In the bottom layer the Hg content controlled by both Seasonal variation and transportation source

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Abstract: Based on the investigation data of Jiaozhou Bay in 1992, the vertical distribution and seasonal variation of Hg in the surface and bottom layers from the center of the bay to the southeast of the bay were studied, and the seasonal distribution, variation range and horizontal distribution trend of Hg content in the surface and bottom layers were determined. The results showed that in May, August and October, in Jiaozhou Bay, from the central water area to the coastal water area in the southeast of the Bay, from the surface layer to the bottom layer, the range of Hg content in the bottom layer and the surface layer was: 0.007-0.040 μg/L, which conformed to the national water quality standard of class I seawater, and the water was not polluted by any Hg content. From May to October, in the central waters of Jiaozhou Bay, the seasonal changes of Hg content in the surface layer from low to high were spring, summer and autumn, and the seasonal changes of Hg content in the bottom layer from low to high were autumn, spring and summer. In the surface of the coastal waters in the southeast of Jiaozhou Bay, the seasonal changes of Hg content in the surface and bottom layers from low to high were autumn, spring and summer. The author put forward the law of Hg deposition: in summer, marine organisms propagated in large numbers, but in spring and autumn, there was no large number of marine organisms propagated. In this way, the Hg content sediment depended entirely on the combination of zooplankton, phytoplankton and floating particles in the sea water. Therefore, in summer, a large amount of Hg was taken to the seabed, while in spring and autumn, no large amount of Hg was taken to the seabed. In May, August and October, the change of Hg content in the surface and bottom layers fully confirmed the settlement law. Moreover, it was believed that a large number of marine organisms in the water were the main carriers to bring a large number of Hg to the seabed. Therefore, the variation of Hg content in the bottom was determined by the surface Hg content and the vehicles that transport Hg content vertically to the sea bottom, which resulted in the fact that the horizontal distribution trend of Hg content in the surface and bottom was same.

1. Introduction
Human discharge mercury (Hg) to the ocean, atmosphere and soil in activities. Through the land, sea and atmosphere, a large number of waste water, waste gas and particles containing Hg reach the surface of the ocean, and then migrate vertically to the seabed through the water body [1-14]. Therefore, based on the investigation data of Hg in Jiaozhou Bay in 1992, the vertical distribution and seasonal variation of Hg in the surface and bottom of Jiaozhou Bay from the center of the bay to the nearshore were studied, and the seasonal distribution, variation range and horizontal distribution trend of Hg in the surface and bottom waters were determined, showing the seasonal variation and vertical settlement process of Hg in Jiaozhou Bay, which provide scientific basis for the study of Hg vertical
settlement and horizontal migration in surface and bottom layers.

2. Investigation Waters, Materials and Methods

2.1 Natural Environments of Jiaozhou Bay. Jiaozhou Bay is located in the south of Shandong Peninsula. Its geographical location is 120°04′-120°23′E, 35°58′-36°18′N. It is bounded by the line between Tuan island and Xuejia island and connected with the Yellow Sea, covering an area of about 446km², with an average water depth of about 7m. It is a typical semi closed Bay. There are more than ten rivers flowing into the sea in Jiaozhou Bay, among which Dagu River, Yang River and Haibo River, Licun River and Loushan River are the ones with large runoff and sediment concentration. These are all seasonal rivers. The hydrological characteristics of these rivers can alter in different seasons [15, 16].

2.2 Materials and Methods. The survey data of Hg in Jiaozhou Bay in May, August and October 1992 were provided by the North Sea Monitoring Center of The State Oceanic Administration. In May, August and October, 2 stations were set up in Jiaozhou Bay to take water samples: 55 and 60 stations (Figure 1). The samples were taken in May, August and October of 1992 respectively. According to the water depth, water samples were taken (> 10m, surface layer and bottom layer, and < 10m, only surface layer). The Hg content of Jiaozhou Bay water body was investigated according to the national standard method, which was included in the National Marine Monitoring Code (1991) [17].

3. Results

3.1 Surface and Bottom Waters. In May, from the central water area to the coastal water area in the southeast of the bay, the Hg content in the surface layer was 0.011-0.022 μg/L, and that in the bottom layer was 0.013-0.019 μg/L. This showed that the Hg content in whole surface and bottom layers of the Jiaozhou Bay was less than 0.030 μg/L from the central water area to the coastal water area in the southeast of the Bay, which conformed to the water quality standard of the class I sea water of China. And the water was not polluted by any Hg content.

In August, the content of Hg in the surface layer was 0.021-0.035 μg/L, and that in the bottom layer was 0.021-0.025 μg/L. This showed that the Hg content of the whole surface and bottom layers in Jiaozhou Bay was less than 0.040 μg/L from the central water area to the coastal water area in the southeast of the Bay, which conformed to the water quality standard of class I sea water of China, and the water was not polluted by any Hg content.
In October, the Hg content in the surface layer was 0.011-0.040 μg/L, and that in the bottom layer was 0.007-0.018 μg/L. This showed that the Hg content of the whole surface and bottom layers in Jiaozhou Bay was less than 0.050 μg/L from the central water area to the coastal water area in the southeast of the Bay, which conformed to the water quality standard of the class I sea water of China, and the water was not polluted by any Hg content.

Therefore, in May, August and October, in Jiaozhou Bay, from the central water area to the coastal water area in the southeast of the Bay, from the surface layer to the bottom layer, the range of Hg content in the surface and bottom layers was 0.007-0.040 μg/L, which conformed to the national water quality standard of class I seawater, and the water was not polluted by any Hg content.

3.2 Seasonal Change of Hg Content in Surface Layer. From the central water area to the coastal water area in the southeast of the Bay, in May, the Hg content of surface in the water body was 0.011-0.022 μg/L; in August, the Hg content of surface in the water body was 0.021-0.035 μg/L; in October, the Hg content of surface in the water body was 0.011-0.040 μg/L. This showed that in May, August and October, the range of Hg content in the surface layer was 0.011-0.040 μg/L, and the sequence of Hg content from low to high was May, August and October. Therefore, the seasonal variation of Hg content in water body from low to high was spring, summer and autumn.

3.3 Seasonal Change of Hg Content in Bottom Layer. From the central water area to the coastal water area in the southeast of the Bay, in May, the Hg content of bottom layer in the water was 0.013-0.019 μg/L; in August, the Hg content of bottom layer in the water was 0.021-0.025 μg/L; in October, the Hg content of bottom layer in the water was 0.007-0.018 μg/L. This showed that in May, August and October, the range of Hg content in the bottom layer of the water body was 0.007-0.025 μg/L, and the sequence of Hg content from low to high was May, August and October. Therefore, the seasonal variation of Hg content in the bottom layer of water body from low to high was autumn, spring and summer.

3.4 The Variation Range of Hg Content in Surface and Bottom Layers. In May, when the Hg content in the surface layer was relatively low, between 0.011-0.022 μg/L, the Hg content in the corresponding bottom layer was 0.013-0.019 μg/L, a relatively level. In August, when the Hg content in the surface reached a relatively high level of 0.021-0.035 μg/L, the Hg content in the corresponding bottom layer was relatively high, 0.021-0.025 μg/L. In October, when the Hg content in the surface layer reached the highest level of 0.011-0.040 μg/L, the Hg content in corresponding bottom layer reached the lowest level of 0.007-0.018 μg/L. Moreover, the variation range of Hg content in the surface layer was 0.011-0.040 μg/L, which was larger than that in the bottom layer, 0.007-0.025 μg/L, and the amplitudes of variation was basically the same. Therefore, in May, the Hg content of surface was relatively low, and the Hg content in corresponding bottom layer was relatively low; in August, when the Hg content in surface was relatively high, the Hg content in corresponding bottom layer was relatively high; however, in October, when the Hg content of surface was very high, that in the corresponding bottom layer reached the lowest level.

3.5 Horizontal Distribution Trend of Surface and Bottom Layers. In May, from station 55 in the central waters of the bay to station 60 in the coastal waters in the southeast of the bay, in the surface layer, Hg content increased from 0.011 μg/L to 0.022 μg/L along the gradients. In the bottom layer, Hg content increased from 0.013 μg/L to 0.019 μg/L along the gradients. This showed that the horizontal distribution trend of Hg content in the surface and bottom layers was same.

In August, from station 55 in the central waters of the bay to station 60 in the coastal waters in the southeast of the bay. In the surface layer, Hg content increased from 0.021 μg/L to 0.035 μg/L along the gradients. In the bottom layer, Hg content increased from 0.021 μg/L to 0.025 μg/L along the gradients. This showed that the horizontal distribution trends of Hg content in the surface and bottom layers were same.
In October, from station 55 in the central water area of the bay to station 60 in the coastal water area in the southeast of the bay, in the surface layer, Hg content decreased along the gradients from 0.040 μg/L to 0.011 μg/L. In the bottom layer, Hg content increased from 0.007 μg/L to 0.018 μg/L along the gradients. This showed that the horizontal distribution trends of Hg content in the surface and bottom layers were opposite.

In May and August, the horizontal distribution of Hg in the surface layer of Jiaozhou Bay was consistent with that in the bottom layer of the bay. In October, the horizontal distribution of Hg in the surface layer of Jiaozhou Bay was opposite to that in the bottom layer of the bay.

4. Discussions

4.1 The Process of Deposition. In water body, Hg appeared in the form of ions and had strong hydrophilicity. In summer, marine organisms multiplied in large numbers and increased rapidly [16]. It was easy for Hg to combine with zooplankton, phytoplankton and floating particles in the sea water. The colloid formed on the surface of floating particles and had the strongest adsorption capacity. In this way, when the Hg content passed through the water body, a large number of Hg ions would be adsorbed on the surface of the floating particles. When the floating particles settled, the Hg would continuously settle to the seabed [1-11]. Therefore, under the action of gravity and water flow, Hg was influenced by the effect of vertical water body [12-14], continuously settling from the surface to the seabed, presenting the process of Hg settlement and migration.

4.2 Seasonal Waters in Central Waters of the Bay. In the surface of the central waters of the Jiaozhou Bay, in May, the Hg content began to rise from a low level of 0.011 μg/L, and gradually increased. In August, the Hg content reached the high level of 0.021 μg/L, then continued to rise, and gradually increased. In October, the Hg content reached the high level of 0.040 μg/L. Therefore, the seasonal variation of Hg content from low to high was spring, summer and autumn.

In the surface of the central waters of the Jiaozhou Bay, in spring, summer and autumn, there was no source of Hg content, and the settlement of Hg content only depended on the combination of plankton and floating particles in the sea water. In summer, marine organisms propagated in large numbers, and the number increased rapidly, while in spring and autumn, there was not a large number of marine organisms propagated. Therefore, in summer, a large amount of Hg was taken to the seabed, while in spring and autumn, there was no large amount of Hg taken to the seabed. Thus, in the bottom of the central waters of Jiaozhou Bay, in May, the Hg content began to change from a low level of 0.013 μg/L, then began to rise, gradually increased, and in August, the Hg content reached a high level of 0.021 μg/L. In October, the Hg content reached the lowest level of 0.007 μg/L. Therefore, the Hg content in bottom layer changed from low to high in autumn, spring and summer.

4.3 Seasonal Variation of Coastal Waters in the Southeast of the Bay. In the surface of the coastal waters in the southeast of the Jiaozhou Bay, in May, the Hg content began to change from a low level of 0.022 μg/L, then began to rise, gradually increased. And in August, the Hg content firstly reached a high level of 0.035 μg/L, then began to decline, gradually decreased. In October, the Hg content reached a lowest level of 0.011 μg/L. Therefore, the seasonal variation of Hg content from low to high was autumn, spring and summer.

In the surface of coastal waters in the southeast of Jiaozhou Bay, there was no source of Hg content in spring and autumn. In summer, the Hg content came from atmospheric subsidence, and the Hg content in transportation reached a very high level of 0.050 μg/L. In summer, marine organisms propagated in large numbers, and the number increased rapidly, while in spring and autumn, there was not a large number of marine organisms production. Therefore, the Hg content settlement not only depended on the combination of plankton and floating participle in the sea water, but also depended on a large amount of Hg content from atmospheric deposition. Therefore, in summer, a large amount of Hg was taken to the seabed, while in spring and autumn, there was no large amount of Hg taken to the
seabed. Thus, in the bottom of the coastal waters in the southeast of Jiaozhou Bay, in May, the Hg content began to change from a low level of 0.019 μg/L, then began to rise, gradually increased, and in August, the Hg content reached a high level of 0.025 μg/L. By October, it began to decline and gradually decreased, and the Hg content reached the lowest level of 0.018 μg/L. Therefore, the Hg content in bottom layer changed from low to high in autumn, spring and summer.

4.4 Different Processes of Seasonal Change. The seasonal variation in the central waters of Jiaozhou Bay was totally different from that in the coastal waters in the southeast of Jiaozhou Bay. In the central waters of Jiaozhou Bay, the seasonal variation of Hg content in the surface layer from low to high was spring, summer and autumn, and the seasonal variation of Hg content in the bottom layer from low to high was autumn, spring and summer. In the coastal waters in the southeast of Jiaozhou Bay, the seasonal changes of Hg content in the surface and bottom layers from low to high were autumn, spring and summer. Although the seasonal variation of Hg content in the surface layer from low to high was different between the Central Bay and the coastal waters in the southeast of Jiaozhou Bay, the seasonal variation of Hg content in the bottom layer from low to high was the same. This showed the different sedimentation process of Hg content in the two waters.

In the surface of the central waters of Jiaozhou Bay, in spring, summer and autumn, there was no source of Hg content. The Hg content settlement only depended on the combination of plankton and floating participle in the sea water. In summer, marine organisms propagated in large numbers, and the number increased rapidly, while in spring and autumn, there was not a large number of marine organisms propagated. Therefore, when there was no source of Hg content, the Hg content in the bottom layer was controlled by the seasonal variation.

In the surface of the coastal waters in the southeast of Jiaozhou Bay, in spring and autumn, there was no source of Hg content. In summer, there was the source of Hg content, the Hg content came from atmospheric subsidence, and the content in transportation reached a very high level of 0.050 μg/L. In summer, marine organisms propagated in large numbers, and the number increased rapidly, while in spring and autumn, there was not a large number of marine organisms propagated. Therefore, the Hg content settlement not only depended on the combination of plankton and floating participle in the sea water, but also depended on a large amount of Hg content from atmospheric deposition. Therefore, when there was the source of Hg content, the Hg content in the bottom layer was jointly controlled by the seasonal variation and source transport.

4.5 Deposition Changes. On the scale of variation, from the central water area to the coastal water area in the southeast of Jiaozhou Bay, in May, August and October, the variation range of Hg contents in the surface and bottom layers was basically the same. In May, the Hg content in surface was relatively low, and that in the corresponding bottom layer was also relatively low; in August, when the Hg content in surface was relatively high, that in the corresponding bottom layer was relatively high; however, in October, when the Hg content of surface was very high, that in the corresponding bottom layer reached the lowest level, which revealed the law of Hg deposition: in summer, marine organisms propagate in large numbers, and the amount increases rapidly, while in spring and autumn, there is no large number of marine organisms propagated. Therefore, the Hg content settlement depends entirely on the combination of plankton and floating participle in the sea water. Therefore, in summer, a large amount of Hg was taken to the seabed, while in spring and autumn, there was no large amount of Hg taken to the seabed.

In May, August and October, the change of Hg content in the surface and bottom layers fully confirmed the settlement law. In May, the Hg content in surface was relatively low. At this time, without a large number of marine organisms breeding, a large amount of Hg will not be brought to the seabed, so the Hg content in corresponding bottom layer was relatively low. In August, when the Hg content of the surface was relatively high, there would be a large number of marine organisms breeding, which will bring a large amount of Hg to the bottom of the sea, so the Hg content in corresponding bottom was relatively high. In October, no matter the Hg content of surface was very
high or very low, there was no large amount of marine organisms breeding at this time, so a large amount of Hg will not be brought to the sea bottom, and the Hg content in corresponding bottom was very low. Therefore, it is believed that a large number of marine organisms in the water are the main carriers to bring a large amount of Hg to the seabed.

4.6 Spatial Deposition. In May, in the central waters of the Bay and the coastal waters in the southeast of the Bay, there was no source of Hg, and the Hg content in surface was relatively low. At this time, there was not a large number of marine organisms breeding in the water body, and there was no vertical transportation of Hg content to the sea floor. Thus, the horizontal distribution trends of Hg content in the surface and bottom layers were consistent.

In August, in the central waters of the Bay, there was no source of Hg, and the Hg content in surface was relatively high. In the coastal waters in the southeast of the bay, there was the source of Hg content being the atmospheric settlements, the Hg content in the surface layer was relatively high. At this time, there were a large number of marine organisms breeding in the water body, and there was a vertical transport of Hg content to the seabed. Thus, the horizontal distribution trends of Hg content in the surface and bottom layers were consistent.

In October, in the central waters of the Bay, there was no source of Hg content, and the Hg content in surface was very high. In the coastal waters of the southeast part of the bay, there was no source of Hg content, and the Hg content in surface was very low. At this time, there was not a large number of marine organisms breeding in the water body, and there was no vertical transportation of Hg content to the sea floor. Thus, the horizontal distribution trends of Hg content in the surface and bottom layers were opposite.

The variation of Hg content in the bottom and the consistency of Hg content in the surface and bottom layers were determined by the Hg content in surface and the vertical transportation carriers.

5. Conclusions
In May, August and October, in Jiaozhou Bay, from the central water area to the coastal water area in the southeast of the Bay, from the surface layer to the bottom layer, the range of Hg content in the surface and bottom layers was 0.007-0.040 μg/L, which conformed to the national water quality standard for class I seawater, and the water was not polluted by any Hg content.

From May to October, in the central waters of Jiaozhou Bay, the seasonal changes of Hg content in the surface layer from low to high were spring, summer and autumn, and the seasonal changes of Hg content in the bottom layer from low to high were autumn, spring and summer. In the surface of the coastal waters in the southeast of Jiaozhou Bay, the seasonal changes of Hg content in the surface and bottom layers from low to high were autumn, spring and summer.

When there was no source of Hg content in the surface layer, the Hg content in the bottom layer was controlled by the seasonal variation. When there were sources of Hg content in the surface layer, the Hg content in the bottom layer was jointly controlled by the seasonal variation and source transport. This revealed the law of Hg deposition: in summer, marine organisms propagate in large numbers, and the number increases rapidly, while in spring and autumn, there is no large number of marine organisms propagate. In this way, the Hg content settlement depended entirely on the combination of plankton and floating participle in the sea water. Therefore, in summer, a large amount of Hg was taken to the seabed, while in spring and autumn, no large amount of Hg was taken to the seabed. In May, August and October, the change of Hg content in the surface and bottom layer fully confirmed the settlement law. Moreover, it is believed that a large number of marine organisms in the water are the main carriers to bring a large number of Hg to the seabed. Therefore, the variation of Hg content in the bottom water area is determined by the Hg content in surface and the carriers that transport Hg content vertically to the sea bottom, which resulted in the fact that the horizontal distribution trends of Hg content in the surface and bottoms are consistent.
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References
[1] Chen Yu, Gao Zhenhui, Qu Yanheng, Yang Dongfang and Tang Hongxia. Mercury distribution in the Jiaozhou Bay[J]. Chin. J. Oceanol. Limnol. 2007, 25(4): 455-458.
[2] Dongfang Yang, Hairong Cao, Zhenhui Gao, Qing Lu, Yanfeng Qu. Hg in Jiaozhou Bay I. Distribution and transition [J]. Marine Environmental Science, 2008, 27 (1): 37-39.
[3] Dongfang Yang, Leilei Wang, Zhenhui Gao, Lian Ju, Jiping Zeng. Hg in Jiaozhou Bay II. Distribution and pollution sources [J]. Marine Environmental Science, 2009, 28 (5): 501-505.
[4] Yu Chen, Yinjiang Zhang, Junhui Guo, Qiang Shi, Dongfang Yang. Distribution and Seasonal Variation of Hg (Heavy Metal) in the Waterbody of Jiaozhou Bay [J]. Ocean Development and Management, 2013, 30(6):81-83.
[5] Dongfang Yang, Peiyuan Sun, Lian Ju, Yuhui Zhao, Yanfeng Qu. Content and Distribution of Hg in the Water of the Jiaozhou Bay [J]. Coastal Engineering, 2013, 32(4): 65-76.
[6] Dongfang Yang, Zijun Xu, Yanfeng Qu, Yanrong Zhou, Fei Teng. Distribution and Input Way of Hg in the Jiaozhou Bay [J]. Coastal Engineering, 2014, 33 (1): 67-78.
[7] Yu Chen, Yanfeng Qu, Renlin Pei and Dongfang Yang. Effect of Hg in Jiaozhou Bay waters- The aquatic transfer process[J]. Advanced Materials Research Vols.955-959. 2014, 2491-2495.
[8] Dongfang Yang, Sixi Zhu, Fengyou Wang, Xiuqin Yang and Yunjie Wu. Effect of Hg in Jiaozhou Bay waters- The land transfer process[J]. Advanced Materials Research Vols.955-959. 2014, 2496-2500.
[9] Dongfang Yang, Sixi. Zhu, Fengyou Wang, Huazhong He and Yunjie Wu. Effect of Hg in Jiaozhou Bay waters- The Temporal variation of the Hg content[J]. Applied Mechanics and Materials Vols.556-562. 2014, 633-636.
[10] Dongfang Yang, Fengyou Wang, Huazhong He, Youfu Wu and Sixi Zhu. Effect of Hg in Jiaozhou Bay waters- The change process of the Hg pollution sources[J]. Advanced Materials Research Vols.955-959. 2014, 1443-1447.
[11] Dongfang Yang, Xiao Geng, Yanfeng Qu, Hongyan Bai, Zijun Xu. Distribution and Gravity Characteristics of Hg (Heavy Metal) in the Waterbody of Jiaozhou Bay [J]. Ocean Development and Management, 2014, 31 (12): 71-77.
[12] Dongfang Yang, Fengyou Wang, Huazhong He, Sixi Zhu and Yunjie Wu. Vertical water body effect of benzene hexachloride[J]. Proceedings of the 2015 international symposium on computers and informatics. 2015, 2655-2660.
[13] Dongfang Yang, Fengyou Wang, Xiaoli Zhao, Yunjie Wu, Sixi Zhu. Horizontal waterbody effect of hexachlorocyclohexane [J]. Sustainable Energy and Environment Protection. 2015, 191-195.
[14] Dongfang Yang, Fengyou Wang, Xiuqin Yang, Yunjie Wu and Sixi Zhu. Water’s effect of benzene hexachloride [J]. Advances in Computer Science Research. 2015, 2352: 198-204.
[15] YANG D F, CHEN Y, GAO Z H, et al. Silicon Limitation on primary production and its destiny in Jiaozhou Bay, China IV transect offshore the coast with estuaries [J]. Chin. J. Oceanol. Limnol. 2005, 23(1): 72-90.
[16] Dongfang Yang, Fan Wang, Zhenhui Gao, et al. Ecological Phenomena of Phytoplankton in Jiaozhou Bay [J]. Marine Science, 2004, 28 (6): 71-74.
[17] State Oceanic Administration. The Specification for Marine Monitoring [Z]. Beijing: China Ocean Press, 1991.