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Mass-Transport Complex Top Surface Morphology Controls

Turbidity Current Evolution Over Millennial Timescales

Wenjing Li¹, Nan Wu^{1*}, Christopher A.-L. Jackson², Harya Dwi Nugraha³, Zhen Guo⁴, Yu Huang⁴

¹State Key Laboratory of Marine Geology, Tongji University, 1239 Siping Road, Shanghai, 200092, China

²Department of Earth Science and Engineering, Imperial College, Prince Consort Road, London, SW7 2BP, UK

³Center for Sustainable Geoscience and Outreach (CSGO), Universitas Pertamina, Jakarta, Indonesia

⁴College of Civil Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China

*Nan Wu (nanwu@tongji.edu.cn)

0 Abstract

Slope failures and related gravity currents are key mechanisms by which sediment is remobilized, transported, and deposited on most of continental margins. Their deposits, which include mass-transport complexes (MTCs) and turbidites, are commonly deposited in close spatial and temporal association and constitute key depositional elements filling sedimentary basins. Previous studies have revealed that buried relief developed above MTCs can influence the evolution of turbidity currents and the distribution and character of their related deposits. However, the precise mechanisms by which this occurs remain poorly understood. Here we use 3D seismic reflection data from the Taranaki Basin, northwest New Zealand, to investigate how a buried MTC influences the initiation and evolution of subsequent turbidity currents. We interpret ten MTCs (MTC-1 to MTC-10) that constitute ~70% of the total post-Miocene stratigraphy, with turbidites developed intermittently between successive MTCs. We select the near-seabed MTC-9 (c.150 ms below the seabed), which extends over 250 km² and is very well imaged by the 3D seismic data, as the main focus of this study. We reveal that differential compaction driven by rheological contrasts between transported blocks and debrite can produce a rugose top surface with asymmetrical depressions and pronounced variations in slope gradient. When subsequent turbidity currents flow over

the MTC-9 top surface, the rugose relief promotes turbidity current acceleration and facilitates transition to a supercritical flow regime, leading to the development of a chain of cyclic steps directly above the transported blocks. This geomorphic influence is preserved up to the modern seabed, indicating that the topographic control of MTC-9 on turbidity-current behavior has persisted for an extended geological time. In turn, hydraulic jumps associated with these turbidity currents can strongly rework the lee sides of transported blocks, thereby reshaping the topography of the buried MTC-9. We also show that retrogressive slope failures, which supplied MTC-9, generated trough-like depressions near its headwall, reaching tens of kilometers in length and tens of meters in depth. These depressions can repeatedly deflect and reflect the incoming turbidity currents, ultimately promoting the formation of a submarine channel. Given that retrogressive slope failure and differential compaction are common processes during and after MTC emplacement, respectively, we suggest that these mechanisms could exert a fundamental control on turbidity-current evolution, thereby influencing deep-water sediment distribution and stratigraphic architecture.

Keywords: Slope failures, Mass-transport complex; Turbidity current; Deep-water sediment distribution; Turbidite; Debride

1 Introduction

Slope failures and turbidity currents are gravity-driven processes that play vital roles in subaqueous sediment routing (Middleton and Hampton 1973; Hampton et al. 1996; Hühnerbach and Masson 2004; Talling et al. 2007; Talling et al. 2024). The deposits of slope failures, which include mass-transport complexes (MTCs) and turbidites, constitute some of the most volumetrically significant infill elements in sedimentary basins (Pickering and Corregidor 2005; Moscardelli et al. 2006; Jackson et al. 2009; Nelson et al. 2011; Olafiranye et al. 2013; Ortiz-Karpf et al. 2015).

Slope failures, debris flows, and turbidity currents are often genetically, spatially, and temporally linked (Hampton 1972; Shanmugam et al. 1994; Mulder and Cochonat 1996; Talling et al. 2007; Haughton et al. 2009; Talling et al. 2012; Kneller et al. 2016;

Scarselli 2020; Talling et al. 2023). For example, during slope failure, intense internal deformation causes the failed mass to disaggregate, at least initially, into a debris flow (Hampton 1972; Mulder and Cochonat 1996; Scarselli 2020). This debris flow may then become diluted due to the progressive entrainment of ambient seawater, causing it to evolve into a turbidity current (Heezen and Ewing 1952; Shanmugam et al. 1994; Shanmugam 1996; Mohrig and Marr 2003; Ilstad et al. 2004; Felix and Peakall 2006; Lee 2019). The following slope failure and MTC emplacement, progressive retrogressive failures can trigger turbidity currents and the flow over the receding MTC (Ayckbourn et al. 2023). In contrast, dense turbidity currents may decelerate near their base, undergo basal freezing, and transform into debris flows (Talling et al. 2007; Haughton et al. 2009; Talling et al. 2012; Talling et al. 2023). As a result, an individual bed may comprise elements deposited by both debris flow and turbidity current.

MTCs can be very large, with single deposits covering 1,000 km² in map view and with volumes exceeding hundreds of km³. For example, the Gorgon Slide offshore NW Australia covers ~1,760 km² and contains of ~500 km³ of sediment (Nugraha et al. 2022), the Baiyun Slide in the northern South China Sea covers ~11,000 km² and contains ~1,035 km³ (Sun et al. 2018), and the Storegga Slide offshore Norway extends over ~35,000 km² with a volume of ~3,500 km³ (Bondevik et al. 2005). After emplacement, due to the cohesive nature of the source flows, the top surfaces of MTCs can form significant relief, with seabed depressions diverting and trapping (i.e., ponding) subsequent turbidity currents, promoting the development of erosionally based submarine channel systems, or more weak sheets or lobes (Appendix 1; Qin et al. 2017; Wu et al. 2022; Buso et al. 2025). For example, offshore Tanzania, the updip scarp on the top surface of a Miocene MTC redirected seven originally subparallel turbidity currents into a single giant submarine channel, thereby greatly enhancing sediment transfer to the deep sea (Stagna et al. 2023). Transported blocks within MTCs can also generate small-scale depressions that are a few kilometers long and tens of meters deep (Alves 2015; Ortiz-Karpf et al. 2015; Ward et al. 2018; Bull et al. 2020; Buso et al. 2024). These local depressions can divert or pond subsequent turbidity currents, and their influence may persist over extended geological timescales (Alves 2015; Ortiz-

Karpf et al. 2015; Ward et al. 2018; Bull et al. 2020; Amaechi et al. 2022; Buso et al. 2025; Wu et al. 2026). Similar effects also occur in fault-and-fold systems typically towards the distal end of MTCs, where the associated seabed geomorphology can also influence subsequent turbidity-current evolution (Ortiz - Karpf et al. 2018; Steventon et al. 2019; Wu et al. 2022; Wu et al. 2024).

Although many studies have demonstrated that MTCs can influence turbidity current development over geological timescales and the stratigraphic record of deep-water systems, the mechanistic feedback between MTC-related relief and subsequent gravity currents remain poorly understood. In this study we focus on the Taranaki Basin, offshore northwest New Zealand (Figure 1a), where >70% of post-Miocene succession comprises MTCs and turbidites (Figure 1c and 1d; Kroeger et al. 2019; Nwoko et al. 2020a). We investigate (i) how topography generated by MTC emplacement influences the initiation and long-term evolution of subsequent turbidity currents and (ii) how subsequent turbidity currents, in turn, rework underlying MTCs. Given that slope failures, debris flows, and turbidity currents are among the most common submarine gravity-driven processes, these results provide a basis for interpreting sediment transport and depositional evolution in deep-water Taranaki Basin and other sedimentary basins globally.

2 Geological setting

The Taranaki Basin is located offshore the west coast of New Zealand's North Island (Figure 1a; King and Thrasher 1996; Higgs et al. 2010; Kroeger et al. 2025). The Taranaki Basin is bounded by the Taranaki Fault to the east and extends westward beneath the present-day New Caledonia Trough (Figure 1a; Thrasher 1992; King and Thrasher 1996; Higgs et al. 2010). Structurally, it comprises a tectonically active Eastern Mobile Belt and a relatively stable Western Platform (Figure 1a; Holt and Stern 1994; King and Thrasher 1996). Within the Eastern Mobile Belt, reverse reactivation of the Taranaki Fault initiated in the Early Miocene, with deformation subsequently propagating westward toward the Cape Egmont Fault Zone, progressively partitioning strain across the belt (Nodder 1993; Holt and Stern 1994; Muir et al. 2000; Rajabi et al.

2016). This westwards migration of contractional deformation culminated in the Late Miocene, triggering significant uplift of the Southern Alps and the central North Island, both of which supplied sediment to the deep-water Taranaki Basin (Fitzsimons et al. 2001; Kamp et al. 2004; Hansen and Kamp 2006; Dunlevy 2020; Strogon et al. 2023). The resulting high-relief catchments, combined with the prevailing atmospheric westerly circulation, enhance orographic precipitation and drive, and continue to drive, exceptionally high denudation rates through fluvial incision and mass-wasting processes (Fitzsimons et al. 2001; Korup et al. 2005). These processes deliver large volumes of clastic sediment eastward to the unstable shelf edge, driving the gravity-driven sediment transport to the slope (Hood and Nelson 2012; Bull et al. 2019). In the post-Miocene stratigraphy, this shift is expressed by the widespread development of deep-water depositional elements, including channel-levee systems and basin-floor fans (King and Browne 2001; Higgs et al. 2010; Lutome 2025). Since the Late Pliocene, rapid clinoform progradation and deposition of the up to 1.5 km-thick, Giant Foresets Formation, and repeated slope failure events jointly lead to the frequent alternation of MTCs and turbidite channel systems on the continental slope (Salazar et al. 2016; Rusconi 2017; Kroeger et al. 2019; Nwoko et al. 2020a).

The study area is situated on the western edge of the Western Stable Platform, where water depths range from 900 to 1400 m (Figures 1a and 1b; Holt and Stern 1994; King and Thrasher 1996). The study interval extends from the late Miocene unconformity to the present seabed and is primarily composed of MTCs and submarine channel deposits (Figures 1c and 1d; Omeru 2014; Nwoko et al. 2020a; Silver et al. 2021; Li et al. 2023; Wang et al. 2025b). Previous studies show that the rugose top surfaces of these MTCs create complex relief that strongly influences subsequent depositional patterns (Rusconi 2017; Bull et al. 2020; Nwoko et al. 2020a; b). However, the specific mechanisms by which MTCs influence the flow regime and routing of subsequent turbidity currents remain poorly constrained. Within the post-Miocene interval, ten regionally distributed MTCs (MTC-1 to MTC-10) and associated channel complexes are recognized; we focus on MTC-9, which is exceptionally well-imaged and therefore provides the opportunity to understand MTC-turbidity current interactions (Figure 1d). Lithological

data from the Romney-1 well indicate this interval is predominantly composed of siliciclastic sediments (Uruski 2008; Li et al. 2017; Nwoko et al. 2020a).

3 Dataset and methodology

3.1 Dataset

This study uses the Vulcan and Romney 3D seismic reflection surveys, which together cover the continental slope to rise along the western margin of the Taranaki Basin (Figures 1a and 1b). The Vulcan 3D covers c.1086 km² in water depths of 175–1360 m, and the Romney 3D covers c.1826 km² in water depths of 1340–1550 m. Both 3Ds are post-stack time-migrated, with a vertical sample interval of 2 ms and a bin size of 25 × 25 m. Within the study interval, the dominant frequency is ~50 Hz. Using a sediment velocity of 1850 m s⁻¹, this yields an estimated vertical resolution of ~9 m based on the $\lambda/4$ criterion. The Vulcan survey is displayed in SEG reverse polarity (downward increase in acoustic impedance shown as blue/black negative troughs), whereas the Romney survey is displayed in SEG normal polarity. Although no wells are located within Vulcan 3D seismic survey areas, the age and lithology of the studied stratigraphic interval are constrained by well-to-seismic calibration using the nearby Romney-1 well in Romney 3D (Figure 1a). Regional 2D seismic reflection profiles were also used to provide regional stratigraphic and structural context for the studied MTC and overlying stratigraphy (Figure 1a).

3.2 Methodology

(i) Characterisation of MTCs

We follow the regional seismic-stratigraphic framework scheme established by Stroger and King (2014), which allows the assignment of approximate ages to the studied stratigraphic interval (Figures 1c and 1d). Two-way time (TWT) structure maps are generated for the basal shear surfaces and top surfaces of the MTCs to characterise the overall morphology of the study area and to document the distribution of the main depositional elements. Seismic attribute maps are then draped to investigate detailed kinematic indicators that may reveal transport direction and emplacement-related deformation of MTCs. These attributes include root-mean-square (RMS) amplitude and

variance.

The variance attribute calculates trace-to-trace variability over a specified sample interval, highlighting reflection discontinuities that enable the recognition of faults, folds, intra-MTC structural boundaries (e.g., shear zones), and the margins of erosionally based submarine channels (Van Bemmelen and Pepper 2000). RMS amplitude, computed as the square root of the average squared amplitude within a specified vertical window around key horizons, maps reflection strength and delineates zones of contrasting acoustic impedance (Chopra and Marfurt 2007). This attribute effectively distinguishes coherent blocks (typically high-amplitude) from the sheared, more homogenous, debritic matrix (typically low-amplitude) within MTCs; it also helps delineate internal lithological boundaries and shear surfaces (Richardson et al. 2011; Ford et al. 2023).

(ii) Channel Morphometric Analysis

Quantitative analysis of channel curvature, width, and depth is used to quantify the influence of underlying MTC topography on subsequent turbidity current behaviour. The radius of curvature (R) is estimated using a discrete three-point method by fitting the circumcircle through three consecutive, equally spaced points along the channel thalweg centerline, with curvature being defined as $\kappa = 1/R$ (Zulkifli et al. 2024). Channel width and depth are measured from seismic cross-sections orientated perpendicular to the channel thalweg. Channel margins are defined as the lateral break in slope of the channel flank (Figure 2c). Channel width was measured as the horizontal distance between the opposing margins of the channel. Channel depth is measured as the vertical distance from the thalweg to the higher of the levee crest.

(iii) Supercritical turbidity-current bedform analysis

We evaluate whether inherited relief on the MTC-9 top surface can drive overspilling turbidity currents into a supercritical regime using the densimetric Froude number and a depth-averaged momentum balance from Equations (1) to (3) from Chanson (2004). The equivalent local slope angle across the MTC-9 top surface is expressed as:

$$S_{eq} = \arctan\left(\frac{\Delta Z}{L}\right), \quad (1)$$

where S_{eq} is the seabed slope measured from the lee side of a topographic high on the top surface of MTC-9, ΔZ is the height between a crest and the adjacent depression of the topographic high, and L is the horizontal distance between them (Figure 2d).

Assuming a steady and uniform overspilling flow, flow regime is evaluated using the densimetric Froude number:

$$Fr = \frac{U}{\sqrt{g'H}}. \quad (2)$$

And a depth averaged momentum balance yields:

$$U \approx \sqrt{\frac{S_{eq}g'H}{C_{fb}}}, \quad (3)$$

where U is depth-averaged flow velocity, H is flow thickness, g' is the reduced gravity $g' = g \cdot (\rho_{mix} - \rho_w)/\rho_w$, and C_{fb} is the coefficient of friction at the bed, ranging from 0.003 to 0.01 (Chanson 2004). Following Konsoer et al. (2013), we adapt $C_{fb} = 0.005$ as representative of submarine environments.

4 Results

We interpreted seven submarine channels (SC1–SC7) on the modern seabed (Figure 1b). SC1 and SC2 are locally highly sinuous, whereas the other channels are relatively straight along their lengths (Figure 1b). Beneath the modern seabed, we interpret ten regionally developed MTCs (MTC-1 to MTC-10) and associated channel complexes within the post-Miocene interval (Figure 1d). Among these, the near-seabed MTC-9 lies directly beneath SC1 and SC2, indicating at least a spatial association between the buried MTC and the overlying channels (Figures 2a and 2b). Two buried channel systems (BC-1 and BC-2) are also identified between the top surface of MTC-9 and the modern seabed (Figures 2a and 2b). BC-1 is developed directly above the main body of MTC-9 and appears to represent a precursor version of the modern seabed channel SC2 (Figures 1b and 2b), whereas BC-2 occurs near the SE, closer to the headwall scarp, underneath and seemingly corresponding to a precursor version of SC1 (Figures 1b and 2b).

4.1 MTC-9

Description

MTC-9 is bounded by horizons H1 and H2 at its base and top, respectively (Figure 2a).

H1 is a continuous, gently NW-dipping, high-amplitude, positive polarity seismic reflection, whereas H2 is defined by a medium- to high-amplitude, negative polarity, highly rugose reflection (Figure 2a).

H1 exhibits a scallop-shaped geometry, defined by two NNE-trending, terrace-like scarps along its upstream margin and an NNW-trending scarp defining the western margin (Figures 3a and 3b). MTC-9 is characterised by two main seismic facies: chaotic, variable-amplitude reflections and block-shaped features (Figure 2a). The block-shaped features are mainly developed in the western part of MTC-9 and are encased within the chaotic seismic facies (Figure 3b). Internally, they are characterised by coherent reflections and asymmetric steep flanks, with the northwest-facing downdip margins showing truncations and are characterised with erosional scarps (Figure 2a). In contrast, the southeast-facing updip margins are relatively intact and less eroded (Figure 2a).

H2 exhibits highly rugose relief, resulting in pronounced variations in slope gradient (Figure 4a). Along its upstream margin, terrace-like scarps on H1 define two elongated, NNE-trending, trough-like depressions that are 100-200 m wide and 35-50 m deep on H2 (Figures 3b, 4b). In the western part of MTC-9, the presence of blocks generates alternating topographic highs and lows, making this region markedly more rugose than the eastern part (Figure 4a). The block-dominated areas form crest-shaped topographic highs, whereas zones underlain by chaotic seismic packages form negative-relief depressions (Figures 2a, 4a and 4b). A channel developed above H2, and its morphology and relationship with the underlying MTC topography are described in detail in Section 4.2 (Figure 4a).

Interpretation

H1 is interpreted as the basal shear surface of MTC-9, along which the failed mass was transported and emplaced (Figure 2b; Bull et al. 2009). The chaotic reflections are interpreted as debrites (Figure 2b; Frey-Martinez et al. 2005; Moscardelli and Wood 2008), whereas the block-shaped packages are interpreted as transported blocks based on their coherent internal reflections and well-preserved internal stratigraphy (Figures

2b and 3c; Jackson 2012).

The NNE-trending scarps at the upstream margin of MTC-9 are interpreted as the headwall scarps of the source slope failure, separating the failed mass from the adjacent undeformed slope (Figure 3c; Hampton et al. 1996; Bull et al. 2009; Tang et al. 2022).

The NNW-trending scarp along the western margin of MTC-9 is interpreted as the western lateral margin, where strike-slip shear occurred between the moving failed mass and the flanking, undeformed strata (Figure 3c; Brooks et al. 2018). Because the headwall scarps typically form perpendicular to the MTC emplacement direction, and the lateral margin parallel or slightly oblique to this, MTC-9 is thus inferred to have been transported north-westwards (Figure 3c; Brooks et al. 2018; Scarselli 2020; Abu et al. 2022). The terrace-like scarps observed in the headwall of MTC-9 are interpreted to result from retrogressive slope failure, in which failure propagates upstream by successive failure events (Figures 2a and 3b; Bull et al. 2009; Sawyer et al. 2009; Wu et al. 2022).

H2 defines the top surface of MTC-9 and marks the boundary between the MTC and the overlying strata (Figure 2b). Given that the transported blocks preserve well-defined internal structure and show minor tilting or rotation, this suggests that they underwent only limited transport and therefore experienced relatively minor internal deformation, indicating that they behaved as comparatively competent bodies relative to the surrounding, strongly disaggregated debrite (Figure 2b; Frey-Martinez et al. 2005; Alves 2015; Ward et al. 2018). After their emplacement, the tops of these transported blocks projected above the surrounding debrite, causing MTC-9 to have an irregular upper surface (Figures 2b and 4a). This relief may have been enhanced by differential compaction between the relatively competent transported blocks and debrite that due to the ingestion of seawater during their transport, would have been more compactable (Major and Iverson 1999; Major 2000; Alves 2010; 2015; Ward et al. 2018; Buso et al. 2025). As a result, accommodation would have been developed above debrite-dominated areas (Ward et al. 2018; Nwoko et al. 2020a).

The terrace-like scarps developed on H1 are also expressed on H2 after burial due to ongoing differential compaction across block-related relief, producing elongate,

trough-like depressions that are bounded by, and broadly parallel to, the underlying scarp steps (Figures 4B and 4C; Sawyer et al. 2009; Micallef et al. 2016). To characterise the spatial variability of this compaction-related relief, we measured the heights of the transported blocks and classified the MTC-9 top surface into different relief zones. Large blocks (≥ 100 ms high) define high-relief zones, smaller blocks (< 100 ms high) define moderate-relief zones, whereas debrite-dominated areas form smoother, low-relief zones above the top surface of MTC-9 (red, yellow, and blue, respectively, in Figure 4c).

4.2 BC-1

Description

BC-1 directly overlies and erodes into the top surface of MTC-9 and contains multiple stacked channel fills (Figures 2a and 2b). These channel-fills transition upwards from being laterally to vertically stacked, with the uppermost channel-fill being defined by SC-2 (Figures 2a and 2b). In map view, the lower part of BC-1 (the channel shaded dark blue in Figure 4c) exhibits a sinuous geometry, whereas its upstream end trends NW before reaching the headwall scarp of MTC-9 (Figures 4a and 4b). The middle and upper channel fills exhibit similar planform geometries (shaded light blue in Figures 4b and 4c). As it approaches the headwall scarp, the channel is progressively deflected from NW to N before sharply swinging to trend NNE. Upon entering the high-relief zones created by transported blocks within MTC-9, BC-1 is further deflected from NNE to NE before finally turning to NNW (Figures 4a and 4c). In map view, BC-1 undergoes at least seven bends within high- and moderate-relief zones dominated by transported blocks (Figure 4c), with each high-curvature bend located immediately upstream of abrupt changes in MTC thickness (Figure 5).

The cross-sectional geometry and overall scale of BC-1 also vary as it crosses MTC-9 (Figure 5). Before BC-1 enters MTC-9, BC-1 is relatively wide (c. 350–800 m) moderately incised (c. 35–60 ms TWT), and only moderately sinuous, with its curvature ranging from 0.07 to 0.15. Across the high-relief zones of MTC-9, BC-1 narrows (c. 300–500 m) and becomes more deeply incised (c. 50–75 ms TWT) and straighter, with curvature values decreasing to 0.03–0.10. Further downstream, across the moderate- to

low-relief zones, BC-1 widens (c. 300–650 m) and shallows (c. 18–40 ms TWT), with its curvature generally increasing but becoming more variable, ranging from 0.05 to 0.25.

Scour-shaped bedforms are developed on the top surface of MTC-9, corresponding to the zones where the sinuosity and flow direction of BC-1 abruptly changes (Figures 4b and 4c). In cross-section, these scour-shaped bedforms are asymmetric, with a steeper, slightly erosional side that faces NW and a gentler SE-facing side (Figure 6a). These scour-shaped bedforms display clear upstream (i.e., south-eastwards) migration, expressed by the upstream-stepping of the erosional, NW-facing step developed along successive reflections up to the seabed (Figures 6a and 6b). These bedforms occur in two regions (Region 1 and Region 2; Figure 4c). Region 1 occurs downstream and to the west of the outer banks of BC-1 bends 1, 2, and 6, where several NW-facing, crescent-shaped scours are developed on the western part of MTC-9 (Figures 4b and 4c). Region 2 occurs downstream of the outer banks of bends 4 and 5, where numerous gullwing-shaped bedforms are developed (Figures 4b and 4c).

The scour-shaped bedforms occur from the top surface of MTC-9 (H2) through successive overlying horizons to the modern seabed (H3–seabed; Figures 6a, 6b, 7a and 7b). These bedforms progressively decrease in scale and become increasingly subtle upward from H2 to the modern seabed (Figure 7b). To illustrate the geomorphology and geophysical (e.g., amplitude) characteristics of these bedforms, we selected a representative horizon immediately above the top surface of MTC-9 (H3; Figure 7a). The RMS-amplitude map of H3 shows that the steep side of the scour-shaped bedforms has higher amplitude than the gentler stoss sides and surrounding areas (Figure 7a). Seismic sections indicate that these high-amplitude steep sides correlate with erosional scarps defining the downdip margins of the underlying transported blocks (Figure 7a). In contrast, the low-amplitude zones correspond to the relatively smooth, less-eroded sides of the blocks (Figure 7a).

Interpretation

BC-1 incised into MTC-9, with morphometric data indicating the planform evolution of the former was strongly controlled by relief along the top surface of the latter

(Figures 4c and 5). The initial deflection of BC-1 as it approaches the headwall scarp of MTC-9 is interpreted to be caused by the significant negative topography between the upper slope and the headwall scarp, which funneled and deflected the turbidity current into the evacuation zone, upstream of MTC-9 (Figure 4c; Qin et al. 2017; Li et al. 2020). Downstream of the headwall scarp, differential compaction between transported blocks and surrounding debrite generated a rugged relief that repeatedly diverted the channel before entering the low-relief zone (Figure 4c; Alves 2015; Nwoko et al. 2020a). In detail, with curvature maxima systematically occurring immediately upstream of abrupt, block-related changes in MTC thickness (Figures 4c and 5) and the channel thalweg being preferential routing along interconnected, intra-block lows (Jolly et al. 2017; Ward et al. 2018; Bull et al. 2020).

In addition to influencing channel curvature, MTC-related relief, associated with the headwall scarp and MTC-9 itself, caused the channel to narrow and deepen, suggesting this relief caused the source turbidity currents to become more focused and erosive (Taking the lower part of BC-1 in Figure 5 as an example; Kneller et al. 2016; Ward et al. 2018; Nwoko et al. 2020a). Farther downstream, across the moderate- to low-relief zones, BC-1 became wider, shallower and more variable in terms of its sinuosity curvature, reflecting reduced confinement and increased lateral mobility of the channel as constraining relief diminishes (Figure 5; Posamentier and Kolla 2003; Nwoko et al. 2020a; Soutter et al. 2021). In summary, the rugose topography of MTC-9 exerted a first-order control on the routing, confinement, and erosional character of BC-1.

Based on their 3D geometry (e.g., downstream-widening, steep upstream flanks and gentle downstream flanks), decametre-scale, weakly erosional bases, and systematic upstream migration, the scour-shaped bedforms are interpreted as cyclic steps (Figures 4c, 6a and 6b; Fildani et al. 2006; Covault et al. 2014; Zhong et al. 2015). Cyclic steps are interpreted to form under supercritical flow conditions (i.e., flows moving faster than the propagation speed of surface or internal gravity waves; Froude number > 1) and to involve repeated hydraulic jumps (i.e., abrupt transitions from supercritical to subcritical flow accompanied by rapid energy dissipation) (Cartigny et al. 2011; Postma and Cartigny 2014). In our study, the concentration of cyclic steps downstream of the

outer-bends of the BC-1 suggests they formed due to the overflow of turbidity currents otherwise contained within the channel (Piper and Normark 1983; Fildani et al. 2006; Fildani et al. 2013; Traer et al. 2015; Traer et al. 2018). As these overspilling flows traversed the undulating MTC-9 top surface produced by differential compaction, local slope breaks promote rapid flow acceleration and hydraulic jumps, initiating the formation of cyclic steps (Alves 2010; 2015; Ward et al. 2018; Bull et al. 2020). The lowest preserved cyclic steps are developed directly on the MTC-9 top surface, with no seismically resolvable intervening strata, indicating that MTC-related relief influenced turbidity currents from the earliest preserved stage of post-MTC deposition (Figure 6). Cyclic steps subsequently recur on successive stratigraphic surfaces from H3 to the seabed, suggesting that hydraulic jumps were repeatedly triggered as later turbidity currents encountered relief inherited from earlier cyclic steps, with the primary topographic relief ultimately generated by the initial differential compaction of MTC-9 (Figures 7a and 7b). However, cyclic steps progressively decrease in size upward, suggesting that supercritical-flow regime transitions weakened through time as the relief above MTC-9 was progressively buried and smoothed (Figure 7b; Martinez - Doñate et al. 2023; Englert et al. 2024).

Erosional scarps along the downdip margins of transported blocks are interpreted to record locally enhanced erosion caused by hydraulic jumps (Figure 6a). The hydraulic jumps can erode and remobilize sediment from the transported blocks, with part of the reworked sediment subsequently redeposited near the lee sides of the cyclic steps (Postma and Cartigny 2014; Pohl et al. 2019; Ono et al. 2023). This erosion and reworking process recurred during successive turbidity current events following the deposition of MTC-9. High RMS amplitudes preferentially occur on the lee sides of the cyclic steps; we interpret that this reflects strong impedance contrasts between the underlying MTC-9 deposits and the younger deposits that are eroded, reworked, and redeposited during successive turbidity current events. (Figure 7a; Dorrell et al. 2016; Pohl et al. 2019; Chilton et al. 2025). The updip margins of the transported blocks are relatively well-preserved, indicating that these areas were dominated by deposition rather than erosion (Figure 7a; Postma and Cartigny 2014; Slootman and Cartigny

2020). The low RMS-amplitude responses on the stoss side of cyclic steps are interpreted to reflect weaker impedance contrasts between the underlying MTC-9 deposits and the younger deposits, resulting from the preferential deposition of finer-grained sediment as the turbidity currents decelerated downstream of the hydraulic jumps (Figure 7a; Postma and Cartigny 2014; Vellinga et al. 2018; Englert et al. 2021; Ono et al. 2023). This may also be influenced by downstream flow depletion, as coarser grains were progressively deposited in upstream cyclic steps, meaning more distal cyclic steps were richer in finer-grained material deposited by lower-concentration flows (Ghienne et al. 2021; Ono et al. 2023).

4.2.2 BC-2

Description

BC-2 extends northeastwards of an outer bend of BC-1 located immediately downstream of the headwall scarp for MTC-9 (Figure 8a). In contrast to BC-1, which displays marked curvature development above the main body of MTC-9, BC-2 has a low-sinuosity, near-linear planform that along its southeastern margin is confined within a trough-like depression adjacent and parallel to the headwall scarp. Along its northwestern margin, BC-2 is bound by the updip slope of debrite within MTC-9 (Figures 8b and 8c). Along its southwestern segment, BC-2 is relatively narrow and deeply incised, being ~330 m wide and ~35 ms deep (Figure 8b). Downstream to the northeast, however, the channel widens and deepens, becoming ~550 m wide and ~50 ms deep (Figure 8c).

Interpretation

BC-2 is interpreted as being mainly supplied by turbidity currents stripped from the outer bend of BC-1, this explains why BC-2 initiated near the western end of the headwall scarp of MTC-9 (Figure 8a). As these overspilling flows reached the headwall scarp, they were captured and confined by the adjacent trough-like depression, such that they were routed north-eastwards (Figures 8a and 9; Kneller et al. 2016; Ayckbourne et al. 2023). The close spatial alignment between the base of BC-2 and the trough-like depression suggests that turbidity currents were axially focused within the negative-relief corridor, enhancing basal erosion (Figures 8b and 8c). Such topographic

confinement may have increased flow volume and erosional capacity, consistent with the observed downstream widening and deepening of BC-2 (De Leeuw et al. 2016; Soutter et al. 2021). Therefore, terrace-like headwall scarps produced by retrogressive failure, with trough-like depressions generated by differential compaction near the headwall, captured overspilling turbidity currents and focused them along the negative-relief corridor, promoting the initiation and evolution of BC-2.

5 Discussion

We show that buried MTCs can redirect turbidity currents, promote their transformation into supercritical flows, and, through headwall-related residual topography, trap subsequent turbidity currents and initiate the formation of new channels. In this section, we explore the triggers and processes responsible for these effects, which are critical for understanding the evolution of gravity-driven currents and key source-to-sink processes along continental margins worldwide.

5.1 Differential Compaction in MTCs: A Key Control on the Formation of Supercritical Turbidity Currents

Differential compaction refers to the unequal post-depositional compaction of lithologies with contrasting rheological properties, producing inherited topographic relief during burial (Alves 2010; 2015). Following MTC emplacement, the remoulded, water-rich debrite compacted more readily than the adjacent coherent transported blocks due to the expulsion of ingested pore water. This rheological heterogeneity generated differential compaction, preserving positive relief above transported blocks and creating adjacent accommodation above debrite-dominated areas. Relief between the blocks and adjacent debrite locally exceeded 100 m (Alves and Cartwright 2010; Ward et al. 2018; Nwoko et al. 2020a; Buso et al. 2025). Given that transported blocks within MTC-9 underwent only limited transport, the strong topographic contrast between the transported blocks and surrounding debrite is well-preserved, providing the rheological heterogeneity required for differential compaction. We therefore interpret differential compaction as the primary mechanism responsible for generating the rugose relief on the top surface of MTC-9 (Figure 10a). Such compaction generated relief may persist for millions of years and continue to influence seabed morphology

and subsequent slope depositional processes over prolonged timescales (Ward et al. 2018; Bull et al. 2020; Nwoko et al. 2020a; Buso et al. 2025; Wu et al. 2026).

To quantify the rugosity of the MTC-9 top surface and characterise local slope breaks that may promote supercritical flow and hydraulic jumps, we calculated the equivalent local slope angle (S_{eq}) using Eq. 1 (see Appendix 2 for detailed calculations). The calculated S_{eq} ranges from 1.91° to 21.80° , exceeding the $\sim 0.5^\circ$ slope commonly inferred to promote hydraulic jumps in natural turbidity currents, particularly where downdip gradients enhance local flow acceleration (Figure 10b; Sequeiros 2012; Postma and Cartigny 2014; Talling et al. 2015; Wang et al. 2025a). To assess whether the topography of MTC-9 was capable of sustaining supercritical flow conditions required for cyclic step formation, we calculated the Froude number (F_r) using Eq. 2 and Eq. 3. The calculated F_r values range from ~ 2.58 to 8.94 , confirming that turbidity currents traversing the MTC-9 top surface remained supercritical ($F_r > 1$) (Komar 1971; Fildani et al. 2006). The presence of cyclic steps on successive horizons from H3 to the seabed above MTC-9 indicates that inherited relief continued to influence turbidity current behaviour after MTC deposition, although their progressively subtler expression toward the seabed suggests gradual weakening during topographic healing (Figures 6 and 8b). The sediment accumulation rate of $\sim 2.0 \text{ m kyr}^{-1}$ documented by Maier et al. (2016) from broadly age-equivalent (i.e., late Miocene) exposures along the north Taranaki coast provides a basis for constraining how long MTC-related relief may have persisted. Using this (undeformed) accumulation rate, the $\sim 180 \text{ m}$ thick succession between the MTC-9 top surface and the seabed suggests that the topographic influence of MTC-9 may have persisted for at least $\sim 90 \text{ kyr}$ (Figure 10d). Given that sediment compaction occurred during burial, and considering the vertical resolution limitations of seismic data, the measured thickness is likely a minimum estimate, and the actual periods over which relief persisted were probably longer. Therefore, differential compaction enabled MTC-related topography to influence turbidity current evolution over thousands to tens of thousands of years.

Similar conclusions have been made from studies in Lake Geneva, Switzerland, and the Xisha Islands in the South China Sea. In both cases, cyclic steps and/or sediment waves

are developed directly above the rugose top surfaces of buried MTCs, which are characterised by large, transported blocks embedded within surrounding debrite (Corella et al. 2016; Liu et al. 2023). The undulating relief and variable slope angles of the MTCs upper surface, with the close spatial association with overlying cyclic steps and sediment waves, indicate that differential compaction-generated topography can exert a primary control on the evolution of subsequent turbidity currents. These examples, together with our findings from the Taranaki Basin, demonstrate that differential compaction is a fundamental yet underappreciated mechanism for generating rugose seafloor topography that persistently influences turbidity current evolution.

5.2 Hydraulic Jump: A Major Deformation Mechanism for Buried MTCs

A hydraulic jump is the transition of a turbidity current from a Froude supercritical state ($F_r > 1$) to a subcritical state ($F_r < 1$), typically triggered by an abrupt reduction in slope gradient (Komar 1971; Garcia and Parker 1989). This supercritical-to-subcritical transition is the key process responsible for the formation and upstream migration of cyclic steps (Cartigny et al. 2011). In MTC-9, the steep downdip margins of transported blocks provides local slope breaks that promotes flow acceleration and subsequent hydraulic-jump formation as turbidity currents traversed the MTC top surface (Figure 10b; Garcia and Parker 1989). These block margins therefore acted as topographic and kinematic boundaries that localized flow transformation, enhanced erosion, and promoted the development of cyclic steps (Cartigny et al. 2011). The spatial alignment between the lee sides of cyclic steps and the steep downdip margins of transported blocks suggests that hydraulic jumps repeatedly impinged upon and eroded the block lee sides as turbidity currents traversed the MTC top surface (Figure 7a; Dorrell et al. 2016).

Previous studies of cyclic-step deposits based on outcrops and cores have shown that sand-rich deposits commonly occur around lee sides, whereas finer-grained deposits are preferentially preserved on stoss sides (Day-Stirrat et al. 2013; Postma and Cartigny 2014; Corella et al. 2016; Zhong 2025). Flume experiments and numerical studies show that hydraulic jumps locally enhance turbulence and bed shear stress, promoting the

development of scours and erosional surfaces, with erosion commonly occurring upstream of the jump and deposition downstream as the flow decelerates (Dorrell et al. 2016; Pohl et al. 2019; Chilton et al. 2025). These results suggest that hydraulic jumps preferentially eroded the lee sides of transported blocks, reworking block-derived sediment that accumulated around the lee sides of the cyclic steps, whereas finer-grained sediment was preferentially deposited on the stoss sides as the flow decelerated downstream. This interpretation is consistent with the contrasting RMS-amplitude responses observed across the cyclic steps (Figure 7a). The lee sides of the cyclic steps are characterised by erosional surfaces and high RMS amplitudes, which reflect strong impedance contrasts between the underlying MTC deposits and younger deposits, indicating the accumulation of relatively coarse-grained lag deposits on the lee sides (Figure 7a; Dorrell et al. 2016; Pohl et al. 2019; Chilton et al. 2025). In contrast, lower RMS amplitudes on the stoss sides of the cyclic steps may reflect finer-grained deposition or draping as the flows decelerated downstream of hydraulic jumps (Figure 7a). These observations suggest that hydraulic jumps not only reworked and locally eroded the upper surfaces of underlying MTC blocks but also controlled sediment distribution above MTCs. Lee-side depressions adjacent to transported blocks may have acted as preferential sites for sand-rich accumulation, favouring the development of high-quality turbidite reservoirs above buried MTCs (Figure 10d). Hydraulic jumps therefore act as a major erosional force that locally deforms buried MTC deposits while redistributing sediment into adjacent lee-side accommodation.

5.3 Retrogressive Failure-related Depressions atop MTCs: Depocenters for Subsequent Turbidity Current Deflection and Initiation

Most MTCs developed on continental slopes often initiate from the lower slope and propagate upslope through a retrogressive pattern, forming terrace-like scarps in the headwall domain (Haflidason et al. 2004; Bryn et al. 2005; Wu et al. 2022). This upstream-propagating pattern is interpreted as retrogressive failure, a mechanism common to many slope-attached MTCs in subaqueous settings (Moscardelli and Wood 2008; Sawyer et al. 2009; Badhani et al. 2020).

The terrace-like scarps in the headwall domain of MTC-9 indicate that it underwent

retrogressive failure, which generated a series of elongate, trough-like depressions on its top surface (Figures 8a and 9). BC-2 is confined to one of these trough-like depressions, suggesting that this negative-relief feature exerted a strong control on subsequent channel evolution (Figures 8b and 8c). When overspilling turbidity currents from the outer bend of BC-1 encounter such topography, they first interact with the downdip slope of the headwall scarp, where an increase in local gradient may have promoted flow acceleration (Figures 8b and 10c; Dorrell et al. 2016; Ge et al. 2017; Ge et al. 2018). As the turbidity current then advances to the updip slope of the debris, near-perpendicular incidence promotes flow reflection, whereas more oblique incidence favours flow deflection (Figures 8b and 10c; Ge et al. 2017; Ge et al. 2018; Keavney et al. 2025; Wang et al. 2025c). Reflected flows then be redirected back toward the downdip slope of the MTC-9 headwall scarp, undergoing secondary reflection and deflection, setting up a complex recirculation pattern within the scarp-confined depression (Figures 8b and 10c; Patacci et al. 2015; Reece et al. 2024). This topographic confinement promotes flow concentration, thereby enhancing the erosive capacity of the turbidity current and enabling incision of a depression-confined channel system orientated parallel to the trough axis (i.e., BC-2) (Figures 8b and 10c; De Leeuw et al. 2016).

The terrace-like headwall scarps in MTC-9 are geomorphologically comparable to normal fault-bounded topography, as both comprise steep scarp slopes and adjacent elongate negative-relief depressions confined between the downdip scarp and opposing upstream-facing slopes. Flume experiments and 3D numerical models have shown that such fault-related topography can strongly modify turbidity-current pathways by promoting flow stratification, reflection, deflection, local ponding, and axial focusing along the depression (Ge et al. 2017; Ge et al. 2018; Howlett et al. 2019; Soutter et al. 2021; Wang et al. 2025c). In particular, for slope gradients of 20–40° and incidence angles of 15–90°, turbidity-current behaviour systematically shifts from reflection-dominated to deflection-dominated as incidence angle decreases and slope gradient increases (Wang et al. 2025c). The terrace-like headwall scarps of MTC-9 define local slope gradients of 20–30°, whereas the inferred incidence angle of overspilling turbidity

currents is $\sim 70\text{--}90^\circ$, placing the MTC-9 headwall geometry well within the experimentally constrained parameter range. We therefore infer that the scarp-bounded trough-like depressions in the headwall domain of MTC-9 acted in the similar manner as fault-bounded depressions, capturing, reflecting, and axially focusing overspilling turbidity currents, thereby enhancing near-bed sediment transport and facilitating the initiation and confinement of BC-2 (Figures 9 and 10c).

A similar example has been documented above, a buried MTC in the Aínsa Basin, Spain, where channels preferentially developed within elongate negative-relief corridors formed in the hangingwalls of extensional faults above creeping MTCs headwall domain (Ayckbourne et al. 2023). Similar to BC-2, these channels are laterally confined by slope-failure-generated scarps and remain focused within narrow depressions. However, the origin and persistence of the confining topography differ between the two examples. Ayckbourne et al. (2023) demonstrate that syn-depositional creep and sequential extensional faulting generated migrating hangingwall depressions that focused turbidity currents and controlled channel incision and avulsion; in contrast, our study shows that retrogressive headwall failure created terrace-like scarps and that subsequent differential compaction generated and maintained trough-like depressions that persistently captured overspilling turbidity currents. Because retrogressive failure and differential compaction are widely documented in the headwall domains of many continental-margin MTCs, the terrace-like headwall topography and associated depressions they generate may represent a widespread control on subsequent turbidity current pathways, with broader implications for interpreting submarine source-to-sink systems.

6 Conclusion

Using high-resolution 3D seismic data from the Taranaki Basin, we identified ten post-Miocene MTCs and associated channel systems, with MTC-9 selected to examine how buried MTC topography controls subsequent turbidity-current evolution. Our results show that buried MTCs exert a direct control on the initiation, evolution, and long-term behaviour of subsequent turbidity-current systems. The main conclusions are as follows:

- (1) Differential compaction driven by rheological contrasts between relatively

competent transported blocks and more compactable debris generated a rugose topography on the MTC-9 top surface. This inherited relief persisted for c. 90 kyr, deflecting turbidity-current pathways, modulating their erosivity, and enhancing local seabed gradients, thereby promoting supercritical flow and cyclic-step formation. Hydraulic jumps associated with supercritical turbidity currents, in turn, exert strong erosive forces that excavate and reshape the underlying MTC topography.

(2) Retrogressive failure during MTC emplacement produces terrace-like scarps and associated scarp-bounded depression at the headwall domain, creating confined accommodation for subsequent turbidity currents. These depressions directly captured incoming turbidity currents and promoted repeated reflection and deflection within this confined topography, progressively focusing flow along the axis and ultimately forming a new axial channel orientated nearly perpendicular to the regional slope dip.

(3) Because differential compaction and retrogressive failure are common during MTC emplacement along continental margins, the mechanisms identified in this work provide a useful framework for interpreting source-to-sink systems in MTC-dominated settings. They may also help predict sand-prone reservoir distribution, evaluate organic carbon transport and burial, and assess seafloor engineering hazards.

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Figure Captions

Figure 1. (a) Location and seismic dataset coverage of the study area. The black dotted line marks the boundary between the Taranaki Basin and the Deepwater Taranaki Basin. The red polygon outlines the 3D seismic survey area shown in Figure 1b, and the yellow line marks the regional 2D seismic section. (b) Structure map of the modern seabed, calculated from the Romney and Vulcan 3D seismic datasets, showing modern seabed channel systems (SC1 to SC7). (c) Uninterpreted 2D regional seismic section traversing and connecting Vulcan and Romney 3Ds. (d) Interpreted the regional 2D seismic section shown in Figure 1c, highlighting the study interval from the Top Miocene to the seabed, ten buried MTCs, and inter-MTC buried channel complexes. The location of Figure 1c is indicated in 1a.

Figure 2. (a) Seismic section from the Vulcan 3D, showing the internal seismic reflection pattern of MTC-9, its basal shear surface (H1), top surface (H2) and overlying stratigraphic packages. Location is shown in Figure 1b. (b) Interpreted version of Figure 2a, showing the internal kinematic indicators of MTC-9 (e.g., transported blocks and debrite) and their spatial relationship with the overlying buried channels. (c) Schematic diagram showing the parameters used to analyse channel morphometry. (d) Schematic diagram showing the parameters used to analyse supercritical turbidity-current bedforms.

Figure 3. (a) Structure map of Horizon H1, illustrating the map-view morphology of the basal shear surface of MTC-9. (b) Variance attribute extracted along Horizon H1, highlighting headwall scarp, lateral margin and transported blocks within MTC-9. (c) Interpreted sketch of Figure 3b, showing MTC-9 boundaries, key kinematic indicators and inferred transported direction.

Figure 4. (a) Structure map of Horizon H2, illustrating the map-view morphology of the top surface of MTC-9. (b) Variance attribute extracted along a horizon slice 30 ms above Horizon H2, highlighting BC-1 and trough-like depressions above MTC-9. (c)

Interpreted sketch of Figure 4b, showing zones of varying relief, overlying channels, scours and the locations of the seven bends (1–7) of BC-1.

Figure 5. Quantitative geometric analysis of BC-1, including curvature, width, and incision depth. Note that 'bend' refers to planform deflections of BC-1, and the locations of the seven major bends (1–7) are shown in Figure 4c.

Figure 6. (a) Seismic section cutting across region 1 of MTC-9, showing scour-shaped bedforms with steep lee-side scarps, gentle stoss sides, and an upstream migration pattern. (b) Seismic section cutting across the region 2 of MTC-9, showing gull-wing-shaped bedforms, characterised by steep lee-side scarps, gentle stoss sides, and upstream migration. The locations of Figure 6a and 6b are shown in Figure 4c.

Figure 7. (a) 3D view of the MTC-9 top surface in the western part. Location is shown in Figure 4c. (b) TWT structure maps of horizons H3 to seabed, showing the progressive reduction in scour-shaped bedform scale. Location is shown in Figure 4c.

Figure 8. (a) Variance attribute time slice showing BC-2 and its spatial relationship with the underlying MTC-9 headwall scarp associated topography associated with the MTC-9 headwall scarp. Location is shown in Figure 4c. (b) Seismic section across the western part of BC-2, illustrating that BC-2 is spatially aligned with the depression bounded by the terrace-like scarps of MTC-9. Location is shown in Figure 8a. (c) Seismic section across the eastern part of BC-2, illustrating that SC-1 incises upstream of BC-2. Location is shown in Figure 8a.

Figure 9. 3D view of the MTC-9 top surface near the headwall scarp. See Figure 9 for location.

Figure 10. Schematic diagram illustrating interactions between MTCs and subsequent turbidity currents, showing how MTCs control subsequent turbidity-current evolution

and how turbidity currents, in turn, modify MTC morphology. (a) Emplacement of MTC-9. During emplacement, retrogressive failure formed step-like headwall scarps. Differential compaction between transported blocks and surrounding debrite generates a rugose topography on the MTC-9 top surface. (b) The undulating MTC-9 top surface promotes transformation of turbidity currents into a supercritical regime, triggering repeated hydraulic jumps and the formation of cyclic steps. (c) Terrace-like scarps associated with retrogressive failure during MTC emplacement cause turbidity currents to undergo repeated reflection and deflection within trough-like topography, initiating BC-2. (d) Residual MTC topography can persist over multi-millennial timescales, exerting a long-term topographic influence on basin-scale stratigraphic evolution.

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Appendix 1

MTC

Topographic Features	Location	Influence on Subsequent Sedimentation	Key References
Graben-like depressions associated with headwall evacuation zones	Northern Santos Basin, SE Brazil	Created large accommodation space for subsequent turbidity currents and enhanced sediment transport efficiency	(Buso et al. 2024)
	Mafia Slide, Somalia Basin, Tanzania	Focused turbidity currents and enlarged channel systems, promoting accumulation of turbidite sands and coarse-grained terrigenous sediments in proximal areas	(Stagna et al. 2023)
	Espírito Santo Basin, SE Brazil	Converged turbidity currents to enhance flow energy and erosive capacity, thereby promoting canyon development	(Qin et al. 2017)
	Offshore Brunei, Gulf of Mexico	MTC scarps created seafloor accommodation that captured and influenced turbidity current pathways	(Kneller et al. 2016)
Subparallel, elongate depressions associated with headwall and toe fault systems	Bass Canyon, Gippsland Basin, SE Australia	Provided dynamic forcing for bottom current to turbidity current transformation, enabling sustained sediment transport and erosion	(Wu et al. 2024)
	Otway Basin, SE Australia	Induced continuous gravitational potential energy conversion of subsequent turbidity currents, enhancing flow energy and promoting larger scale channel	(Wu et al. 2022)
	Fish Creek Slide, Northern Alaska	Created axial erosion fairways that promoted channelization	(Homza 2004)
	NW flank of Storegga Slide, mid-Norwegian margin	MTC reactivation increased channel sinuosity and triggered new slope failures	(Jing et al. 2024)
Semi-enclosed to closed irregular depressions associated with	Offshore Indonesia, Nigeria	Controlled sandbody distribution and channel morphology via local ponding and lateral spreading	(Posamentier and Kolla 2003)
	Deepwater Taranaki Basin, New Zealand	Internal blocks deflected and bifurcated subsequent channels, thereby controlling the distribution of depocenters.	(Bull et al. 2020)
	Espírito Santo Basin, SE Brazil		(Ward et al. 2018)
	Deepwater Taranaki Basin, New Zealand		(Nwoko et al. 2020b; a)

deformed blocks within MTCs	Magdalena Fan, Caribbean Sea, offshore Colombia	Megaclasts controlled the distribution, morphology, and evolution of subsequent avulsion lobe complexes	(Ortiz-Karpf et al. 2015)
	Kangaroo Syncline, NW Australia	Influenced the distribution and stratigraphy of subsequent slope failures	(Wu et al. 2026)

Appendix 2

We evaluate whether inherited relief on the MTC-9 top surface can drive overspilling turbidity currents into a supercritical regime using the densimetric Froude number and a depth averaged momentum balance from Equations (1) to (3) from Chanson (2004).

The equivalent local slope angle across the MTC-9 top surface is expressed as:

$$S_{eq} = \arctan\left(\frac{\Delta Z}{L}\right), \quad (1)$$

where S_{eq} is defined as the local flow-parallel slope experienced by turbidity currents as they traverse the local relief on the MTC-9 top surface, ΔZ is the relief between a block crest and the adjacent depression (or sill height), and L is the horizontal distance between them (Figure 2b). The observed relief ΔZ is 10 to 20 m and the inter block spacing L is 50 to 300 m, giving $\Delta Z / L = 0.03\text{--}0.4$ and thus S_{eq} is about 1.91° to 21.80° .

Assuming a steady and uniform overspilling flow, flow regime is evaluated using the densimetric Froude number:

$$Fr = \frac{U}{\sqrt{g'H}}. \quad (2)$$

And a depth averaged momentum balance yields:

$$U \approx \sqrt{\frac{S_{eq}g'H}{C_{fb}}}, \quad (3)$$

where C_{fb} is the coefficient of friction at the bed, ranging from 0.003 to 0.01 (Chanson 2004); U is depth averaged flow velocity, H is flow thickness. g' is the reduced gravity defined as $g' = g \cdot (\rho_{mix} - \rho_w) / \rho_w$, g is gravitational acceleration (9.81m/s^2), ρ_{mix} is the bulk density of the levee overspill turbidity currents and ρ_w is the density of the clear water. We use a friction coefficient of 0.005, as the best fits for submarine environments (Konsoer et al. 2013).

Figure 1

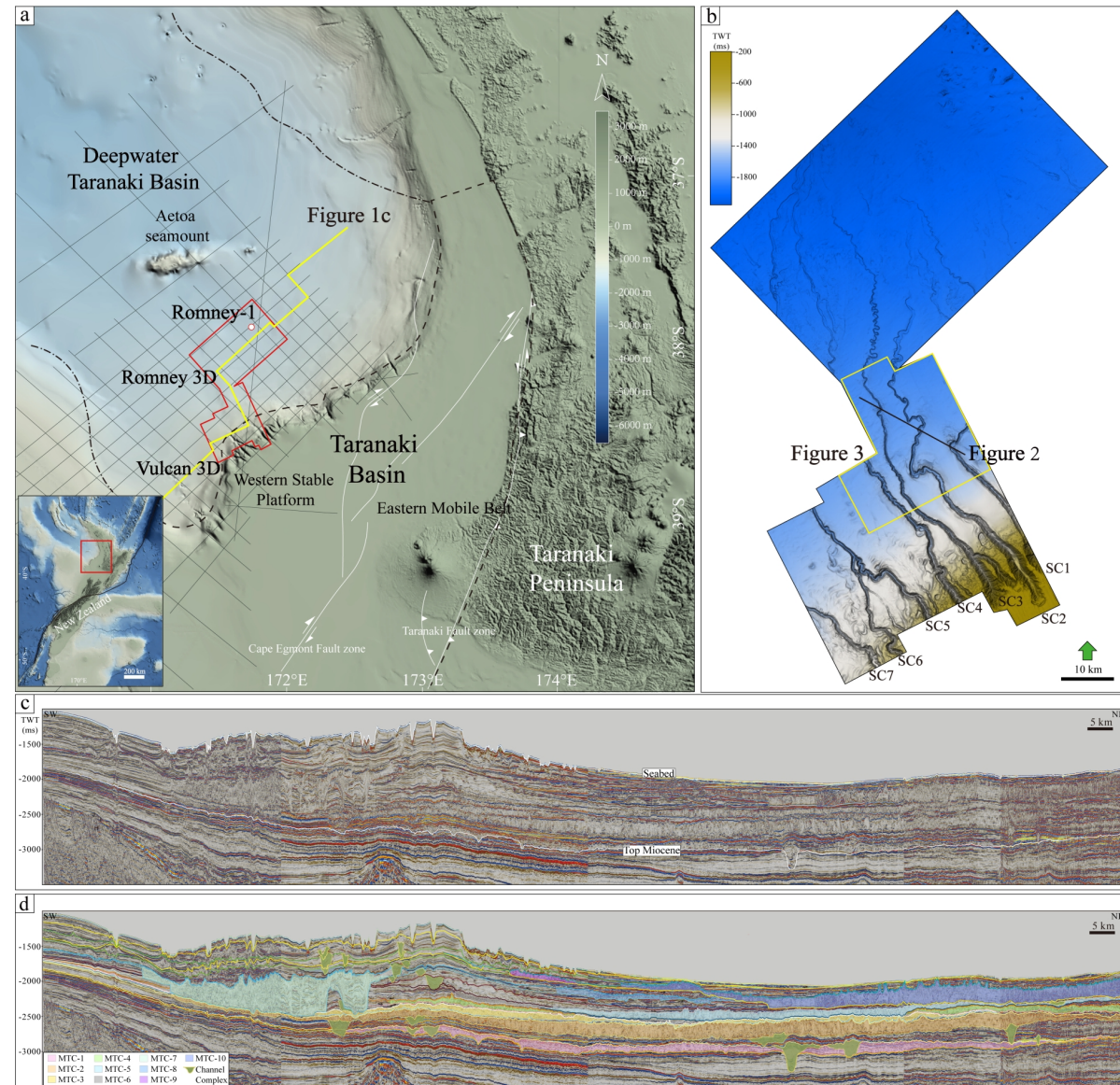


Figure 2

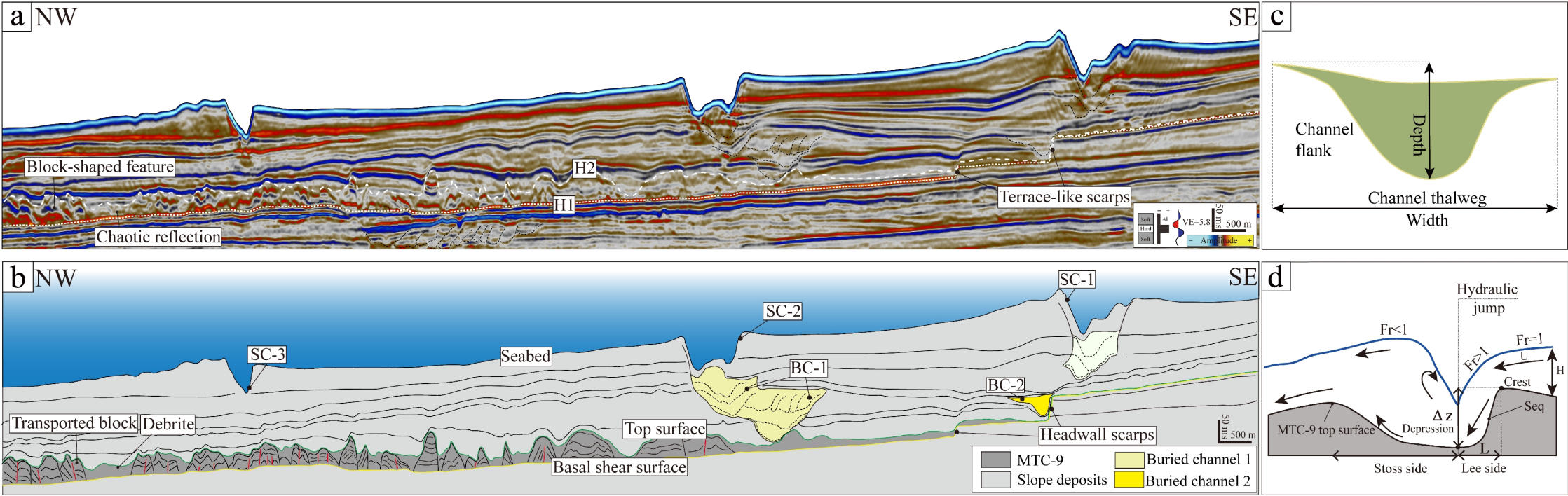


Figure 3

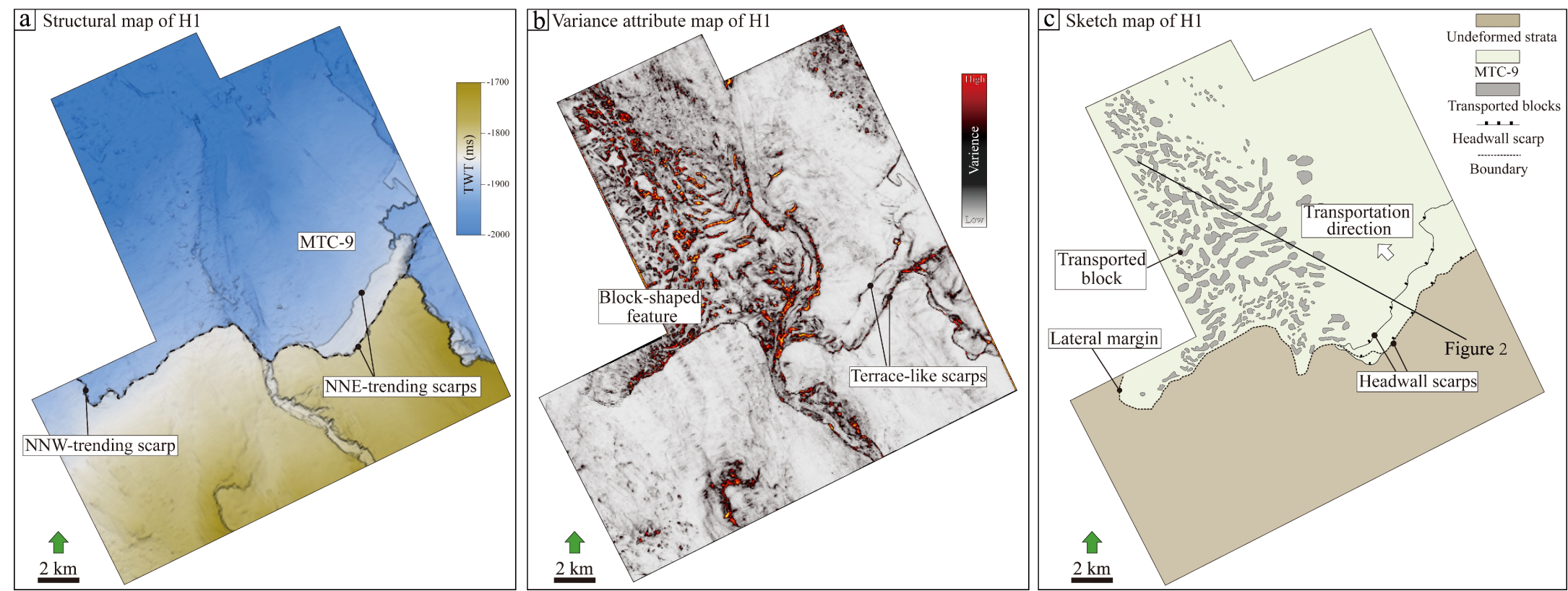


Figure 4

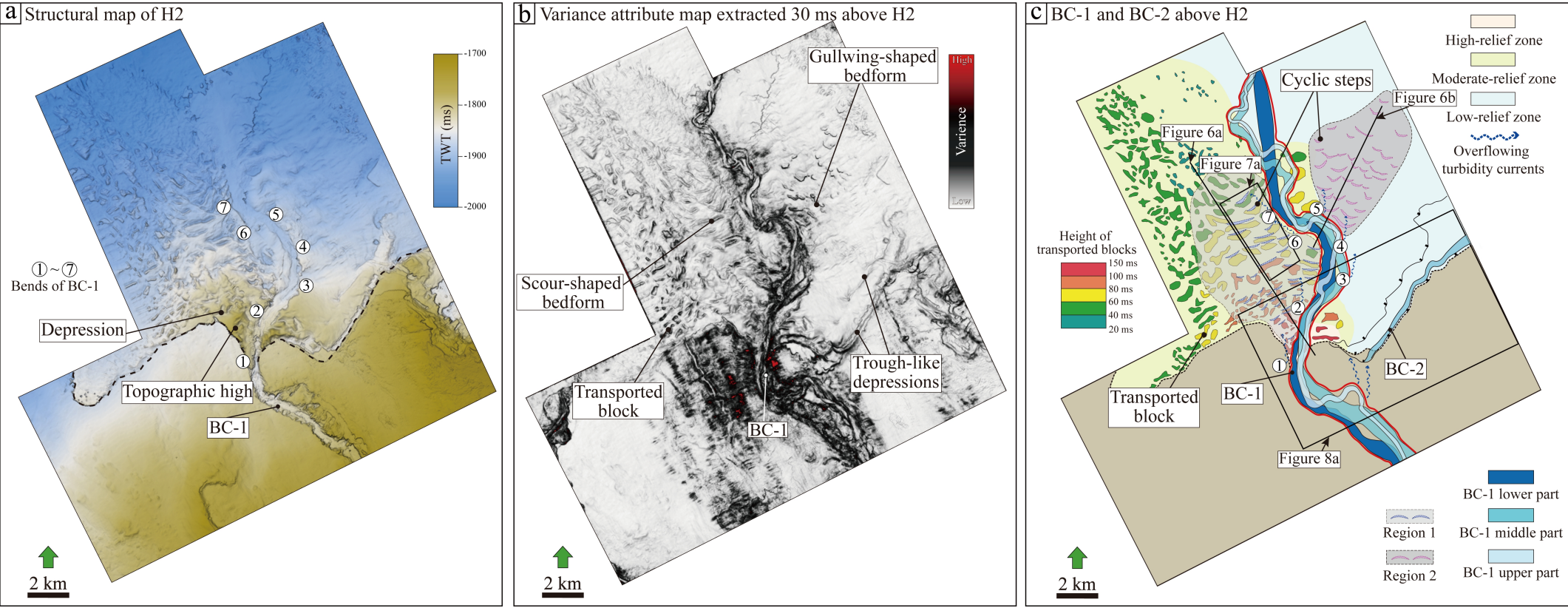


Figure 5

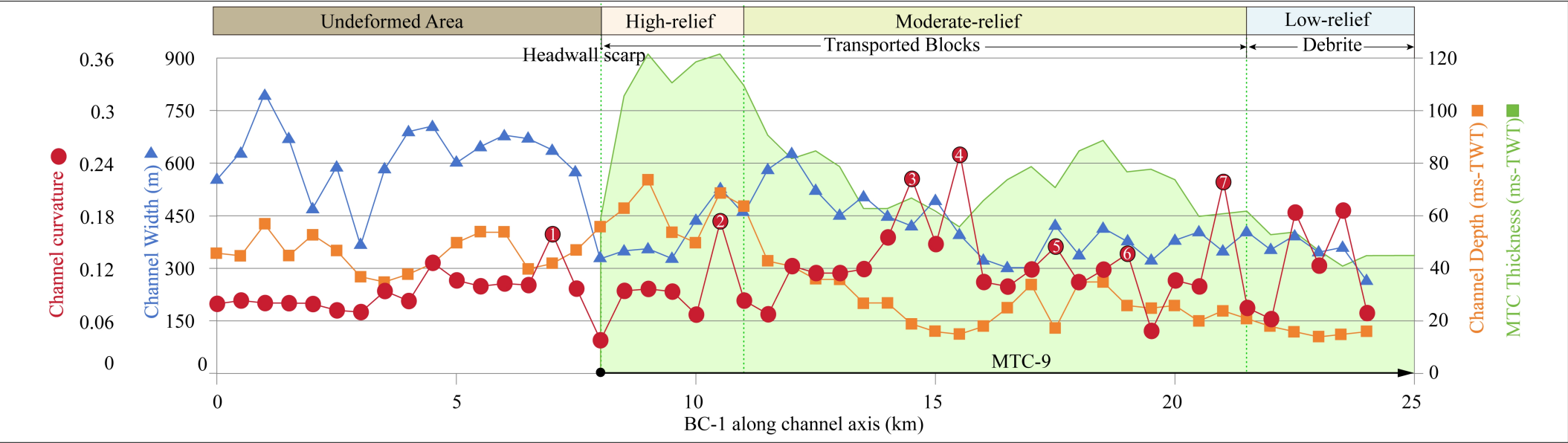


Figure 6

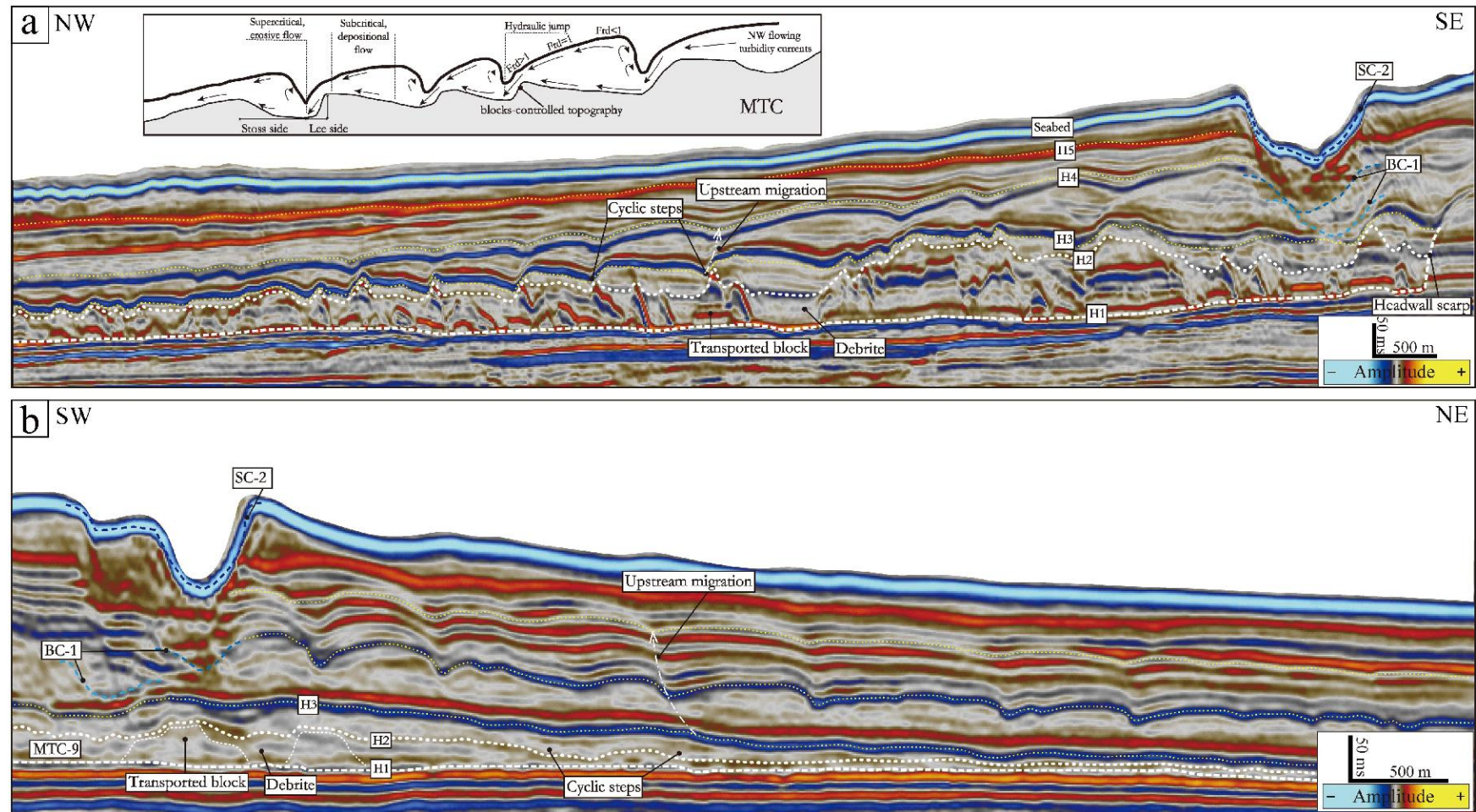


Figure 7

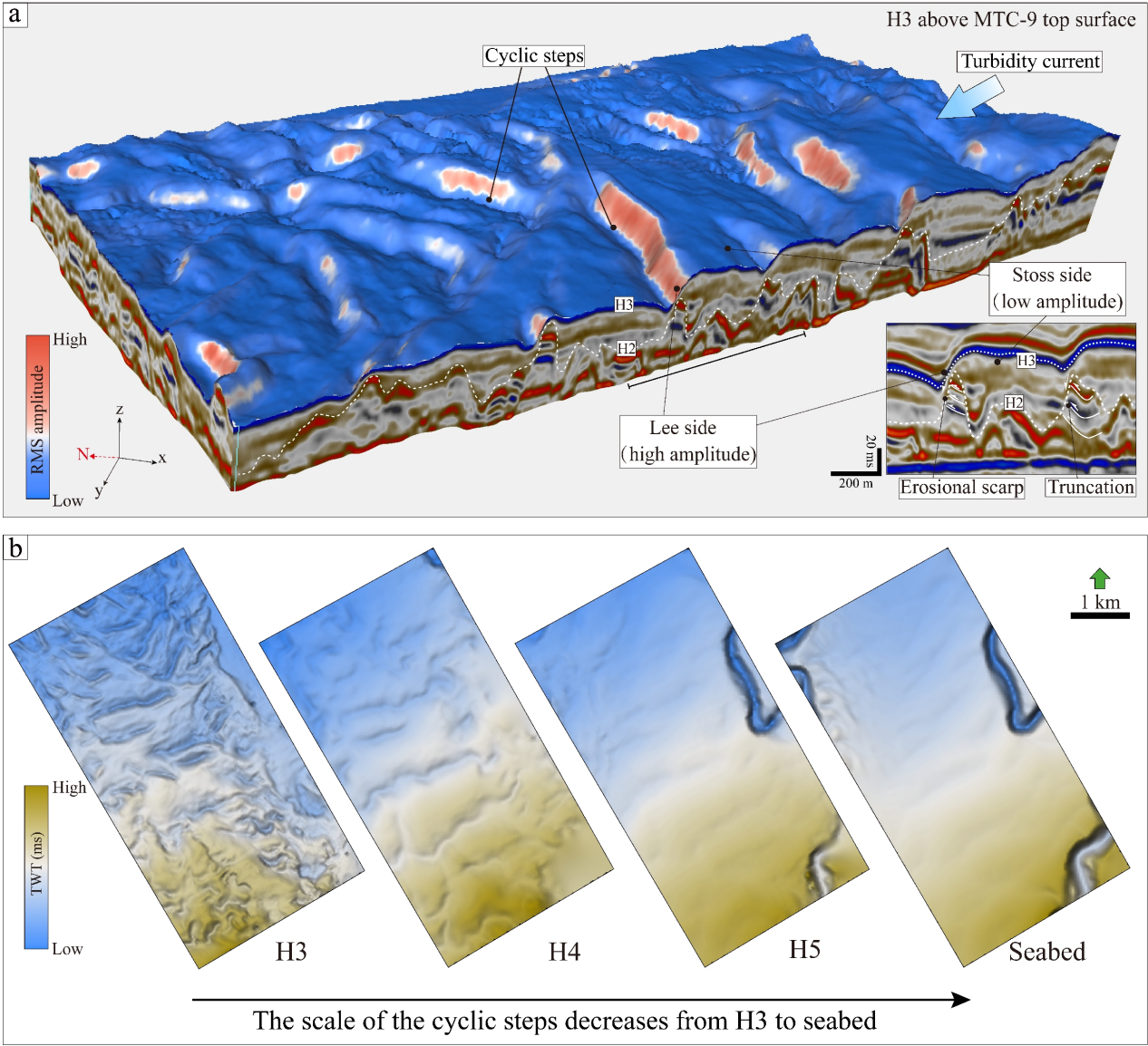


Figure 8

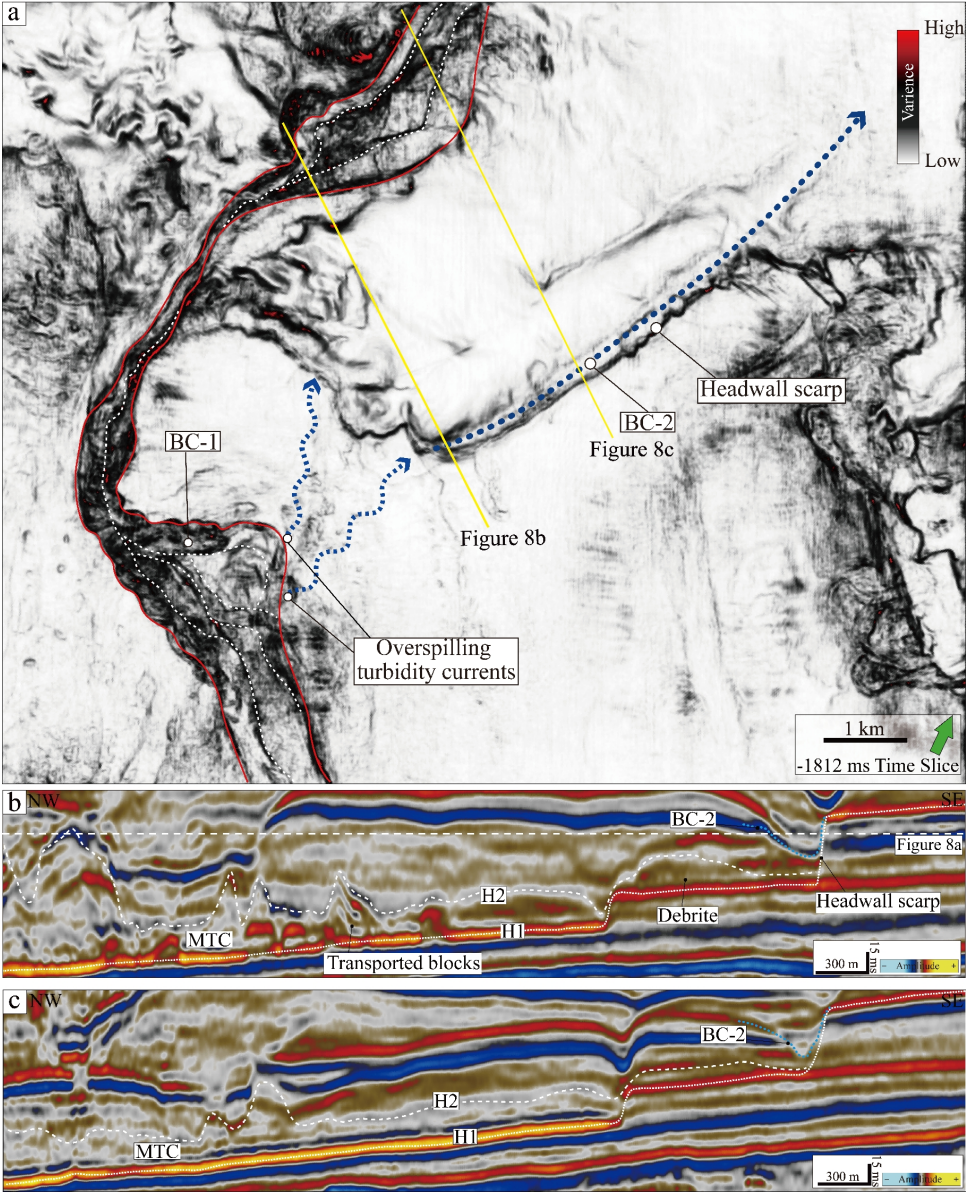


Figure 9

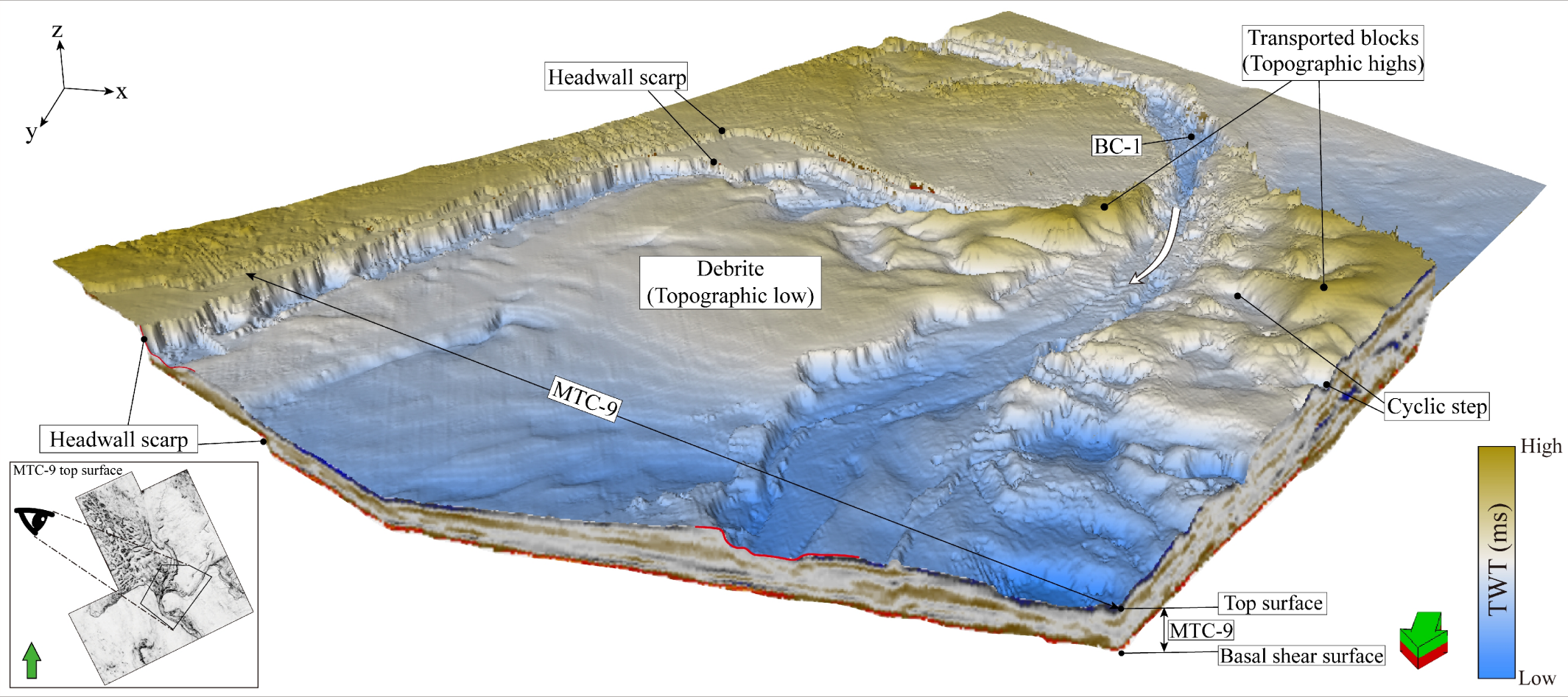


Figure 10

