Remobilization of Arsenic in Sub-Oxic Sediments from the Seafloor of the Continental Margin

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This study investigates the diagenetic remobilization of As in sediments collected from two different regions. One is the Hidaka Trough under the eutrophic Oyashio water, and another is the continental slope to the Shikoku Basin under the oligotrophic Kuroshio water. The concentrations of total dissolved As (AsIII + AsV) in pore waters from the Hidaka Trough and the continental slope off Shikoku increase with core depth. The average concentrations in the top 2 cm layer are several times higher than those in the overlying bottom water. Consequently, dissolved As diffuses upward across the sediment-water interface due to the concentration gradient. In contrast, in the Nankai Trough and Shikoku Basin, the concentrations of total dissolved As in the pore waters of the surface sediments are rather low relative to those in the bottom sea water. This fact suggests that the diffusion of dissolved As takes place in the opposite direction, viz., into the pore water. The total sedimentary As mean concentrations in the top 2 cm layer of each core from the Oyashio transect decrease with the depth of water at the sampling site (i.e., with distance from the coast). On the other hand, the concentration in the Kuroshio transect increases with the water depth, the maximum appearing in the middle of the continental slope, as with reducible Mn. Consequently, we infer that the behavior of As is influenced by the organic carbon content reaching the seafloor in the eutrophic Oyashio transect. In particular As in surfacial sediments is transported out of the continental margin toward the ocean floor through the near-benthic boundary layer with Mn and Fe oxides in the oligotrophic Kuroshio transect. In the Kuroshio transect, the behavior of As is influenced by the fate of both Fe and Mn oxides in sediments. Recycling and remobilization of As in the seafloor of the continental slope, trough, and abyssal basin are controlled by the flux and decomposition of organic matter. The formation and dissolution of metal oxides also play an important role in determining the behavior of As.

Keywords:
- Arsenic
- pore water
- marine sediment
- sediment-seawater boundary layer
- benthic boundary
- diagenesis
- recycling
- transport
- Kuroshio transect
- Oyashio transect.

1. Introduction

The presence of four As (arsenic) species has been confirmed in seawater (Braman and Foreback, 1973; Braman, 1975). Among them, arsenate (AsV) is the dominant species in seawater. The concentration of arsenate in seawater generally increases with water depth. The arsenate profile is similar to those of both phosphate as a nutrient (Andreae, 1979) and dissolved vanadium in an oxyanion form (Middelburg et al., 1988). Arsenic is taken up by planktonic organisms in the surface water, leading to the production of methylated forms (Sanders and Windom, 1980; Sanders, 1985). Sediment trap experiments indicate that As is scavenged from seawater by the organic matter fraction, in a manner somewhat similar to the behavior of Se, Sb, Ag, Zn and Br (Masuzawa, 1989). In other words, As can be regarded as a biophile element in the ocean.

The study of As in sediments and pore waters has been conducted progress in areas under reducing conditions area, and in lakes; for example, studies have been conducted in the Laurentian Trough, Canada (Belzile, 1988), the basin of Loch Lomond, Scotland (Farmer and Lovell, 1986), Lake Biwa, Japan (Takamatsu et al., 1985) Lake Ohakuri, New Zealand (Aggett and O’Brien, 1985) and Lake Washington, U.S.A. (Peterson and Carpenter, 1986). But the behavior of As on the sea floor is not known from the continental slope (suboxic condition) to abyssal basin (oxic conditions).

The vertical profiles of As in sediments have been tentatively attributed to the combined effects of upward migration, following diagenetic remobilization under reducing conditions, and subsequent reabsorption on oxides
and hydroxides of iron in the aerobic layer. Studies of pore water profiles in suboxic pelagic sediments have established that the oxidants involved in the diagenesis of organic matter are consumed in order of decreasing energy production per mole of Org-C oxidized (O$_2$ > Mn oxides > nitrate > Fe oxides > sulfate) (Froelich et al., 1979; Klinkhammer, 1980; Emerson et al., 1980). Thus, under reducing conditions accompanying the microbiological decomposition of organic matter (which is lower in the sediment column), Fe oxides and hydroxides are solubilized, releasing absorbed arsenate, which then undergoes reduction to arsenite and As$_2$S$_3^-$ depending on pH and the activity of HS$^-$ (Farmer and Lovell, 1986).

Material transport occurs between pore water and sediments due to chemical reaction and the associated concentration gradients. The kinds of chemical species transported and their fluxes depend on the reduction stage of diagenesis in the above mentioned model. The reduction stage is balanced by the supply of oxidizing materials and the metabolism of organic matter. In this way, chemical reactions at the sediment-water interface exert an effect by governing the amounts of organic matter that reaches the sea floor.

In this study we obtained sediment cores from the sea floor beneath the eutrophic Oyashio water and the oligotrophic Kuroshio water. According to Saijo and Ichimura (1960), the primary productivity in Oyashio water off northern Japan is as high as 0.2–0.4 gC m$^{-2}$day$^{-1}$, as against 0.05–0.1 gC m$^{-2}$day$^{-1}$ in Kuroshio water. Although the rate at which the biogenic organic matter to rains into the sea floor decreases with increasing water depth (Suess, 1980; Tsunogai and Noriki, 1987, 1991) and with distance from the continent (Martin et al., 1987), it promotes diagenetic processes in sediments of marginal regions. This paper provides the results of a comparative study of the behavior of As in the sediment in the two marginal regions mentioned above, determining As in both pore waters and sediments which have been collected from each transect extending offshore from the coast.

2. Sampling and Methods

Sediment cores were collected with a stainless-steel box corer at sea floor sites along two transects during four cruises of the R.V. Tokaidaiigaku Maru II in May 1987, October 1987, October 1988 and April 1990. Sampling locations are shown in Fig. 1, and detailed positions and water depths are summarized in Table 1. The line E-F, the Oyashio transect, crosses the Oyashio current, and the line A-B, the Kuroshio transect, crosses the Kuroshio current in the Shikoku Basin. The core NT-3 was located at the center axis of the Nankai Trough.

The detailed lithologies of cores from the two transects have been published by Kato et al. (1995). In NT-3, the upper 4 cm layer was yellowish brown, while the rest was greenish olive, and the core included fine sand in the dark gray layers of 11–16 and 27–29 cm.

Table 1. Locations of box cores collected during R.V. Tokaidaiigaku Maru II cruises.

<table>
<thead>
<tr>
<th>Core</th>
<th>Cruise</th>
<th>Date</th>
<th>Lat. N</th>
<th>Long. E</th>
<th>Water depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hidaka Trough</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HB-1</td>
<td>TO-87-16</td>
<td>1987/10/15</td>
<td>42°14.9 '</td>
<td>141°32.8 '</td>
<td>540</td>
</tr>
<tr>
<td>HB-2</td>
<td>TO-87-16</td>
<td>1987/10/15</td>
<td>41°50.5 '</td>
<td>142°11.9 '</td>
<td>1080</td>
</tr>
<tr>
<td>HB-3</td>
<td>TO-87-16</td>
<td>1987/10/15</td>
<td>41°09.4 '</td>
<td>143°10.1 '</td>
<td>2050</td>
</tr>
<tr>
<td>HB-4</td>
<td>TO-87-16</td>
<td>1987/10/15</td>
<td>40°42.0 '</td>
<td>144°02.8 '</td>
<td>4620</td>
</tr>
<tr>
<td>Continental slope off Shikoku</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-4</td>
<td>TO-87-03</td>
<td>1987/05/10</td>
<td>33°09.4 '</td>
<td>133°40.5 '</td>
<td>620</td>
</tr>
<tr>
<td>T-3</td>
<td>TO-87-03</td>
<td>1987/05/09</td>
<td>32°53.5 '</td>
<td>133°54.2 '</td>
<td>1060</td>
</tr>
<tr>
<td>T-1</td>
<td>TO-87-03</td>
<td>1987/05/08</td>
<td>32°26.3 '</td>
<td>134°14.1 '</td>
<td>2860</td>
</tr>
<tr>
<td>TT-5</td>
<td>TO-88-17</td>
<td>1988/10/26</td>
<td>32°33.3 '</td>
<td>134°03.1 '</td>
<td>1830</td>
</tr>
<tr>
<td>Shikoku Basin</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-3</td>
<td>TO-88-17</td>
<td>1988/10/25</td>
<td>31°47.1 '</td>
<td>134°43.2 '</td>
<td>4400</td>
</tr>
<tr>
<td>TT-2</td>
<td>TO-88-17</td>
<td>1988/10/24</td>
<td>31°36.2 '</td>
<td>134°56.0 '</td>
<td>4430</td>
</tr>
<tr>
<td>TT-1</td>
<td>TO-88-17</td>
<td>1988/10/24</td>
<td>30°58.8 '</td>
<td>135°17.8 '</td>
<td>4360</td>
</tr>
<tr>
<td>Nankai Trough</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-4</td>
<td>TO-88-17</td>
<td>1988/10/27</td>
<td>31°56.6 '</td>
<td>134°11.3 '</td>
<td>4830</td>
</tr>
<tr>
<td>NT-3</td>
<td>TO-90-02</td>
<td>1990/04/26</td>
<td>32°31.7 '</td>
<td>137°10.3 '</td>
<td>4240</td>
</tr>
</tbody>
</table>
The sediment samples were immediately extruded and cut into 0.5 cm sections for the top 2 cm and 1.0 cm sections below 2 cm depth in the core. Pore water was squeezed out of the extruded sediment samples under airtight conditions in a thermostated refrigerator at in-situ (bottom water) temperature. The squeezing was carried out by pressure filtration through a 0.45 µm Millipore filter, using a Manheim type squeezer. The pore waters were acidified with 1 M HCl and preserved to determine total dissolved As (As$^{III}$ + As$^{V}$), Fe and Mn. Sediment samples were placed into in sealed vinyl bags and stored in a freezer.

Total dissolved As in pore waters, ΣAs, was determined using the method of Yanagi (1980) and Yanagi and Ambe (1981). This method is based on atomic absorption spectrophotometry of As hydride (AsH$_3$) released from acidified sample solutions containing sodium borohydride. The pore water sample (500 µl) was transferred into a reaction vessel containing 25 ml of 0.72 M hydrochloric acid. AsH$_3$ released by the addition of alkaline sodium borohydride solution was dried by passage through an ethanol cold trap, and condensed in a quartz glass coil immersed a liquid nitrogen bath. The AsH$_3$ aor which is regenerated by warming the coil in warm water was carried into a hydride atomizer with a double path quartz cuvette (Jarrel Ash HYD-2) heated to 1000°C. Arsenic was determined using a Hitachi 180-80 atomic absorption spectrophotometer.

Total carbon dioxide in pore water, TCO$_2$, was measured in the closed line with a Beckman 865 infrared gas analyzer (Kato, 1981). A micro-syringe was used to add 500 µl of the pore water sample to a reaction vessel contain 0.3 M hydrochloric acid, purged by bubbling a N$_2$ stream through a sintered glass plate. After drying with concentrated H$_2$SO$_4$ and magnesium perchlorate, the CO$_2$ chromatogram was analyzed using Shimadzu Chromatopac C-R6A.

Dissolved Fe and Mn in the pore water were determined by graphite-furnace and flame atomic-absorption spectrophotometry, respectively.

Sediment samples were freeze-dried and powdered in the laboratory ashore. The powdered sample was digested in a HNO$_3$-HCl-HClO$_4$ acid mixture in a Teflon bomb (Sanai...
NT-25) following the procedure of Noriki et al. (1980). Total As in sediments, TAs, was analyzed using the same method described above. The water content of the sediment was found by measuring weight loss after heating at 110°C for 2 h.

3. Results and Discussion

3.1 Arsenic in pore water

The vertical profiles of ΣAs in the pore waters in the Oyashio transect are shown in Fig. 2. Although the profile

![Fig. 2. Profiles of ΣAs in pore waters from the Oyashio transect. Arrow on the concentration axis indicates the average ΣAs concentration in the bottom water, 21 nmol l⁻¹ (Bruland (1983) and the bottom water of TT-3 was surveyed).](image)

<table>
<thead>
<tr>
<th>Core</th>
<th>Distance* (km)</th>
<th>Depth (km)</th>
<th>Sample No.</th>
<th>Org-C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min.</td>
<td>Max.</td>
<td>Mean in top 2 cm</td>
</tr>
<tr>
<td>Oyashio Transect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HB-1</td>
<td>44</td>
<td>0.54</td>
<td>17</td>
<td>2.11 1.95 2.24 2.13</td>
</tr>
<tr>
<td>HB-2</td>
<td>114</td>
<td>1.08</td>
<td>20</td>
<td>2.31 2.07 2.58 2.50</td>
</tr>
<tr>
<td>HB-3</td>
<td>230</td>
<td>2.05</td>
<td>15</td>
<td>1.65 0.97 2.13 2.04</td>
</tr>
<tr>
<td>HB-4</td>
<td>320</td>
<td>4.62</td>
<td>19</td>
<td>2.03 1.83 2.23 2.08</td>
</tr>
<tr>
<td>Kuroshio Transect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-4</td>
<td>43</td>
<td>0.62</td>
<td>14</td>
<td>1.49 1.28 1.62 1.56</td>
</tr>
<tr>
<td>T-3</td>
<td>76</td>
<td>1.06</td>
<td>27</td>
<td>1.84 1.47 2.07 2.02</td>
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<td>TT-5</td>
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<td>1.83</td>
<td>36</td>
<td>1.38 1.16 1.70 1.53</td>
</tr>
<tr>
<td>T-1</td>
<td>137</td>
<td>2.86</td>
<td>36</td>
<td>1.52 1.13 1.87 1.55</td>
</tr>
<tr>
<td>TT-4</td>
<td>182</td>
<td>4.83</td>
<td>37</td>
<td>0.73 0.39 0.96 0.52</td>
</tr>
<tr>
<td>TT-3</td>
<td>222</td>
<td>4.44</td>
<td>20</td>
<td>0.44 0.33 0.51 0.50</td>
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<tr>
<td>TT-2</td>
<td>249</td>
<td>4.43</td>
<td>29</td>
<td>0.57 0.48 0.69 0.61</td>
</tr>
<tr>
<td>TT-1</td>
<td>325</td>
<td>4.36</td>
<td>18</td>
<td>0.54 0.45 0.63 0.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oyashio Transect</td>
<td>71</td>
<td>2.05</td>
<td>0.97</td>
<td>2.58</td>
</tr>
<tr>
<td>Kuroshio Transect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All cores</td>
<td>217</td>
<td>1.09</td>
<td>0.33</td>
<td>2.07</td>
</tr>
<tr>
<td>T-4 to T-1</td>
<td>113</td>
<td>1.55</td>
<td>1.13</td>
<td>2.07</td>
</tr>
<tr>
<td>TT-3 to TT-1</td>
<td>67</td>
<td>0.52</td>
<td>0.33</td>
<td>0.69</td>
</tr>
</tbody>
</table>

*From the coast.
patterns are somewhat different from core to core, the distributions tend to increase in concentration with depth in the core as a whole. These profiles resemble those which Belzile (1988) has found in reducing coastal sediments. Especially in HB-2, the concentration increases rapidly below 10 cm depth to reach 2081 nmol l$^{-1}$ at the bottom of core, decreasing somewhat of an decrease in the 20–24 cm layer, where hydrogen sulfide is generated. The maximum concentration in the Oyashio transect is 2 orders of magnitude higher than that in the bottom water. The concentration of dissolved As in deep oceanic water is ca. 21 nmol l$^{-1}$ (cited in Bruland, 1983) and the bottom water of TT-3 surveyed by us. In HB-3, the profile shows a gap in the 5–10 cm layer where coarse sands with pumice are included (Kato et al., 1995).

The vertical profiles of $\Sigma$As in the Kuroshio transect are shown in Fig. 3. The $\Sigma$As increases with core depth here, too. However, in the TT-1 to TT-3 cores from the margin of the Shikoku Basin, the $\Sigma$As concentrations are equal to or slightly less than those in the overlying waters. The highest concentration of $\Sigma$As measured in this transect is 350 nmol l$^{-1}$ in the 10–11 cm layer of T-4, which is 17 times higher than in the bottom water. From T-4 to T-1 in the continental slope off Shikoku, the concentration levels of $\Sigma$As are almost five times higher than in the Shikoku Basin. In comparison, the concentration levels in the Shikoku Basin are less than 1/30 of those in the Hidaka Trough.

3.2 Arsenic diagenesis

Two processes are active that cause the comparable distribution patterns of As; regeneration into pore waters during the degradation of planktonic organic matter, and release from Mn and Fe oxide phases by reduction of these oxides. In this section we describe the processes that predominate in the two transects.

The Oyashio transect

The Org-C contents in sediment cores from the two transects have been measured by Kato (1994). The mean values of Org-C content are summarized in Table 2. In the Oyashio transect, the mean value for all measurements is 2.05% ($n = 71$), which is about twice as high as in all cores from the Kuroshio transect (1.09%, $n = 217$), which means that the sediments under the Oyashio region are more easily reducible than those under the Kuroshio region.

![Fig. 3. Profiles of $\Sigma$As in pore waters from the Kuroshio transect. Arrow on the concentration axis indicates the As concentration in oceanic deep water, 21 nmol l$^{-1}$ (Bruland (1983) and the bottom water of TT-3 was surveyed).]
The relationships between the mean concentrations of Org-C and \( \Sigma As \) are shown in Fig. 4. The concentration of dissolved As in pore water increases rapidly with increasing Org-C in the HB-3 core. In particular, the contents of Org-C in HB-3 core are reduced due to inclusion of sand-size pumice (Kato et al., 1995). This dilution effect is also revealed by the distributions of Fe oxides in this transect, as shown in Fig. 5. The concentration of Fe oxide in HB-3 core is as low as 2 g kg\(^{-1}\), although concentrations in the other three cores are higher than ca. 3 g kg\(^{-1}\). Consequently, it is emphasized that the elevation of dissolved As concentration with core depth in the Oyashio transect results from the degradation of organic matter. Indeed, As in seawater is scavenged by marine plankton (Andreae, 1977) and is classified among the a group of biogenically scavenged elements (Masuzawa, 1989). These facts can lead to the conclusion that As is transported to the seafloor with organic matter in the hemipelagic region with a high organic matter rain rate (Tsunogai and Noriki, 1987) and is diagenetically liberated into pore water during burial.

**The Kuroshio transect**

As mentioned in the previous section, Org-C concentrations in the Kuroshio transect are lower than those in the Oyashio transect and decrease with water depth. In particular, the content of Org-C in the Shikoku Basin has into an average value of 0.52%, which is a quarter of that in the Hidaka Trough. The concentrations of dissolved As increase with distance from the coast, but decrease in the abyssal basin off Shikoku. Arsenic in surface sediments also displays the same behavior.

In the previous study by Kato et al. (1995) on diagenetic element recycling in the Kuroshio transect, the following distinct features were discovered: a seaward increase in thickness of the surface oxidizing layer, the formation of a Mn oxide peak in the subsurface layer, the reduction of Fe oxides below the MnO\(_2\)-Mn\(^{2+}\) redox boundary, etc. Such types of element behaviour reflect typical suboxic diagenesis (Froelich et al., 1979; Sawlan and Murray, 1983). It is known that the presence of Fe and Mn oxides in surface sediments may be controlled by scavenging the distributions of trace elements (Whitfield and Turner, 1979; Li, 1981, 1982; Balistrieri and Murray, 1984), including As (Neal et al., 1979; Langston, 1980; Peterson and Carpenter, 1986). In oxic surface sediments in the lake, As is strongly associated with Fe, presumably in the form of arsenate absorbed on Fe oxides and hydroxides or as precipitated FeAsO\(_4\) (Kanamori, 1965; Ferguson and Gavis, 1972; Crecelius, 1975; Price, 1976).

Comparing the profiles of \( \Sigma As \) in Fig. 3 with those of reducible Fe and Mn published by Kato et al. (1995) (shown in Fig. 6), no downward increase of \( \Sigma As \) concentration is observed in the offshore area, but does occur in the slope area, at least under the Mn redox boundary (indicated as MnRB) the depth of which corresponds to the layer at which Mn\(^{2+}\) first appears in pore water. Reducible Mn profiles...
Fig. 6. Reducible Fe and Mn profiles in the Kuroshio transect (after Kato et al., 1995).

Fig. 7. Description of sediment core, and profiles of water content in the sediment and TCO₂, Fe, Mn, and ΣAs in the pore water of NT-3 from the Nankai Trough. Arrows on the concentration axis indicate the concentrations in the bottom water, 2.1 mmol l⁻¹, 0 µmol l⁻¹, 0 µmol l⁻¹, and 21 nmol l⁻¹ (Bruland (1983) and the bottom water of TT-3 was surveyed), respectively.

reveal an offshore deepening of the redox boundary with decreasing Org-C content from the upper slope to the margin of the Shikoku Basin. On the other hand, reducible Fe decreases under MnRB. In this area, As distributions are closely related to the behaviour of Mn and Fe oxides.

In order to check the affinity of As for Fe oxides, we analyzed the pore water composition of the NT-3 core taken from the Nankai Trough. The vertical distributions of water
content, TCO$_2$, Mn, Fe and ΣAs in NT-3 are summarized in Fig. 7. Remarkably, water content is somewhat lower, except for the upper oxidizing layer of 0–4 cm depth. This implies that the sediment is composed of sand size particles, and is well graded vertically by fine-sand-sized particles at two depths, 11–17 cm and 27–29 cm. As mentioned earlier, the dark gray layers of fine sand were inserted in the beds at each depth. TCO$_2$ increases gradually with depth due to the degradation of organic matter. The profile of dissolved Mn shows a sharp concentration gradient below the upper oxidizing layer. Dissolved Fe increases under this Mn concentration line and decreases with depth in the lower part, but there is a large loss at the boundary between two graded layers. ΣAs is somewhat lower in the upper oxidizing layer than in seawater, and beneath this layer. This increasing trend is similar to that of dissolved Fe, but not to dissolved Mn. Besides, the depth of the upper ΣAs peak is at least coincidental with that of the dissolved Fe peak. The loss of ΣAs in two layers may result from the adsorption onto particles composed of the dark gray sediment, which implies the presence of Fe sulfide. Because a higher TCO$_2$ concentration is due to the active degradation of organic matter, we infer the possibility of Fe sulfide or As$_2$S$_3$ and As$_2$S$_5$ formation (Farmer and Lovell, 1986) in such layers. Therefore, as Belzile (1988) has already pointed out, dissolved As released upon the dissolution of Fe oxides may be immediately removed by an Fe sulfide phase.

### 3.3 Horizontal behavior of arsenic in surface sediment

The correlation between Org-C in the top 2 cm layer and water depth at each sampling site is shown in Fig. 8. In these sampling regions, the water depth is representative of
distance from the coast. The surface Org-C contents in the Oyashio transect are higher and their decreasing rate with water depth is smaller than those in the Kuroshio transect. The decreasing rate of Org-C with water depth is calculated by regression to be \( 2.0\% \text{ km}^{-1} \) in the Oyashio transect, while it is \( 2.7\% \text{ km}^{-1} \) in the Kuroshio transect (Kato, 1994). The difference in concentration levels as well as the decreasing rates can be attributed to the flux of planktonic organic matter to the seafloor.

The horizontal changes of the \( \Sigma \)As in pore waters of the 0–2 cm layers are shown in Fig. 9. The concentration decreases gradually with water depth in both transects, as does Org-C. Although the concentrations are higher than those in the bottom water inside the Hidaka Trough and the continental slope off Shikoku, they are rather lower offshore beyond the Nankai Trough. Accordingly, As in the Hidaka Trough and continental slope off Shikoku diffuse into seawater from the sediment through the sediment-water boundary layer due to the concentration gradient. In the Shikoku Basin, As diffused into the sediments from the seawater.

The relationship between the sum of reducible Mn and Fe concentrations and water depth, as shown in Fig. 10, indicates that in the Kuroshio transect the development of the oxidizing layer and the resulting surface enrichment of Fe and Mn oxides are enhanced seaward relative to the trend in the Oyashio, as discussed by Kato et al. (1995).

The changes in TAs in surface sediments with water depth are depicted in Fig. 11. TAs decreases with depth in the Oyashio transect. On the other hand, it increases with depth off Shikoku, reaching a maximum at T-1. The trend of TAs in the Kuroshio transect is contrary to that of Org-C, but resembles that of the sum of the concentrations of reducible Fe and Mn shown in Fig. 10. There is a good correlation between TAs and the sum of reducible Mn and Fe in the Kuroshio transect, as shown in Fig. 12 \((r = 0.88)\). These facts indicate that As is well preserved in more oxidizing sediments from the Kuroshio transect. Therefore, it is suggested that As in surface sediments is transported offshore with Mn and Fe oxides under the oligotrophic Kuroshio regions.

4. Conclusion

We have examined the remobilization of As in sediments studied at two transects offshore from the coast under the eutrophic Oyashio and oligotrophic Kuroshio regions.

The Oyashio transect had a high concentration of \( \Sigma \)As in pore waters and high Org-C contents in sediments, these values and TAs in the surface sediments decreasing with water depth. This transect also showed low Fe and Mn oxides contents in the sediments. For these reasons, it may be concluded that the degradation of organic matter in the sediments had an influence on the behavior of As in the Oyashio transect.

On the other hand, in the Kuroshio transect the enrichment of Fe and Mn oxides in the oxidizing surface sediment layer due to the low supply of organic matter causes an accumulation of As in such sediments. Furthermore, As in this transect migrates offshore to be deposited in more oxidizing deep sea sediments, along with Fe and Mn oxides.

Consequently, we have been able to understand the behavior of As in the sediments of two different transects under different conditions; it is controlled by the productivity in the surface water, taking account of the benthic flux of organic matter and the behavior of other metals.

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