Oil spill off the Taean Peninsula, South Korea, on December 7th, 2007-surveys one month, ten months, and one year after the accident

Sci. Rep. Kanazawa Univ.
Vol.53, p.1-23, 2009

Oil spill off the Taean Peninsula, South Korea, on December 7th, 2007–surveys one month, ten months, and one year after the accident

Kazue TAZAKI

Graduate School of Natural Science and Technology, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1192, Japan
E-mail: Kazue Tazaki: kazuet@kenroku.kanazawa-u.ac.jp
Phone: +81–76–264–6512
Fax: +81–76–264–6545

Abstract : An oil spill occurred when a Hong Kong-registered supertanker, *Hebei Spirit*, was accidentally rammed by a South Korean-owned barge that came unmoored from its tugboat in rough seas about 10 km off Mallipo Beach on Taean Peninsula, South Korea, at 7:00 a.m. on December 7th, 2007. A total of 12,547 kl of heavy oil and crude oil entered the ocean, which is more than twice as the amount in South Korea's previous worst spill, in 1995. The seafood, oyster farming and tourism industries in the Taean region were adversely affected. Oil blanketed the sand of Mallipo Beach, the rocks of Euhang Beach, and the mud flats of Gaemok Harbor on Taean Peninsula. Sites surveys were conducted on January 5–6th, October 15–16th, and December 7–9th, 2008. The sandy Mallipo Beach was clean of oil within one month of the accident, whereas there was still abundant oil between rocks on the rocky Euhang Beach. Abundant oil remained underneath the mud flats after ten months. However, some organisms managed to survive in the oily mud. The cultivation of oysters almost completely ceased. Marine plants yielded poorly at the rocky Euhang Beach (Chalipo) in October 2008, whereas marine plants were present for the first time at Penlipo Beach owing to effective microorganism treatments. The sand of Mallipo Beach and rocks of Euhang Beach were almost completely clean by December 2008.

The on-site surveys carried out in this research measured the characteristics of water (pH and EC) and the air quality at the beaches. Toluene concentrations in the air in January 2008 in Korea were 100–1000 times the levels measured for the C-type heavy oil accident of the *Nakhodka* tanker off the coast of Japan in January 1997, but the toluene concentrations returned to normal values in October 2008. Volunteers succeeded in cleaning-up sandy and rocky beaches, but mud flats retain an abundance of oil below the surface one year after the accident. We need to find a better solution for areas of oily mud, and bacterial remediation using clays is one method for removing oil without the use of man-made chemicals.

Keywords: Oil spill accident, Taean Peninsula in South Korea, Mallipo Beach, Euhang Beach (Chalipo), Penlipo Beach, Gaemok Harbor, clean-up methods, sandy beach and rocky beach, mud flat area, Toluene, bioremediation

Introduction

On December 7th, 2007, there was an oil spill in the Yellow Sea off the coast of Taean. A collision between the oil tanker *Hebei Spirit* and a Samsung Heavy Industry crane vessel led to the disastrous petroleum spill. It was one of the worst manmade disasters in history and devastated ocean and land environments and affected people's health and property. The oil slick, which spread over 70 km of coastline, 59 islets, and 15 beaches, adversely affected 500,000 residents in the six surrounding countries (UNEP, 2008). A total of 12,547 kl of heavy oil and crude oil entered the ocean, more than twice the amount in South Korea's previous worst spill in 1995. Seafood, oyster farming and tourism industries in the Taean region were devastated. The Marine Environmental Risk Assessment Research Division of the Korea Ocean Research and Development Institute released a hazard map on December 18–19th, 2007.

The objective of this study is to introduce the natural ability of microorganisms in oil spill-polluted areas, such as Gaemok Harbor, Penlipo Beach, Euhang Beach (Chalipo), and Mallipo Beach in Korea (Fig. 1). Characteristics of oils, seawater, sea plants, sediments and air quality one month, ten months, and one year after the oil spill are described.

The 2007 Korean oil spill

The oil blanketing the sand of Mallipo Beach and rocks of Euhang Beach on January 5–6th, 2008, one month after the accident, was studied. Residents wore overalls and used shovels, buckets, adsorption mats, scraps of fabric, oil fences, hand-made adsorption rollers, 50–70℃ water, washing baths, and high-pressured nozzles to clean up the oil on these beaches (Fig. 2 top). The clean-up was completed within one month. Ten months after the accident, the sand of Mallipo Beach was clean with no visible trace of oil and sea birds had returned to the coast (Fig. 2 bottom). One year after the accident, the sound of stepping on sand suggested there was no oil residue between the sand grains. During December 2008, a further return of many sea birds to the coast was observed. One month after the accident, the oil level line on the stone wall of the embankment was sharp (Fig. 3 top, arrow) and there were oily waves of seawater on the beaches. Ten months after the accident, there was only a faint oil line remaining on the embankment (Fig. 3 bottom, arrow) and the sandy beach had recovered to natural conditions. High-pressured nozzles were used to clean up the oily rock wall one month after the accident (Figs. 4 and 5 top), and the surface of the wall was clean or lightly colored 10 months after the accident (Fig. 4 bottom). The guardrail was rusty 10 months after the accident (Fig. 5 bottom).

At the rocky Euhang Beach, abundant oil between rocks and oil slicks on the seawater surface remained one month after the accident (Fig. 6 top). The oil line was clearly marked by color (Fig. 6 top, arrow). Oil slicks covered the surfaces of rocks one month after the accident. Ten months after the accident, the rock surfaces were clean (Fig. 6 bottom). However, a small amount of dried black oil remained on the rocks, as shown in Fig. 7 (bottom), and shelled creatures returned to the beach 10 months after the accident

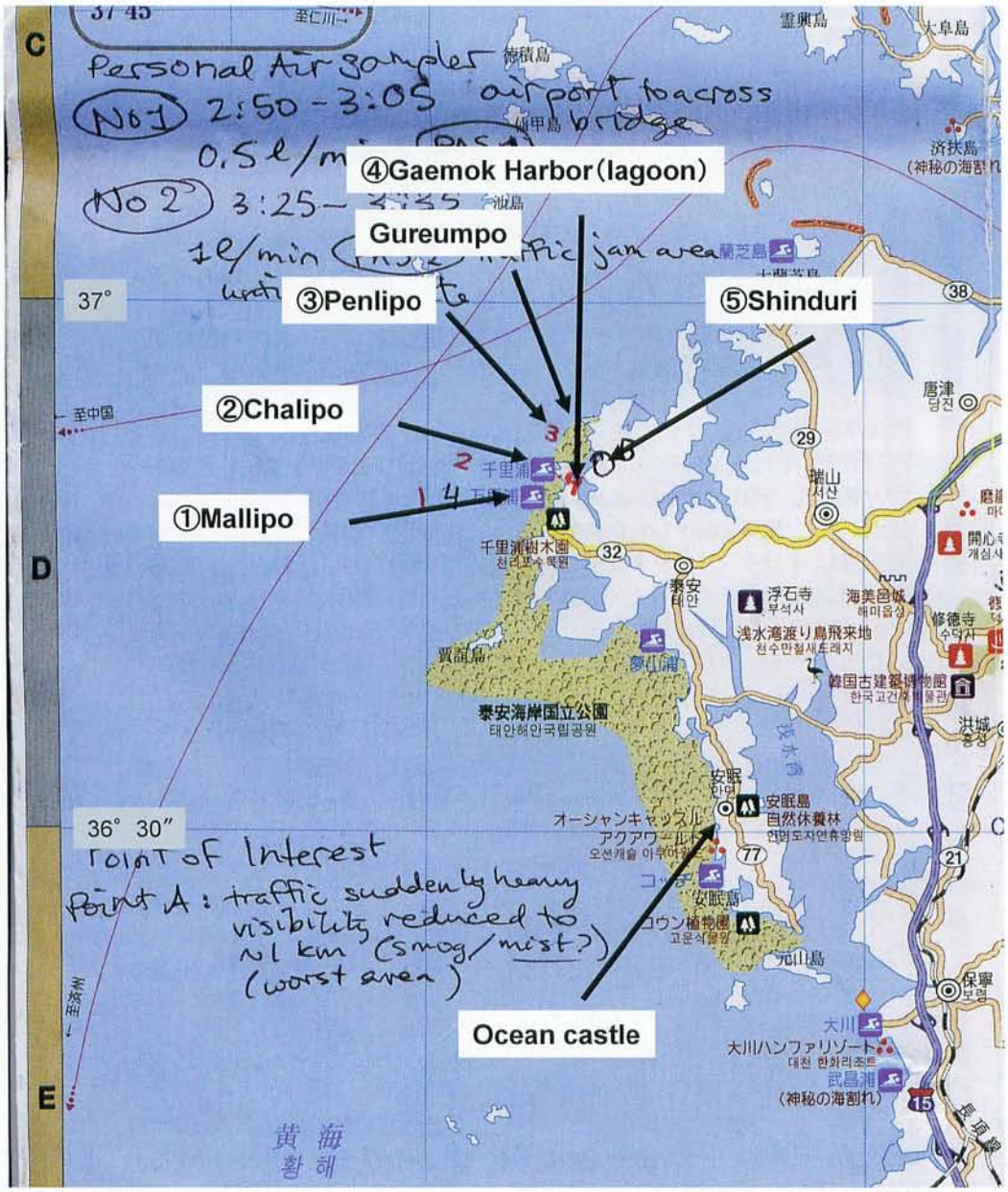

Fig. 1. Map of the study area of oil-contaminated beaches on the Taean Peninsula, South Korea.

Mallipo 1

January, 2008

October, 2008

Fig. 2. Local residents, soldiers, police, and volunteers removing, scraping away and scooping up crude oil spilled on Mallipo Beach, southwest of Seoul, in January and October 2008. The spill was the worst in South Korean history and a disaster for the environment and local economy. The beach was clean and sea birds (circled) returned 9 months after the accident.

(indicated by arrows). On January 5th, 2008, rocks covered with black oil (Fig. 8 top, arrow) were not covered by marine plants, but by October 16th, 2008, a large amount of green marine plant life had grown along the sea water level and were being picked by fishermen (Fig. 8 bottom). The fishermen reported that the harvest of green marine plants decreased after the accident.

At Penlipo Beach, which has both rocky and sandy areas, abundant living shells and green marine plants were seen on October 16th, 2008 (Fig. 9). However, the green marine plants were not seen in 2007. Following the oil spill, fishermen spread effective microorganisms (EM) on the beach, which is one of the reasons why the green marine plants grew in 2008. The heavy oil carries nutrition for the EM. Marine plants yielded poorly at Euhang Beach in October 2008, whereas they were present for the first time at Penlipo Beach because of the EM treatment. The oil line on the cliff (shown by arrows), oil

Mallipo 2

January, 2008

October, 2008

Fig. 3. An oil line can be seen on the rocky bank (left) but oily waves cannot be seen on the sandy beach (right) at Mallipo Beach in October 2008, 9 months after the accident.

drops, and stained rock surfaces can still be observed at Penlipo Beach (Fig. 10).

The Gaemok Harbor mudflat is good for cultivation oysters and crabs, but the oil spill greatly damaged the natural ecosystem there. There was almost no cultivation of oysters even on October 16th, 2008 (Fig. 11). The oil line can be seen on the rock wall. The top surface mud, brown in color only for the top 5 cm, was relatively clean, but underneath the sediment was oily, black and odorous. Many dead crabs were present but some small organisms survived in the oily mud (Fig. 12). The absorbents and absorbing tools used in the clean-up were poorly managed and the oil they contained has reportedly contaminated the earth and tidal flats, causing secondary pollution. Many living shell organisms grew and were picked by fishermen at Gureumpo Beach one year after the accident (Fig. 19).

Bioremediation of oils

Bioaugmentation of oil on the surfaces of the rock samples collected from Euhang (left) and Mallipo (right) Beaches is shown in Fig. 13. The oily shining surface of a rock

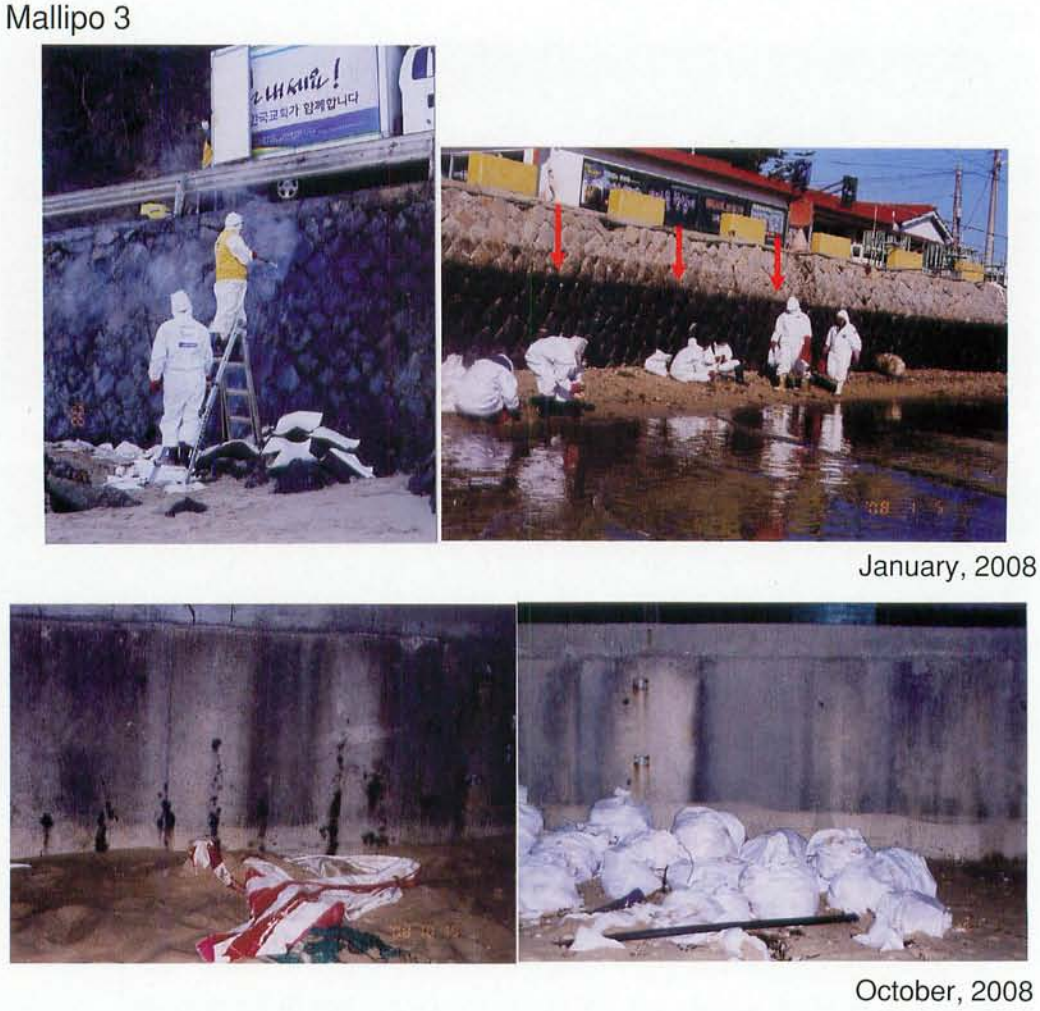

Fig. 4. Local residents and volunteers removing and washing away oil from the walls at Mallipo Beach on January 5th, 2008. The walls were relatively clean in October 2008.

was clean after 5 and 13 days using bacteria and nutrients. The chromatographic results clearly show the differences between before and 6 weeks after bio–treatment. The control without bacteria showed no change in the carbon 12–26 peaks whereas the aliphatic compound peaks due to the cultivation of the sample by bacteria GHK dramatically decreased after 6 weeks (Fig. 14).

Characteristics of seawater

Measurements of the characteristics of seawater, pH and electric conductivity (EC), at Mallipo and Euhang Beaches compared with values for normal seawater around Niigata and Ishikawa prefectures in Japan are shown in Table 1. The normal seawater in Japan had

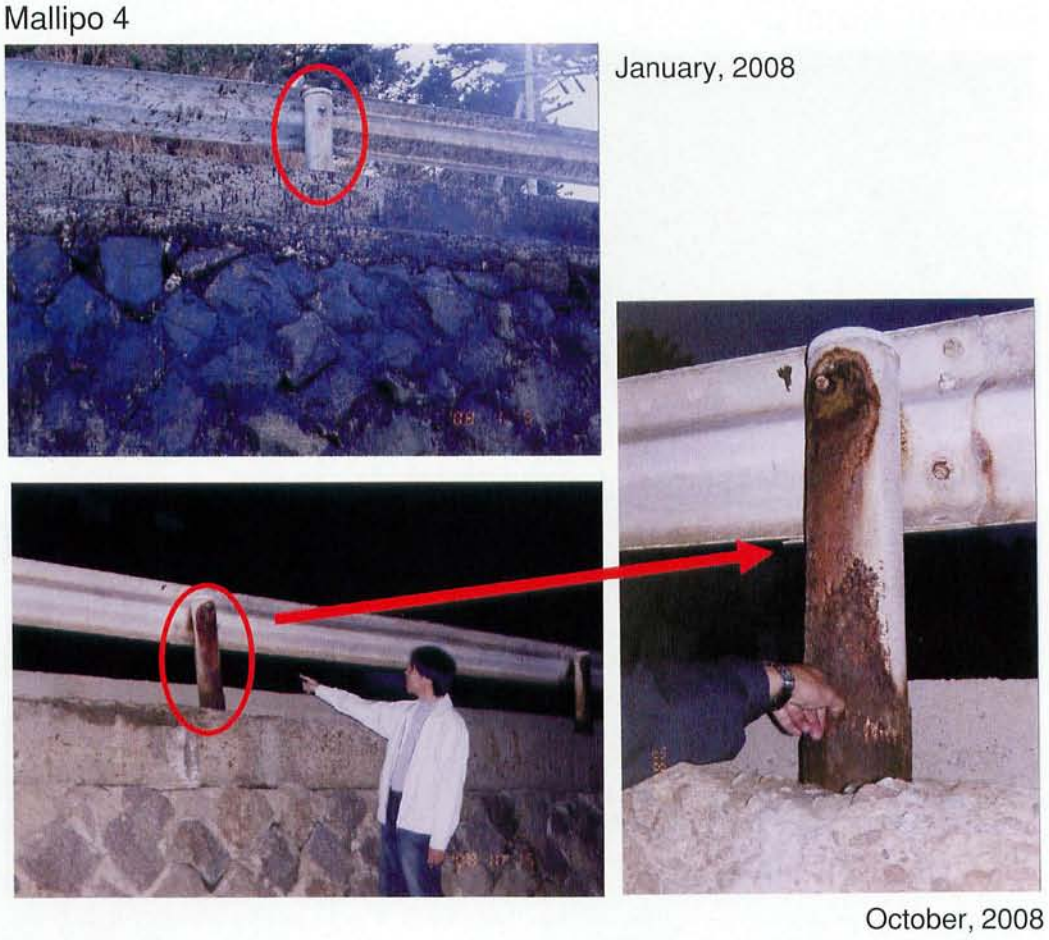

Fig. 5. The metallic guardrail has rusted (circled) after volunteers attempted to soak up crude oil on Mallipo Beach using a high-temperature and high-pressure nozzle. Images are for before washing (January) and after washing (October 2008).

a pH of 8 whereas the oil contaminated seawater at Mallipo and Euhang Beaches in Korea had a pH of 7 in January and October 2008, suggesting that microorganisms play the role of changing pH in seawater.

In this study, on-site surveys for checking and observing the oil conditions were conducted on January 5–6th 2008, one month after the spill, at Mallipo and Euhang Beaches. Compared with common natural seawater (pH of 8.2–8.3; EC of 37.5–45.5 mS/cm) of the Sea of Japan (East Sea), the pH and EC values at the two Korean beaches indicated that the bioremediation of oil took place under neutral conditions (pH of 7.2–7.4; EC of 26.1–43.9 mS/cm). Ten months after the accident, the pH and EC values were the same (pH of 7.4–7.8; EC of 43–45 mS/cm) (Table 1).

Fig. 6. Young volunteers attempt to wipe oil from the surfaces of rocks one by one at Chalipo Beach, Taean Peninsula, in January 2008. The oil pollution line is indicated by arrows. Oil drops on the surface of rocks are still present in October 2008.

Beach air sampling

The volatile aromatic hydrocarbon concentrations in the atmosphere at Mallipo and Euhang Beaches were measured using personal air samplers on January 5–6th, 2008 (Table 2). The analytical data of the volatile aromatic hydrocarbon concentrations for 0.5 l/min at both beaches indicate the concentrations of toluene in the atmosphere were much higher than levels measured for C-type heavy oil spilt from the *Nakhodka* tanker in Japan in January 1997 (Table 3). The concentrations of other elements, such as benzene, xylene, naphthalene and fluorine (8 μg/cm^3) were clearly higher than the allowable standards for Japan. In particular, toluene concentrations at all 10 investigation sites were 100–1000 times higher than concentrations measured for the *Nakhodka* tanker accident in Japan, because the origins of the oils differed. The concentrations of toluene were normal at Mallipo and Euhang Beaches 10 months after the spill. Volunteers needed to use masks

Chalipo(Euhang)2

January, 2008

October, 2008

Fig. 7. Oil slicks on the surfaces of rocks have changed to dry oil spots at Chalipo Beach in October 2008, 9 months after the accident.

containing active carbon during clean--up work in the oil-contaminated areas. The oils in the Korean and Japanese accidents both contained compounds high in S that have characteristics similar to those of Si (Fig. 15).

Physical clean-up methods for oils

The clean-up projects in Korea were successful within one month because of the efforts of 1.3 million volunteers. However, we must find new defensive measures that are safe, low cost, easily implemented, and sustainable using local natural materials without manmade chemical substances. Samples of the oil-contaminated gravel at Euhang Beach were studied in a cleaning experiment. One of the best ways to clean beach sand and gravel is to thoroughly soak oily materials in heated sea water. After soaking in the warm seawater, the oil separates from the sand and gravel and is suspended on the surface of the

Fig. 8. Young volunteers attempt to wipe oil from the surfaces of rocks one by one at Chalipo Beach in January 2008. The oil pollution line is indicated by arrows. Green algae (indicated by an arrow) were present along the seashore in October 2008, 9 months after the accident.

water. The suspended oil is absorbed into "pine charcoal", which only absorbs oil and not water. Thus both the water and gravel are cleaned. Only the natural materials of water and pine charcoal are used. This method can be used not only on beaches, but also around small islands where large machines cannot be used.

The 1997 *Nakhodka* tanker oil spill

The biodegradation of hydrocarbons by microorganisms is one of the primary ways by which the effects of oil spills have been eliminated at contaminated sites (Jeffrey, 1980; Tyzesicka-Mlynarz and Ward, 1995; Whyte et al., 1997). One such spill was that of the Russian tanker *Nakhodka*, which spilled heavy oil into the Sea of Japan on January 2nd, 1997, off the Mikuni Peninsula of Fukui, Japan. Owing to the slow volatility of the oil and 9 years of weathering, there was dendrite crystal growth of paraffin (a mixture of alkanes)

Fig. 9. Green algae were present on the sandy beach at Penlipo Beach in October 2008 because EM bacteria were distributed on the beach; there was no algae growth the previous year. Some organisms returned to the beach (circled).

in the oil crust under natural conditions. Heavy metals were found in original heavy oil samples from the shores of the Sea of Japan; Si, S, Ti, Cr, Ni, Cu, and Zn were predominantly found in the *Nakhodka* oil, whereas these heavy metals and S were not present after 9 years of weathering. The anaerobic underside of the oil crust contained numerous coccus-type bacteria associated with halite. The finding of hydrocarbon-degrading bacteria, paraffin wax and graphite in the oil crust may indicate they have had a significant role in the weathering of the *Nakhodka* oil during the 9-year bioremediation.

The biodegradation of heavy oil from the *Nakhodka* oil spill by indigenous microbial consortia was monitored over 429 days at the laboratory scale. The indigenous microbial consortia consisted of bacteria and fungi, as well as the bacterium *Pseudomonas aeruginosa* isolated from the Atake seashore, Ishikawa prefecture, Japan. Both bacteria and fungi had a significant role in the observed biodegradation of heavy oil during the 429 day bioremediation with respect to the pH of the solution. Hydrocarbon-degrading bacteria tended to play the greatest role under neutral–alkaline conditions (pH of 7–7.8). On the

Fig. 10. An oil line (indicated by arrows) showing the pollution at the Penlipo rocky beach by heavy oil. Oil drops have dried by October 2008, 9 months after the accident.

other hand, when the conditions became acidic (pH of 2–4), the fungi took over the degrading of the heavy oil. During that period, the amount of aliphatic hydrocarbons reduced significantly, whereas the amount of aromatic hydrocarbons remained relatively constant after 429 days of bioremediation. An experimental study was undertaken to investigate the bioavailability of kaolinite clay minerals and how they play an important role in seawater polluted during the *Nakhodka* oil spill, since kaolinite clays have enabled hydrocarbon-degrading bacteria to grow well. Transmission electron microscopy-energy dispersive X-ray spectroscopy imaging suggested the clays present in oil-polluted seawater were capable of stimulating oil-degrading bacteria, probably because (1) Si from clay facilitates bacterial usage of oil and (2) C-O-Na-Si complexes on the surfaces of bacterial cell walls are a stimulator for oil-degrading bacterial growth in seawater contaminated by the *Nakhodka* oil spill (Chaerun et al., 2004, 2005, 2007). Degradation of aromatic hydrocarbons by microorganisms likewise indicates a close relationship between heavy oil and microorganisms (Tazaki et al., 1997; Tazaki, 2003; Chaerun and Tazaki, 2003, 2005;

Fig. 11. The mud flat of Gaemok Harbor is a good area for cultivating oysters and crabs, but the oil spill greatly damaged the natural ecosystems there. There was almost no cultivation of oysters even on October 16th, 2008. The oil line can be seen on the rock wall.

Chaerun et al., 2004; Tazaki et al., 2006). Sequence analysis of 16S rDNA showed the bacterial communities of the *Nakhodka* oil spill-contaminated coastal sites were dominated by genus *Pseudomonas* during the 5-year bioremediation. Sulfur is the third most abundant element in crude oil. It is important to note, however, that the high S content in heavy oil might affect the oxidation rate of oil by bacteria during the bioremediation. Genus *Pseudomonas* is apparently equipped to cope with aliphatic hydrocarbon toxicity and may, therefore, have been a primary catalyst for aliphatic hydrocarbon degradation close to the origin of the *Nakhodka* oil spill during the 9-year bioremediation (Tazaki et al., 2006). The clays are capable of stimulating microbial growth in combination with biofilm formation, and the clays act as microbial growth-support materials.

Taean declaration on the environment and development

One year after the *Hebei Spirit* oil spill, the 2008 Taean International Environmental Forum assembled to remember the accident and resolve that it never happen again, and to

Fig. 12. The top surface mud at Gaemok Harbor, brown in color only for the top 5 cm, is relatively clean, but underneath the sediment is oily, black and odorous in October 2008. Many dead crabs were present but some small living organisms survived in the oily mud.

urgently seek initiatives for overcoming the disaster and restoring the area's once–pristine environment. The 1.3 million volunteers who addressed and redressed the environmental contamination are to be recognized, encouraged, and supported for their contribution to environmental protection and enhancement (Fig. 16). The clean state of the sandy beach at Mallipo can be observed one year after the accident (Fig. 17). The sandy beaches at Ocean Castle (left) and Gureumpo Beach (right) were clean one year after the accident. Many sea birds and other organisms are returning to the beaches (Fig. 18). Fisherman recommenced the harvesting of shells at Gureumpo Beach one year after the accident (Fig. 19). Abundant floats have drifted ashore from China to Ocean Castle in Korea (Fig. 20). Because many Asian countries share the Japan Sea, international cooperation, agreements and support

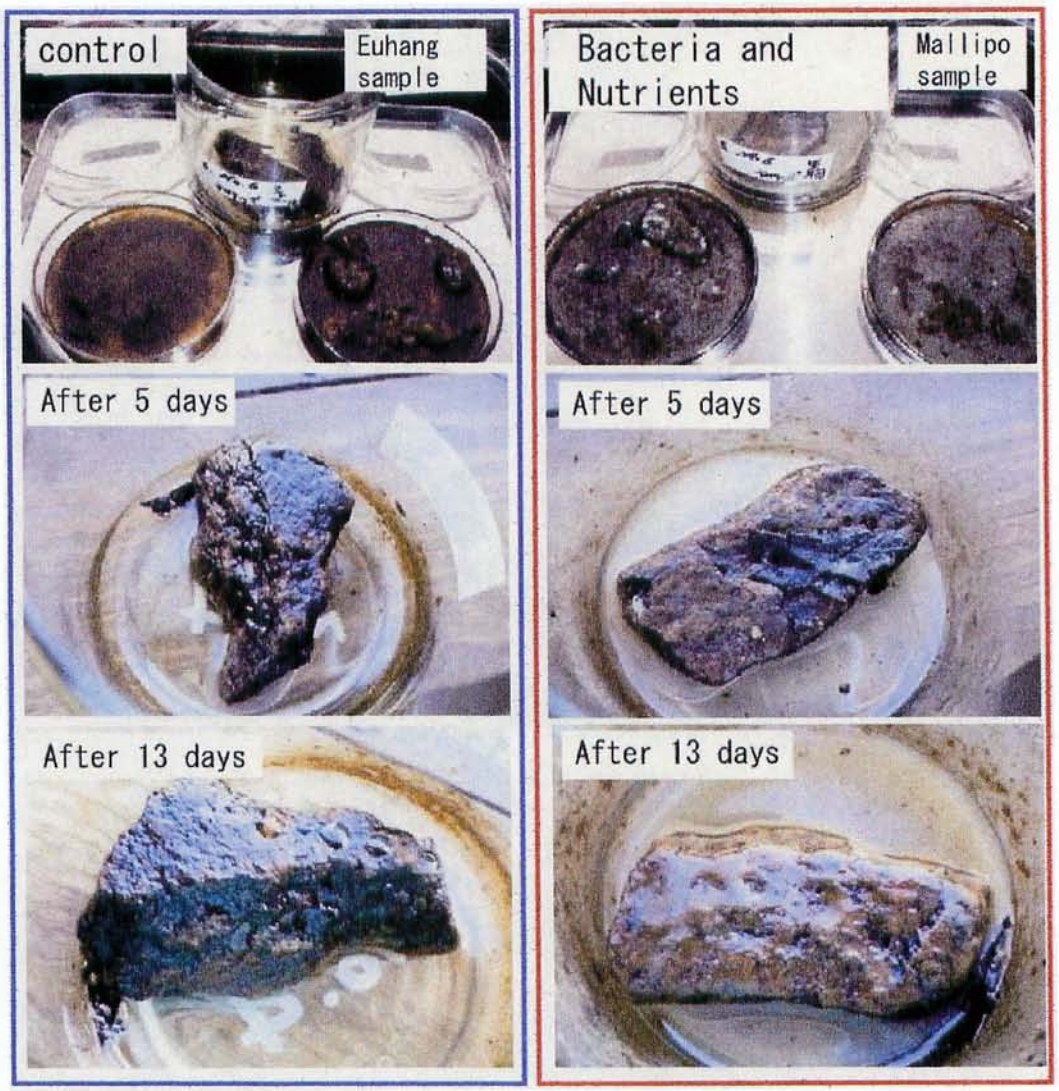

Fig. 13. Bioaugmentation of oil on the surfaces of the rocks collected from Euhang and Mallipo Beaches. The surfaces were clean 13 days after the addition of bacteria and nutrients (right).

systems are required to maintain the clean, natural conditions of the sea in a sustainable future.

Summary

An oil spill occurred when a Hong Kong-registered supertanker, *Hebei Spirit*, was accidentally rammed by a South Korean-owned barge that came unmoored from its tugboat in rough seas about 10 km off Mallipo Beach on the Taean Peninsula, South Korea, on December 7th, 2007. A total of 12,547 kl of heavy oil and crude oil entered the ocean. This

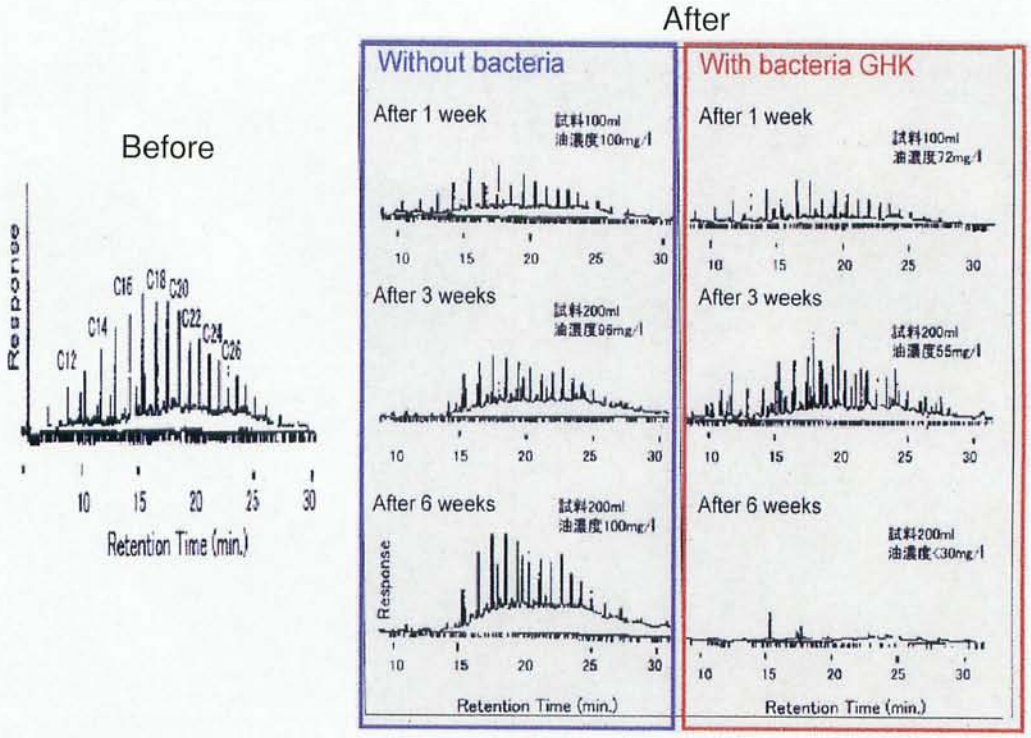

Fig. 14. Representative gas chromatograms of aliphatic compounds for a control (left) and heavy oil weathered by bacteria (right) after 1, 3, and 6 weeks. The effect of the presence of Euhang bacteria, is clearly seen.

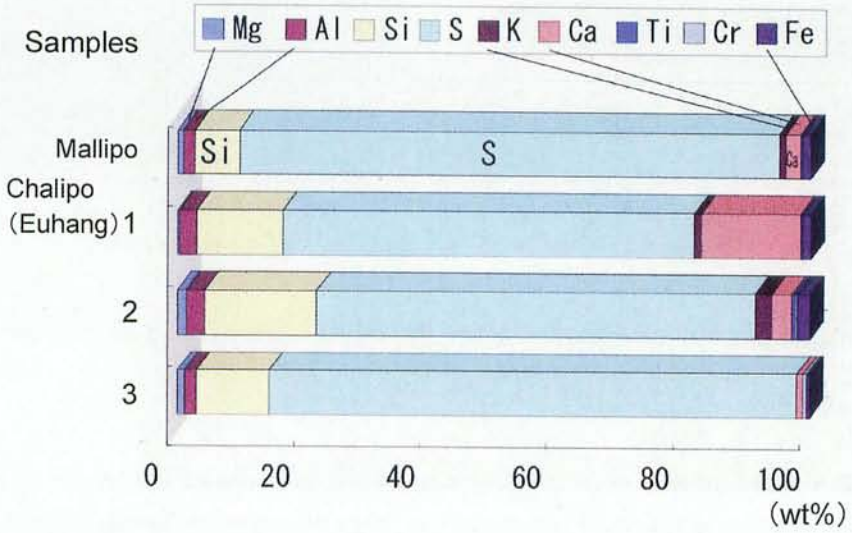

Fig. 15. Energy dispersive X-ray fluorescent analyses of contaminated oil collected from Mallipo and Chalipo Beaches.

Table 1. Measurements of the characteristics of seawater, pH and EC, at Mallipo and Euhang Beaches compared with normal seawater values around Niigata and Ishikawa prefectures in Japan.

Sampling Site	pH	EC (mS/cm)	Date
Mallipo	7.2	43.9	January 5, 2008
Mallipo	7.4	45.1	October 15, 2008
Euhang	7.4	26.1	January 5, 2008
Euhang 1	7.7	44.0	October 15, 2008
Euhang 2	7.8	42.9	October 15, 2008

Sampling Site	pH	EC (mS/cm)	Date
Niigata	8.2	43.5	July 21 , 2007
Ishikawa	8.3	37.5	July 27 , 2007

Table 2. Volatile aromatic hydrocarbon concentrations in the atmosphere at Mallipo and Chalipo Beaches on the Taean Peninsula measured using a personal air sampler ($\mu g/m^3$).

No.	Benzene	Toluene	*m*-and *p*-Xylene	*o*-Xylene	Naphthalene	Fluorene
1	23	[460]	4	<3	<3	<3
2	<8	[1300]	<8	<8	<8	<8
3	<8	[1100]	<8	<8	<8	<8
4	<8	[1300]	<8	<8	<8	<8
5	<8	[1600]	<8	<8	<8	<8
6	24	[550]	5	<3	<3	<3
7	<8	[1600]	<8	<8	<8	<8
8	<8	[1300]	<8	<8	<8	<8
9	<8	[1700]	<8	<8	<8	<8
10	<8	[1400]	<8	<8	<8	<8

Table 3. Volatile aromatic hydrocarbon concentrations in the atmosphere at the site of the *Nakhodka* tanker oil spill off the coast of Japan in 1997 measured using personal air samplers ($\mu g/m^3$).

No.	Atmospheric concentration ($\mu g/m^3$)			
	Benzene	**Toluene**	*m*-and *p*-Xylene	*o*-Xylene
1	1.02	2.06	0.85	0.26
2	1.36	4.82	8.36	3.80
3	1.15	2.22	1.16	0.14
4	n.d.	11.70	33.34	16.32

2007.12.8

2007.12.10
2007.12.11

Fig. 16. The oil spill occurred when the Hong Kong-registered supertanker *Hebei Spirit* was accidentally rammed by a South Korean-owned barge that came unmoored from its tugboat in rough seas about 10 km off Mallipo Beach on Taean Peninsula, South Korea, on December 7th, 2007. A total of 12,547 kl of heavy oil and crude oil entered the ocean (left). 1.3 million volunteer workers (right) succeeded in cleaning up sandy and rocky beaches in December 2007.

was more than twice as much as in South Korea's previous worst spill, in 1995. In this study, on-site surveys for checking and observing the oil condition were conducted at Mallipo and Euhang Beaches on January 5–6th, 2008, one month after the spill, and again on October 15–16th and December 7–9th, 2008, one year after the accident. 1.3 million volunteers succeeded in cleaning up sandy and rocky beaches, but the mud flat area retained an abundance of oil below the surface one year after the accident. Thus we need to find a better way to clean up an area of oily mud. Bacterial remediation using clays is one such method for removing oil without the use of man–made chemicals.

Acknowledgments

I would like to thank Sachie Suzuki, Atsuko Fukuyama, and Keely Brandon of Kanazawa University for assistance with the fieldwork.

Fig. 17. The cleaned sandy beach at Mallipo in December 2008, one year after the accident.

Fig. 18. The cleaned sandy beaches at Ocean Castle (left) and Gureumpo Beach (right) in December 2008, one year after the accident. Many sea birds and organisms returned to the beaches.

References

Chaerun, S.K. and Tazaki, K. (2005) How kaolinite plays an essential role in remediation of Oil–polluted seawater. *Clay Miner*. **40**: 481–491.

Chaerun, S.K., Tazaki, K., Asada, R. and Kogure, K. (2004) Bioremediation of coastal areas 5 Years after the *Nakhodka* oil spill in the Sea of Japan: Isolation and characterization of Hydrocarbon-degrading bacteria. Environ Intern 2004, **30**: 911-922.

Chaerun, S.K., Tazaki, K., Asada, R. and Kogure, K. (2004) Alkane-degrading bacteria and heavy metals from the *Nakhodka* oil spill-polluted seashores in the Sea of Japan after five Years of bioremediation. Sci Rep Kanazawa Univ, **49**: 25–46.

Chaerun, S.K. and Tazaki, K. (2003) Hydrocarbon-degrading bacteria in the heavy oil polluted soil and seawater after 5 years of bioremediation. In Water and soil environments: Microorganisms play an important role. Edited by Tazaki K: 21st century COE Kanazawa University, 187- 204.

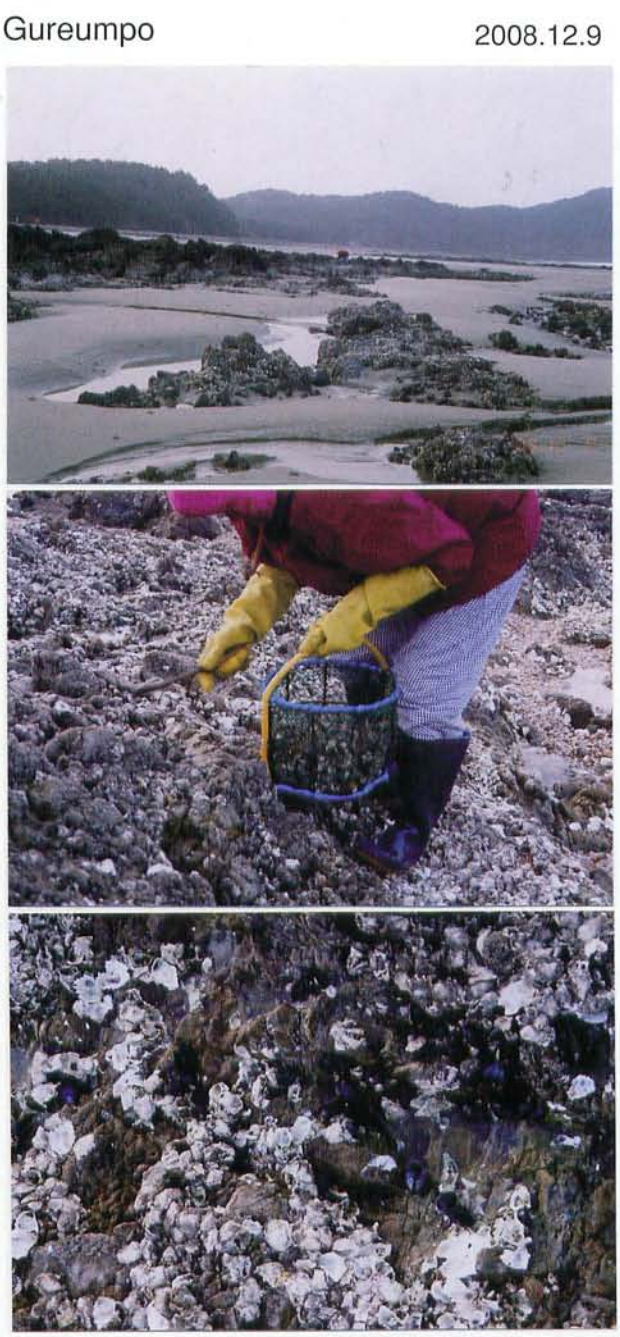

Fig. 19. Fisherman began harvesting shells at Gureumpo Beach in December 2008, one year after the accident.

Fig. 20. Abundant floats have drifted ashore from China to Ocean Castle in Korea in December 2008.

Chaerun, S.K., Tazaki, K., Asada, R. and Kogure, K. (2005) Interaction between clay minerals and hydrocarbon-utilizing indigenous microorganisms in high concentrations of heavy oil: implications for bioremediation. Clay Miner, **40**: 105–114.

Chaerun, S.K., Asada, R. and Tazaki, K. (2007) Biodegradation of heavy oil from the *Nakhodka* oil spill by indigenous microbial consortia, *Intern J Appl Env Sciences*, **2**: 19-30.

Jeffrey, L.M. (1980) Petroleum residues in the marine environment. In Marine environmental pollution: 1-hydrocarbon. Edited by Geyer RA: Elsevier Amsterdam, 163-179.

Tazaki, K., Sawano, N., Nagasaka, M., Aoki, A., Matsumoto, K., Nishida, S., Tawara, K., Ueshima, M. (1997) Heavy oil spilled from the wrecked Russian tanker "*Nakhodka*" attacked the coast of Hokuriku district, and remarkable microbial remediation is advancing. Jour Geol Soc Japan, 103: 7-8. (in Japanese)

Tazaki, K. (2003) Heavy oil spilled from Russian tanker "*Nakhodka*" in 1997: towards eco-responsibility, earth sense. Kanazawa: 21st Century COE Kanazawa University, 440 pp.

Tazaki, K., Watanabe, H., Chaerun, S.K., Shiraki, K., and Asada, R. (2006) Hydrocarbon-degrading bacteria and paraffin from polluted seashores 9 years after the *Nakhodka* oil spill in the Sea of Japan. ACTA GEOLOGICA SINICA, **80**, 432-440.

Trzesicka-Mlynarz, D. and Ward, O.P. (1995) Degradation of polycyclic aromatic hydrocarbons (PAHs) by a mixed culture and its components pure cultures, obtained from PAH-contaminated soil. Canad Jour Microbiol, **41**: 470-476.

UNEP (2008) Taean International Environment Forum: West coast oil spill accident, 1 year from then. Taean Chungnam Province Republic of Korea, pp 100.

Whyte, L.G., Bourbonniere, L. and Greer, C.W. (1997) Biodegradation of petroleum hydrocarbons by psychrotrophic *Pseudomonas* strains possessing both alkane (*alk*) and naphthalene (*nah*) catabolic pathways. Appl Env Microbiology, **63**: 3719-3723.