Chapter 36
Contrasting Development of the Latest Quaternary Slope Failures and Mass-Transport Deposits in the Ulleung Basin, East Sea (Japan Sea)

Sang Hoon Lee, Jang-Jun Bahk, Han Joon Kim, Gil-Young Kim, Seong-Pil Kim, Sueng-Won Jeong, and Sung-Sik Park

Abstract In order to understand how the variations in shelf morphology and sediment supply to the shelf within a basin can change the occurrence styles of slope failures and mass-transport deposits (MTDs), this chapter details dimensions and morphology of the latest Quaternary slope failures and MTDs on the western and southern margins of the Ulleung Basin. On the western margin, the slides and slumps have relatively small dimensions with a few small, scoop-shaped scars and gullies deeper than 700 m water depth. The downslope mass-flow deposits occur as small, solitary lobes restricted at the base-of-slope. On the western margin, the small sediment input to the shelf and the prominent Hupo Bank and Hupo Trough blocking sediment delivery to the slope probably caused relatively low accumulation of muddy sediments in the slope, most likely resulting in the small dimensions of slope failures, and the restricted occurrence of small MTDs at the base-of-slope. In contrast, the southern margin is characterized by large dimensions of gullied scars with huge slides and slumps deeper than 250 m water depth. These catastrophic failures evolved into extensive mass flows, which travelled downslope for several tens of kilometers. On the southern margin, the flat, broad shelf and the high sediment supply to the shelf during the last glacial period probably caused relatively high accumulation of mixed muddy and sandy sediments in the upper slope. These conditions could have promoted large-scale slope failures along the entire upper slope, forming the extensive occurrence of MTDs in the middle to lower slopes.

S.H. Lee (✉) • H.J. Kim
Department of Marine Environment Research, Korea Institute of Ocean Science and Technology, Ansan 426-744, South Korea
e-mail: sanglee@kordi.re.kr; sanglee@kiost.ac

J.-J. Bahk • G.-Y. Kim • S.-P. Kim • S.-W. Jeong
Korea Institute of Geoscience and Mineral Resources, Daejeon 305-330, South Korea

S.-S. Park
Kyungpook National University, Daegu 702-701, South Korea

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This study provides an example that the variations in shelf morphology and sediment supply to the shelf within a basin can affect the styles of slope failures and MTDs by controlling sediment input and sediment types to the slope.

Keywords Submarine slope failure • Submarine mass-transport deposits • Mass-flow deposits • Ulleung Basin • East Sea (Japan Sea)

36.1 Introduction

Submarine slope failures are common in various sedimentary environments worldwide, particularly along open continental slopes, submarine canyons, flanks of volcanic ridges and islands, prodelta slopes, and fjord slopes (Piper et al. 1985; Hampton et al. 1996; Locat and Lee 2002). These slope failures are generally controlled by various factors, such as sedimentation rate, sediment types, sea-level changes, earthquakes, gas-hydrate dissociation, etc., giving rise to a variety of the slope-failure styles (Mulder and Cochonat 1996; Locat and Lee 2002; Canals et al. 2004). The styles of submarine slope failures affect sedimentary features (dimension, run-out distance, geometry, etc.) of the downslope associated mass-transport deposits (Mulder and Cochonat 1996; Piper et al. 1999; Lastras et al. 2004; Lee et al. 2004; Tripsanas et al. 2008).

In the Ulleung Basin, East Sea (Japan Sea), a variety of slope failures and mass-transport deposits (MTDs) formed during the last glacial period occur along the entire basin margins (Fig. 36.1; Chough et al. 1997; Lee et al. 1999, 2004). Even though the MTDs and slope failures show a contour-parallel distribution along the basin margins in general (Fig. 36.1), the styles of slope failures and MTDs are contrasting between the western and the southern margins, reflecting different types of shelf morphology and sediment supply to the shelf along the margins. In this chapter, we detail the dimensions, occurrence and morphology of slope failures and MTDs and the linked shelf morphology on the western and southern margins. Based on these characteristics, this chapter illustrates how the variations in shelf morphology and sediment supply to the shelf within a basin can affect the occurrence styles of slope failures and MTDs by controlling sediment input and sediment types to the slope.

36.2 Geological Setting

The Ulleung Basin is a semi-enclosed back-arc basin formed behind the Japanese Arc (Fig. 36.1; Yoon and Chough 1995). The basin is bordered by the continental margin of the Korean Peninsula, the Korea Plateau, the Oki Bank and the Japanese Arc. The continental shelf of the Korean Peninsula is narrow (<25 km wide) and is flanked by a steep (4–10°) slope (Fig. 36.1). The shelf includes the N–S-trending

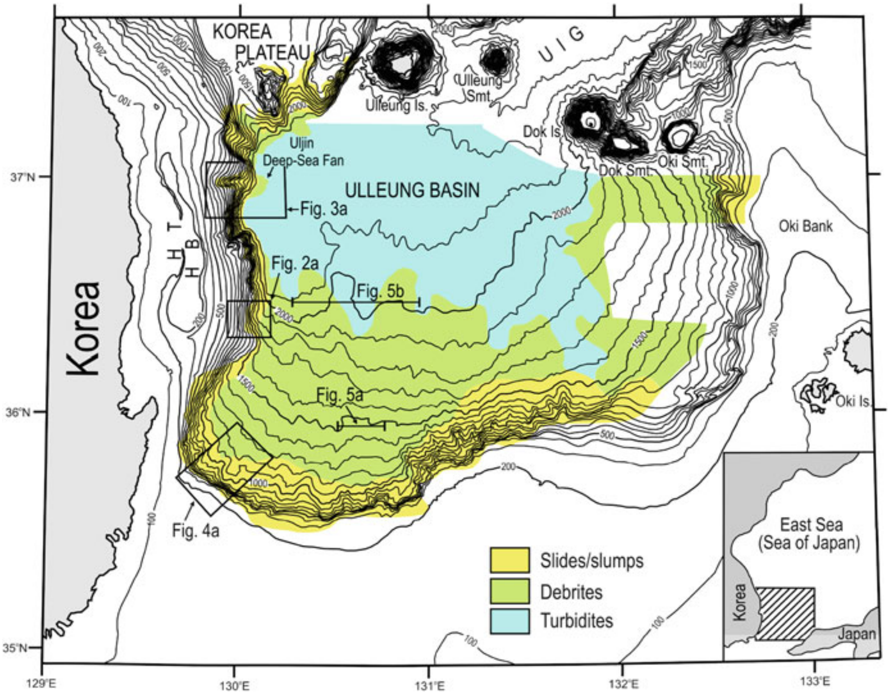

Fig. 36.1 Physiography of the Ulleung Basin and adjacent areas in the East Sea. Nearly contour-parallel distribution of slides/slumps, debrites and turbidities identified from chirp (2–7 kHz) profiles (Lee et al. 1999, 2004). Water depth in meters. *HB* Hupo Bank, *HT* Hupo Trough, *Smt.* seamount, *UIG* Ulleung Interplain Gap

topographic low (Hupo Trough; >150 m deep) and high (Hupo Bank). The Hupo Bank is about 84 km long, and rises more than 100 m above the surrounding seafloor (Fig. 36.1). Along the east coast of the Korean Peninsula, there are a few small streams without major rivers, resulting in small amount of sediment input into the continental shelf of the Korea Peninsula (Chough et al. 2000). In the south and east, the Ulleung Basin is bordered by broad (30–150 km wide) shelf and rather gentle (less than 2°) slope (Fig. 36.1). The northeastern part of the basin is punctuated by volcanic islands (Ulleung and Dok islands) and seamounts. The basin floor gradually deepens toward the northeast, and is connected to the Japan Basin through the Ulleung Interplain Gap.

On the entire margins and plain of the basin, the uppermost sedimentary sequence (less than ca. 30 m thick) of the Ulleung Basin consists mostly of various MTDs formed during the last glacial period (Chough et al. 1997; Lee et al. 2004). The MTDs in the basin show a contour-parallel distribution: slides and slumps on the upper to middle slope, debris-flow deposits on the lower slope (or base-of-slope), and turbidities on the basin plain (Fig. 36.1; Chough et al. 1997). The zonal distribution of MTDs suggests that mass transports were mostly derived from regional slope failures with large-scale transformation from slide/slump through debris flows to turbidity currents (Chough et al. 1997). The sediment failures were plausibly triggered by earthquakes, in combination with the last sea-level lowering and the associated gas-hydrate dissociation (Lee et al. 2004, 2010).

36.3 Materials and Methods

In order to describe sedimentary features of the slope failures and associated MTDs, we used bathymetric/back-scattering data, high-resolution subbottom profiles, and single-channel air-gun seismic profiles. The bathymetric and back-scattering data were acquired using a 13 kHz deep-water multi-beam echo sounder (EM12S). The high-resolution subbottom profiles were obtained using a chirp (2–7 kHz) subbottom profiling system (Datasonics CAP-6000W and Benthos Chirp II). Seismic profiles were acquired using a single channel streamer (MESH200P Hydrophone Array) and air-gun sources (299 cubic inches).

36.4 Sedimentary Features of Latest Quaternary Slope Failures and Mass-Transport Deposits

36.4.1 Western Basin Margin

On the western basin margin, slope sediments failed deeper than 700 m water depth where the slope gradient begins to increases. A few distinct scoop-shaped (or horseshoe-shaped) slope-failure scars are present at water depths of 700–1,200 m (Figs. 36.2a and 36.3a). These scars rarely coalesce with neighboring ones. The horseshoe-shaped scars are less than 15–20 km^2 in area, and less than 50 m in scarp height (Fig. 36.2b). Some scars are associated downslope with gullies which extend to the base-of-slope (Figs. 36.2a and 36.3a). Besides the scoop-shaped scars, the slope failures also occur as very small-scale, subdued gullies deeper than 1,200 m water depth (Fig. 36.3a). On the upper to lower slopes of the western margin, core sediments (3–11 m long) from the undisturbed areas are dominated by hemipelagic mud consisting of more than 60–70 % of clay fractions with less than 1 % of sand fractions (Chough and Lee 1987; Lee et al. 2004).

At the base-of-slope, the downslope mass-flow deposits generally occur as small-scale, solitary lobes (Figs. 36.2a and 36.3). Near 37°00′N, a distinct fan-shaped lobe (Uljin deep-sea fan) occurs at the downslope of gully mouth (Fig. 36.3). This fan consists of acoustically transparent masses with slightly convex-up, smooth surfaces (Fig. 36.3b). It is about 5 km long in longitudinal direction. Its thickness is up to ca. 10 m off the gully mouth, and thins laterally (Fig. 36.3b). Except Uljin deep-sea

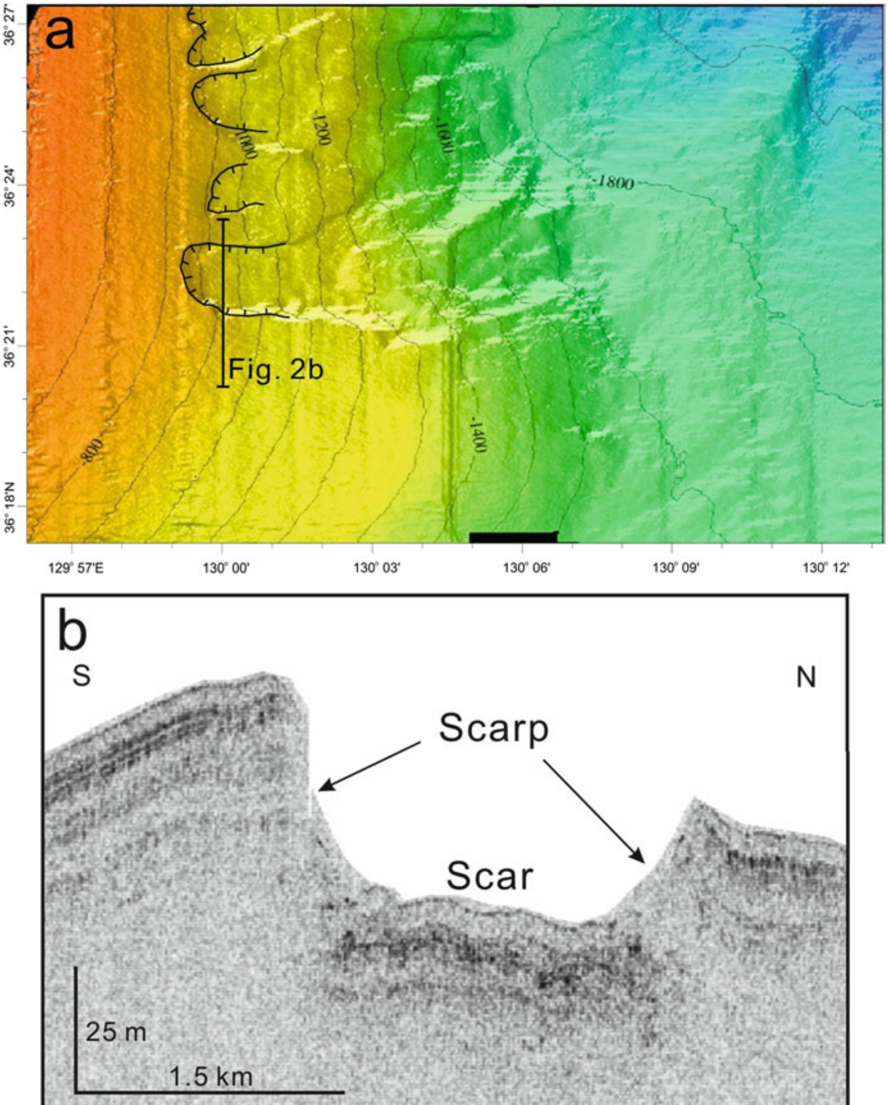

Fig. 36.2 (**a**) *Scoop-shaped* slope-failure scars on the western slope of the Ulleung Basin. Water depth in meters. For location of Fig. 36.2a, see Fig. 36.1. (**b**) A chirp (2–7 kHz) subbottom profile showing sedimentary features of the *scoop-shaped* scars in cross section

fan, most mass-flow deposits at the base-of-slope are very small (<2 km long in longitudinal direction) and subdued (Fig. 36.3a). These subdued mass-flow lobes cannot be easily recognized in chirp (2–7 kHz) subbottom profiles, indicating that the deposits are most likely thin in thickness.

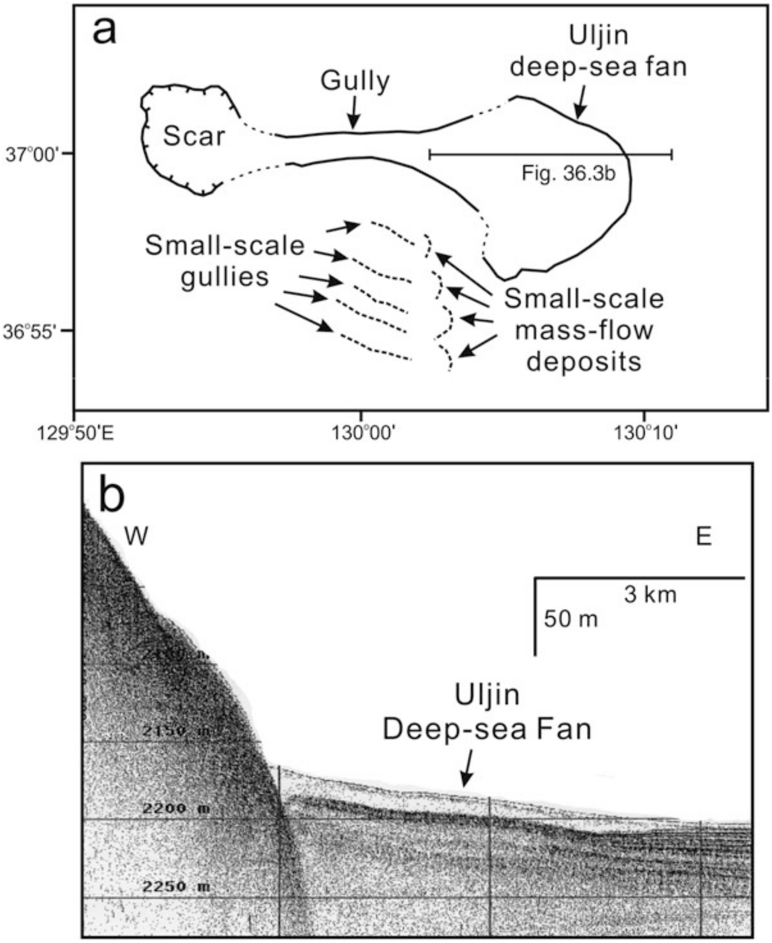

Fig. 36.3 (**a**) Line drawings of *scoop-shaped* scars, gullies, and downslope associated mass-transport deposits (MTDs) from sonar images on the western slope of the Ulleung Basin. For location of Fig. 36.3a, see Fig. 36.1. (**b**) A chirp (2–7 kHz) subbottom profile showing a distinct fan-shaped mass-flow deposits (Uljin deep-sea fan) at the base-of-slope

36.4.2 Southern Basin Margin

Along the entire southern margin, slope failures occur extensively at water depths of ca. 250–1,000 m, and there are no prominent submarine canyons and channels on the upper to lower slope (Fig. 36.1). The uppermost slope in water depths of 250–500 m is dominated by gullied slope-failure scars (Fig. 36.4), showing steep (4.0–10.3°) slope gradient. These gullied slope-failure scars are more than ca. 70–80 m deep and several kilometers wide, and coalesce downslope with adjacent ones,

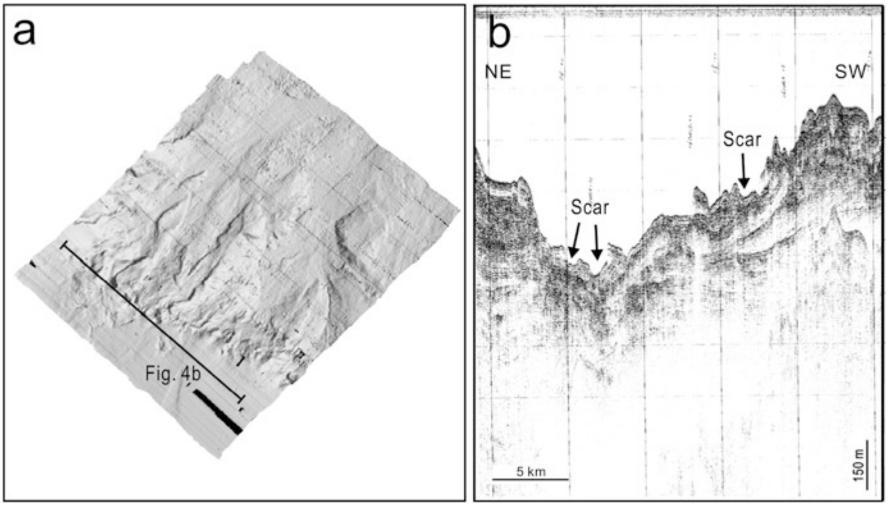

Fig. 36.4 *Shaded relief* image (**a**) and a single-channel air-gun seismic profile (**b**) showing gullied slope-failure scars on the *upper* slope of the southern Ulleung Basin. For location of images and seismic profile, see Fig. 36.1

forming larger-scale gullied morphology. Within the gullied slope-failure scars, highly rugged or irregularly blocky failed masses occasionally present along the axis of scars (Fig. 36.4). On the upper slope of the southern margin, core sediments (4–10 m long) from the undisturbed areas, deeper than 350–400 m water depth, consist mostly of hemipelagic muds (>70 % clay contents) with interbedded fine-sand layers (Lee et al. 2004). In contrast, sediment cores (several meters long) retrieved from the uppermost slope, shallower than 350–400 m water depth, consist mostly of fine to medium sands with abundant shell fragments (Chough and Lee 1987; Lee et al. 1993).

Along the entire southern margin, large-scale, composite failed masses showing irregularly rugged, blocky, or lumpy morphology are dominantly present at downslope of the gullied scars (Chough et al. 1997). These slide and slump masses change downslope to mass-flow deposits showing hyperbolic surface echoes with convex-up upper surface geometry in transverse section (Fig. 36.5a). These deposits cover extensively on the middle slope (Chough et al. 1997; Lee et al. 1999). The lower slope area is mostly dominated by mass-flow lobes consisting of lens- or wedge-shaped, acoustically transparent masses (Fig. 36.5b; Lee et al. 1999). Each mass-flow lobe is elongated downslope (i.e., N–S direction), and commonly fills topographic depressions, forming shingled internal architecture (Fig. 36.5b). These lobes are 10–40 km thick and >20 km long, and range from several meters to ca. 30 km in width. The mass-flow lobes were transported downslope for more than at least several tens of kilometers from the slope failing areas (i.e., upper to middle slope).

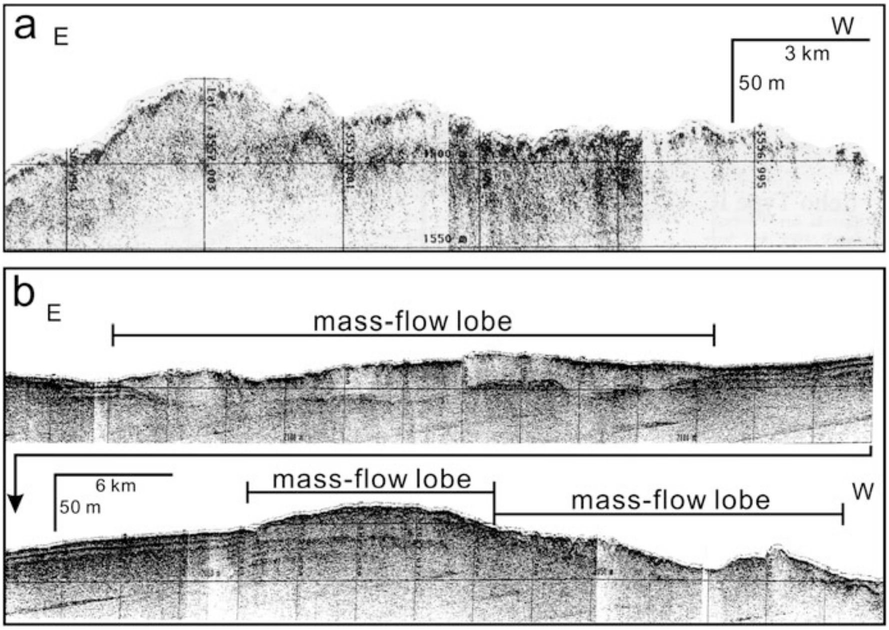

Fig. 36.5 Chirp (2–7 kHz) subbottom profiles showing hyperbolic surfaced mass-flow deposits on the southern middle slope (**a**) and sedimentary features of mass-flow lobes on the southern lower slope (**b**). For location of profiles, see Fig. 36.1

36.5 Discussion and Conclusions

The Ulleung Basin shows contrasting styles of the MTDs between the western and southern margins. The contrasting styles of MTDs can be ascribed to difference in dimensions of slope failures between the two basin margins. On the western basin margin, a few small-scale, scoop-shaped slope-failure scars with small gullies suggest that small amount of slope sediments failed. The small volume of failed sediment masses in the western basin margin would have formed small-sized slides and slumps on the middle slope and small, subdued solitary mass-flow deposits restricted at the base-of-slope. In contrast, the southern basin margin exhibits extensive occurrence of large-scale, gullied slope-failure scars along the entire upper slope, implying that huge amount of slope sediments failed. The large volume of failed sediment masses would have caused the extensive occurrence of large-scale, composite slides and slumps on the entire upper to middle slopes. Furthermore, the large momentum induced by the huge volume of failed sediments along the southern margin could have formed the extensive mass-flow deposits in the middle to lower slope areas, which travelled for more than several tens of kilometers from the failing areas (Lee et al. 1999, 2010).

The difference in dimensions of slope failures between the western and southern basin margins could be closely linked to the variation in shelf morphology and supply of riverine sediments to the shelf which can control sediment input and sediment types to slope. The western basin margin is characterized by a narrow (<25 km wide) shelf including the N–S-trending, prominent Hupo Trough and Hupo Bank (Fig. 36.1). Along the shelf of the western margin, there are only a few small streams without major rivers, implying a relatively small amount of sediment input into the western shelf during the last glacial period (Chough et al. 2000). The prominent Hupo Trough and Hupo Bank in the narrow western shelf (Fig. 36.1) could most likely block the sediment delivery from the shelf to the slope. These features suggest that relatively low accumulation of hemipelagic muds with rare sands prevailed in the western slope. These conditions probably caused the small-dimension of a few scoop-shaped slope-failure scars and gullies in the western slope. In contrast, the southern basin margin has a broad (30–150 km wide) shelf consisting of sandy sediments with paleo-channels, probably fed from the Nakdong River, during the last glacial period (Chough et al. 1997; Bahk et al. 2004). The high input of the riverine sediments to the southern shelf could form the prograding sedimentary sequences to the shelf break (Chough et al. 1997, 2000). These features indicate that relatively large amount of muddy and sandy sediments transported from the southern shelf most likely accumulated in the upper slope. The relatively high accumulation of sediments could probably promote large-scale, gullied slope failures along the entire southern slope.

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References

Bahk JJ, Han SJ, Khim BK (2004) Variations of terrigenous sediment supply to the southern slope of the Ulleung Basin, East/Japan Sea since the Last Glacial Maximum. Geosci J 8:381–390

Canals M, Lastras G, Urgeles R, Casamor JL, Mienert J, Cattaneo A, De Batist M, Haflidason H, Imbo Y, Laberg JS, Locat J, Long D, Longva O, Masson DG, Sultan N, Trincardi F, Bryn P (2004) Slope failure dynamics and impacts from seafloor and shallow sub-seafloor geophysical data: case studies from the COSTA project. Mar Geol 213:9–72

Chough SK, Lee HJ (1987) Stability of sediments on the Ulleung Basin slope. Mar Geotechnol 7:123–132

Chough SK, Lee SH, Kim JW, Park SC, Yoo DG, Han HS, Yoon HS, Oh SB, Kim YB, Back GG (1997) Chirp (2–7 kHz) echo characters in the Ulleung Basin. Geosci J 1:143–153

Chough SK, Lee HJ, Yoon SH (2000) Marine geology of Korean seas. Elsevier, Amsterdam

Hampton MA, Lee HJ, Locat J (1996) Submarine landslides. Rev Geophys 34:33–59

Lastras G, Canals M, Urgeles R, De Batist M, Calafat AM, Casamor JL (2004) Characterisation of the recent BIG'95 debris flow deposits on the Ebro margin, Western Mediterranean Sea, after variety of seismic reflection data. Mar Geol 213:235–255

Lee HJ, Chun SS, Yoon SH, Kim SR (1993) Slope stability and geotechnical properties of sediment of the southern margin of Ulleung Basin, East Sea (Sea of Japan). Mar Geol 110:31–45

Lee SH, Chough SK, Back GG, Kim YB, Sung BS (1999) Gradual downslope change in high-resolution acoustic characters and geometry of large-scale submarine debris lobes in Ulleung Basin, East Sea (Sea of Japan), Korea. Geo-Mar Lett 19:254–261

Lee SH, Bahk JJ, Chough SK (2004) Late Quaternary sedimentation in the eastern continental margin of the Korean Peninsula. In: Clift P, Kuhnt W, Wang P, Hayes D (eds) Continent – ocean interactions within east Asian marginal seas, vol 149, Geophysical monograph. American Geophysical Union, Washington, DC, pp 205–233

Lee SH, Bahk JJ, Kim HJ, Lee KE, Jou HT, Suk BC (2010) Changes in the frequency, scale, and failing areas of latest Quaternary (<29.4 cal. ka B.P.) slope failures along the SW Ulleung Basin, East Sea (Japan Sea), inferred from depositional characters of densely dated turbiditic successions. Geo-Mar Lett 30:133–142

Locat J, Lee HJ (2002) Submarine landslides: advances and challenges. Can Geotech J 39:193–212

Mulder T, Cochonat P (1996) Classification of offshore mass movements. J Sediment Res 66:43–57

Piper DJW, Farre JA, Shor A (1985) Late Quaternary slumps and debris flows on the Scotian slope. Bull Geol Soc Am 96:1508–1517

Piper DJW, Cochonat P, Morrison ML (1999) The sequence of events around the epicentre of the 1929 Grand Banks earthquake: initiation of debris flows and turbidity current inferred from sidescan sonar. Sedimentology 46:79–97

Tripsanas E, Piper DJW, Jenner KA, Bryant WR (2008) Submarine mass-transport facies: new perspectives on flow processes from cores on the eastern North American margin. Sedimentology 55:97–136

Yoon SH, Chough SK (1995) Regional strike slip in the eastern continental margin of Korea and its tectonic implications for the evolution of Ulleung Basin, East Sea (Sea of Japan). Bull Geol Soc Am 107:83–97