

A note on initial nitrate and initial phosphate as tracers for the origin of East Sea (Japan Sea) Proper Water

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Abstract: The East Sea (Japan Sea) is a mid-latitude marginal sea with average depth over 1,500 meters in the North Western Pacific. The deep waters below several hundred meters over the entire basins, as generally known as the East Sea Proper Water (ESPW), show extreme homogeneous characteristics with relatively large concentration of dissolved oxygen over $230 \mu\text{M}$, reflecting rather rapid replenishment of these waters in the basins. Even though ESPW, consisting over 84% of the total volume of the East Sea, may not be a single homogeneous water mass, further analysis imposes serious difficulties due to homogeneous nature of these waters.

We explored the possibility of utilizing initial nutrients as tracers for these waters, providing further constraints on their origins. With respiration coefficients of 76 and 6.5 for phosphate and nitrate, respectively, the initial analysis indicates that ESPW consists of two components; one with larger initial nutrients ($11 \mu\text{M}$ of NO_3^- and $0.6 \mu\text{M}$ of PO_4^{3-}) and the other with smaller values ($3 \mu\text{M}$ of NO_3^- and $0.1 \mu\text{M}$ of PO_4^{3-}), possibly corresponding to upper portion and deep water of ESPW, respectively.

The lack of data, especially over northernmost region in winter time, prevents further analysis at the present moment. The future study in this direction appears to be of significant importance in understanding and clarifying major oceanographic problems regarding the origin of rapidly replenishing deep waters in the East Sea.

1. Introduction

The East Sea (Japan Sea) is a typical mid-latitude marginal sea in the North Western Pacific. With an average depth of more than 1,500 meters, the topography of the East Sea shows three major basins (Fig. 1). The Japan Basin with a depth of more than 3,500 meters occupied most of the northern part of the East Sea, and the Ulleung and Yamato basins consist of the major part of the southern East Sea to the west and east of the Yamato Rise, respectively.

Though the shallow waters of the East Sea are continually exchanged with the Pacific waters through narrow straits with depth of less than 150 m, it is generally believed that deep convection is occurring within the East Sea (e.g., SUDA, 1932; NITANI, 1972), with the relatively rapid replenishment of the deep waters in the basins. The high concentrations of dissolved

oxygen over $230 \mu\text{M}$ in deep waters of the entire basins reflect the above circulation; the average residence time of 300 to 400 years for the deep waters has been suggested (HARADA and TSUNOGAI, 1986; GAMO and HORIBE, 1983).

The waters below several hundred meters to the bottom in the East Sea show extremely homogeneous characteristics; temperature of $0\sim 1^\circ\text{C}$ and salinity of $33.96\sim 34.14\text{‰}$ (e.g., MORIYASU, 1972), which are rather in contrast with the characteristics of deep waters observed in Northwest Pacific; $1\sim 2^\circ\text{C}$ in temperature and $34.6\sim 34.7\text{‰}$ in salinity (e.g., SVERDRUP *et al.*, 1942; ROEMMICH *et al.*, 1991). YASUI *et al.* (1967) calculated by T-S analysis that this homogeneous water mass, generally known as the East Sea (Japan Sea) Proper Water (hereafter ESPW), consists of more than 84% of the total volume of the East Sea waters. Though ESPW may not be a single homogeneous water mass, further analysis and identification of source regions of these waters with temperature and

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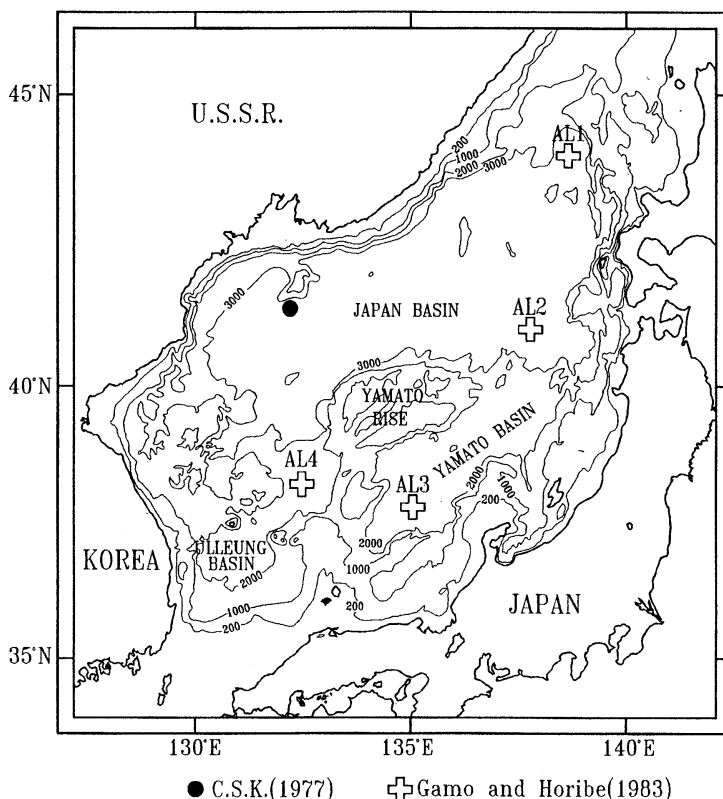


Fig. 1. The topographic map of the East Sea (Japan Sea) showing three major basins: Japan Basin, Ulleung Basin and Yamato Basin. The stations by CSK (Japan Oceanographic Data Center, 1977) and Gamo and Horibe (1983) are also shown in the map.

salinity distributions impose serious difficulties due to extremely narrow ranges of their variation. SUDO (1986) recently reviewed these problems extensively, as discussed further in the later section.

Initial phosphate and initial nitrate are typical examples of chemical parameters applied in water mass analysis in recent years (e.g., BROECKER *et al.*, 1985; BIGG and KILLWORTH, 1990). The terms, initial nitrate and initial phosphate, are identical to the terms, preformed nitrate and preformed phosphate used by some earlier investigators (e.g., REDFIELD *et al.*, 1963; PYTKOWICZ, 1971). Furthermore, the information carried by these initial nutrients is essentially the same as that conveyed by "NO" (BROECKER, 1974) and "PO" (BROECKER *et al.*, 1985). These quantities are the concentrations of nitrate and phosphate generally observed in surface waters at high latitude regions, especially

in winter time. When the surface waters sink and start their deep-sea circulation, these quantities are preserved in the waters along their journey in the deep sea as conservative components. The fact that these quantities in surface waters vary geographically, provides the possibility of using these quantities as tracers for the deep waters in the ocean.

Figure 2 shows distribution patterns of 20-year-average phosphate concentrations in surface waters of the East Sea in winter time, collected by Maizuru Marine Observatory (1985). Two important points can be made:

- (1) there are relatively large amounts of phosphate present in surface waters in winter, and
- (2) significant geographical variations in phosphate concentration exist in the area with relatively small values in southern regions and along the coast.

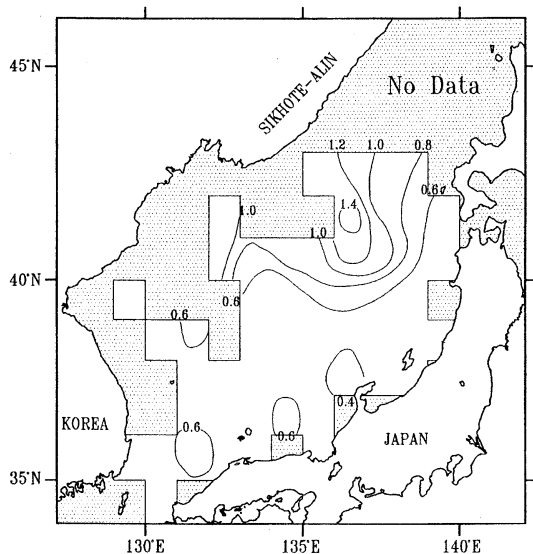


Fig. 2. The distribution pattern of 20-year-average phosphate concentrations in surface waters in winter time, collected by Maizuru Marine Observatory (1985). The large geographical variation ranging from below $0.4 \mu\text{M}$ to above $1.4 \mu\text{M}$ with northward increase with relatively lower concentrations along the coast, in general, is clearly seen. However, the lack of data over the northernmost regions along the coast and at north of 43°N in particular, the most critical area for deep water formation in the East Sea, typically represent the present status of data base available in the area.

However, the lack of data over the northernmost regions along the coast and above 43°N in particular, the most critical areas for possible deep water formation, typifies the present status of data base available in the area. With this limitation in mind, if the source region of the deep waters in the East Sea, ESPW, is confined in relatively small areas, then, the initial nutrient concentrations of these waters, if any, may provide additional constraints on the origin of these waters.

In this paper, we explore the possibility of utilizing these excess nutrients for tracing and extracting information on the source regions of ESPW, present in deep layers of the East Sea.

2. Data set and analysis

Oceanographic data with complete nutrient

analysis for deep waters in the northern East Sea are rather scarce, especially in winter time. Two sets of data are selected in the analysis: data from CSK survey during February, 1976 (Japan Oceanographic Data Center, 1977) and data from GAMO and HORIBE (1983). Though the data from Gamo and Horibe do not cover the upper 1,000 meters of the water columns, these data represent deep waters in all major basins in the East Sea as shown in Figure 1.

The vertical profiles of potential temperature, salinity, DO (Dissolved Oxygen), AOU (Apparent Oxygen Utilization), nitrate, and phosphate are shown in Figure 3. The homogeneity of all properties for the waters below several hundred meters over the entire basins is remarkable as mentioned earlier. There appears a slight difference in salinity profiles between CSK data and those by GAMO and HORIBE (1983). The difference may be real or simply reflect the calibration difference.

Initial phosphate, PO_4^0 and initial nitrate, NO_3^0 are calculated from the relationships as follows:

$$\text{PO}_4^0 = \text{PO}_4 - \frac{\text{DO}_{\text{sat}} - \text{DO}}{76} = \text{PO}_4 - \frac{\text{AOU}}{76}$$

$$\text{NO}_3^0 = \text{NO}_3 - \frac{\text{DO}_{\text{sat}} - \text{DO}}{6.5} = \text{NO}_3 - \frac{\text{AOU}}{6.5}$$

where PO_4 , NO_3 and DO are the observed concentrations, DO_{sat} is the saturation concentration of dissolved oxygen at the potential temperature and salinity of water samples and AOU is the apparent oxygen utilization.

The respiration coefficients, 76 and 6.5 in the above formulae are calculated from CSK data (Japan Oceanographic Data Center, 1977) for waters in upper 400 meters layer as shown in Figure 4.

These coefficients are rather different from the values observed in open oceans: 175 for phosphate (BROECKER *et al.*, 1985) and 9 for nitrate (BROECKER, 1974), possibly reflecting different ecology, especially different chemical characteristics of DOC and POC in the East Sea compared to those in open oceans. The lack of available data especially over northern part of the East Sea prevents any further discussions on the validity of these values at the present time: further careful and extensive analysis on this

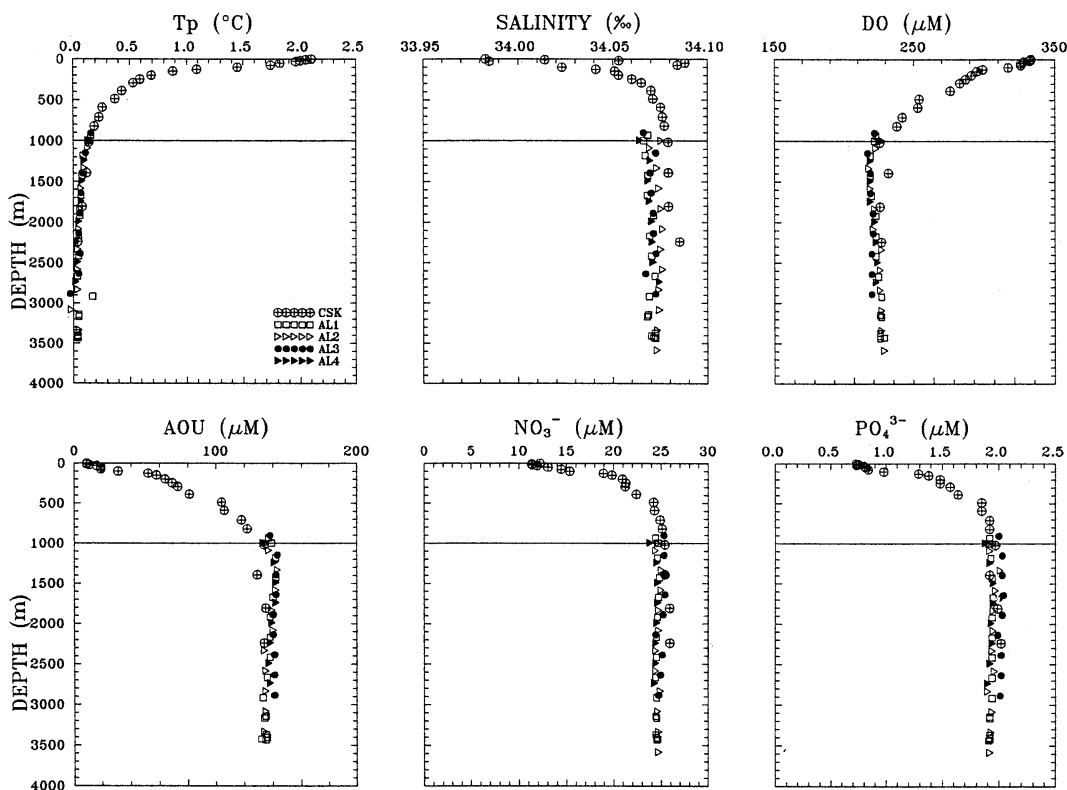


Fig. 3. The vertical profiles of potential temperature, salinity, dissolved oxygen (DO), apparent oxygen utilization (AOU), nitrate and phosphate at CSK and Gamo and Horibe stations. No data at depths shallower than 1,000 meters were available at Gamo and Horibe stations, unfortunately. The extremely homogeneous nature of these properties below 1,000 meters over the most of the basins in the East Sea is clearly seen, especially considering the location of these stations as shown in Fig. 1.

subject is needed in the future.

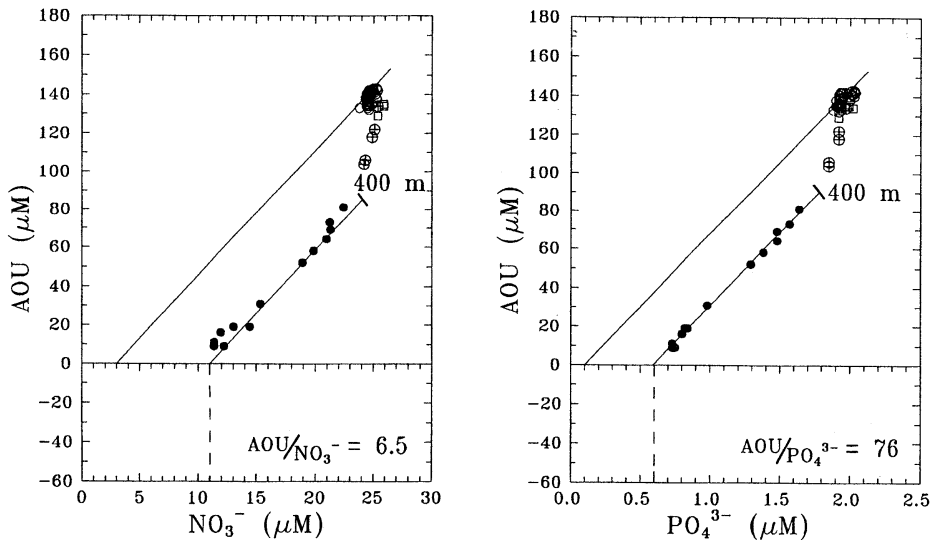
3. Results and Discussion

Figure 5 shows the vertical profiles of initial nitrate and initial phosphate. While the waters in surface 400 meters show about $10\sim 11\ \mu\text{M}$ of NO_3^0 and about $0.6\ \mu\text{M}$ of PO_4^0 , these values decrease with depth to about 1,000 meters and then remain fairly constant to the bottom at about $3\sim 4\ \mu\text{M}$ of NO_3^0 and about $0.1\sim 0.2\ \mu\text{M}$ of PO_4^0 . There appears to be a minimum at about 1,000 meters for these initial nutrients, and the significance of it, if any, is not clear at this point.

It is also noted that waters below 1,000 meters over the most of the deep basins in the East Sea, as covered by the stations from Gamo and Horibe, show remarkably similar concentrations

of initial nutrients. The exception is the result from CSK station in the northwestern East Sea, where the initial nutrients appear to be higher than in other areas; a possible mechanism producing this difference is discussed in the later section.

Figure 6 shows the correlation between initial phosphate and initial nitrate. A rather well-defined linear relationship is clear, indicating a possibility of mixing between two components: one component with about $11\ \mu\text{M}$ of NO_3^0 and $0.6\ \mu\text{M}$ of PO_4^0 , observed in upper 400 meters at CSK station, and the other with about $3\ \mu\text{M}$ of NO_3^0 and $0.1\ \mu\text{M}$ of PO_4^0 , observed over most of the basins below 1,000 meters. It is also important to observe that the thermocline waters and deep waters at CSK station lie on the mixing line between these two components.



○ Gamo & Horibe (1983) ● CSK(0-400 m) ⊗ CSK(400-1000 m) □ CSK (>1000 m)

Fig. 4. The plot of AOU vs. nitrate and phosphate. The data at depths shallower than 400 meters at CSK station show respiration coefficients of 6.5 and 76 for nitrate and phosphate, respectively, with about $11 \mu\text{M}$ of initial nitrate and about $0.6 \mu\text{M}$ of initial phosphate concentrations. The deep waters below 1,000 meters show about $3 \mu\text{M}$ of initial nitrate and about $0.1 \mu\text{M}$ of initial phosphate concentrations, if assuming respiration coefficients in these deep waters as the same as those observed in shallow waters at CSK station; this has to be verified with further investigations in the future.

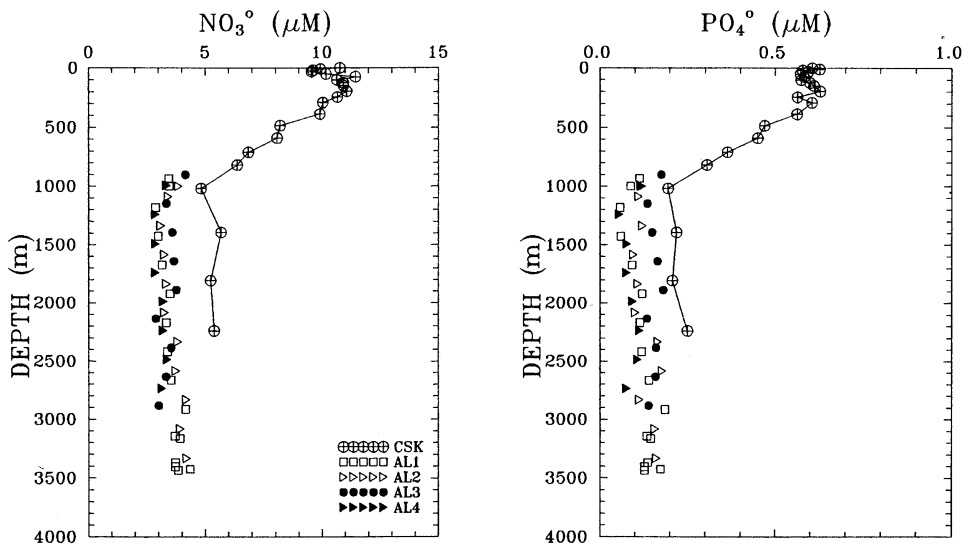


Fig. 5. The vertical profiles of initial nitrate and phosphate at CSK and Gamo and Horibe stations, calculated with respiration coefficients of 6.5 and 76 for nitrate and phosphate, respectively. The necessity of profiles in shallow waters are most urgent. The initial nutrients in deep waters at CSK station are clearly larger than those in deep waters over all other major basins; a possible cause for this difference is discussed in the text.

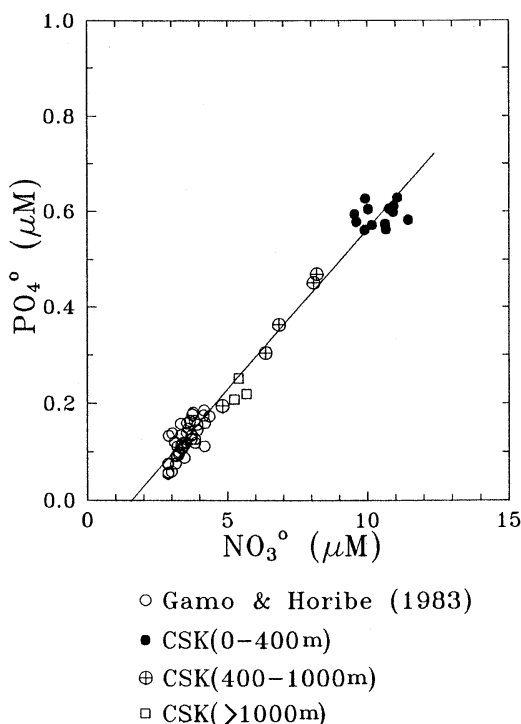


Fig. 6. The initial nitrate-initial phosphate plot at CSK and Gamo and Horibe stations.

In his lengthy analysis of temperature, salinity and dissolved oxygen distributions, SUDO (1986) concluded that ESPW can be further divided into two groups: the upper portion and the deep water with the boundary at the depth of potential temperature ca 0.1°C (typically at 800 ~1,000 meters in northern East Sea). He proposed, furthermore, that the upper portion of ESPW originates from the northwestern area, west of 134°E and north of 41°N , and the most of the deep water has been formed in northern area, probably north of 43°N . The apparent two-component mixing trend observed in Figure 6 may be consistent with the Sudo's above conclusion: the upper portion of ESPW corresponding to a component with higher initial nutrient concentrations ($11\ \mu\text{M}$ of NO_3° and $0.6\ \mu\text{M}$ of PO_4°) and the deep water to the other end member with lower initial nutrient concentrations ($3\ \mu\text{M}$ of NO_3° and $0.1\ \mu\text{M}$ of PO_4°). In this regard, it is very interesting to note as mentioned earlier that the initial nutrient concentrations in deep waters below 1,000 meters at CSK station, the

closest station from the proposed source region of the upper portion of ESPW in northwestern section of the East Sea, are rather higher than those at all the other stations, quite possibly reflecting the effect of proximity to the source region of higher initial nutrients in upper waters.

The magnitude of these initial nutrients, especially in upper waters, are rather significant. This observation clearly indicates that the sinking waters in the East Sea contain enough of these initial nutrients, which can be later calculated and used as tags for the particular water masses. It is interesting, however, to observe that deep waters of ESPW show much smaller concentrations of NO_3° and PO_4° than the upper portion of ESPW, especially considering the possibility of further northern origin of deep waters as discussed above.

First of all, it has to be verified in the future that respiration coefficients for the deep waters are similar to the values in shallow waters as used here. In fact, the very limited amounts of data available at NODC indicate that the chemistry of waters in the area as north as 43°N in winter time does not seem to show any significant differences compared to that at CSK station, discussed in this paper, suggesting that the respiration coefficients in the northernmost region may not be drastically different from the values used in the paper. Therefore, it could be also possible that phosphate concentrations in surface waters over northernmost region may, indeed be very low, due to fresh water inputs, resulting in lower initial nutrient concentrations in deep waters.

As shown in Figure 2, as an example of best data set available at present, concentrations of nutrients in surface waters over northernmost regions of the East Sea are poorly known at the present time. The information on these chemical components over possible source regions of ESPW, especially in winter time, appears to be of paramount importance in understanding and clarifying major oceanographic problems, regarding the origin of rapidly replenishing deep waters in the East Sea.

4. Conclusion

In order for these initial phosphate and nitrate to be applied successfully in distinguishing

water types, two conditions must be met as summarized by BROECKER *et al.* (1985):

- (1) the respiration coefficients must be fairly constant over water depth and geographic location of interest, and
- (2) the average value of these coefficients must be precisely known.

Both of the above conditions in the East Sea could not be verified yet due to lack of data available at the present time. The respiration coefficients used in this paper, 76 for PO_4^0 and 6.5 for NO_3^0 , are rather different from those used in the open ocean, 175 for PO_4^0 and 9 for NO_3^0 . All these points are the subjects for the close examination with new data in the future. However, the present preliminary analysis of nutrient results over northern part of the East Sea does show that ESPW may contain significant amounts of initial nitrate and initial phosphate. The application of these apparent conservative parameters, initial phosphate and initial nitrate, will be a very important addition in investigating the sources and dynamics of the deep waters present in the East Sea, especially considering the difficulties encountered in conventional approaches, which are originating from the extreme homogeneous nature of deep waters in the area.

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