A comparison of sedimentary aliphatic hydrocarbon distribution between East China Sea and southern Okinawa Trough

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Abstract

In this study, 34 surface sediments were collected from the East China Sea (ECS) shelf, and their aliphatic hydrocarbon concentrations measured. The hydrocarbon distribution of the ECS was compared with that of the southern Okinawa Trough (SOT) to explore for possible relations between the two coastal marine areas. Results from principal component analysis performed on hydrocarbon data of ECS and SOT sediments indicated that the first two components explained 74% of the total variance and that the score plot of the two components showed three groups. The first group defined by the 12 SOT sediments contained three sediments on the ECS inner shelf. Eight sediments except one on the ECS inner shelf formed group II, and the remaining 21 sediments located away from the inner shelf (mainly on the mid-to-outer shelf) formed group III. Even though three inner shelf sediments cluster with group I, the separation between groups I and II suggests that the hydrocarbon relation between the inner shelf and the SOT is very weak. Groups II and III do not cluster together; their separation is supported by previous studies showing that Changjiang River sediment tends to remain in the coastal waters and is transported to the south by the coastal currents along the Chinese coast. Also, group I does not cluster with group III, signifying a great difference between them; this can be attributed to little material exchange between the ECS and the SOT because of the Kuroshio Current. In addition, the SOT and ECS inner shelf had carbon preference index values averaging $2.92 \pm 0.79$ ($n=12$) and $4.56 \pm 0.93$ ($n=8$), terrestrial/aquatic ratios averaging $9.64 \pm 4.33$ ($n=12$) and $50.4 \pm 58.0$ ($n=8$), and $(nC_{29} + nC_{30} + nC_{31})$TOC ratios averaging $1731 \pm 482 \times 10^{-7}$ g/g C$^{-1}$ ($n=12$) and $3016 \pm 868 \times 10^{-7}$ g/g C$^{-1}$ ($n=8$), respectively; strongly indicating considerable differences between the two areas. Based on the present results, hydrocarbon export from the ECS inner shelf to the SOT appears to be unlikely.

Keywords: Sediment; Hydrocarbon; East China Sea; Southern Okinawa Trough

1. Introduction

The main circulation patterns of the Changjiang Estuary and adjacent East China Sea (ECS) can be characterized by the northward flow of warm (13°C) and saline (34 psu) waters of the Taiwan Warm Current (TWC) and a southward flow of the colder (5°C) and less saline (30 psu) waters of the Yellow Sea Coastal Current (YSCC) (Fig. 1). During high river runoff, one part of the Changjiang plume with the freshest water extends to the south along the coast, and the other part with low salinity extends offshore on average toward the northeast. However, during low river runoff, the surface plume spreads toward the south only, possibly because of the influence of the TWC and YSCC convergence (Beardsley et al., 1985).

The ECS has a very broad continental shelf. The Changjiang River annually discharges $\sim 5 \times 10^8$ tons of sediment directly into the ECS (Milliman and Meade, 1983). This sediment is confined to the coastal zones of the ECS and ultimately transported south and southwestward by the Changjiang Coastal Water (Milliman et al., 1985); offshore transport has been prevented by tidal currents and by the northward movement of the Taiwan Warm Water (Milliman et al., 1989). DeMaster et al. (1985) have reported that the accumulation rates of ECS shelf sediments are relatively high in muddy areas and low in
consist almost entirely of silty mud (Chen et al., 1995); for instance, mud accounts for over 97% (Jeng and Chen, 1995), while the upper slope (>1000 m) sediments are composed of sand with little mud (Chen et al., 1995).

The sedimentation rates on the ECS shelf range from ~2 to 0.02 cm yr\(^{-1}\), and generally decrease southward along the inner shelf and eastward offshore (Huh and Su, 1999). On the other hand, the southern Okinawa Trough (SOT) has high sedimentation rates located approximately in the lower trough, deeper than 1000 m (range from 0.25 to 0.52 cm yr\(^{-1}\) estimated from the excess \(^{210}\)Pb profiles of cores), while low sedimentation rates are generally in the upper trough, shallower than 1000 m (Chung and Chang, 1995). Based on results from a site (24°48.24’N, 122°30.00’E) of ODP Leg 195 in the SOT, the sedimentation rate has always been high, reaching 325 cm ky\(^{-1}\) (0.325 cm y\(^{-1}\)) since the late Holocene (ODP, 2001). Therefore, the SOT is apparently an area of focused sedimentation along the path of the Kuroshio Current (KC). Furthermore, the lower slope (>1000 m) sediments consist almost entirely of silty mud (Chen et al., 1995); for instance, mud accounts for over 97% (Jeng and Chen, 1995), while the upper slope (<1000 m) sediments are composed of sand with little mud (Chen et al., 1995).

Transport processes of particulate matter in the marginal seas were first investigated in the middle Atlantic Bight during the SEEP (Shelf Edge Exchange Processes I and II) program (Walsh et al., 1988; Biscaye et al., 1988) and later in several other seas in the world. For the ECS and the SOT, it is the KEEP (Kuroshio Edge Exchange Processes) program (Wong et al., 2000; Liu et al., 2003). Using the results of field observations and diagnostic numerical experiments, Yanagi et al. (1996) have concluded that suspended matter is transported from the shelf edge to the inner shelf in summer and from the inner shelf to the shelf edge in autumn (which is maximum) and winter due to the vertical circulation mainly induced by the monsoon wind. Studying time-series sediment trap samples collected at SST-1 (29°21.6’N, 128°13.5’E, 1100 m water depth), Katayama and Watanabe (2003) have concluded that lateral transport through the bottom layer is important in the transport of terrigenous particles from the ECS shelf to the mid-OT and that Changjiang influence is relatively high during winter. As far as organic carbon is concerned, analyzing 11 sediment cores from the mid-ECS, Oguri et al. (2003) have reported that organic carbon accumulation rates range from 0.42 to 3.1 mg C cm\(^{-2}\) yr\(^{-1}\) and are higher in the inner shelf edge and the slope areas. Based on the balance of organic carbon budget in the shelf sediments, Kao et al. (2003) consider that a major fraction of adsorbed carbon from primary production must be exported out of the ECS shelf. They further propose that one possible mechanism is the cross-shelf export of particulate organic matter (POM) and that the most likely site for deposition of exported POM from the ECS is the SOT. Liu et al. (2000) propose a conceptual model illustrating the possible route of transporting sediment. From isotopic evidence, Kao et al. (2003) conclude that a major fraction of the sedimentary organic matter in the SOT may originate from the inner shelf of the ECS.

In the present study, 34 surface sediments from the ECS were analyzed for their aliphatic hydrocarbons. A comparison of hydrocarbon distribution in sediments between ECS and SOT (data from Jeng and Huh, 2006) was made in order to understand the significance of cross-shelf export of particulate organic carbon to the SOT. To find the possible relation of hydrocarbon distribution between the two areas, principal component analysis (PCA) was employed since it was a data reduction technique used to simplify data sets while retaining the underlying patterns within the data. This result of comparing hydrocarbon similarity between ECS and SOT may shed some light on the transport of sedimentary lipids between them, and might provide some information about the question “Does the ECS export organic carbon to the SOT?”

2. Experimental

In the present study, 34 surface sediments were collected from the ECS shelf on board R/V Ocean Researcher I using a box corer (Fig. 1). The top 3–4 cm of sediment was stored in stainless steel boxes (pre-cleaned with solvent) and kept frozen (−20°C) until analyzed. Prefixes A, B, C, D, E, F and G of sample codes denote cruise numbers 551 (May 29–June 4, 1999), 542 (March 8–11, 1999), 525 (August 17–24, 1998), 493 (July 8–13, 1997), 460 (August 20–26, 1996), 456 (July 6–12, 1996) and 417 (April 24–May 1, 1995), respectively.
In the lab, frozen sediments were freeze-dried. Following the 
adoption of an internal standard (\(n\)-C\(_{24}\)D\(_{50}\)), the dried 
sediment was extracted with a mixture of dichloromethane 
and methanol (1:1; v/v) for 24 h in a Soxhlet apparatus. 
The lipid extract was then saponified by reflux for 3 h with 
0.5 N KOH solution in methanol. The non-saponifiable 
lipids were isolated by hexane extraction four times and 
concentrated using N\(_2\) gas. The aliphatic hydrocarbon 
fraction was isolated from the neutral lipids by silica gel 
(deactivated with 5% H\(_2\)O) column chromatography using 
hexanes.

For gas chromatography (GC) analysis, an HP 5890A 
gas chromatograph equipped with a split/splitless injector 
and a flame ionization detector (FID) was used. Separation 
of aliphatic hydrocarbons was achieved by an SPB-1 
capillary column (30 m \(\times\) 0.25 mm i.d. \(\times\) 0.25 \(\mu\)m). Oven 
temperature programming was 45–90 °C at 15 °C min\(^{-1}\) 
and 90–270 °C at 3 °C min\(^{-1}\) for analyzing aliphatic 
hydrocarbons. Identification was made with co-injection 
of authentic standards and gas chromatography–mass 
spectrometry (GC–MS). The GC–MS analyses were 
performed with an HP 5973 quadrupole mass 
selective detector (electron ionization, electron energy 
70 eV, scanned from 50 to 550 Da).

An SGE (Australia) OCI-5 cool on-column injector was 
also fitted in the gas chromatograph for obtaining the best 
quantification. GC peak areas of all hydrocarbons and the 
internal standard were obtained using an electronic 
integrator (Chromatopac C-R6A, Shimadzu, Japan). Each 
hydrocarbon concentration was determined using the 
internal standard. Based on eight replicate analyses, the 
analytical precision (expressed as the percent coefficient 
of variation) of hydrocarbon abundances was calculated to 
be 2–8%.

All sediment samples were determined for their total 
organic carbon by the dichromate–acid oxidation method 
(Gaudette et al., 1974) modified by addition of Ag\(_2\)SO\(_4\) to 
H\(_2\)SO\(_4\) at the rate of 15 g L\(^{-1}\). Titration was carried out 
with an automatic titrator (Metrohm 702 SM Titirino, 
Switzerland). The relative standard deviation of TOC 
determination was generally <1%.

PCA was performed on GC data of aliphatic hydro- 
carbons. Each compound was used as a variable. Prior to 
PCA, all hydrocarbon data were standardized by subtract- 
ing each data from the mean and dividing by the standard 
deviation. PCA was performed using xSTAT version 5.1 
(Addinsoft, France).

3. Results and discussion

From the GC chromatograms of aliphatic hydrocar- 
bons, the sediments showed a general picture of similar 
distribution patterns with \(n\)-alkanes predominant along 
with squalene, diploptene, UCM (unresolved complex 
mixtures), etc. (Fig. 2). In general, higher-molecular-weight 
\(n\)-alkanes of terrigenous sources—\(C_{25}\), \(C_{27}\), \(C_{29}\) and \(C_{31}\) 
(Rieley et al., 1991) dominated over lower-molecular- 
weight ones of marine sources such as phytoplankton— 
\(C_{15}\), \(C_{17}\), \(C_{19}\) and \(C_{21}\) (Winters et al., 1969; Blumer et al., 
1971). This result can be attributed to \(n\)-alkanes derived 
from marine sources being degraded faster than those from 
terrogenous ones (Meyers et al., 1984; Gagosian 
and Peltzer, 1986). Also, land plants have proportionally larger 
amounts of hydrocarbons than do marine algae. Squalene 
exhibited a wide concentration range as compared to \(n\)- 
alkanes (Table 1) probably because it is a lipid constituent 
of most marine organisms and particularly of phytoplank- 
ton (Bieger et al., 1997; Salas et al., 2006). Also, it possesses 
relatively high stability like \(n\)-C\(_{18}\) and pristane (Jeng and 
Huh, 2004). Diploptene (hop-22(29)-ene) is derived from 
terrestrial higher plants and is also formed by bacteria 
(Rohmer et al., 1984). If higher plants are the sole source of 
diploptene, a strong correlation between diploptene and 
terrestrial higher plant \(n\)-alkanes has been demonstrated 
(Prah et al., 1992). A positive correlation between 
diploptene and higher plant \(n\)-alkanes was found for 
34 ECS sediments (\(\Sigma C_{25-33} = -152 + 13.2 Di, r = 0.96\), 
strongly indicating a higher plant source to the sediments. 
UCM, consisting of cyclic and branched alkanes, is known 
to resist microbial degradation more effectively than 
\(n\)-alkanes and thus has a greater tendency to remain in 
the environment after \(n\)-alkanes have degraded (Gough 
and Rowland, 1990; Bouloubassi and Saliot, 1993). It has a 
linkage to degraded or weathered petroleum residues 
(Venkatasean et al., 1980; Readman et al., 1987). Most 
marine sediments analyzed generally contained a medium 
UCM (Fig. 2; Table 1). This does not necessarily reflect the 
presence of degraded petroleum in the sediments since in 
some cases concentrations of UCM< 10 \(\mu\)g g\(^{-1}\) are common 
in coastal marine environments far from petrogenic 
hydrocarbon sources (Matsumoto, 1983; Tolosa et al., 
1996). In addition, the distribution of the lower molecular 
weight \(n\)-alkanes (<\(C_{33}\)) looked like a petrogenic origin 
(carbon preference index (CPI)) close to 1) which could 
probably be attributed to recycled organic matter since the 
mid-to Outer shelf was composed mainly of relict sediments 
(Niino and Emery, 1961). Further, only five stations gave 
Pr/Ph ratios close to 1 (A14, 0.82; B7, 0.81; D16, 0.86; D27, 
1.21; E49, 1.05; calculated from Table 1). Combining the 
UCM and Pr/Ph ratio results, it can be concluded that 
the petrogenic hydrocarbon contamination on the ECS 
shell is minimal.

The sediment textures varied greatly as reflected by the 
TOC content of sediments ranging from 0.043 to 
0.85 g C(100 g\(^{-1}\)) (Table 2). To compensate for the grain 
size difference, all hydrocarbon data were normalized to 
TOC before performing multivariate analysis.

Prior to PCA, cluster analysis was performed on all 
variables (e.g. individual aliphatic hydrocarbons) of ECS 
and SOT sediments (Tables 1 and 3). The resulting 
dendrogram (not shown) illustrated that UCM, diploptene, 
and squalene merged with the clusters in the final stages
Fig. 2. Gas chromatograms of the aliphatic hydrocarbon fraction from station A40 (upper) and OT8 (lower). Numbers denote carbon numbers of \( \eta \)-alkanes. I.S., internal standard; Pr, pristane; Ph, phytane; Sq, squalene; Di, diploptene; and UCM, unresolved complex mixtures.

Table 1
Hydrocarbon concentrations (ng g\(^{-1}\)) for East China Sea (ECS) sediments

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</tr>
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Table 1 (continued)

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<tr>
<td>C30</td>
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<sup>a</sup>Sample Aliphatic hydrocarbons: D<sub>16</sub>, D<sub>17</sub>, D<sub>20</sub>, D<sub>21</sub>, D<sub>22</sub>, D<sub>27</sub>, E<sub>45</sub>, E<sub>49</sub>, F<sub>1</sub>, F<sub>3</sub>, F<sub>6</sub>, G<sub>6</sub>, C<sub>30</sub>, C<sub>31</sub>, C<sub>32</sub>, D<sub>16</sub>, D<sub>17</sub>, D<sub>20</sub>, D<sub>21</sub>, D<sub>22</sub>, D<sub>27</sub>, E<sub>45</sub>, E<sub>49</sub>, F<sub>1</sub>, F<sub>3</sub>, F<sub>6</sub>, G<sub>6</sub>, C<sub>30</sub>, C<sub>31</sub>, C<sub>32</sub>, Di, C<sub>33</sub>, C<sub>34</sub>, C<sub>35</sub>, UCM, CPI.
with Euclidean distances of 6.246, 7.034 and 8.717, respectively, indicating that the three components had very weak relation with other hydrocarbons. As a consequence, these three components were excluded for performing PCA. The score plot of the first two components explaining 74% of the total variance is shown in Fig. 3. To facilitate discussion, peripheral samples of all OT samples were connected by line segments, forming a polygon; those in positive PC1 and negative PC2 as well as those in negative PC1 were, respectively, connected in the same way. Therefore, three groups are visible in the score plot, those virtually with a positive score on PC1 and with low positive and low negative scores on PC2 (group I), those with a positive score on PC1 and a high negative score on PC2 (group II), and those with negative scores on PC1 (group III). Of the three groups, group I contained 12 OT samples and three inner shelf samples (C8, D7 and F6). With the exception of sample D27, group II comprised seven samples on the inner shelf. The majority of samples (21) on the ECS shelf located away from the inner shelf constituted group III. In addition, samples F1 and F3, situated in high positive scores on PC1 and high positive scores on PC2, were fairly peculiar and might be considered outliers.

It is of importance to note that group I defined by 12 OT samples includes three samples on the inner shelf; this is especially unreasonable because group I clusters with distant samples instead of nearby samples. This requires more discussion. The Lanyang River (nearest river to the SOT, not shown) has been reported to be not a major hydrocarbon source for OT sediments, but to a less extent it does influence two stations OT 1 and OT 12 closest to the river mouth based on the individual TAR (terrigenous/aquatic ratio) and CPI values (Jeng and Huh, 2006). This also reflects in OT1 in Fig. 3 that the sample is situated relatively away from the cluster of other OT samples. That is, sample OT1 has a low similarity to the other OT samples.

Table 1 (continued)

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*Pr, pristane; Ph, phytane; Sq, squalene; Di, diploptene; UCM, unresolved complex mixtures; CPI, carbon preference index = \((1/2)[(nC_{25} + nC_{27} + nC_{29} + nC_{31} + nC_{33})/(nC_{24} + nC_{26} + nC_{28} + nC_{30} + nC_{32}) + (nC_{25} + nC_{27} + nC_{29} + nC_{31} + nC_{33})/(nC_{26} + nC_{28} + nC_{30} + nC_{32} + nC_{34})].*

Table 2

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OT samples were connected by line segments, forming a polygon; those in positive PC1 and negative PC2 as well as those in negative PC1 were, respectively, connected in the same way. Therefore, three groups are visible in the score plot, those virtually with a positive score on PC1 and with low positive and low negative scores on PC2 (group I), those with a positive score on PC1 and a high negative score on PC2 (group II), and those with negative scores on PC1 (group III). Of the three groups, group I contained 12 OT samples and three inner shelf samples (C8, D7 and F6). With the exception of sample D27, group II comprised seven samples on the inner shelf. The majority of samples (21) on the ECS shelf located away from the inner shelf constituted group III. In addition, samples F1 and F3, situated in high positive scores on PC1 and high positive scores on PC2, were fairly peculiar and might be considered outliers.

It is of importance to note that group I defined by 12 OT samples includes three samples on the inner shelf; this is especially unreasonable because group I clusters with distant samples instead of nearby samples. This requires more discussion. The Lanyang River (nearest river to the SOT, not shown) has been reported to be not a major hydrocarbon source for OT sediments, but to a less extent it does influence two stations OT 1 and OT 12 closest to the river mouth based on the individual TAR (terrigenous/aquatic ratio) and CPI values (Jeng and Huh, 2006). This also reflects in OT1 in Fig. 3 that the sample is situated relatively away from the cluster of other OT samples. That is, sample OT1 has a low similarity to the other OT samples.
samples. If sample OT1 is excluded from Fig. 3, the area of group I is greatly reduced, and samples C8, D7 and F6 are not included in group I. In other words, the relation between these three samples and group I depends entirely on sample OT1, and it can be concluded that this relation is very weak, or even does not exist at all.

It is of great interest to examine the hydrocarbon distribution in the southwestern part of the ECS since it is an important area proposed for transporting POM from the ECS to the SOT by Liu et al. (2000). In their conceptual model, the possible route of transporting sediment is from the Changjiang River mouth, southward along the southeastern coast of China, eastward across northern Taiwan Strait, along offshore northern Taiwan to the SOT. Considering the samples collected from the Changjiang River mouth to the SOT (22 samples on the shelf west of longitude 123° and 12 in the SOT), it was found that only three samples (C8, D7 and F6) clustered with group I (OT samples) and the other 19 samples do not. This suggests that the hydrocarbon relation between the inner shelf and the SOT is actually weak, implying that the possibility of transporting hydrocarbons along the route of the conceptual model to SOT is very low. This result can be quite reliable because n-alkanes are relatively unreactive and

### Table 3

Hydrocarbon concentrations (ng g⁻¹) for Okinawa Trough (OT) sediments (from Jeng and Huh, 2006)

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<tr>
<th>Sample</th>
<th>Aliphatic hydrocarbons</th>
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<th>C₁₆</th>
<th>C₁₇</th>
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*Pr, pristine; Ph, phytane; Sq, squalene; Di, diploptene; UCM, unresolved complex mixtures; CPI, carbon preference index = \((1/2)(\sum nC_{25} + nC_{27} + nC_{29} + nC_{31} + nC_{33})/\sum nC_{24} + nC_{26} + nC_{28} + nC_{30} + nC_{32})\).
unlikely to be affected by any mechanism that would be selective for alternating homologs in the sequence (Hedges and Prahl, 1993).

One marked feature is that groups II and III are, respectively, located in positive and negative PC1, signifying their difference in hydrocarbon distribution. This is supported by the literature result that Changjiang sediments have been transported to the south via the coastal current along the Chinese coast and that offshore transport has been prevented by tidal currents and by the northward movement of the TWC (Milliman et al., 1989). Another reason may be that the inner shelf consists largely of muddy sediments, which are considered recent deposits, and the mid-to-outer shelf is composed chiefly of sandy sediments (Huh and Su, 1999), which are known as relict sediments (Niino and Emery, 1961). In addition, stations F1 and F3 located near the inner shelf have no relation with group II, which might be attributed to the influence of the TWC (Fig. 1). Furthermore, sample locations G6, F1 and F3 are very close to each other geographically (Fig. 1), but sample G6 separates clearly from samples F1 and F3 in the score plot (Fig. 3), suggesting that the deposition of Changjiang River sediments terminates at station G6.

As expected, groups I and III are separated from each other in Fig. 3, likely attributable to little material exchange between them. The KC flows northward and turns northeastward when approaching the ECS shelf although it intrudes onto the shelf in the winter and spring time (Chern and Wang, 1992; Hsueh et al., 1992).

Fig. 3. Score plot of PCA for ECS and SOT sediments. Sample codes for ECS samples have prefixes of A–G, and those for SOT samples have a prefix of OT. Group I contains 12 SOT sediments and three sediments on the inner shelf, group II consists of eight but one sediments on the inner shelf, and group III is composed of 21 sediments mainly on the mid-to-outer shelf.

Note that the SOT contains 12 stations within a relatively small area, but the hydrocarbon distribution of the samples varies widely. For example, the areas covered by groups I and III in Fig. 3 are comparable, but their respective geographical areas in the SOT and on the mid-to-outer shelf differ greatly (Fig. 1). The reason can be explained as follows. The lipid inputs by suspended matter/sediment transport to the seas off northeastern Taiwan can derive from three sources (Fig. 1). From the northwest, a small alongshore flow just off northern Taiwan (south of station D27) along with the eddy flow (Tang et al., 1999) may carry materials from the southern ECS and Taiwan Strait to the SOT. The Lanyang River (from the west) exerts small influence on the SOT sediments as discussed earlier. Another source from south is other river runoffs from eastern Taiwan carried by the Kuroshio Current to the SOT.

Terrestrial higher plant wax contribution to sediment or soil is generally expressed by the CPI of n-alkanes. Higher CPI\(_{25-33}\) values indicate greater contribution from vascular plants (Rieley et al., 1991); CPI\(_{25-33}\) values close to one are thought to indicate greater input from marine microorganisms, recycled organic matter, and/or petroleum (Kennicutt et al., 1987). The present CPI\(_{25-33}\) values of the ECS ranged widely from 1.41 to 5.82 with an average of 3.12 (calculated from Table 1), suggesting non-uniform distribution of terrigenous hydrocarbons. In general, high CPI values were found on the inner shelf, and low values on the mid-to-outer shelf. This suggests that the Changjiang River contributes more to the former than to the latter, consistent with the literature result indicated earlier. On the other hand, the average CPI value (3.12, \(n = 34\)) of the ECS was comparable to that (average 2.92, \(n = 12\)) of the SOT. These two averages are considered to be relatively high, suggesting that fossil fuel contamination is minimal. However, it should be noted that CPI values would become smaller if there is any addition of ‘old’ hydrocarbons (e.g., CPI of petroleum close to 1; Bray and Evans, 1961) to the sediments from pollution. Some samples were found to contain different proportions of ‘old’ hydrocarbons as evidenced by the presence of 17(\(z\))H,21(\(\beta\))H-hopanes. This fossil component could be contributed from fossil fuels through contamination (Albaigés and Albrecht, 1993).
indicating different inputs of higher plant
from Tables 1 to 3), showing no difference between the
insensitive.

(1979; Shaw et al., 1985; Readman et al., 1996) from boat
traffic or a spill. The addition of ‘old’ hydrocarbons will
lower some CPI values observed in ECS sediments. The
purpose of this study is to compare hydrocarbon distribu-
tion between ECS and SOT and to explore if they are
related. For comparing the two areas, eight samples (C14,
C12, C10, C8, C7, C6, D7 and F6; Fig. 1) on the ECS inner
shell and 12 samples in the SOT were chosen; their average
CPIs were, respectively, 4.56 ± 0.93 and 2.92 ± 0.79, sug-
gesting that the hydrocarbon sources to the two areas were
quite different. The result is quite dependable because the
CPI is a diagenetically insensitive ratio (Hedges and Prahl,
1993), implying that the CPI would not change over time
during transport.

The ratio of terrigenous-to-aquatic \( n \)-alkanes were

\[
\text{TAR} = \frac{(nC_{27} + nC_{29} + nC_{31})}{(nC_{15} + nC_{17} + nC_{19})}.
\]

This ratio is valuable for determining changes in relative
contributions of organic matter from land and aquatic
flora although it may over-represent the absolute amounts
terrestrial sources (Meyers, 1997). This ratio was
adopted in the present study to estimate the relative
contribution of terrigenous and marine sources to ECS and
SOT sediments. The average TAR for the ECS inner shell
was 50.4 ± 58.0 \((n = 8)\), and that for the SOT was
9.64 ± 4.33 \((n = 12)\) (calculated from Tables 1 to 3). This
suggests that the two areas receive different hydrocarbon
inputs. The TAR values are expected to be larger for SOT
sediments than for ECS sediments (since the ECS is much
deeper than the ECS and since aquatic components
degrade faster) if they have the same source. The present
result is reversed and suggests the ECS and SOT having
different sources. Note that this ratio is one of the factors
used for comparing the differences of the multiple study
sites. Higher plant \( n \)-alkanes were the predominant
components in the sediments from the ECS and SOT; to
correct for the grain size effect, \((nC_{27} + nC_{29} + nC_{31})/\text{TOC}\)
was used to estimate the input of higher plant \( n \)-alkanes to
the two areas (Prah, 1985). The SOT and ECS inner shelf
gave \((nC_{27} + nC_{29} + nC_{31})/\text{TOC}\) averages of 1731 ± 482 \times
\(10^{-7}\) g( gC \(\text{C}^{-1}\) \((n = 12)\) and 3016 ± 868 \times \(10^{-7}\) g( gC \(\text{C}^{-1}\) \((n = 8)\) (calculated from Tables 1 to 3), respectively,
demonstrating different inputs of higher plant \( n \)-alkanes to
the two areas. In the HMW region, the \( C_{27} \) and \( C_{29} \)
\( n \)-alkanes are diagnostic of waxes from trees and shrubs,
and the \( nC_{31} \) alkane is diagnostic of grass waxes
(Cranwell, 1973). The \( nC_{31}/(nC_{27} + nC_{29} + nC_{31}) \) ratio
was employed to see if any difference existed between the
two areas. The average ratios of \( nC_{31}/(nC_{27} + nC_{29} + nC_{31}) \) for
the SOT and ECS inner shell were, respectively, 0.478 ± 0.012 \((n = 12)\) and 0.483 ± 0.018 \((n = 8)\) (calculated from
Tables 1 to 3), showing no difference between the
two averages. This can be attributed to \( n \)-alkane distribu-
tion maximizing at \( C_{31} \), which makes the change in \( C_{31} \)
insensitive.

Seven stations (not shown) between Taiwan and 12 SOT
sample sites were selected for collecting total suspended
matter \((2 \text{ m below sea surface})\) on July 23–26, 2000 (cruise
#590). The average CPI of the seven samples was
1.01 ± 0.12. This low CPI average reflects the contribution
from a nearby river (Lanyang River), which is known to
contain ‘old’ hydrocarbons in its suspended matter and
sediments (Jeng and Kao, 2002; Jeng and Huh, 2006). In
addition, one of our cruises (#525 on August 17–24, 1998)
to the ECS happened to be the high runoff period of the
Changjiang River. The runoff of the river had a very
different color than the offshore seawater of the ECS. Two
stations—C14 and C15 \((31°19.96’N, 122°30.09’E, \text{not}
shown) representing the runoff of the river were occupied,
and one sample of total suspended matter \((2 \text{ m below sea}
\text{surface})\) for each station was collected. CPI values of the
two stations were 1.55 and 1.32, which differed greatly
from those of off northeastern Taiwan. These results indicate
that transport of suspended sediment from the Changjiang
River mouth to the SOT is quite unlikely.

In conclusion, most sediments on the ECS inner shelf
did not group with those in the SOT, indicating dissim-
ilarity in hydrocarbon distribution between the two areas.
Moreover, striking differences in CPI, TAR and
\((nC_{27} + nC_{29} + nC_{31})/\text{TOC}\) values were found between SOT
and ECS inner shelf. In addition, hydrocarbon distribution
differences in suspended matter from Changjiang River
runoff and off northeastern Taiwan were also observed,
suggesting that hydrocarbon sources to the two areas were
different. Based on these results, it can be concluded that
hydrocarbon contribution from the ECS inner shelf to the
SOT appears to be minimal.

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