The Movement Track of the Ocean Current in Jiaozhou Bay

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Abstract: According to the data on the investigation of Jiaozhou Bay in May, August and October, 1992, the Pb content and the horizontal distribution in the surface of Jiaozhou Bay were studied. The results show that in May, the open ocean current with a high content of Pb entered Jiaozhou Bay surrounding the nearshore waters of the bay. In August, in the waters of Jiaozhou Bay, there was only one high Pb content source - open ocean current transportation. The open ocean current entered Jiaozhou Bay with a high content of Pb. The ocean current passed from the outside of the bay to the inside through the bay mouth with 37.53 μg/L Pb content. Then the ocean current made a circle around the inshore waters of Jiaozhou Bay, bringing a high Pb content zone of 11.30 - 27.44 μg/L. At this point, a low Pb content area of 5.53 μg/L appeared in the central waters of Jiaozhou Bay. So, in August, the open ocean current with a high content of Pb moved into Jiaozhou Bay. Then it surrounded the nearshore waters of the bay. By the authors’ Dongfang Yang’s migration law of material content, it is obtained that the open ocean current with high Pb content moves into Jiaozhou Bay. And with the continuous decrease of Pb content, the flow path of the open ocean current in the bay, illustrated by a model block diagram, is left. Furthermore, the migration law reveals that the unit water body with the ocean current returns to the inlet water in a counterclockwise direction along the inshore water in the bay. Thus, under the combined action of ocean current and tide, this unit of water body shows zigzag movement from east to north and to west along the eastern, northern and western coastal waters of Jiaozhou Bay, leaving the center of the bay barely affected by the unit water. The unit body of water has a circular center in the center of the bay and a zigzag motion along the edges. Moreover, the topography and geomorphology of the bottom of Jiaozhou Bay also confirm the movement track of the ocean current in the waters of Jiaozhou Bay proposed by the authors.

1. Introduction
The Pb content eventually goes to the marine water body through the migration process and settles to the seabed [1-6]. Therefore, the migration process and migration trajectory of Pb content have become the focus of research. According to the survey data in 1992, the content, horizontal distribution, and sources of Pb in the water body of Jiaozhou Bay were analyzed, and the migration path, migration process and migration law of Pb in the water body of Jiaozhou Bay were studied.

2. The waters and methods of investigation

2.1.Investigation waters. Jiaozhou Bay located at 120°04' - 120°23'E and 35°58' - 36°18'N, which looked like a typical semi-closed bay between Tuan Island and Xuejia Island, facing forward the Yellow Sea. Jiaozhou Bay has a large area of about 446 km² and showed about 7 m by the average water
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depth. Dagu River, Yanghe River and Haibo River, Licun River and Loushan River, and so on flowed into the sea in Jiaozhou Bay, the estuaries of the rivers surrounded the Qingdao City. Moreover, these rivers presented the large runoff and sediment content with obvious seasonal change [7, 8].

2.2. Materials and methods. The North Sea Monitoring Center of the State Oceanic Administration showed the Pb survey data used in this study, the investigation of the data contributed to the Jiaozhou Bay water body in May, August and October 1992. We would pick up the water samples at 13 stations in the Jiaozhou Bay waters in May, August and October 1992. The stations included the stations from station 52 to station 61, and from station 2014 to station 2016 (Figure 1). We got the water samples by the water depth. If the water depth is more than 10 m, we would pick up the water samples from surface layer and bottom layer. If the water depth is less than 10 m, we would pick up them from only the surface layer. The method used during the investigation of Pb in Jiaozhou Bay water body abided by the national standard method included in the National Marine Monitoring Specification (1991) [9].

3. Results and Discussions

3.1. Ocean Current Transport. In May, there were three sources of high Pb content in the waters of Jiaozhou Bay - open ocean current transport, ships and wharf transport, and transport via Licun River. The open ocean current entered Jiaozhou Bay through the mouth with a high content of Pb20.79 μg/L. In the bay, the ocean current moved along the shore to the northeast and reached the waters in the southeast of the bay where the Pb content transported via ocean current was 5.54 μg/L. Then, the ocean current continued to move along the nearshore to the northeast and reached the eastern nearshore waters of Jiaozhou Bay. Pb content here was transferred via ships and wharf and was 16.34 μg/L. After that, the ocean current continued to migrate along the nearshore to the northeast and reached the waters in the northeast of the bay. The Pb content transported via open ocean current was 7.09 μg/L. Afterwards, the open ocean current continued to move along the nearshore to the northeast and got to the coastal waters near the mouth of the Licun River in Jiaozhou Bay with 37.90 μg/L Pb content transported from the Licun River. Then, the ocean current continued to migrate along the nearshore to the northeast and got in the northeastmost of the bay. The Pb content transported via open ocean current was 18.27 μg/L. After that, the ocean current turned westward along the near-shore direction and reached the northern waters of the bay where Pb content transported via ocean current was 13.72 μg/L here. Then, the ocean current continued to move along the nearshore to the west and arrived at the westernmost waters in the northwest of the bay with 12.84 μg/L Pb content transported via ocean current. After that, the ocean current turned southward along the near-shore and reached the waters in the southwest of the bay. Here, the Pb content transported via ocean current was 8.62 μg/L. At this
moment, a low Pb content area of 7.37 μg/L appeared in the central waters of Jiaozhou Bay. Therefore, in May, the open ocean current enters Jiaozhou Bay with a high content of Pb and surrounds the nearshore waters of the bay (Figure 2).

Figure 2 The ocean current’s track including high Pb content in Jiaozhou Bay in May (μg/L)

The arrow indicates the direction of the ocean current, and the circle indicates the high Pb content input in the ocean current.

In August, in the waters of Jiaozhou Bay, there was only one high Pb content source, which was from open ocean current transport. The open ocean current entered Jiaozhou Bay with a high content of Pb. The ocean current passed from the outside of the bay to the inside of the bay through the bay mouth. The Pb content was 37.53 μg/L in the estuary. The ocean current made a circle around the inshore waters of Jiaozhou Bay, bringing a high Pb content zone of 11.30 - 27.44 μg/L to a circle of inshore waters in the bay. At this time, a low Pb content area of 5.53 μg/L appeared in the central waters of Jiaozhou Bay. Therefore, in August, the open ocean current with a high content of Pb enters Jiaozhou Bay and surrounds the nearshore waters of the bay (Figure 3).

Figure 3 The ocean current’s movement track including high Pb content in Jiaozhou Bay in August (μg/L)
3.2. **Running Track of Ocean Current.** According to Dongfang Yang’s transport law of material content put forward by the authors: the longer the transport route of material content is, the greater the loss of material content in the journey is. If the material contents come from the same starting point, reach the same ending point, and the material contents at the starting point are the same, then the longer the material content travels, the lower the value of the material content is at the end point, which proves that the open ocean current enters Jiaozhou Bay with a high content of Pb. With the continuous decrease of Pb content, the movement path of the ocean current in the waters of Jiaozhou Bay is left.

Unit water body with the ocean current moves from the mouth of the bay along the northeast coastal waters to the waters in the northeastmost of the bay. Then it reaches the Loushan River estuary waters. After that, it turns to the west through the coastal waters in the north of the bay to the far west in the northwest and arrives at the mouth of the Dagu River. Finally, it turns to the south along the western nearshore of the bay and reaches the mouth of the bay.

Thus, under the combined action of ocean current and tide, this unit of water body shows zigzag movement from east to north and west along the eastern, northern and western coastal waters of Jiaozhou Bay. The unit water body takes the center of the bay as the center of the circle and moves in a zigzag shape towards the edge. So, the center of the bay is barely influenced by unit water (Figure 4).

![Figure 4 Movement path of unit water body of open ocean current](image)

3.3. **Submarine Landforms and Ocean Current.** Jiaozhou bay is a shallow-water bay, which generally has a dustpan shape. But it slopes to the east at the mouth of the bay. It is shallow in the northwest and deep in the southeast. While the average depth of the bay is only 7 meters, the maximum depth is 51 meters. In some places near the mouth of the bay, the maximum depth is even up to 64 meters. The seabed below the low tide line, except for a few waterways and sand ridges, generally slopes gently towards the middle of the bay. From the low water lines of Dagu River estuary and the south bank of red island to the 20-meter isobath in the middle of the gulf, the average slope of the gulf is 2.0‰ and 2.1‰ respectively. And the slope near the mouth of the bay is up to 2.3‰. The east side is "Cangkou Waterway" where the 10-meter and 15-meter isobath lines form an open gully extending to the top of the bay in a west-north direction. And the west side is the "Front Reef Channel" where the 10-meter isobath extends along the west-north direction towards the mouth of Dagu River. Between the Central Channel and the Cangkou Channel is a prominent plateau known as the Central Sand Ridge, with only four meters of water above it. In the southeast of Yellow Island, there is a depression extending from south to north which is about 12 kilometers long and 1 kilometer wide, with a maximum depth of 51 meters. Nevertheless, the northeastern part of Yellow Island is adjacent to a shallow bank with a water depth of only 6 meters at its top. On either side of Tuan Island there is also a north-northeast to
south-southwest trough with a maximum depth of 29 meters at the southern end. And the north end can be connected to Cangkou Channel with a maximum width of 8.5 km. The southeast where the deep channel alternated with the shallow uplands is close to the mouth of Jiaozhou Bay. Along the direction from Tuan Island to the north end of Xuejia Island, the slope of the bay bottom is large and the submarine topography is steep. The channel of the strait leans to the side of Xuejia Island. The south bank of its slope, on the side of Xuejia Island, is steeper, with an average slope of up to 30‰. Nonetheless, on the side of the north shore, the seabed is relatively gentle, with an average slope of 16‰ (Figure 5).

According to the track of ocean current, we obtained that the ocean current passes through the mouth of Jiaozhou Bay into the inside from the outside along the north-northeast - west-southwest direction deep trough. Then the ocean current goes to the northeast along the "Cangkou Channel" in the direction of north by west and reaches the mouth of Loushan River. After that, it turns west, passing the nearshore waters to the north of the bay. Afterwards, it arrives at the estuary of Dagu river to the northwest of the bay. Finally, it turns southward, following the "fore-reef channel", the nearshore waters of the western part of the bay, to the mouth of the bay.

The northeastern part of the Yellow Island borders a shoal. The water depth at the top of the shoal is only 6 meters, which indicates that the ocean current is flowing from the inside of the bay to the outside. Due to the barrier of Yellow Island, the ocean current slows down in the northeast of Yellow Island forming a shoal in this water area. However, in the southeast of Yellow Island, there is a depression extending from south to north, about 12 kilometers long and 1 kilometer wide, with a maximum depth of 51 meters. The steeper slope of the seafloor shows that around the top of Yellow Island, the channel narrows and the ocean current speeds up, washing away the deep "front reef channel".

Between the "Central Water Channel" and "Cangkou Channel" is a prominent plateau known as the "Central Sand Ridge". The water is only four meters deep above it, making it impossible for the ocean current to cross between the two channels. Thus, an open ocean current with a high Pb content would not bring a high Pb content to the center of the bay.

Therefore, based on the distribution of high Pb content brought by the open ocean current to the waters of Jiaozhou Bay, the movement track of the open ocean current in the waters of Jiaozhou Bay is defined, and the movement process and direction are disclosed. Further, the topography and geomorphology of the bottom of Jiaozhou Bay also confirm the translocation of the ocean current in the waters of Jiaozhou Bay proposed by the authors.
4. Conclusion

In May, the high-content Pb transported via Licun River migrated along the coastal waters of Jiaozhou Bay with the ocean current, first to the northeast, then to the west, after that to the south, finally to the waters on the west side of the mouth of the bay. In addition, with the high content of Pb transported via ocean current in the bay, the Pb content was continuously decreasing. Similarly, the high-content Pb transported via the ships and wharf migrated northeastward along the coastal waters with the ocean current to the waters in the northeast of Jiaozhou Bay. Further, with the high content of Pb transported via ocean current in the bay, the Pb content was continuously decreasing. In almost the same way, the high-content Pb transported via the open ocean current moved northeastward along the estuary of Jiaozhou Bay with the ocean current to the southeastern waters of Jiaozhou Bay. In addition, with the high content of Pb transported via ocean current in the bay, the Pb content was continuously decreasing. Nonetheless, at that time, the central waters of Jiaozhou Bay were in the low Pb content area.

In August, the high content Pb transported via open ocean current migrated along the coastal waters of Jiaozhou Bay with the ocean current. Along a circle of nearshore waters of Jiaozhou Bay, the open ocean current moved from the outside to the inside through the bay mouth. With the high content of Pb transported via ocean current in the bay, a circle of coastal waters in Jiaozhou Bay had a high content of Pb. But at this moment, the central waters of Jiaozhou Bay were in the low Pb content area.

According to the authors’ Dongfang Yang’s migration law of material content, it is reached that the open ocean current with high Pb content enters Jiaozhou Bay. And with the continuous decrease of Pb content, the movement track of the open ocean current in the bay is left, which is shown with the model block diagram. Further, the law reveals that the unit water body returns to the inlet water in a counterclockwise direction along the inshore water in the bay with the ocean current from the inlet. Thus, under the combined action of ocean current and tide, this unit of water body which has a circular center in the center of the bay shows zigzag movement from east to north and west along the eastern, northern and western coastal waters of Jiaozhou Bay. However, the center of the bay is barely affected by the unit water.

Therefore, through the change and distribution of high Pb content brought by the offshore current with high Pb content to the waters of Jiaozhou bay, the movement track of the offshore current in the waters of Jiaozhou bay was determined, and the movement process and direction were revealed. Furthermore, the topography and geomorphology of the bottom of Jiaozhou Bay also confirm the movement track of the ocean current in the waters of Jiaozhou Bay proposed by the authors.

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