Sedimentation process of Cr and the mechanism in the bay mouth of Jiaozhou Bay 1983

Dongfang Yang1,2,3,*, Fengyou Wang1,2, Sixi Zhu1,2, Chengling Huang1,2, Bailing Fan1,2*

1Research Center for Karst Wetland Ecology, Guizhou Minzu University, Guiyang 550025, China;
2College of Chemistry and Environmental Science, Guizhou Minzu University, Guiyang 550025, China;
3North China Sea Environmental Monitoring Center, SOA, Qingdao 266033, China.
*dfyang_dfyang@126.com

Abstract. The investigation data on Chromium (Cr) in waters around the bay mouth in Jiaozhou Bay in May, September and October 1983 showed the sedimentation process of Cr, and tried to reveal the mechanism. Results showed that the change ranges of absolute horizontal loss and relative horizontal loss were 0.04-0.89 μg L⁻¹ and 3.44-80.00%, respectively. The absolute vertical accumulation amount and relative vertical accumulation amount were 0.14-0.86 μg L⁻¹ and 8.86-86.86%, while the absolute vertical dilution amount and relative vertical dilution amount were 0.01-0.62 μg L⁻¹ and 0.85-37.50%, respectively. The absolute vertical dilution amounts in waters in the bay mouth were very high (86.86%) and relative high (37.50%) in May and September, respectively. The bay mouth was playing a role of parclose in which a big part of Cr was filtering continuously. The mechanism of the sedimentation process was that, the horizontal loss of substance content was very high when the marine current was moving across the bay mouth, and there was high sedimentation process in the bay mouth. In spite of the flow rate of marine current was increasing in the bay mouth, Cr in the open waters was difficult to be transported to the bay, and Cr in the bay was also difficult to be transported to the open waters.

1. Introduction
A large amount of Cr-containing waste water, gas and residue were discharged into the environment because of the rapid development of industry and urbanization. In this way, Cr pollutants have finally been come into the ocean by the transportation of the rivers and rainfall-runoff, and then were sinking through the waters body to the sea bottom by means of sedimentation. So, the migration processes of Cr in marine waters were presented in Jiaozhou Bay, as is a semi-closed bay. The investigation dataset in waters around the bay mouth in Jiaozhou Bay, in May, September and October 1983, described the sedimentation process of Cr, and tried to reveal the mechanism in order to construct scientific basis to better determine the horizontal and vertical migration processes of Cr in marine bay for pollution control.

2. Material and method
**Study area and data collection.** Jiaozhou Bay in the south of Shandong Province, eastern China (35°55′-36°18′ N, 120°04′-120°23′ E) has the total area of 446 km² (Fig. 1), surrounded by cities of Qingdao, Jiaozhou and Jiaonan. Around the bay, many rivers such as Dagu River, Haibo River, Licun River, and Loushan River etc. appeared. Cr dataset from North China Sea Environmental Monitoring Center showed the investigations, by National Specification for Marine Monitoring[1], in May, September and October 1983. There were three sampling sites in waters inside the bay mouth (H37), in the middle of the bay mouth (H35), and the outside of the bay mouth (H34) (Fig. 1).

![Fig. 1  Jiaozhou Bay with sampling sites](image)

**Modelling for horizontal loss.** The contents of the substances in waters in marine bays were keeping continuously water exchange between the open waters and the internal waters in the bay [2]. Supposed that substance contents in surface waters inside the bay mouth, in the middle of the bay mouth and the outside of the bay mouth were A, B and C, respectively.

In surface waters, and from waters inside the bay mouth to waters in the middle of the bay mouth, the calculation formula horizontal loss is:

\[
D = A - B, \quad E = \frac{|A - B|}{\max(A, B)} \tag{1}
\]

where, \(D\) is the absolute horizontal loss amount in surface waters, \(E\) is the relative horizontal loss amount in surface waters.

In surface waters, and from waters in the middle of the bay mouth to the outside of the bay mouth, the calculation formula horizontal loss is:

\[
F = B - C, \quad G = \frac{|B - C|}{\max(B, C)} \tag{2}
\]

where, \(F\) is the absolute horizontal loss amount in surface waters, \(G\) is the relative horizontal loss amount in surface waters.

In bottom waters, and from waters inside the bay mouth to waters in the middle of the bay mouth, the calculation formula horizontal loss is:

\[
d = a - b, \quad e = \frac{|a - b|}{\max(a, b)} \tag{3}
\]

where, \(d\) is the absolute horizontal loss amount in surface waters, \(E\) is the relative horizontal loss amount in surface waters.

In bottom waters, and from waters in the middle of the bay mouth to the outside of the bay mouth, the calculation formula horizontal loss is:

\[
f = b - c, \quad g = \frac{|b - c|}{\max(b, c)} \tag{4}
\]
where, $f$ is the absolute horizontal loss amount in surface waters, $g$ is the relative horizontal loss amount in surface waters.

**Modelling for vertical loss.** Supposed that substance contents in surface and bottom waters in a certain sampling site are $A$ and $a$, respectively. From surface waters to bottom waters, the calculation formula for this migration process is:

$$V_{na} = A - a, \quad V_{nr} = (100 \times \left| A - a \right| / \max(A, a)) \% \quad (5)$$

where, $V_{na}$ is the absolute horizontal dilution amount from surface waters to bottom waters if $V_{na} > 0$, $V_{nr}$ is the relative horizontal dilution amount. If $V_{na} < 0$, $V_{na}$ refers to the absolute horizontal accumulation amount, and $V_{nr}$ refers to the relative horizontal accumulation amount.

3. Results

**Horizontal loss amount.** The horizontal changes of Cr in surface and bottom waters in Jiaozhou Bay were calculated in accordance to Cr contents in Site H34, H35 and H37, respectively. It could be seen from Table 1 that the change ranges of absolute horizontal loss and relative horizontal loss were 0.04-0.89 μg L$^{-1}$ and 3.44-80.00%, respectively.

| Month  | From H37 to H35 | From H35 to H37 |
|--------|----------------|-----------------|
|        | $D$/μg L$^{-1}$ | $E$/%           | $F$/μg L$^{-1}$ | $G$/%           |
| May    | 0.11           | 45.83%          | -0.52         | 80.00%          |
| September | 0.47           | 40.17%          | -0.26         | 27.08%          |
| October | -0.13          | 9.02%           | 0.84          | 58.33%          |

Table 2 Horizontal loss amount of Pb in bottom waters

| Month  | From H37 to H35 | From H35 to H37 |
|--------|----------------|-----------------|
|        | $d$/μg L$^{-1}$ | $e$/%           | $f$/μg L$^{-1}$ | $g$/%           |
| May    | 0.09           | 8.33%           | 0.59          | 59.59%          |
| September | 0.04           | 3.44%           | -0.05         | 4.27%           |
| October | -0.89          | 56.32%          | 0.77          | 48.73%          |

**Horizontal loss amount.** The vertical changes of Cr in waters in Jiaozhou Bay were calculated according to Cr contents in Site H34, H35 and H37, respectively. It could be seen from Table 3 that the absolute vertical accumulation amount and relative vertical accumulation amount were 0.14-0.86 μg L$^{-1}$ and 8.86-86.86%, while the absolute vertical dilution amount and relative vertical dilution amount were 0.01-0.62 μg L$^{-1}$ and 0.85-37.50%, respectively.

| Month | Site | $V_{na}$/μg L$^{-1}$ | $V_{nr}$/% |
|-------|------|----------------------|------------|
| May   | H37  | -0.84                | 77.77%     |
|       | H35  | -0.86                | 86.86%     |
|       | H34  | 0.25                 | 38.46%     |
| September | H37  | 0.01                 | 0.85%      |
|       | H35  | -0.42                | 37.50%     |
|       | H34  | -0.21                | 17.94%     |
| October | H37  | 0.62                 | 47.32%     |
|       | H35  | -0.84                | 77.77%     |
|       | H34  | -0.86                | 86.86%     |

4. Discussion

**Horizontal and vertical changes of Cr.** In May 1983, from waters in the inside of the bay mouth to
the bay mouth, the horizontal loss amount of Cr in surface and bottom waters was 65.34% and 8.33%, while from water in the outside of the bay mouth to the bay mouth was 80.00% and 59.59%, respectively (Fig. 2). Meanwhile, the vertical accumulation amounts of Cr in waters in the inside of the bay mouth and the bay mouth were relatively high (77.77% and 86.86%, respectively), and the vertical dilution amount of Cr was also relatively high (38.46%) in waters in the outside of the bay mouth (Fig. 2). In September 1983, from waters in the inside of the bay mouth to the bay mouth, the horizontal loss amount of Pb in surface and bottom waters were 40.17% and 3.44%, while from water in the outside of the bay mouth to the bay mouth were 27.08% and 4.27%, respectively (Fig. 3). Meanwhile, the vertical accumulation amounts of Cr in waters in the bay mouth and the outside of the bay mouth were relatively high (37.50% and 17.94%, respectively), while the vertical dilution amount of Cr was relatively low (0.85%) in waters in the inside of the bay mouth (Fig. 3). In October 1983, from waters in the bay mouth to the inside of bay mouth, the horizontal loss amount of Pb in surface and bottom waters were 9.02% and 56.32%, while from water in the bay mouth to the outside of the bay mouth were 58.33% and 48.73%, respectively (Fig. 4). Meanwhile, the vertical accumulation amounts of Cr in waters in the bay mouth and the outside of the bay mouth were relatively low (8.86% and 25.92%, respectively), while the vertical dilution amount of Cr was relatively high (47.32%) in waters in the inside of the bay mouth (Fig. 4). In general, the horizontal absolute loss and relative loss of Cr in 1983 were 0.04-0.89 μg L⁻¹ and 3.44-80.00%, the vertical absolute accumulation and relative accumulation were 0.14-0.86 μg L⁻¹ and 8.86-86.86%, and the vertical absolute dilution and relative dilution were 0.01-0.62 μg L⁻¹ and 0.85-47.32%, respectively.

Fig. 2 Block diagram model for horizontal-vertical changes of Cr in May 1983

Fig. 3 Block diagram model for horizontal-vertical changes of Cr in September 1983
Fig. 4 Block diagram model for horizontal-vertical changes of Cr in October 1983

Mechanism of the sedimentation process of Cr. Cr in waters in the inside of the bay mouth was mainly sourced from river discharge. In May, the horizontal relative loss of Cr in surface waters from the inside of the bay mouth to the bay mouth were relatively high (45.83%). In September, the horizontal relative loss of Cr in surface waters from the inside of the bay mouth to the bay mouth were also relatively high (40.17%). In September, the horizontal relative loss of Cr in surface waters from the bay mouth to the inside of bay mouth were relatively low (9.02%). In waters in the inside of the bay mouth, there were very high vertical accumulation in May (77.77%), very low vertical dilution in September (0.85%), and relative high vertical accumulation in October (47.32%). In waters in the bay mouth, there were very high vertical accumulation in May (86.86%), relative high vertical accumulation in September (37.50%), and very low vertical accumulation in October (8.86%). In waters in the outside of the bay mouth, Cr was mainly sourced from marine current. In May, the horizontal relative loss of Cr in surface waters from the outside of the bay mouth to the bay mouth were very high (80.00%). In September, the horizontal relative loss of Cr in surface waters from the outside of the bay mouth to the bay mouth were very low (27.08%). In October, the horizontal relative loss of Cr in surface waters from the outside of the bay mouth to the bay mouth were relatively high (58.33%). In general, the absolute vertical dilution amounts in waters in the bay mouth were very high (86.86%) and relatively high (37.50%) in May and September, respectively. The bay mouth was playing a role of parclose in which a big part of Cr was filtering continuously. The mechanism of the sedimentation process was that, the horizontal loss of substance content was very high when the marine current was moving across the bay mouth, and there were high sedimentation process in the bay mouth. In spite of the flow rate of marine current was increasing in the bay mouth, Cr in the open waters was difficult to be transported to the bay, and Cr in the bay was also difficult to be transported to the open waters (Fig. 5).
5. Conclusion
The horizontal absolute loss and relative loss of Cr in 1983 were 0.04-0.89 μg L⁻¹ and 3.44-80.00%, the vertical absolute accumulation and relative accumulation were 0.14-0.86 μg L⁻¹ and 8.86-86.86%, and the vertical absolute dilution and relative dilution were 0.01-0.62 μg L⁻¹ and 0.85-47.32%, respectively. The absolute vertical dilution amounts in waters in the bay mouth were very high (86.86%) and relatively high (37.50%) in May and September, respectively. The bay mouth was playing a role of parclose in which a big part of Cr was filtering continuously. The mechanism of the sedimentation process was that, the horizontal loss of substance content was very high when the marine current was moving across the bay mouth, and there was high sedimentation process in the bay mouth. In spite that the flow rate of marine current was increasing in the bay mouth, Cr in the open waters was difficult to be transported to the bay, and Cr in the bay was also difficult to be transported to the open waters.

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