# THE ENVIRONMENTAL IMPACTS ON HEAVY OIL SPILLED FROM THE WRECKED RUSSIAN TANKER *NAKHODKA* ATTACKED THE COAST OF HOKURIKU DISTRICT, JAPAN, IN 1997

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## ABSTRACT

<The *Nakhodka*> shortly after heavy oil spill attacked the Hokuriku district, Japan, scientists from various specialties cooperated together to act quickly on the environmental impacts. We carried out on – the – site investigations immediately, and measured the level of air pollution, studied C – typed heavy oil ingredients and its toxicity, developed methods of removing heavy oil, and also carried on studies, such as soluble substances in seawater, sedimental movement, effects on inter – tidal organisms and micro – bioremediations. In this paper, we introduce field states, and discuss what we have done since then for the future action.

## INTRODUCTION

The *Nakhodka*, a Russian tanker loaded with C – typed heavy oil of 19,000 kl was sunk off Oki Island, Shimane Prefecture on January 2nd, 1997. Five days later, the bow – part had reached to Anto, Mikuni Town, Fukui Prefecture, spilling heavy oil of no less than 6,200 kl (Fig. 1A). After oil spill attacked not only Echizen seashore, Fukui Prefecture, but also Katano seashore, Ishikawa Prefecture on January 8th, it had extended over 250 km of seashores including Kanazawa, Wajima, and Suzu in Ishikawa Prefecture. Especially, Anto, Mikuni Town in Fukui Prefecture (Figs. 1B, 2A, B), Shioya seashore (Figs. 3, 4), Katano seashore, Kaishi – misaki, Togi Town and Shiota Village (Fig. 5) in Ishikawa Prefecture were significantly damaged. In Mikuni, oil – removal effort was started by local residents, government officers, members of the Self – Defense Forces, and volunteers on January 8th (Fig. 1B, Fig. 2). It involved 202,900 people who helped for the cleaning, and victimized five lives of them due to physically heavy tasks under severe and cold winter weather condition (Fig. 6B). Scientists of local academic institutions, such as Kanazawa University, Seiryo Women's Junior College, and Kanazawa Seiryo University (former Kanazawa College of Economics) started investigation quickly to follow possible impacts on air, seawater, and ecosystem, as well as to specify impacts from heavy oil and ocean currents, with a multi – disciplinary basis. We, in Tazaki's Lab of Environmental Earth Sciences of Kanazawa University, investigated the areas to start out studies on air, water, soils and bacteria, which are key factors for the start of our environmental study. Also, we encouraged students to go for help, so that the total number of students who joined the man – power cleaning counted one hundred at least (Figs. 4, 5, 7, 8). After field – observations and sampling, we sent those samples to four national universities, such as the Hokkaido, Niigata, Shimane, and Kyusyu. On February 8th, Tazaki, Tawara and Yajima examined the distribution of heavy oil sheets and oil slick on the surface of sea by helicopter of aerial research (Fig. 9). Although one month had already passed, we could see broad – band of heavy oil, sash – like oil slick and oil chunk with seaweeds (Fig. 10). On April 8th, a big collaboration among Japan Advanced Institute of Science and Technology (JAIST), Kimitsu City of Chiba Prefecture, Kanazawa University, Seiryo Women's Junior College and boring technicians in Fukui Prefecture, was held on Hamaji and Katano seashores. As a result of boring on sandy beaches, we recognized that layers of heavy oil had been deposited for 60 cm in depth, despite of the fact that surface of those beaches looked perfectly clean (Fig. 11A). Therefore, even after each countermeasure team had been broken up, we, local scientists kept carrying on follow – up examinations. The oil had been sunk toward the bottom after two days, also after three months and four months (Figs. 11 B, C, D). The color of oily sand had turned from brown to black.

Ishikawa Prefecture and Environment Agency Government of Japan (present Ministry of the Environment) established the task force on each section from the beginning, as well as investigated (1) the environment (Ishikawa Prefectural Institute of Public Health and Environmental Science), (2) wild life (Noto Marine Center, Nature Conservation Division), and (3) oceanic organisms (Fisheries Division), as "Effects of Russian Tanker's Heavy Oil Spill". The Environmental Agency checked water and sedimental chemistry at eighty spots in nine prefectures from Yamagata Prefecture to Shimane Prefecture where heavy oil reached.

According to Ishikawa Prefecture's quick check, the calorific value of the heavy oil was 3,800 cal/gr, specific gravity: 0.97, water content: 54.56 %, fluidity: 45 degree, sulfur content: 0.52 %, and residual carbon content: 4.23 %. The Environmental Agency reported that carcinogenic substances, such as benzo (a) pyrene, heavy metals, such as vanadium, and polycyclic aromatic hydrocarbons (PAHs) were detected from floating heavy oil. The n – hexane extracts were also detected through water examinations on January 11$^{th}$, 16$^{th}$, and 24$^{th}$, 1997.

Our results were shown by Chiba, Matsumoto and Sampei. Hayakawa also reported PAHs, n – paraffin series, and n – hexane extracts in oil from the *Nakhodka* and in drift – oil as well. Each research result was reported in the Emergency Conference on March 23$^{rd}$, 1997 (Tazaki, 1997a).

## DISTRIBUTION OF HEAVY OIL SPILL AND REMOVAL EFFORTS

The day before the inspection of January 9$^{th}$, we did experiment with A – typed heavy oil which resulted dissolving into surfactants and absorbing to kitchen – oil absorbent material. That prompted us that the treatment would be easy on – the – site. However, seeing the sea surface covered with dark thick sheet of heavy oil (Fig. 1A) made us realize the seriousness, which remained me the Kuwait's case in Persian Gulf. Tried to absorb heavy oil with cellulose sponge in a beaker, its viscosity was too high to be absorbed, and we could bring up the whole beaker with the sponge. Additionally, floating heavy oil was not dissolvable to surfactant. After the dawn, the wrecked part of *Nakhodka* was visible (Fig. 1A right side), and local fishermen gathered to clean up with their buckets and ladles. Japan Self – Defense Forces task force officers in black rain coat, vacuuming trucks, crane trucks, and tank trucks surrounded the seashore. What we saw was that people ladled heavy oil with dippers, handed them from hand to hand to tanks (Fig. 1B), which technologically highly developed Japan was so proud of herself that she had never imagined her people would have done such a thing. Yet, that was the only thing which people could have done in that place at that time. That night was the start calling up specialists who had known about the incident of Mizushima back in 1974 (Azuma *et al.*, 1976, 1985, 1990) and we also asked various local scientists to pay an attention.

On the very next day, January 10$^{th}$, I started emergency inspections with my students, sampling the oil, seawater, seaweeds, and shellfish, and measuring seawater chemistry and volatilizable substances in the air. The color of C – typed heavy oil was black, while it changed to brown overnight (Figs. 3, 4). Conditions of emulsified oil were rapidly changed within a few days. This phenomenon found through field examinations that heavy oil in mass was viscous in one to two days, and the color of oil turned from black to dark brown, and finally to light brown as the viscosity grew. One night was long enough that seawater came into the heavy oil in 60 to 80 %. Those experiences of the *Exxon Valdez* in Alaska (43,000 kl) (Owens, 1994; Wolfe *et al.* 1994; Neff and Stubblefield, 1995; Bence *et al.*, 1996; Pairk *et al.*, 1996), Kuwait, Mizushima (7,500 to 9,500 kl) (Tsuda, 1975; Okaichi, 1976), and the *Juliana* in Niigata (7,200 kl) (Chihara, 1972; Honma and Kitami, 1974; Aoki *et al.*, 1975) insist on the importance to remove oil in sea water in forty eight hours before oil gets more volume with water and its viscosity gets high (Azuma, 1990; Maruzen Oil Co. (present Cosmo Oil Co., Ltd.), 1990; Hanashima, 1995; Paine *et al.*, 1996).

In fact, as we examined the coastline, it looked impossible to remove heavy oil on beaches by machinery. Through the field observation from Mikuni to Kaga, Wajima, and Suzu, the Hokuriku coastline is quite complicated with rocky, sandy, and pebble beaches. Addition to geophysical difficulties, main drive ways which those trucks can get in are twenty to fifty meters away from the seashores. Only way to remove oil should rely heavily on what we could do with our own hands. After volunteers tried to separate oil and sands by sieving, small sand grains were also coated by heavy oil (Fig. 12). The stormy weather around the Hokuriku district in winter, however, prevented removing oil for days either from air, by ship, or from shores. On January 22$^{nd}$, the oil collected in sandy bags on beach was taken by surf due to the terrible weather. More than 6,000 oil – filled bags arranged on the beach from Katano to Kurosaki, weighed at least 10 kg each, got lost into the sea because of windstorm (Fig. 13). While people ladled heavy oil in Anto, dippers were no use in sandy beaches, where people ended up using butter – knife – like spatula and their own hands. They put oil in drums and holes dug nearby or in rice field at Sosogi (Fig. 14). Although the sandy beach in the coast of Shiota looked no oil on it, we got much stick oil on the back of our rubber boots after walking there (Fig. 5), and oil – soaked seaweeds were washing ashore (Fig. 8). In Shioya and Katano, sixty to seventy trucks and cranes came in to make mounts of oil filled with sands (Fig. 3). As a result of mixing heavy oil and sands, it got the condition worsened. The heavy oil leaked out from the sandy mounts (Fig. 3 arrow). Both clean and oily sand grains were mixed up together. The government decided to add about five thousand cubic – meters of sands in late June, waiting for tourist season. On the other hand, Tsuruga City decided not to open local beaches to tourists because they did not complete oil removal. On July 3rd, black oil was still stuck to the inlet of Anto, Mikuni (Fig. 15) and Aramiko Island, a preservation area of wildlife (Fig. 16).

## EFFECTS ON THE AIR

Department of Welfare and Environment, Fukui Prefecture reported that air pollution became severe at Anto day – care center. Hydrogen – carbon five to six times as much as the standard was detected there (the max: 1.51 ppm). Therefore, the children had to evacuate to a safety place for a while. The amount of floating particles was as much as in downtown in Fukui City. Moreover, local people and volunteers who joined the clean – up activities complained those symptoms, such as headaches, sore throat and pains in eyes and noses, despite the fact they did wear activated carbon masks. Some other cases were that contact lenses got dirty and the allergy got worse in fumes from heavy oil and kerosene used for wiping oily rainwear and rain boots. Volunteers who irrigated oily seabirds complained the same symptoms. Hayakawa's research group analyzed the air with a portable air – sampler (Fig. 17). We also collected aerosols with a portable sucking air – sampler twice on seacoast in Nagahashi Seashore, Suzu City. The dark gray sucking filter paper suggested that the air contained a lot of heavy oil ingredients. K. Ando's research group reported compositions of vaporized contents (benzene, toluene, and xylene). The concentrations of toluene and xylene were higher than that of benzene. Compared to fixed air collection system and portable air collection equipment attached to people's body on the cleaning scene of vaporized contents, every content from portable air collection equipment was two to three times higher than that from fixed air collection system. The result presumed that working people's temperature made it vaporized or some chemicals did exist (Fig. 17).

Then, in April, vaporizing contents started to effect on vegetations. Watanabe *et al.* (1997) reported that abnormality of narcissuses on seacliff in Anto was observed by means of SEM. In June, oil slick was still observed on the sea near the shore of Anto, Mikuni Town, and toxic organic solvent was used in some fishery bays around Anto, which we have to concern about influences on vegetation. Sawano (1997) pointed out the danger which the Exxon's ISOPAR H was in use in Mikuni area due to wiping the heavy oil. In general, if oil is attached to plants, it will cause leaf - , flower - , or root – shrinking, death, and abnormality of chlorophyll. C – typed heavy oil contains similar substances to plant growth hormone, which would disturb vegetation or distribution of vegetation. A certain area of vegetation involves long – life plants, that is, following – up investigation will be essential every decade.

## WATER EXAMINATION

Independent Administrative Institution of Ministry of the Environment (former Environment Agency Government of Japan), National Institute for Environment Studies (NIES) did emergency investigations concerning about the ecosystem including air quality and water chemistry from January 15th to 17th in 1997. They reported that higher concentrated benzo (a) pyrene than usual was detected from the seawater collected from four points, such as Mikuni, on February 26th. The worst concentration was from Ojima off shore of Mikuni: 0.036 $\mu$g/l.

We did carry out water examinations for a couple of times on approximately thirty points throughout Mikuni Town in Fukui Prefecture to Suzu City in Ishikawa during the term January 10th to April 21st in 1997, shown on Table 1. In each site, we checked the status of oil slick and measured pH, DO, Eh, EC and water temperature. At the point of Oogawa in Wajima City, freshwater coming from the river resulted in lower pH, EC, and water temperature than the other seashore points. At most points we had observed, oil slick on seawater was visual, while pH, DO, Eh, EC and water temperature were almost all normal on site. Our collaboration team, Chiba *et al.* (1997) determined the concentration of PAHs in seawater samples collected from points we did water examinations. Through our observation of the status of seawater on site, the contamination by heavy oil and oil slick were observed just on water surface, but did not seem to reach under the surface.

Separately, Ishikawa Prefecture and the Environmental Agency also checked water chemistry, such as water temperature, pH, DO, COD, SS, chlorine, n – hexan extracts, oil percentage, PAHs, organosulfur compounds, nickel, vanadium, paraffin series, and non – ionic surfactants at thirty points, collected from 50 – cm – deep seawater as for their standard. Oil was detected at a few points, while PAHs, organosulfur compounds, nickel, vanadium, and non – ionic surfactants were not detected. The n – hexan extracts which are an indication of heavy oil were not detected at all, either. However, in both Fukui and Ishikawa Prefectures, the maximum concentration of benzo (a) pyrene during January $15^{th}$ to $17^{th}$ was 0.036 $\mu$m/l, while the concentration in March went down to 0.0037 $\mu$m/l, which suggested a concern about accelerating the distribution and degradation of heavy oil.

Yajima reported effects on supralittoral and mediolittoral organisms. Snails (*Radiate* sp. and *Patelloid saccharina*) as representive supralittoral organisms, and laver, calcareous algae, and acmaea as mediolittoral indicators for oil contamination were observed closely but found no significantly damage. Yet, mediolittoral organisms' life spans are usually more than one year, thus, as a result of food web, they could be in danger eventually. As those organisms concentrate oil in their body, the community structure could change, so that middle to long term following up investigations are highly essential, considering the pattern of ecology. In the Gulf War, 1991, following over two million tons of oil spill contamination, toxic components, such as benzo (a) pyrene, caused supralittoral and mediolittoral organisms' death. When the water became clean again, planktons started rebuilding the food web, and then seaweeds, sea urchin, and ear shell did as well. Taken this example, it would take five to seven years that the healthy environment gets back (Tokuda, 1997).

Ishikawa Prefecture and the Environmental Agency were also checking influences on wild lives, such as mediolittoral organisms, supralittoral vegetation, and birds. In particular, they emphasized in investigating *Synthliboramphus wumizusume* in Nanatsu

– jima (Aramiko – jima) where heavy oil reached, distributing there was no immediate influence on nesting (Fig. 16). On the other hand, an autopsy of dead seabirds in heavy oil was in progress.

## COLLECTING HEAVY OIL AND SEPARATION

Taken the example of the supertanker *Exxon Valdez* incident in Alaska (Whitney, 1994), it would be the most effective to collect oil at sea after building oil fences. The *Nakhodka* accident in Hokuriku in winter time was not the case because oil – collecting ship could not leave harbor due to strong north – west wind, which caused environmentally big shock on a large number of famed seashores. In fact, this was not the first oil spill happened around Hokuriku district, which had experienced similar incidents off shore of Kyouga, Kyoto in January, 1990, and off shore of Niigata in 1971. According to Japan Coast Guard source, the number of oil tanker – related incidents counted 48 in 1995, 46 in 1994, and 64 in 1993 around Japan, and oil spill incidents counted as 243. Although Japan had experienced that many incidents, we did not learn enough from them and this time local people had to face the severe reality with their own hands and ladles as a result of our laziness (Sawano 1997; Tazaki, 1997a, b).

Cleanup ways of oil spill are machinery, chemical or biological, that vary depending on each geographical, geomorphological, and sedimental condition. Machinery methods are suction by vacuum tank (Fig. 2A, Fig. 14), separation by rollers and brushes, using with fishery net and sieve (Fig. 12), cleaning by high pressure and hot water with detergents, and spraying an amount of seawater to push the oil back to the ocean (Fig. 5). Given the situations of high wave in Hokuriku, especially in winter, the heavy oil was viscous, and the coastline was complicated, it was very difficult to remove oil on sandy and pebble beaches (Fig. 6B, Fig. 8, Fig. 13). Thus, removal technology which the *Exxon Valdez*'s case had developed was not just simply brought to the *Nakhodka*'s case in the Hokuriku district with the severe winter weather. How could we clean up those oil – contaminated sands and pebbles? We tried to separate sands and pebbles from oil on beach: after warming up seawater about 40 ℃ on beach, adding the oily sands and pebbles in it, resulting quickly in heavy oil, seawater, sand and pebbles separately (Fig. 18). Cleaned – up pebbles, sands and seawater could be back on the scene, and heavy oil after the treatment could be reused (Fig. 19). We developed the separation equipment with using oil drums to reduce cost and risk (Mukai *et al.*, 1997) (Fig. 20). Using drift wood and trash on beach for fuel to warm up seawater was like "kill three birds with one stone" in Japanese way (Fig. 19). When Matsumoto, one of my students, observed the sand granules under fluorescence microscope to know if it was perfectly clean or not, he accidentally witnessed that the oil was decomposed by the exposure of ultraviolet, which would suggest strong sunshine during summer accelerates to decompose the rest of heavy oil (Fig. 21). Matsumoto *et al.*, (1997) reported the separation method and oil separation experiments later in separated paper. Also, the Institute of Physical and Chemical Research (RIKEN) successfully reported a resonator using electromagnetic waves to break down the carbon bond into monomers, and then they succeeded to extract kerosene from 85 % of original C – typed heavy oil after they put together carbons again in 230 ℃. Furthermore, we considered a separation method with using clay minerals. Separated oil was useful as a fuel and could be in recycle. We should think of not only for – the – moment treatments, such as burning or burying, but also practical methods like recycling.

Here, 15,000 cubic – meters of oily sands were nothing but a burden since a practical way of separation had not established. There were some other cases that only a few percentages of oil was included in drums which people meant to collect heavy oil. Ishikawa Prefecture decided to consider oily sands containing less than 5 % of oil as dirt which would be buried in industrial waste plants, and finally in May the oily sands were literally buried in a "managing – typed" plant, which cost two – thirds of burning all of them and left worries to contaminate underground water and soil as well. We had to take examples seriously that treatments with chemical detergents and high temperature and pressure pumping method destroyed ecosystems around coast or delayed recovery of healthy ecosystems after oil spill in the past, because the method killed all kinds of microorganisms that have an important role to keep well – balanced food webs. In the *Exxon Valdez*'s case, a neutralization treatment withdrew a good outcome at some points, but left a little concern on the ecosystem, such as decreasing the number of ocean animals (Radwan *et al.*, 1995; Bence *et al.*, 1996; Azuma, 1990; Morita, 1997).

# HEAVY OIL – DEGRADATION BY BACTERIA

As long as it would be impossible to remove all heavy oil physically and chemically, the rest will be degradated by bacteria in seawater and sediments. We only could hope those bacteria will be a great deal on heavy oil since removal activity by human is limited. This kind of oil spill incident happens all time over the world, so that bioremediations should be getting attentions. Hydrocarbon – degradating bacteria are distributed all over the Japan coast, which could be used as a bioremediation with using nitrogen and phosphorous nutrients. Although a bioremediation method was taken at some level in the Mizushima incident, it had not developed enough. Therefore, this time we challenged the method again (Tazaki *et al.*, 1997) (Figs. 22, 23, 24). In the *Exxon Valdez*'s case, EPA and the oil company collaborated together over four years to report (NOAA, 1994, 1995) that the rate of degradation became three to five times faster than usual with spreading nutrition and it was no significant damage to the environment. Today, the US alone has more than three hundred organizations which have bioremediation technology and we thank some of which gave us practical advice. If we really hope to conserve the natural environment and the fishery environment, we have to think which way to damage the nature the least.

In our group, K. Tawara, J. Akai, and S. Nakamura reported heavy oil degrading bacteria. In each case, natural cultivation of seawater, sand and heavy oil sampled in the scean showed cocci, bacilli, and filamentous bacteria (Figs. 22, 23, 24). Hydrocarbon – degrading bacteria are known to exist in many aquatic environments. Which hydrocarbon ingredient of oil can be degraded by those bacteria is the most essential (Shimizu, 1978, 1982; Higashibara and Suzuki, 1990). It is known that saturated hydrocarbon, such as n – alkane is the most micro –biodegradable and the next most bio – degradable is PAHs. The least degradable is reported asphalt and resin. Indeed, the decrease of n – alkane was found from a sample of floating oil on January 10$^{th}$ (Sampei, 1997; Murakami, 1997; Higashibara, 1997). Bacteria can not necessarily degrade all ingredients of heavy oil but main ingredients degraded by bacteria depended on saturated and aromatic fraction: the rate of degradation was approximately 60 to 80 % and 20 to 30 %, respectively. However, the resin and asphaltene fractions tended to grow (Fujita *et al.*, 1997).

The asphaltene fraction in heavy oil was very slow to be degraded by bacteria so that it left on rocks and sank down to the sea bed. Temperature has rules on the rate of degradation very much: the higher, the faster, and the number of the bacteria was greater in sand than in seawater (Fig. 24). On January 15$^{th}$ in 1997, the number of all bacteria was $10^5$ to $10^6$ per 100 ml, while it decreased in March (Higashibara, 1997). The Gulf War in 1990 ended up creating more than 300 oil lakes after abundant oil spill on land, which contaminated the soil around there and a reason that the ecosystem was slow to recover was that surfactants and high – temperature water treatments killed bacteria (Tsuji and Chino, 1997). Furthermore, not a single type of bacterium but dozens species of bacteria interact each other to degrade oil (Fig. 23). A purified species of bacterium did not work well, while various types of local bacteria did degrade oil much (Higashibara, 1997). There, adding potassium phosphate, inorganic nitrogen, and ammonium sulfate could help and organic compounds like peptone and yeast extract could activate the growth of bacteria. Thus, there is no need for foreign oil – degradation bacteria, and it is important to maximize the ability of local bacteria on – the – site (Swannell *et al.*, 1996; Yamamoto and Hiraishi personal comments). In another case, Cyto Culture, the USA succeeded to emulsify the oil on Katano sandy beach in six weeks with using Biosorbent made from soy beans (Sawano's personal statement). Moreover, Marine Biotechnology Institute Co., Ltd collected floating heavy oil in both Fukui and Ishikawa Prefectures and the research to grow *Pseudomonas* sp. was in progress.

## NECESSITY OF FOLLOW – UP INVESTIGATIONS

In the mid April in 1997, people, such as fishermen, tourism industry and the government, wanted to finish up removal activities for protecting the resource. In fact, in many places where a great number of volunteers came in and cleaned up, it became clean and a part of the mixture of sand and oil was burnt by constructors. In April, high temperature and pressure cleaning method was taken place in Suzu, the surface was covered with mountain soils in Atake, and oily sand was buried in Kaga area so that none could see heavy oil any more on the surface. The truth was that people had been very exhausted physically and mentally, and fishermen needed to get started their job again. On April 27th, the Beach Recovery Day, the local government called it and started pulling up the empty bow – part of *Nakhodka*.

In May, however, the temperature got over 25 ℃ and heavy oil was observed in quite several spots on Shioya and Katano seashores. The boring investigation in April showed that heavy oil was 50 to 60 cm in depth, which became a realistic nightmare (Fig. 11). Also, in Mitsuko seashore, some oil balls were found to be washing ashore. Though in Nagahashi seashore rocky parts were washed by hot and high pressure water with detergents, the yellow – rose detergent was left in some hollows. Moreover, in December, 1999, heavy oil was coming out on the surface through Katano to Shioya (Fig. 25 lower). More significantly, the stern – part of *Nakhodka* was abandoned on seabed in 2,500 m depth, still holding 9,900 kl of heavy oil near Oki Island. The heavy oil has been leaked out 3 to 14 kl/day from the stern – part. The *Nakhodka* was aged about 25 years, so that iron body was not strong enough any more. The oily sands buried shallowly in the beach sand of Katano seashore, put head out on the partial cross section of sand beach (Fig. 25 upper, arrow).

We have been observing "water – oil – sediment interaction" experimental systems both outside and indoor testings. It is quite clear to resolve oil faster outside (right) than indoor (left), because of sunlight effects (Fig. 26). The pH, Eh and DO conditions of each system have been stable without EC for six years. The degradation bacteria in the system are still active after six years passed (Fig. 27).

On the other hand, heavy oil was still visible under rocks at Atake seashore on November 21st, 2001 (Fig. 28). In our latest follow – up field investigations, we found almost no evidence of C – typed heavy oil at Katano seashore (Figs. 28, 29, see also Figs. 12 and 25 for a comparison).

## FOR FUTURE GENERATION

We held the Emergency Conference in Kanazawa on March 23rd, 1997, counting 107 scientists over various specialties all over Japan. I have to say that it was a very rare case in Japan, which this many scientists were convened. Our work resulted in 200 – page report, and we were aware of continuing follow – up investigation in eco – system in spite of our specialties, which is very challenging for Japanese scientists. The Saudi – Arabian beach has still been contaminated since 1991. Also, in Alaska, oil still can be found in parts of the bay or under rocks. However, in the *Exxon Valdez*'s case, scientists have kept eyes on it very closely for more than fourteen years.

Since Japan introduced the fixed – 5 – year – tenure employment system in universities by implementing "Law Concerning the Term of Office for University Staff", who will be able to continue follow – up study for more than fourteen years ?

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**Figure 1** The bow – part of *Nakhodka* off shore of Anto, Mikuni Town, Fukui Prefecture and "carpet" of heavy oil (A) (January 9th, 1997). Removal efforts of heavy oil with ladles and buckets (B) (January 10th, 1997).


**Figure 2** Collecting heavy oil at Anto, Mikuni Town. SDF officers trying to suck heavy oil in the oily sea (A). Collected heavy oil by "man – power" (B). (January 10$^{th}$, 1997).

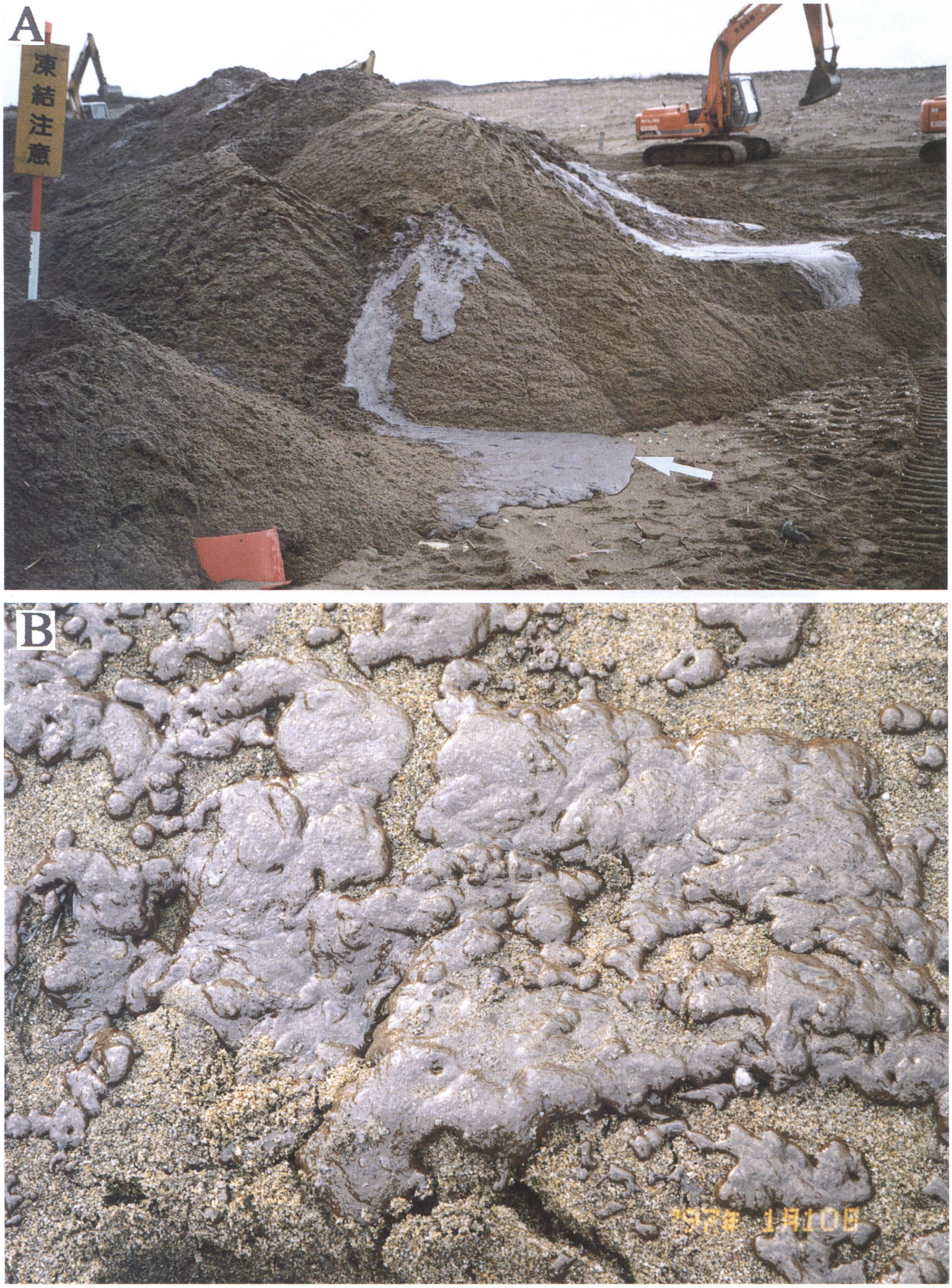


**Figure 3** Machinery collecting in the beach of Shioya seashore (A) and the leaking heavy oil from sandy mount (arrow). Emulsified heavy oil chunks drifted to sandy beach (B) (January 10th, 1997).



**Figure 4** Shioya seashore in Kaga (January 10th, 1997). Can you imagine how difficult to walk on oily pond – like beach? That was one thing we had to deal with during field investigations (left). Waves of heavy oil (right).

**Figure 5** Cleaning efforts of heavy oil drifted to graveled beach in Shiota Village of Wajima City (left), the oily waves washing ashore (right upper), and sticky heavy oil which we could collect with our boots (right down) (January $26^{th}$, 1997).

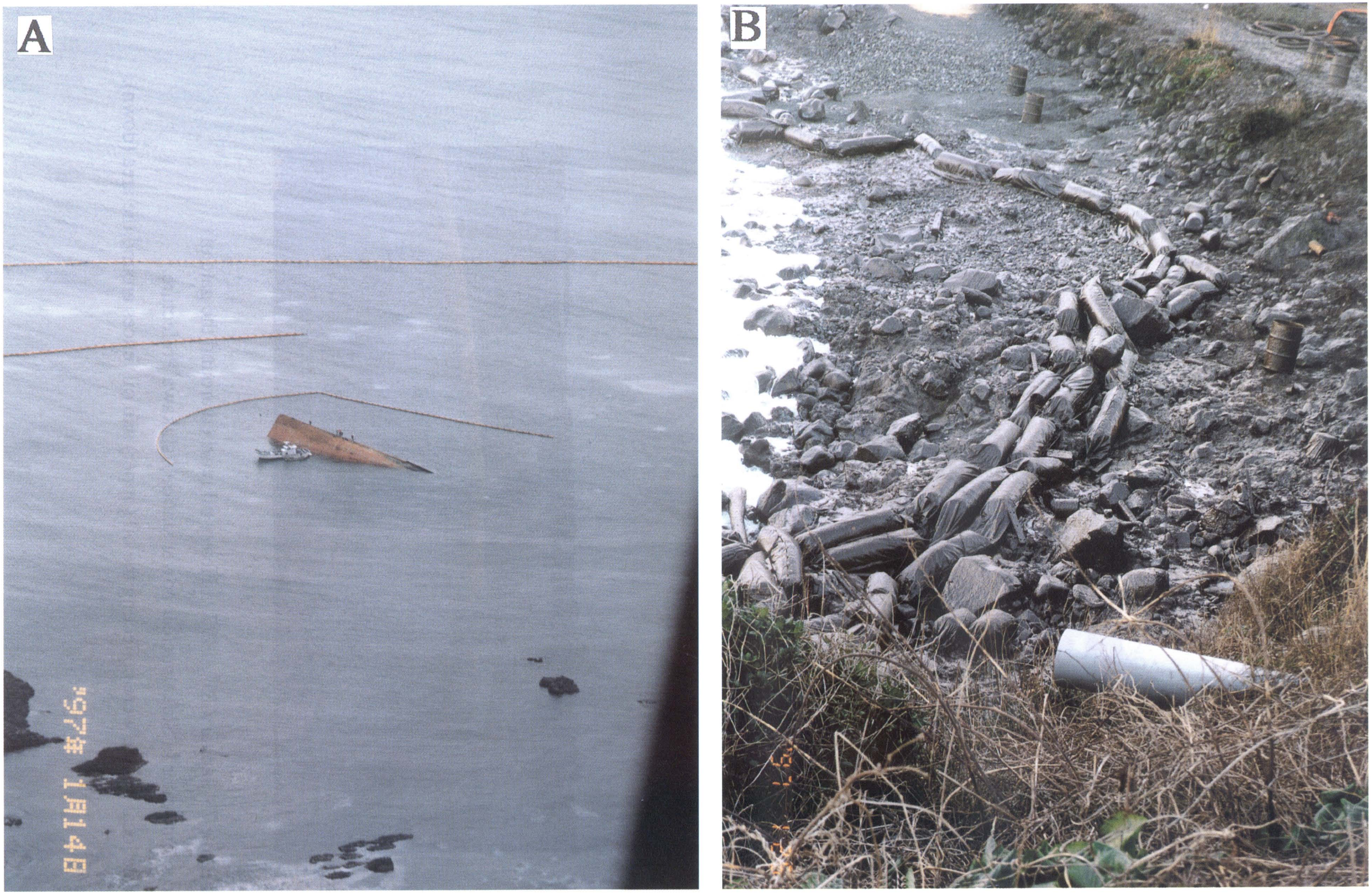


**Figure 6** Aerial research from Mikuni Town, Fukui Prefecture to Suzu City in Ishikawa Prefecture. The bow – part of the *Nakhodka* and three – layered oil fences to the ocean (A) (January 14th, 1997). The same oil fences soaked with heavy oil (January 25th, 1997).

**Figure 7** January 15$^{th}$, 1997. Heavy oil reached around the gate of coolant water in Shika nuclear power station, Ishikawa Prefecture.
The local people were collecting the oil (upper) and oil fences around the area (down).

**Figure 8** Atake seashore, Wajima City, covered with chocolate - like heavy oil (January 27th, 1997).


**Figure 9** Pumping up heavy oil from the bow – part of *Nakhodka* (upper) and widespread oil slick on the ocean (down) seen from the helicopter (February 8th, 1997).

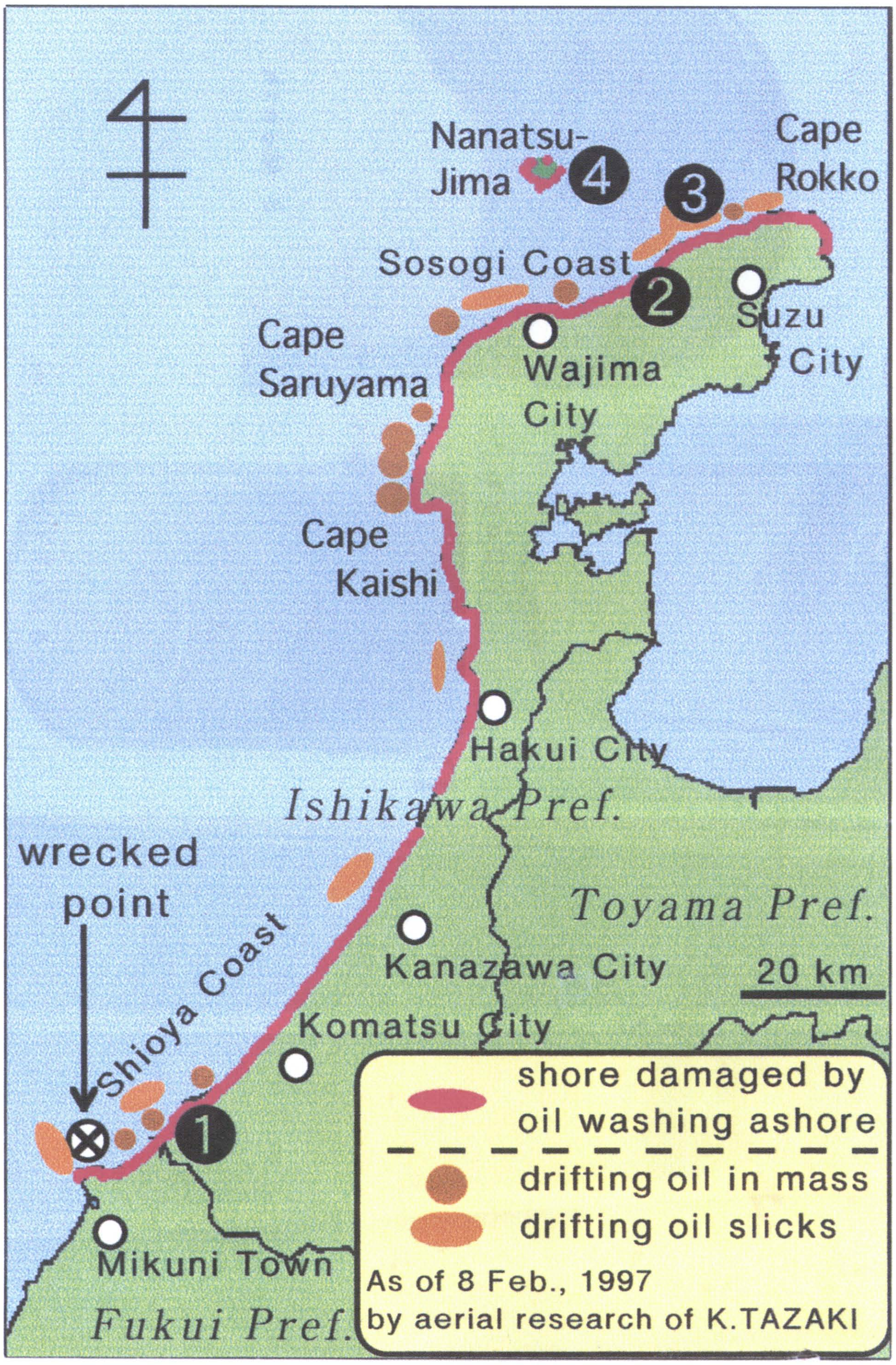


**Figure 10** Oil – contaminated hazard map by aerial investigations. Almost outer side of Noto Peninsula was visibly oil – polluted.

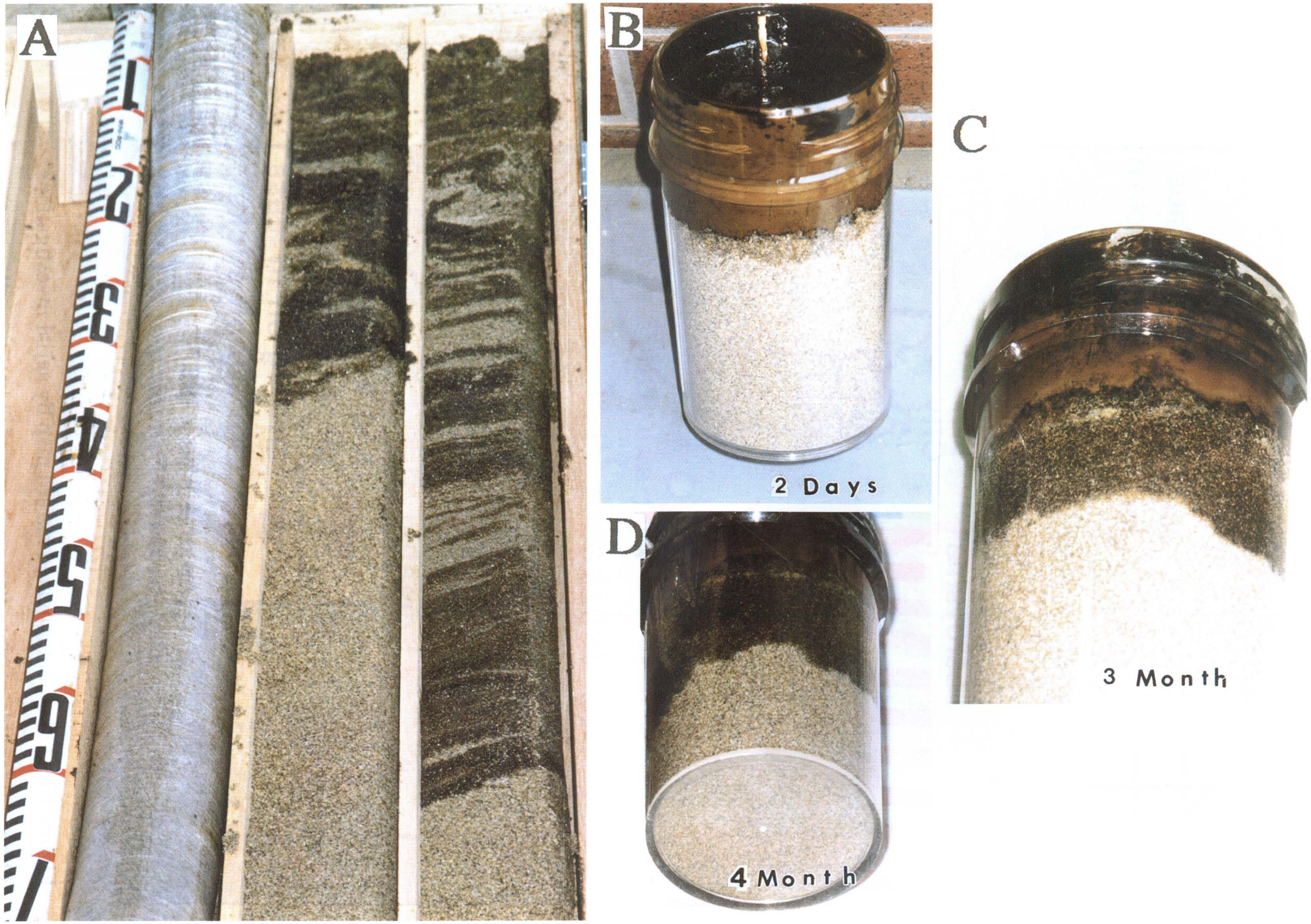


**Figure 11** The boring core of Onji seashore (left). 30 – 60 cm oil layers were visible (April 8th, 1997). Oil – seeping experiments with sands and oil collected from Shioya seashore in Kaga (right). The oil was exuded in more than 10 cm in three to four months.

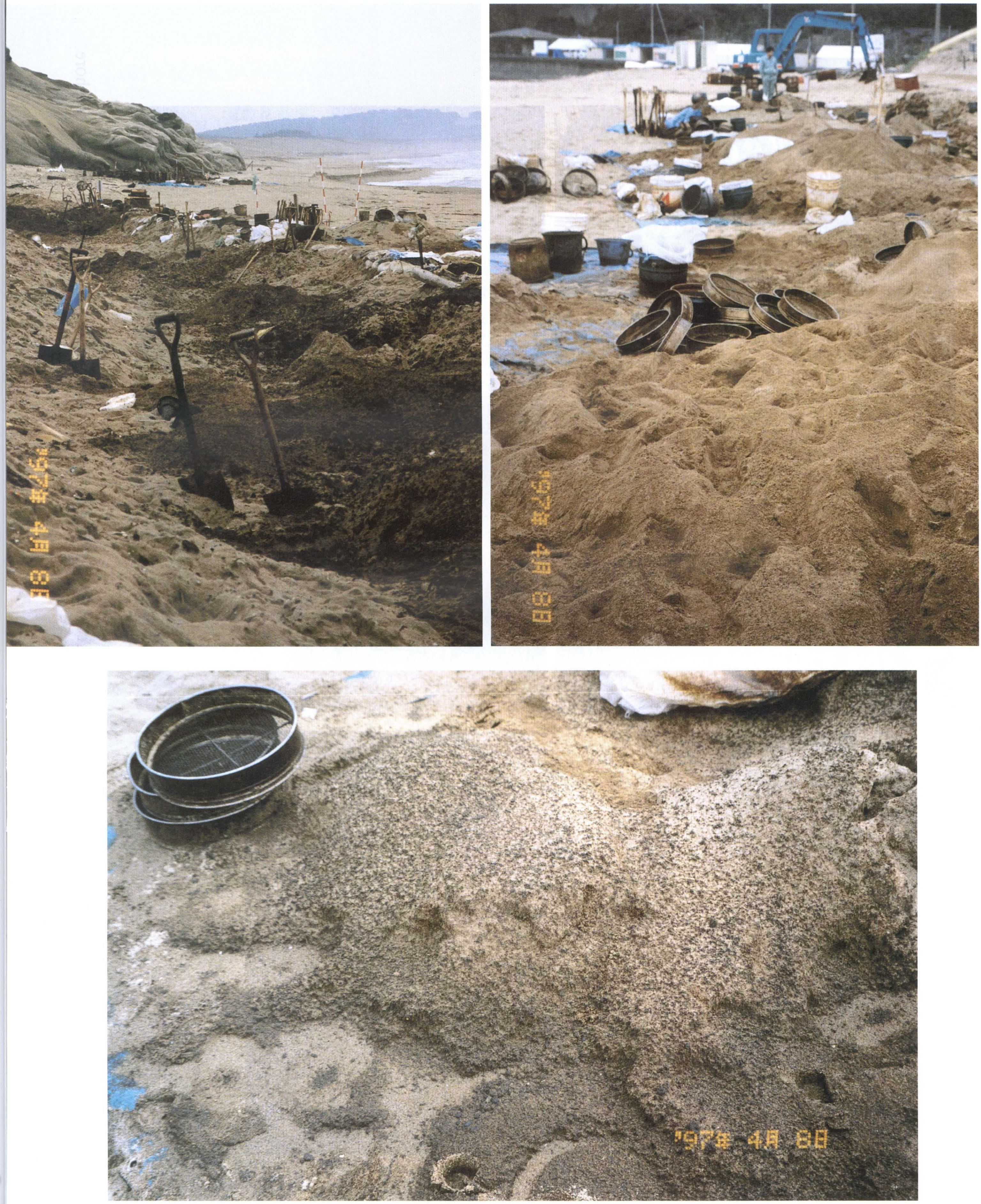

**Figure 12** April 8th, 1997. In Katano seashore, after volunteers tried to separate oil and sands by sieves, each small amount of sands was coated by heavy oil.

**Figure 13** The storm took thousands of sand bags filled with collected heavy oil, and they made it again as oil dumping to Sosogi seashore in Wajima City (January 26th, 1997).

**Figure 14** Quick – made pool covered with plastic sheet in rice field to keep heavy oil collected from Sosogi seashore in Wajima City (left). Vacuum truck carrying the oil to waste plants (right upper), and the heavy oil was too viscous to suck, so a man was helping the machine (right down) (January 26th, 1997).

**Figure 15** Oily smell all around Anto, Mikuni Town, and heavy oil everywhere, even on water surface (July 3rd, 1997).

**Figure 16** The heavy oil waves made it to Aramiko Island, wildlife sanctuary (March 14th, 1997).

**Figure 17** Taking on personal samplers at Nagahashi seashore in Suzu City (January 26$^{th}$, 1997).

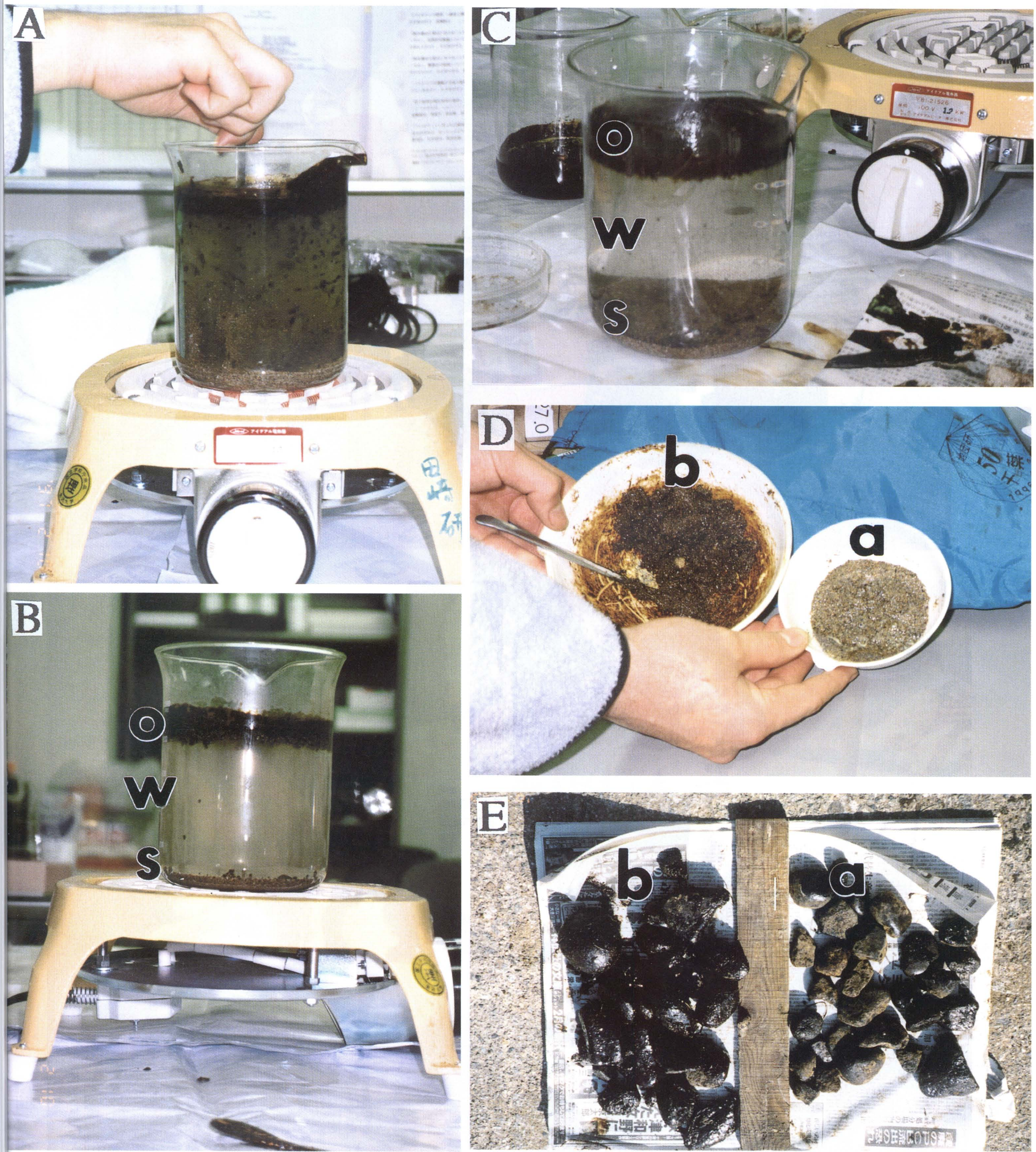


**Figure 18** Separation experiments of C – typed heavy oil and sands or gravels by warmed seawater. O; oil, W; water, S; sands, b; before, a; after.


**Figure 19** Separation tasks of heavy oil and sands or gravels on the site. Warming up seawater in about 40 ℃ , adding contaminated sands or gravels, then getting the oil on the surface.

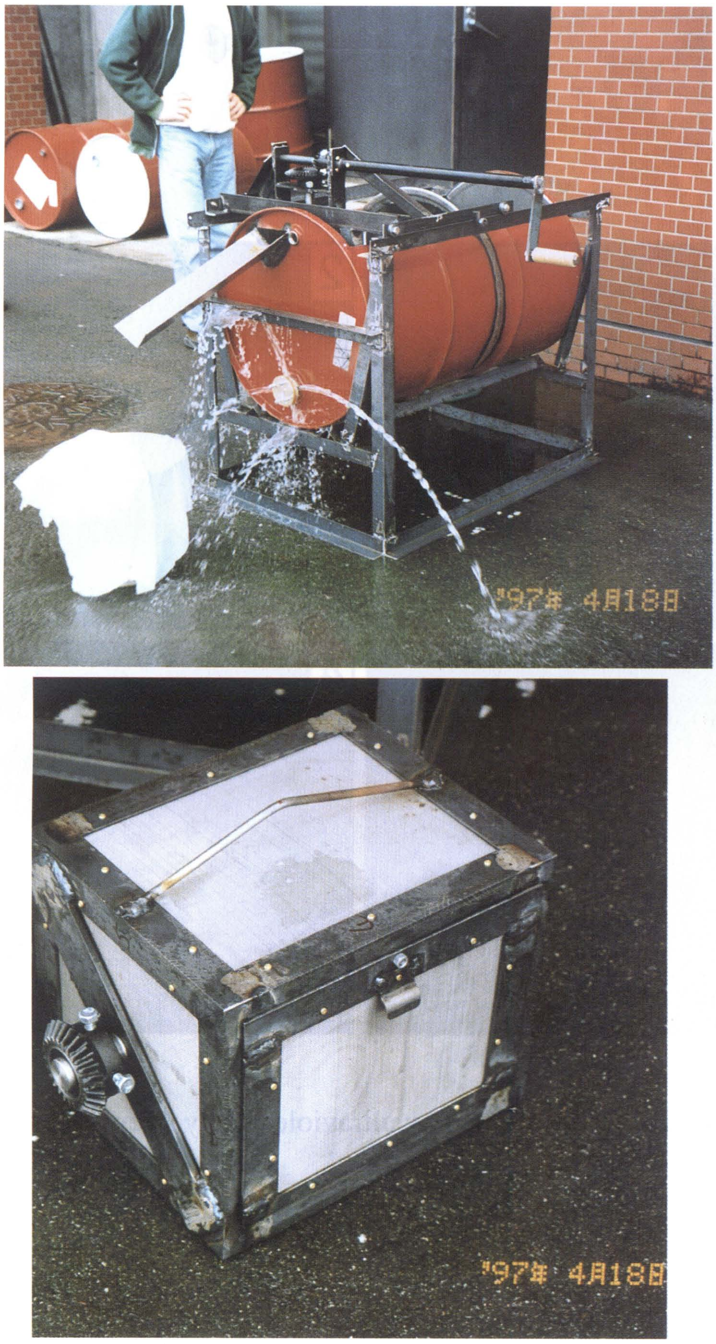


**Figure 20** The separating device (upper) and the metal sieve – like tool which contaminated pebbles put in (down).

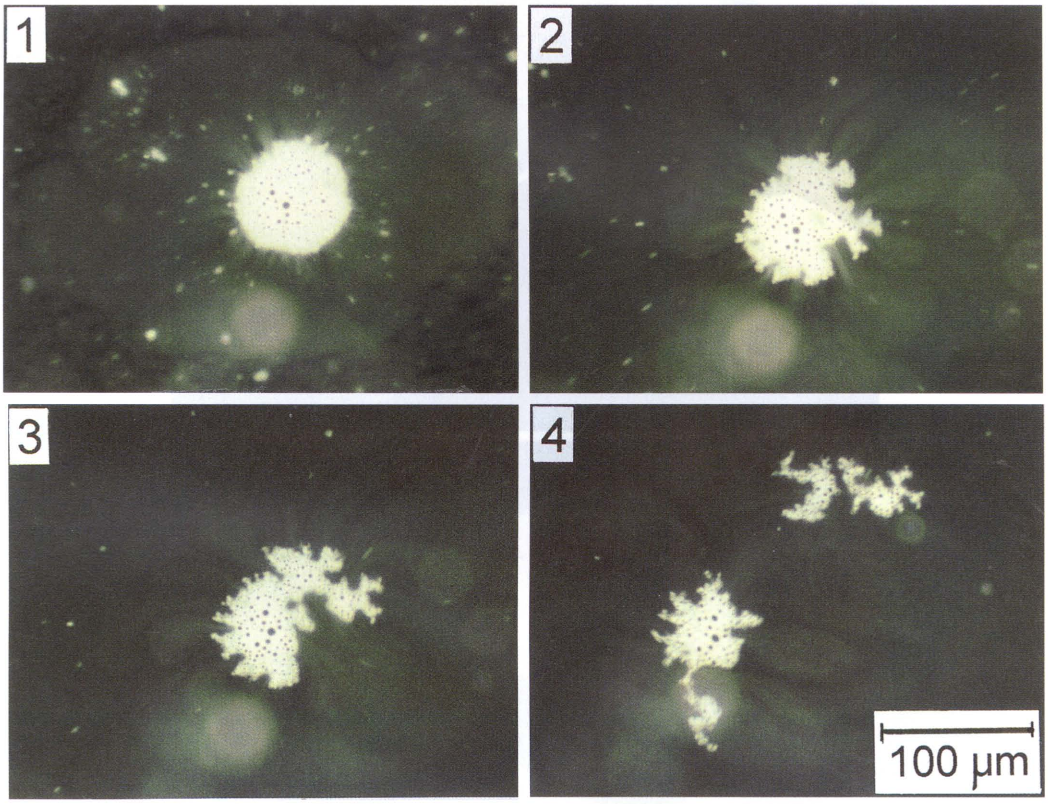


**Figure 21** C – typed heavy oil degraded by ultraviolet. Only a few seconds to degrade from 1 to 4.

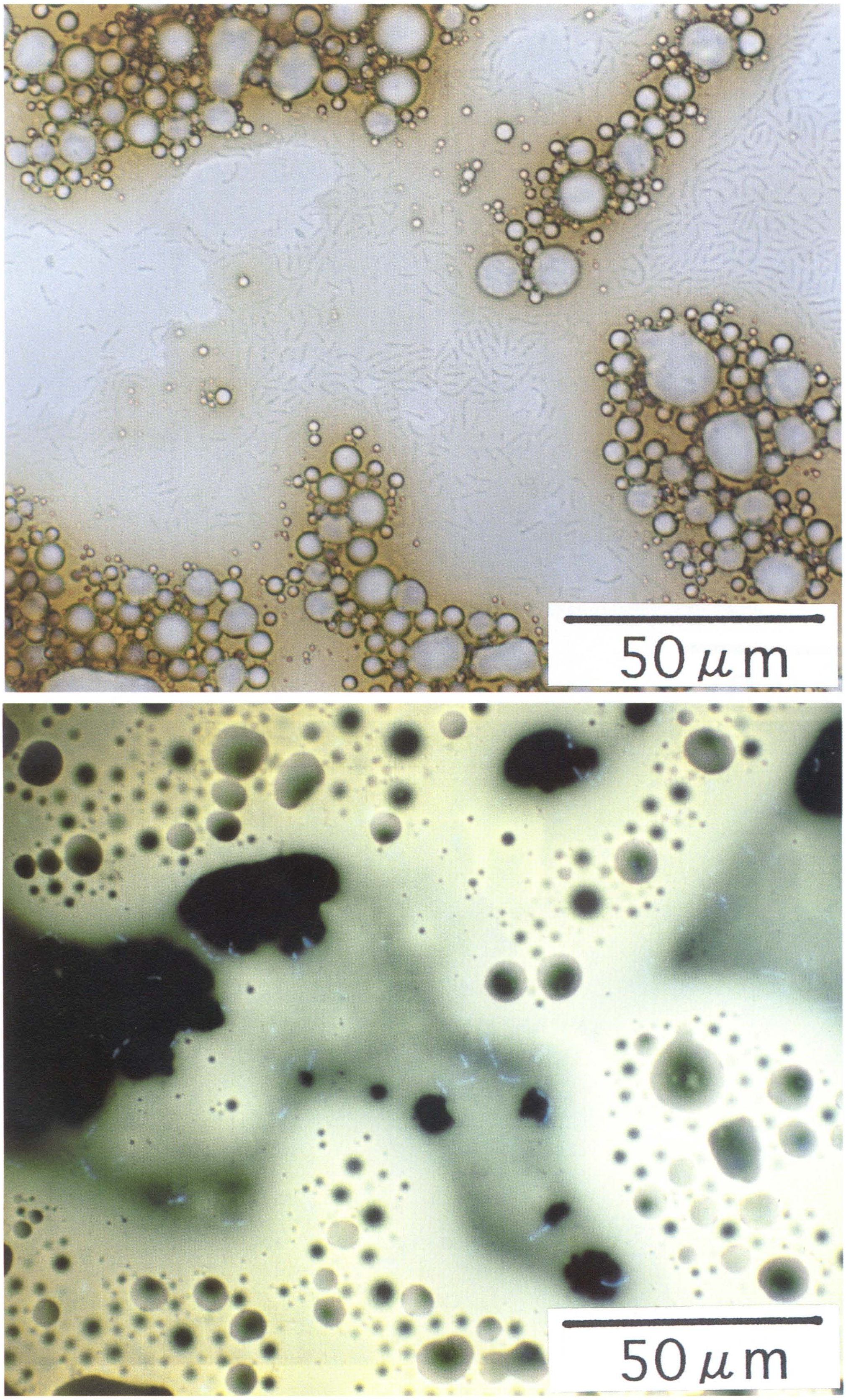


**Figure 22** A large quantities of C – typed heavy oil degradation bacteria (blue) living in emulsified heavy oil (brown ivory). Fluorescence microscopic images: open (upper) and cross (down).

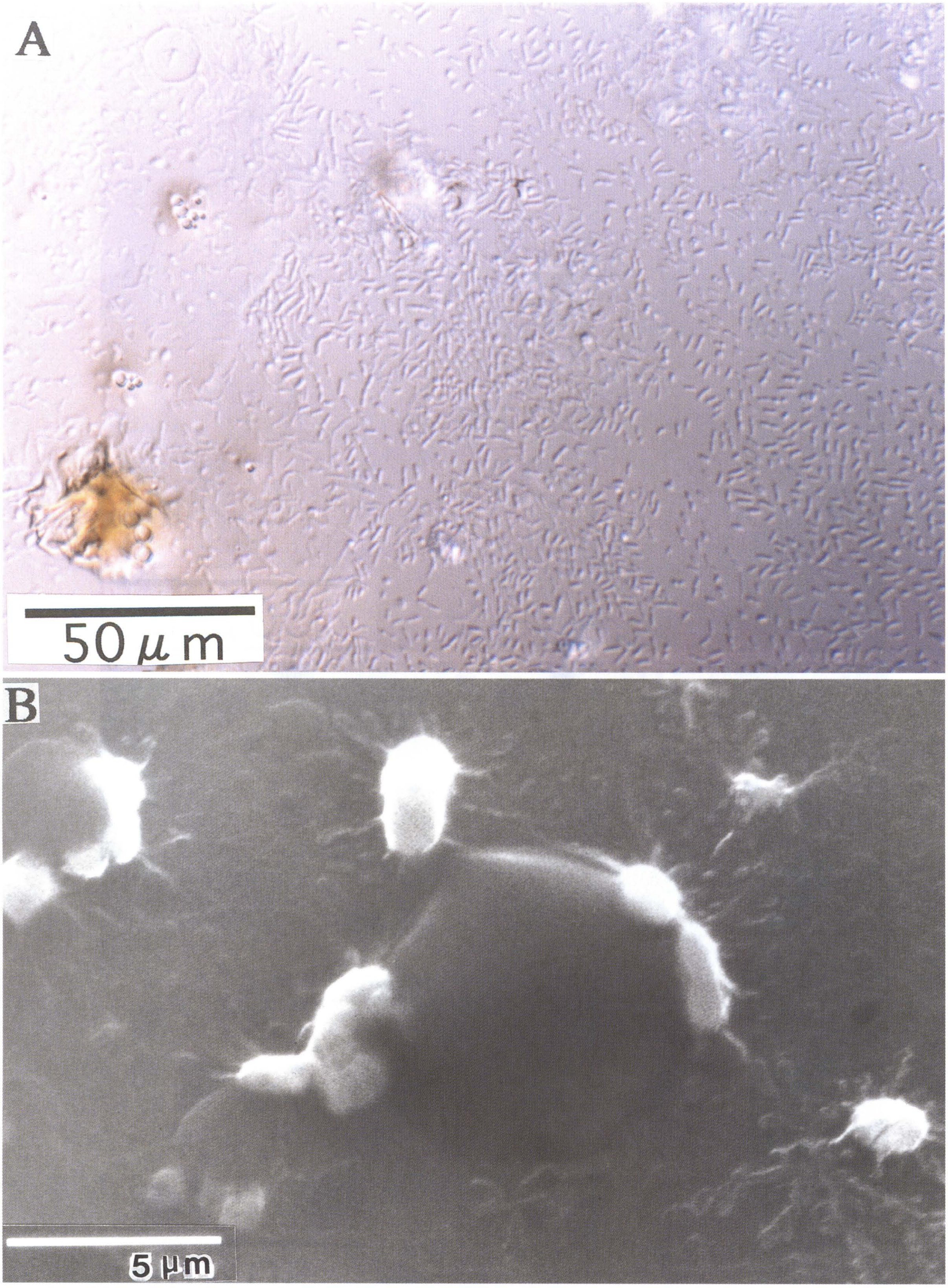


**Figure 23** Optical micrograph of C – typed heavy oil degradation bacteria (upper) and scanning electron micrograph (down). Bacteria adhere to oil ball.

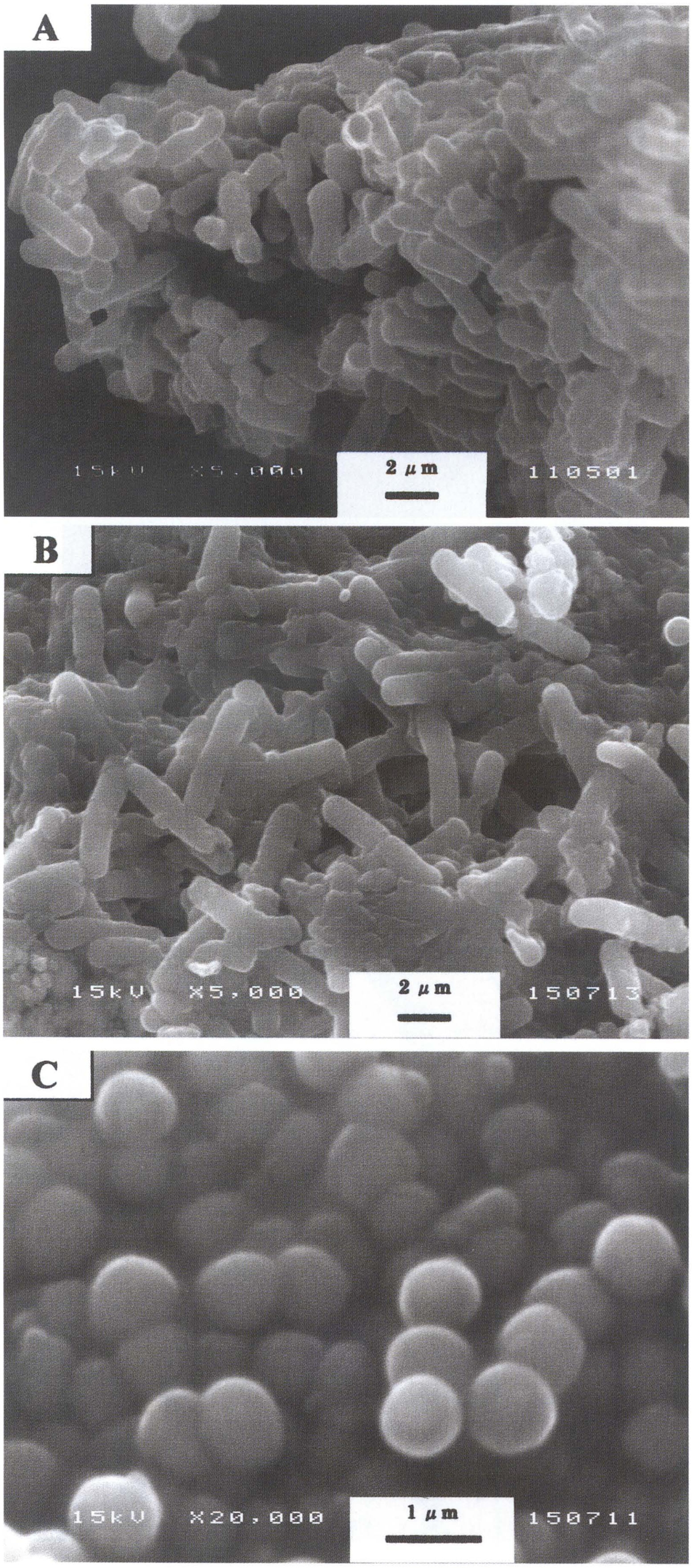


**Figure 24** Scanning electron micrographs of various local bacteria in natural cultivation experiments (December, 2001). A; *Nakhodka* tanker (heavy oil + seawater), B; Katano seashore (sand + heavy oil), and C; Ozawa seashore (heavy oil).

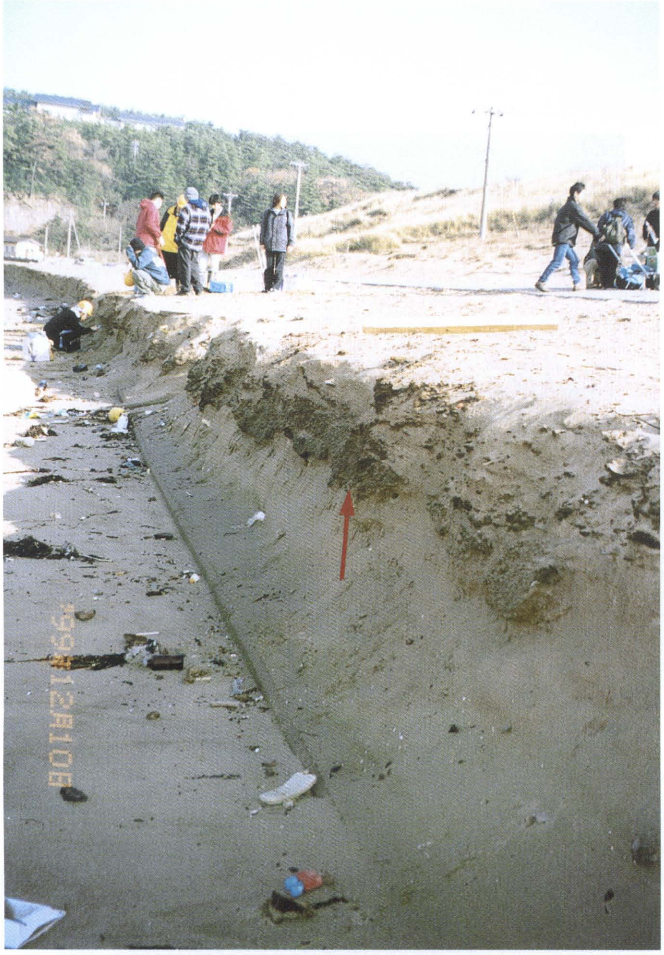

**Figure 25** Following – up investigations at Katano seashore (December 10th, 1999).
60 cm layers of heavy oil (upper, arrow) and heavy oil chunks scattered on the beach (down, arrow).

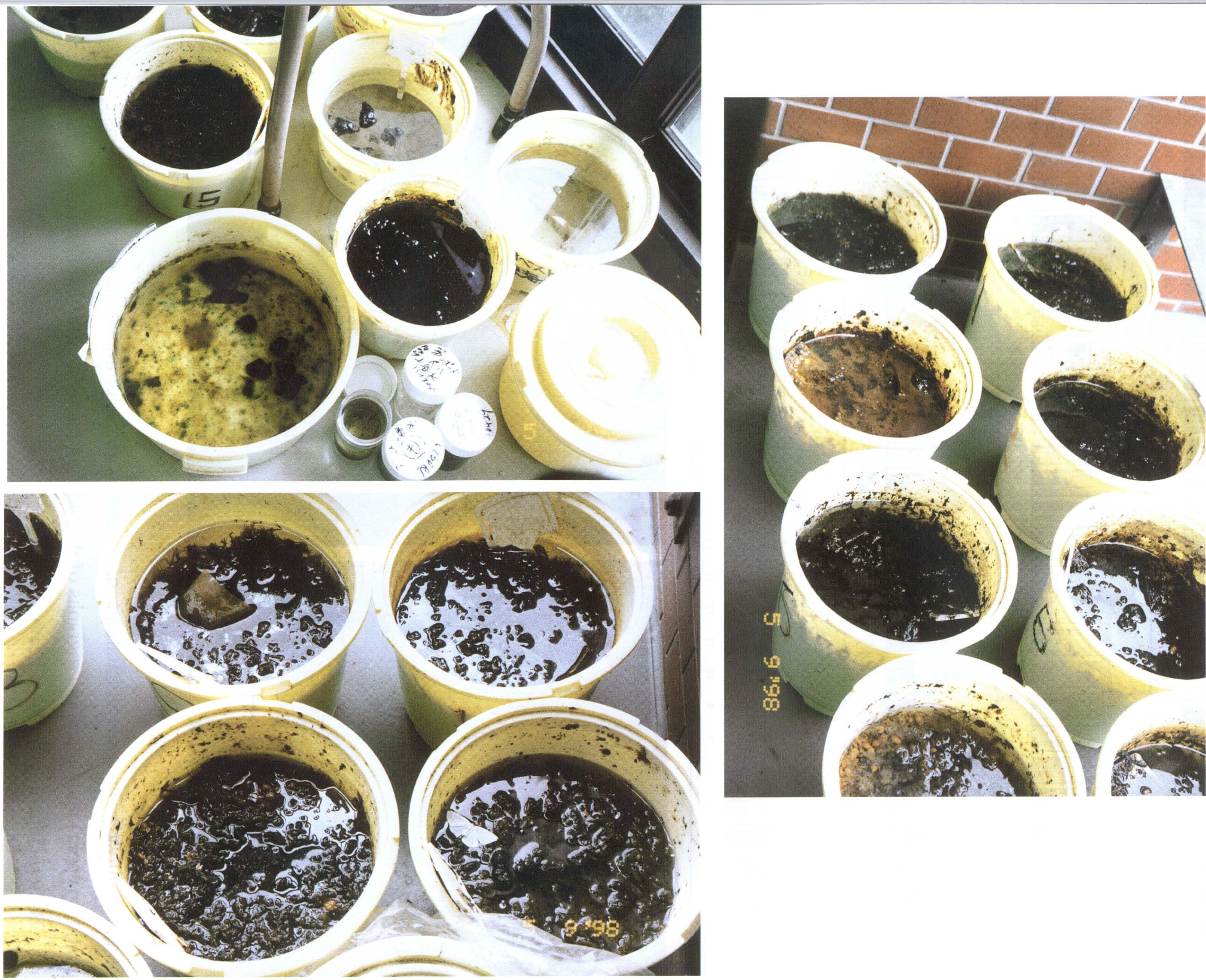


**Figure 26** "Water – oil – sediment interaction" experiments inside of building (left) and outside (right) (May 9$^{th}$, 1998).
The heavy oil in outside pots is degraded faster.

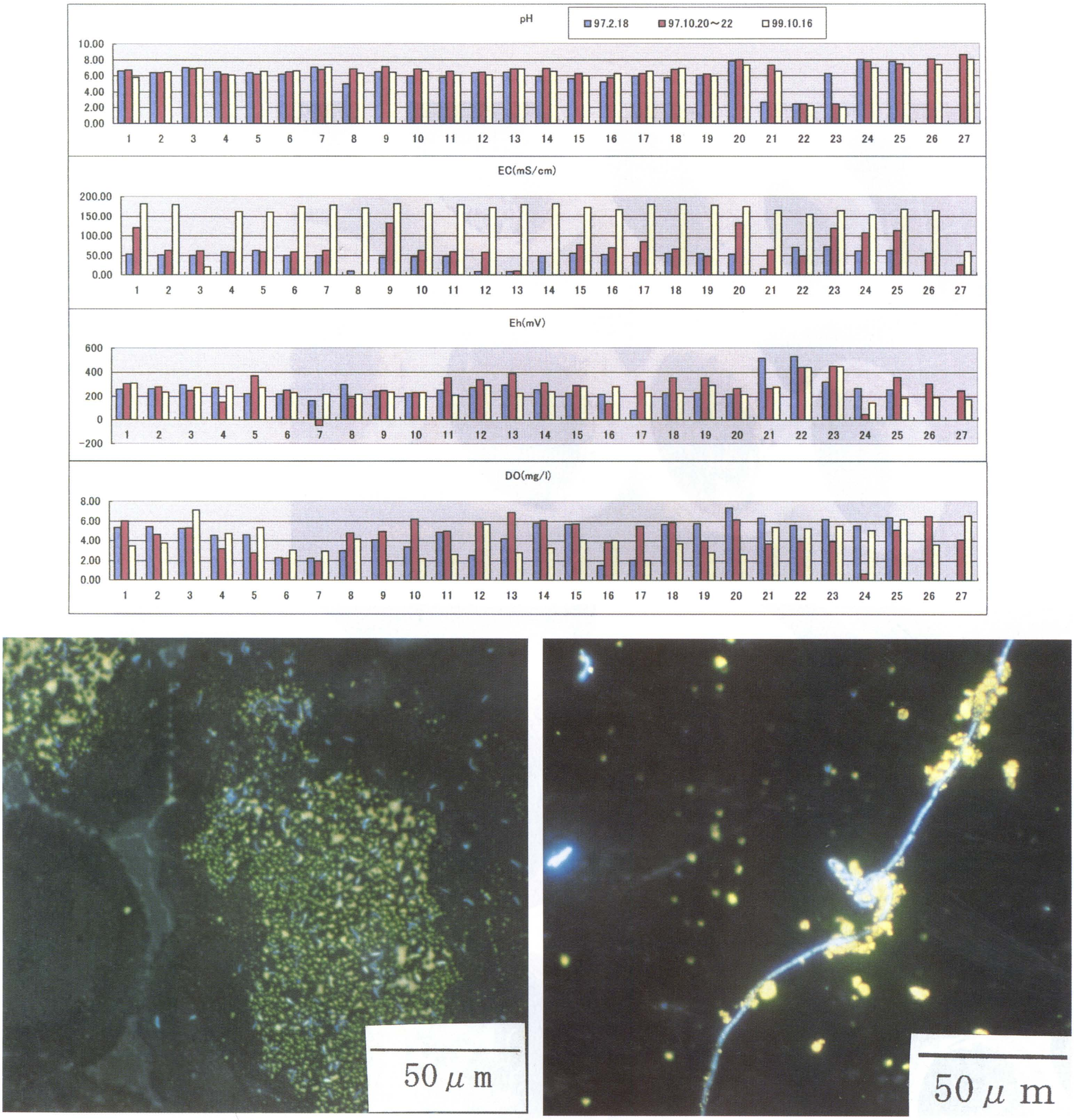


**Figure 27** Follow – up experimentations of “water – oil – sediment interaction”. Water examinations (upper) and optical micrographs of degradation bacteria in the experimental system (down). Bacteria inhabit granulated heavy oil.

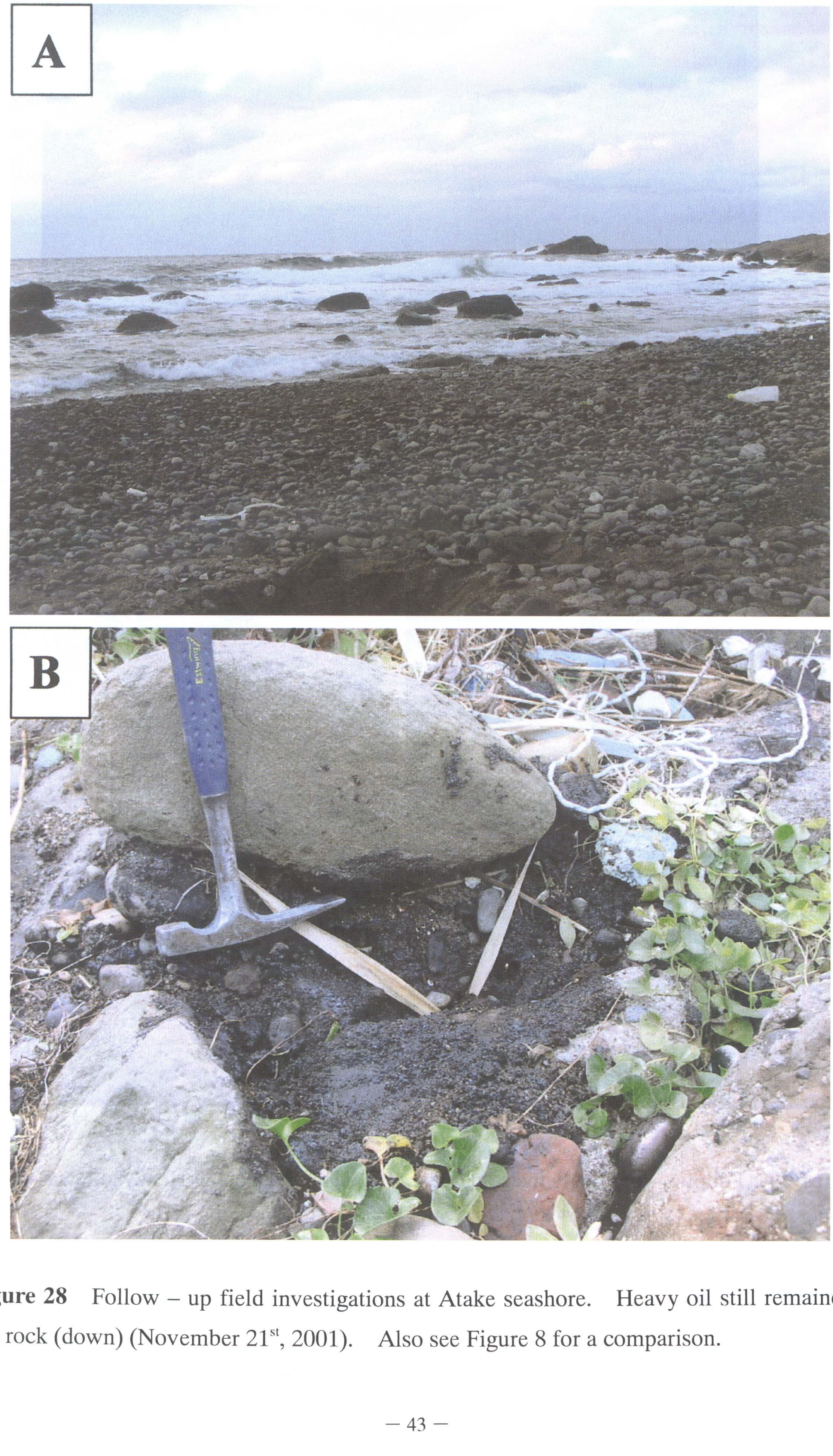


**Figure 28** Follow – up field investigations at Atake seashore. Heavy oil still remained under the rock (down) (November 21st, 2001). Also see Figure 8 for a comparison.


**Figure 29** Follow – up field investigations at Katano seashore. Heavy oil was not visible finally after six years (April 19th, 2003). Compare with Figures 12 and 25.

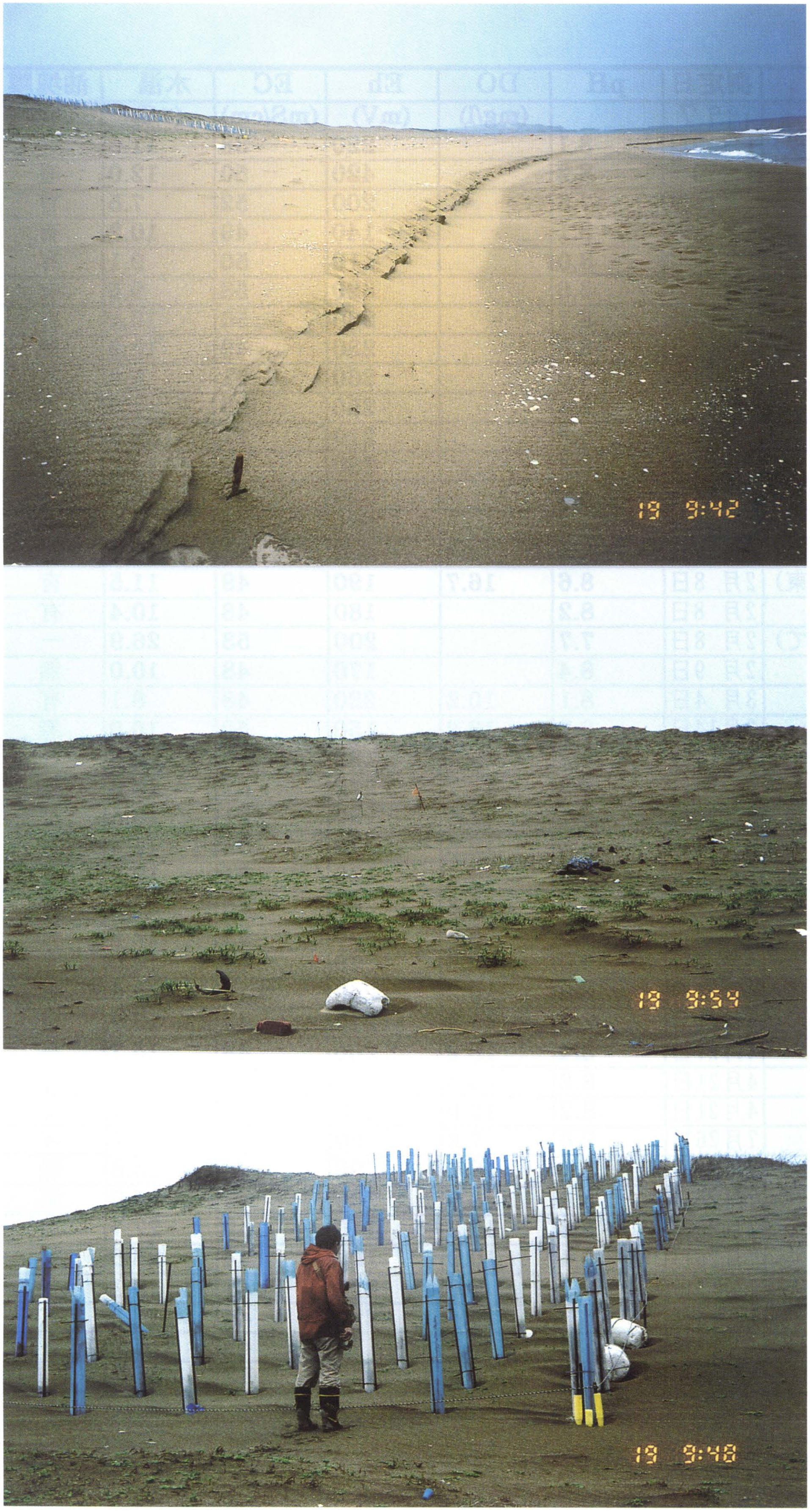


**Figure 30** Follow – up field investigations at Katano seashore. Almost no heavy oil on the surface, whereas found slightly after digging in a part of the bottom photograph (April 19th, 2003).

| 測定地 | 測定日 | pH | DO | Eh | EC | 水温 | 油塊膜 | 備考 |
|---|---|---|---|---|---|---|---|---|
| | 1997 | | (mg/l) | (mV) | (mS/cm) | (°C) | | |
| 三国町安島（船首東） | 1月10日 | 8.1 | | 220 | 38 | 11.3 | 有 | |
| 加賀市塩屋海岸 | 1月10日 | 8.2 | | 420 | 50 | 12.0 | 有 | |
| 志賀町志賀原発前 | 1月15日 | 7.8 | | 200 | 52 | 7.5 | 有 | |
| 富来町増穂ヶ浦 | 1月15日 | 8.1 | | 140 | 49 | 10.2 | 有 | |
| 富来町赤崎 | 1月15日 | 8.0 | | 110 | 50 | 9.1 | 有 | |
| 珠洲市長橋 | 1月18日 | 8.0 | | 320 | 53 | 9.5 | 有 | |
| 珠洲市赤神 | 1月18日 | 8.1 | | 280 | 50 | 10.4 | 有 | |
| 内浦町鵜飼（非漂着） | 1月19日 | 8.3 | | 230 | 49 | 10.8 | 無 | |
| 珠洲市長橋 | 1月26日 | 8.0 | | 260 | 51 | 8.2 | 有 | |
| 輪島市大川(河口) | 1月26日 | 7.4 | | 250 | 9.9 | 4.0 | 有 | |
| 輪島市上大沢 | 1月27日 | 8.3 | | 210 | 51 | 9.8 | 有 | |
| 輪島市アタケ海岸 | 1月27日 | 8.4 | | 220 | 49 | 10.5 | 有 | |
| 輪島市鵜入漁港 | 1月27日 | 8.2 | | 320 | 50 | 10.8 | 有 | |
| 輪島市袖ヶ浜 | 1月27日 | 8.1 | | 290 | 50 | 9.6 | 有 | |
| 三国町安島（船首西） | 2月 8日 | 8.6 | 14.4 | 230 | 51 | 10.1 | 有 | |
| 三国町安島（船首東） | 2月 8日 | 8.6 | 16.7 | 190 | 49 | 11.5 | 有 | |
| 加賀市塩屋海岸 | 2月 8日 | 8.2 | | 180 | 48 | 10.4 | 有 | |
| 洗浄残液（塩屋にて） | 2月 8日 | 7.7 | | 200 | 53 | 26.9 | ー | |
| 内灘町西荒屋 | 2月 9日 | 8.4 | | 170 | 48 | 10.0 | 無 | |
| 輪島市アタケ海岸 | 3月 4日 | 8.1 | 10.2 | 220 | 48 | 8.1 | 有 | |
| 七ツ島大島岩礁 | 3月14日 | 8.3 | 13.2 | 150 | 50 | 10.9 | 無 | |
| 七ツ島大島船着場 | 3月14日 | 8.5 | 15.4 | 120 | 50 | 11.0 | 有 | |
| 七つ島荒三子島 | 3月14日 | 8.3 | 14.7 | 270 | 52 | 10.8 | 無 | |
| 輪島市上大沢 | 3月24日 | 8.1 | 11.9 | 130 | 51 | 10.5 | 有 | |
| 輪島市アタケ海岸 | 3月24日 | 8.3 | 12.5 | 170 | 51 | 11.4 | 有 | |
| 輪島市袖ヶ浜 | 3月24日 | 8.4 | 14.3 | 120 | 51 | 12.3 | 有 | |
| 三国町浜地海岸 | 4月 8日 | 8.0 | 9.8 | 60 | 45 | 11.9 | 有 | |
| 三国町浜地海岸 | 4月 8日 | 8.0 | 8.8 | 50 | 43 | 12.9 | 有 | |
| 三国町安島 | 4月 8日 | 9.0 | 10.5 | 70 | 46 | 14.0 | 有 | |
| 珠洲市真浦（河口） | 4月21日 | 6.8 | 10.3 | 240 | 0.15 | 13.5 | 有 | |
| 珠洲市真浦（海水） | 4月21日 | 8.3 | 11.4 | 210 | 49 | 13.7 | 有 | |
| 珠洲市赤島 | 4月21日 | 8.4 | 16.2 | 200 | 48 | 15.7 | 有 | |
| 珠洲市長橋 | 4月21日 | 8.2 | 10.5 | 190 | 51 | 14.6 | 有 | |
| 珠洲市馬緤 | 4月21日 | 8.2 | 12.0 | 170 | 51 | 13.9 | 有 | |
| 三国町安島 | 7月26日 | 7.6 | 7.2 | 20 | 46 | 25.7 | 有 | |
| 加賀市塩屋海岸 | 7月26日 | 8.0 | 8.1 | 90 | 45 | 25.8 | 無 | |
| 加賀市片野海岸 | 7月26日 | 8.1 | 8.1 | 90 | 45 | 27.5 | 無 | |
| 輪島市袖ヶ浜 | 7月26日 | 8.3 | 10.3 | 110 | 49 | 27.7 | 無 | |
| 輪島市アタケ海岸 | 7月26日 | 8.4 | 10.9 | 100 | 44 | 28.0 | 有 | |
| 輪島市アタケ海岸 | 12月6日 | 8.5 | 2.6 | 210 | 41 | 13.1 | 有 | 10cmボール |
| 輪島市袖ヶ浜 | 12月6日 | 8.3 | 2.4 | 220 | 44 | 14.3 | 有 | 5-10cmボール |
| 珠洲市長橋海岸 | 12月7日 | 8.4 | 7.5 | 170 | 42 | 15.2 | 有 | 防波堤に沿って |
| 長橋（界面活性剤） | 12月7日 | 8.3 | 8.3 | 140 | 12 | 13.2 | 以前界面活性剤で黄色 | |

**Table 1** Water analysis of oil – contaminated areas at the Hokuriku District in 1997.