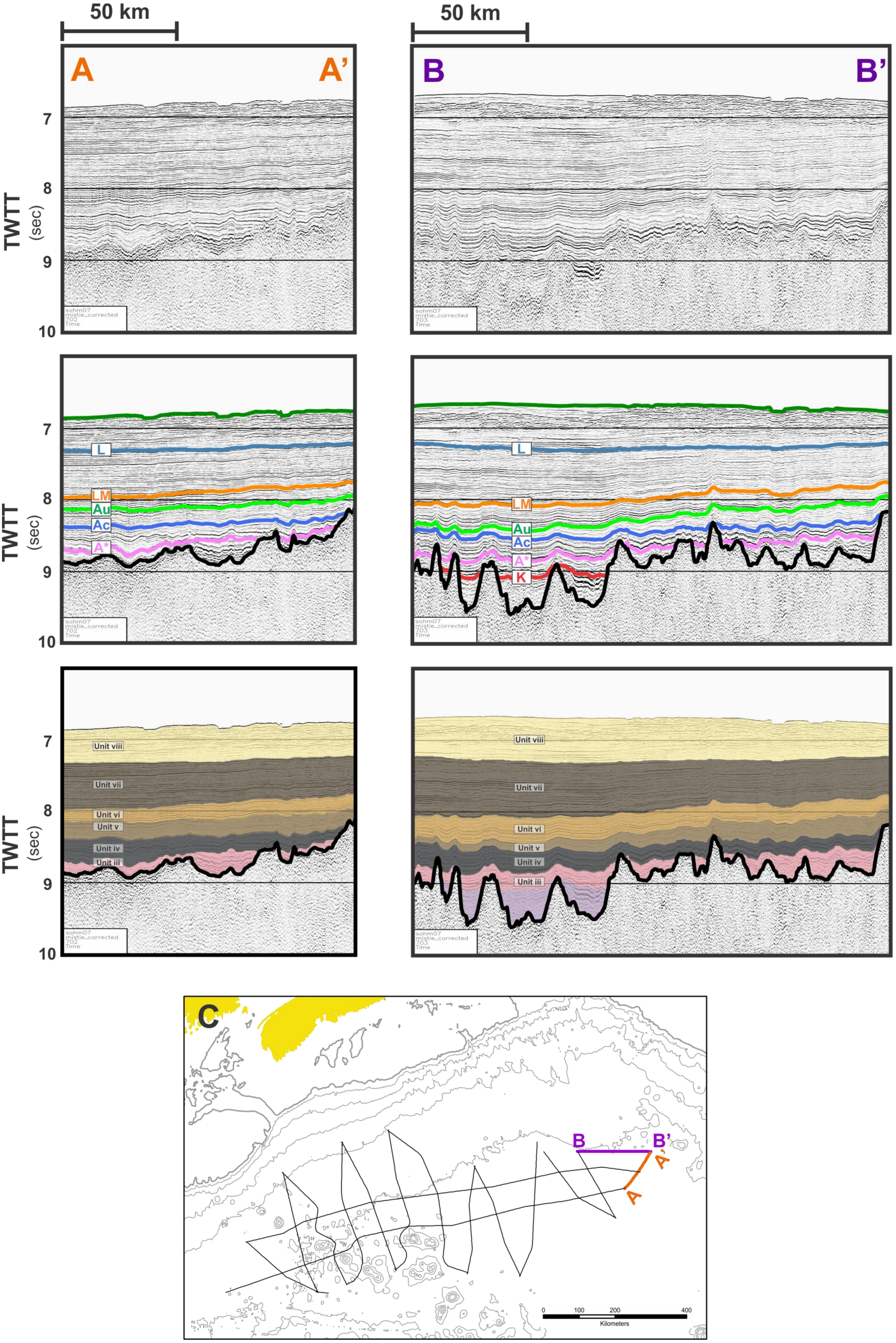

Fig. A - 3: Multichannel seismic reflection lines (A) GSC0702 and (B) GSC0703. Location for the lines shown in (C).

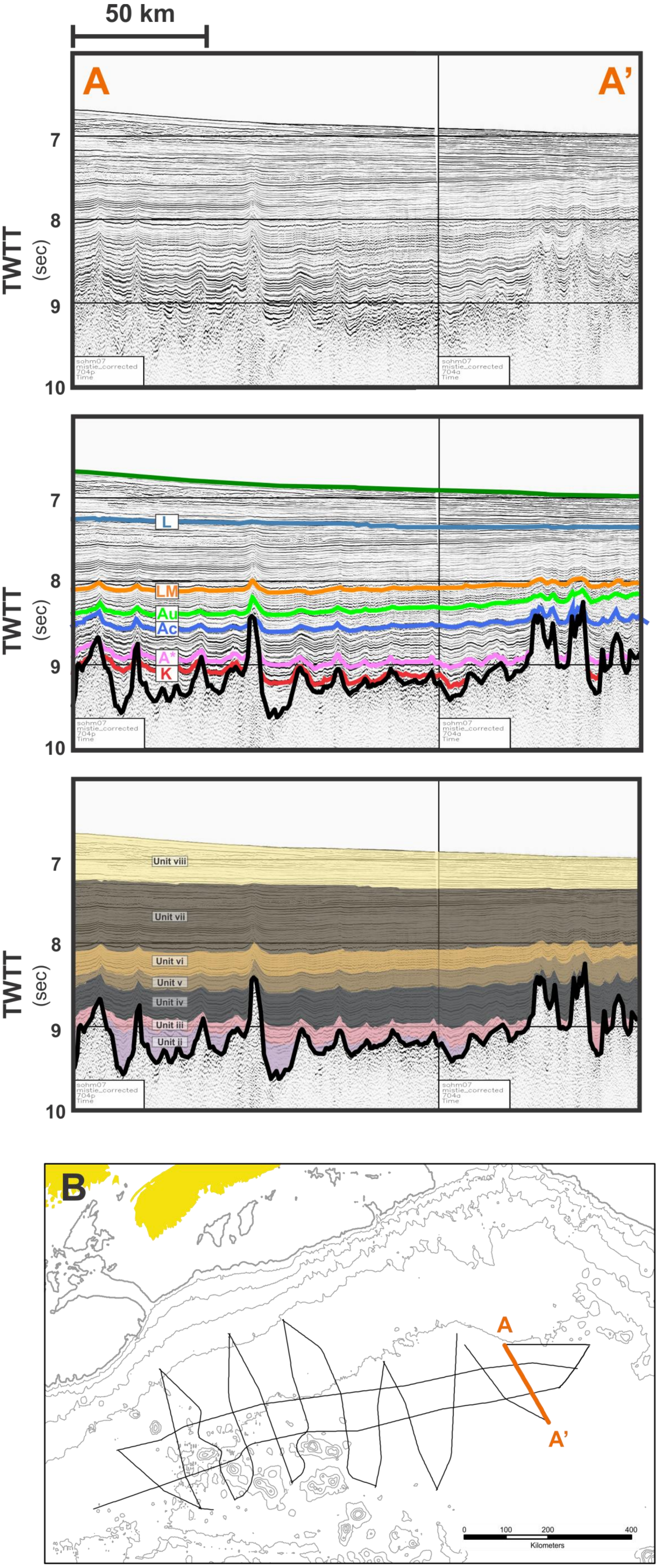

***Fig. A - 4**: Multichannel seismic reflection lines GSC0704. Location for the line is shown in (B).*

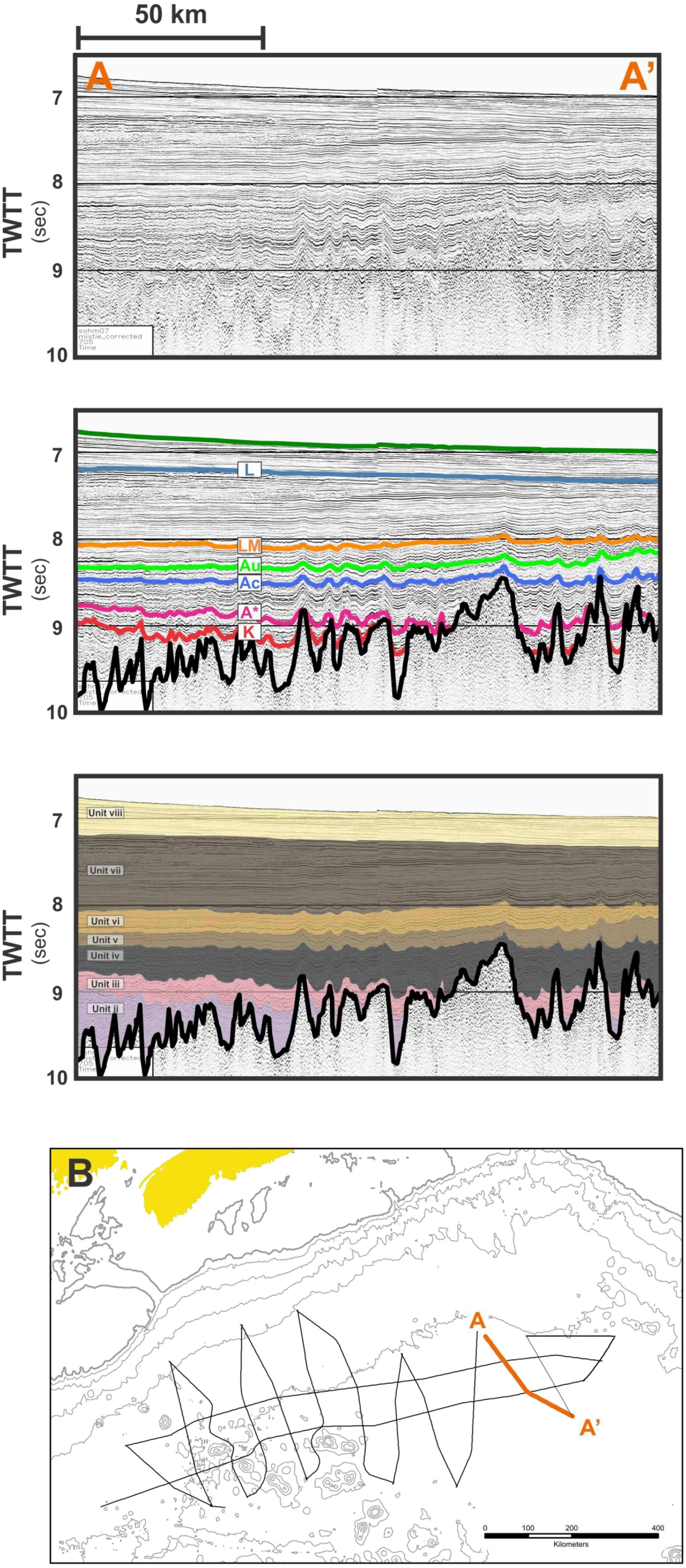

***Fig. A - 5**: Multichannel seismic reflection lines GSC0705. Location for the line is shown in (B).*

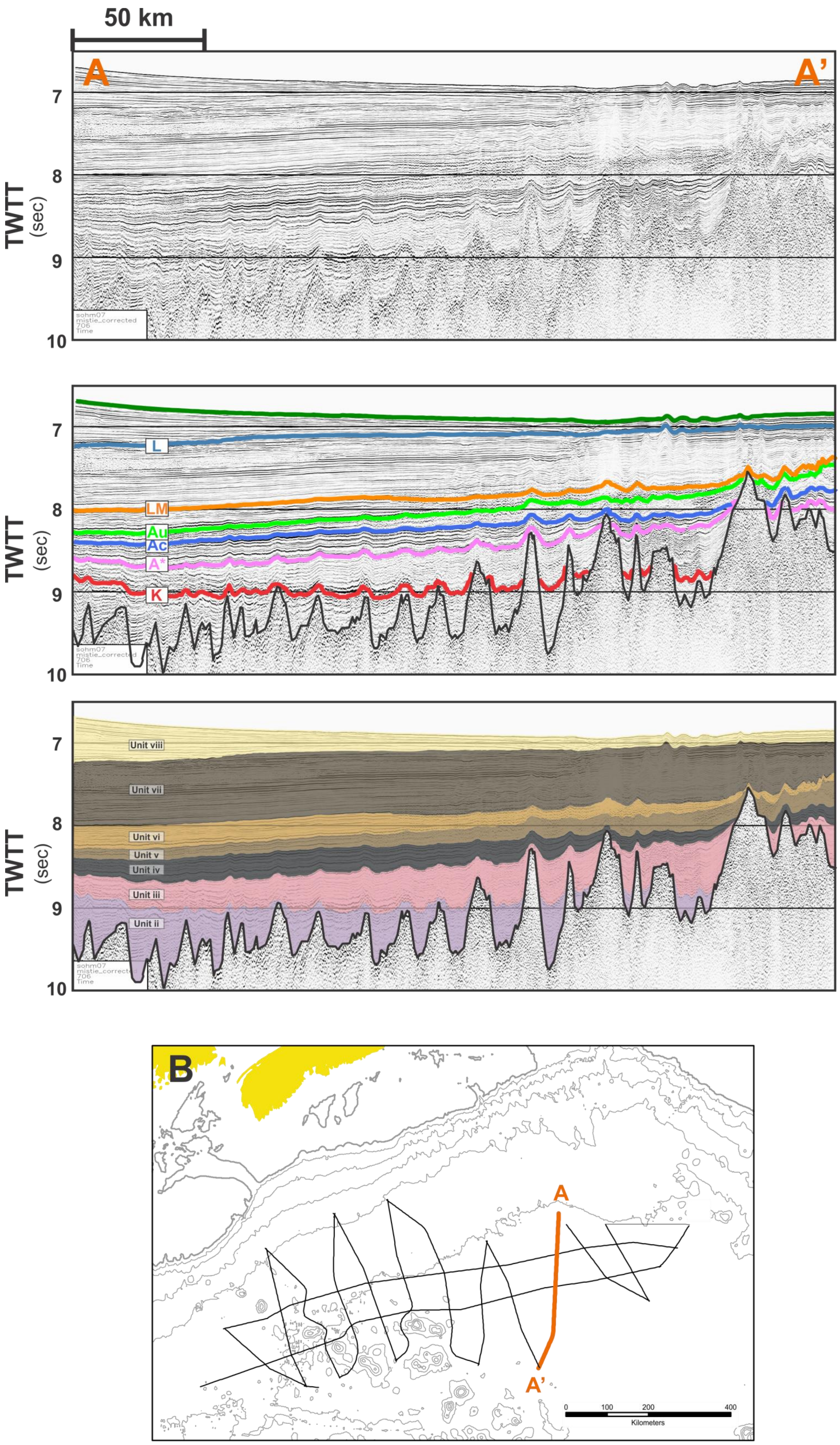

***Fig. A - 6**: Multichannel seismic reflection lines GSC0706. Location for the line is shown in (B).*

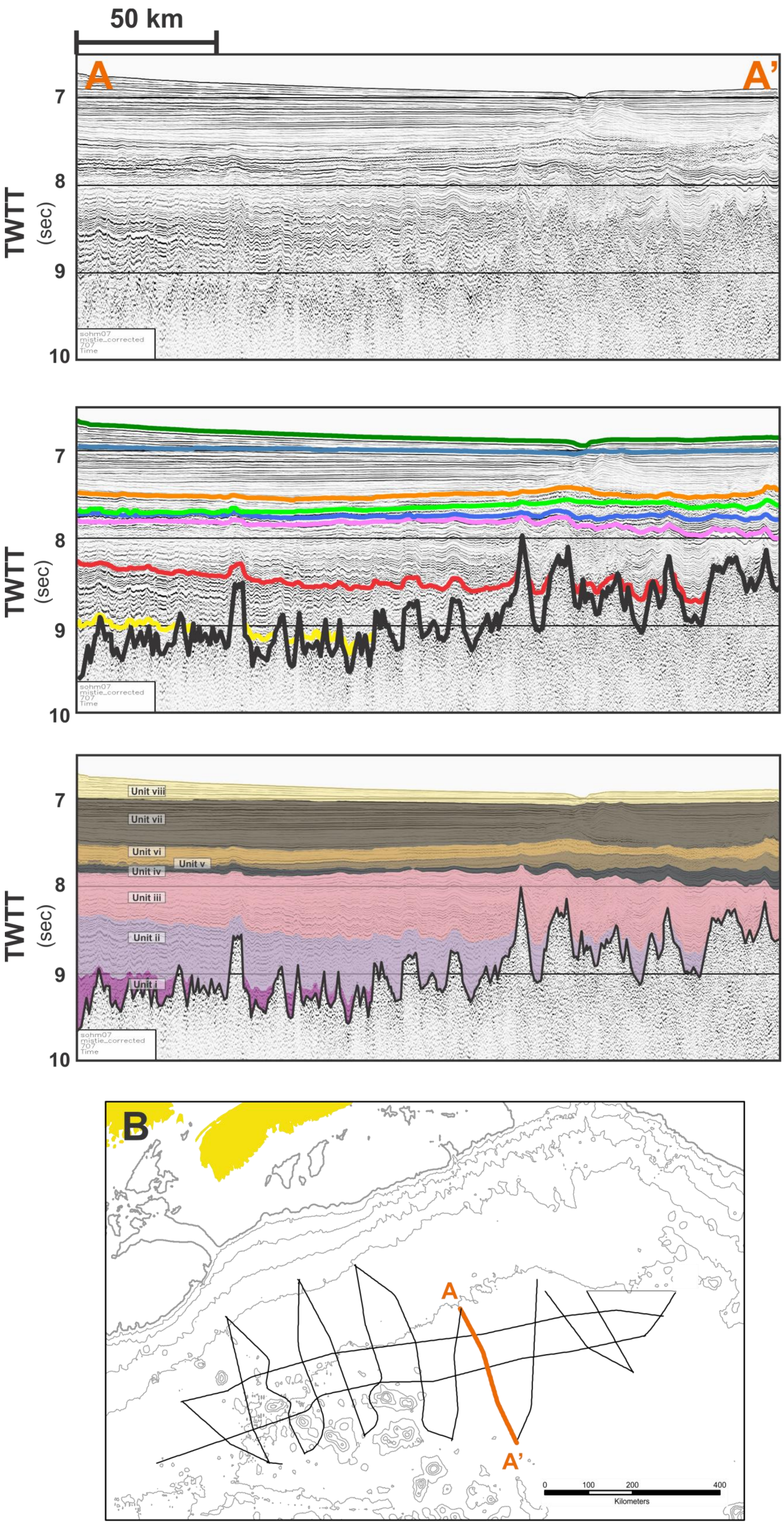

Fig. A - 7: Multichannel seismic reflection lines GSC0707. Location for the line is shown in (B).

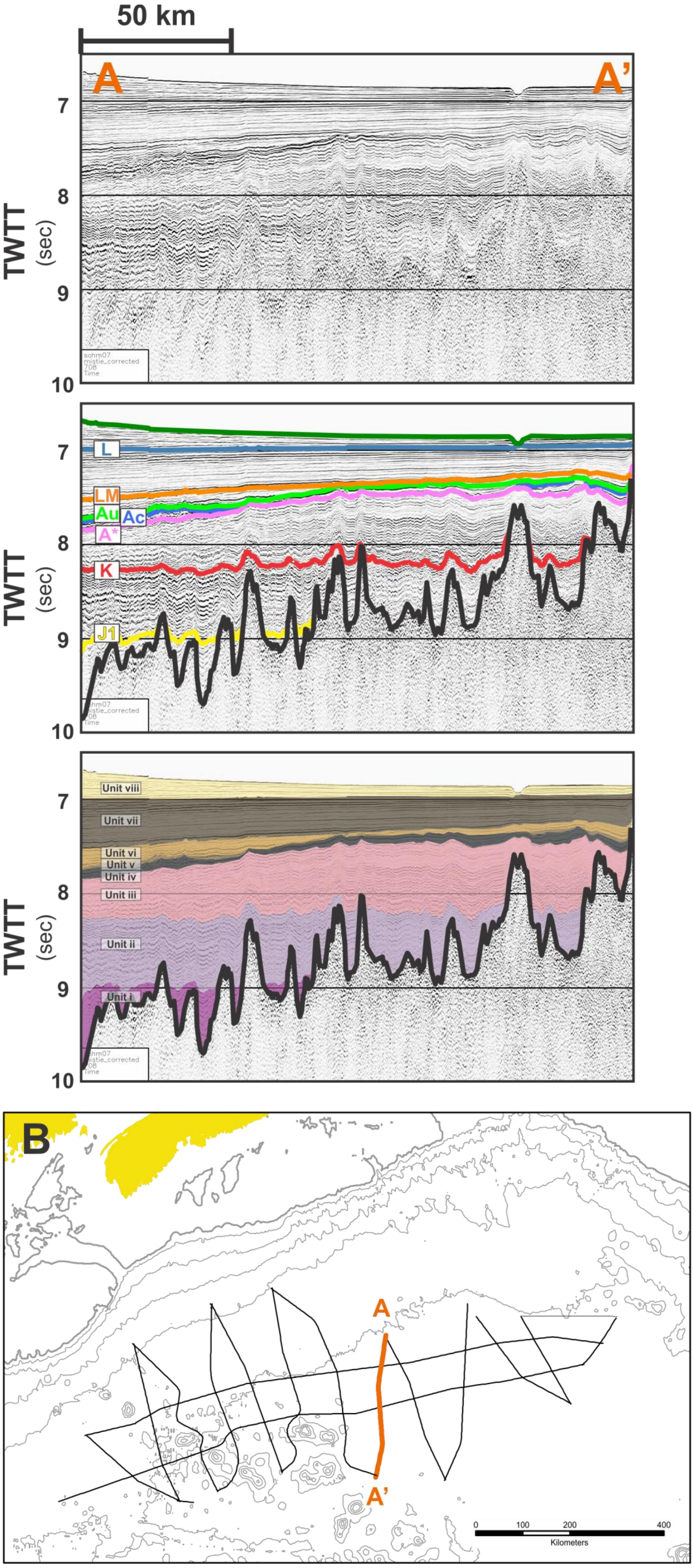

***Fig. A - 8**: Multichannel seismic reflection lines GSC0708. Location for the line is shown in (B).*

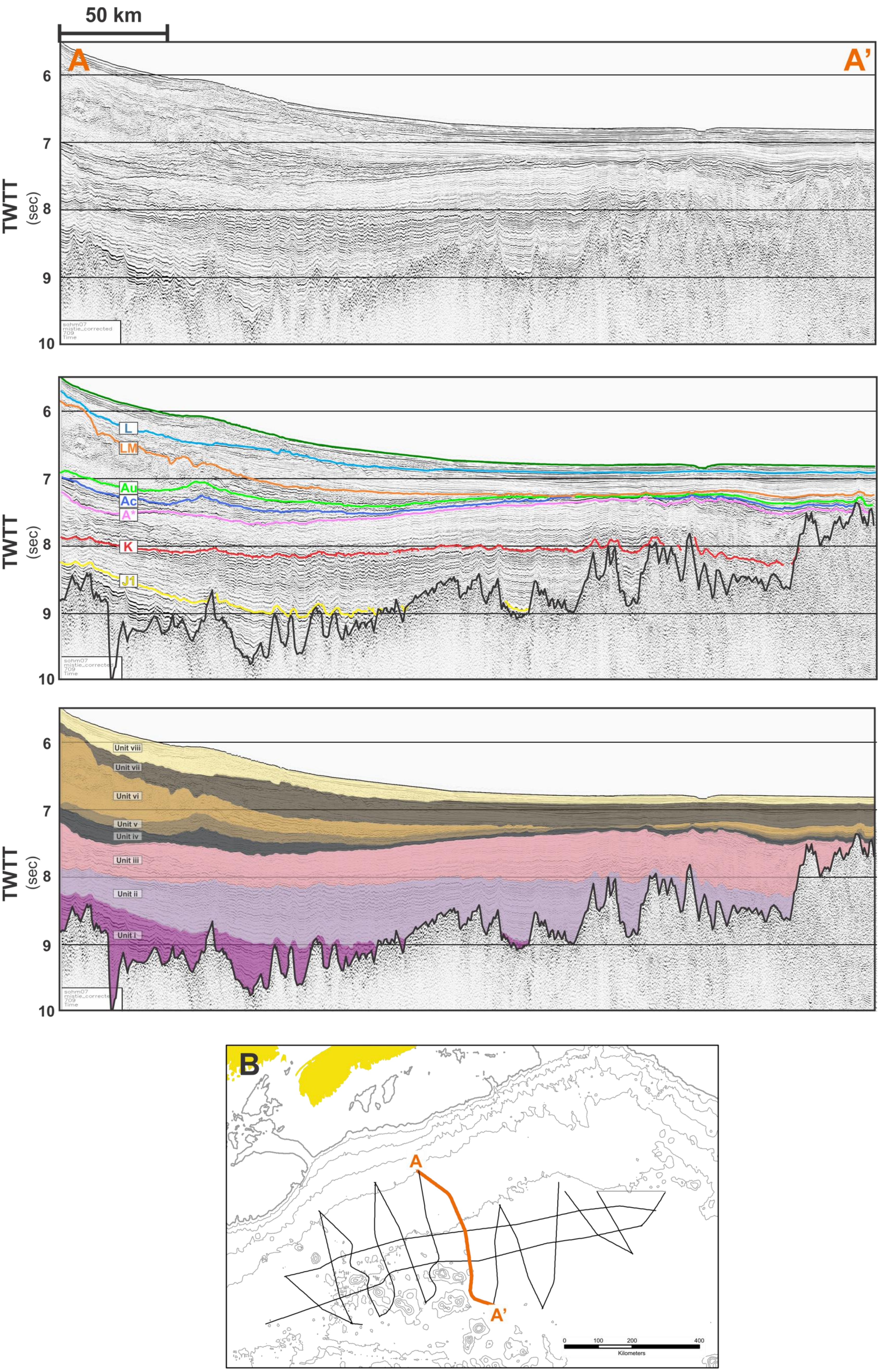

***Fig. A - 9**: Multichannel seismic reflection lines GSC0709. Location for the line is shown in (B).*

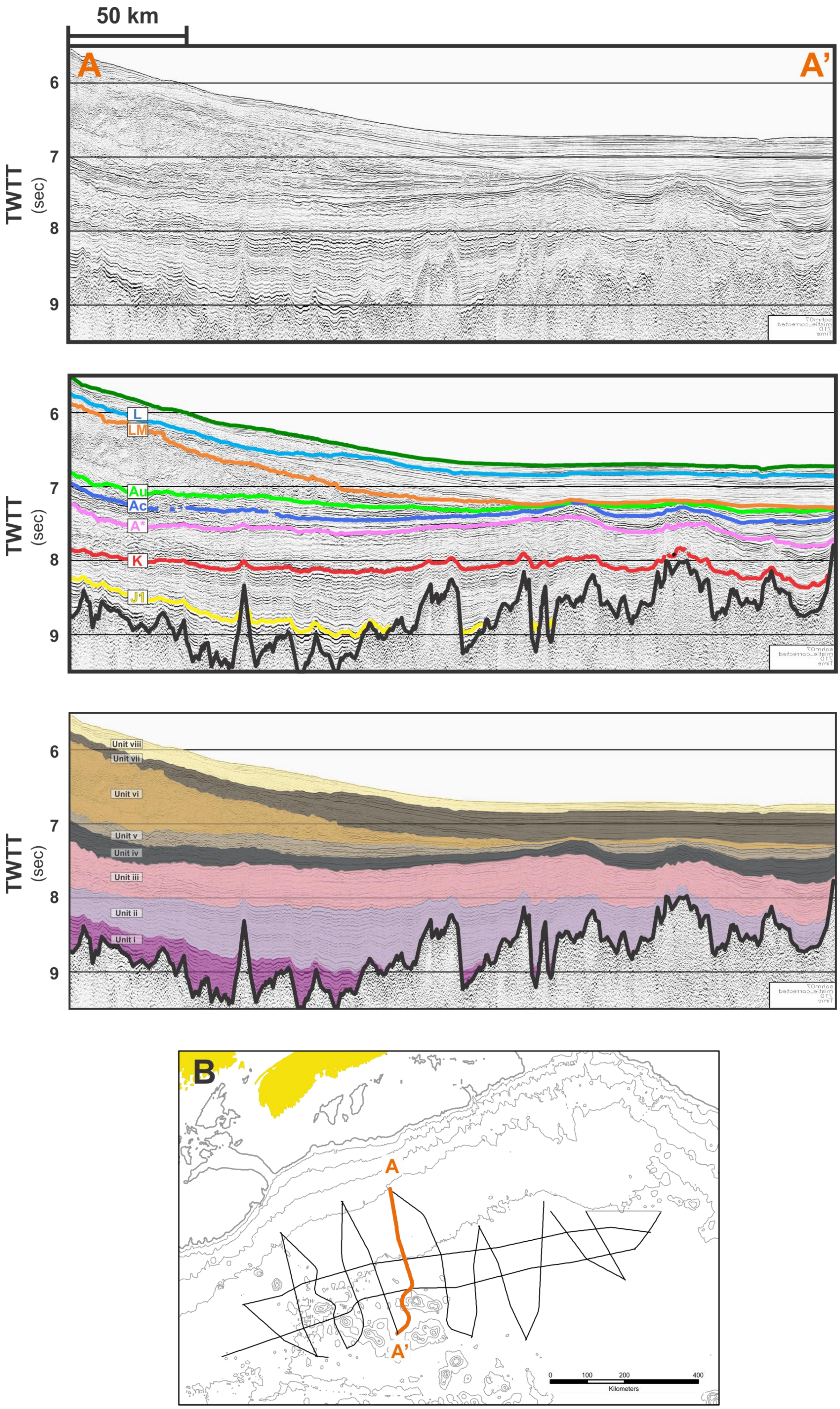

***Fig. A - 10**: Multichannel seismic reflection lines GSC0710. Location for the line is shown in (B).*

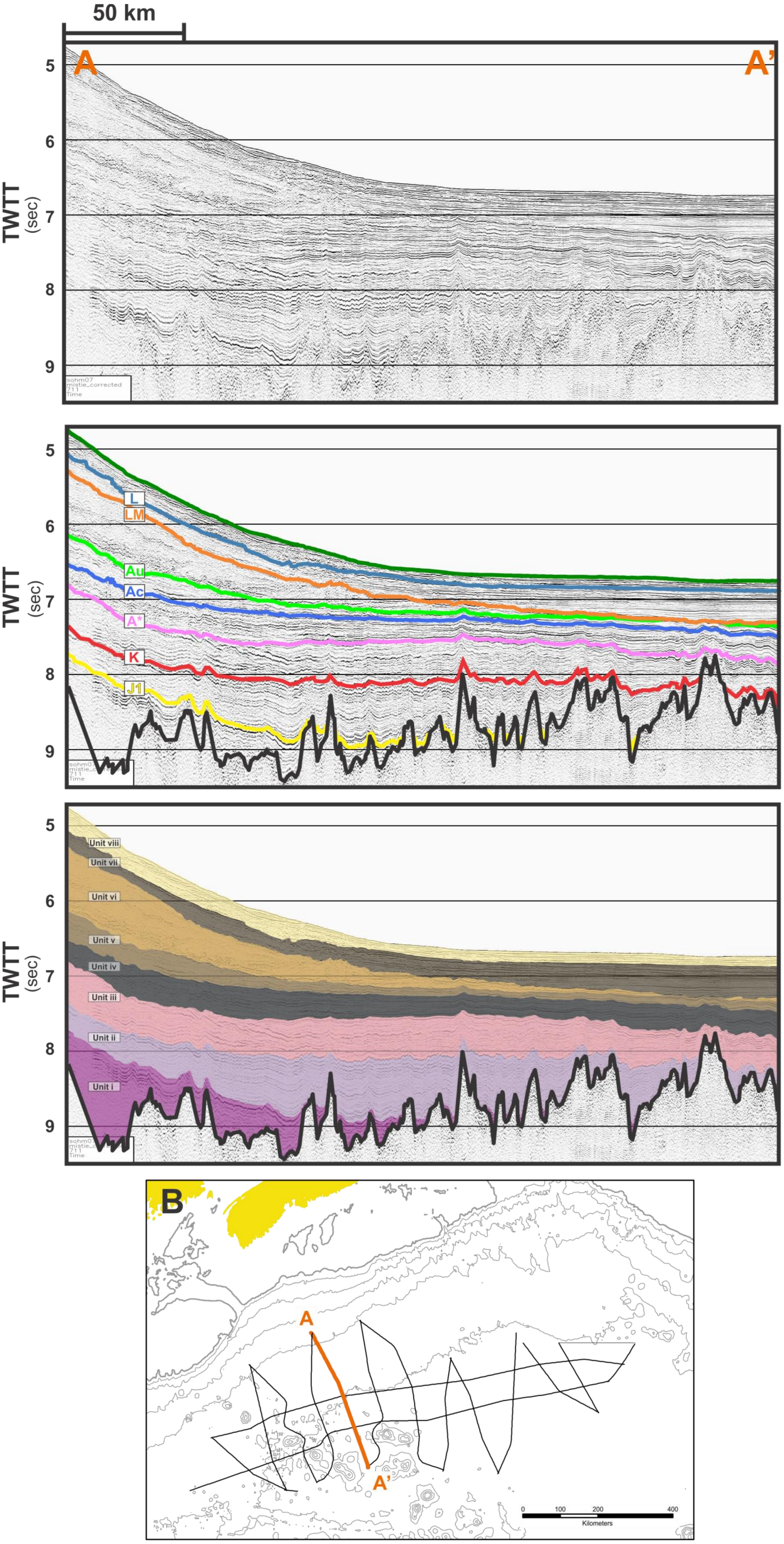

***Fig. A - 11**: Multichannel seismic reflection lines GSC0711. Location for the line is shown in (B).*

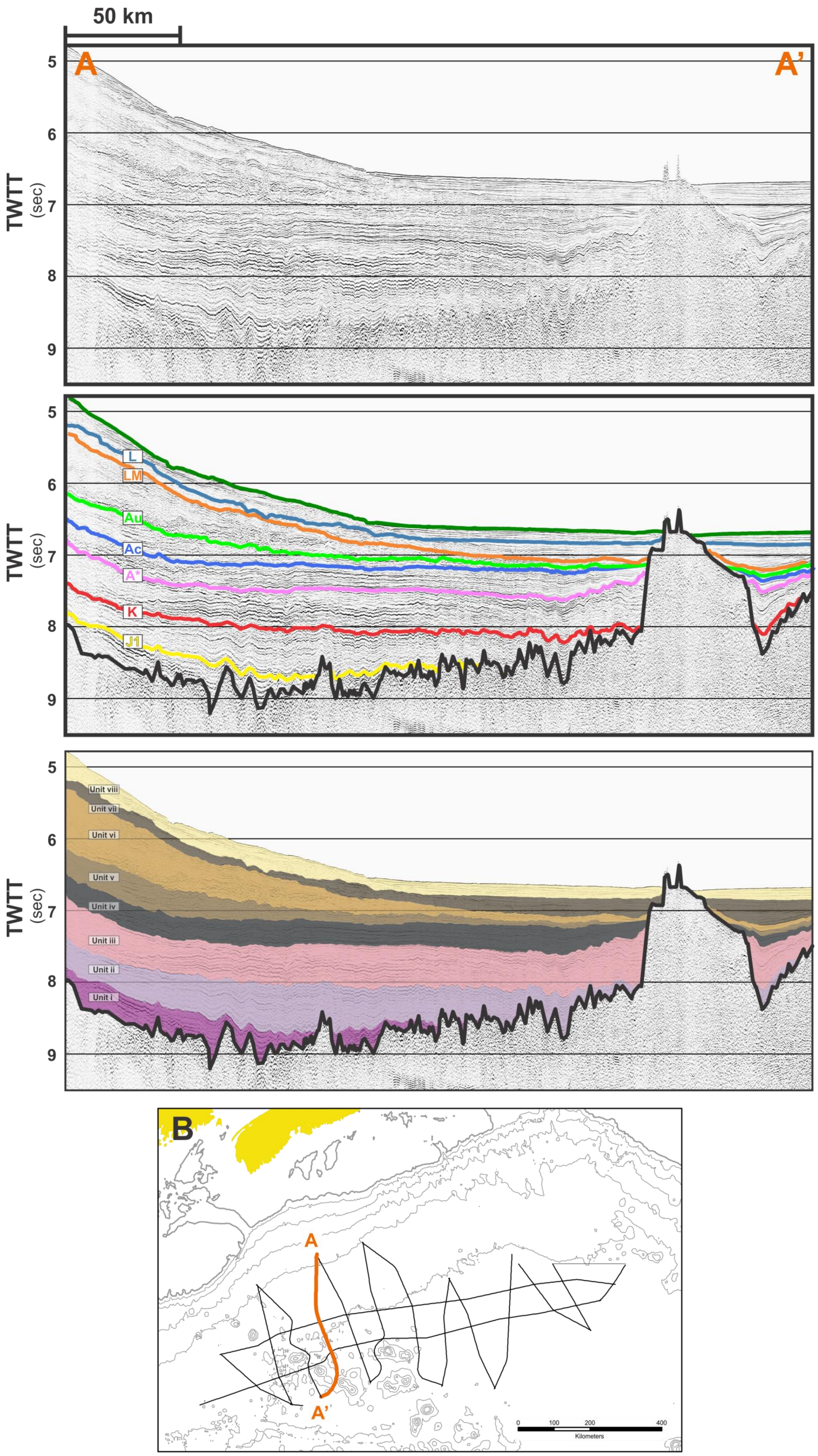

Fig. A - 12*: Multichannel seismic reflection lines GSC0712. Location for the line is shown in (B).*

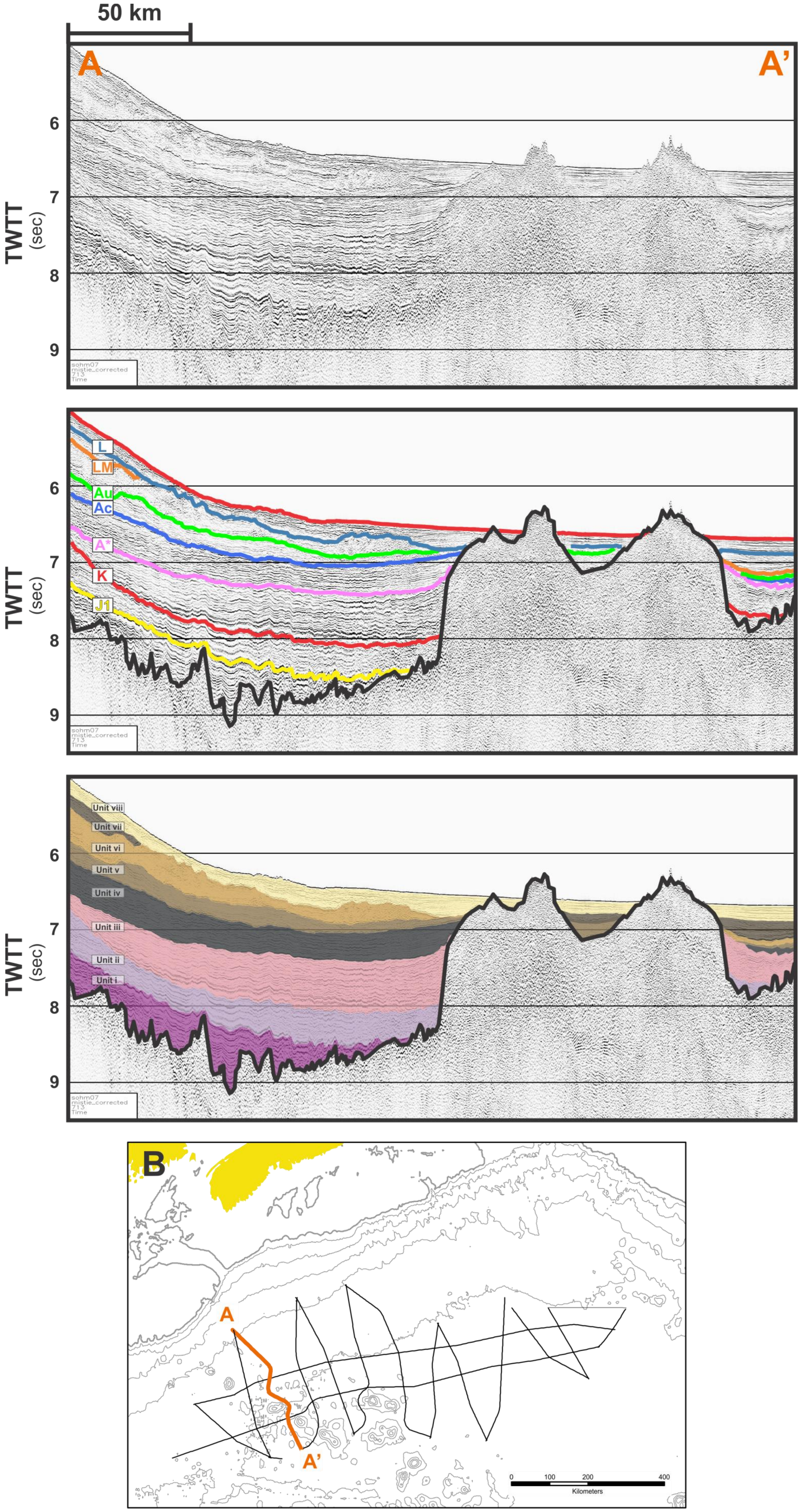

***Fig. A - 13**: Multichannel seismic reflection lines GSC0713. Location for the line is shown in (B).*

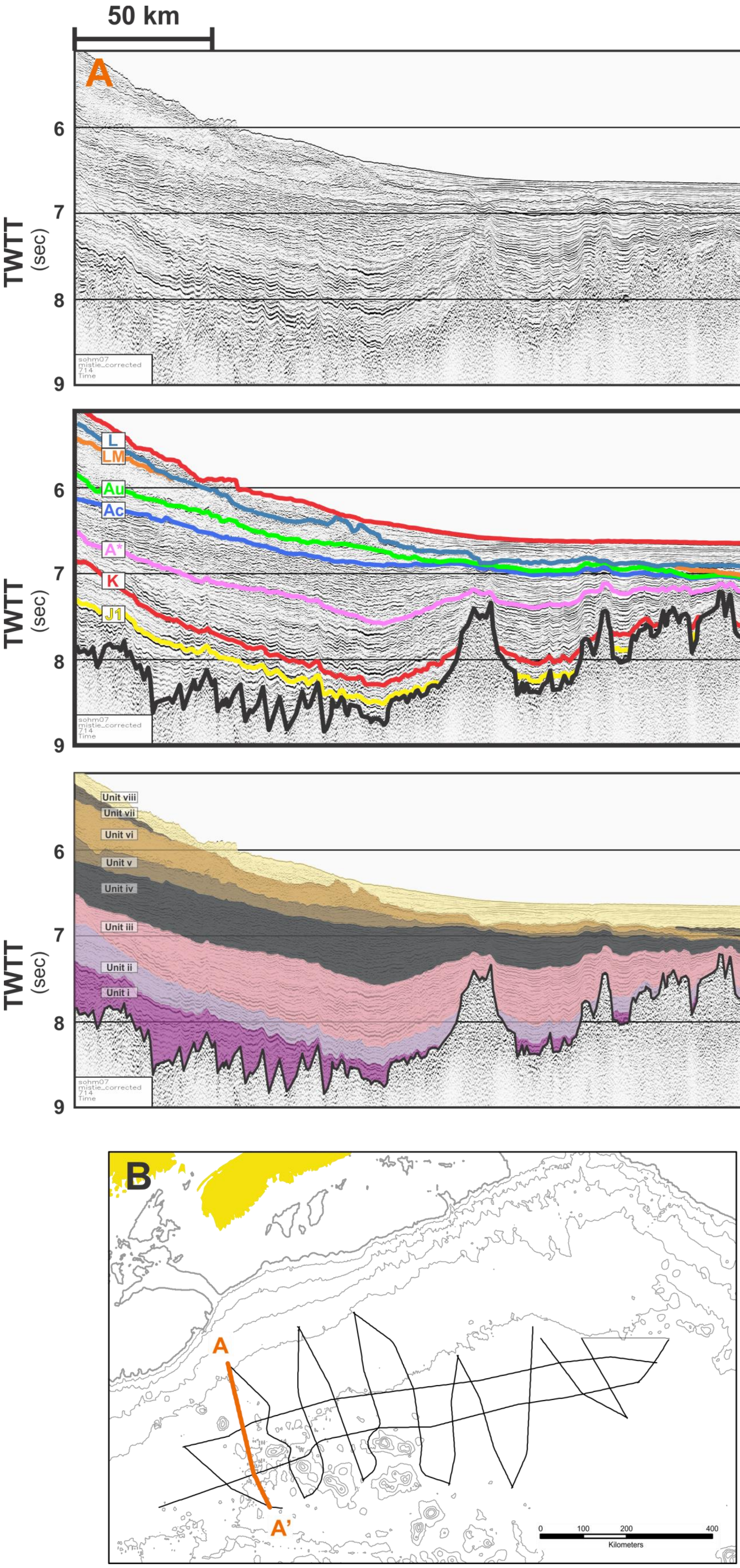

***Fig. A - 14**: Multichannel seismic reflection lines GSC0714. Location for the line is shown in (B).*

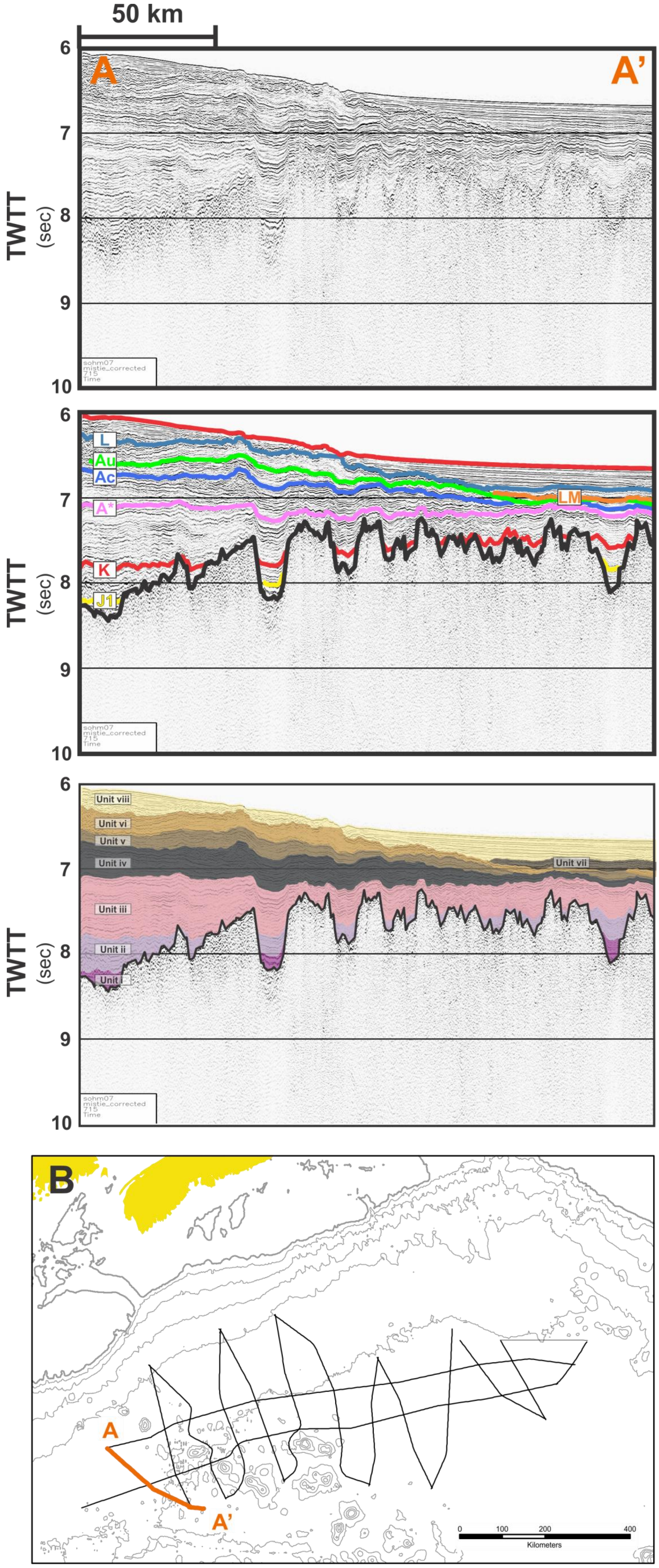

Fig. A - 15: *Multichannel seismic reflection lines GSC0715. Location for the line is shown in (B).*

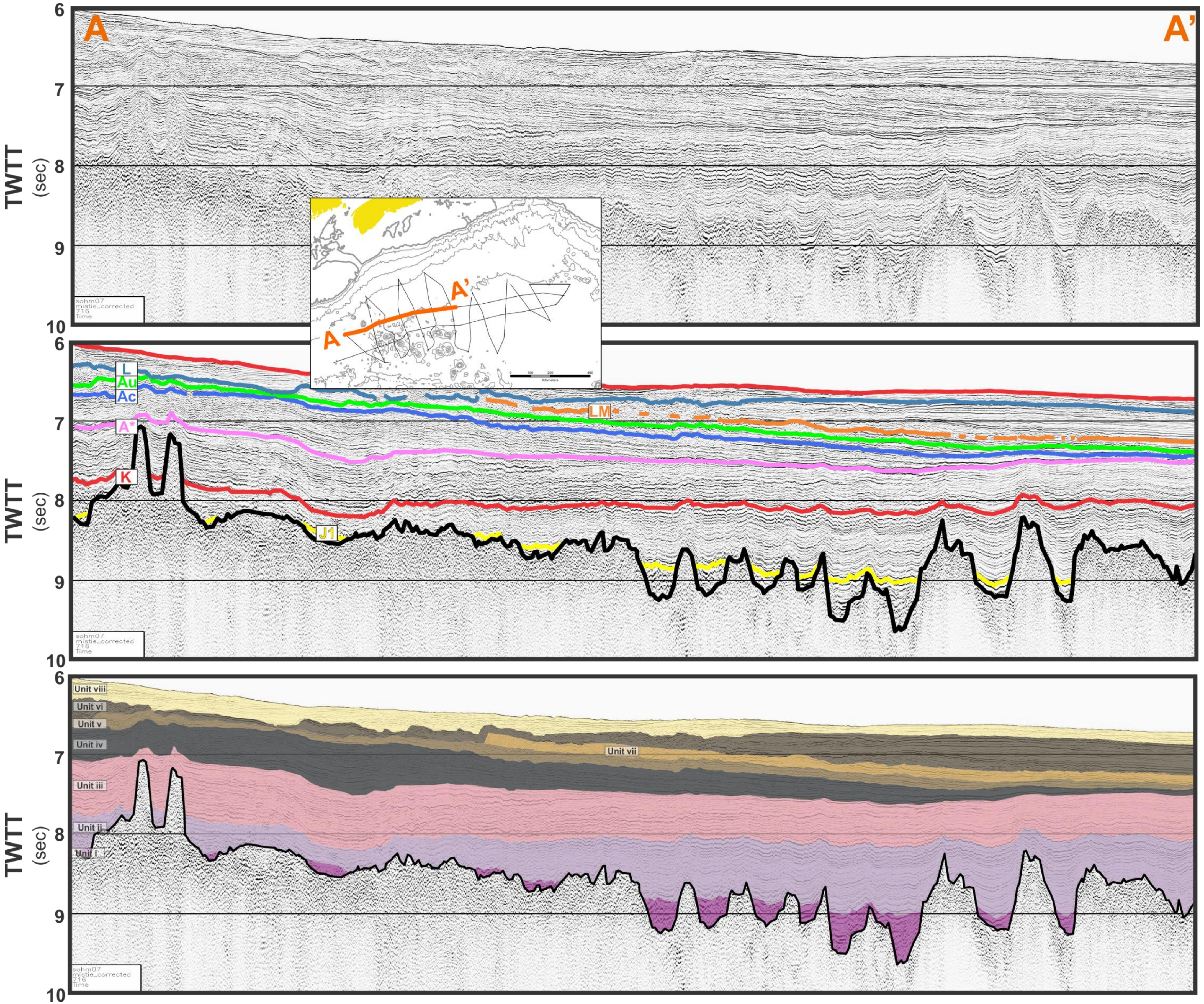

***Fig. A - 16**: The western portion of GSC07 Line 16 (location of profile shown in inset map)*

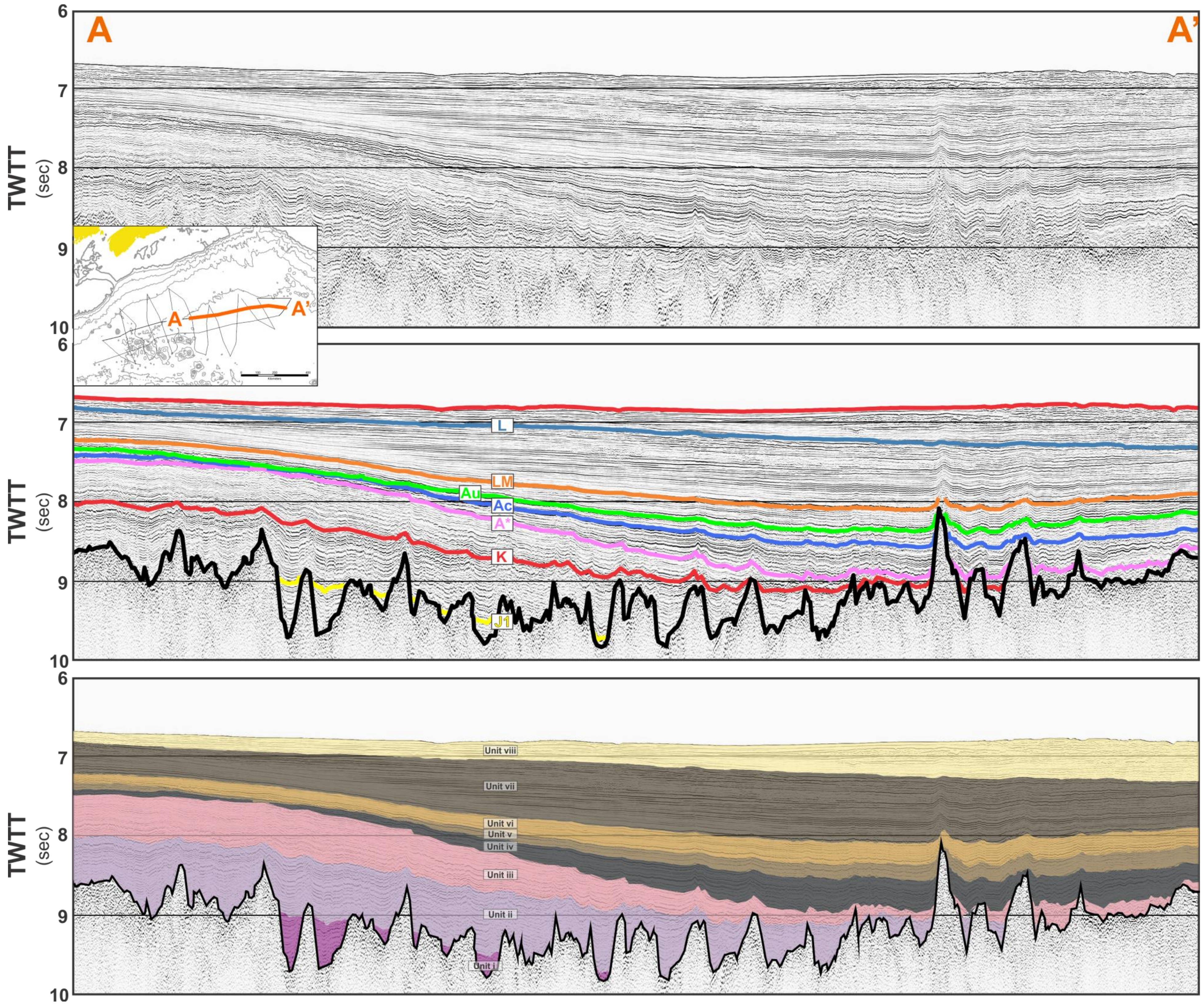

Fig. A - 17: The eastern portion of GSC07 Line 16 (location of profile shown in inset map).