千里金蘭大学紀要　10　71－78（2013）

＜研究ノート＞

Arsenic content in pelagic particulate matter collected from the Pacific Ocean surface

Tsutomu Satoh[1], Ken'ichi Hanaoka[2], Shunshiro Ueno[3], Kota Nagatomo[4], Shoji Tagawa[5]

Summary

Arsenic (As) has a ubiquitous distribution in nature. In organisms, As is more common in marine organisms than it is in terrestrial organisms. In this study, the total As content of pelagic particulate matter collected from 52 consecutive sample sections along a transect extending from Shimonoseki (Japan) through Brisbane (Australia), Auckland (New Zealand), Suva (Fiji), Hawaii (USA), and then back to Shimonoseki was investigated. The particulate matter collected from each section was classified according to whether it was phytoplankton, zooplankton, or unknown matter (detritus). High As concentrations were observed in fractions containing high percentages of detritus, with this tendency observed along the entire transect in the Pacific Ocean.

Keywords：arsenic, particulate matter, detritus, plankton, Pacific Ocean

Introduction

Since ancient times, arsenic (As) has attracted the attention of humans due its extreme toxicity.[1)] Arsenic has a ubiquitous distribution in nature, including living organisms. Compared to terrestrial organisms, the As concentrations of marine organisms is considerably higher.[2)] In seawater, As is present at concentrations of approximately 2 μg/L,[3)] and it can be taken up and accumulated by phytoplankton[4)]. However, the average As concentration in ocean sediments is approximately 40 mg/kg.[3)] It is therefore considered that the As in sediments is derived from As in the water column, although the mechanism of As transport has not yet been thoroughly clarified. Fondekar *et al.*[5)] suggested that the As in sediments may be attributed to zooplankton which sinks when the organisms die. We therefore investigated As concentrations in pelagic particulate matter, including phytoplankton, zooplankton and unknown matter (detritus). In doing so, we sought to elucidate a part of arsenic circulation in marine ecosystems.

Materials and Methods

Pelagic particulate matter

Samples were collected aboard the Koyo-Maru training vessel of National Fisheries University from October 25, 1992, to January 24, 1993. Particulate matter was collected from seawater pumped from a depth of 5.0 m using a Kitahara quantitative plankton net (diameter: 30 cm; mesh size: 100 μm) from 52 sample sections along a transect. This collected material was fractionated and fixed in 2-3% formaldehyde (Wako Pure Chemical Ind., Japan)-seawater solution every day. The 52 collected fractions were stored at 4℃ until analysis. Sample routes and sections along

---

1　Tsutomu SATOH　千里金蘭大学生活科学部食物栄養学科
2　Ken'ichi HANAOKA　水産大学校食品科学科
3　Shunshiro UENO　水産大学校生物生産学科
4　Kota NAGATOMO　水産大学校
5　Shoji TAGAWA　水産大学校

受理日：2013年10月15日

the transect extended from Shimonoseki, Japan (departure: October 25, 1992), through Brisbane, Australia (arrival: November 8, 1992; departure: November 13, 1992), Auckland, New Zealand (arrival: November 18, 1992; departure: November 24, 1992), Suva, Fiji (arrival: November 28, 1992; departure: December 3, 1992), Honolulu, Hawaii, USA (arrival: December 17, 1992), Hilo, Hawaii, USA (departure: January 9, 1993) and then back to Shimonoseki (arrival: January 24, 1993) are shown in Fig. 1. Coordinates of the midpoints of the 52 sample sections are shown in Table 1.

Determination of Arsenic

The particulate matter was separated from the fixing solution by filtration with membrane filters (pore size: 0.40 μm; diameter: 47 mm) and dried under reduced pressure until it reached a constant weight. Each dried fraction was separated from the filter by raking and powdered by mashing with a glass stick. The resulting powders were suspended in 1,000 mg/kg (1,000 ppm) nickel solutions (Wako Pure Chemical Ind.), and those As content was monitored using a graphite furnace atomic absorption spectrometer (GFAA: Nippon Jarrel Ash, model AA845) under the following conditions: 1) Drying at 200℃ for 20 s and ashing at 500℃ for 60 s (both in an air atmosphere), and 2) atomization at 2,400℃ for 10 s in an argon atmosphere (deuterium background correction: monochrometer

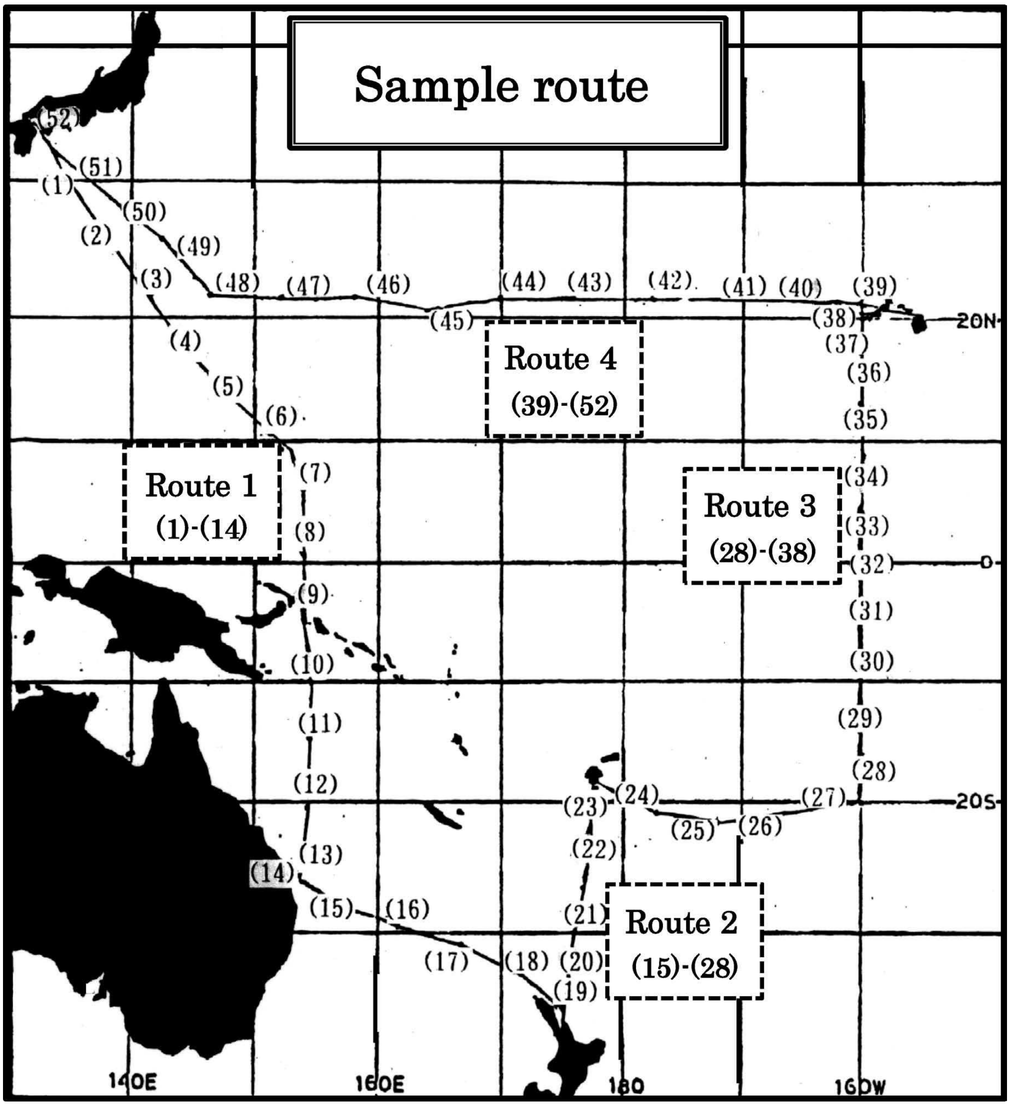

Fig. 1. Sampling route of the transect used for collecting pelagic particulate matter in the study. The numbers in parentheses indicate the midpoint of each sample section. The entire sample route was divided into Routes 1, 2, 3 and 4 to facilitate the study.

Table 1. Coordinates of the midpoints of the 52 sample sections used in this study

Fraction No.	Latitude	Longitude	Fraction No.	Latitude	Longitude
(1)	30° 11’N	134° 25’E	(27)	20° 07’S	160° 49’W
(2)	25° 45’N	138° 02’E	(28)	16° 22’S	159° 60’W
(3)	21° 34’N	141° 17’E	(29)	12° 27’S	160° 00’W
(4)	17° 26’N	144° 19’E	(30)	08° 12’S	159° 59’W
(5)	13° 40’N	147° 44’E	(31)	04° 00’S	160° 00’W
(6)	10° 24’N	151° 08’E	(32)	00° 08’S	159° 60’W
(7)	05° 58’N	153° 54’E	(33)	04° 19’N	159° 60’W
(8)	00° 40’N	154° 01’E	(34)	08° 58’N	159° 60’W
(9)	04° 31’S	153° 60’E	(35)	13° 24’N	160° 00’W
(10)	09° 60’S	154° 27’E	(36)	17° 30’N	160° 00’W
(11)	15° 06’S	154° 23’E	(37)	20° 31’N	159° 04’W
(12)	20° 32’S	154° 02’E	(38)	21° 19’N	157° 50’W
(13)	25° 48’S	153° 32’E	(39)	21° 21’N	160° 05’W
(14)	27° 47’S	153° 02’E	(40)	21° 30’N	165° 41’W
(15)	27° 50’S	156° 52’E	(41)	21° 30’N	171° 48’W
(16)	29° 19’S	161° 40’E	(42)	21° 30’N	177° 57’W
(17)	30° 50’S	166° 45’E	(43)	21° 30’N	176° 01’E
(18)	33° 24’S	171° 36’E	(44)	21° 30’N	169° 52’E
(19)	36° 24’S	174° 59’E	(45)	20° 31’N	163° 56’E
(20)	31° 51’S	175° 43’E	(46)	21° 30’N	157° 60’E
(21)	26° 33’S	176° 38’E	(47)	21° 30’N	152° 01’E
(22)	21° 49’S	177° 27’E	(48)	21° 47’N	146° 14’E
(23)	18° 08’S	178° 25’E	(49)	25° 49’N	142° 28’E
(24)	20° 51’S	177° 12’E	(50)	28° 48’N	138° 22’E
(25)	21° 34’S	171° 57’W	(51)	32° 17’N	133° 45’E
(26)	20° 50’S	166° 24’W	(52)	33° 56’N	131° 02’E

at 193.7 nm).

Estimation of pelagic particulate matter composition

Each fixed fraction extended in a Petri dish was observed using a microscope with a magnification of×40 and photographed five times at random. The apparent ratio of organisms (%) derived from phytoplankton, zooplankton, and detritus in each of 52 fractions (apparent composition) was estimated from overall observation of the five images obtained.

Calculation of apparent weight of phytoplankton, zooplankton and detritus in pelagic particulate matter

Each apparent weight (mg) was calculated by multiplying the dry weight of particulate matter (mg) by the ratio of phytoplankton, zooplankton, and detritus (%) as determined using the method described above. The apparent weight (mg) values represent alternative rather than actual values.

Results and Discussion

Relationship between apparent composition and arsenic concentration in pelagic particulate matter

The apparent composition and As concentrations of 52 fractions of pelagic particulate matter are shown in Fig. 2. The up-and-down variation of the ratio of detritus in particulate matter from small to large in terms of fraction numbers (1,2,3,4-a) is mostly seen to be reflected in the variation of arsenic concentration in the same series (1,2,3,4-b). In short, similar up-and-down profiles are observed in both graphs over the whole sample route.

The relationship between As content and the apparent weight of phytoplankton, zooplankton and detritus in pelagic particulate matter are shown in Fig. 3. Arsenic content shows a positive correlation to the apparent weight of detritus (r = 0.81), but no correlation is observed between As content and the apparent weights of phytoplankton or zooplankton. These results suggest that most As in particulate matter was concentrated and remained in detritus

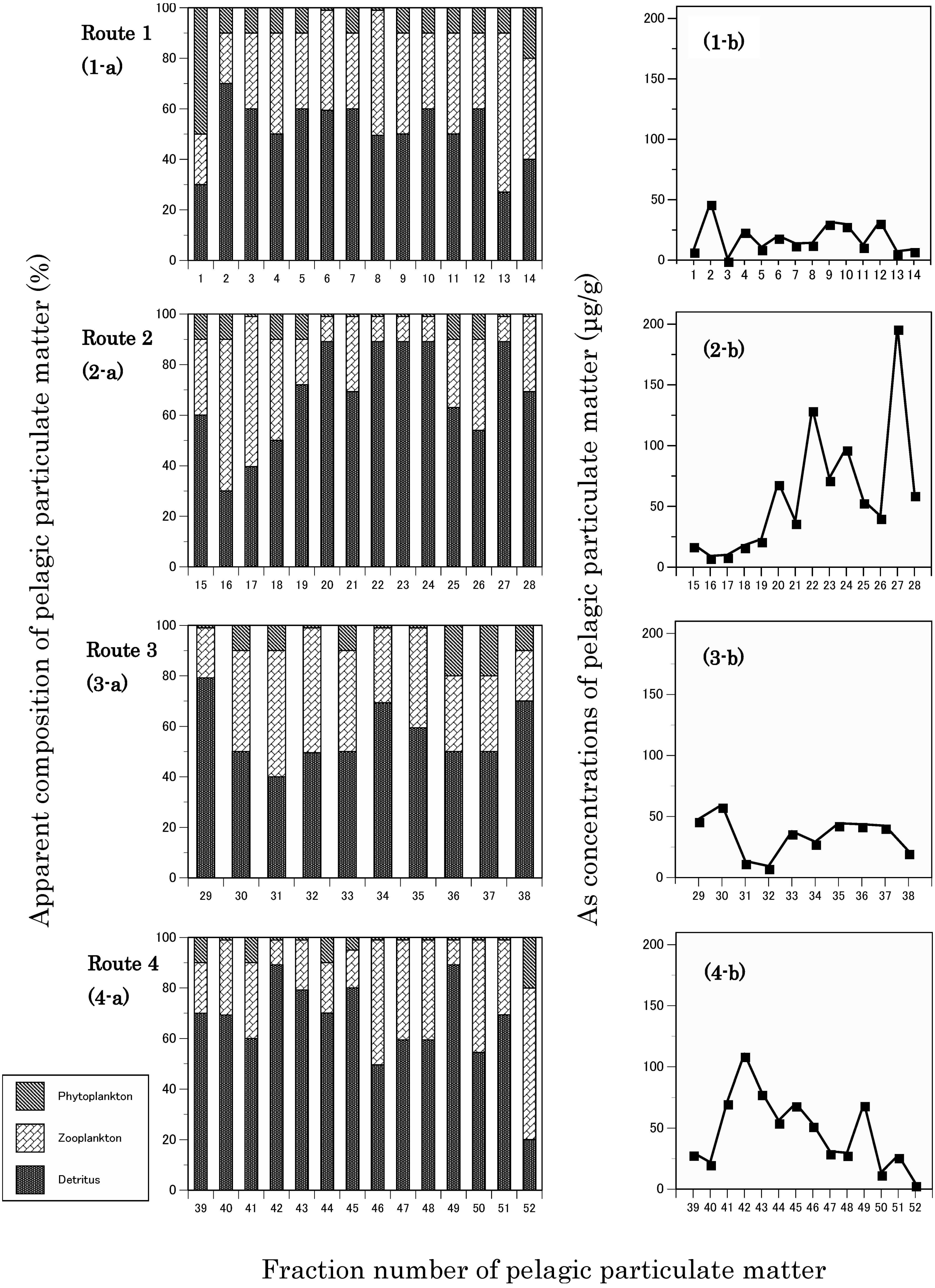

Fig. 2. Apparent composition and arsenic concentrations of pelagic particulate matter.
Each point of arsenic concentration indicates the measured value (n = 1).

for various reasons, and this tendency appeared to be universal along the route navigated in the Pacific Ocean.

Difference in species composition and arsenic content of pelagic particulate matter

Photographs of eight fractions of pelagic particulate matter are shown in Fig. 4. Fraction (1) had a high ratio of phytoplankton, (8), (13) and (16) had high ratios of zooplankton, and (20), (27), (34) and (42) had high ratios of detritus. Specific differences were observed for each fraction even if the organism ratios were at the same level. Fondekar *et al.*5) reported that variations of total As content in zooplankton caught in the sea off the Goa coast were attributable to differences in plankton species composition. In the research reported here, large fraction differences were also seen in relation to species composition, particularly with navigation over significant degrees of latitude from north to south (Route 1) and south to north (Route 3). With such long-distance navigation, species composition changed not only in phytoplankton and zooplankton but also in detritus. There were large As content differences even when each of the fractions was compared with the high ratio of detritus as shown in Figs. 4 (20), (27), (34) and (42). Also in this case, the species composition differences are considered to have contributed to the As content differences among fractions.

Meanwhile, Takimura *et al.*6) reported that the maximum accumulation of As in *Dunaliella sp.* green algae depended on the growth phase. In general, As can be taken up and accumulated by marine organisms, especially by phytoplankton.4) Also in this research, the high concentrations of As in fractions might have derived from phytoplankton in the growth phase and subsequent growth of zooplankton, which might have produced fecal pellets that were observed as detritus.

Besides the effects of bioactivity, the physical absorption of As by iron has been reported as a factor contributing to high As concentrations in sediment7) and in *Chattonella antiqua* and *Duneliella salina* marine algae.8, 9) This is also thought to be a factor behind high As concentrations in particulate matter because significant percentages were derived from organisms containing trace elements including iron. However, it is considered that the As content in marine organisms can vary with age, organ, organism tissue and season.4)

Conclusion

The study's results suggested that the amount of As content in pelagic particulate matter depends on the quantity of detritus present in the matter. This tendency was largely observed over the whole sea route navigated in the research, and can be taken as universal because the route

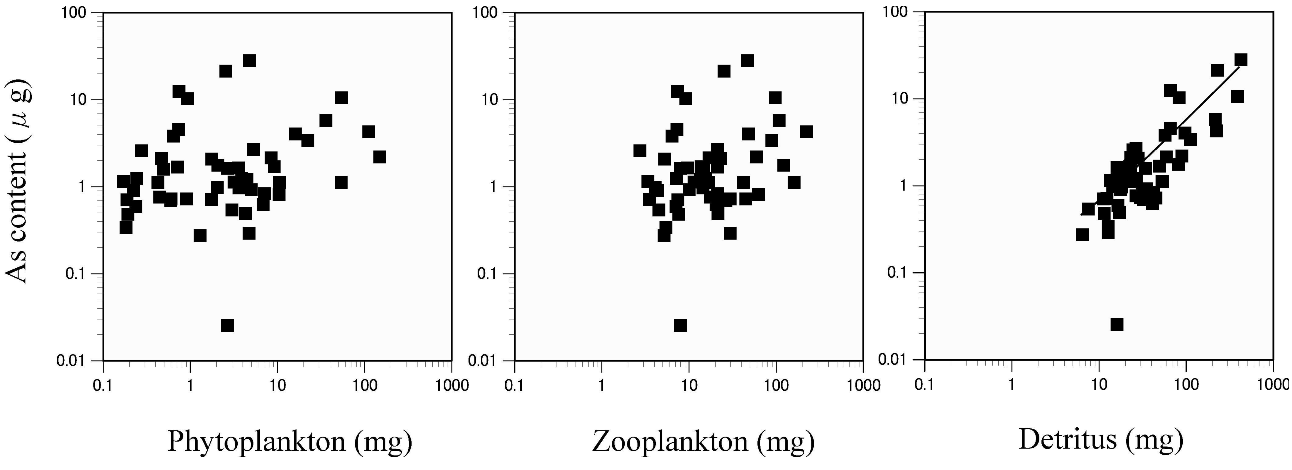

Fig. 3. Relationship between arsenic content and apparent weight of phytoplankton, zooplankton and detritus in pelagic particulate matter.

covered various areas of the Pacific Ocean. It can be considered that pelagic particulate matter may sink and absorb As before becoming ocean sediment over time.

References

1）Ken'ichi Hanaoka, Shoji Tagawa and Toshikazu Kaise, *Trends in Comparative Biochemistry & Physiology, Research Trends*, 319-334 (1993)

2）Ken'ichi Hanaoka, Shoji Tagawa and Toshikazu Kaise, *Applied Organometallic Chemistry*, 6, 139-146 (1992)

3）Kevin A. Francesconi and John S. Edmonds, Biotransformation of Arsenic in the Marine Environment, *Arsenic in the Environment Part1: Cycling and Characterization*, 221-261, John Willey & Sons, Inc. (1994)

4）Lu Xiankun, Li Jing and Ma Xinian, Arsenic in Several Chinese Estuaries and Coastal Seas, *Arsenic in the Environment Part1: Cycling and Characterization*, 309-336, John Willey & Sons, Inc. (1994)

5）S.P. Fondekar, P.V. Shirodkar and T. Joseph, *Indian Journal of Marine Science*, 10, 377-378 (1981)

6）Osamu Takimura and Yukiho Yamaoka, *Nippon kagakukaishi*, (5), 819-822 (1988)

7）D.K. Bhumbla and R.F. Keefer, Arsenic Mobilization and Bioavailability in soils, *Arsenic in the Environment Part1: Cycling and Characterization*, 51-82, John Willey & Sons, Inc. (1994)

8）Yukiho Yamada, Osamu Takimura and Hiroyuki Fuse, *Applied Organometallic Chemistry*, 8, 229-235 (1994)

9）Yukiho Yamaoka, *Nihon Kaisui Gakkaishi (Bulletin of the Society of Sea Water Science, Japan)*, 53, 258-266 (1999)

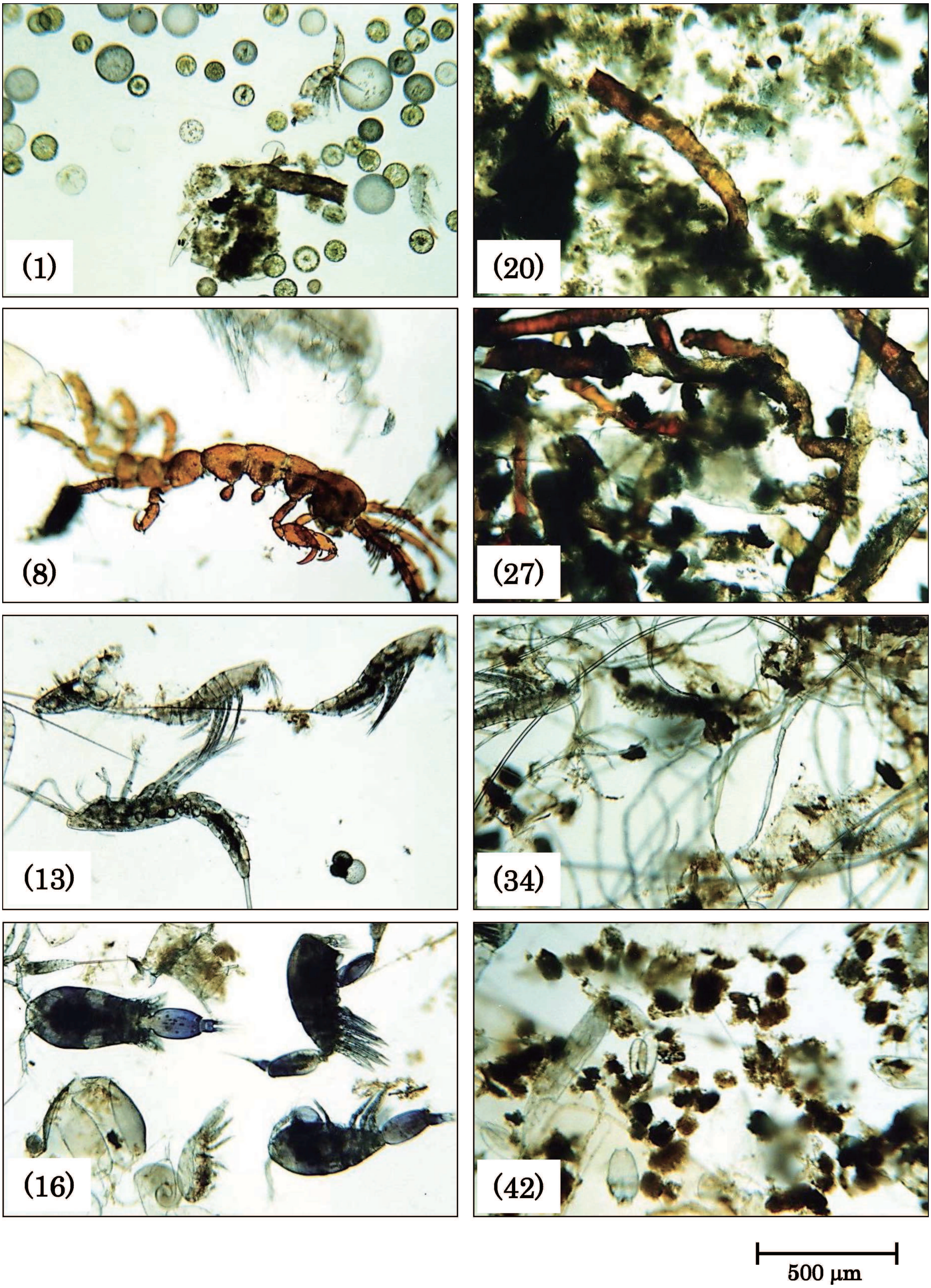

Fig. 4. Photographs of pelagic particulate matter collected using a Kitahara quantitative plankton net from sea water pumped up from a depth of 5.0 m during navigation. The parentheses indicate fraction numbers.

＜研究ノート＞

太平洋の様々な海域の表層から採取した浮遊懸濁物のヒ素含有量

佐藤　努，花岡　研一，上野　俊士郎，長友　洪太，田川　昭治

要　約

ヒ素は、古くから毒性元素として理解されている傍ら、海産動植物に多く含まれる元素である。海水中においては、ヒ素はそのほとんどが無機態として存在し、その濃度は約２μg/Lときわめて低い。しかし、海水から植物プランクトンや海藻に取り込まれ、海洋生態系で生物濃縮を受ける結果、海産動植物のヒ素濃度は、乾物あたり数10 mg/kgから100 mg/kgにも達する。この濃度は、陸上動植物の値に比較して２～３桁高いものであり、海産動植物のヒ素濃縮については、食品衛生学的にも関心が払われてきた。

本研究では、海洋生態系において、海水からのヒ素取り込みに関与するものを含む浮遊懸濁物に焦点を当て、太平洋の様々な海域の表層からそれらを採取し、懸濁物のヒ素含有量と、懸濁物の組成（植物プランクトン由来のもの、動物プランクトン由来のもの、その他のものとしてのデトライタス）を分析することで、浮遊懸濁物のヒ素含有特性について、海域を越えた普遍的な見解を得ることを目的とした。

採取海域は日本、オーストラリア、ニュージーランド、フィジー、ハワイ、そして帰路を経て日本を結ぶ航路上であり、一日毎に分取した試料は合計52個となった。分析の結果、航路上全体に認められる傾向として、懸濁物のヒ素含有量は、懸濁物に占めるデトライタスの割合が高いほど多く、デトライタス量に依存していることが明らかになった。ヒ素は海水中には約２μg/Lという低い濃度で存在するが、海底の堆積物中の濃度は約40 mg/kgとされる。海洋表層の浮遊懸濁物は、鉛直移動を経て海底に到達し、海底堆積物の高いヒ素濃度に寄与している可能性が推察された。

キーワード：ヒ素，浮遊懸濁物，デトライタス，プランクトン，太平洋