Deepwater Taranaki Basin, New Zealand - New Interpretation and Modelling Results for Large Scale Neogene Channel and Fan Systems: Implications for Hydrocarbon Prospectivity*

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Abstract

The deep-water Taranaki Basin, located off the north west coast of New Zealand, is an underexplored, frontier area with one recent exploration well and limited 2D seismic coverage. The basin developed through multiple tectonic cycles, including Mesozoic rifting, followed by Late Cretaceous and Paleogene subsidence associated with seafloor spreading in the Tasman Sea. Large-scale Neogene channel systems that developed throughout the basin provided transport of significant volumes of sediment into the deeper water areas. The channel systems confirm that large fan complexes are likely to be present, however, poorly understood due to the limited extent of 2D seismic coverage. New regional interpretation has been carried out to improve understanding of key stratigraphic sequences, structural elements and basin evolution, providing new insights into the prospectivity of this underexplored region. A key focus of this interpretation was to enhance understanding of the distribution and configuration of the channel systems, providing new insights into prospective potential outboard of the shelfal areas which have been the focus for exploration drilling to date. A significant amount of public domain seismic and well data, primarily covering the shallow water shelfal areas, provided the basis for interpretation in this study. The study was undertaken with an integrated approach, utilizing all available well and seismic data, combining sequence stratigraphy to identify and map key sequence boundaries, seismic reservoir characterization to produce rock property and lithological probability for key seismic lines, and a comprehensive review of previous studies carried out in the area. In addition to new regional interpretation, the study provides detailed mapping of the large Neogene channel systems and encouraging evidence for associated large-scale depositional features beyond the extent of previous exploration.

Introduction

Large-scale channel-turbidite systems developed within the Taranaki Basin throughout the Neogene, contributing significant volumes of sediment into the deep-water area to the north-west of the New Zealand land mass (Uruski, 2006). Significant uplift and climate-driven erosion throughout the Miocene, led to the development of a major submarine channel system, which transported large volumes of sediment from onshore areas into the Taranaki and New Caledonia basins. Several major sea-channels exist on the present day seafloor of offshore New Zealand, which provide directly observable, modern day analogues for these depositional systems. Sediments derived from the New Zealand landmass currently contribute 1% of the entire sedimentary input into the world's ocean basins, demonstrating the scale of sedimentary transport from these sub-marine channel systems (Carter et al., 1996).

Project overview

The project area covers approximately 250,000 km^2 of the largely underexplored Taranaki, deep-water Taranaki, Northland and Reinga basins, located off the northwest coast of New Zealand (Figure 1). All publicly available well and seismic data was utilised with an integrated methodology, leveraging several key disciplines including seismic interpretation, sequence stratigraphy, biostratigraphic and sedimentological analysis, core analysis and seismic reservoir characterization. The dataset includes over 260,000 km of 2D seismic data for the Taranaki, Deepwater Taranaki and Reinga basins. Fifteen study wells were available from the Taranaki Basin margin and Northland Basin, of which five had cores or sidewall cores available for petrographic analysis.

Prominent sequence boundaries were identified though a comprehensive review of available seismic data and tied to biostratigraphic results to identify ages. Seven regional surfaces were mapped; Basement, Top Cretaceous, Top Paleocene, Top Eocene, Top Miocene, Intra Pliocene and Sea floor. A seismic reservoir characterisation exercise was performed to provide qualitative insights into reservoir quality within the deeper basin.

Project objectives

The key objective of the study was to provide insights into the prospective potential of Cretaceous to Miocene sediments of the Reinga, Northland and Deep-water Taranaki basins. Inversion volumes were produced to aid interpretation and provide predictive rock and fluid distributions to better constrain subsurface reservoir models. A key focus of the seismic interpretation was to identify and map key depositional features, including basin floor fans, turbidites and submarine channel complexes. Large-scale, Late Miocene channels and associated depositional elements were identified throughout the Taranaki Basin, confirming that significant volumes of sediment were transported into the deeper areas beyond the extent of available data. The Late Miocene channel system identified and mapped within the Taranaki, Deepwater Taranaki and New Caledonia basins, represents the key focus for this paper.

Regional Geological Setting

Basin overview

The Taranaki Basin is a Mesozoic rift basin, formed largely as a result of Late Cretaceous and Paleogene extension and subsidence, and subsequent compression associated with Neogene evolution of the modern plate boundary (Figure 2; Schellart et al., 2006). The offshore basin is located north-west of the New Zealand landmass, within the Zealandia continental block, which moved to the east of Australia with the opening of the Tasman Sea following subduction of the Pacific plate along the eastern Gondwana margin. The basin hosts up to 10km of Mid-Cretaceous to recent sedimentary section, primarily offshore, covering an area of approximately 100,000 km^2 (Stagpoole et al., 2001). Sediments were deposited during a marine transgression from the Late Cretaceous to the Early Miocene followed by a regressive phase that continues to the present day. The Taranaki Basin is bounded to the west by the Challenger Plateau and to the north and north-west by the Northland and New Caledonia basins. The major east-dipping reverse fault, known as the Taranaki Fault, represents the eastern margin of the Taranaki Basin (King et al., 1996).

The basin architecture is characterised by several structural elements that formed during multiple phases of tectonic development (Figure 3). The Eastern Mobile Belt comprises several sub-divisions including the Northern and Central Grabens, which are regions of extension, and the Southern Tarata Thrust and Southern Inversion Zones, which developed during the Neogene compressive phase (King et al., 1996). The Western Stable Platform hosts several Cretaceous to Paleocene rift grabens that formed during Late Cretaceous to Early Eocene extensional tectonic phases (Pilaar et al., 1984).

Tectono-stratigraphy

From the Late Triassic to Early Cretaceous the Murihiku Supergroup was deposited contemporaneous with subduction of the Pacific plate along the eastern Gondwana margin. Sediments of the Murihiku Supergroup, comprising primarily volcanoclastics, were deposited in a fore-arc basin, which formed within the eastern Gondwana plate margin (Bache et al., 2013). In general, rocks older than 100Ma are considered part of geological basement within the Zealandia continental block. Subsequent tectonic development occurred from the Early to Late Cretaceous with the initiation of Gondwana breakup and subsequent onset of rifting associated with the opening of the Tasman Sea, which continued through to the Early Eocene.

During the Early Cretaceous, a depositional hiatus occurred over much of the area because of widespread uplift and subaerial erosion associated with the transition from the convergent Gondwana margin to the extensional phase with the opening of the Tasman Sea. This was coeval with development of the Taranaki Delta, which deposited the coal-rich Taniwha and Rakopi formations, which represent the main source rocks within the Taranaki Basin (Uruski et al., 2003). Subsequent deposition of the Paleocene to Oligocene Kapuni Group occurred, comprising the Mckee, Mangahewa, Turi, Kaimiro and Farewell Formations (Figure 4). Opening of the Tasman Sea and associated rifting continued to the Late-Early Eocene, contemporaneous with deposition of the Ngatoro Group, which comprises the Otoraoa, Tikorangi and Taimana Formations (Bache et al., 2013).

Onset of subduction along the Tonga-Kermadec arc during the Eocene initiated the phase of inversion and uplift, which continues to the present day, markedly changing the structural configuration of the basin (Bache et al., 2013). During this time, the Miocene Wai-ti Group was deposited comprising the Manganui, Moki, Mohakatino, Mt. Messenger and Urenui formations (Figure 4). This was followed by deposition of the Pliocene to Pleistocene Rokatore Group sediments, which comprise the Ariki and Giant Foresets formations.

An Eocene-Oligocene unconformity and an Early Cretaceous unconformity associated with the transition from Gondwana subduction to extension are the two main erosional surfaces identified within the basin (Bache et al., 2013).

Petroleum systems

Source rocks within the Taranaki Basin include coal-rich facies deposited from the Cretaceous to the Paleogene in shallow to non-marine environments. Additional source rocks include marine shales deposited in the Early Cretaceous and Paleocene (Strogen et al., 2012). Throughout the Late Cretaceous, cyclical deposition of reservoir quality sandstones within the Rakopi Formation coal units took place. These were likely derived from the granitic Challenger Plateau and Taranki shelfal areas (Uruski et al., 2002). Shelfal sands and sea floor fans of the Late Cretaceous North Cape Formation also represent reservoir targets within the Taranaki Basin, as well as Paleocene to Eocene Kapuni Group sands and Miocene turbidite deposits (Uruski et al., 2002, 2003). Eocene to Oligocene Kaimiro and Mangahewa Formations are potential source rocks, primarily within onshore areas (Figure 4).

Widespread deposition of marine mudstones provides effective seals for clastic reservoir sandstones throughout the Taranaki Basin. These include the Cretaceous to Eocene Turi Formation and the Miocene Manganui Formation. The Oligocene to Miocene Tikorangi Formation carbonates also provide an effective seal in the absence of pervasive fracturing (King et al., 1996). Structural traps constitute the primary trapping mechanism associated with most discoveries within the Taranaki Basin. These include inversion structures and normal fault blocks formed throughout the Neogene, coinciding with peak maturation and expulsion of hydrocarbons (King et al, 1996). The critical moment for hydrocarbon expulsion within the Taranaki Basin occurred at approximately 7 ma (Sarma et al., 2014).

Taranaki - Neogene Channel System

Outline

The channel system that represents the key focus for this paper is located in the offshore area to the west of the present day New Zealand landmass, comprising the Taranaki, Deepwater Taranaki and New Caledonia basins (Figure 5). Using available 2D seismic data, the depositional limits of the channel system can be mapped from the Late Miocene paleo-shelf edge, through the Deepwater Taranaki Basin, and into the southern margin of the New Caledonia Basin, to a distance of approximately 880km from the present day coastline. The exact limit of the main sea-channel is unknown given the limitations of data coverage over the deep-water areas. Some 3D coverage of the feeder canyons and tributary channel systems exists in the shallower areas.

Channel forming processes

Discharge of river sediments at the shelf edge is controlled by sediment gravity flows, which transfer sediments to tributary channel systems, which develop into distributary systems and fan complexes in deep-water areas (Babonneau et al., 2010). Several key factors are important in understanding the modes of formation and evolution of submarine channel / fan systems. The most critical factor is considered sediment supply variation over time, primarily influenced by fluctuations in sea level and variation in the rate of sediment supply and source provenance (Broucke et al., 2003). Deep-water channels can exhibit very similar features and modes of formation to fluvial channels. These similarities, which have been well documented by Kolla et al., 2007, include point-bar deposits on the inner bends of meander loops, high sinuosities, avulsions and meander cutoffs.

The degree of sinuosity of channels in deep-water settings is controlled by several key factors, primarily, slope gradients and seafloor topography, sediment flow parameters (velocity, density, and sediment source fluctuations), grain-size, effects of sea-level variation and initial channel morphology (Kolla et al., 2007). Highly sinuous sections of channel often develop with laterally migrating terraced fill, very similar to point-bar deposits within the inner meander loop of meandering fluvial systems (Babonneau et al., 2010). These stepped terraces indicate lateral migration towards the outer channel bank producing higher sinuosity (Kolla et al., 2007). Flow velocity of turbidity currents is controlled by parameters such as slope gradient, grain-size distribution and sand / mud ratio (Pratson et al., 2000). Flow velocities of seismically activated turbidity flows have been documented as they sever water bottom coaxial cables located some distance from each other along the ocean floor (Heezen et al., 1964).

Submarine channels are typically hosted within a large master channel valley with large master overbanks (Kolla et al., 2007). The secondary sinuous channel networks, within the master valley, can develop overbanks that overflow beyond the confines of the master system (Kolla et al., 2007). Overbank flows can develop asymmetrical levee banks due to the effect of the Coriolis force on ocean bottom currents. Channel asymmetry is therefore observed at higher latitudes with the channel flow deflected to the right hand side in the Northern Hemisphere, and the left hand side in the Southern Hemisphere (looking downstream) (Wahlin et al., 2011).

With adequate seismic resolution, significant variation of seismic amplitude character can be seen within the fill of many submarine channels, indicating intra-channel stratigraphy. A change from sand-prone lithologies in the deeply incised basal portion of the channel to mud prone lithology in the upper channel fill can commonly be identified with such variation in seismic reflector characteristics. Channel morphological parameters such as mounded, convex upward geometries (in cross-section) often associated with well-developed overbanks, are good indications of differential compaction due to the presence of both sand and mud within the channel. Understanding the internal stratigraphic architecture of submarine channels is critical in evaluating reservoir and hydrocarbon trapping potential. In some cases, post-depositional remobilization and injection can occur within channels, significantly modifying their primary internal geometry (Jackson, 2007). The conditions for this to occur are a combination of over-pressured, unlithified sands with high porosity and permeability, sealed within low permeability mudstones (Jackson, 2007).

Morphological parameters typically used to describe submarine channels include width of channel at crest of levee banks, width of thalweg, vertical channel thickness and sinuosity of channel axis (Babonneau, 2002).

Depositional setting - provenance

Onset of Pacific-Australian plate subduction in the Oligocene, at approximately 25Ma, led to a significant bathymetric deepening, and increased accommodation space over a large area, including the Western Stable Platform. Compression along the active margin led to development of a major thrust belt, which was uplifted above sea level by the Early Miocene, resulting in significant increase of sedimentation into the Taranaki Basin (Holt and Stern, 1994). The rate of uplift increased throughout the Miocene due to isostatic rebound of the plate as large volumes of material were removed by climate driven erosion, further increasing sedimentation rates. Deposition within the Taranaki Basin throughout the Miocene mainly consisted of thick mudstones (Manganui Formation), interbedded with sandstone units including the Moki, Mt. Messenger formations and intra-Manganui sandstones (Figure 4). Deposition of the Mt. Messenger Formation sands was contemporaneous with the onset of andesitic volcanism along the subduction arc (Kamp et al., 2004). Large volumes of Late Miocene sediments were transported along the basin axis as gravity flows via the large turbidite-channel complex, which incised into the Manganui Formation mudstones.

Depositional styles of sediments from the Late Cretaceous to the Eocene were dominated by a prolonged transgressive phase combined with tectonic subsidence, reaching maximum water depth in the Early Miocene (King et al., 1996). By the Middle Miocene, an ongoing regressive phase was initiated that continues to the present day, punctuated by relative low-stands where deep-water successions were deposited (King et al., 1996).

Taranaki Basin - Late Miocene channel system

The spatial configuration of the channel system reflects the interplay between ocean floor topography, basin architecture and regional tectonics. In general, the main channel flowed along the basin axis, which characterizes the present day sea floor topography. The basin morphology during the Late Miocene is therefore the dominant controlling factor of the axis of channel flow.

The system initiates at the shelf edge where sediments were transferred to tributary channels via large feeder canyons which incised into the Late Miocene shelf and slope (Figure 5). As the tributary channels reached lower slope to bathyal depths they coalesced to form the main channel trending north-west through the axis of the Deepwater Taranaki and New Caledonia basins. The tributary systems cover approximately 37,000 km^2 and represent the offshore continuation of Late Miocene onshore fluvial systems. A large, westward-draining fluvial system existed in the Late Miocene, which transported voluminous quantities of sediment across the paleo-shelf into the feeder canyon systems, which were then mobilised into the main channel system (Maier et al., 2013). Rivers with high concentrations of suspended sediments are commonly associated with active margins undergoing rapid uplift, which is representative of the Late Miocene depositional environment. The tributary system transitioned from lower slope to deep bathyal depth at approximately 130km from the present day coastline, where the entire system gradually changes direction to north-west, flowing around the flanks of the Aotea Seamount, a prominent bathymetric feature, trending ENE on the present day seafloor, which formed as a large fissure eruption, likely basaltic, during the Miocene (Davey, 1973). The feature is approximately 11km wide and 50km long and therefore would have had a profound influence on the channel system configuration as the distributary system flowed and deflected around its flanks (Figure 5).

The morphological parameters that define the channel geometries and scales are summarized as follows: tributary channel widths range from approximately 2-5 km with vertical channel thickness up to approximately 470m. The main distributary channel in the Deepwater Taranaki Basin is up to 8km wide with 360m vertical thickness. The channels exhibit variable sinuosity controlled primarily by slope gradients, topography and sediment flow parameters. The degree of sinuosity of the channels is illustrated spectacularly on seismic line ATB10-036 (Figure 8). The line was acquired directly along, and parallel with the channel axis of flow, which has the effect of imaging what appears to be multiple channels at the same stratigraphic level intersecting the line in a northeast direction. Close examination and mapping of the features reveal that this is a single channel, meandering ‘in and out’ of the line ATB10-036 with a north-west trending axis of flow.

The channels incise deeply into the host, marine mud dominated strata, well below the overbank levees, with distinct erosional bases. Distinct sheet-like, wing-shaped anomalies can be identified, particularly along the eastern-most major tributary channel, immediately to the east of line ATB10-036 (Figure 6, Figure 7, and Figure 9). The channel bifurcates in this area and appears to have exploited an older channel flow path, which can be seen to incise deeper into the host strata and develop large wing-shaped overbank flows before finally developing into two depositional lobes (Figure 10). These genetically related features may be of particular interest as potential reservoir sand deposits.

In many places, the channel fill can be divided into two distinct stratigraphic packages, which exhibit a distinct change in seismic character. It can be seen from Figure 6 and Figure 7 that the basal (confined) channel fill, is characterised by higher amplitude, coherent reflectors characteristic of sand-prone lithologies. The upper channel fill is unconfined with well-developed overbank flows, exhibiting lower amplitude, incoherent seismic character, consistent with mud-prone lithologies. The mounded, convex-upward geometry of the channels is a strong indication of differential compaction, which further supports the presence of both reservoir and sealing facies, making up the basal and upper channel fill respectively. Channels with significant sands making up the basal channel fill and finer grained overlying section typically exhibit this mounded geometry. The depositional processes that led to the distinct variation in upper and lower channel fill are primarily controlled by source provenance and sea level fluctuation. Higher energy flows of coarser, sandier deposits typically occur in the early stage of canyon evolution, followed by lower-density, fine-grained sediments comprising the upper channel. Lateral channel migration features (terraced fill) can be observed within the master channels as illustrated on Figure 10.

Within the limitations of available 2D data, the main distributary channel can be mapped to a distance of approximately 880km from the present day coastline, into the head of the New Caledonia Basin. Based on observations of the channel scale, basin-ward distance from the Late Miocene shelf, and similarities with modern day analogs, it can be inferred that a large, likely mud-dominated turbidite fan complex was deposited within the New Caledonia Basin as the channel emerged on to the lower basin plain. The morphology of the fan complex would have been largely controlled by ocean bottom currents at the time of deposition. Several examples of seismic anomalies indicative of vertical gas/fluid migration can be seen emanating from the top of the channels particularly in the main tributary system to the east where the channels overlie deep-seated, Cretaceous faults (Figure 11 and Figure 12). Localised water bottom pockmarks distributed along the ocean floor immediately above the anomalies, strongly support the presence of vertical fluid/gas migration. Gay et al. (2006), proposed a dynamic model for such vertical migration, which is strongly consistent with observations made on seismic data for the Taranaki channels (Figure 13). The proposed model suggests that as submarine channels are buried within shallow depths, pore fluids are expelled which migrate vertically producing belts of pockmarks along the newly deposited sea floor. With further deposition of overlying strata, the pockmarks are buried, resulting in a stacked vertical succession of sealed pockmarks. At a later stage, as the channels are buried to sufficient depth, vertical migration of thermogenic oils and gases into the channel fill can exploit the vertical pathways overlying the channels, resulting in expulsion at the seafloor with associated pockmark features. Further investigation utilizing oil slick data and geochemical analysis would be greatly beneficial in identifying thermogenic-derived hydrocarbons at these sites.

Modern Analogues

Examples of submarine channels have been well documented within the world's present-day ocean basins, transporting large volumes of sediment from continental landmasses to basin floor plains through gravity flow processes. Several examples exist within the present-day offshore basins of New Zealand with remarkably similar configurations and depositional features to the Late Miocene system. These modern day channel-turbidite complexes provide excellent analogues for the Late Miocene system, whereby direct observations can be made of the interplay between channel evolution and depositional environment. The effects of sedimentary flow parameters, provenance, climate, tectonics and sea floor morphology can be understood in greater detail by observing these modern day systems. Numerous studies have been undertaken of modern systems using high-resolution bathymetry, reflection seismic profiling and core sampling to enhance understanding of submarine channel evolution and architecture.

The Hikurangi Channel is an active system fed by turbidity sediment flows derived from canyons along the narrow shelf of the Cook Strait on the east coast of New Zealand (Figure 14; Lewis et al., 2013). Sediments are transported along the main channel, which follows the axis of the Hikurangi Trough approximately 2000km into the deeper basin, whereupon they emerge onto the basin floor as a large, mud-dominated fan. The fan morphology is heavily influenced by a significant ocean current to the east of New Zealand known as the Ocean Conveyor, which diverts the sediment fan a considerable distance to the north-west (Lewis et al., 2013). Typically, channels of this length correspond to passive margin depositional settings. However, by contrast, the channels to the east of New Zealand currently transport sediments a great distance across an active margin setting.

The Bounty sea-channel occupies and traverses the axis of a failed rift known as the Bounty Trough, oriented east-west from the east coast of New Zealand's South Island (Figure 15; Neil et al., 2015). Sediments derived from the Southern Alps are transported across the Otago shelf into feeder canyons and tributary systems of the Otago fan complex. The Otago complex bears remarkable similarity to the Late Miocene channels that developed within the Taranaki Basin. Cyclicity of sediment transport into the Bounty sea-channel is controlled primarily by eustatic sea-level fluctuation (Neil et al., 2015). The Bounty sea channel exhibits asymmetrical geometry in cross-section because of the Coriolis force influencing ocean bottom currents.

Petroleum potential

Deepwater depositional systems such as the Late Miocene channels described herein are known to transport coarse-grained, terrigenous derived sediments into deep water, even bathyal and abyssal environments. The scarcity of well-developed, coarse-grained sediments in these environments makes these channel/fan systems of particular interest in deep-water exploration as potential hydrocarbon bearing reservoirs. The internal architectures of submarine channels are known to have constructional and erosional features comparable with fluvial systems. Understanding the depositional and post-depositional processes is critical in evaluating internal geometries and architecture of these channel systems and their genetically related features.

The Late Miocene channels discussed herein exhibit internal seismic character and basal erosional characteristics consistent with coarse-grained, high-density flows within the lower portion of the channels. The seismic character of the upper channel fill is consistent with that of fine-grained, muddy sediments with well- developed overbank flows. The mounded, convex upward geometry of the channels strongly indicates differential compaction, further supporting the presence of significant coarse-grained, reservoir quality sands overlain by potential sealing facies upper fill. Genetically related features such as overbank flows and fans, as evidenced by seismic data, represent additional potential reservoir deposits within the Deepwater Taranaki Basin. Internal features include terraced, laterally migrated fill characteristic of meandering submarine and fluvial systems, indicating the presence of inner loop point bar deposits at the later stages of channel maturity. Stacked successions of sealed pockmarks above the channels in combination with overlying water bottom pockmarks strongly indicates vertical migration of fluids or gas into the channel fill from underlying deep-seated faults.

Further work needs to be undertaken, specifically seep analysis and ocean bottom sampling, to confirm the presence of thermogenic hydrocarbons. Future acquisition and analysis of high quality seismic data would be highly beneficial in confirming the presence of effective sealing units where channels are in fluid connection with vertical migration pathways. The timing of formation and subsequent burial of the channels is favorable to hydrocarbon charge where source rocks are present and at sufficient depth, as maturity and expulsion has been taking place from the Late Cretaceous to the present-day.

Conclusions

The Late Miocene channel turbidite system within the Taranaki, Deep-water Taranaki and New Caledonia basins is remarkably similar to modern day systems depositing large volumes terrigenous derived sediments into the present- day offshore basins of New Zealand. Large-scale uplift and climate driven erosion gave rise to transport of significant volumes of sediment, discharged at the shelf edge via gravity flows throughout most of the Miocene. The Taranaki channel system exhibits the same geospatial characteristics and internal features as onshore fluvial systems, including high degree of sinuosity, lateral migrations, point bars and overbank flows.

The internal seismic stratigraphy within the channels is consistent with significant, coarse-grained sandy basal fill and fine grained, muddy upper fill. The channels exhibit mounded, convex upward channel geometries, indicating differential compaction resulting from the presence of both reservoir and sealing facies. Genetically related features such as overbank flows and fans, as evidenced by seismic data, represent additional potential reservoir deposits within the Deepwater Taranaki Basin.

Strong indications of vertical fluid migration are present where channels overly deep-seated faults likely connected to thermally mature source rocks. The presence of seafloor pockmarks in combination with seismically evidenced vertical pathways connecting the channels to the seafloor strongly supports the occurrence of vertical fluid/gas migration. Further acquisition and analysis of high quality seismic data would critical in confirming the presence of effective sealing units where channels are in fluid connection with vertical migration pathways. Seep analysis and ocean bottom sampling would be highly beneficial to confirm the presence of thermogenic hydrocarbons.

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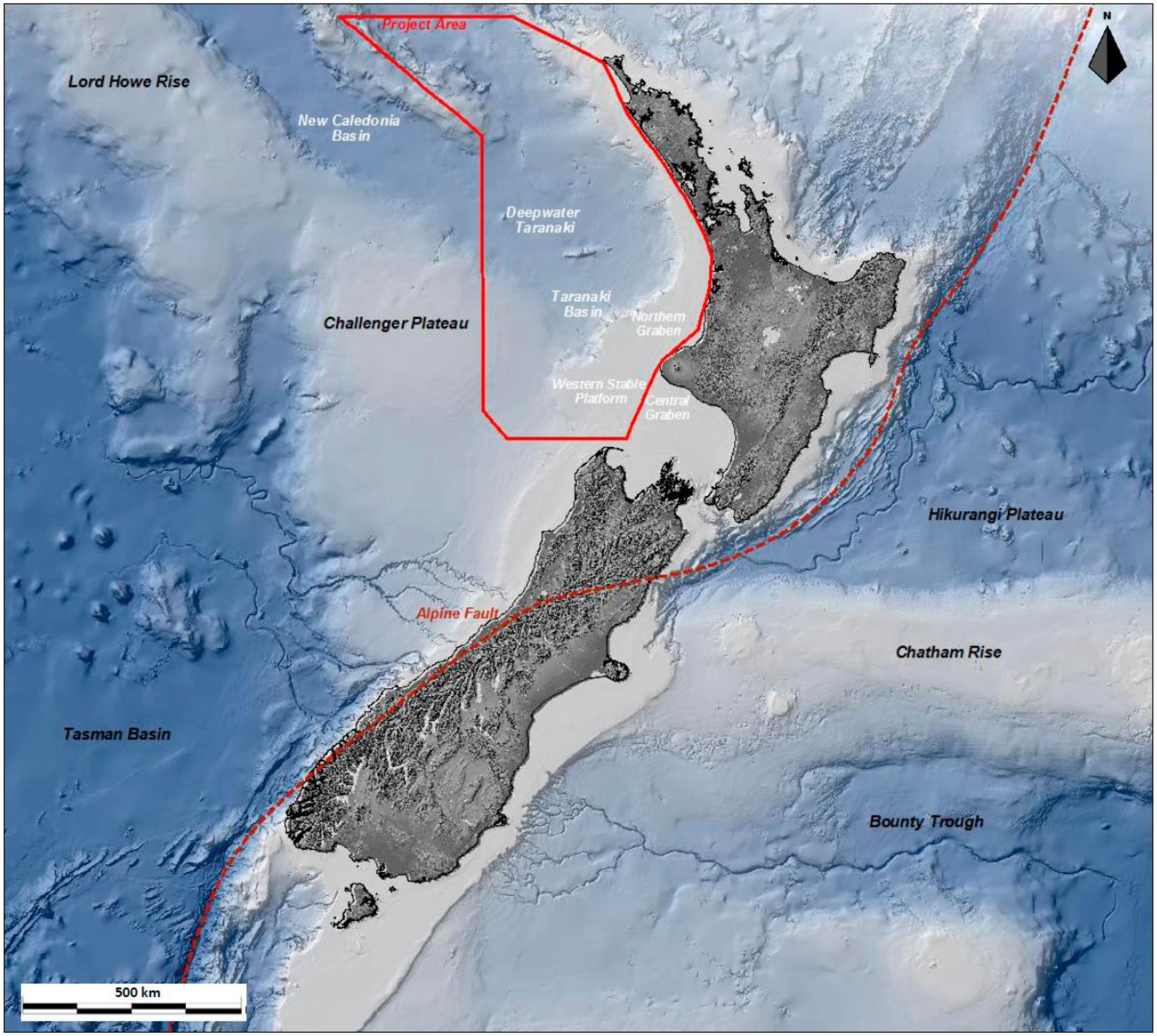

Figure 1. Study Area

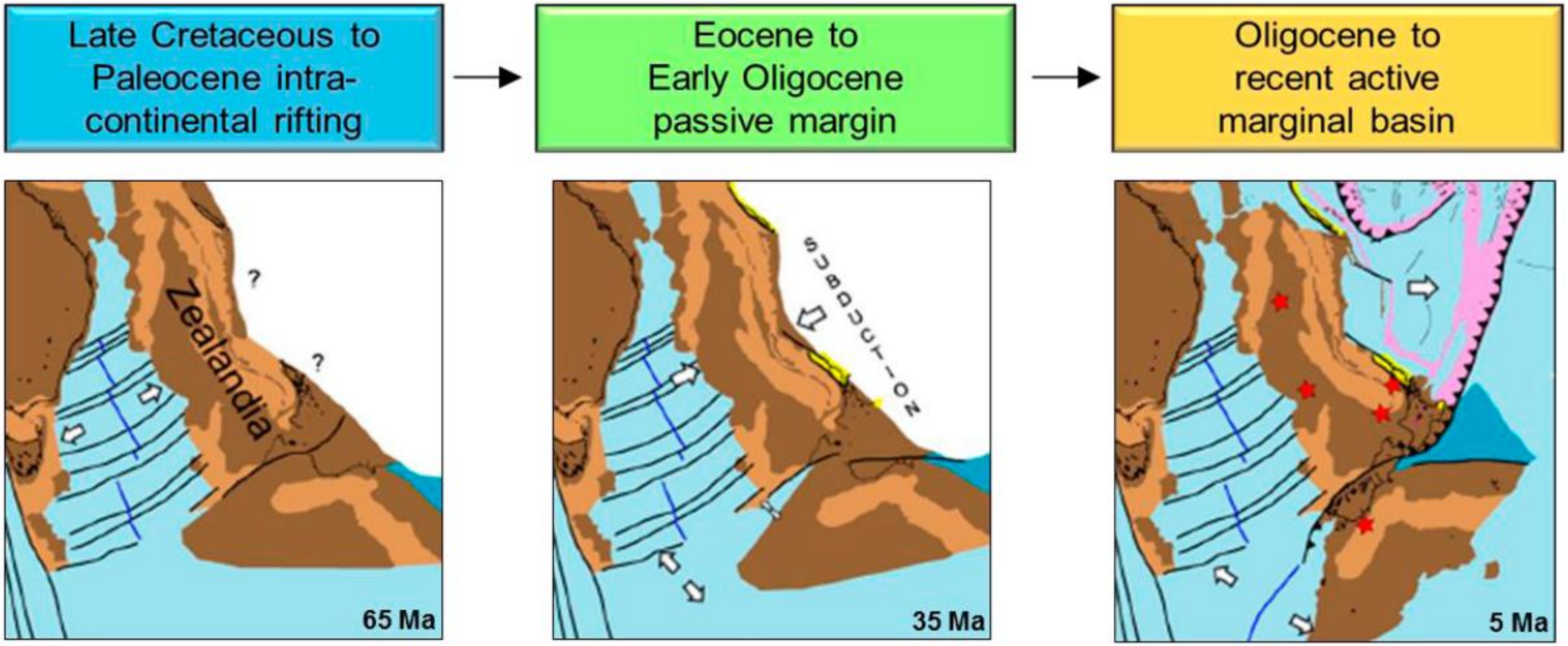

Figure 2. Tectonic development

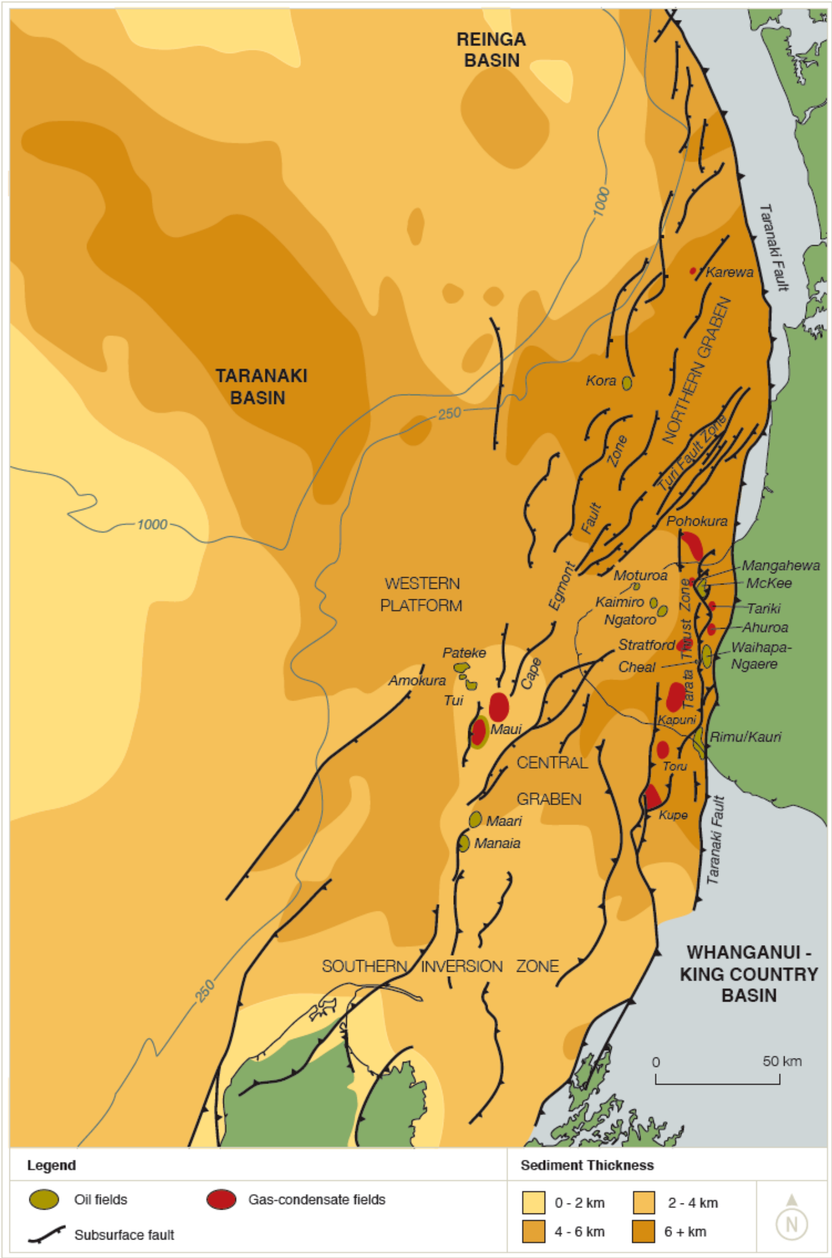

Figure 3. Taranaki Basin – tectonic elements

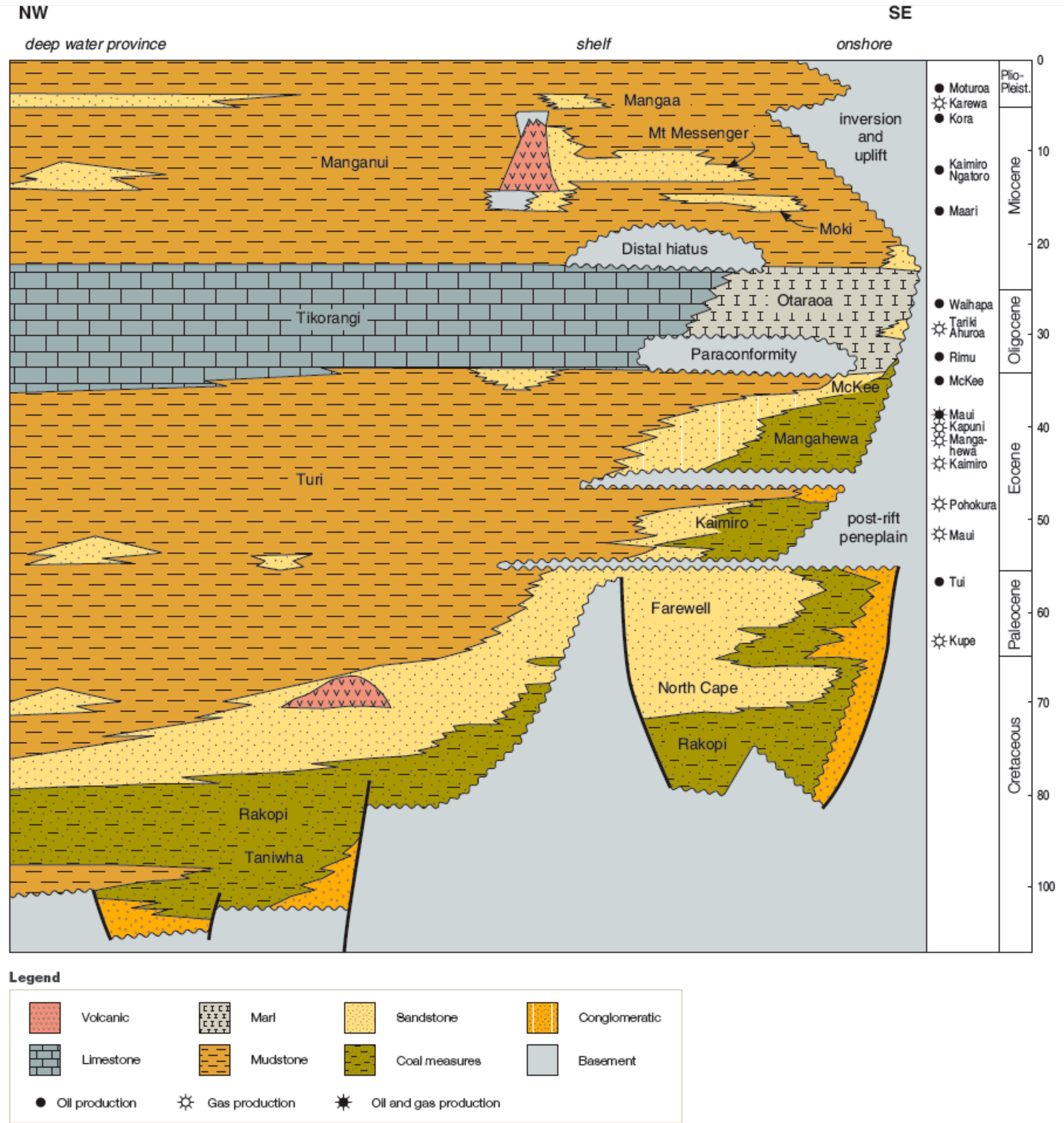

Figure 4. Taranaki Basin stratigraphy

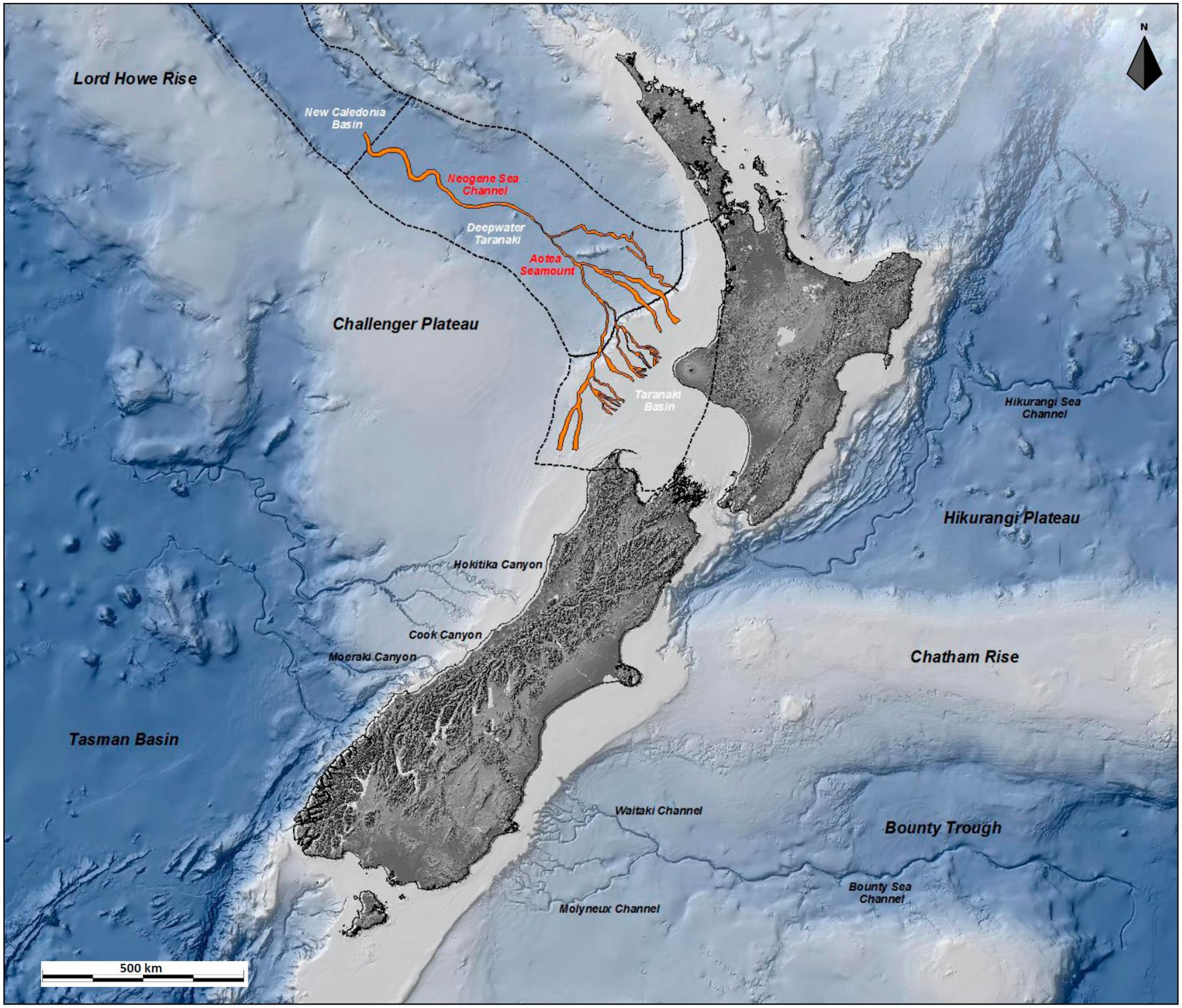

Figure 5. Bathymetric image of New Zealand region with Neogene channel system discussed in this paper (orange) illustrated, together with other present day channel systems

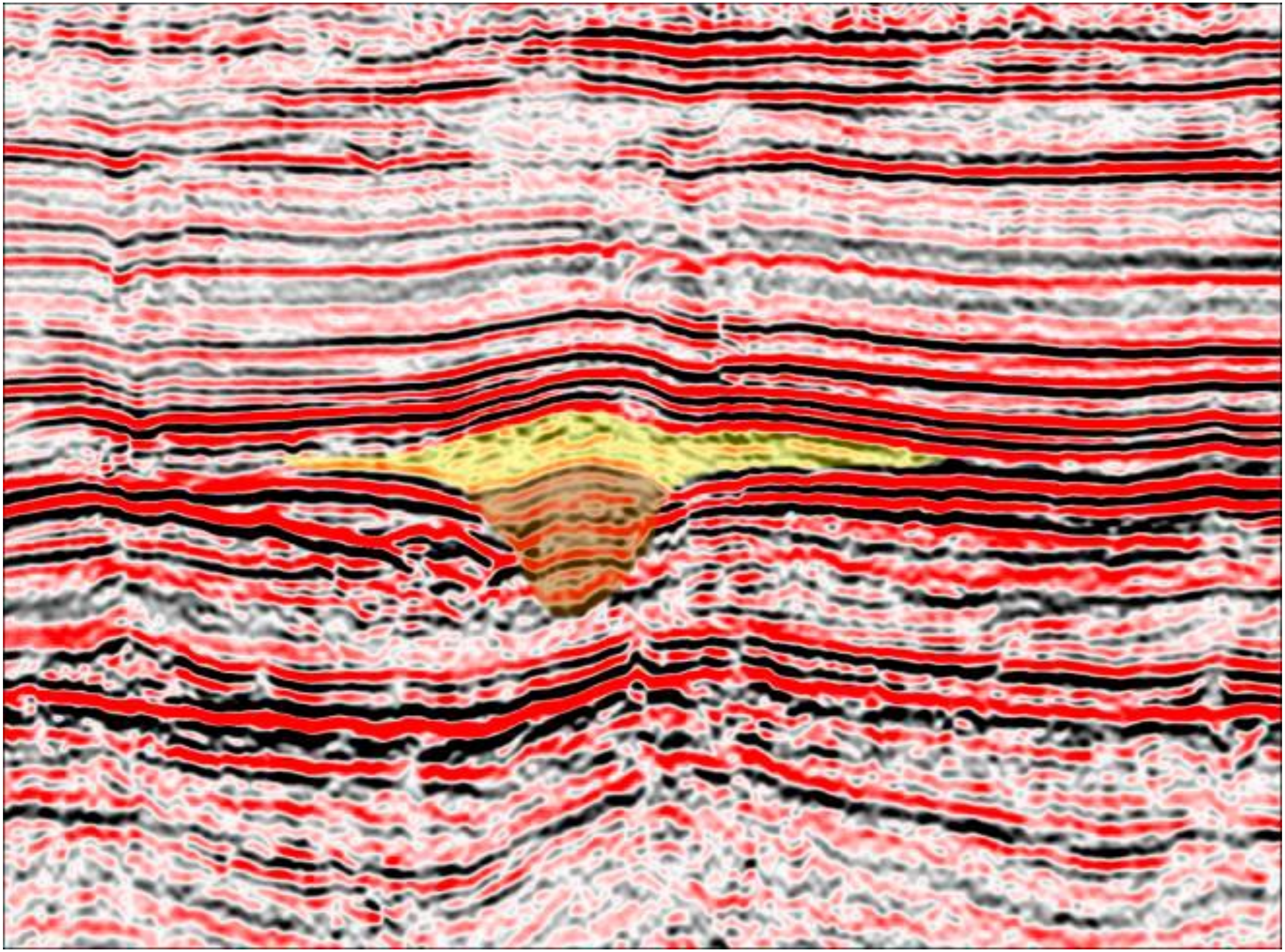

Figure 6. Channel wing-shaped overbank flow – eastern tributary channel

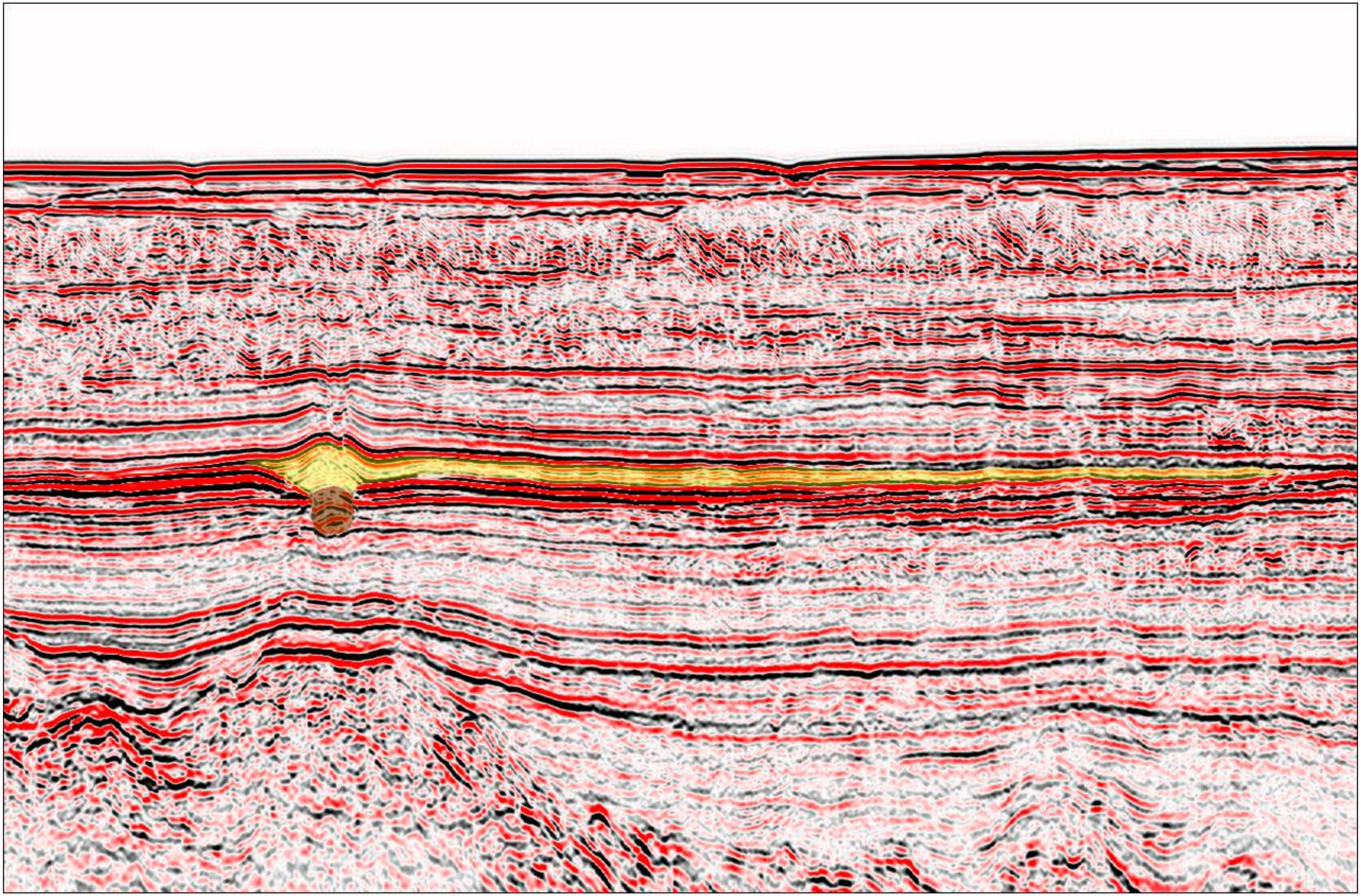

Figure 7. Sheet-like overbank flow – eastern tributary channel

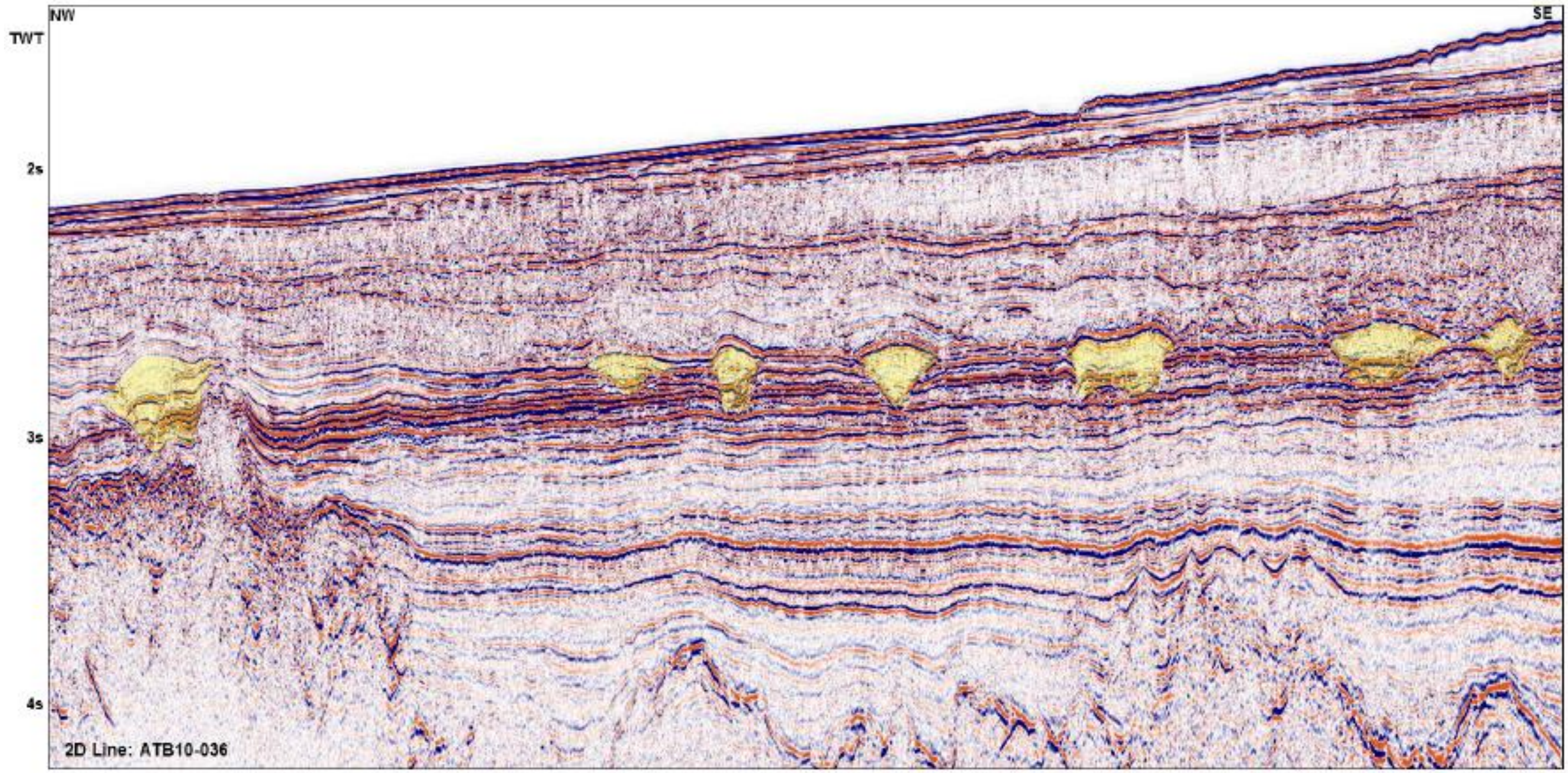

Figure 8. 2D seismic line ATB10-036 – channel intersections

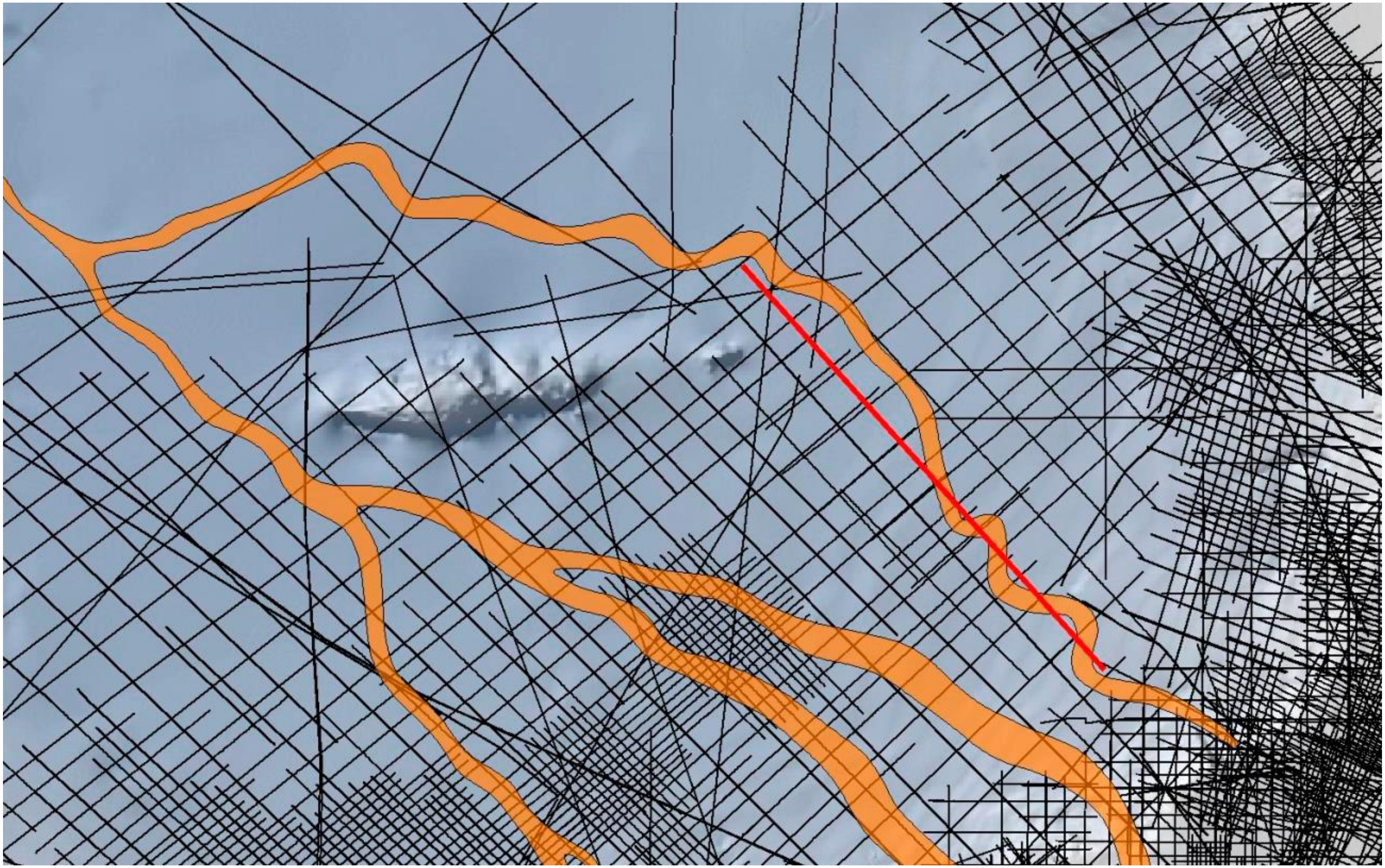

Figure 9. 2D Line ATB10-036

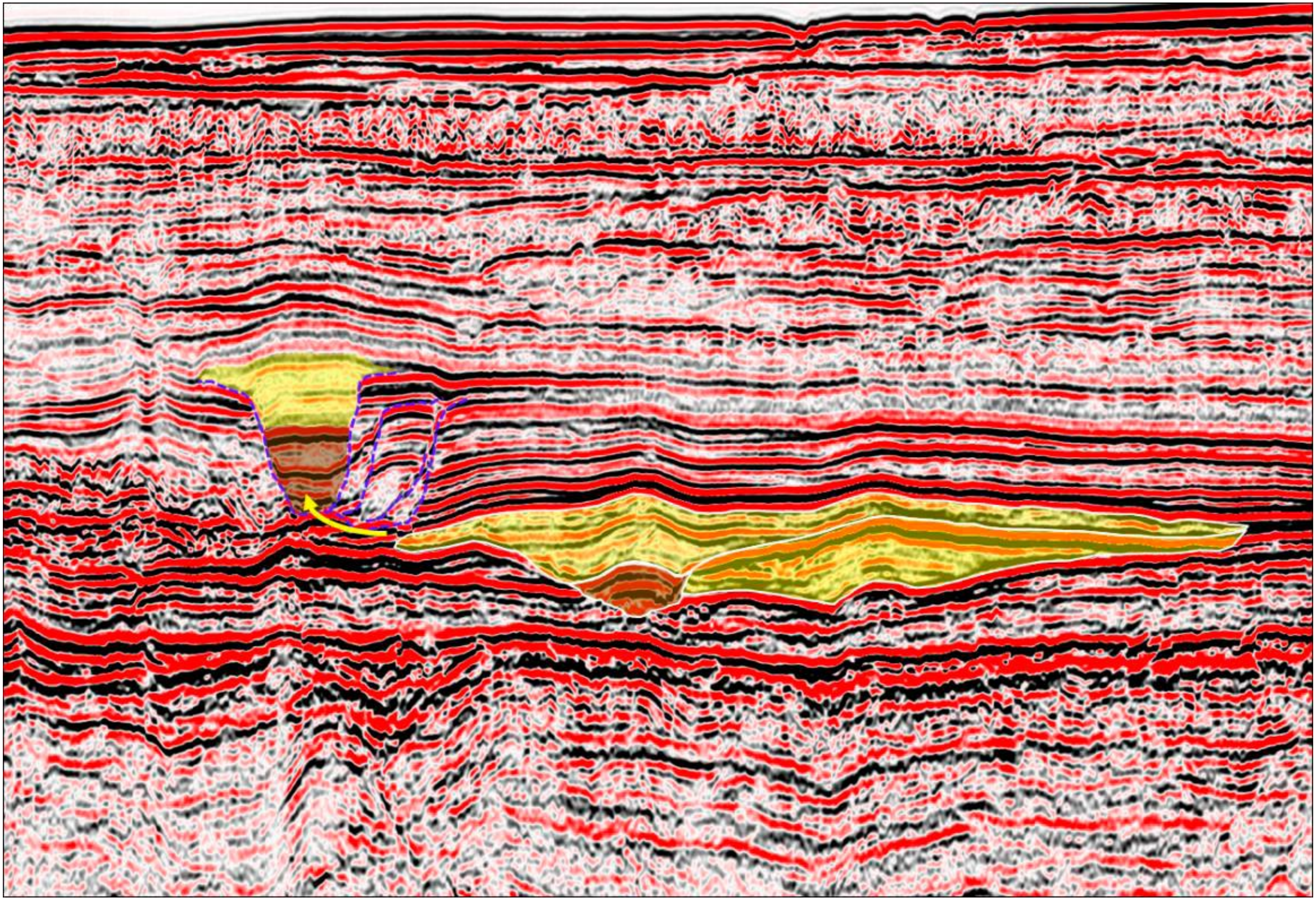

Figure 10. Secondary channel – depositional lobes

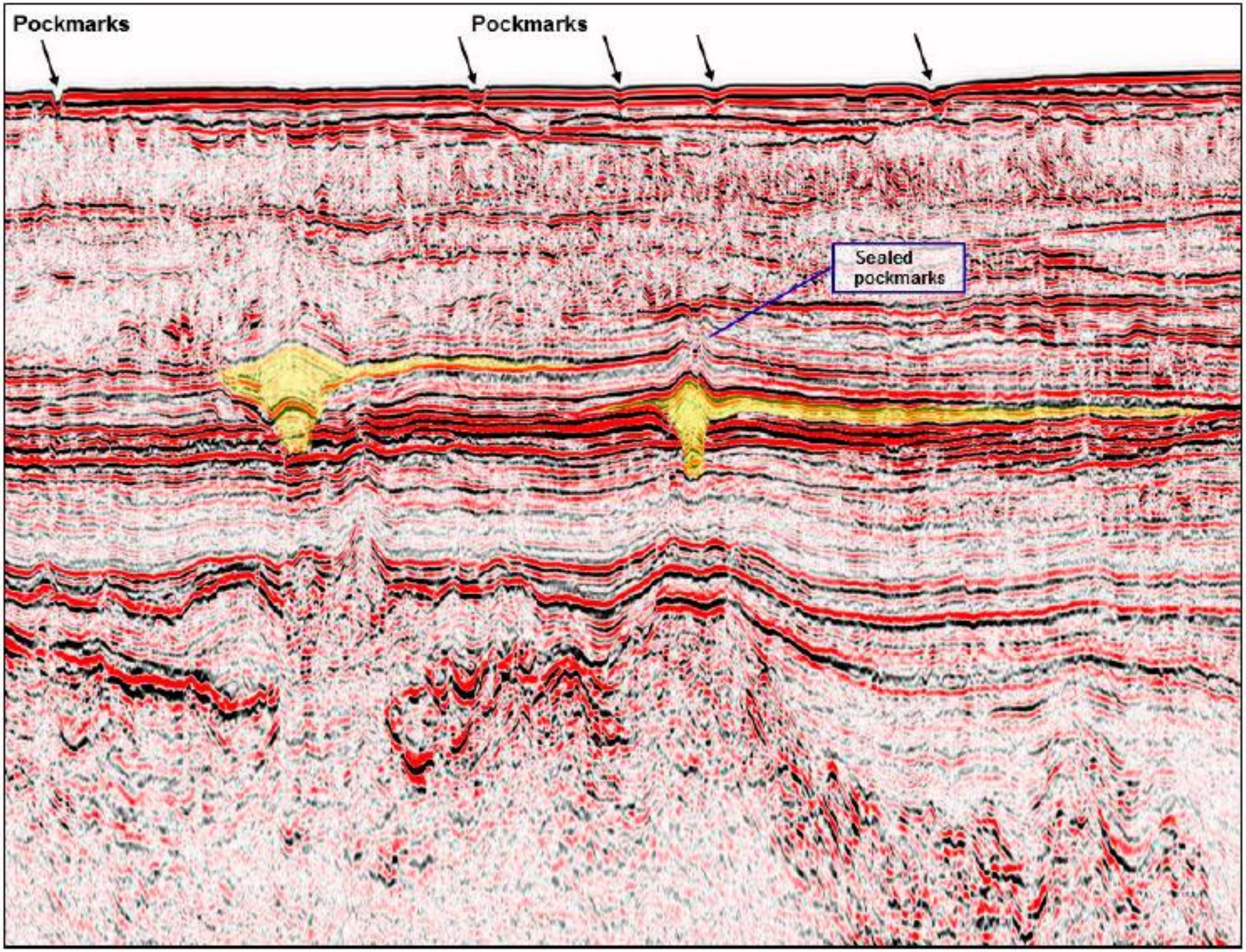

Figure 11. Evidence of vertical fluid / gas migration – seafloor pockmarks

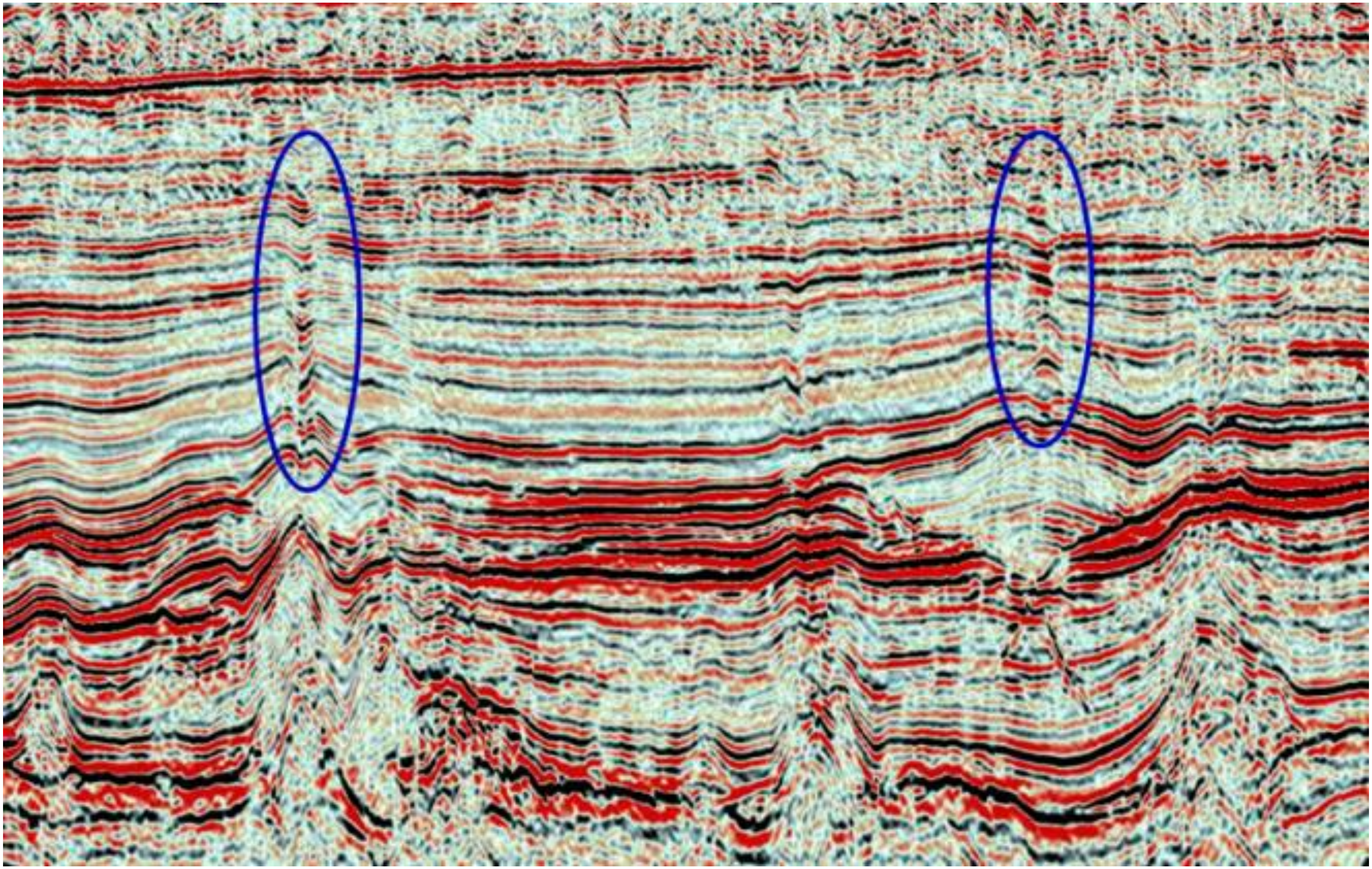

Figure 12. Sealed pockmarks – pore fluid expulsion

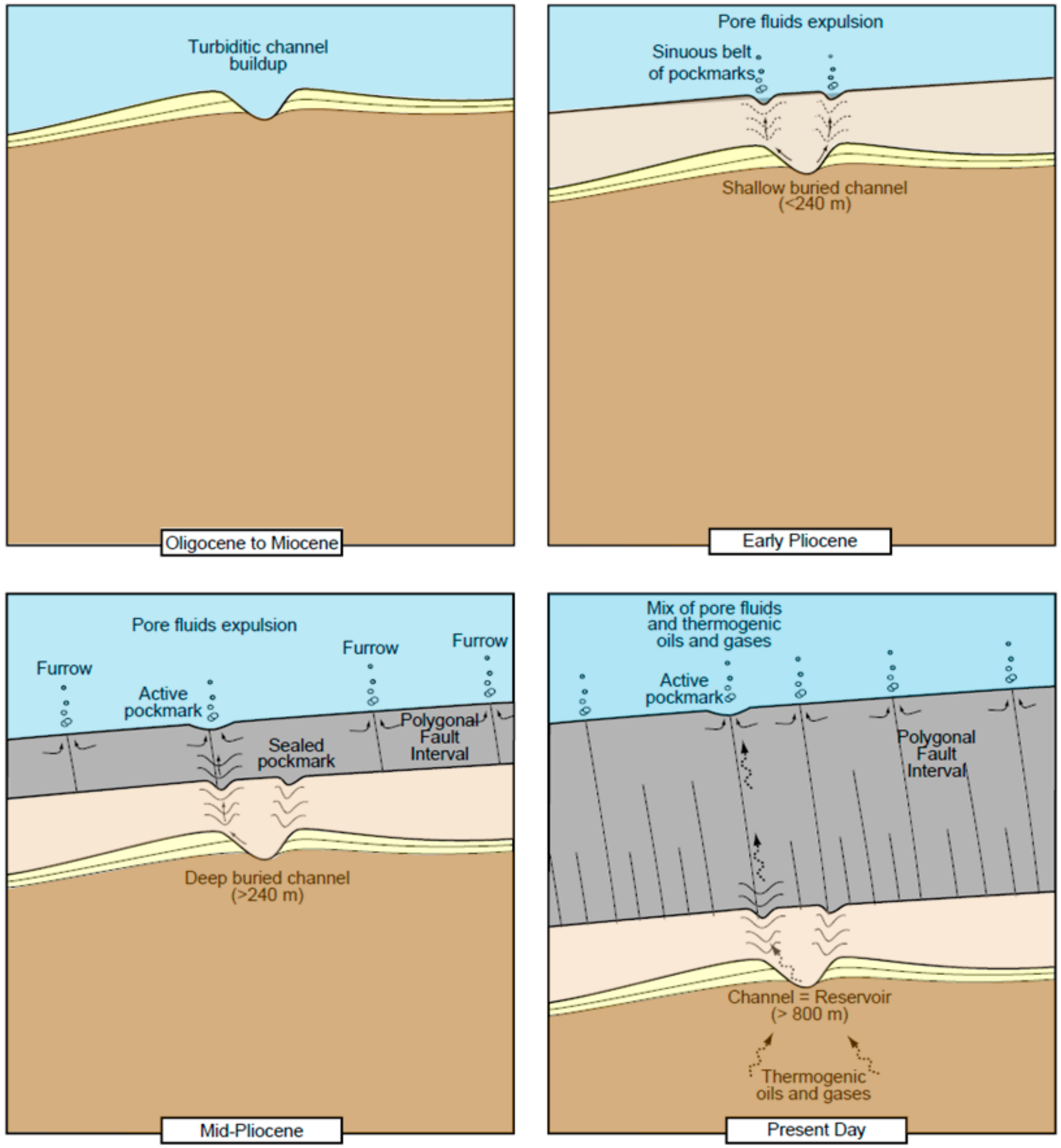

Figure 13. Dynamic model proposed by Gay et al, 2006. Vertical migration of gas / fluids through sealed pockmarks overlying deeply buried channel

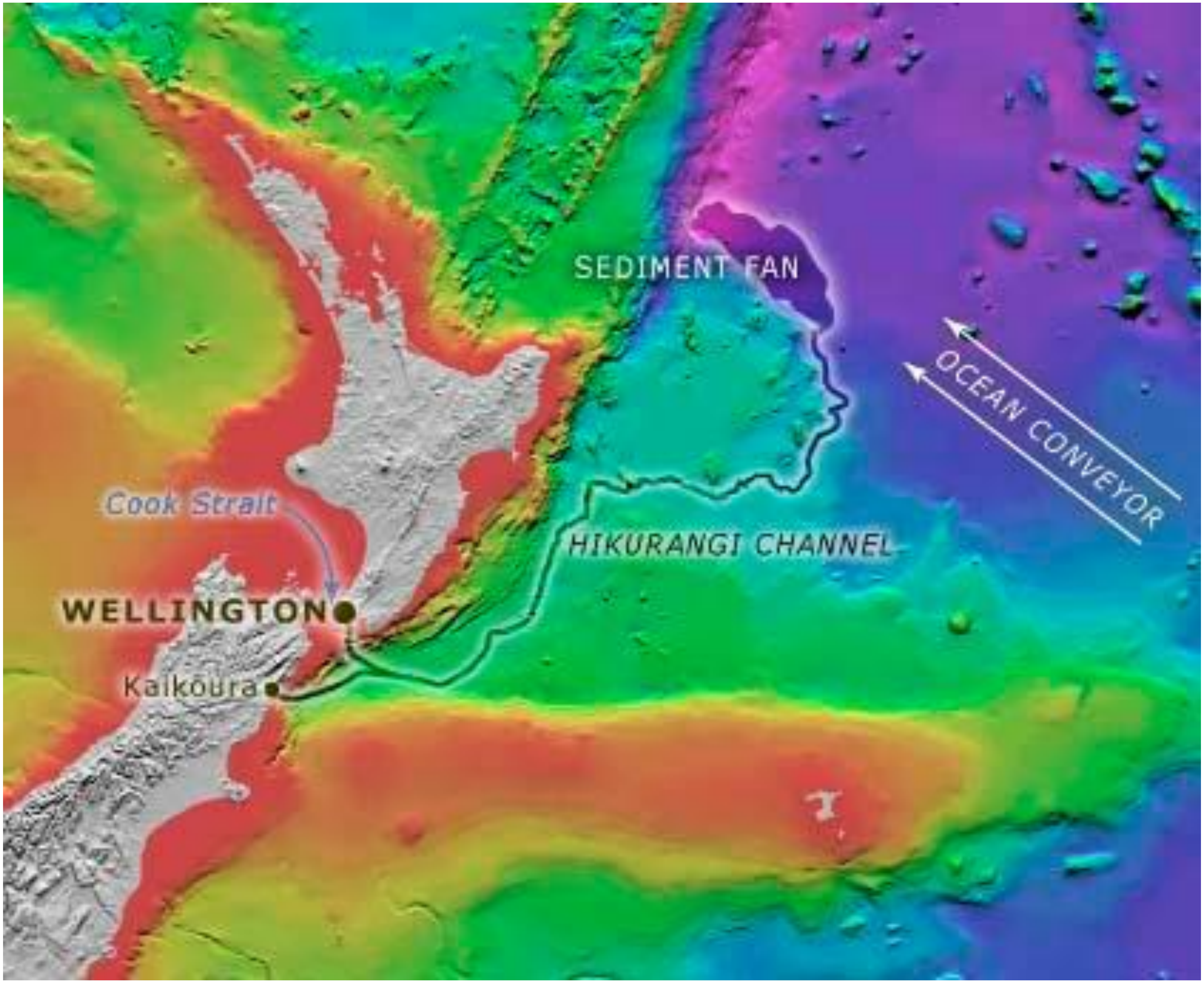

Figure 14. Hikurangi Sea-channel (NIWA)

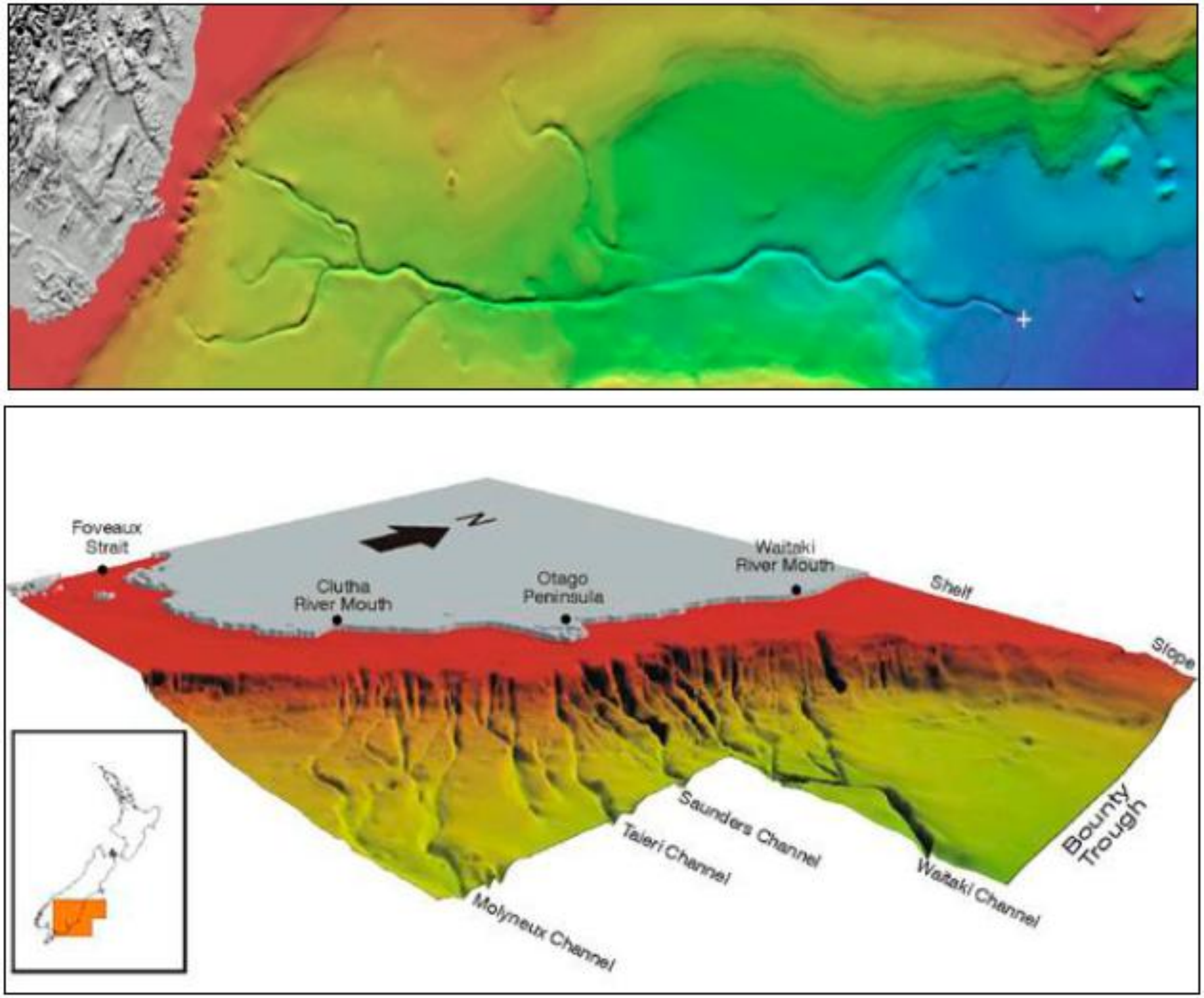

Figure 15. Bounty Trough channel (NIWA)