Seismic stratigraphy and depositional history in the SW margin of the Ulleung Basin, East Sea

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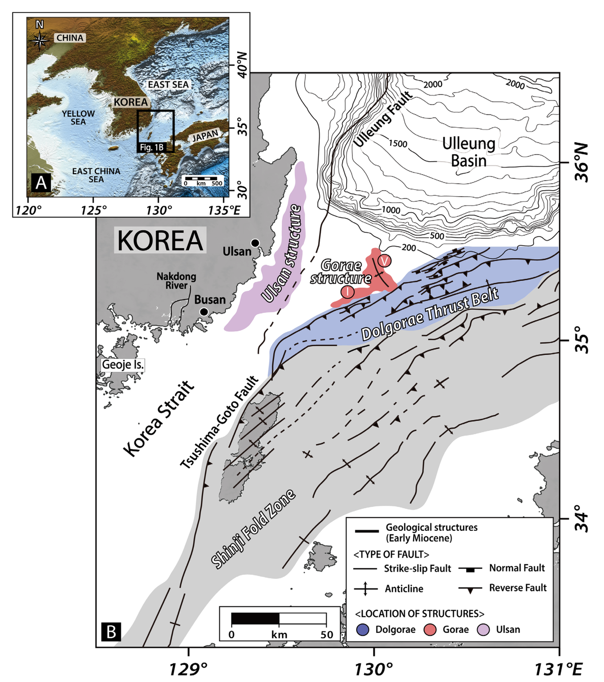
Abstract

Interpretion of the 2D seismic data set revealed the depositional history and structural forming processes in the southwestern margin of the Ulleung Basin, East Sea. Based on the seismic facies and sediment succession with various unique structures in the study area, they were divided into five depositional sequences (DS1 to DS5), separated by erosional unconformities (H1–H5). The lower two depositional sequences (DS1-DS2) show deformed succession with faults and folds, whereas the upper three depositional sequences (DS3-DS5) indicate non-deformed succession. DS1 and DS2, regarded as the late Miocene strata, comprise hummocky and chaotic seismic facies. During the late Miocene, the Dolgorae Thrust Belt (DTB) and Gorae Structure (GS) were created sequentially and are strongly associated with the creation of the DS1 and DS2. On the other hand, the upper three sequences (DS3–DS5), which are part of the Plio-Quaternary strata, are acoustically distinguished by reflection configurations that are both well-stratified and progressive. Since the Pliocene, the tectonic movement associated with the regional structures (US, DTB, and GS) has been nearly stopped. On the other hand, a portion of the GS has been developed until now. As a result of these findings, it was determined that DS1 and DS2 were mainly controlled by tectonic activity. The sedimentation of the upper three sequences (DS3-DS5) after the Pliocene was driven primarily by periodic and repeated sea-level changes rather than by tectonic activity.

Introduction



The southwestern margin of the Ulleung Basin is a passive margin located between the Korean Peninsula and the Japanese archipelago (Fig. 1). Various studies have been conducted in the southwest margin of the Ulleung Basin to reconstruct basin evolution related to regional tectonic events and comprehend the source-to-sink system (Yoon et al. 2002, 2003; Lee et al. 2011; Choi et al., 2018; Park et al. 2019; Yi et al. 2020; Park et al. 2021a, b). These found that the Neogene-Quaternary sedimentary record of the southwestern margin of the Ulleung Basin provides insights into the complex interactions among regional tectonic movements, sea-level fluctuation, and sediment supply. Previous research has primarily focused on the Miocene sedimentary succession. However, there has been little research into the sequence stratigraphy of the latest Neogene-Quaternary succession in the southwestern margin of the Ulleung Basin. Therefore, this paper aims to: (1) discuss the development of depositional sequences controlled by the regional tectonic activity and sea-level fluctuation since the late Miocene and (2) propose a sequence stratigraphic model for the latest Neogene-Quaternary succession in the southwestern margin of Ulleung Basin.

Fig. 1. A Physiographic map of the southwest margin of Ulleung Basin. The insert black box is the study area shown in (B). B The regional geological structures in the southwest margin of the Ulleung Basin and adjacent areas (Minami 1979; KIER 1982; Choi 1995; Yoon et al. 2014)

Data & Method

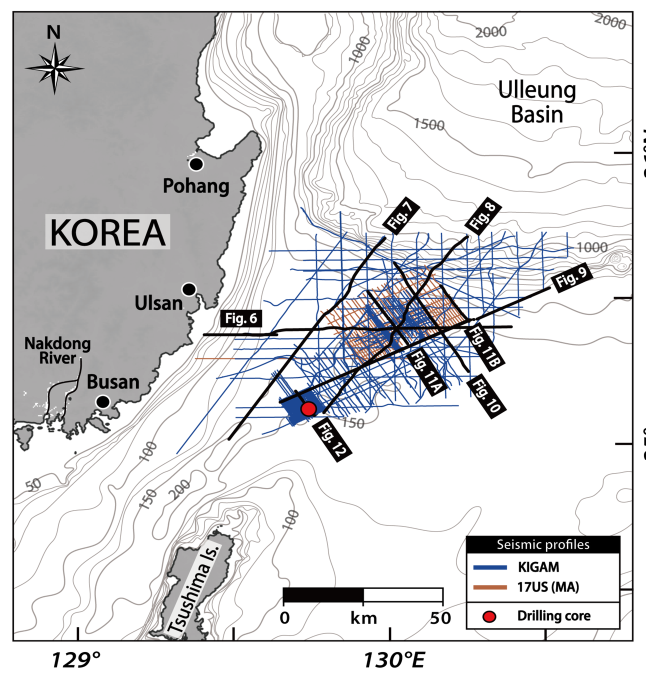


Fig. 2 Tracklines of seismic profiles with the site of drilling core. The heavy black lines are shown in other figures (Figs. 6, 7, 8, 9, 10, 11 and 12)

This study uses seismic profiles of 18,660 km acquired by the Korea Institute of Geoscience and Mineral Resources (KIGAM) and the Korea Marineaid corporation (MA) (Fig. 2). The KIGAM seismic profiles were acquired using the R/V TAMHAE II from 2004 to 2006. A Bolt airgun (volume 1,035– 5,370 in³) was fired every 25 and 50 m using an equal-distance shooting system. Recordings were made on 48 channels with Sercel Sentinel solid-type streamers and on 160 channels with 2,000 m Nessie-3 distal streamers. A 24-channel sparker system and 750–1,300 J mini-sparker source were collected by Korea Marineaid Co., Ltd. IHS Kingdom Suite software, Petrel E&P software platform, and SeiSee (version 2.22) were used for mapping and interpretation of the various seismic profiles.

The drilling core 19ESDP-104 (100.7 m) was retrieved at the 148 m water depth using the Patra Offshore vessel (1,200 tons) in October 2019 by the Korea Institute of Geoscience and Mineral Resources (KIGAM). It was collected on the reactivated fault related to the Dolgorae Thrust Belt (DTB) (Fig. 2). The lithology and age data that used optically stimulated luminescence (OSL) and radiocarbon dating (^{14}C) methods have been conducted to correlate between drilling core and depositional sequences in the southwest margin of the Ulleung Basin.

Acknowledgements

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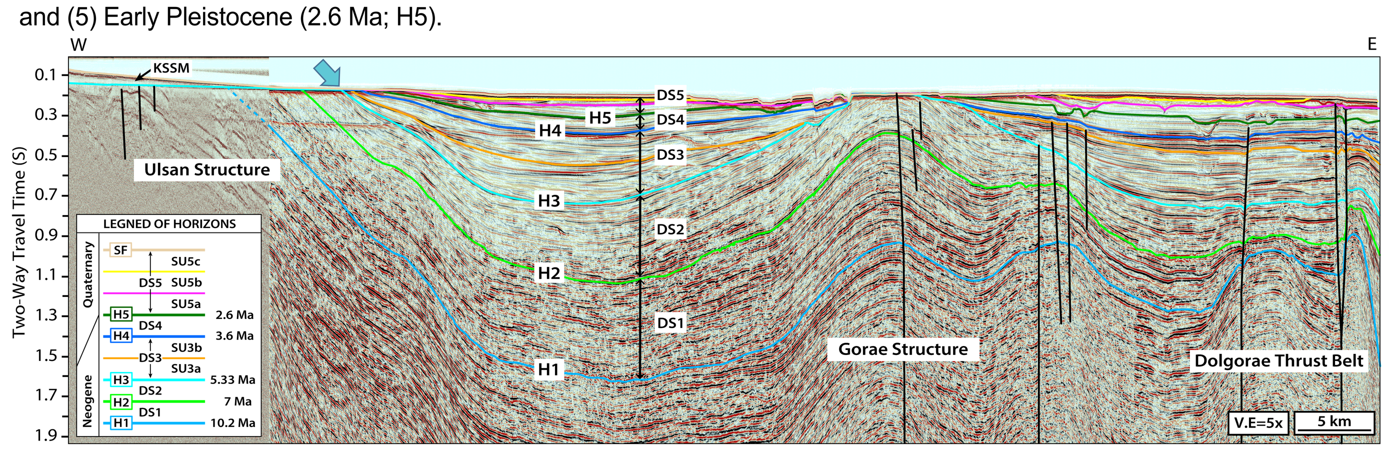
Results & Discussion

Chronostratigraphy and total sediment thickness

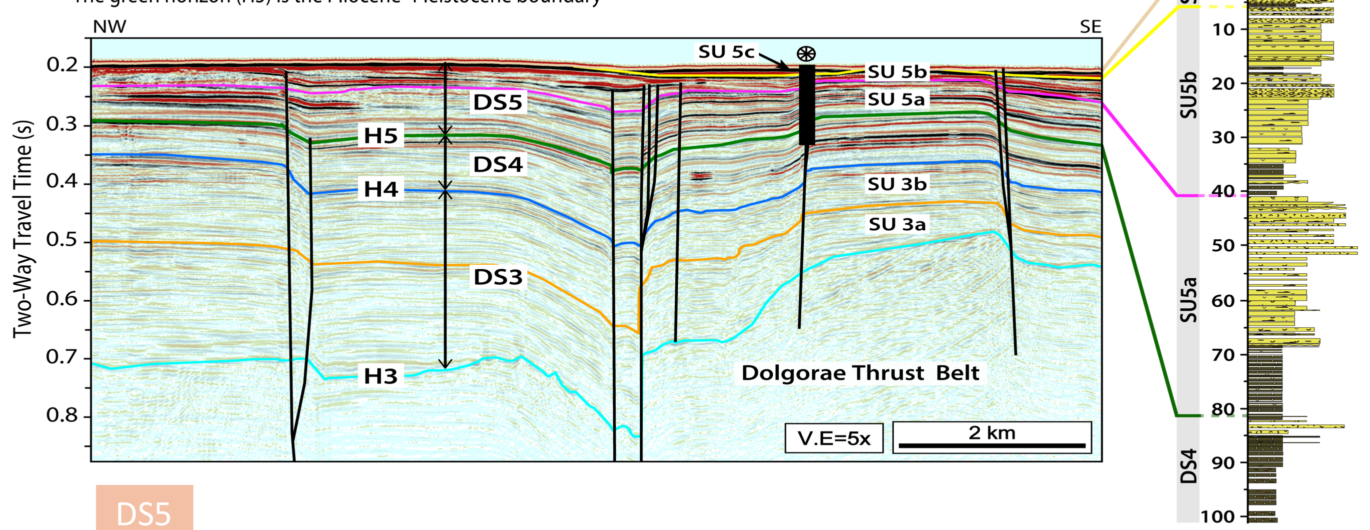
Stratigraphic correlation of key horizons

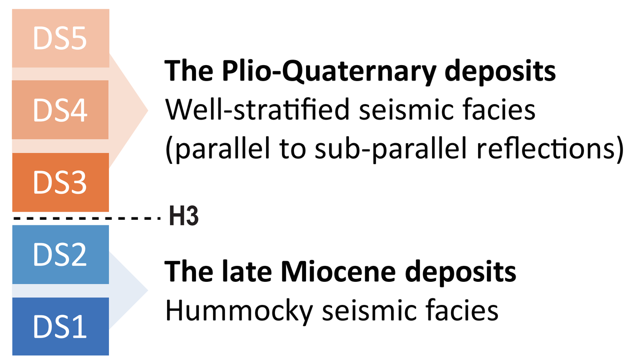
Based on careful examination and evaluation of seismic records, five key horizons were identified in the southwest margin of the Ulleung Basin, designated H1 to H5 in ascending order (Fig. 3). The key horizons are defined by relatively continuous reflectors with high amplitude on seismic records (Figs. 3 and 4). The geological ages of key horizons were estimated from correlation with the sequence boundaries defined by Yoon et al. (2002, 2003), Lee et al. (2011), Park et al. (2019), and Yi et al. (2020). Based on the inferred stratigraphic framework, the five key horizons correlate well with specific ages, respectively: (1) Late Miocene (10.2 Ma; H1), (2) Late Miocene (7 Ma; H2), (3) Early Pliocene (5.33 Ma; H3), (4) Late Pliocene (3.6 Ma; H4), and (5) Early Pleistocene (2.6 Ma; H5).



▲Fig. 3 Selected seismic profile across the continental margin and its interpretation showing five depositional sequences (DS1-DS5) separated by erosional unconformities (for location, see Fig. 2)

▼ Fig. 4 Selected seismic profile and its interpretation, showing the correlation drilling core (for location, see Fig. 3). Three depositional sequences (DS3-DS5) related to faults and fold structures were accumulated on the Dolgorae Thrust Belt (DTB). The green horizon (H5) is the Pliocene–Pleistocene boundary





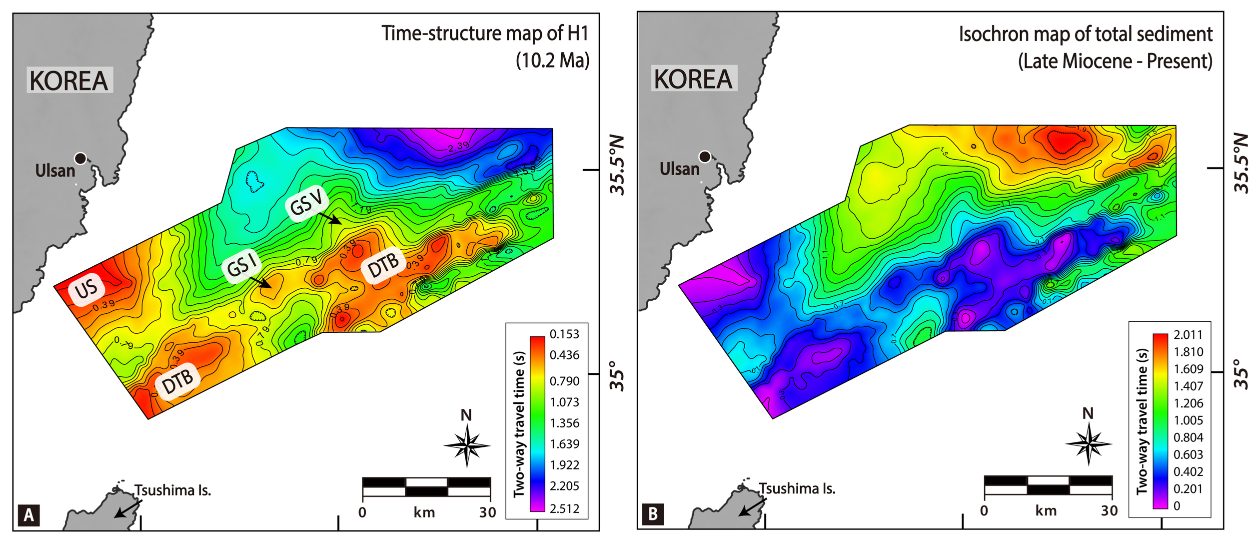
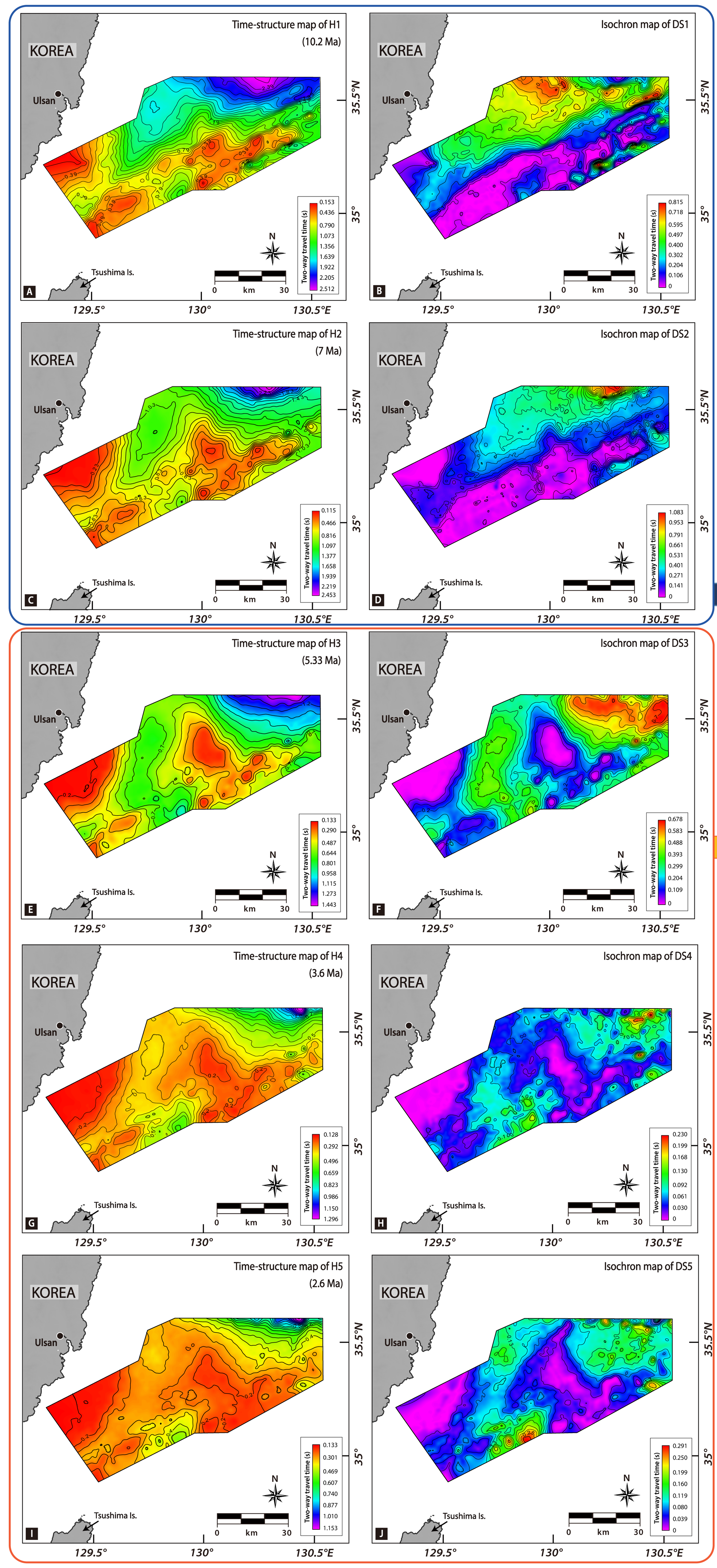


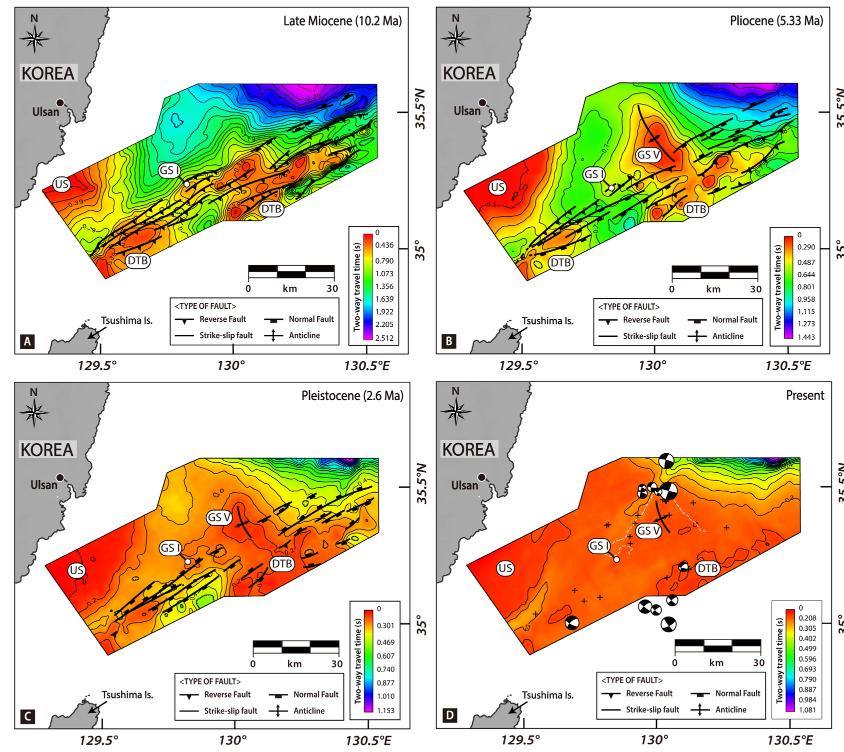
Fig. 5 A Time-structure map of H1, showing Dolgorae Thrust Belt (DTB), Gorae structure (GS), and Ulsan structure (US). B Isochron map of total thickness above the H1. H1 is the lowest erosional unconformity in this study

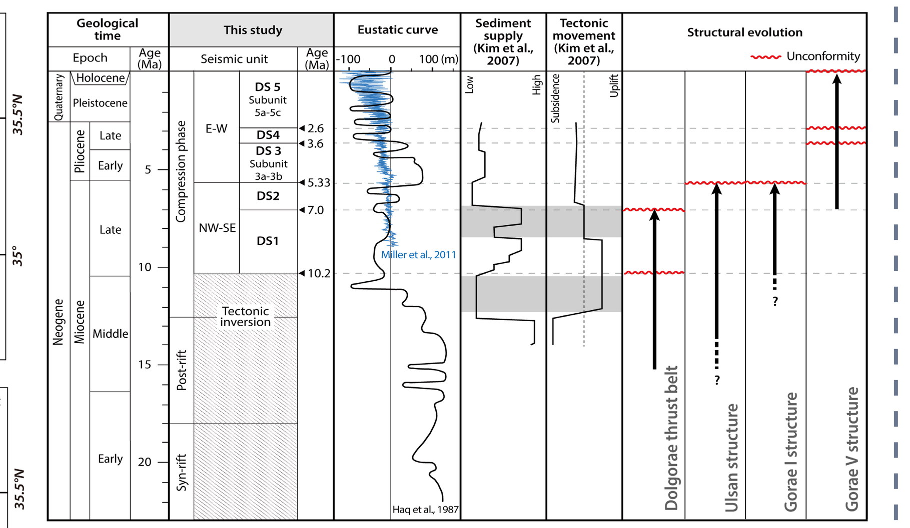
Depositional sequences

According to the interpretation of the 2D seismic profiles, the latest Neogene-Quaternary sequence in the study area consists of five depositional sequences (DS1–DS5) separated by regional unconformities (Figs. 3 and 4). Based on the geological ages (Fig. 2), the lower two sequences (DS1 and DS2) belonged to the late Miocene strata. DS3 represents the early Pliocene strata, whereas the overlying sequence DS4 is of the late Pliocene (Yi et al. 2020). The youngest sequence (DS5) is Quaternary strata (Yi et al. 2020).



▲ Fig. 6 A, C, E, G, I Time structure map of the sequence boundary (H1 to H5). B, D, F, H, J Isochron map of five depositional sequence (DS1 to DS5)





▲ Fig. 8 Summary control factors in the southwest margin of the Ulleung Basin

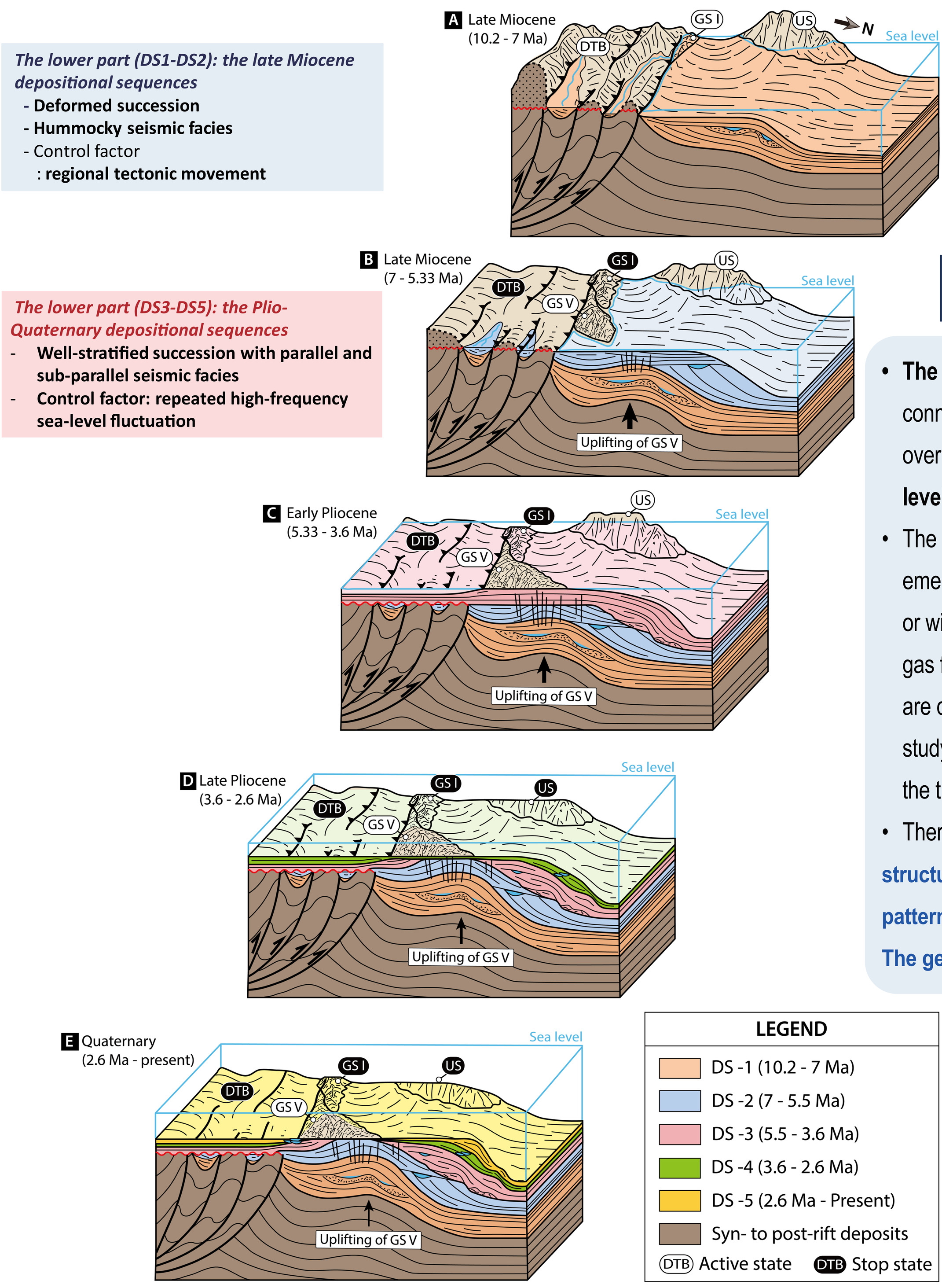
◀ Fig. 7 Distribution map of the faults and folding structure in the study area. A Time structure map of late Miocene (10.2 Ma). B Time structure map of Pliocene (5.33 Ma). C Time structure map of Pleistocene (2.6 Ma). D Time structure map of the present day including the focal mechanism solutions of recent earthquakes (modified after Hong et al. (2020)). The cross marks indicate faults that develop up to the seafloor. The contour interval of A and B is 0.1 s, the contour interval of C and D is 0.05 s.

Conclusion

The latest Neogene-Quaternary seismic stratigraphy framework for the southwestern margin of the Ulleung Basin comprises five depositional sequences (DS1–DS5) separated by erosional unconformities (H1–H5). The late Miocene sequences (DS1 and DS2) are mainly characterized by hummocky seismic facies, whereas well-stratified seismic facies are identified in the Plio-Quaternary sequences (DS3–DS5). Five depositional sequences accumulated under the compressional tectonic regime. During the late Miocene, with dominant NW–SE compressional stress, regional structures (i.e., DTB, GS I and V, and US) actively developed. As a result of tectonic activity, DS1 and DS2 were deformed. During the early Pliocene (5.33 Ma), the compressional regime abruptly changed to an E–W stress regime. GS V then showed remarkable evolution in the central part of the study area. Subsequently, tectonic activity gradually weakened over time. Although slow uplifting of GS V persisted, DS3 to DS5 were mainly influenced by repeated high-amplitude and high-frequency sea-level fluctuations.

The lower part (DS1-DS2): the late Miocene depositional sequences
- **Deformed succession**
- **Hummocky seismic facies**
- Control factor
  : **regional tectonic movement**

The lower part (DS3-DS5): the Plio-Quaternary depositional sequences
- **Well-stratified succession with parallel and sub-parallel seismic facies**
- **Control factor: repeated high-frequency sea-level fluctuation**



Summary & Implication

- **The depositional sequences (DS1-DS5)** were closely connected to the main two control factors that changed over time from **tectonic movement to high-frequency sea-level fluctuations.**
- The southwestern margin of the Ulleung Basin has emerged as a site for carbon capture and storage (CCS) or wind farm construction as Korea's only Donghae-1natural gas field has been stopped. However, complex fault lines are distributed in the vicinity, as shown in the results of this study, and focal mechanism solutions of earthquakes show the trend of strike-slip faults.
- Therefore, **a deep understanding of the complex regional structures, fault lines, and the closely related developmental patterns (thickness and distribution) of sediments is required. The geological information necessary for this can be provided.**