Changing Degree Model of Pb Content Transported by Ocean Currents

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Abstract: Based on the survey data of the waters of Jiaozhou Bay in May, August and October 1992, the change of Pb content and its deposition process in the surface and bottom waters of Jiaozhou Bay were studied. According to the definition and model of Dongfang Yang's content changing degree, the variation of Pb content at surface and bottom and of Pb content transported by main sea current formed a peak line in the southeast waters of Jiaozhou Bay. The Pb content on the surface reached its peak in August. From May to August, Dongfang Yang's content changing degree was 79.84°. However, from August to October, it was -85.29°. Specifically, in surface water, Dongfang Yang's content changing degree from May to August was 62.48°. From August to October, Dongfang Yang's content changing degree was -39.00°. In the bottom water, Dongfang Yang's content changing degree from May to August was 70.41°. From August to October, Dongfang Yang's content changing degree was -80.03°. It indicates that the change of Pb content in surface nearshore waters passed through by the main sea current was determined by the change of Pb content transported by the current. The change of Pb content in surface seawater through the change of ocean currents increases or decreases the increase or decrease of Pb content in surface water —The Pb content of surface water increased or decreased with the increase or decrease of Pb content transported by main sea currents. The Pb content temporal variation in the surface and bottom of the southeastern waters of Jiaozhou Bay from May to October reveals the Pb content settling law: With the increase of Pb content in surface water, the Pb content in bottom water rose faster than that in surface water. When the Pb content in surface water decreased, the Pb content in bottom water decreased much faster than that in surface water. Therefore, the change mechanism of surface and bottom water caused by source transport is proposed with the corresponding model block diagram and changing degree model of Pb content transported by ocean currents.

1. Introduction

The main sea current entered Jiaozhou Bay through the bay mouth and surrounded the coastal waters with high lead (Pb) content. Then it left the inner waters of Jiaozhou Bay. When the current flowed into the bay, Pb content was transported horizontally and vertically, settling to the seabed through surface water from surface and rising to the sea surface through the current [1-6]. Therefore, it is of great significance to study the deposition and migration process of Pb content in the main sea current transport to protect the marine environment and maintain ecological sustainable development. According to the survey data in 1992, the increasing and decreasing process of Pb content in Jiaozhou Bay was determined, which provides scientific theoretical basis for the study of source and sedimentation process of Pb content in Jiaozhou Bay.

2. Water Areas, Materials and Methods of Survey

2.1 Natural Environment of Jiaozhou Bay. Jiaozhou Bay lies in the south of the Shandong Peninsula. Its geographical position is between 120°04'-120°23'E and 35°58'-36°18'N. It is bounded by the line from Tuan Island to Xuejia Island and connected to the Yellow Sea, with an area of about 446km2 and an average water depth of about 7m. It is a typical semi-enclosed bay. Jiaozhou Bay has more than ten rivers entering the sea, among which Dagu River, Yang River and Haibo River as well as Licun River and Loushan River in Qingdao city are rivers with large runoff and sediment concentration. These rivers belong to seasonal rivers, whose hydrological characteristics have obvious seasonal changes [7, 8].

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2.2 Materials and Methods. The North China Sea Environmental Monitoring Center provided the survey data of Pb in May, August and October 1992 in Jiaozhou Bay. Two water sampling stations were set up in the waters of Jiaozhou Bay: station 52 and station 60 (Figure 1). The water samples were taken in May, August and October 1992 respectively by depth (Take the surface and bottom when depth > 10m. Only take the surface when depth < 10m). The investigation of Pb content in Jiaozhou Bay water body was carried out according to the standard method stipulated in the National Specification for Marine Monitoring (1991)[9].

3. Results

3.1 Definition and Model of Dongfang Yang's Content Changing Degree. Taking time as x-axis and material content as y-axis, the XOY plane is formed. x changes from x1 to x2. y changes from y1 to y2. Therefore, in the XOY plane, the material content y is the linear change along the surface points A (x1, y1) and B (x2, y2) (Figure 2). Its slope is

$$k_{AB}=(y_2-y_1)/(x_2-x_1) \quad (1)$$

The angle between the line and the x-axis is

$$\alpha_{AB}=\text{arctg}k_{AB} \quad (2)$$

It is called Dongfang Yang's content changing degree whose range is $-90°<\alpha_{AB}<90°$.

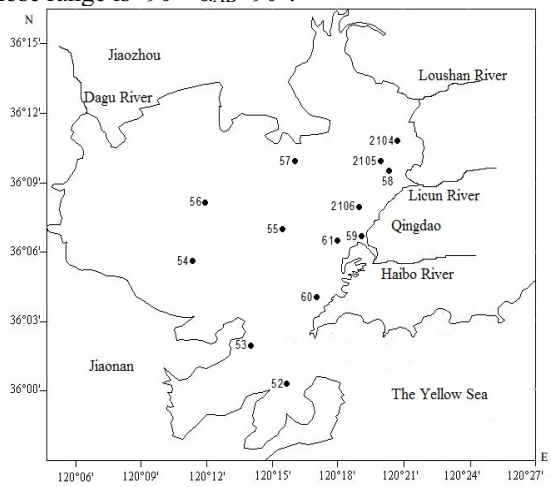

Figure 1 Investigation stations in Jiaozhou Bay

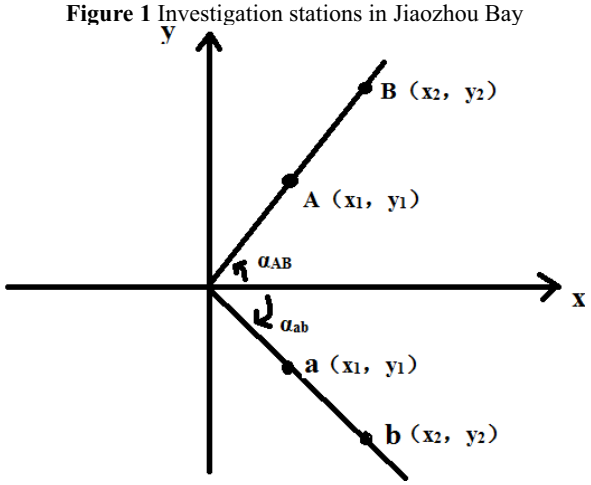

Figure 2 The model diagram of Dongfang Yang's content changing degree

3.2 Scope and Standards of Dongfang Yang's Content Changing Degree. According to the change process of Dongfang Yang's content changing degree (Figure 2), the change degree of material content with time is determined, and its standard is given.

When $0°<\alpha AB<90°$, the substance content rises with time. Moreover, the greater the Dongfang Yang's content changing degree, the faster the content rises with time. The smaller the Dongfang Yang's content changing degree, the slower the rise of material content with time.

When $\alpha AB=45°$, αAB is called the Dongfang Yang's content standard risedegree. In this case, the substance content rises standardly over time.

When $0°<\alpha AB<30°$, αAB is called the Dongfang Yang's content very slow rise degree. At this point, the substance content very slowly rises over time.

When $30°<\alpha AB<45°$, αAB is called the Dongfang Yang's content slow rise degree. At this time, the substance content rises slowly over time.

When $45°<\alpha AB<60°$, αAB is called the Dongfang Yang's content quick rise degree. At this point, the substance content rises quickly over time.

When $60°<\alpha AB<90°$, αAB is called the Dongfang Yang's content very quick rise degree. At this point, the substance content rises quickly over time.

When $-90°<\alpha AB<0°$, the substance content falls with time. Moreover, the greater the Dongfang Yang's content changing degree, the slower the content falls with time. The smaller the Dongfang Yang's content changing degree, the faster the fall of material content with time.

When $\alpha AB=-45°$, αAB is called the Dongfang Yang's content standard fall degree. In this case, the substance content falls standardly over time.

When $-30°<\alpha AB<0°$, αAB is called the Dongfang Yang's content very slow fall degree. At this point, the substance content very slowly falls over time.

When $-45°<\alpha AB<-30°$, αAB is called the Dongfang Yang's content slow fall degree. At this time, the substance content falls slowly over time.

When $-60°<\alpha AB<-45°$, αAB is called the Dongfang Yang's content quick fall degree. At this point, the substance content falls quickly over time.

When $-90°<\alpha AB<-60°$, αAB is called the Dongfang Yang's content very quick fall degree. At this point, the substance content falls quickly over time.

When $\alpha AB=0°$, the Dongfang Yang's content changing degree is 0. In this case, substance content remains constant over time.

The above is the quantitative description and standard of substance content changing over time when the Dongfang Yang's content changing degree is $-90°<\alpha AB<90°$.

3.3 Transport of Main Sea Current. The main sea current carried the high Pb content to Jiaozhou Bay through the bay mouth. The water flowed into the south of the bay mouth and then entered the southeast waters of Jiaozhou Bay.

In May, August and October, in the southeast waters of Jiaozhou Bay lies station 60. In the surface waters, the

main sea current entered the bay through the bay mouth and reached station 60. As a result, it affected surface water in the southeast of the bay.

The Pb content in the main sea current in Jiaozhou Bay in May was 20.79μg/L. The Pb content in the main sea current in August was 37.53μg/L. The Pb content in the current in October was 13.25μg/L. Therefore, the change of Pb surface content also formed a peak line (Figure 3). Surface Pb content changed from the lowest to high then to low in October, August and May.

In the southeast waters of Jiaozhou Bay lies station 60. Pb content in surface water of station 60 increased from the lowest value 5.54μg/L in May. Pb content peaked at 11.30μg/L in August, and then began to decline. In October, Pb content decreased to low value 9.67μg/L. Thus, the change of Pb surface content also formed a peak line (Figure 3). The variation of surface Pb content from the lowest to high then to low was as follows: May, August and October.

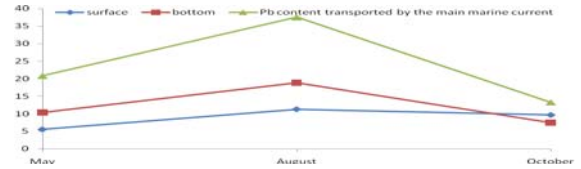

Figure 3 The change process of Pb contents at the surface and bottom

Pb content in bottom water of station 60 increased from 10.43μg/L in May. Pb content began to decline after reaching a peak of 18.88μg/L in August. In October, Pb content reached a minimum of 7.49μg/L. So the change of Pb content in the bottom layer formed a peak line (Figure 3). Change rule of Pb bottom content from low to high then to low was October, August and May.

3.4 Dongfang Yang's Content Changing Degree of Main Sea Current Transport.

The time variation of Pb transported by main sea current in the waters of Jiaozhou Bay in May, August and October is quantitatively determined.

Take time as x-axis and Pb content transported by main sea current as y-axis. The linear change of Pb content in main sea current transport is along the surface points A(5,20.79) and B(8,37.53) from May to August.The slope of the line is kAB=5.58, and the angle between the line and the x-axis is αAB= Dongfang Yang's content changing degree =79.84°.The linear variation of Pb content transported by main sea currentis along surface points B(8,37.53) and C(10,13.25) from August to October.The slope of the line is kBC=-12.14, and the angle between the line and the x-axis is αBC= Dongfang Yang's content changing degree = -85.29°.

3.5 Dongfang Yang's Content Changing Degree in the Southeastern Waters of the Bay.

The temporal variation of Pb content in the southeast waters of Jiaozhou Bay in May, August and October is quantitatively determined.

Take time as x-axis and Pb content in southeast bay waters as y-axis. From May to August, Pb content in the southeastern waters of the bay changed along a straight line formed by surface points A (5, 5.54) and B (8, 11.30) whose slope is kAB = 1.92. The angle between the line and the x-axis was αAB = Dongfang Yang's content changing degree = 62.48°. From August to October, Pb content in the southeastern waters of the bay changed along a straight line formed by surface point B (8, 11.30) and surface point C (10, 9.67). The slope of the line is kBC= -0.81. The angle between the line and the x-axis was αBC = Dongfang Yang's content changing degree = -39.00°.

The effect of vertical water [10-13] made Pb vary greatly after passing through water. Pb ion has strong hydrophilicity and is easy to combine with phytoplankton and particles in seawater. In the summer, marine life proliferated and increased rapidly. In addition, the propagation of plankton made the surface of suspended particles colloidal. At this time, the adsorption capacity of them was the strongest, and a large number of Pb ions were adsorbed into surface water. Due to gravity and water flow, Pb content continuously sank to the seabed [1-6].

The Pb content of the southeast bay waters reached the bottom from the surface through water through deposition. From May to August, Pb content in the bottom layer changed along a (5, 10.43) and b (8, 18.88). The slope of the line is kab = 2.81. The angle between the line and the x-axis was αab = Dongfang Yang's content changing degree =70.41°. From August to October, Pb content in the bottom layer changed along a straight line formed by points b (8, 18.88) and c (10, 7.49), the slope of which was kbc = -5.69. The angle between the straight line and the x-axis was αbc= Dongfang Yang's content changing degree = -80.03°.

4. Discussion

4.1 Variation of Content Transported by Main Sea Current.

In the surface water at the bay mouth of Jiaozhou Bay, the main sea current transported Pb content to the sea area in May, August and October. No matter whether Pb content increased or decreased with time, the degree of Pb content increase or decrease can be quantified according to the Dongfang Yang's content changing degree proposed by the authors.

The surface Pb content increased from May to August, and the Dongfang Yang's content changing degree was 79.84°. 60°<αAB<90°, so it is the Dongfang Yang's content very quick rise degree. At this time, Pb content in the surface layer increases rapidly with time. It indicates that the main sea current transported Pb to surface waters of Jiaozhou Bay. From May to August, transport amount increased significantly and reached a high level.

From August to October, the surface Pb content decreased, and the Dongfang Yang's content changing degree was -85.29°. -90°<αAB<-60°, so it is the Dongfang Yang's content very quick fall degree. At this time, Pb content in the surface layer decreased rapidly with time. It indicates that the main sea current

transported Pb to surface waters of Jiaozhou Bay. From August to October, transport amount fell sharply to a low level.

4.2 Content Variation in Southeastern Waters of the Bay. In the southeastern surface waters of Jiaozhou Bay, Pb was transported by the main sea current in May, August and October. No matter whether Pb content increased or decreased with time, the degree of Pb content increase or decrease can be quantified according to the Dongfang Yang's content changing degree proposed by the authors.

The Pb content in the surface layer was on the rise from May to August, and the Dongfang Yang's content changing degree was 62.48°. 60°<αAB<90°,so it is the Dongfang Yang's content very quick rise degree.At this time, Pb content in the surface layer increased rapidly with time. It suggests that the current carriedPb to the southeastern surface waters of Jiaozhou Bay.From May to August, the amount of main sea current transport in the southeast bay increased sharply and reached a high level.

The Pb content in the surface layer decreased from August to October, and the Dongfang Yang's content changing degree was -39.00°. -45°<αAB<-30°, the angle is the Dongfang Yang's content slow fall degree.At this time, Pb content in the surface layer decreased slowly with time. It suggests that the current carriedPb to the southeastern surface waters of Jiaozhou Bay.From August to October, the volume of main sea currenttransport gradually decreased to a relatively low level.

The Pb content in the bottom layer increased from May to August, and the Dongfang Yang's content changing degree was 70.41°. 60°<αAB<90°, so it is the Dongfang Yang's content very quick rise degree. At this time, Pb content in the bottom layer increased rapidly with time. It suggests that the current carried Pb to the southeastern surface waters of the bay. From May to August, after Pb content passed through the water body, the bottom settlement increased sharply and reached a high level.

Pb content in the bottom layer decreased from August to October, and the Dongfang Yang's content changing degree was -80.03°. - 90°<αAB<-60°, so it is the Dongfang Yang's content very quick fall degree. At this time, Pb content in the bottom layer decreased rapidly with the change of time. It suggests that the current carried Pb to the southeastern surface waters of the bay. From August to October, after Pb content passed through the water body, the bottom settlement dropped sharply to a low level.

4.3 Changes of Surface Content Transported by Main Sea Current. In May, August and October, the main sea current transported Pb to the surface waters of the southeast bay, which affected the temporal variation of Pb content here

From May to August, Pb content transported by main sea current increased, and the Dongfang Yang's content changing degree was 79.84°. The Pb content in the surface area of the southeast bay increased, and the Dongfang Yang's content changing degree was 62.48°. The Dongfang Yang's content changing degree of main sea current transport was larger than that in southeastern bay, indicating that Pb content transported by main sea current increased faster than that in surface water in the southeast bay.

Pb content in the main sea current transport decreased from August to October, and the Dongfang Yang's content changing degree was -85.29°. Meanwhile, Pb content in the surface waters of the southeastern bay decreased, and the Dongfang Yang's content changing degree was -39.00°. The Dongfang Yang's content changing degree in main sea current transport was less than that in the southeastern waters of the bay, which indicates that the Pb content in the main sea current transport decreased faster than that in the surface layer in the southeast bay.

Therefore, the rise or fall of Pb content transported by main sea current in surface water determined the rise or fall of Pb content in surface water in southeastern bay. It indicates that the variation of Pb content transported by main sea current in surface waters determined the variation of Pb content in all nearshore waters where main sea current passed, and Pb content of surface water in these waters increased or decreased with the increase or decrease of Pb content transported by main sea current.

4.4 Surface and Bottom Subsidence of the Southeastern Waters of the Bay. The temporal variations of Pb content in surface and bottom waters were compared in May, August and October in the southeastern waters of Jiaozhou Bay.

Pb content in the surface layer increased from May to August, and the Dongfang Yang's content changing degree was 62.48°. The Pb content in the bottom layer increased, and the Dongfang Yang's content changing degree was 70.41°. The Dongfang Yang's content changing degree of Pb content in the surface layer is less than that in the bottom layer. It indicates that when Pb content in surface water increased, under the action of gravity and water flow, Pb content continuously and rapidly sank to the sea floor, leading to a faster rise of Pb content in bottom water than in surface water.

The Pb content in the surface layer decreased from August to October, and the Dongfang Yang's content changing degree was -39.00°. The Pb content in the bottom layer also decreased, and the Dongfang Yang's content changing degree was -80.03°. Therefore, the Dongfang Yang's content changing degree of Pb content in the surface layer was far less than that in the bottom layer, which indicates that when the Pb content of surface water dropped, under the action of gravity and water flow, the Pb content settling to the seabed dropped rapidly, resulting in the Pb content of bottom water falling much faster than that of surface water.

Therefore, in the southeast waters of Jiaozhou Bay from May to October, the time-varying Pb content in

surface water and bottom water reveals the settlement rules of Pb: When Pb content in surface water increased,Pb content in bottom water rose faster than that in surface water. When the Pb content in surface water decreased, the Pb content in bottom water decreased much faster than that in surface water.

4.5 Mechanism of Surface and Bottom Water Changes Caused By Source Transport. The main sea current carried high Pb content into Jiaozhou Bay, surrounded the coastal waters of the bay, and left the bay to reach the western waters of the bay mouth (Figure 4).

In May, August and October, station 60 lies in waters southeast of Jiaozhou Bay. In surface water, the main sea current entered Jiaozhou Bay through the bay mouth and reached station 60. The main sea current affected surface water southeast of the bay. According to the effect theory of vertical water bodies, horizontal water bodies and water bodies [13], Pb content of surface rapidly and constantly sank to the sea floor, obtaining sediment effect and dilution effect, which affect the change of Pb content at the bottom of the water body.

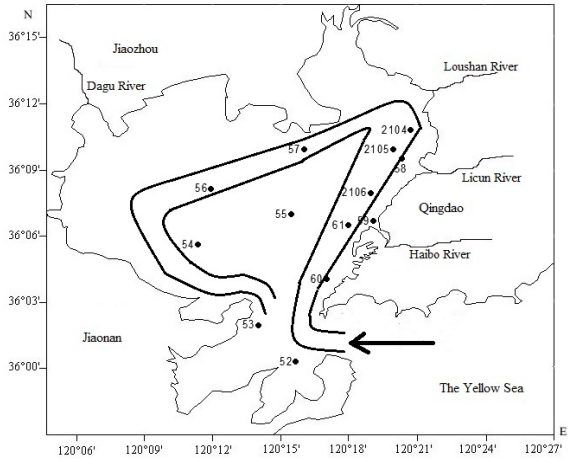

Figure 4 The flow path of the main sea current with a high content of Pb in Jiaozhou Bay (μg/L)

From May to August, the surface Pb content in main sea current transport increased, and the Dongfang Yang's content changing degree was 79.84°. The Pb content in the surface waters of the southeastern bay increased, and the Dongfang Yang's content changing degree of Pb content was 62.48°. Pb content in the bottom layer increased, and the Dongfang Yang's content changing degree was 70.41° (Figure 5). Therefore, when Pb content transported by main sea current in the surface layer rose from May to August, Pb in the bottom layer rose first due to rapid and continuous subsidence. With the continuous increase of Pb content transported by main sea current in the surface layer, the Pb content in the surface layer increased.

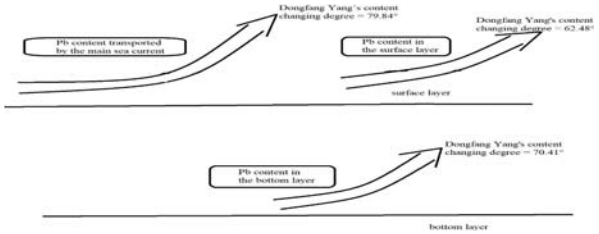

Figure 5 The rising process of Pb contents at the surface and bottom

From August to October, Pb content on the surface of main sea current transport decreased, and the Dongfang Yang's content changing degree of Pb content was -85.29°. The Pb content in the surface waters of the southeastern bay decreased, and the Dongfang Yang's content changing degree changed to -39.00°. Pb content in the bottom layer decreased, and the Dongfang Yang's content changing degree was -80.03° (Figure 6). Thus, when the Pb content in the surface layer of main sea current transport decreased from August to October, the Pb content in the bottom layer decreased immediately due to the rapid decrease of Pb content sediment. However, with the continuous decrease of Pb content in the surface layer transported by main sea current, the decrease of Pb content in the surface layer was very slow.

Therefore, the authors put forward the mechanism of surface and bottom water changes caused by source transport: when the Pb content of surface water exceeded a certain threshold, the Pb content of surface water would rapidly and continuously settle to the seabed through water bodies. When Pb content in surface water was lower than a certain threshold, Pb content in surface water would stay in water for a long time and settle to the seabed slowly.

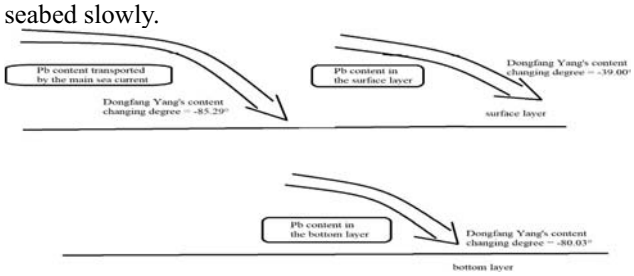

Figure 6 The falling process of Pb contents at the surface and bottom

5. Conclusion

According to the definition and model of Dongfang Yang's content changing degree, the change degree of material content with time is determined through the change process of Dongfang Yang's content changing degree, and the standard of the change degree of material content with time is given.

In May, August and October, the Pb content was transported to the surface waters in the southeast bay by main sea current in the surface waters, which affected the time variation of Pb content in the surface and bottom waters in the southeast bay.

In the southeast of Jiaozhou Bay, the variation of Pb content in the surface and bottom layer and of Pb content transported by main sea current formed a peak line. The surface Pb content reached its peak in August. According

to the definition and model of the Dongfang Yang's content changing degree, the variation of Pb content transported by main sea current was calculated —from May to August, the Dongfang Yang's content changing degree was 79.84°. From August to October, the Dongfang Yang's content changing degree was -85.29°. The Dongfang Yang's content changing degree in surface water from May to August was 62.48°. From August to October, the Dongfang Yang's content changing degree was -39.00°. In the bottom water, the Dongfang Yang's content changing degree from May to August was 70.41°. From August to October, the Dongfang Yang's content changing degree was -80.03°.

In terms of timescale, Pb content in surface water transported by main sea current from May to August rose faster than that in southeastern bay waters. From August to October, Pb content in surface water transported by main sea current decreased faster than that in the southeast bay.

In the southeast waters of Jiaozhou Bay from May to August, under the action of gravity and water flow, Pb content in surface water was increasing and rapidly sank to the seabed, leading to a faster rise of Pb content in bottom water than in surface water. On the contrary, from August to October, Pb content in surface water decreased. Under the action of gravity and water flow, Pb content in bottom water decreased rapidly, and the rate of decline was much faster than that in surface water.

Therefore, when Pb content of main sea current transport in the surface layer rose from May to August, Pb content in the bottom layer rose first, because it rapidly and continuously settled to the seabed. With the increasing of Pb content transported by main sea current in the surface layer, the Pb content in the surface layer also increased. From August to October, when the Pb content transported by main sea current in the surface layer decreased, the Pb content in the bottom layer decreased rapidly due to its less settlement to the sea floor. However, with the continuous decrease of Pb content transported by main sea current in the surface layer, the decrease of Pb content in the surface layer was very slow.

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