Topic Editor Decision: Publish subject to technical corrections (01 Sep 2020) by Arvind Singh

Comments to the Author:

Dear Authors,

I am happy with the revision. The manuscript may please be accepted after considering the following suggestions in addition to the couple of changes suggested by Referee#2. Best wishes, Arvind

Line 8 and line 24; replace “mud” by “Mud”

ANSWER. We revised as mentioned

line 69-70: delete “amount of”

ANSWER. We deleted the ‘amount of’ as mentioned

line 82: replace “AMS 14C data” by “Accelerator Mass Spectrometer based 14C dates”

ANSWER. We revised as mentioned

Lines 104-105: I would suggest to define εNd fully, i.e. εNd = [(143Nd/144Nd)/0.512638 – 1] × 10^4

ANSWER. We added the definition for εNd. ($\varepsilon Nd = [(^{143}Nd/^{144}Nd)/0.512638-1] \times 10^4$)

Line 267: replace “is” by “was”

ANSWER. We revised as mentioned

Line 288: replace “All” by “Both the”

ANSWER. We revised as mentioned

Referee #2 (in Report #1) - Suggestions for revision or reasons for rejection

Instead of using "During Unit" write "During the deposition of Unit" throughout the manuscript.

ANSWER. We revised "during Unit" and "during the Unit" to "during the deposition of Unit" throughout the manuscript.

Line 54: instead of "become" use "are"

ANSWER. We revised as mentioned

Changes in detrital sediment supply to the central Yellow Sea since the last deglaciation

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Abstract. The sediment supply to the central Yellow Sea since the last deglaciation was uncovered through clay mineralogy and geochemical analysis of core 11YS-PCL14 in the Central Yellow Sea M~~m~~ud (CYSM). The core can be divided into four units based on the various proxies such as grain size, clay mineralogy, geochemistry, and Sr–Nd isotopes: Unit 4 (700–520 cm; 15.5–14.8 ka), Unit 3 (520–310 cm; 14.8–12.8 ka), Unit 2 (310–130 cm; 12.8–8.8 ka), and Unit 1 (130–0 cm; < 8.8 ka). Unit 2 is subdivided into two subunits Unit 2-2 (310–210 cm; 12.8–10.5 ka), Unit 2-1 (210–130 cm; 10.5–8.8 ka) according to smectite content. Comparison of the clay mineral compositions, rare earth elements, and εNd indicate distinct provenance shifts in core 11YS-PCL14. Moreover, the integration of clay mineralogical and geochemical indices show different origins according to particle size. During the late last deglaciation (Units 3 and 4, 15.5–12.8 ka), Unit 4 sediments originated from all potential provenance rivers such as the Huanghe, Changjiang, and western Korean rivers, while the source of coarse sediments changed to Huanghe when beginning the Unit 3. Fine-grained sediment still supplied from all rivers during the deposition of Unit 3. Early Holocene (Unit 2) sediments were characterized by oscillating grain size, clay minerals, and moderate εNd values. In this period, the dominant fine sediment provenance changed from the Huanghe to the Changjiang, whereas coarse sediments most likely originated from western Korean rivers. The Unit 1 CYSM sediments were sourced primarily from the Changjiang, along with minor contributions from the western Korean rivers. Possible transport mechanisms concerning such changes in the sediment provenance include paleo-river pathways, tidal stress evolution, and the development of the Yellow Sea Warm Current and coastal circulation systems, depending on the sea-level fluctuations.

Keywords: Central Yellow Sea M~~m~~ud (CYSM), clay mineralogy, sediment provenance, Sr–Nd isotopes, Rare earth elements

1 Introduction

The Yellow Sea, located between the China and Korean Peninsula, is a semi-enclosed epicontinental shelf with a complex oceanic circulation system (Fig. 1). It is notable for its large amount of runoff and terrigenous sediment supplied from several adjacent rivers, including two of the world's largest rivers, the Changjiang and Huanghe, as well as from several smaller Korean rivers, including the Han, Keum, and Yeongsan River. Although most riverine sediments are trapped in estuaries and along coastal areas, some are deposited on adjacent shelves (Milliman *et al*., 1985; Milliman *et al*., 1987), forming several shelf mud patch depositions such as Central Yellow Sea Mud (CYSM), Southeastern Yellow Sea Mud and Southwestern Cheju Island Mud (Fig 1). These deposits provide abundant information on paleo-environmental changes as well as sediment supply, marine hydrodynamics, and climate variation (*e.g.* Wang *et al*., 1999; Kim and Kucera, 2000; Li *et al*., 2014a; Cho *et al*., 2015; Kwak *et al*., 2016; Hu *et al*., 2018).

The provenance of CYSM sediments have attracted many researchers over the last three decades. Many studies have indicated that CYSM sediments originated mostly from the Huanghe considering the large amount of sediment load carried by that river (Milliman *et al*., 1987; Lee and Chough, 1989; Liu *et al*., 2002; Yang and Liu, 2007; Shinn *et al*., 2007; Xiang *et al*., 2008). On the other hand, other studies have used mineralogical, geochemical, and magnetic observations and determined that the CYSM was formed from a complex mixture of sediments from the Huanghe as well as the Changjiang and several Korean rivers (Zhao *et al*., 1990; Wei *et al*., 2003; Zhang *et al*., 2008; Li *et al*., 2014a; Wang *et al*., 2014; Koo *et al*., 2018). In addition, recent studies using core sediments suggested that the provenance of CYSM changed mainly from Huanghe to Changjiang with minor contribution from the Korean rivers during the Holocene (Lim *et al*., 2015; Hu *et al*., 2018). However, the timing of the CYSM formation and the deposition environment prior to the Holocene are remains unclear.

Discrimination of sediment source and reconstruction of paleo-environmental changes can be undertaken based on grain size, clay mineralogy, and elemental signals. In particular, clay mineralogy and geochemistry have been utilized as a powerful tool to trace provenance of the terrigenous fraction of marine sediments in the Yellow sea (Yang *et al*., 2002; Yang and Youn, 2007; Liu *et al*., 2007, 2010b; Dou *et al*., 2010; Hu *et al*., 2012; Wang and Yang, 2013; Li *et al*., 2014a; Koo *et al*., 2018). Several additional factors can also control sedimentary characteristics, including terrigenous inputs, sea level and climate conditions (Wang et al., 1999; Duck et al., 2001; Hwang et al., 2014; Li et al., 2014a; Lim et al., 2015; Badejo et al., 2016; Hu et al., 2018). In addition, paleo-river pathways, recently reconstructed by high-resolution seismic researches in the Yellow Sea, can account for sedimentation and sediment provenance since the last deglaciation because they are~~become~~ an important route of sediment transport during the low stand period (KIGAM, 1993; Xu *et al*., 1997; Yoo *et al*., 2015, 2016).

In this study, we aim to determine the sediment provenance and transport mechanism of CYSM using clay mineralogy and geochemistry multi-proxy. The purposes are to provide a broad insight into the supply of CYSM sediments and to reconstruct the paleo-environment since the last glacial maximum.

2. Oceanography

The hydrodynamic system in the Yellow Sea is characterized by two major circulation patterns (Fig. 1). One is a counterclockwise gyre in the western part consisting of the Yellow Sea Warm Current (YSWC) and Yellow Sea Coastal Current (YSCC) (Beardsley *et al*., 1985; Yang *et al*., 2003). The other is a clockwise gyre in the eastern part made up of the YSWC and the Korea Coastal Current (KCC) (Beardsley *et al*., 1985; Yang *et al*., 2003). The YSWC is one of the most important dynamic phenomena in the East China Sea and Yellow Sea. It is a branch of the Kuroshio Current that carries warm, salty water into the Yellow Sea roughly along the Yellow Sea Trough (Xu *et al*., 2009; Liu *et al*., 2010a; Wang *et al*., 2011, 2012). The YSCC and KCC flow south along the coasts of the China and the Korean Peninsula, respectively. Besides, the Transversal Current (TC), identified in recent studies, separates from the KCC southwest of the Korean Peninsula, and some of its water flows northward along the YSWC (Lie *et al*., 2013, 2016; Hwang *et al*., 2014) (Fig. 1). On the other hand, ~~amount~~

~~of~~ freshwater input from the Changjiang to the Yellow Sea forms the plume of low-salinity water, called as the Changjiang Diluted Water (CDW) (Sukigara et al., 2017). A part of the CDW spreads eastward, reaching as far as Jeju Island and Korea Strait (Hwang *et al*., 2014; Li *et al*., 2014a). The oceanic fronts include the Shandong Front (SDF), Jiangsu Coastal Front (JSCF) and Western Korean Coastal Front (WKCF) located in the western and eastern boundaries of the Yellow Sea. These fronts play an important role in shaping Yellow Sea currents as well as in understanding sediment transport, as they separate different water masses in the centre and coast of the Yellow Sea and appear a barrier effect for sediment (Huang *et al*., 2010; Li *et al*., 2014a; Koo et al., 2018) (Fig. 1).

3. Materials and methods

Core 11YS-PCL14 (35°785' N, 124°115' E), which was 702 cm in length, was collected from CYSM at a water depth of approximately 80 m for multi-proxy paleo-environmental reconstruction. The core was subsampled at 10 cm intervals for grain size, clay mineralogy and geochemical analyses. The core 11YS-PCL14 is 702 cm recovered deeper than other studied cores around here (YSC-1; 437 cm, EZ06-1; 370 cm, EZ06-2; 360 cm) (Li et al., 2014; Lim et al., 2015).

The grain size and Accelerator Mass Spectrometer based ^{14}C dates~~AMS ^{14}C data~~ were reported in Badejo *et al*. (2016). Radiocarbon ages for five selected depths (99 cm, 300 cm, 540 cm, 580 cm, and 698 cm) and the age-depth model was constructed based on the linear interpolation between the calibrated calendar ages (Badejo *et al*., 2016) (Table 1). The bottom of the core 11YS-PCL14 dated approximately 15.5 ka, that 11YS-PCL14 provides a continuous record of the late last deglaciation to Holocene in the CYSM.

The clay mineral analysis was conducted using X-ray diffraction (XRD) on preferred-orientation specimens of fine-grained sediment (< 2 μm) following the method in Cho et al. (2015). Semi-quantitative estimation of clay mineral abundances was completed using the Eva 3.0 program with the empirical factors from Biscaye (1965).

The composition of major and trace elements in 13 bulk samples was determined by Actlabs, Ontario, Canada, following the '4 LithoRes' methodology. The samples were fused using a lithium metaborate-tetraborate mixture. The melt produced by this process was completely dissolved with 5% HNO_3. Major elements were analysed in the resulting solution by inductively coupled plasma-optical emission spectrometry (ICP-OES), with an analytical accuracy of < 6%. Trace element analyses were done by inductively coupled plasma-mass spectrometry (ICP-MS). The analytical reproducibility ranged between 5 and 12%.

A total 18 samples of core 11YS-PCL14 and riverine sediments (Huanghe, Changjiang and Keum River) were selected for Sr–Nd isotopic analysis and were processed on the <63 μm fraction of each sample (Table 3). The inorganic silicate fraction was extracted from 18 samples following the method described by Rea and Janecek (1981). The samples were treated with acetic acid buffered to pH 5 with sodium acetate to remove calcium carbonate. They were subsequently treated with a hot sodium citrate-sodium dithionite solution buffered with sodium bicarbonate to remove coarse biogenic components and finally treated with Na_2CO_3 solution to remove biogenic silica. $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ analyses, including chemical separation and multicollector thermal ionization mass spectrometry (VG54-30, Isoprobe-T) analyses were performed at the Korea Basic Science Institute following Cheong *et al*. (2013). Sr and Nd isotope ratios were normalized to $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$, respectively. Analysis of the Sr standard NBS 987 and the Nd standard JNdi-1 resulted in $^{87}Sr/^{86}Sr = 0.710246 \pm 3$ (2SD, n = 10) and $^{143}Nd/^{144}Nd = 0.512115 \pm 6$ (2SD, n = 10). For convenience, the εNd parameter was calculated using a $^{143}Nd/^{144}Nd$ value of 0.512638 for the Chondritic Uniform Reservoir ($\varepsilon Nd = [(^{143}Nd/^{144}Nd)/0.512638-1] \times 10^4$) (Hamilton *et al*., 1983).

4. Results

Core 11YS-PCL14 could be divided mainly into four units considering downcore patterns especially mean grain size and clay mineral compositions (Figs. 2 and 3): Unit 4 (700–520 cm; 15.5–14.8 ka), Unit 3 (520–310 cm; 14.8–12.8 ka), Unit 2 (310–

130 cm; 12.8–8.8 ka), and Unit 1 (130–0 cm; < 8.8 ka). In addition, Unit 2 could be subdivided into Unit 2-2 (310–210 cm; 12.8–10.5 ka), Unit 2-1 (210–130 cm; 10.5–8.8 ka) based on the variation trends of clay mineral compositions, especially smectite content. The content of smectite increases slightly during the deposition of Unit 2-2 but tends to decrease in Unit 2-1 (Fig. 3). Wang *et al*. (2014) reported that the CYSM mud blanket becomes thicker going westward based on a seismic profile. The mud layers in core sediments are thinner than expected from the seismic profile, but the trend is consistent (Fig. 2). Core EZ06-2, located east of 11YS-PCL14, contains a 100-cm-thick mud layer, while YSC-1, to the west, has a 375-cm-thick layer (Fig. 2). The lower part of the mud layer is known as the transgressive deposit and contains many sands (Fig. 2). This coarse layer appears in all cores in the CYSM, with a boundary of ~10 ka (Li *et al*., 2014a; Lim *et al*., 2015). However, core 11YS-PCL14 has additional mud layers with a high proportion of silt underneath the transgressive deposit and a coarse layer at the bottom. Therefore, core 11YS-PCL14 provides more records of the CYSM since the LGM which could not be reconstructed in previous cores (Li et al., 2014a; Lim et al., 2015), because the core 11YS-PCL14 not only recovered deeper than other studied cores.

The vertical granularity, clay mineralogical, and geochemical characteristics of core 11YS-PCL14 are plotted against the calibrated age on the *y*-axis in Fig. 3. The four clay minerals were dominated by illite (60.1–74.7%), followed by chlorite (12.0–22.6%), kaolinite (9.6–14.8%), and smectite (1.2–6.8%). The $^{87}Sr/^{86}Sr$ ratios ranged from 0.719 to 0.724 (mean 0.721) and the εNd values from −16.2 to −12.3 (mean −14.0).

Tables 2 and 3 list the detailed characteristics of the clay minerals and geochemistry in each unit and their main potential provenances (the Huanghe, Changjiang, and western Korean rivers). Each unit had distinct dissimilarities in clay mineral content and mean grain size, especially the sand content (Fig. 2). The Unit 2 sediments were 1.8–44.2% (mean 17.6%) sand with a mean grain size of 6.6 ϕ (10.3 μm) and Unit 4 sediments had a high sand content (8–58.7%, mean 26.3%) with a mean grain size of 6.0 Φ (15.6 μm). In comparison, Unit 1 contained only fine sediment with a mean grain size of 8.8 Φ (2.2 μm) and Unit 3 sediments were clayey silt with a mean grain size of 7.3 Φ (6.3 μm). The downcore variation in the clay mineral composition showed that the illite content decreased gradually from Unit 2 to 3 and was constant in the other parts of the core. Overall, the variations in the smectite and kaolinite+chlorite contents were opposite that of illite (Fig. 3). Units 3 and 4 had relatively constant compositions in terms of clay minerals, although their granularity was heterogeneous. The $^{87}Sr/^{86}Sr$ ratio was constant at the bottom and tended to increase in the upper part. The εNd value was low in Units 2 and 4. ΣLREE/ΣHREE was low only in Unit 3, and was mostly constant.

5. Discussion

5.1. Provenance discrimination based on clay mineralogy

Relative clay mineral contents and ratios can be used as powerful proxies for determining fine-grained marine sediment provenance, especially in terms of the rivers from China and Korea that may contribute to CYSM (Yang *et al*., 2003; Choi *et al*., 2010; Li *et al*., 2014a; Xu *et al*., 2014; Lim *et al*., 2015; Kwak *et al*., 2016). Generally, Huanghe sediments are characterized by high smectite, and Changjiang sediments contain a lot of illite contents. Western Korean rivers (e.g. the Han, Keum, and Yeongsan) contain more kaolinite and chlorite than do Chinese rivers (Table 2).

A ternary diagram of smectite–(kaolinite+chlorite)–illite is utilized to determine the provenance of fine sediments in core 11YS-PCL14 (Fig. 4). Although Unit 4 and 3 sediments differed in granularity, they had similar clay mineral compositions and plotted near the center of the three possible provenance end-members, indicating that fine-grained sediments were supplied with constant amounts from all potential rivers to the study area during these periods (Fig. 4a). Unit 2 sediments overall were characterized by an increasing illite content (Figs. 3 and 4b). It means that the influence of Changjiang-derived materials began to increase during this period. However, Unit 2-2 sediments displayed an increase in smectite content with illite, and then clay mineral compositions except illite decrease in Unit 2-1 (Fig. 4b). Variation of smectite content in Unit 2 appears to be closely related to the change in coarse sediments (Figs. 3 and 4b). The relationship between smectite and coarse grains was also observed in the early Holocene sedimentary unit of core YSC-1 (Li *et al*., 2014a) and nearby core EZ06-2 between ~14.1 and ~9.0 ka (Lim *et al*., 2015). Unit 1 sediments had clay mineral compositions quite similar to those of Changjiang sediments, indicating that they might be originate mainly from the Changjiang (Fig. 4b). Consequently, clay mineralogical results suggest that the provenance of fine-grained sediments are changed according to each unit as follow; fine-grained sediments during the depositions of Unit 3 and 4 were supplied from all potential provenances, the influence of the Changjiang increased gradually during the deposition of Unit 2, Unit 1 sediments were mainly originated from the Changjiang.

5.2. Provenance discrimination based on geochemistry

Geochemical proxies for provenance discrimination in the Yellow Sea have been investigated actively and verified by several studies (*e.g.* Yang *et al*., 2002; Xu *et al*., 2009; Song and Choi, 2009; Jung *et al*., 2012; Ha *et al*., 2013; Lim *et al*., 2015; Hu *et al*., 2018; Koo *et al*., 2018). The chemical compositions of Korean and Chinese rivers differ, especially in their rare earth elements (REE) and Sr–Nd contents (Xu *et al*., 2009; Jung *et al*., 2012; Lim *et al*., 2014; Hu *et al*., 2018). The trace elements and isotopes are essentially unaltered during weathering, transport, and sedimentation, and can be a powerful tool for tracing the provenance of the terrigenous fraction of marine sediments (McLennan, 1989; Blum and Erel, 2003; Xu *et al*., 2009; Chaudhuri *et al*., 2020).

Recent studies have emphasized caution for misinterpretation of sediment provenance due to other factors which influence the geochemical composition of riverine and marine sediments such as grain size and biogenic component (Yang *et al*., 2002; Song and Choi, 2009; Lim *et al*., 2015; Hu *et al*., 2018). For example, major elements Fe and Mg as well as some trace elements have been proposed to be useful elements as provenance indicator in the Yellow Sea (Song and Choi, 2009; Koo et al., 2018), but they are closely correlated with particle size, which can lead to misinterpretation of sediment provenance (Fig. 5a). In addition, Ca has a problem based on biogenic carbonate despite the poor correlation with grain size (Fig. 5a). To complement the grain size effect, recent studies have suggested ratios of the binding of abundant elements at comparable grain sizes (*e.g.*, the La/Sc and Zr/Th ratios) (Yang *et al*., 2002; Lim *et al*., 2014). However, we observed that these ratios and mean grain size were strongly negatively correlated in our dataset (Fig. 5b), implying that these ratios are also unsuitable for studying provenance. Normalization of REE values to upper continental crust (UCC) is a widely accepted method for discriminating the sediment provenances of various geological materials (Taylor and McLennan, 1985; Song and Choi, 2009; Xu et al., 2009; Lim *et al*., 2015). This method can better offset differences caused by grain size, and could be a useful geochemical proxy (Fig. 5c). In addition, the Nd isotope ratio of silicate particles is essentially unaltered during weathering, transport, and sedimentation and can be a powerful tool for tracing the provenance of the terrigenous fraction of marine sediments (Blum and Erel, 2003; Hu *et al*., 2018). However, recent studies indicated that the Sr isotope composition in both Chinese and Korean riverine sediments was a function of grain size, with a higher $^{87}Sr/^{86}Sr$ in clay-dominated fractions than in silt-dominated fractions (Fig. 5d) (Hu *et al*., 2018). For these reasons, we used only the UCC-normalized REE and Nd isotope, independent of grain size effect, to distinguish sediment provenance.

Korean rivers are characterized by a high LREE and low εNd, while Chinese rivers have abundant MREE (middle REE) and high εNd (Table 3, Fig. 6). Figs. 6 are discrimination plots using the REE and εNd values that clearly separate the Chinese and Korean rivers. The REE and εNd values in these plots could represent the source of all sediments including coarse and fine sediments because the REE analysis performed using the bulk powder samples. Unit 1 sediments are generally close to the Changjiang, which is consistent with results in clay mineralogy (Figs. 4 and 6). Unit 4 sediments are plotted between China and Korean river end-members in all discrimination plots (Fig. 6), consistent with the results for clay minerals, which suggests that the coarse sediments included in Unit 4 were from contributions from all potential rivers.

Interestingly, the fine-grained sediments of Unit 2 were a composite of the Huanghe and Changjiang in Fig. 4, but the geochemical data were similar to Unit 4 (Fig. 6). This probably means that a significant amount of coarse sediments in Unit 2 was supplied from Korean rivers with a high LREE (Fig. 6a). The results of the isotope analysis in the core YSC-1 also showed an increased impact of Korean rivers and coarse sediments before ~8 ka, which is consistent with our results (Hu *et al*., 2018). Thus, the supply of smectite in fine-grained sediments and sand grains is synchronic, but possibly has different sources. In addition, Unit 3 sediments, identified as the homogenous origin as Unit 4 in clay mineralogy (Fig. 4), are biased towards Chinese rivers (Fig. 6), especially close to the Huanghe. A scatter plot of clay mineral ratio *vs*. εNd distinguished three possible provenances for particles smaller than 63 μm (Fig. 6c). Unit 3 sediments in this plot are certainly plotted close to the Huanghe, which is different distribution than previous plots.

This result is likely to be due to the influence of silt-sized particles that is not considered in clay mineralogy, because Unit 3 sediments contain much of silt content (Fig. 2). Therefore, fine-grained sediments were supplied from all rivers to the study area, but coarse-grained sediments appear to have been mainly sourced from the Huanghe during the deposition of Unit 3 (Figs. 4 and 6). Consequently, the estimated sediment provenances in each unit based on the clay mineralogical and geochemical indices were as follows. During the deposition of Unit 4, both coarse and fine sediments were influenced by all of these provenances. However, in Unit 3, silt-sized fractions were predominantly affected by the Huanghe. Unit 2 represented a period of great change in the sediment sources. The fine grains in the Unit 2-2 sediments were derived primarily from Chinese rivers, especially the Huanghe, while the Unit 2-1 samples were supplied mainly from the Changjiang, with minor contributions from the Huanghe and western Korean rivers. However, coarse sediments source in Unit 2 were identified as western Korean rivers based on geochemical indices. The source of CYSM sediments in Unit 1 was primarily the Changjiang.

5.3. Paleo-environmental implications for sediment provenance changes

The four units could be distinguished based on the characterization of the major sediment source changes in the CYSM over the last 15.5 kyr (Figs. 4–6). Identification of sediment sources is a useful method for understanding paleo-environmental dynamics and sediment transport mechanisms in the Yellow Sea since the late last deglaciation. The main factors that potentially influenced provenance changes in the Yellow Sea include pronounced sea-level fluctuations that regulate the positions of shorelines, paleo-river pathways, tidal stress amplitude, and the formation of modern ocean currents (Liu *et al*., 2004; Lim *et al*, 2007, 2015; Choi *et al*., 2010; Wang *et al*., 2014; Yoo *et al*., 2015, 2016). Here, we discuss how these complex processes have affected sedimentation in the CYSM during the last 15.5 kyr.

The sea level during the depositions of Units 3 and 4, which corresponds to the late last deglaciation (15.5–12.8 ka), was approximately 60–100 m lower than the present sea level (Li *et al*., 2014b). The high signatures of C/N values in Unit 4 indicated a significant influx of terrigenous materials (Badejo *et al*., 2016). Mixed deposits of fine and coarse sediments with high influx and sedimentation rates (Figs. 2 and 3) allows us to infer Unit 4 as a delta or prodelta environment. The paleo-river pathways of potential provenances, recently reconstructed based on seismic profiles, merged around the study area and were connected to the East China Sea (Yoo *et al*., 2015, 2016). During sedimentation of Unit 4, sediments in the study area would have been affected most strongly by direct inflow from paleo-rivers, because the low sea level led to the exposure of shelves in and near the Yellow Sea (Li *et al*., 2014b).

Sediment fining during the deposition of Unit 3 reflects an increase in distance between the river mouths and study area due to transgression, and the study area probably formed a mud flat during sedimentation of Unit 3. During this period, fine-grain sediments were supplied from all rivers (Fig. 4), while silt-sized particles were supplied mainly from the Huanghe (Figs. 4 and 6). The record for the same period in core EZ06-1 shows significant coarse sediments with a high sand content (Lim *et al*., 2015), indicating that the Huanghe was relatively close to the west side of the study area (Fig. 2). In addition, the substantial flux from the Huanghe would have supported the distant movement of coarse grains.

In Unit 2 (12.8~~1~~–8.8 ka), corresponding to the early Holocene, the sea level was approximately 20−60 m lower than at present (Li *et al*., 2014b). The Unit 2 period was thought to be cold and dry (Badejo *et al*., 2016) and was characterized by oscillating grain sizes and clay mineral and geochemical compositions (Fig. 3). In addition, increasing and decreasing trends of grain size with sand content, S/I ratio divided into two subsections (Fig. 3). This variation is also reported in the surrounding YSC-1 (Li *et al*., 2014a) EZ06-1, and EZ06-2 cores. In this period, the low sea level led to the seaward progradation of the shoreline and formation of a thin sand layer (generally < 3 m) called the transgressive deposit throughout the Yellow Sea (Cummings *et al*., 2016). The change in the coastline configuration caused shifts of the tidal fields therein, with tidal currents being more energetic than at present (Uehara and Saito, 2003; Lim *et al*., 2015), which supplied coarse grains to the central Yellow Sea. In addition, the bottom stress in the Unit 2 period was stronger around the Korean Peninsula (Uehara and Saito, 2003), which caused most of the coarse sediment to be of western Korean river origin (Fig. 6). The supply of fine sediments from the Huanghe was temporarily strengthened during sedimentation of Unit 2-2, but weakened in Unit 2-1 (Fig. 4). This could be due to a change in distance between the Huanghe and the study area as the sea level rose. In addition, the paleo-Changjiang Shoal moved northeastward into the Yellow Sea at ~12 ka (Li *et al*., 2000) and may have contributed some materials to the study area (Lim *et al*., 2015). The reduction in Huanghe-derived materials due to the increased distance could be strengthen the influence of the Changjiang in Unit 2-1.

Since sedimentation of Unit 1 (< 8.8 ka), the sea level rose slowly from −20 m to the present level (Li *et al*., 2014b). The tidal field of the Yellow Sea became similar to that of the present (Uehara and Saito, 2003), leading to obviously decreasing contributions from sea bed erosion. A modern-type circulation in the Yellow Sea may have developed between 8.47 and 6.63 ka, characterized by an increase in bottom-water salinity (Kim and Kucera, 2000). The clay minerals and geochemical composition generally point to the Changjiang, with minor influence from the western Korean rivers (Figs. 4 and 6), which is consistent with the reported 'multiple origin' concept (Wei *et al*., 2003; Li *et al*., 2014a; Lim *et al*., 2015; Koo *et al*., 2018). Therefore, the formation of the CYSM and modern ocean circulation could have been synchronic around ~8 ka. The timing of mud patch formation in the central Yellow Sea was inferred to be 9~8 ka with low tidal bottom stress (< 0.35 N/m^2) (Uehara and Saito, 2003), which is consistent with our results.

The YSWC played a major role in the unique passage of sediment into the study area since the Unit 1 (Li *et al*., 2014a; Lim *et al*., 2015; Koo *et al*., 2018). The Changjiang Diluted Water can spread some finer sediments to Cheju and nearby areas (Hwang *et al*., 2014; Li *et al*., 2014a; Lim *et al*., 2015; Kwak *et al*., 2016; Koo *et al*., 2018). And then, fine-grained materials could be carried northward along the YSWC path to the CYSM, where the weak tidal-current system and cyclonic eddies provided favorable environment for the formation and maintenance of muddy sediment (Shi *et al*., 2003; Lim *et al*., 2015). Meanwhile, barrier effect of oceanic fronts and strong coastal currents restricts to enter the sediments from the Huanghe and western Korean rivers into the CYSM (Li *et al*., 2014a; Koo *et al*., 2018). However, some fine-grained particles from western Korean rivers may influence the CYSM through the Transversal Current (Hwang *et al*., 2014; Koo *et al*., 2018).

6. Conclusions

The purpose of this study was~~is~~ to better understand the CYSM in terms of provenance changes and transport mechanisms and to reconstruct the paleo-environment of the Yellow Sea since late last deglaciation using clay mineralogy and geochemical indices from core 11YS-PCL14. The major conclusions are as follows.

Core 11YS-PCL14 provides a continuous record of the late last deglaciation to Holocene in the CYSM. The core could be divided mainly into four units: Unit 4 (700–520 cm; 15.5–14.8 ka), Unit 3 (520–310 cm; 14.8–12.8 ka), Unit 2 (310–130 cm; 12.8–8.8 ka), and Unit 1 (130–0 cm; < 8.8 ka). Unit 2 is divided into two subunits Unit 2-2 (310–210 cm; 12.8–10.5 ka), Unit 2-1 (210–130 cm; 10.5–8.8 ka) according to smectite content.

The integration of clay mineralogical and geochemical data distinguished the CYSM sediments into different provenances by grain size. During the deposition of Unit 4, fine and coarse sediments were supplied from all possible rivers in the Korea and China by direct inflow from paleo-rivers with the exposure of shelves. Sediment fining in the Unit 3 reflects an increase in distance between the river mouths and study area. In this period, Fine-grain sediments were still supplied from all rivers, while silt-sized particles were supplied mainly from the Huanghe. During the deposition of Unit 2, the bottom stress was stronger around the Korean Peninsula, which caused most of the coarse sediment to be of western Korean river origin. However, the supply of fine sediments from the Huanghe temporarily strengthened in the Unit 2-2, but weakened in Unit 2-1, due to a change in distance between the Huanghe and the study area as the sea level rose. Unit 1 sediments were composed mainly of the Changjiang. After the oceanic circulation was formed, the YSWC played a major role in the unique passage of sediment into the study area. In addition, barrier effect of oceanic fronts and strong coastal currents restricts to enter the sediments from the Huanghe and western Korean rivers into the study area.

Author contribution

H.G.Cho designed the experiment, and H.J. Koo carried them out and wrote the paper. Both the~~All~~ authors contributed to interpreting and discussing the results and reviewing the paper.

Competing interests

The authors declare that they have no conflict of interest

Acknowledgements

This study was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2017R1D1A1B03027818) and Korea Polar Research Institute project PM16050 funded by the Ministry of Oceans and Fisheries, Korea.

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Figure captions

Figure 1. Schematic map showing the location of core 11YS-PCL14 as well as the surface circulation in the Yellow Sea (modified from Li et al., 2014a; Wang et al., 2014). The gray dotted line indicate the paleo-river pathways (Yoo et al., 2016). ① Central Yellow Sea Mud (CYSM); ② Southeastern Yellow Sea Mud (SEYSM); ③ Southwestern Cheju Island Mud (SWCIM); KC = Kuroshio Current; YSWC = Yellow Sea Warm Current; SDCC = Shandong Coastal Current; YSCC = Yellow Sea Coastal Current; KCC = Korean Coastal Current; SDF = Shandong Front; JSCF = Jiangsu Coastal Front; WKCF = Western Korean Coastal Front.

Figure 2. (a) Isolines in thickness (m) of mud deposit CYSM (after Wang et al., 2014), (b) vertical lithology profile of core 11YS-PCL14 and other reference cores (YSC-1, Li et al., 2014a; EZ06-1 and EZ06-2, Lim et al., 2015).

Figure 3. Downcore variations of mean grain size, clay mineralogical and geochemical data in core 11YS-PCL14 with sea level changes (Li et al., 2014b). Note the overall distribution into four units.

Figure 4. Ternary diagrams showing variations in clay mineral compositions of core 11YS-PCL14. Published data of potential source sediments including the Changjiang, Huanghe, and western Korean rivers (the Han, Keum, and Yeongsan Rivers) (Cho et al., 2015; Koo et al., 2018), which are plotted for comparison.

Figure 5. Correlation plots of grain size or clay/silt ratio with (a) major elements, (b) Zr/Th and La/Sc, (c) Upper Continental Crust (UCC)-normalized REEs (Taylor and McLennan, 1985), and (d) $^{87}Sr/^{86}Sr$ and εNd for core 11YS-PCL14.

Figure 6. Discrimination plots showing variations in (a) ∑LREE/Yb *vs*. $(La/Lu)_{UCC}$, (b) $(La/Yb)_{UCC}$ *vs*. εNd, and (c) (smectite+kaolinite+chlorite)/illte *vs*. εNd. Clay mineral (Cho et al., 2015; Koo et al., 2018), rare earth element (Xu et al., 2009), and isotope data of potential sources are also shown for comparison.

Fig. 7. Schematic diagram showing the influence of shoreline changes, and paleo-river pathways on riverine sediment supplied to the study area during (a) Unit 4 and 3 (15.5–12.8 ka), (b) Unit 2 (12.8–8.8 ka), and (c) Unit 1 (8.8 ka–present) (modified Lim et al., 2015).

Interactive comment on "Changes in detrital sediment supply to the central Yellow Sea since the Last Glacial Maximum" by Hyo Jin Koo and Hyen Goo Cho

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Received and published: 23 July 2020

This work study provenance and dynamics of sediments from a core raised from the Central Yellow Sea using clay mineralogy and geochemical compositions since the Last Glacial Maximum. Based on the patterns of various proxies, the core was divided into four units as Unit 4 (15.5 ka–14.8 ka), the bottommost, Unit 3 (14.8 ka–12.1 ka), Unit 2 (12.1 ka–8.8 ka) and Unit 1 (< 8.8 ka), the topmost. Comparison of mineralogical and geochemical compositions suggested the late last deglaciation sediments (Units 4 and 3) originated from all potential provenance rivers like Huanghe, Changjiang and western Korean rivers. The coarser sediments in Unit 3 were exclusively de-rived from Huanghe. In Unit-2 (early Holocene), the provenance of fine sediment changed from the Huanghe to the Changjiang whereas the source of coarse-grainedsediments was most likely the western Korean rivers. The Changjiang source was dominant during the deposition of Unit 1 sediments with minor contributions from the western Korean rivers. The shift of river mouth positions, tide levels, and sea circulation patterns in tune with the fluctuating climate and sea levels were mainly held responsible for varying patterns in various proxies and transport mechanism from the river sources.

The manuscript will be important work for researchers working on provenance of marine sediments and understanding sea circulations in the past. The manuscript is well-written in terms of English and in good structure. Scientifically, the interpretations are well-supported by the data and illustrations and there are no specific questions/issues.

Some modifications are suggested in lines 154-164. Some citations are not referenced and some references are not cited. Other minor comments/technical corrections are highlighted/given in the annotated pdf.

ANSWER. We have modified the manuscript according to your suggestion. We would like to thank for constructive reports with helpful comments and suggestions.

◆ PDF-os-2020-60-RC1-supplement

Line 9 : On what basis? or what was the criteria for dividing into four units? Write as 'Based on....'

ANSWER. We added the appropriate sentence. “The core can be divided into four units based on the various proxies such as grain size, clay mineralogy, geochemistry, and Sr–Nd isotopes: …”

Line 80: delete ‘for’

ANSWER. We deleted the ‘for’ as mentioned

Line 154-164 : Here, I don't understand whether you want to explain how factors such as grain size, heavy mineral content, and biogenic component affected your bulk sediment analysis or you want justify the use of REE or Nd isotopes as provenance indicator. If it is the first case, you need to modify para on that line and if it is the second case, I think you better mention this in 'Introduction' part.

ANSWER. We acquired the major and trace elements data from bulk sediments but Nd isotopes from the <63 μm fractions. In this study, we don’t used the major elements because they are different with grain size.

We only used the UCC-normalized REE and Sr-Nd isotopes independent of grain size. Therefore, this corresponds to the first case mentioned above, and we modified the paragraph accordingly.

“Recent studies have emphasized caution for misinterpretation of sediment provenance due to other factors which influence the geochemical composition of riverine and marine sediments such as grain size and biogenic component (Yang *et al*., 2002; Song and Choi, 2009; Lim *et al*., 2015; Hu *et al*., 2018). For example, major elements Fe and Mg as well as some trace elements have been proposed to be useful elements as provenance indicator in the Yellow Sea (Song and Choi, 2009; Koo et al., 2018), but they are closely correlated with particle size, which can lead to misinterpretation of sediment provenance (Fig. 5a). … … For these reasons, we used only the UCC-normalized REE and Nd isotope, independent of grain size effect, to distinguish sediment provenance.”

Line 243: Kwak et al., 2014 - Reference missing.

ANSWER. We had wrote this reference incorrectly, thus revised it to ‘Kwak et al., 2016’.

Reference

Delete - Dong, Y.G., Guan, W.G., Chen, Q., Li, X.H., Liu, X.H. and Zeng, X.M.: Sediment transport in the Yellow Sea and East China Sea, Estuar. Coast. Shelf Sci., 93, 248–258, https://doi.org/10.1016/j.ecss.2011.04.003, 2011.

ANSWER. We deleted unmentioned reference in the manuscript

Delete - Hu, B.Q., Yang, Z.S., Qiao, S.Q., Zhao, M.X., Fan, D.J., Wang, H.J., Bi, N.S. and Li, J.: Holocene shifts in riverine finegrained sediment supply to the East China Sea Distal Mud in response to climate change, Holocene, 24, 1253–1268, https://doi.org/10.1177/0959683614540963, 2014.

ANSWER. We deleted unmentioned reference in the manuscript

Delete - Li, T.G., Nan, Q.Y., Jiang, B., Sun, R.T., Zhang, D.Y. and Li, Q.: Formation and evolution of the modern warm current system in the East China Sea and the Yellow Sea since the last deglaciation, Chin. J. Oceanol. Limnol., 27, 237–249, https://doi.org/10.1007/s00343-009-9149-4, 2009.

ANSWER. We deleted unmentioned reference in the manuscript

Delete - Liu, S., Shi, X., Fang, X., Dou, Y., Liu, Y. and Wang, X.: Spatial and temporal distributions of clay minerals in mud deposits on the inner shelf of the East China Sea: Implications for paleoenvironmental changes in the Holocene. Quat. Int., 349, 270–279, https://doi.org/10.1016/j.quaint.2014.07.016, 2014.

ANSWER. We deleted unmentioned reference in the manuscript

Interactive comment on "Changes in detrital sediment supply to the central Yellow Sea since the Last Glacial Maximum" by Hyo Jin Koo and Hyen Goo Cho

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Received and published: 23 July 2020

The study by Koo and Cho, is relevant and appropriate for the journal. I have attached an annotated copy with my detailed comments.

ANSWER. Thank you for the valuable remarks. We modified the manuscript according to comments.

There are a few points in the manuscript which need clarification:

1) The study mentions that the core PCL14 provides more records of the CYSM since the LGSM, compared with previous cores studied. Why is this so? Is it because the core recovery of PCL14 is better than the previous studies? If yes than this point should be mentioned.

ANSWER. The core 11YS-PCL14 is 702 cm recovered deeper than other studied cores around here (YSC-1; 437 cm, EZ06-1; 370 cm, EZ06-2; 360 cm). Since the thickness of the Central Yellow Sea Mud (CYSM) becomes thinner from the west to the east, our core, which is located in the eastern CYSM, involves older records than surrounding studied cores. We added this in the Materials and methods part. "The core 11YS-PCL14 is 702 cm recovered deeper than other studied cores around here (YSC-1; 437 cm, EZ06-1; 370 cm, EZ06-2; 360 cm) (Li et al., 2014; Lim et al., 2015)."

2) It is not clear why Unit 2 was further subdivided and what was the basis for it. If it was subdivided further than one should include difference in the provenance using trace element, clay minerals or Nd isotopes in the conclusion part as well. The conclusions should be rewritten and be split into points. Avoid using sentences in the past tense throughout the manuscript. Overall, the manuscript is well structured and presents an important study.

ANSWER. During the Unit 2, geochemical proxies and grain size were largely similar, but clay mineral compositions (especially the content of smectite) differed significantly. Therefore, we subdivided Unit 2 into two units based on the variation of clay mineral composition and explained in more detail in the manuscript.

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Abstract

Line 12: The last deglaciation - late last deglaciation (mention kyr)

ANSWER. We added the period.

1. Introduction

Line 26: continent?

ANSWER. We removed this word.

Line 53-55: avoid past tense

ANSWER. We revised as mentioned.

2. Oceaonography

Line 57-61: This sentence is too long and confusing. Rephrase

ANSWER. We revised this sentence to avoid confusion. "The hydrodynamic system in the Yellow Sea is characterized by two major circulation patterns (Fig. 1). One is a counterclockwise gyre in the western part consisting of the Yellow Sea Warm Current (YSWC) and Yellow Sea Coastal Current (YSCC) (Beardsley *et al*., 1985; Yang *et al*., 2003). …"

Line 67: CDW - Is this a river? Please state if it is so. Not very clear here.

ANSWER. The Changjiang Diluted Water (CDW) is low-salinity water flow by the amount of freshwater input from the Changjiang. We revised the content related to CDW more clearly. "On the other hand, amount of freshwater input from the Changjiang to the Yellow Sea forms the plume of low-salinity water, called as the Changjiang Diluted Water (CDW) (Sukigara et al., 2017). A part of the CDW spreads eastward, reaching as far as Jeju Island and Korea Strait (Hwang *et al*., 2014; Li *et al*., 2014a)."

Line 67 : delete 'most'

ANSWER. We revised the sentence related to CDW including this word.

Line 70-71: What kind of different water masses? Why is it important here in the paper? Please state a reason.

ANSWER. The oceanic fronts such as SDF, JSCF, and WKCF separate different water masses in the central and coast of the Yellow Sea. These are closely related to the sediment transports and sedimentation in the area. Since the formation of modern oceanic circulation, the oceanic fronts restrict river-derived sediment from entering the center of the Yellow Sea and cause them to move along the coastal currents. We revised this sentence more clearly. "These fronts play an important role in shaping Yellow Sea currents as well as in understanding sediment transport, as they separate different water masses in the centre and coast of the Yellow Sea and appear a barrier effect for sediment

(Huang et al., 2010; Li et al., 2014a; Koo et al., 2018) (Fig. 1).”

3. Materials and metods

Line 76: AMS14C - space should be added between AMS and 14C

ANSWER. We revised as mentioned.

Line 87: Word missing. 'riverine sediments'?

ANSWER. We revised as mentioned.

Line 89: Which method was followed for sample dissolution?

ANSWER. We added detailed method and appropriate references in regard with the isotope analysis. “The inorganic silicate fraction was extracted from 18 samples following the method described by Rea and Janecek (1981). The samples were treated with acetic acid buffered to pH 5 with sodium acetate to remove calcium carbonate. They were subsequently treated with a hot sodium citrate-sodium dithionite solution buffered with sodium bicarbonate to remove coarse biogenic components and finally treated with Na2CO3 solution to remove biogenic silica. 143Nd/144Nd and 87Sr/86Sr analyses, including chemical separation and multicollector thermal ionization mass spectrometry (VG54-30, Isoprobe-T) analyses were performed at the Korea Basic Science Institute following Cheong et al. (2013).”

4. Results

Line 99: based on the variation trends - variation trends of what? why this division was done further is not very clear

ANSWER. During the Unit 2, geochemical proxies and grain size were largely similar, but clay mineral compositions (especially the content of smectite) differed significantly. Therefore, we subdivided Unit 2 into two units based on the variation of clay mineral composition and explained in more detail in the manuscript.

Line 104-106: Why is this so? Was the recovery better in the core of this study than the previous study? Please give a reference about which previous studies you are mentioning here.

ANSWER. We added the references (Li et al., 2014a and Lim et al., 2015) about previous studied cores (YSC-1, EZ06-1, and EZ06-2) in the central Yellow Sea. The core 11YS-PCL14 is 702 cm recovered deeper than other studied cores around here (YSC-1; 437 cm, EZ06-1; 370 cm, EZ06-2; 360 cm). Since the thickness of the Central Yellow Sea Mud (CYSM) becomes thinner from the west to the east, our core, which is located in the eastern CYSM, involves older records than surrounding studied cores. We added this in the Materials and methods part. “The core 11YS-PCL14 is 702 cm recovered deeper than other studied cores around here (YSC-1; 437 cm, EZ06-1; 370 cm, EZ06-2; 360 cm) (Li et al., 2014; Lim et al., 2015).”

5. Discussion

5.1. Provenance discrimination based on clay mineralogy

Line 130: was utilized - is utilized, Please avoid writing in past tense

ANSWER. We revised as mentioned.

Line 135-136: what is every clay mineral composition? Rephrase

ANSWER. We removed the 'every'. "And then clay mineral compositions except illite decrease in Unit 2-1"

Line 141: were suggested - suggest

ANSWER. We revised as mentioned.

Line 144: Repetition marked highlighted. Consider omitting the first highlighted line about Unit 1.

ANSWER. We modified this sentence. "Consequently, clay mineralogical results suggest that the provenance of fine-grained sediments are changed according to each unit as follow; fine-grained sediments during the Unit 3 and 4 were supplied from all potential provenances, the influence of the Changjiang increased gradually during the Unit 2, Unit 1 sediments were mainly originated from the Changjiang."

5.2. Geochemical approaches

Chapter title - Consider changing the section heading to "provenance discrimination based on geochemistry"

ANSWER. Thank you for your valuable advice. We revised as mentioned.

Line 146-149: Start of the sentence should be different. These can mean anything mentioned in the previous sentence, not just REE or trace

ANSWER. We revised the start of the sentence to 'The trace elements and isotopes' as mentioned.

Line ~155: Various other major and trace elements are used as proxies. This section can be improved.
Please refer to Chaudhuri et al., 2020, Marine and Petroleum Geology or Chaudhuri et al., 2020, Geological Magazine and more references on use of trace elements and Sr-Nd isotopes. May compare composition of Huanghe, Changjiang and other rivers with those of your samples.

ANSWER. Thanks for the valuable and constructive comments. We checked the references mentioned, and compared various proxies (e.g. Th/Sc, Cr/V, Th/Co, CIA, ICV). However, when we applied these proxies to this study, the potential provenances (the Huanghe, Changjiang, and western Korean rivers) were not distinguished well, and the difficulty due to the grain size effect remained, so we did not add these proxies.

Line ~170: Fig. 5 legend missing

Cite the reference for the values used for normalisation? Original paper reporting the values. Mention in figure caption as well.

ANSWER. We added the reference 'Taylor and McLennan (1985)' about original paper reporting the values of upper continental crust.

Line 180-181: 'The association between an increased impact of Korean rivers and coarse sediments was identified in an isotope analysis before ~8 ka in core YSC-1 (Hu et al., 2018).' Please rephrase the sentence for clarity.
ANSWER. This sentence was rewritten more obviously. "The results of the isotope analysis in the core YSC-1 also showed an increased impact of Korean rivers and coarse sediments before ~8 ka, which is consistent with our results (Hu *et al*., 2018)."

5.3. Paleo-environmental implications for sediment provenance changes
Line 213: delete 'still'
ANSWER. We revised as mentioned.

Line 214: showed – shows
ANSWER. We revised as mentioned.

Line 228: study area - the study area
ANSWER. We revised as mentioned.

Line 245: sedimentation – sediments
ANSWER. We revised as mentioned.

6. Conclusions
Line 251-253: Split the conclusion into seperate points, especially for the various units.
ANSWER. We rewrote the conclusions by subdividing each unit.

Line 255: Unit 2 (280–130 cm; 12.1–8.8 ka) - What about unit 2-1 and unit 2-2? why was unit 2 subdivided?
ANSWER. We rewrote the conclusions part by dividing Unit 2 into Unit 2-1 and Unit 2-2.

Figure 2
What is contents, marked in this figure? Not very clear
ANSWER. We modified the Figure 2 clearly. Figure 2 shows thickness of uppermost mud deposit (a) and the correlation between the present study core (11YS-PCL14) and surrounding reference cores (YSC-1, EZ06-1, and EZ06-2) (b). Our core is divided into four units by grain size, and extends well with the reference cores. In addition, the core 11YS-PCL14 provides more records than other cores, because the core has long length and thin uppermost mud layer.

Figure 5

What is UCC? Mention the fullform in the fig caption

ANSWER. We added the full form of UCC (Upper Continental Crust) in the figure caption.

Interactive comment on "Changes in detrital sediment supply to the central Yellow Sea since the Last Glacial Maximum" by Hyo Jin Koo and Hyen Goo Cho

Anonymous Referee #3

Received and published: 24 July 2020

1. General comments: This manuscript discussed the sediment provenance of Central Yellow Sea mud (CYSM) and their controlling factors based on the analysis of clay mineral composition, rare earth elements and radiogenic Nd isotope of core 11 YS-PCL14 in the Yellow Sea. This manuscript present some new evidences to trace the sediment provenance of the mud deposition in the middle Yellow Sea since late deglaciation.

It is helpful to better understand the variation of sediment supply to this area and the formation history of the mud deposition in the Yellow Sea. However, some key parts of the manuscript are not clearly displayed or described. There are some inconsistence in the manuscript. The language should be polished further because some expression are hard to understand. Therefore, I suggest that this manuscript should be major revised before it can be accepted.

ANSWER. Thank you for the valuable remarks. We modified the manuscript according to comments.

2. Specific comments:

(1)The time period in the title need to be revised. The core records the sedimentary history for the last 15.5ka (from the last deglaciation to present). The whole text of the manuscript also use the last delgaciation, why the title use the Last Glacial Maximum?

ANSWER. We agree with the comment. The time period in the title was revised to 'last deglaciation' as mentioned.

(2)The core name is different in the manuscript. Two different names are used in the manuscript, e.g. 11YS-PCL14 and PCL14. Although this research use the same core sediemnt as Badejo et al. (2016), the core name is different from Badejo's paper.

ANSWER. We revised all core names in manuscript to '11YS-PCL14'.

(3) In the abstract, the meaning of this sentence is not clear. "The late last deglaciation (Units 3 and 4) sediments originated from all potential provenance rivers, while the source of coarse sediments changed to Huanghe in Unit 3". What does all the potential provenance rivers mean? Which rivers are not clear here and should be indicated.

ANSWER. Potential provenance rivers means the Huanghe, Changjiang, and western Korean rivers (Han River, Yeongsan River, and Keum River) that can supply sediments to the Yellow Sea. We added river names as well as revised this sentence to understand clearly.

The authors argue that the late last deglaciation (Units 3 and 4) sediments originated from all potential provenance rivers, here, sediments indicate fine sediments or not? If the answer is no, then it is contradict with the following

sentence: “while the source of coarse sediments changed to Huanghe in Unit 3.”
ANSWER. We suggested that the provenances of fine and coarse sediments during Unit 3 and 4 are different. Fine sediments were supplied from all rivers (the Huanghe, Changjiang, and western Korean rivers) during these periods based on the clay mineral compositions. Coarse sediments were supplied from all rivers during the Unit 4, but mainly from the Huanghe during the Unit 3 based on the Nd isotopes. We modified this sentence clearly. “During the late last deglaciation (Units 3 and 4, 15.5–12.8 ka), Unit 4 sediments originated from all potential provenance rivers such as the Huanghe, Changjiang, and western Korean rivers, while the source of coarse sediments changed to Huanghe when beginning the Unit 3. Fine-grained sediment still supplied from all rivers during the Unit 3”

(4) The age boundary of unit 3 and unit 2 are inconsistent in the manuscript. In some parts (e.g. Abstract, Discussion, Conclusion and Fig.7), the boundary is 12.1ka, in other parts, it is 12.8ka, which one is correct?
ANSWER. Thank you for your great effort to check our manuscript thoroughly. The boundary between Unit 3 and Unit 2 is 310 cm and 12.8 ka. All miswritten parts including the abstract, discussion, conclusion, and figures were checked and revised.

(5) The last sentence in the abstract is hard to understand. “Possible transport mechanisms in the riverine sediment sources change and contributions to this include position shifts of river mouths, tidal stress evolution, and the development of the Yellow Sea Warm Current and coastal circulation systems”.
ANSWER. We revised the sentence more clearly. “Possible transport mechanisms concerning such changes in the sediment provenance include paleo-river pathways, tidal stress evolution, and the development of the Yellow Sea Warm Current and coastal circulation systems, depending on the sea-level fluctuations.”

(6) Lines 50-52: this sentence is hard to understand. “Particularly, paleoriver pathway associated with sea-level change that was recently reconstructed using highresolution seismic data in the Yellow Sea can be explained reasonable for understanding CYSM formation during low stand period (KIGAM, 1993; Xu et al., 1997; Yoo et al., 2015, 2016).”
ANSWER. We revised the sentence more clearly. “In addition, paleo-river pathways, recently reconstructed by high-resolution seismic researches in the Yellow Sea, can account for sedimentation and sediment provenance since the last deglaciation because they become an important route of sediment transport during the low stand period.”

(7) Figure 1 have some errors. The boundarie lines between different countries are missing. Some locations are missing, for example, Cheju Island and Tsushima Strait etc.
ANSWER. We added a location (Jeju Island) mentioned in the manuscript. However, national boundaries were not expressed because they are not important in this study and are generally not expressed in research papers.

(8) Biogenic carbonate is a major component in the marginal sea sediments, it may significantly influence the grain size, and Sr-Nd isotopic compositions. However, the authors didn’t clearly describe what kind of samples are use to be analyzed, bulk sediments or siliclasitic fractions. In addition, the content of biogenic carbonate composition of the

core should be displayed.

ANSWER. We acquired the major and trace elements data from bulk sediments but Nd isotopes from the <63 µm fractions. In this study, we don't used the major elements because they are different with grain size.

We only used the UCC-normalized REE and Sr-Nd isotopes independent to grain size. Besides, Sr-Nd isotope composition was measured after removal biogenic carbonate. We added detail procedure for Sr-Nd isotope analysis in the Materials and method. "The inorganic silicate fraction was extracted from 18 samples following the method described by Rea and Janecek (1981). The samples were treated with acetic acid buffered to pH 5 with sodium acetate to remove calcium carbonate. They were subsequently treated with a hot sodium citrate-sodium dithionite solution buffered with sodium bicarbonate to remove coarse biogenic components and finally treated with Na2CO3 solution to remove biogenic silica. 143Nd/144Nd and 87Sr/86Sr analyses, including chemical separation and multicollector thermal ionization mass spectrometry (VG54-30, Isoprobe-T) analyses were performed at the Korea Basic Science Institute following Cheong et al. (2013)." In addition, the total organic carbonate (TOC) was already reported in Badejo et al. (2015) which studied the same core (11YS-PCL14).

(9) Line 80: The clay mineral analysis for was conducted: : :. "for" should be deleted.

ANSWER. We deleted the 'for' as mentioned

(10) The discussion part are poorly written. There are some mistakes, especiall in the provenance parts, I list some of them as follows:

Line 172, "while Chinese rivers have abundant MREE (middle REE) and "Nd (Table 3, Fig. 6)". This description is not accurate. Abundant cannot be used to describe "Nd.

ANSWER. We revised this description to "abundant MREE (middle REE) and high εNd".

LINE 173, "In these plots, the REE values represented the source of both coarse and fine sediments because the analysis was performed with coarse grains." This sentence is very hard to understand.

ANSWER. We revised this sentence clearly. "In these plots, the REE values could represent the source of all sediments including coarse and fine sediments because the REE analysis performed using the bulk powder samples."

Line 174-175: Unit 1 is generally close to the Changjiang with slightly influence of the Korean rivers, as well as the clay mineralogy(Fig.4 and 6). This sentence is very confused.

In addition, the author didn't mention the influence of Korea Rivers on the sediment of UNIT1 in the former discussion. It is contradict with this discussion.

ANSWER. We revised this sentence and deleted the content related to the Korean rivers because it was not clearly observed. "Unit 1 sediments are generally close to the Changjiang, which is consistent with results in clay mineralogy (Figs. 4 and 6)."

Line177: "the clay-sized particles of Unit 2" are not correct. Clay-sized paritcles indicate <4 m particles. However, the autohr only analysis the provenance of clay minerals (finer than 2m). Actually, the authors use clay-sized particles to represent clay minerals in the manuscript for many times, which should be revised.

ANSWER. We modified the expression ‘clay-sized particles’ to ‘fine-grained sediments’.

Lines 185-186: These sentences: “Unit 3 sediments in this plot are certainly plotted close to the Huanghe. This is caused by the many silt fractions in Unit 3 and probably represents a relatively close supply from the Huanghe.” is hard to understand, and it is hard to demonstrate the contribution of silt fractions from Huanghe increase.

ANSWER. We revised this sentence clearly. Figure 6c was formed using the clay mineral contents and εNd values. This figure can distinguish three potential provenances, and Unit 3 in this figure shows in a distinctly different distribution (close to the Huanghe) than previous plots. Unit 3 contains very little sand, and silt-sized particles dominate. In addition, Nd isotope analysis was performed using the particles smaller than 63 μm (i.g. clay and silt fraction). Therefore, difference in the distribution of Unit 3 in Figure 4 and Figure 6c can be inferred to be caused by silt particles included in the Nd isotope analysis.

Lines 188-189: However, in Unit 3,silt-sized fractions were predominantly affected by the Huanghe. This conclusion is lack of evidence to support.

ANSWER. This comment seem to be the same content as the Line 188-189 above. Figure 6c was made from the clay mineral contents and εNd values. This figure can distinguish three potential provenances, and Unit 3 in this figure shows in a distinctly different distribution (close to the Huanghe) than previous plots. Unit 3 contains very little sand, and silt-sized particles dominate. In addition, Nd isotope analysis was performed using the particles smaller than 63 μm (i.g. clay and silt fraction). Therefore, difference in the distribution of Unit 3 in Figure 4 and Figure 6c can be inferred to be caused by silt particles included in the Nd isotope analysis.

Line 213: The authors write “while silt-sized particles were supplied only from the Huanghe (Fig. 5)”, but I cannot get this information from Figure 5.

ANSWER. Mentioned information can get by comparing figures 4 and 6. This figure number was incorrectly and was modified to ‘Figs. 4 and 6’.

Changes in detrital sediment supply to the central Yellow Sea since the last deglaciation~~Last Glacial Maximum~~

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Abstract. The sediment supply to the central Yellow Sea since the last deglaciation~~Last Glacial Maximum~~ was uncovered through clay mineralogy and geochemical analysis of core 11YS-PCL14 in the Central Yellow Sea mud (CYSM). The core can be divided into four units based on the various proxies such as grain size, clay mineralogy, geochemistry, and Sr–Nd isotopes: Unit 4 (700–520 cm; 15.5–14.8 ka), Unit 3 (520–310~~280~~ cm; 14.8–12.8~~1~~ ka), Unit 2 (310~~280~~–130 cm; 12.8~~1~~–8.8 ka), and Unit 1 (130–0 cm; < 8.8 ka). Unit 2 is subdivided into two subunits Unit 2-2 (310–210 cm; 12.8–10.5 ka), Unit 2-1 (210–130 cm; 10.5–8.8 ka) according to smectite content. Comparison of the clay mineral compositions, rare earth elements, and εNd ~~values~~ indicate~~d~~ distinct provenance shifts in core 11YS-PCL14. Moreover, the integration of clay mineralogical and geochemical indices show~~ed~~ different origins according to particle size. During the late last deglaciation (Units 3 and 4, 15.5–12.8 ka), Unit 4 sediments originated from all potential provenance rivers such as the Huanghe, Changjiang, and western Korean rivers, while the source of coarse sediments changed to Huanghe when beginning the Unit 3. Fine-grained sediment still supplied from all rivers during the Unit 3. ~~The late last deglaciation (Units 3 and 4) sediments originated from all potential provenance rivers, while the source of coarse sediments changed to Huanghe in Unit 3.~~ Early Holocene (Unit 2) sediments were characterized by oscillating grain size, clay minerals, and moderate εNd values. In this period, the dominant fine sediment provenance changed from the Huanghe to the Changjiang, whereas coarse sediments most likely originated from western Korean rivers. The Unit 1 CYSM sediments were sourced primarily from the Changjiang, along with minor contributions from the western Korean rivers. Possible transport mechanisms concerning such changes in the sediment provenance include paleo-river pathways, tidal stress evolution, and the development of the Yellow Sea Warm Current and coastal circulation systems, depending on the sea-level fluctuations. ~~Possible transport mechanisms in the riverine sediment sources change and contributions to this include position shifts of river mouths, tidal stress evolution, and the development of the Yellow Sea Warm Current and coastal circulation systems.~~

Keywords: Central Yellow Sea mud (CYSM), clay mineralogy, sediment provenance, Sr–Nd isotopes, Rare earth elements

1 Introduction

The Yellow Sea, located between the China ~~continent~~ and Korean Peninsula, is a semi-enclosed epicontinental shelf with a complex oceanic circulation system (Fig. 1). It is notable for its large amount of runoff and terrigenous sediment supplied from several adjacent rivers, including two of the world's largest rivers, the Changjiang and Huanghe, as well as from several smaller Korean rivers, including the Han, Keum, and Yeongsan River. Although most riverine sediments are trapped in estuaries and along coastal areas, some are deposited on adjacent shelves (Milliman *et al.*, 1985; Milliman *et al.*, 1987), forming several shelf mud patch depositions such as Central Yellow Sea Mud (CYSM), Southeastern Yellow Sea Mud and Southwestern Cheju Island Mud (Fig 1). These deposits provide abundant information on paleo-environmental changes as well as sediment supply, marine hydrodynamics, and climate variation (*e.g.* Wang *et al.*, 1999; Kim and Kucera, 2000; Li *et al.*, 2014a; Cho *et al.*, 2015; Kwak *et al.*, 2016; Hu *et al.*, 2018).

The provenance of CYSM sediments have attracted many researchers over the last three decades. Many studies have indicated that CYSM sediments originated mostly from the Huanghe considering the large amount of sediment load carried by that river (Milliman *et al.*, 1987; Lee and Chough, 1989; Liu *et al.*, 2002; Yang and Liu, 2007; Shinn *et al.*, 2007; Xiang *et al.*, 2008). On the other hand, other studies have used mineralogical, geochemical, and magnetic observations and determined that the CYSM was formed from a complex mixture of sediments from the Huanghe as well as the Changjiang and several Korean rivers (Zhao *et al.*, 1990; Wei *et al.*, 2003; Zhang *et al.*, 2008; Li *et al.*, 2014a; Wang *et al.*, 2014; Koo *et al.*, 2018). In addition, recent studies using core sediments suggested that the provenance of CYSM changed mainly from Huanghe to Changjiang with minor contribution from the Korean rivers during the Holocene (Lim *et al.*, 2015; Hu *et al.*, 2018). However, the timing of the CYSM formation and the deposition environment prior to the Holocene are remains unclear.

Discrimination of sediment source and reconstruction of paleo-environmental changes can be undertaken based on grain size, clay mineralogy, and elemental signals. In particular, clay mineralogy and geochemistry have been utilized as a powerful tool to trace provenance of the terrigenous fraction of marine sediments in the Yellow sea (Yang *et al.*, 2002; Yang and Youn, 2007; Liu *et al.*, 2007, 2010b; Dou *et al.*, 2010; Hu *et al.*, 2012; Wang and Yang, 2013; Li *et al.*, 2014a; Koo *et al.*, 2018). Several additional factors can also control sedimentary characteristics, including terrigenous inputs, sea level and climate conditions (Wang et al., 1999; Duck et al., 2001; Hwang et al., 2014; Li et al., 2014a; Lim et al., 2015; Badejo et al., 2016; Hu et al., 2018). In addition, paleo-river pathways, recently reconstructed by high-resolution seismic researches in the Yellow Sea, can account for sedimentation and sediment provenance since the last deglaciation because they become an important route of sediment transport during the low stand period~~Particularly, paleo-river pathway associated with sea level change that was recently reconstructed using high resolution seismic data in the Yellow Sea can be explained reasonable for understanding CYSM formation during low stand period~~ (KIGAM, 1993; Xu *et al.*, 1997; Yoo *et al.*, 2015, 2016).

In this study, we aim~~ed~~ to determine the sediment provenance and transport mechanism of CYSM using clay mineralogy and geochemistry multi-proxy. The purposes are to provide a broad insight into the supply of CYSM sediments and to reconstruct the paleo-environment since the last glacial maximum.

2. Oceanography

~~The Yellow Sea is characterized by a complex hydrodynamic system (Fig. 1), with two major circulation patterns. One is a basin-scale counterclockwise (cyclonic) gyre consisting of northward inflow via the Yellow Sea Warm Current (YSWC) in the central Yellow Sea and southward inflow via the Yellow Sea Coastal Current (YSCC) along the east coast of China (Beardsley *et al.*, 1985; Yang *et al.*, 2003) (Fig. 1).~~ The hydrodynamic system in the Yellow Sea is characterized by two major circulation patterns (Fig. 1). One is a counterclockwise gyre in the western part consisting of the Yellow Sea Warm Current (YSWC) and Yellow Sea Coastal Current (YSCC) (Beardsley *et al.*, 1985; Yang *et al.*, 2003). The other is a clockwise gyre in the eastern part made up of the YSWC and ~~southward inflow from~~ the Korea Coastal Current (KCC) (Beardsley *et al.*, 1985;

Yang *et al*., 2003). The YSWC is one of the most important dynamic phenomena in the East China Sea and Yellow Sea. It is a branch of the Kuroshio Current that carries warm, salty water into the Yellow Sea roughly along the Yellow Sea Trough (Xu *et al*., 2009; Liu *et al*., 2010a; Wang *et al*., 2011, 2012). The YSCC and KCC flow south along the coasts of the China and the Korean Peninsula, respectively. Besides, ~~T~~the Transversal Current (TC), identified in recent studies, separates from the KCC southwest of the Korean Peninsula, and some of its water flows northward along the YSWC (Lie *et al*., 2013, 2016; Hwang *et al*., 2014) (Fig. 1). On the other hand, amount of freshwater input from the Changjiang to the Yellow Sea forms the plume of low-salinity water, called as the Changjiang Diluted Water (CDW) (Sukigara et al., 2017). A part of the CDW spreads eastward, reaching as far as Jeju Island and Korea Strait (Hwang *et al*., 2014; Li *et al*., 2014a). ~~The Changjiang Diluted Water (CDW) that provides the most freshwater discharge into the Yellow Sea from the Changjiang spreads eastward, reaching as far as Cheju Island and Tsushima Strait (Hwang *et al*., 2014; Li *et al*., 2014a).~~The oceanic fronts include the Shandong Front (SDF), Jiangsu Coastal Front (JSCF) and Western Korean Coastal Front (WKCF) located in the western and eastern boundaries of the Yellow Sea. These fronts play an important role in shaping Yellow Sea currents as well as in understanding sediment transport, as they separate different water masses in the centre and coast of the Yellow Sea and appear a barrier effect for sediment (Huang *et al*., 2010; Li *et al*., 2014a; Koo et al., 2018) (Fig. 1).

3. Materials and methods

Core 11YS-PCL14 (35°785' N, 124°115' E), which was 702 cm in length, was collected from CYSM at a water depth of approximately 80 m for multi-proxy paleo-environmental reconstruction. The core was subsampled at 10 cm intervals for grain size, clay mineralogy and geochemical analyses. The core 11YS-PCL14 is 702 cm recovered deeper than other studied cores around here (YSC-1; 437 cm, EZ06-1; 370 cm, EZ06-2; 360 cm) (Li et al., 2014; Lim et al., 2015).

The grain size and AMS ^{14}C data were reported in Badejo *et al*. (2016). Radiocarbon ages for five selected depths (99 cm, 300 cm, 540 cm, 580 cm, and 698 cm) and the age-depth model was constructed based on the linear interpolation between the calibrated calendar ages (Badejo *et al*., 2016) (Table 1). The bottom of the core 11YS-PCL14 dated approximately 15.5 ka, that 11YS-PCL14 provides a continuous record of the late last deglaciation to Holocene in the CYSM.

The clay mineral analysis ~~for~~ was conducted using X-ray diffraction (XRD) on preferred-orientation specimens of fine-grained sediment~~clay-sized particles~~ (< 2 µm) following the method in Cho et al. (2015). Semi-quantitative estimation of clay mineral abundances was completed using the Eva 3.0 program with the empirical factors from Biscaye (1965).

The composition of major and trace elements in 13 bulk samples was determined by Actlabs, Ontario, Canada, following the '4 LithoRes' methodology. The samples were fused using a lithium metaborate-tetraborate mixture. The melt produced by this process was completely dissolved with 5% HNO_3. Major elements were analysed in the resulting solution by inductively coupled plasma-optical emission spectrometry (ICP-OES), with an analytical accuracy of < 6%. Trace element analyses were done by inductively coupled plasma-mass spectrometry (ICP-MS). The analytical reproducibility ranged between 5 and 12%. A total 18 samples of core 11YS-PCL14 and riverine sediments (Huanghe, Changjiang and Keum River) were selected for Sr–Nd isotopic analysis and were processed on the <63 µm fraction of each sample (Table 3). ~~Sr–Nd isotopic measurements were performed on a thermal ionization mass spectrometry (TIMS) at the Korea Basic Science Institute.~~ The inorganic silicate fraction was extracted from 18 samples following the method described by Rea and Janecek (1981). The samples were treated with acetic acid buffered to pH 5 with sodium acetate to remove calcium carbonate. They were subsequently treated with a hot sodium citrate-sodium dithionite solution buffered with sodium bicarbonate to remove coarse biogenic components and finally treated with Na_2CO_3 solution to remove biogenic silica. ^{143}Nd/^{144}Nd and ^{87}Sr/^{86}Sr analyses, including chemical separation and multicollector thermal ionization mass spectrometry (VG54-30, Isoprobe-T) analyses were performed at the Korea Basic Science Institute following Cheong *et al*. (2013). Sr and Nd isotope ratios were normalized to ^{86}Sr/^{88}Sr = 0.1194 and ^{146}Nd/^{144}Nd = 0.7219, respectively. Analysis of the Sr standard NBS 987 and the Nd standard JNdi-1 resulted in ^{87}Sr/^{86}Sr = 0.710246 ± 3 (2SD, n = 10) and ^{143}Nd/^{144}Nd = 0.512115 ± 6 (2SD, n = 10). For convenience, the εNd parameter was calculated using a $^{143}Nd/^{144}Nd$ value of 0.512638 for the Chondritic Uniform Reservoir (Hamilton *et al.*, 1983).

4. Results

Core 11YS-PCL14 could be divided mainly into four units considering downcore patterns especially mean grain size and clay mineral compositions (Figs. 2 and 3): Unit 4 (700–520 cm; 15.5–14.8 ka), Unit 3 (520–310 cm; 14.8–12.8 ka), Unit 2 (310–130 cm; 12.8–8.8 ka), and Unit 1 (130–0 cm; < 8.8 ka). In addition, Unit 2 could be subdivided into Unit 2-2 (310–210 cm; 12.8–10.5 ka), Unit 2-1 (210–130 cm; 10.5–8.8 ka) based on the variation trends of clay mineral compositions, especially smectite content. The content of smectite increases slightly during the Unit 2-2 but tends to decrease in Unit 2-1 (Fig. 3). Wang *et al*. (2014) reported that the CYSM mud blanket becomes thicker going westward based on a seismic profile. The mud layers in core sediments are thinner than expected from the seismic profile, but the trend is consistent (Fig. 2). Core EZ06-2, located east of 11YS-PCL14, contains a 100-cm-thick mud layer, while YSC-1, to the west, has a 375~~00~~-cm-thick layer (Fig. 2). The lower part of the mud layer is known as the transgressive deposit and contains many sands (Fig. 2). This coarse layer appears in all cores in the CYSM, with a boundary of ~10 ka (Li *et al*., 2014a; Lim *et al*., 2015). However, core 11YS-PCL14 has additional mud layers with a high proportion of silt underneath the transgressive deposit and a coarse layer at the bottom. Therefore, core 11YS-PCL14 provides more records of the CYSM since the LGM which could not be reconstructed in previous cores (Li et al., 2014a; Lim et al., 2015), because the core 11YS-PCL14 not only recovered deeper than other studied cores.

The vertical granularity, clay mineralogical, and geochemical characteristics of core 11YS-PCL14 are plotted against the calibrated age on the *y*-axis in Fig. 3. The four clay minerals were dominated by illite (60.1–74.7%), followed by chlorite (12.0–22.6%), kaolinite (9.6–14.8%), and smectite (1.2–6.8%). The $^{87}Sr/^{86}Sr$ ratios ranged from 0.719 to 0.724 (mean 0.721) and the εNd values from −16.2 to −12.3 (mean −14.0).

Tables 2 and 3 list the detailed characteristics of the clay minerals and geochemistry in each unit and their main potential provenances (the Huanghe, Changjiang, and western Korean rivers). Each unit had distinct dissimilarities in clay mineral content and mean grain size, especially the sand content (Fig. 2). The Unit 2 sediments were 1.8–44.2% (mean 17.6%) sand with a mean grain size of 6.6 ϕ (10.3 μm) and Unit 4 sediments had a high sand content (8–58.7%, mean 26.3%) with a mean grain size of 6.0 Φ (15.6 μm). In comparison, Unit 1 contained only fine sediment with a mean grain size of 8.8 Φ (2.2 μm) and Unit 3 sediments were clayey silt with a mean grain size of 7.3 Φ (6.3 μm). The downcore variation in the clay mineral composition showed that the illite content decreased gradually from Unit 2 to 3 and was constant in the other parts of the core. Overall, the variations in the smectite and kaolinite+chlorite contents were opposite that of illite (Fig. 3). Units 3 and 4 had relatively constant compositions in terms of clay minerals, although their granularity was heterogeneous. The $^{87}Sr/^{86}Sr$ ratio was constant at the bottom and tended to increase in the upper part. The εNd value was low in Units 2 and 4. ΣLREE/ΣHREE was low only in Unit 3, and was mostly constant.

5. Discussion

5.1. Provenance discrimination based on clay mineralogy

Relative clay mineral contents and ratios can be used as powerful proxies for determining fine-grained marine sediment provenance, especially in terms of the rivers from China and Korea that may contribute to CYSM (Yang *et al*., 2003; Choi *et al*., 2010; Li *et al*., 2014a; Xu *et al*., 2014; Lim *et al*., 2015; Kwak *et al*., 2016). Generally, Huanghe sediments are characterized by high smectite, and Changjiang sediments contain a lot of illite contents. Western Korean rivers (e.g. the Han, Keum, and Yeongsan) contain more kaolinite and chlorite than do Chinese rivers (Table 2).

A ternary diagram of smectite–(kaolinite+chlorite)–illite is~~was~~ utilized to determine the provenance of fine sediments in core 11YS-PCL14 (Fig. 4). Although Unit 4 and 3 sediments differed in granularity, they had similar clay mineral compositions and plotted near the center of the three possible provenance end-members, indicating that fine-grained~~clay-sized~~ sediments were supplied with constant amounts from all potential rivers to the study area during these periods (Fig. 4a). Unit 2 sediments overall were characterized by an increasing illite content (Figs. 3 and 4b). It means that the influence of Changjiang-derived materials began to increase during this period. However, Unit 2-2 sediments displayed an increase in smectite content with illite, and then ~~every~~ clay mineral compositions except illite decrease in Unit 2-1 (Fig. 4b). Variation of smectite content in Unit 2 appears to be closely related to the change in coarse sediments (Figs. 3 and 4b). The relationship between smectite and coarse grains was also observed in the early Holocene sedimentary unit of core YSC-1 (Li *et al.*, 2014a) and nearby core EZ06-2 between ~14.1 and ~9.0 ka (Lim *et al.*, 2015). Unit 1 sediments had clay mineral compositions quite similar to those of Changjiang sediments, indicating that they might be originate mainly from the Changjiang (Fig. 4b). ~~Consequently, clay mineralogical results were suggested that the finer detrital sediments in Units 3 and 4 were affected by all potential provenances. During Unit 2, the influence of the Changjiang increased gradually with temporary influx containing coarse particles and high smectite, and the later Unit 1 sediments were derived primarily from Changjiang inputs.~~ Consequently, clay mineralogical results suggest that the provenance of fine-grained sediments are changed according to each unit as follow; fine-grained sediments during the Unit 3 and 4 were supplied from all potential provenances, the influence of the Changjiang increased gradually during the Unit 2, Unit 1 sediments were mainly originated from the Changjiang.

5.2. ~~Geochemical approaches~~ Provenance discrimination based on geochemistry

Geochemical proxies for provenance discrimination in the Yellow Sea have been investigated actively and verified by several studies (*e.g.* Yang *et al.*, 2002; Xu *et al.*, 2009; Song and Choi, 2009; Jung *et al.*, 2012; Ha *et al.*, 2013; Lim *et al.*, 2015; Hu *et al.*, 2018; Koo *et al.*, 2018). The chemical compositions of Korean and Chinese rivers differ, especially in their rare earth elements (REE) and Sr–Nd contents (Xu *et al.*, 2009; Jung *et al.*, 2012; Lim *et al.*, 2014; Hu *et al.*, 2018). The trace elements and isotopes~~These~~ are essentially unaltered during weathering, transport, and sedimentation, and can be a powerful tool for tracing the provenance of the terrigenous fraction of marine sediments (McLennan, 1989; Blum and Erel, 2003; Xu *et al.*, 2009; Chaudhuri *et al.*, 2020).

~~Recent studies have emphasized that in addition to the source rock, many other factors influence the geochemical composition of riverine and marine sediments, such as grain size, heavy mineral content, and biogenic component, especially in bulk sediment analysis (Yang *et al.*, 2002; Song and Choi, 2009; Lim *et al.*, 2015; Hu *et al.*, 2018).~~ Recent studies have emphasized caution for misinterpretation of sediment provenance due to other factors which influence the geochemical composition of riverine and marine sediments such as grain size and biogenic component (Yang *et al.*, 2002; Song and Choi, 2009; Lim *et al.*, 2015; Hu *et al.*, 2018). For example, major elements Fe and Mg as well as some trace elements have been proposed to be useful elements as provenance indicator in the Yellow Sea (Song and Choi, 2009; Koo et al., 2018), but they are closely correlated with particle size, which can lead to misinterpretation of sediment provenance (Fig. 5a). ~~For example, the major elements Fe and Mg were suggested to be useful proxies in the Yellow Sea (Lim *et al.*, 2007). However, they are closely correlated with particle size because they are abundant in clay minerals, making them unconformable for provenance tracing in bulk sediments (Fig. 5a).~~ In addition, Ca has a problem based on biogenic carbonate despite the poor correlation with grain size (Fig. 5a). ~~Trace elements also exhibit positive and negative correlations with grain size (Yang *et al.*, 2002; Lim *et al.*, 2014).~~ To complement the grain size effect~~this~~, recent studies have suggested ratios of the binding of abundant elements at comparable grain sizes (*e.g.*, the La/Sc and Zr/Th ratios) (Yang *et al.*, 2002; Lim *et al.*, 2014). However, we observed that these ratios and mean grain size were strongly negatively correlated in our dataset (Fig. 5b), implying that these ratios are also unsuitable for studying provenance. Normalization of REE values to upper continental crust (UCC) is a widely accepted method for discriminating the sediment provenances of various geological materials (Taylor and McLennan, 1985; Song and Choi, 2009; Xu et al., 2009; Lim *et al.*, 2015). This method can better offset differences caused by grain size, and could be a useful geochemical proxy (Fig. 5c). In addition, the Nd isotope ratio of silicate particles is essentially unaltered during weathering, transport, and sedimentation and can be a powerful tool for tracing the provenance of the terrigenous fraction of marine sediments (Blum and Erel, 2003; Hu *et al*., 2018). However, recent studies indicated that the Sr isotope composition in both Chinese and Korean riverine sediments was a function of grain size, with a higher $^{87}Sr/^{86}Sr$ in clay-dominated fractions than in silt-dominated fractions (Fig. 5d) (Hu *et al*., 2018). For these reasons, we used only the UCC-normalized REE and Nd isotope, independent of grain size effect, to distinguish sediment provenance. ~~Therefore, we used only the UCC-normalized REE and εNd values for discriminating sediment provenance; these could be useful indicators for distinguishing the contributions of Chinese and Korean rivers.~~

Korean rivers are characterized by a high LREE and low εNd, while Chinese rivers have abundant MREE (middle REE) and high εNd (Table 3, Fig. 6). Figs. 6 are discrimination plots using the REE and εNd values that clearly separate the Chinese and Korean rivers. The REE and εNd values in these plots could represent the source of all sediments including coarse and fine sediments because the REE analysis performed using the bulk powder samples. ~~In these plots, the REE values represented the source of both coarse and fine sediments because the analysis was performed with coarse grains.~~ Unit 1 sediments are generally close to the Changjiang, which is consistent with results in clay mineralogy (Figs. 4 and 6). ~~Unit 1 is generally close to the Changjiang with slightly influence of the Korean rivers, as well as the clay mineralogy (Figs. 4 and 6).~~ Unit 4 sediments are plotted between China and Korean river end-members in all discrimination plots (Fig. 6), consistent with the results for clay minerals, which suggests that the coarse sediments included in Unit 4 were from contributions from all potential rivers.

Interestingly, the fine-grained sediments~~clay-sized particles~~ of Unit 2 were a composite of the Huanghe and Changjiang in Fig. 4, but the geochemical data were similar to Unit 4 (Fig. 6). This probably means that a significant amount of coarse sediments in Unit 2 was supplied from Korean rivers with a high LREE (Fig. 6a). The results of the isotope analysis in the core YSC-1 also showed an increased impact of Korean rivers and coarse sediments before ~8 ka, which is consistent with our results (Hu *et al*., 2018). ~~The association between an increased impact of Korean rivers and coarse sediments was identified in an isotope analysis before ~8 ka in core YSC-1 (Hu *et al*., 2018).~~ Thus, the supply of smectite in fine-grained sediments~~clay-sized particles~~ and sand grains is synchronic, but possibly has different sources. In addition, Unit 3 sediments, identified as the homogenous origin as Unit 4 in clay mineralogy (Fig. 4), are biased towards Chinese rivers (Fig. 6), especially close to the Huanghe. A scatter plot of clay mineral ratio *vs*. εNd distinguished three possible provenances for particles smaller than 63 μm (Fig. 6c). Unit 3 sediments in this plot are certainly plotted close to the Huanghe, which is different distribution than previous plots.

This result is likely to be due to the influence of silt-sized particles that is not considered in clay mineralogy, because Unit 3 sediments contain much of silt content (Fig. 2). Therefore, fine-grained sediments were supplied from all rivers to the study area, but coarse-grained sediments appear to have been mainly sourced from the Huanghe during the Unit 3 (Figs. 4 and 6). ~~This is caused by the many silt fractions in Unit 3 and probably represents a relatively close supply from the Huanghe.~~ Consequently, the estimated sediment provenances in each unit based on the clay mineralogical and geochemical indices were as follows. During Unit 4, both coarse and fine sediments were influenced by all of these provenances. However, in Unit 3, silt-sized fractions were predominantly affected by the Huanghe. Unit 2 represented a period of great change in the sediment sources. The fine grains in the Unit 2-2 sediments were derived primarily from Chinese rivers, especially the Huanghe, while the Unit 2-1 samples were supplied mainly from the Changjiang, with minor contributions from the Huanghe and western Korean rivers. However, coarse sediments source in Unit 2 were identified as western Korean rivers based on geochemical indices. The source of CYSM sediments in Unit 1 was primarily the Changjiang.

5.3. Paleo-environmental implications for sediment provenance changes

The four units could be distinguished based on the characterization of the major sediment source changes in the CYSM over the last 15.5 kyr (Figs. 4–6). Identification of sediment sources is a useful method for understanding paleo-environmental dynamics and sediment transport mechanisms in the Yellow Sea since the late last deglaciation. The main factors that potentially influenced provenance changes in the Yellow Sea include pronounced sea-level fluctuations that regulate the positions of shorelines, paleo-river pathways, tidal stress amplitude, and the formation of modern ocean currents (Liu *et al*., 2004; Lim *et al*, 2007, 2015; Choi *et al*., 2010; Wang *et al*., 2014; Yoo *et al*., 2015, 2016). Here, we discuss how these complex processes have affected sedimentation in the CYSM during the last 15.5 kyr.

The sea level during Units 3 and 4, which corresponds to the late last deglaciation (15.5–12.8~~1~~ ka), was approximately 60–100 m lower than the present sea level (Li *et al*., 2014b). The high signatures of C/N values in Unit 4 indicated a significant influx of terrigenous materials (Badejo *et al*., 2016). Mixed deposits of fine and coarse sediments with high influx and sedimentation rates (Figs. 2 and 3) allows us to infer Unit 4 as a delta or prodelta environment. The paleo-river pathways of potential provenances, recently reconstructed based on seismic profiles, merged around the study area and were connected to the East China Sea (Yoo *et al*., 2015, 2016). During sedimentation of Unit 4, sediments in the study area would have been affected most strongly by direct inflow from paleo-rivers, because the low sea level led to the exposure of shelves in and near the Yellow Sea (Li *et al*., 2014b).

Sediment fining during Unit 3 reflects an increase in distance between the river mouths and study area due to transgression, and the study area probably formed a mud flat during sedimentation of Unit 3. During this period, fine-grain sediments~~clay-sized particles~~ were ~~still~~ supplied from all rivers (Fig. 4), while silt-sized particles were supplied mainly~~only~~ from the Huanghe (Figs. 4 and 6~~5~~). The record for the same period in core EZ06-1 shows~~showed~~ significant coarse sediments with a high sand content (Lim *et al*., 2015), indicating that the Huanghe was relatively close to the west side of the study area (Fig. 2). In addition, the substantial flux from the Huanghe would have supported the distant movement of coarse grains.

In Unit 2 (12.8~~1~~–8.8 ka), corresponding to the early Holocene, the sea level was approximately 20−60 m lower than at present (Li *et al*., 2014b). The Unit 2 period was thought to be cold and dry (Badejo *et al*., 2016) and was characterized by oscillating grain sizes and clay mineral and geochemical compositions (Fig. 3). In addition, increasing and decreasing trends of grain size with sand content, S/I ratio divided into two subsections (Fig. 3). This variation is also reported in the surrounding YSC-1 (Li *et al*., 2014a) EZ06-1, and EZ06-2 cores. In this period, the low sea level led to the seaward progradation of the shoreline and formation of a thin sand layer (generally < 3 m) called the transgressive deposit throughout the Yellow Sea (Cummings *et al*., 2016). The change in the coastline configuration caused shifts of the tidal fields therein, with tidal currents being more energetic than at present (Uehara and Saito, 2003; Lim *et al*., 2015), which supplied coarse grains to the central Yellow Sea. In addition, the bottom stress in the Unit 2 period was stronger around the Korean Peninsula (Uehara and Saito, 2003), which caused most of the coarse sediment to be of western Korean river origin (Fig. 6). The supply of fine sediments from the Huanghe was temporarily strengthened during sedimentation of Unit 2-2, but weakened in Unit 2-1 (Fig. 4). This could be due to a change in distance between the Huanghe and the study area as the sea level rose. In addition, the paleo-Changjiang Shoal moved northeastward into the Yellow Sea at ~12 ka (Li *et al*., 2000) and may have contributed some materials to the study area (Lim *et al*., 2015). The reduction in Huanghe-derived materials due to the increased distance could be strengthen the influence of the Changjiang in Unit 2-1.

Since sedimentation of Unit 1 (< 8.8 ka), the sea level rose slowly from −20 m to the present level (Li *et al*., 2014b). The tidal field of the Yellow Sea became similar to that of the present (Uehara and Saito, 2003), leading to obviously decreasing contributions from sea bed erosion. A modern-type circulation in the Yellow Sea may have developed between 8.47 and 6.63 ka, characterized by an increase in bottom-water salinity (Kim and Kucera, 2000). The clay minerals and geochemical composition generally point to the Changjiang, with minor influence from the western Korean rivers (Figs. 4 and 6), which is consistent with the reported 'multiple origin' concept (Wei *et al*., 2003; Li *et al*., 2014a; Lim *et al*., 2015; Koo *et al*., 2018). Therefore, the formation of the CYSM and modern ocean circulation could have been synchronic around ~8 ka. The timing of mud patch formation in the central Yellow Sea was inferred to be 9~8 ka with low tidal bottom stress (< 0.35 N/m^2) (Uehara and Saito, 2003), which is consistent with our results.

The YSWC played a major role in the unique passage of sediment into the study area since the Unit 1 (Li *et al*., 2014a; Lim *et al*., 2015; Koo *et al*., 2018). The Changjiang Diluted Water can spread some finer sediments to Cheju and nearby areas (Hwang *et al*., 2014; ~~Kwak *et al*., 2014;~~ Li *et al*., 2014a; Lim *et al*., 2015; Kwak *et al*., 2016; Koo *et al*., 2018). And then, fine-grained materials could be carried northward along the YSWC path to the CYSM, where the weak tidal-current system and cyclonic eddies provided favorable environment for the formation and maintenance of muddy sediment~~ations~~ (Shi *et al*., 2003; Lim *et al*., 2015). Meanwhile, barrier effect of oceanic fronts and strong coastal currents restricts to enter the sediments from the Huanghe and western Korean rivers into the CYSM (Li *et al*., 2014a; Koo *et al*., 2018). However, some fine-grained particles from western Korean rivers may influence the CYSM through the Transversal Current (Hwang *et al*., 2014; Koo *et al*., 2018).

6. Conclusions

The purpose of this study is to better understand the CYSM in terms of provenance changes and transport mechanisms and to reconstruct the paleo-environment of the Yellow Sea since late last deglaciation using clay mineralogy and geochemical indices from core 11YS-PCL14. The major conclusions are as follows.

Core 11YS-PCL14 provides a continuous record of the late last deglaciation to Holocene in the CYSM. The core could be divided mainly into four units: Unit 4 (700–520 cm; 15.5–14.8 ka), Unit 3 (520–310~~280~~ cm; 14.8–12.8~~1~~ ka), Unit 2 (310~~280~~–130 cm; 12.8~~1~~–8.8 ka), and Unit 1 (130–0 cm; < 8.8 ka). Unit 2 is divided into two subunits Unit 2-2 (310–210 cm; 12.8–10.5 ka), Unit 2-1 (210–130 cm; 10.5–8.8 ka) according to smectite content.

The integration of clay mineralogical and geochemical data distinguished the CYSM sediments into different provenances by grain size. During the Unit 4, fine and coarse sediments were supplied from all possible rivers in the Korea and China by direct inflow from paleo-rivers with the exposure of shelves. Sediment fining in the Unit 3 reflects an increase in distance between the river mouths and study area. In this period, Fine-grain sediments were still supplied from all rivers, while silt-sized particles were supplied mainly from the Huanghe. During the Unit 2, the bottom stress was stronger around the Korean Peninsula, which caused most of the coarse sediment to be of western Korean river origin. However, the supply of fine sediments from the Huanghe temporarily strengthened in the Unit 2-2, but weakened in Unit 2-1, due to a change in distance between the Huanghe and the study area as the sea level rose. Unit 1 sediments were composed mainly of the Changjiang. After the oceanic circulation was formed, the YSWC played a major role in the unique passage of sediment into the study area. In addition, barrier effect of oceanic fronts and strong coastal currents restricts to enter the sediments from the Huanghe and western Korean rivers into the study area. ~~In fine particles, Unit 3 and 4 sediments originated from all possible provenances in the Korea and China, after which the sediment source is gradually shifted to the Changjiang. The inflow of Huanghe-derived fine sediments temporarily increased during Unit 2. On the other hand, the origin of coarse sediments changed in order of all possible rivers (Unit 4), Huanghe (Unit 3), and western Korean rivers (Unit 2). Change in sediment supply are closely related to variations in sea level, positions of paleo-river mouths and tidal stress. Meanwhile, our data suggest that the formation of modern CYSM mud deposition began around ~8 ka with modern ocean circulation and the CYSM sediments are composed mainly of the Changjiang.~~

Author contribution

H.G.Cho designed the experiment, and H.J. Koo carried them out and wrote the paper. All authors contributed to interpreting and discussing the results and reviewing the paper.

Competing interests

The authors declare that they have no conflict of interest

Acknowledgements

This study was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2017R1D1A1B03027818) and Korea Polar Research Institute project PM16050 funded by the Ministry of Oceans and Fisheries, Korea.

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Figure captions

Figure 1. Schematic map showing the location of core 11YS-PCL14 as well as the surface circulation in the Yellow Sea (modified from Li et al., 2014a; Wang et al., 2014). The gray dotted line indicate the paleo-river pathways (Yoo et al., 2016). ① Central Yellow Sea Mud (CYSM); ② Southeastern Yellow Sea Mud (SEYSM); ③ Southwestern Cheju Island Mud (SWCIM); KC = Kuroshio Current; YSWC = Yellow Sea Warm Current; SDCC = Shandong Coastal Current; YSCC = Yellow Sea Coastal Current; KCC = Korean Coastal Current; SDF = Shandong Front; JSCF = Jiangsu Coastal Front; WKCF = Western Korean Coastal Front.

Figure 2. (a) Isolines in thickness (m) of mud deposit CYSM (after Wang et al., 2014), (b) vertical lithology profile of core 11YS-PCL14 and other reference cores (YSC-1, Li et al., 2014a; EZ06-1 and EZ06-2, Lim et al., 2015)~~, YSC-1 (Li et al., 2014a) and EZ06 cores (Lim et al., 2015)~~.

Figure 3. Downcore variations of mean grain size, clay mineralogical and geochemical data in core 11YS-PCL14 with sea level changes (Li et al., 2014b). Note the overall distribution into four units.

Figure 4. Ternary diagrams showing variations in clay mineral compositions of core 11YS-PCL14. Published data of potential source sediments including the Changjiang, Huanghe, and western Korean rivers (the Han, Keum, and Yeongsan Rivers) (Cho et al., 2015; Koo et al., 2018), which are plotted for comparison.

Figure 5. Correlation plots of grain size or clay/silt ratio with (a) major elements, (b) Zr/Th and La/Sc, (c) Upper Continental Crust (UCC)-normalized REEs (Taylor and McLennan, 1985), and (d) $^{87}Sr/^{86}Sr$ and εNd for core 11YS-PCL14.

Figure 6. Discrimination plots showing variations in (a) ∑LREE/Yb *vs*. $(La/Lu)_{UCC}$, (b) $(La/Yb)_{UCC}$ *vs*. εNd, and (c) (smectite+kaolinite+chlorite)/illte *vs*. εNd. Clay mineral (Cho et al., 2015; Koo et al., 2018), rare earth element (Xu et al., 2009), and isotope data of potential sources are also shown for comparison.

Fig. 7. Schematic diagram showing the influence of shoreline changes, and paleo-river pathways on riverine sediment supplied to the study area during (a) Unit 4 and 3 (15.5–12.8~~1~~ ka), (b) Unit 2 (12.8~~1~~–8.8 ka), and (c) Unit 1 (8.8 ka–present) (modified Lim et al., 2015).