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[Hua Huang](#), [Xiaoxia Huang](#)^{*}, [Fanchang Zeng](#)

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Article

Topographic and Sedimentary Controls on Submarine Canyon-Channel Systems Along the Adélie Land Margin

Hua Huang ^{1,2}, Xiaoxia Huang ^{2,*}, Fanchang Zeng ^{2,3}

¹ 1University of Chinese Academy of Sciences, Beijing, China

² 2Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences, Sanya

³ 3Sun Yat-Sen University, Zhuhai, China

* Correspondence: huangxx@idsse.ac.cn

Abstract

Submarine canyon-channel system plays a critical role as potential conduit for warm water upwelling in Antarctica, thereby influencing ice sheet stability. In this study, we identify 29 canyon-channel systems along the Adélie Land margin and conduct systematic morphometric analysis of their length, width, depth, width-to-depth (W/D) ratio, and sinuosity. The results reveal pronounced differences in the distribution and morphological evolution of canyon-channel systems between the Adélie Depression and the Adélie Bank. We propose that these differences are primarily controlled by the shelf-slope topography, sediment supply, and ice sheet dynamic process. As the main catchment area of the Wilkes Subglacial Basin (WSB), the Adélie Depression is fed by a focused, high-flux supply of glacial debris, leading to the development of large-scale progradation wedges and mass transport deposits. These conditions promote the formation of extensive canyon-channel systems with elongated, tortuous, and dendritic morphologies. In contrast, canyon-channel systems on the Adélie Bank are smaller, more isolated, and irregularly distributed, reflecting dispersed and episodic sediment supply combined with strong bottom-current reworking. This study elucidates how canyon-channel system morphology responds to the topography, sedimentation, and ice dynamics in high-latitude glaciated margins, providing important constraints on sediment transport pathways and ice-sheet-ocean interactions in Antarctica.

Keywords: canyon-channel system; sediment supply; topography; Adélie Land

1. Introduction

Submarine canyon-channel systems serve as critical conduits for sediment transport and heat exchange along high-latitude continental margins [3,4,23]. Deeply incised into the Antarctic shelf and slope, these systems are particularly well-developed along the margins of Wilkes Land and Adélie Land [23].

Submarine canyon-channel system represent the primary pathways for downslope transport of glacial sediments, exerting a first-order control on continental-margin stratigraphy [42]. In addition, canyons incising the continental shelf facilitate the cascading of dense shelf water (DSW), which contributes to the formation and export of Antarctic Bottom Water [4,30]. Crucially, these systems also act as topographic corridors that enable the on-shelf transport of modified Circumpolar Deep Water (MCDW) toward ice-covered regions, enhancing basal melting of ice shelves and potentially destabilizing ice-sheet dynamics through the delivery of oceanic heat [32,37,42].

The East Antarctic Ice Sheet stores a sea-level equivalent of approximately 52 m [18,37,40]. Its vulnerability is strongly influenced by the geometry of subglacial basins and the configuration of submarine canyon-channel system that incise the continental shelf and slope [40]. As the largest marine-based catchment in East Antarctica, the WSB lies mainly below sea level, in contrast to other

regions of the ice sheet [1,2] (Figure 1). This configuration renders it highly susceptible to warm-water intrusion and potential ice-sheet instability [25,46]. However, the geomorphic processes that control ocean connectivity to the basin remain poorly understood. In particular, a systematic analysis of morphometric variability and its genetic controls is lacking for the submarine canyon-channel system along the Adélie Land continental margin, which serves as the primary drainage conduit for ice streams from the WSB.

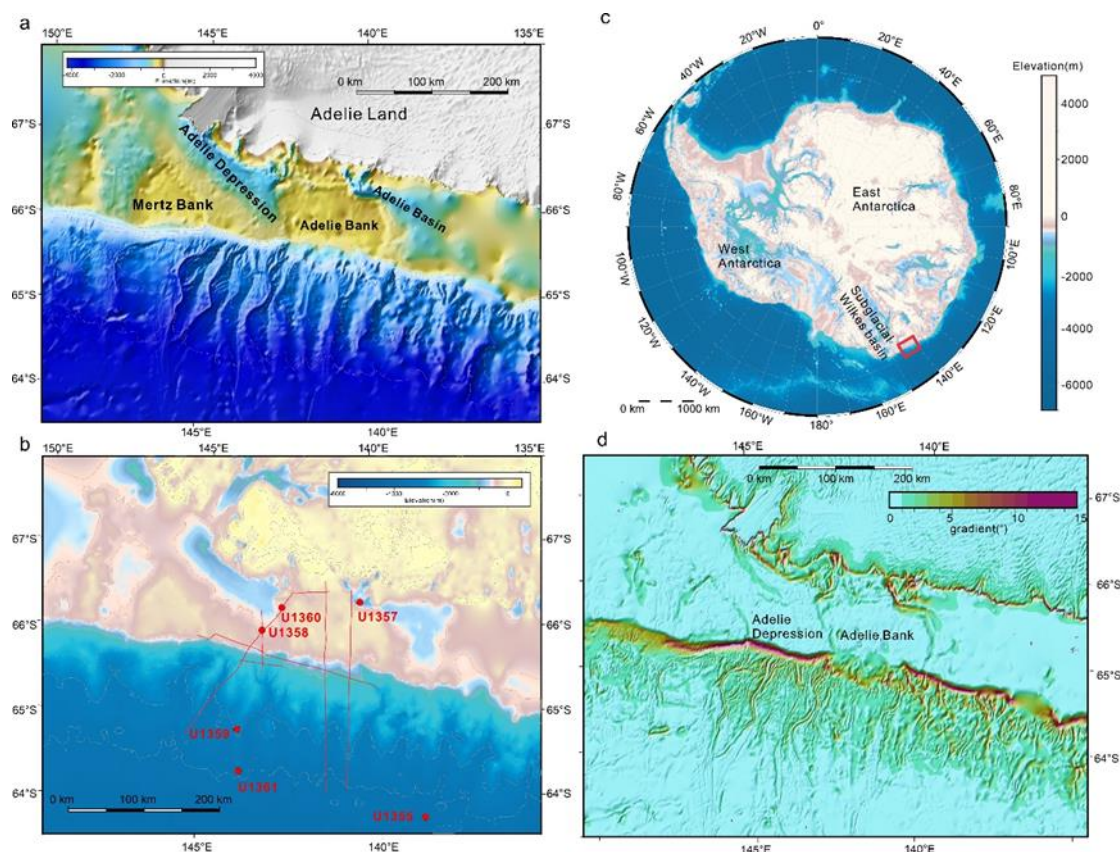


Figure 1. Study area. (a) The bathymetry map and (b) subglacial topography of the Adélie Land. (c) the location of study area in Antarctica (red tangle). (d) slope map of Adélie land.

This study presents a detailed geomorphic analysis of the submarine canyon channel system along the Adélie Land continental margin, with a comparative focus on the contrasting domains of the Adélie Depression and the Adélie Bank. By integrating the IBCSO v2 bathymetric compilation [24], and seismic profiles from the WEGA project, we aim to: (a) quantify key morphometric param, such as canyon length, incision depth, width, width-to-depth (W/D) ratio, and sinuosity; (b) compare the scale and cross-sectional geometries of canyon-channel systems originating from the front of the Adélie Depression with those incising the front of the Adélie Bank; and (c) evaluate the role of glacial dynamics and sediment supply in driving the observed geomorphic differences, supported by regional seismic data, drill-site information, and topographic constraints.

2. Geological Setting

The Wilkes Land margin formed during the Jurassic/Cretaceous period as a result of extensional deformation during the rifting between Australia and Antarctica [10,20,22]. Superimposed on regional post-rift subsidence, late-stage extensional deformation formed a series of longitudinal troughs [1,2]. The Adélie Depression, located seaward of the Mertz Glacier Tongue, incises the continental shelf to depths exceeding 1,000 m and serves as the primary conduit for transporting ice stream from the WSB to the ocean [12] (Figure 1). Its southeastern flank is bounded by the Adélie

Bank, a structural high composed of thinned continental crust that experienced mild flexural uplift during serpentinization of the continent-ocean transition zone [49].

The sedimentary sequence of the Adélie Land continental margin is a dual archive of both tectonic and climatic evolution [44]. These sedimentary layers are distinctly divided into syn-rift and post-rift sequences by major unconformities, recording the growth process of the continental margin [13,14]. Following the rift phase, the region entered a prolonged period of stable thermal subsidence, during which it received extensive hemipelagic turbidite deposits [21,43,48]. Since the gradual formation and expansion of the Antarctic ice sheet from the Eocene onwards, sedimentation has been primarily governed by glacial activity [14,47,48]. The repeated advances and retreats of Antarctic ice sheet have left a complex stratigraphic record on the shelf and continental slope, dominated by glacial deposits and gravity flow deposits [8,20].

The Adélie Bank is characterized by strata that are flat or very gently seaward-dipping (Eittrheim et al., 1995; Figure 1), which are areas bypassed by the most recent ice streams and where grounded ice has been slow moving or relatively immobile [17,26]. The Adélie Depression, with water depths exceeding 800 m and located in front of the Mertz Glacier, provides a favorable site for the accumulation of highly MCDW and DSW [23]. The underlying saline water mass can overflow through canyons on the continental slope, merging into the deep circulation of the Australian-Antarctic Basin and becoming an important component of Antarctic bottom current within the global circulation [10,14]. Moreover, calving events of the adjacent Mertz Glacier Tongue can significantly alter the local hydrological structure and circulation patterns, further highlighting the sensitivity of ice-ocean processes in this region (Bijl et al., 2018).

3. Data and Methods

The geomorphological analyses in this study is based on the International Bathymetric Chart of the Southern Ocean Version 2 (IBCSO v2, with a spatial resolution of 500 m × 500 m; Arndt et al., 2022). Subglacial topographic data were obtained from the MEaSUREs BedMachine Antarctica, Version 3 [40] (also at a 500 m × 500 m spatial resolution). The seismic reflection data were acquired in SEG-Y format from the Antarctic Seismic Data Library System (SDLS; accessible at <http://sdls.ogs.trieste.it>).

A submarine canyon-channel system is here defined as an elongate, negative topographic feature that incises the continental shelf/slope, extends to the abyssal plain, and exceeds 10 km in total length. Systems were initially identified using the automated watershed delineation tool in Global Mapper, followed by manual refinement. A systematic morphometric analysis was performed on canyon-channel systems within the Adélie Bank and Adélie Depression regions. The measured parameters include: (a) length, defined as the actual meandering distance of the channel; (b) straight length, representing the linear distance between the channel's head and terminus; (c) sinuosity index, calculated as the ratio of the system's actual length to its straight-line length; (d) width and depth, measured at cross-sections located at the head, middle, and lower sections of each system; and (e) width-to-depth (W/D) ratio, derived from the width and depth values obtained at each respective section. In addition, to comprehensively analyze the differences in the distribution of submarine canyon-channel systems, the slope of Adélie Land is calculated by the QGIS software. Seismic interpretation was conducted using Petrel software (Schlumberger), utilizing amplitude, internal seismic facies, reflection terminations, and geometry to identify sedimentary features and stratigraphic relationships.

4. Results

4.1. The Morphology of Canyon-Channel Systems

A total of 29 submarine canyon-channel systems were identified within the study area (16 in the Adélie Depression region and 13 in the Adélie Bank region, Table 1, Figures 2–4). On average, the canyon-channel systems of the Adélie Depression are longer (mean:73.4 ± 68.7km, Table 1, Figure 2) and exhibit higher sinuosity (mean sinuosity index: 1.07± 0.05, Table 1, Figure 2). In contrast, those in the Adélie Bank are shorter (average: 62.1 km) and straighter (mean sinuosity index: 1.05). Moreover, systems in the Adélie Bank are consistently wider than those in the Depression across all segments (upper, middle, and lower), with the most pronounced difference occurring in the lower segment (mean width: 11.9 km vs. 8.7 km).

Following the classification of Harris and Whiteway (2011)[33], these systems are categorized into two confinement types: slope-confined, which are restricted to the continental slope (20 in total), and shelf-incised types, which cut into the continental shelf (9 in total). Based on length, we further classify them into three scales: Type 1 (> 100 km), Type 2 (> 40 km), and Type 3 (< 40 km). The detailed morphometric characteristics of the canyon channel systems in both regions are described below.

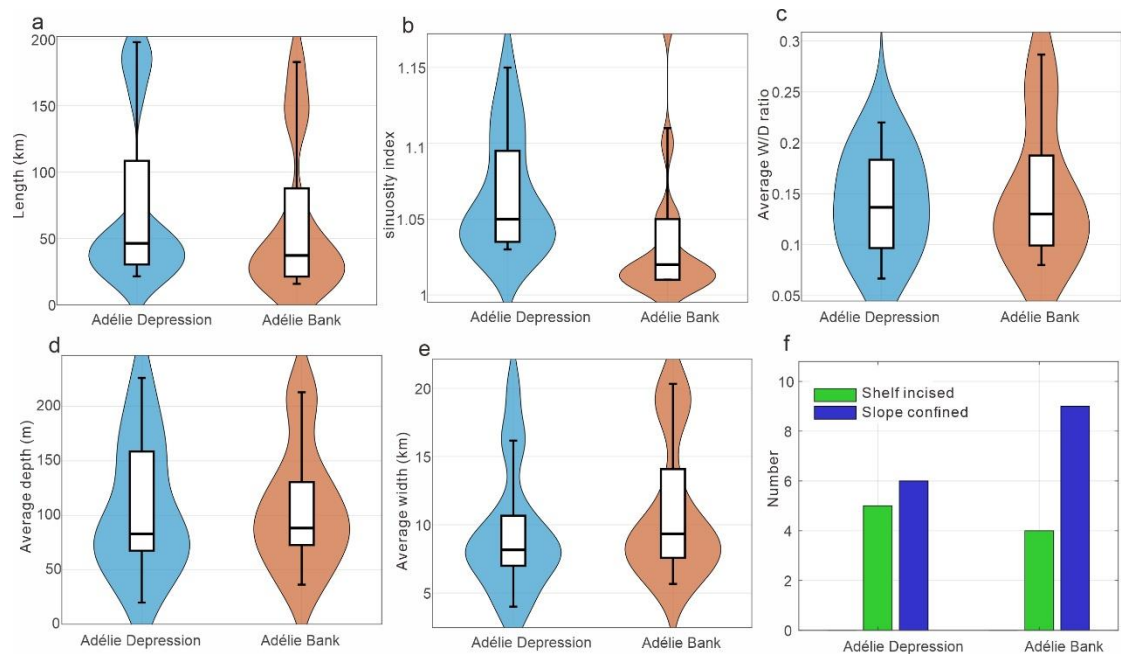


Figure 2. (a) average canyon-channel system length, (b) sinuosity index, (c) W/D ratio, (d) depth, (e) width and (e) canyon-channel type distribution on the Adélie Depression region and Adélie Bank region.

Table 1. Param of canyon-channel systems at the front of Adélie Depression and Adélie Bank

Area	Name	Type	Length (km)	Straight Length (km)	Sinuosity index	Width (km)			Depth(m)			W/D ratio		
						Head	middle	lower	Head	middle	lower	Head	middle	lower
Adélie Depression	C1	slope confine	21.5	20.5	1.05	7.0	9.0	4.0	37	135	89	0.19	0.07	0.04
	C2	slope confine	35.7	32.9	1.09	14.0	6.0	5.0	192	19	25	0.07	0.32	0.20

	C3	shelf-incised	48.6	47.4	1.03	6.0	6.0	4.0	68	40	89	0.09	0.15	0.04
	C4	slope confine	28.3	27.3	1.04	4.0	5.0	3.0	23	23	14	0.17	0.22	0.21
	C5	slope confine	22.8	22.1	1.03	4.0	4.0	4.0	34	62	18	0.12	0.06	0.22
	C6	shelf-incised	32.5	31.6	1.03	8.0	8.0	6.0	345	108	32	0.02	0.07	0.19
	C7	slope confine	198	172.1	1.15	15.0	18.0	16.0	367	253	58	0.04	0.07	0.28
	C8	slope confine	39	35.6	1.10	7.0	8.0	9.0	48	140	20	0.15	0.06	0.45
	C9	shelf-incised	181	170.4	1.06	8.0	16.0	9.0	22	205	65	0.36	0.08	0.14
	C10	slope confine	48.6	47.1	1.03	9.0	8.0	8.0	68	105	293	0.13	0.08	0.03
	C11	slope confine	157	151.4	1.04	10.0	25.0	13.0	137	180	61	0.07	0.14	0.21
	C12	shelf-incised	60	53.7	1.12	9.0	8.0	10.0	140	265	88	0.06	0.03	0.11
	C13	slope confine	185	165.0	1.12	8.0	30.0	22.0	112	427	58	0.07	0.07	0.38
	C14	shelf-incised	44	42.0	1.05	12.0	5.0	6.0	35	57	80	0.34	0.09	0.08
	C15	slope confine	50	48.0	1.04	10.0	9.0	12.0	49	81	81	0.20	0.11	0.15
	C16	slope confine	22	20.6	1.07	9.0	7.0	8.0	65	111	56	0.14	0.06	0.14
	mean	/	73.4±68.7	68.0±63.1	1.07±0.05	8.8± 3.8			109± 105.2			0.14± 0.09		
Adélie Bank	C17	slope confine	34.4	34.1	1.01	8.0	5.0	9.0	88	91	86	0.09	0.05	0.10
	C18	slope confine	15.8	15.5	1.02	6.0	5.0	12.0	23	17	69	0.26	0.29	0.17
	C19	shelf-incised	153	138.6	1.10	17.0	8.0	30.0	169	170	276	0.10	0.05	0.11
	C20	slope confine	48	46.9	1.02	14.0	6.0	6.0	120	93	36	0.12	0.06	0.17
	C21	slope confine	138	137.2	1.01	11.0	26.0	24.0	69	141	46	0.16	0.18	0.52
	C22	slope confine	18	17.2	1.05	4.0	8.0	7.0	20	94	75	0.20	0.09	0.09
	C23	shelf-incised	40.4	38.5	1.05	13.0	16.0	9.0	189	61	86	0.07	0.26	0.10
	C24	shelf-incised	183	180.3	1.01	10.0	29.0	18.0	133	394	112	0.08	0.07	0.16
	C25	shelf-incised	37.2	36.9	1.01	8.0	14.0	7.0	12	264	171	0.67	0.05	0.04
	C26	slope confine	22.6	22.4	1.01	4.0	8.0	5.0	31	58	34	0.13	0.14	0.15

C27	slope confine	22	21.6	1.02	7.0	9.0	12.0	84	110	34	0.08	0.08	0.35
C28	slope confine	71	60.2	1.18	8.0	12.0	8.0	34	105	207	0.24	0.11	0.04
C29	slope confine	19	18.9	1.01	8.0	8.0	8.0	175	57	141	0.05	0.14	0.06
mean	/	62.1± 63.4	59.2± 60.0	1.04± 0.05	11± 6.4			106.7± 78.2			0.15± 0.13		

4.1.1. Canyon-Channel Systems at the Mouth of Adélie Depression

16 submarine canyon-channel systems were identified at the mouth of Adélie Depression (Figure 3, Table 1). These systems typically form a dendritic transport network, where smaller, upstream canyons (e.g., slope-confined types such as C1 and C2)—predominantly developed on the continental slope with lengths under 50 km—converge downstream into larger shelf-incised or slope-confined systems. Type 1 canyon-channel systems (C7, C9, C11, C13) range in length from 157 to 198 km (Table 1). Their widths measure 8–15 km at the head, 16–30 km in the middle, and 9–22 km in the lower section. Head incision depths vary substantially from 22 to 367 m and decrease markedly downstream; for example, in C7, depth declines from 367 m to 58 m. Sinuosity indices range from 1.04 to 1.15. The width-to-depth (W/D) ratio also varies considerably along the thalweg: except for C9, which shows a decrease from 0.36 to 0.14, all other systems exhibit a pronounced increase in W/D. Notably, C13 transitions from a V- to a U-shaped cross-section as its W/D ratio rises from 0.07 at the head to 0.38 in the lower section. Type 2 canyon-channel systems (C3, C6, C10, C12, C14, C15) range in length from 44 to 60 km. Head incision depths range widely from 22 to 345 m and follow divergent downstream trends: C14 deepens from 35 m to 80 m, whereas C6 shallows markedly from 345 m to 32 m. Sinuosity varies from 1.03 to 1.12. Changes in W/D ratio and cross-sectional shape are not uniform: in C15 the ratio decreases from 0.20 to 0.15, while in C6 it increases sharply from 0.02 to 0.19. Type 3 systems (C1, C2, C4, C5, C8, C16) range in length from 21.5 to 39 km, primarily developing on the upper continental slope (Table 1 and Figure 3). Head incision depths range from 23 to 192 m, with generally limited variation along the thalweg. Sinuosity is consistently low (1.03–1.09). Downstream changes in W/D ratio are modest: C2 increases from 0.07 to 0.20, while C16 remains stable around 0.14.

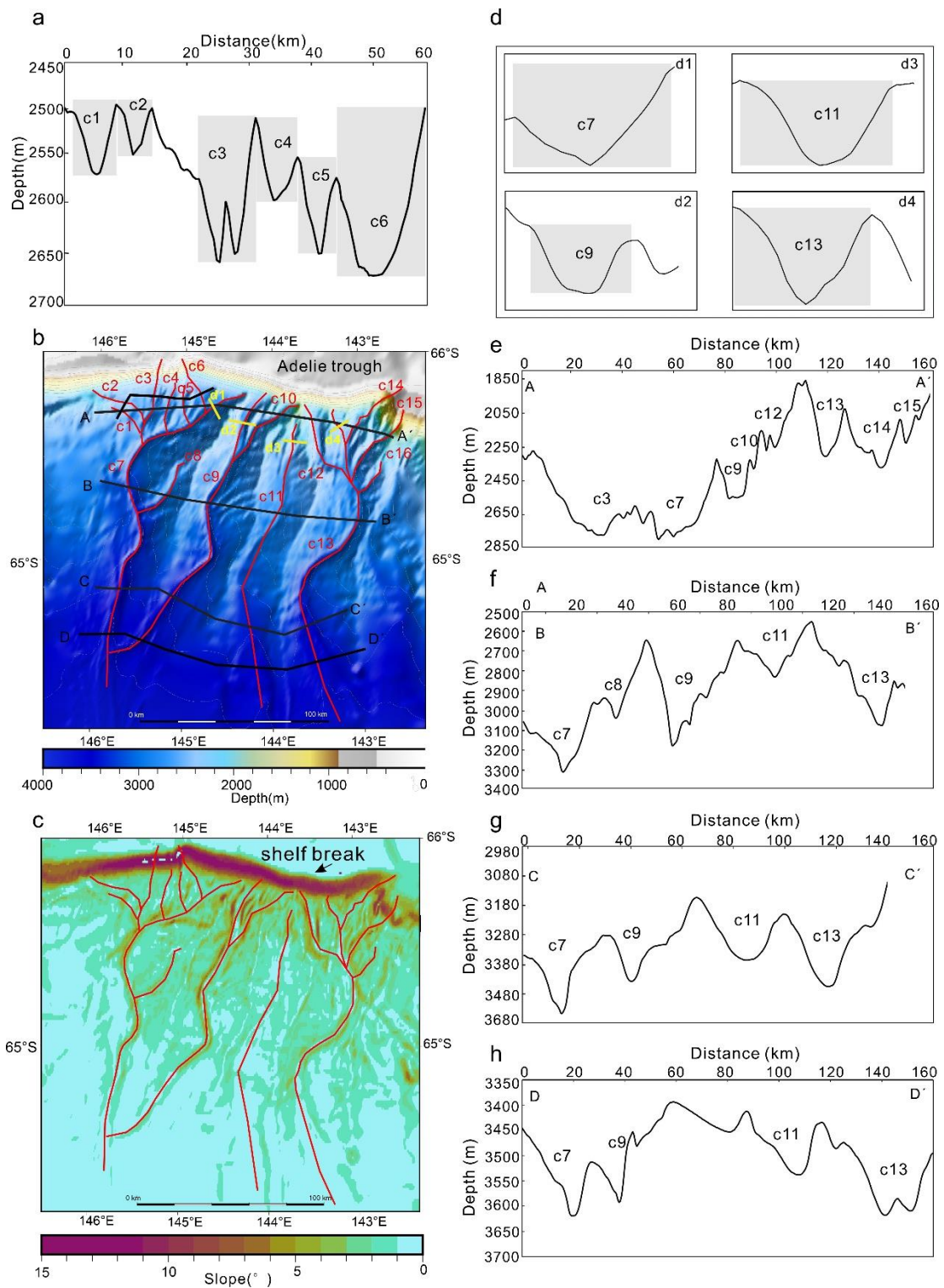


Figure 3. The distribution of canyon-channel systems at the front of Adélie Depression, (b) canyon-channel systems map on the bathymetry map and (c) slope map of Adélie Depression area, (a, d, e, f, g, h) the cross-section profiles of the different sections of canyon-channel system.

4.1.2. Canyon-Channel Systems in Front of Adélie Bank

Morphometric analysis of the Adélie Bank region identified 13 major submarine canyon-channels (C17–C29, Figure 4, Table 1). Most systems are single-branched; only three dendritic networks are present: one formed by C17, C18, and C19; another by C23, C24, and C26; and a third by C28 and C29 (Figure 4).

Type 1 canyon-channel systems (C19, C21, and C24) measure between 138 and 183 km in length. Their widths range from 10–17 km at the head, 8–29 km in the middle section, and 18–30 km toward the lower section (Figure 4, Table 1). Head incision depths vary from 69 to 169 m, and longitudinal depth profiles are complex, C21 deepens initially from 69 m to 141 m before shallowing to 46 m, whereas C24 deepens continuously along its thalweg from 133 m to 394 m and then to 111.6 m (Figure 4, Table 1). The sinuosity index of this group falls between 1.01 and 1.10. Downstream trends in the width-to-depth ratio also differ, as C19 and C24 show gradual increases, from 0.10 to 0.11 and from 0.08 to 0.16 respectively, while C21 exhibits a pronounced rise from 0.16 to 0.52. Type 2 canyon-channel systems (C20, C23, and C28) range from 40.4 to 71 km in length (Figure 4, Table 1). Their widths vary between 8–14 km at the head, 6–16 km in the midsection, and 6–12 km in the lower section. Head depths range from 34 to 189 m, and the down-canyon depth profiles differ markedly. For example, C28 deepens continuously from 34 m to 105 m and then to 207 m, whereas C20 shallows progressively from 120 m to 93 m and then to 36 m (Table 1). Sinuosity indices lie between 1.05 and 1.18. Down-canyon trends in W/D ratio also vary (Figure 4, Table 1). Type 3 canyon-channel systems (C17, C18, C22, C25, C26, C27, C29) have lengths ranging from 15.8 to 37.2 km, with widths of 4–8 km at the head, 5–14 km in the midsection, and 5–12 km in the lower section. The sinuosity indices of this group are very close to 1, ranging from 1.01 to 1.05. As in the other types, both incision depths and W/D ratios show diverse along-thalweg trends (Table 1).

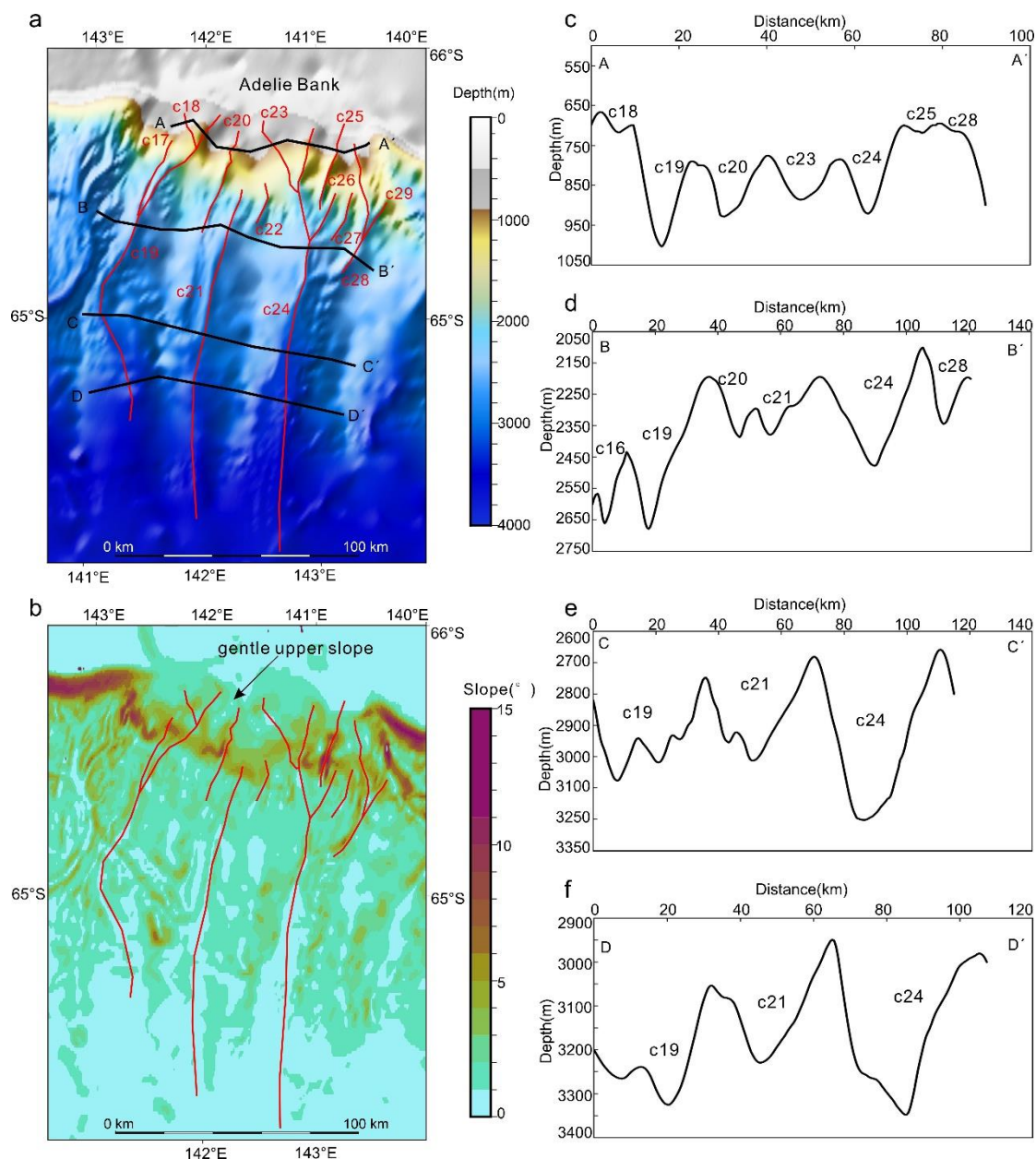


Figure 4. The distribution of canyon-channel systems on the Adélie Bank margin, (b) canyon-channel systems map on the bathymetry map and (c) slope map of Adélie Bank area, (a, d, e, f) the cross-section profiles of the different sections of canyon-channel systems.

4.2. Difference in Continental Margin Morphology Between the Adélie Depression and the Adélie Bank

Bathymetric data and seismic profiles (Figures 4 and 5) reveal distinct topographic and sedimentary characteristics between the continental margins of the Adélie Depression and the Adélie Bank. The Adélie Depression region is characterized by a large-scale depression, with a maximum depth of approximately 340 m near the shelf edge (Figure 5d). The depression extends about 130 km parallel to the shelf edge and shows a clear trend of shallowing seaward (Figure 5d). The shelf break in this area is steep, with local slopes reaching up to 12° (Figure 5f). More notably, the continental slope fronting the depression is exceptionally steep, with the upper slope exceeding 7.62° (Figure 5c). This steep gradient produces a sharp transition in water depth from the shelf edge to the deep basin (Figure 5c), resulting in highly rugged and variable topography. In contrast, the Adélie Bank (corresponding to the profile areas shown in Figure 5b,e) exhibits a gentler morphology. Slopes at the shelf break are significantly lower than those in the depression, with a maximum of only $\sim 8^\circ$ (Figure 5e). The continental slope fronting the bank is broadly gradual, and the maximum gradient on the upper slope is merely 1.99° (Figure 5b). As shown in the profile in Figure 5b, water depth increases gradually from the shelf edge to the deep basin, with minimal topographic variation, forming a wide and uniformly gentle slope.

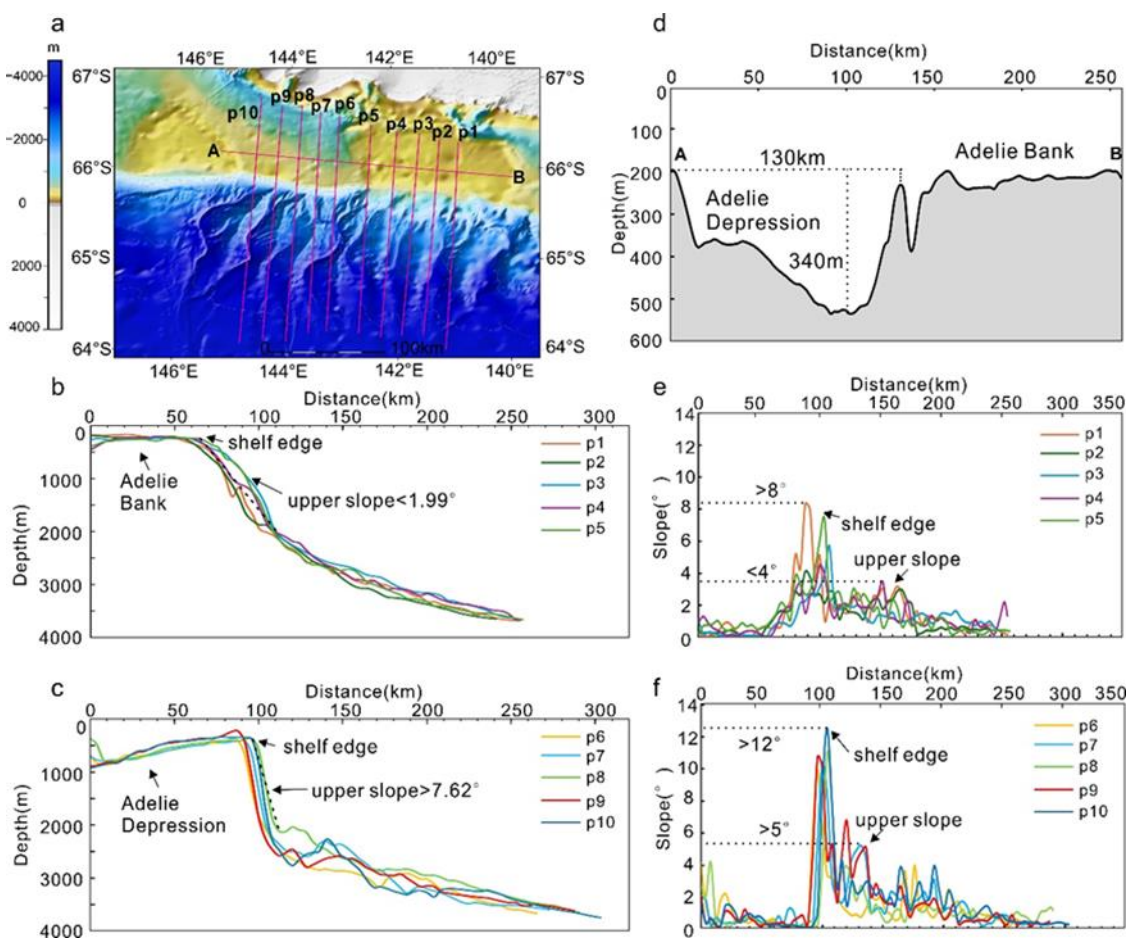


Figure 5. Cross-section along continental margin of Adélie Depression and Adélie Bank region. (a) the location of cross-section profile, (b, c) the depth of these profiles extracted from bathymetry map, (d) The cross section across the outer continental shelf and (e, f) slope profile along the continental slope extracted from slope map.

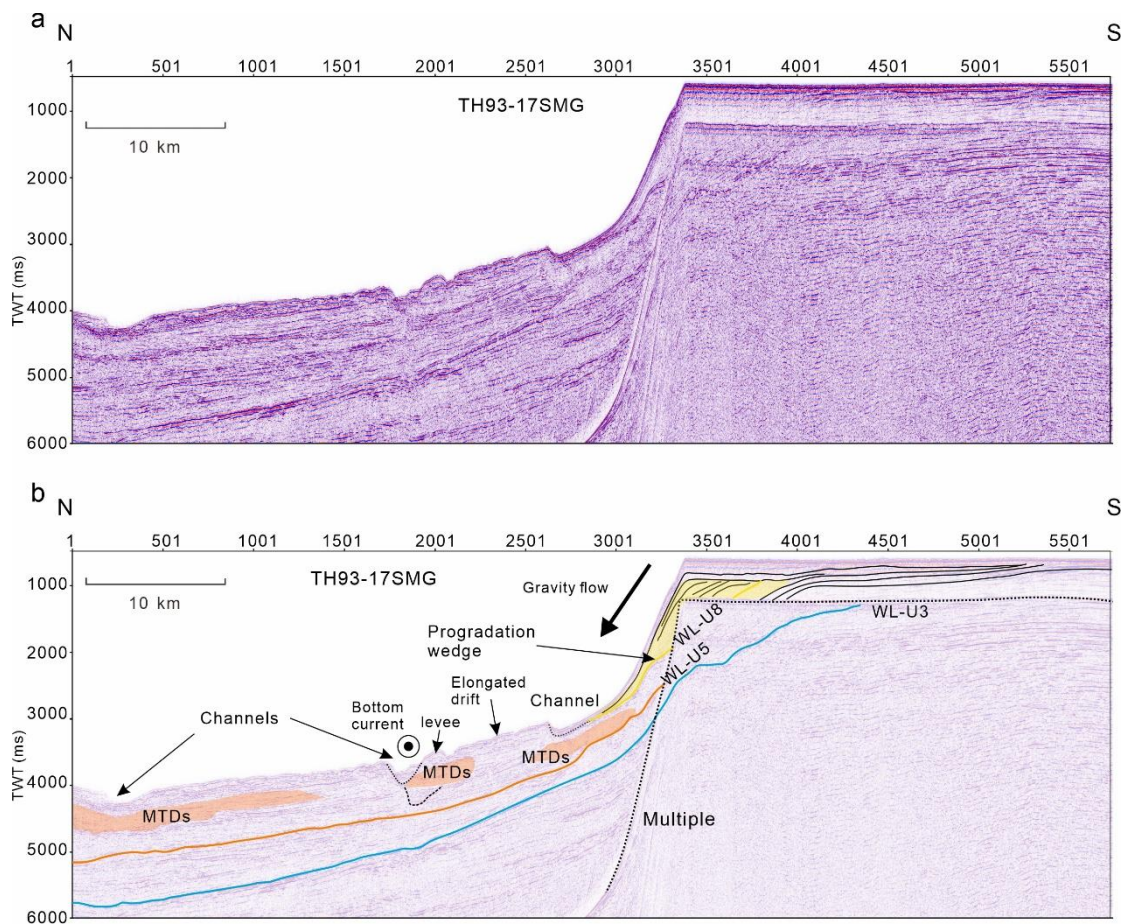


Figure 6. Seismic profile and interpretation showing major Unconformity, channels, mass transport deposits (MTDs), progradation wedge, elongated drift, and direction of Bottom water and gravity flow. The location of this seismic line is displayed in Figure 1a. TWT, two-way travel time.

Based on seismic reflection data and drilling data from the region in Integrated Ocean Drilling Program Expedition 318 [27], three discontinuities are identified in the Adélie Land continental margin: WL-U3, WL-U5, WL-U8, along with various types of sedimentary features. In Profile TH93-17SMG (refer to your figures), we observe a distinct progradation wedge above WL-U8 (CDP 3001-4001), and significant channel erosion is noted in the lower slope to continental rise area, mainly occurring above the WL-U5 discontinuity. Additionally, above the WL-U5 discontinuity, Mass Transport Deposits (MTDs) are prominently developed in the lower slope/rise region. These deposits appear as broadly tabular to lens-shaped bodies, with internally chaotic to semi-transparent structures, underlain by high-amplitude reflectors corresponding to strongly erosional surfaces. The largest MTD measures 400 ms TWT in thickness and 18 km in width, while the smallest is 500 ms TWT thick and 4 km wide (Figure 6). Additionally, an elongated drift deposit with an asymmetrically mounded geometry and laterally inclined edges is identified in the lower slope area, situated between two canyon-channel systems (Figure 6). In Profile TH93-08SMG, landward-migrating sediment waves are clearly developed above the WL-U8 interface in the continental rise area (CDP 1297–2200). The reflection structure is primarily parallel and wavy, with a thickness of 600 ms (TWT) and a width of 10 km. Significant slump deposits were observed on the slope (CDP 3000-3500), with small MTDs found at the lower end of the slump (~thickness of 300 ms and width of 4 km). Additionally, multiple phases of channel burial and migration are observed above the WL-U8 discontinuity in the lower slope to continental rise area (near CDP 2592 and 649).

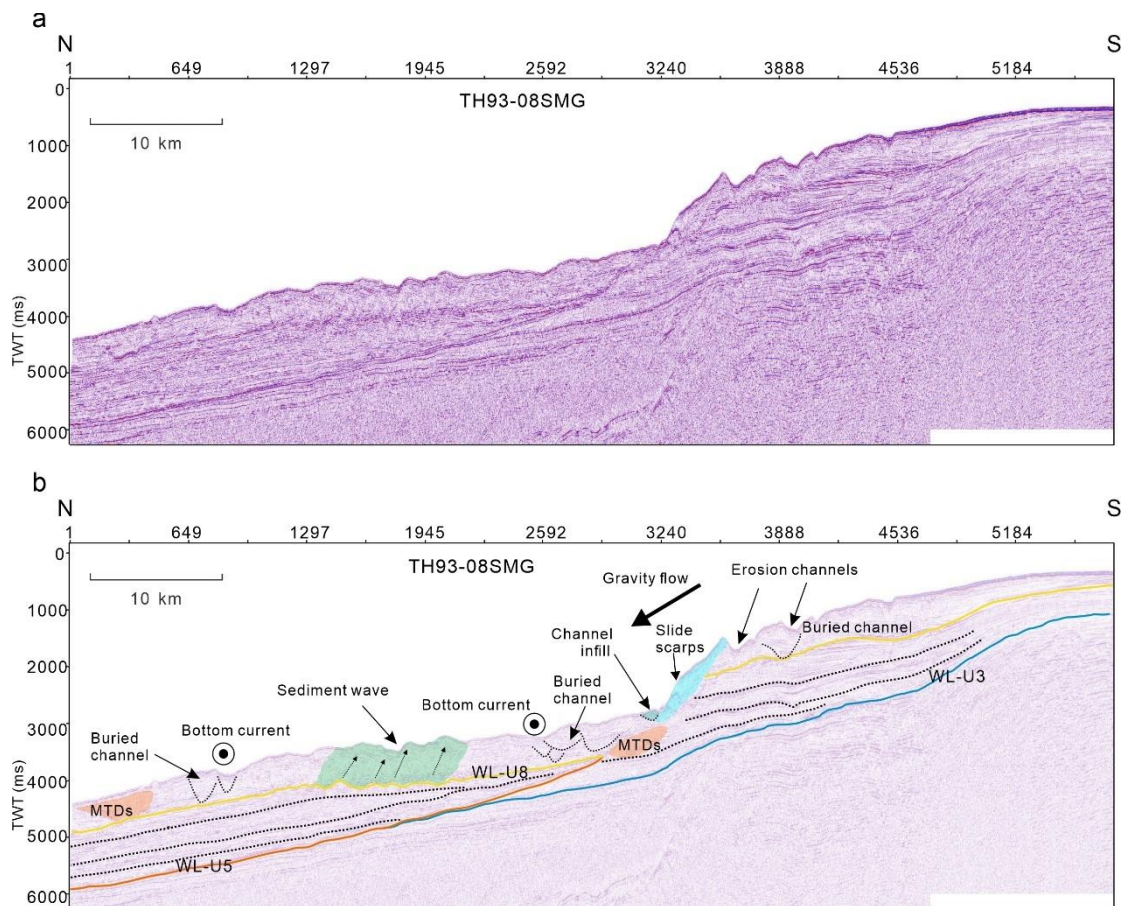


Figure 7. Seismic profile and interpretation showing major Unconformity, channels, sediment waves, mass transport deposits (MTDs), drift, slide scarps, channels, channel infill, and direction of Bottom water and gravity flow. The location of this seismic line is displayed in Figure 1a. TWT, two-way travel time.

5. Discussion

5.1 Influence of Shelf-Slope Topography on Submarine Canyon-Channel Systems

The continental shelf and slope of the Adélie Depression and the Adélie Bank exhibit significant morphological differences (Figures 1 and 6, Table 1). The shelf in the depression is characterized by glacially excavated troughs, while the bank forms a relatively elevated shallow platform. Correspondingly, the slope of the depression is notably steeper, with a more pronounced gradient change at the shelf edge. These topographic differences are reflected in the morphology of the submarine canyon-channel systems developed in each region (Figures 2, 3, 4 and 8, Table 1). The canyon-channel systems formed within the Adélie Depression typically exhibit a more dendritic structure and greater longitudinal extent (Figure 8). In these systems, the W/D ratio of the main trunk canyon-channel generally shows an increasing trend from upstream to downstream (Table 1). In contrast, the canyon-channel systems located at the front of the Adélie Bank are more isolated. They are characterized by shorter lengths, and the W/D ratio within individual systems fluctuates irregularly along their thalwegs (Figure 4, 8, Table 1).

The morphological differences along the continental margin likely explain the divergent development of submarine canyon-channel systems in the two regions. The deep glacial trough developed in Adélie Depression forms a convergent sediment feeder trough [15,29]. And its steep continental slope provides substantial potential energy for gravity flows [31]. This topographic setting directly facilitates the development of extensive, dendritic canyon-channel networks. Large canyons formed under these conditions (e.g., C7, C13) reach lengths of 185–198 km, and their width-to-depth (W/D) ratios show a systematic and marked downstream increase (e.g., C13 from 0.07 to 0.38), indicating a pronounced widening and shallowing trend. This morphological evolution

corresponds with the large-scale mass-transport deposits (MTDs) identified in seismic data downslope (Figure 6). These deposits record the process of high-energy gravity flows losing energy abruptly at the base of the steep slope, resulting in deposition accompanied by lateral accretion, consistent with the typical gravity-flow-dominated model [7] (Figure 8a). In contrast, the shallow bank and gentle slope topography at the front of the Adélie Bank result in dispersed sediment supply and lower energy of gravity flows (Figure 8b). Consequently, canyon-channel systems here are smaller in scale, dominated by relatively isolated, small- to medium-sized canyons, and lack well-developed dendritic networks (Figure 8b). Their morphological param, particularly the along-path variation in W/D ratios, exhibit high diversity (e.g., C21 shows a significant increase while C28 decreases sharply), with no uniform trend. This reflects that, in the gentle slope setting, canyon-channel system morphology is more controlled by local factors [16,35] (such as the intensity of bottom-current reworking and original micro-topography). Their formation process results from the interplay or superimposed modification by various actions of gravity flows and bottom currents [34]. Ultimately, differences in shelf-slope topography, by controlling the concentration of sediment supply and the initial energy of gravity flows, fundamentally determine the distribution and evolution of submarine canyon-channel systems.

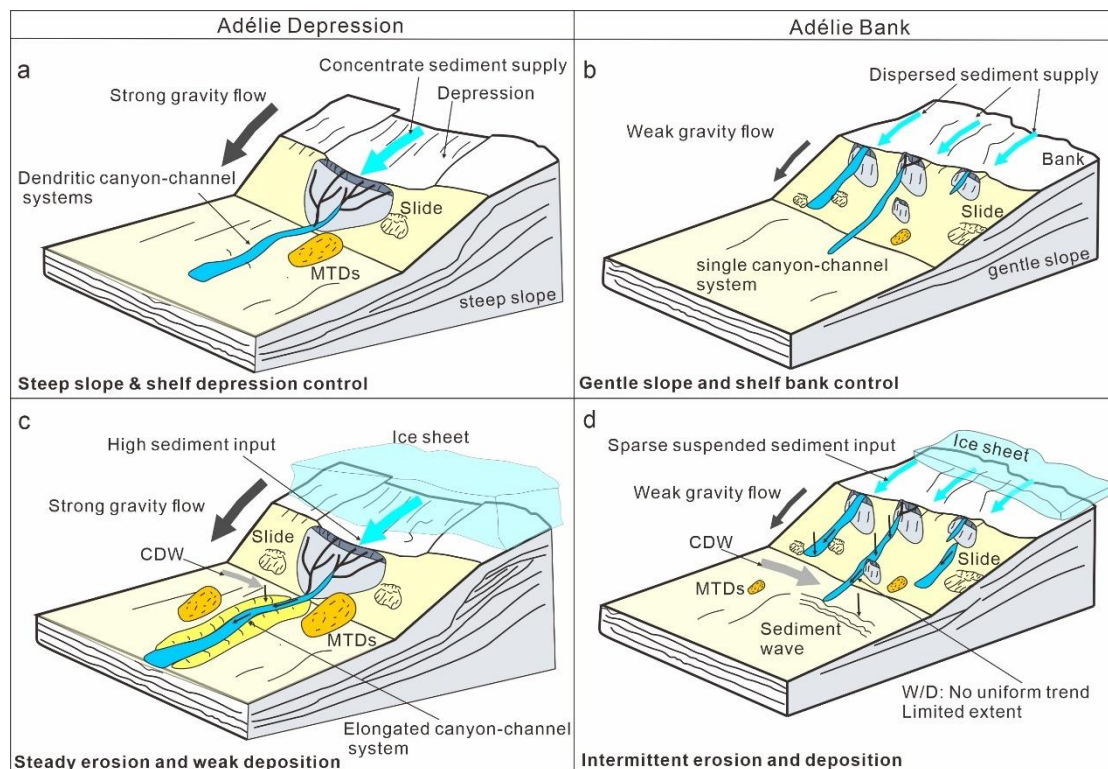


Figure 8. Conceptual model of controlling factors on submarine canyon-channel system morphology along the Adélie Land margin, East Antarctica. Adélie Depression: extensive dendritic canyon-channel systems, Adélie Bank: separated single-branch canyon-channel system. (a-b) Shelf-Slope control on canyon-channel development, (c, d) Ice-sheet dynamics and sediment supply on the evolution of submarine canyon-channel systems.

5.2. Ice-Sheet Dynamics and Sediment Supply on the Evolution of Submarine Canyon-Channel Systems

Adélie Land is situated at the forefront of the WSB, the largest marine-based ice sheet catchment in East Antarctica [18]. The substantial ice melt and ice stream discharge in this region generate dense downslope flows along the continental margin [5]. These dense turbidity currents are likely responsible for the formation of the submarine canyon-channel systems observed on the Adélie Land continental margin [30]. Due to contrasts in topography and setting, sediment sources and supply rates along the Adélie Depression and the Adélie Bank exhibit significant variations due to

differences in topography and location [10,20] (Figure 8), potentially leading to diverse morphological characteristics of submarine canyon-channel systems, such as length, width, and W/D ratios [6,7,33].

The progradation pattern of glaciated margins is typically associated with sediment supplied by ice sheets or ice streams during glacial maxima [38]. A distinct progradation wedge is observed in the upper slope area of Adélie Depression, providing direct evidence of concentrated sediment supply and the episodic, large-scale seaward progradation of deposits [9] (Figure 4, 5, Figure 8c). The channel-levee depositional system at the front of Adélie Depression is primarily formed by sediment transport via downslope turbidity currents and is subsequently reworked by weak to moderate bottom currents [39,51] (Figure 6, Figure 8c). During deglacial and interglacial periods, the rapid retreat or rebound of ice sheets alter pressure fields and hydrology, triggering massive block slides of glacial till and the formation of large-scale MTDs [34]. The emplacement of MTDs initially creates negative topography or slump scars on the continental slope. Along these weak zones flow sustained, high-frequency, and high-density turbidity currents generated by meltwater and sediment resuspension [19,41]. With erosive power far exceeding that of normal sedimentation, these currents intensely scour the valley floor and sidewalls through headward and lateral incision, with erosion being particularly pronounced along the steep discontinuities formed by the MTDs themselves [45]. This process ultimately leads to the formation of large, extensive canyon-channel systems (e.g., C7 extends 198 km, and C9 extends 181 km).

In contrast to Adélie Depression, the Adélie Bank lacks a concentrated and abundant sediment supply, which is sourced from extensive bank, resulting in a dispersed, multi-point input [27,50] (Figure 8d). These discrete source areas deliver sediments of varying grain sizes and volumes, leading to differences in the properties and fluxes of material entering individual canyon-channel systems [11,50]. Furthermore, the landslides and MTDs observed in the profile TH93-08MSG indicate that sediments may be introduced through various mechanisms (Figure 7), such as small-scale landslides, intermittent meltwater runoff, or suspension transport by currents [5,28,36]. This discontinuous, pulsed supply causes alternating periods of depositional events and erosional events within the canyon-channel systems over time and space. Additionally, the presence of extensive landward-migrating sediment waves indicates that bottom currents play a dominant role in current activity in this area (Figure 7), interacting with gravity flows along the margin of the Adélie Bank [34,44]. Different processes may temporarily dominate in various canyon-channel system sections, creating differentiated erosion-deposition balances that lead to irregular fluctuations in W/D ratios along the thalweg (Figure 8d).

6. Conclusions

Based on the integrated bathymetric data and seismic profiles, this study systematically analyzes the significant differences in morphology, distribution, and genetic mechanisms of submarine canyon-channel systems between the Adélie Depression and the Adélie Bank. The main conclusions are as follows:

(a) The canyon systems in the Adélie Depression are generally longer, more sinuous, and exhibit dendritic networks, with width-to-depth ratios typically increasing downstream. In contrast, canyon systems on the Adélie Bank are shorter, straighter, predominantly consist of isolated single branches, and show irregular along-channel variations in width-to-depth ratios. (b) The steep continental slope (with gradients $>12^\circ$) in the Depression favor the acceleration of gravity flows and enhance incision, promoting the development and elongation of large canyon systems. In comparison, the gentle slope of the Bank (maximum gradient $\sim 1.99^\circ$) and uniform topography restrict channel convergence and longitudinal extension. (c) As the primary outlet of the subglacial basin, the Depression receives concentrated and sustained glacial sediment input. During deglacial periods, frequent mass failures and high-density turbidity currents shape large canyon-channel systems. Conversely, sediment supply to the Bank is dispersed, dominated by small-scale landslides, intermittent meltwater runoff, and suspended transport. Depositional processes here are significantly reworked by bottom currents,

leading to the development of extensive landward-migrating sediment waves. This study underscores the critical control exerted by shelf-slope topography and sediment supply on high latitude canyon channel evolution, providing key insights into glacial marine sedimentation and ice sheet–ocean interactions in Antarctica.

7. Patents

Author Contributions: Conceptualization, methodology, and software, Hua Huang; formal analysis, writing—original draft preparation, Hua Huang; writing—review and editing, Fanchang Zeng; visualization, supervision, project administration and funding acquisition, Xiaoxia Huang. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The bathymetric data used for channel identification in the study is available through Dorschel et al., 2022 (The International Bathymetric Chart of the Southern Ocean Version 2, <https://doi.org/10.1038/s41597-022-01366-7>.) Seismic-reflection profiles that were used in this study are available from the Antarctic Seismic Data Library System (SDLS) in SEG-Y format (<http://sdls.ogs.trieste.it>). The data of submarine channel morphometric parameters supporting this study is available in the supporting information during peer review. Upon acceptance, the complete dataset will be permanently archived in Zenodo (<https://zenodo.org/>) with a persistent DOI.

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