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**CONTAMINATION OF MERCURY IN SURFACE SEDIMENT
IN THE GULF OF THAILAND**



Miss Suchada Buakaew

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

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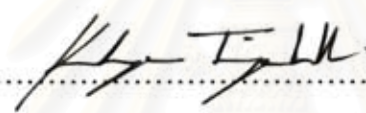
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By Miss Suchada Buakaew
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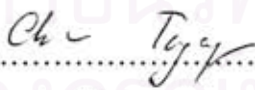
Accepted by the Graduate School, Chulalongkorn University in Partial
Fulfillment of the Requirements for the Master's Degree


.......... Vice President
..... Acting Dean of the Graduate School
(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

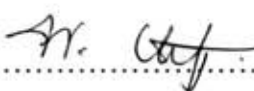
THESIS COMMITTEE

.......... Chairperson
(Assistant Professor Manaskorn Rachakornkij, Ph.D.)

.......... Thesis Principal Advisor
(Assistant Professor Penjai Sompongchaiyakul, Ph.D.)

.......... Member
(Chantra Tongcumpou, Ph.D.)

.......... Member
(Anond Snidvongs, Ph.D.)

.......... External Member
(Assistant Professor Wilaiwan Utoomprurkporn, Ph.D.)

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ตัวอย่างตะกอนจากอ่าวไทยตอนบน 39 สถานี และ อ่าวไทยตอนล่าง 54 สถานี จากการ
 สํารวจในเดือนตุลาคม พ.ศ. 2546 โดยกองทัพเรือ ทำการวิเคราะห์คุณลักษณะของตะกอนโดยการ
 ร่อนเปียกและเทคนิคเลเซอร์ดิฟแฟรคชัน วิเคราะห์ปริมาณคาร์บอนอินทรีย์โดยวิธีออกซิเดชัน
 แบบเปียก และวิเคราะห์ปริมาณแคลเซียมคาร์บอเนตโดยเทคนิคไตเตรชันของกรด-เบส วิเคราะห์
 หาปริมาณปรอททั้งหมดในตะกอน โดยการสกัดด้วยอควาเรจีย (aqua regia) จากนั้นตรวจวัดด้วย
 เทคนิคอะตอมมิกแอบซอร์บชันแบบไอเย็น ผลการศึกษาพบว่าขนาดอนุภาคของตะกอนในอ่าวไทย
 ส่วนใหญ่เป็นทรายแป้งและทราย ปริมาณคาร์บอนอินทรีย์ในตะกอนอ่าวไทยตอนบนและตอนล่าง
 มีค่าเฉลี่ย 0.93 ± 0.61 และ 0.68 ± 0.37 เปอร์เซ็นต์ ตามลำดับ ปริมาณแคลเซียมคาร์บอเนตมี
 ค่าเฉลี่ย 15.1 ± 7.9 และ 16.3 ± 8.6 เปอร์เซ็นต์ ตามลำดับ ปริมาณปรอททั้งหมดในตะกอนอ่าวไทย
 ตอนบนอยู่ในช่วง < 2 ถึง 92.4 ไมโครกรัมต่อกิโลกรัม น้ำหนักแห้ง เฉลี่ย 33.9 ± 27.4 ไมโครกรัม
 ต่อกิโลกรัม น้ำหนักแห้ง ปริมาณปรอทในตะกอนอ่าวไทยตอนล่างมีค่าน้อยกว่าอ่าวไทยตอนบน
 โดยพบอยู่ในช่วง 6.5 ถึง 50.1 ไมโครกรัมต่อกิโลกรัม น้ำหนักแห้ง และมีค่าเฉลี่ยเท่ากับ 24.4 ± 9.0
 ไมโครกรัมต่อกิโลกรัม น้ำหนักแห้ง อย่างไรก็ตาม ค่ามัธยฐานของปริมาณปรอทในทั้งสองบริเวณ
 มีค่าใกล้เคียงกัน ผลการศึกษายังชี้ถึงอิทธิพลของมลพิษจากแผ่นดินที่พามลสารลงสู่อ่าวไทยผ่าน
 ทางแม่น้ำสายหลักทั้ง 4 สาย โดยทั่วไปแล้วค่าปรอทในตะกอนมีความสัมพันธ์โดยตรงกับปริมาณ
 ตะกอนละเอียด (< 63 ไมโครเมตร) แม้ว่าระดับปรอทในตะกอนอ่าวไทยตอนล่างจะมีค่าต่ำกว่าใน
 ตะกอนอ่าวไทยตอนบน แต่ปริมาณปรอทที่ค่อนข้างสูงในบางพื้นที่ของอ่าวไทยตอนล่างค่อนข้าง
 สัมพันธ์อยู่กับกิจกรรมการขุดเจาะปิโตรเลียมในอ่าวไทย

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Prof. Sanyasit

4989474520 : MAJOR ENVIRONMENTAL MANAGEMENT

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SUCHADA BUAKAEW: CONTAMINATION OF MERCURY IN SURFACE SEDIMENT IN THE GULF OF THAILAND. THESIS
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Surface sediment samples were collected from 39 and 51 stations in the Upper and Lower Gulf of Thailand (GOT), respectively, during an expedition of R.V. Suk of the Royal Thai Navy in October 2003. The sediment samples were analyzed for their sedimentological characteristics using wet sieving and laser diffraction techniques. Organic carbon and carbonate contents in sediments were determined by wet oxidation and acid-base titration techniques, respectively. Total mercury contamination in the sediments was determined by cold-vapor atomic absorption techniques after extraction with aqua regia. The results indicated that grain size fraction of sediment from the Gulf was silt and sand. Average organic carbon in the upper and lower GOT were 0.93 ± 0.61 and 0.68 ± 0.37 percent, respectively. Carbonate contents in the upper and lower GOT were 15.1 ± 7.9 and 16.3 ± 8.6 percent, respectively. Total mercury in the upper GOT sediment was ranged from < 2 to 92.4 with an average of 33.9 ± 27.4 $\mu\text{g}/\text{kg}$ dry weight, while total mercury in the lower GOT sediments was less than the upper GOT. Total mercury in the lower GOT was ranged from 6.5 to 50.1 with an average of 24.4 ± 9.0 $\mu\text{g}/\text{kg}$ dry weight. However the median of total mercury in the both parts is similar. This indicated the contribution of mercury from land based sources carrying to the GOT through four major rivers that empty to the upper GOT. In general, the mercury concentration in most places was direct related to the percentage of fine grain particles ($< 63 \mu\text{m}$) presented in the sediments. Although, the level of mercury in the lower GOT sediments was lower than the upper GOT, a petroleum exploration in the lower GOT was shown somewhat related to an elevation of mercury content in some area.

Field of study Environmental Management Student's signature สุชาดา บัวแก้ว
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Prof. Sompongchaiyakul

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CHAPTER I

INTRODUCTION

Mercury, a highly toxic element, is one of the most global concern pollutants among air, water, sediment, soil and organisms (Moreno *et al.*, 2005). It occurs naturally as metallic form and/or its sulfide ores such as cinnabar (HgS). A small concentration of mercury is found throughout the lithosphere, the atmosphere, the hydrosphere and the biosphere. The earth's crust contains 0.5 mg/kg, ambient air may contain 0.002-0.02 pg/dm³, and sea water contains about 0.03 mg/dm³. Mercury is also found in trace amounts in most animal and plant tissues (Morita *et al.*, 1998). It is able to transverse the globe through the atmosphere and its severe neurotoxic effects, especially on fetuses and young children (Hines *et al.*, 2006).

Mercury is emitted by both anthropogenic and natural processes. Due to its chemical properties, environmental mercury is thought to move through various environmental compartments, possibly changing form and species during this process. The emission from industrial use of mercury reached its maximum in the 1950's (Hylander and Meili, 2003). Estimates of global emissions of mercury to the atmosphere are highly variable, ranging from 2,000-3,000 tons/year to 6,000 tons/year, because of the uncertainty about natural emission rates (Morita *et al.*, 1998).

Although anthropogenic mercury emissions have been reduced by half in the last decades (Pacyna *et al.*, 2001 and Brooks, 2003), ongoing contamination is still a seriously worldwide problem. A large amount of mercury is emitted from coal burning and today this is the dominant source in Europe, North America and Asia (Pacyna and Pacyna, 2002). Therefore, mercury pollution needs to be recognized because of its potential impacts on the environment and public health and it is listed by the United States Environmental Protection Agency (US-EPA) as one of 129 priority pollutants (Rodrigues *et al.*, 2006).

Mercury found in ocean waters and sediments comprises a large reservoir of the total mercury on the planet. The conceptualization of oceans as reservoirs of mercury is fitting for they serve both as sources of mercury to the atmosphere as well as environmental mercury sink (Mason and Fitzgerald, 1993; 1996; Cossa *et al.*, 1996). The forms and species of mercury present in the ocean waters and sediments may be transformed as a result of both biotic and abiotic factors within the ocean. In marine environment, however, mercury is considered to be a particle reactive element and is easily associated with the suspended particulate matter and transferred to the bed material on settling (Ram *et al.*, 2003). Therefore, mercury is likely to deposit onto the sediment nearby sources. Contaminated sediments can directly impact bottom-dwelling organisms and represent a continuing source of toxic substances in aquatic environments that may impact wildlife and humans through food or water consumption (Catallo *et al.*, 1995). The most significant species of mercury from an ecologic and human health perspective is monomethylmercury (MHg) (Mason and Fitzgerald, 1996). MHg shows strong evidence of bioaccumulation and biomagnification in the marine food web. As such the sediments play very important roles in the global biogeochemical cycle of mercury, acting both as source and sink (Rodrigues *et al.*, 2006).

Thailand has approximately 2,600 km of coastline from the westerly Andaman Sea to the easterly Gulf of Thailand. The Gulf of Thailand is a shallow arm of the South China Sea continental shelf that is enclosed by the land masses of Thailand, Cambodia, Vietnam, and Malaysia. The Gulf is a major marine resource in terms of fisheries, aquaculture, coral and mangrove resources. Rapidly increasing industrial and economical activities, including major development projects, developments in shipping, petroleum and gas, a large and important fishery sector, intensive coastal aquaculture, and extensive tourism, have exerted considerable stress on the marine environment. As a consequence, heavy metals and other contaminants are introduced, dispersed and accumulated in various environmental media such as water, sediment and organisms (i.e. Hungspreugs *et al.*, 1989; Wattayakorn *et al.*, 1998; Hungspreugs and Utoomprurkporn, 1999; Thongra-ar and Parkpian, 2002; Boonyatumanond *et al.*, 2006).

Mercury contamination in the Gulf of Thailand is commonly ascribed to subsurface natural gas deposit. Nevertheless, recently there is an increment of the number of platforms for natural gas exploration and production in the Gulf of Thailand, as a result of leading to the increasing trace amount of mercury in the Gulf, which is immensely tied to the exploration, development, production, and processing in petroleum and gas operation (Chongprasith and Wilairatanadilok, 1999). However, accumulation of mercury in sediment is affected by organic carbon contents and size distribution of the bed sediments. Water circulation in the Gulf of Thailand may influence transportation of mercury before settling onto the bottom sediments. Mercury may not accumulation only nearby the platforms, thus, distance accumulation is of concern in this study.

1.1 Objectives of the study

The main objective of this study is to investigate total mercury levels accumulated in surface sediments of the Gulf of Thailand after two decades of natural gas exploration activities. The second objective is to clarify main factors controlling geo-spatial distribution patterns of total mercury in surface sediments in the Gulf of Thailand.

1.2 Hypothesis

Total mercury accumulated in recent sediments in the Gulf of Thailand is related to an establishment of natural gas exploration and is controlled by organic carbon content and grain size distribution of such sediments.

1.3 Scope of the study

The geographical area of this study will scope only in exclusive economic zone (EEZ) of Thailand. Exploration of natural gas is suspected to be a major source of mercury contamination in the Gulf of Thailand. Organic carbon content and grain size distribution are considered as two main controlling factors of mercury accumulation in sediments.

1.4 Expected results

Geo-spatial distribution map of total mercury contamination in sediment of the Gulf of Thailand after two decades of gas exploration will be established. Clarification of factor controlling accumulation of mercury contamination and other information from this study is useful for marine environmental management of the Gulf of Thailand.



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CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Mercury

2.1.1 Physical and chemical properties

Elemental mercury is a shiny, silver-white metal that is a liquid at room temperature and is traditionally used in thermometers and some electrical switches. If not enclosed, at room temperature some of the metallic mercury will evaporate and form mercury vapors. Mercury vapors are colorless and odorless. The higher the temperature, the more vapors will be released from liquid metallic mercury. Some people who have breathed mercury vapors report a metallic taste in their mouths. Mercury is mined as mercuric sulfide (cinnabar) ore. The chemical symbol of mercury is “Hg” with atomic number of 81, atomic weight of 200.59, and mass number of stable isotope is 196 to 204. There are two valencies, +1 and +2 with physical properties are: melting point -38.83°C , boiling point 356.73°C , and density 13.6 g/ml at 20°C . Several forms of mercury occur naturally in the environment. The most common natural forms of mercury found in the environment are metallic mercury, mercuric sulfide, mercuric chloride and methylmercury. Some microorganisms and natural processes can change the mercury in the environment from one form to another. Methylmercury is of particular concern because it can build up (bioaccumulate and biomagnify) in many edible freshwater and saltwater fish and marine mammals to levels that are many thousands of times greater than levels in the surrounding water (WHO/IPCS, 1989; UNEP, 2002).

There are numerous inorganic and organic mercury compounds. Inorganic compounds include mercuric sulfide (HgS), mercuric oxide (HgO) and mercuric chloride (HgCl_2). These inorganic mercury compounds are also called mercury salts. Most inorganic compounds of mercury are white powders or crystal,

except for mercuric sulfide, which is red and turns black after exposure to light. Some mercury salts (such as HgCl_2) are sufficiently volatile to exist as an atmospheric gas. However, the water solubility and chemical reactivity of these inorganic (ionic) mercury gases lead to much more rapid deposition from the atmosphere than for elemental mercury. This results in significantly shorter atmospheric lifetimes for these ionic (e.g. divalent) mercury gases than for the elemental mercury gas.

When mercury combines with carbon, the compounds formed are called organic mercury compounds or organomercurials. There are a potentially large number of organic mercury compounds (such as dimethylmercury, phenylmercury, ethylmercury and methylmercury); however, by far the most common organic mercury compound in the environment is methylmercury. Like the inorganic mercury compounds, both methylmercury and phenylmercury exist as 'salts' (for example, methylmercuric chloride or phenylmercuric acetate). When pure, most forms of methylmercury and phenylmercury are white crystalline solids. Dimethylmercury, however, is a colorless liquid.

The chemical forms that have been considered important for mercury in biological and environmental samples are listed in Table 2-1.

Table 2-1 Major mercury species in environmental and biological samples (Morita *et al.*, 1998)

Elemental mercury		Hg^0
Inorganic mercury species:	Mercuric ion	Hg^{2+}
	Mercurous ion	Hg^+
	Mercury sulfide	HgS
Organic mercury species:	Methylmercury	CH_3Hg^+
	Ethylmercury	$\text{C}_2\text{H}_5\text{Hg}^+$
	Phenylmercury	$\text{C}_6\text{H}_5\text{Hg}^+$
	Dimethylmercury	$(\text{CH}_3)_2\text{Hg}$

In the geochemical cycling of the element, the physical properties of the mercury species together with any potential carrier are possibly of greatest importance. For example, gaseous mercury can be transferred for long distances in the atmosphere, while particulate-bound mercury is less mobile. Or dissolved mercury can be transported by sea currents while mercury bound to particulates is settled to seafloor. In this respect, mercury may be classified into several species that are determined by physical properties (Morita *et al.*, 1998). Lindqvist *et al.* (1984) suggested the following classification of environmentally important mercury species:

- *Volatile species*: Hg^0 , $(\text{CH}_3)_2\text{Hg}$ (dimethyl mercury, DMHg)
- *Water soluble particle-borne reactive species*: Hg^{2+} ; HgX_2 , HgX_3^- , HgX_4^{2-} (where X = OH^- , Cl^- or Br^-); HgO on aerosol particles; Hg^{2+} complexes with organic acids
- *Non-reactive species*: CH_3Hg^+ , CH_3HgCl , CH_3Hg (monomethyl-mercury species, MMHg) and other organomercury compounds; $\text{Hg}(\text{CN})_2$; HgS and Hg^{2+} bound to sulfur in fragments of humic matter.

2.1.2 Toxicity

Toxicity is influenced by forms of mercury, environmental media, environmental conditions, sensitivity or tolerance of the organism, and the life history stage (USGS, 2000). Organic mercury compounds are more toxic than inorganic forms. The three common forms of toxic organic mercury are phenyl mercury, methoxy mercury, and alkyl mercury, among which alkyl mercury is the most toxic form. The toxicity of mercury is affected by temperature, salinity, dissolved oxygen and water hardness (WHO/ICPS, 1989). Methyl mercury is easily absorbed into living tissue of aquatic organisms and is highly toxic to mammals, including people, and causes number adverse effects (Kontas, 2006). Human can uptake mercury in three ways: i) as methyl mercury (CH_3Hg^+) from fish consumption; ii) by breathing vaporous mercury (Hg^0) emitted from various sources such as metallic mercury, dental amalgams; and iii) as liquid mercury through dermal absorption (PCD, 2001; Ingham County, 2007).

In the human body, mercury accumulates in the liver, kidney, brain, and blood. Mercury may cause acute or chronic health effects. Exposure to high levels of mercury can lead to severe neurological disorders. This can deteriorate the nervous system, impair hearing, speech, vision, and gait, cause involuntary muscle movements, corrode skin and mucus membranes, and makes it difficult to chew and swallow. Mercury poisoning can progress and possibly even lead to death. It may also create problems for pregnant mothers, leading to birth defects in their children (Ingham County, 2007).

Case of mercury poisoning resulting from marine pollution occurred in Japan. Minamata is a small village located on western coast of Kyushu, Japan's southern island. The town faces to Shiranui Sea, of which Minamata Bay is a part. Closed to Minamata and located on an estuary that flows into Minamata Bay is a petrochemical facility owned and operated since 1907 by the Chisso Corporation. The Chisso Corporation had been primarily a fertilizer manufacturer but, began to manufacture acetaldehyde, used to produce plastics, in 1932. The process for acetaldehyde manufacture used mercury as a catalyst; therefore mercury was a component of the waste stream derived from the process. Waste water from the Chisso factory had since been discharged into and spreading throughout the Shiranui Sea. From 1932 to 1968, the Chisso plant dumped an estimated 25 to 30 tons of mercury compounds into Minamata Bay. The resulting methylmercury poisoning is now known as Minamata disease (Harada, 1995 and 1997).

Minamata disease was first noticed in 1956, and its cause was identified in 1959. Investigations carried out in Minamata Bay in 1959 revealed contamination of sediment as high as 200 ppm near the factory outfall, and declining to 12 ppm at some distance. Plankton contained 5 ppm (dry weight), bivalves from intertidal areas contained 10-39 ppm (dry weight), and fish is contained 10-55 ppm (dry weight). Most of the mercury in the fish was methylated (Clark, 1992). Seventy nine people died and at least 600 people felt severe effects from mercury poisoning after consuming fish and shellfish containing relatively high concentration of methylmercury (Byrne, 1992).

For methylmercury, US-EPA has estimated a safe daily intake level of $0.1 \mu\text{g}/\text{kg}$ body weight per day. This was based on a study in the Faroe Islands, where fish containing significant levels of mercury form a large part of the diet. The study compared development test scores for children whose mothers had been exposed during pregnancy. The European Union scientific review, in 2001, has supported this safe daily intake level. For elemental mercury vapor, several studies show that long-term workplace exposures at around $20 \mu\text{g}/\text{m}^3$ of air or higher have subtle toxic effects on the central nervous system. Other adverse effects of various forms of mercury can be seen in humans, but the findings are less consistent or the doses involved are much higher (Greenfacts, 2007).

2.1.3 Sources of mercury

There are several ways in which mercury enters the environment. Sources of mercury occur both natural and anthropogenic, and can be naturally found in many locations such as sediment outcrops and clouds. The sources and paths of mercury in environment are illustrated in Fig. 2-1.

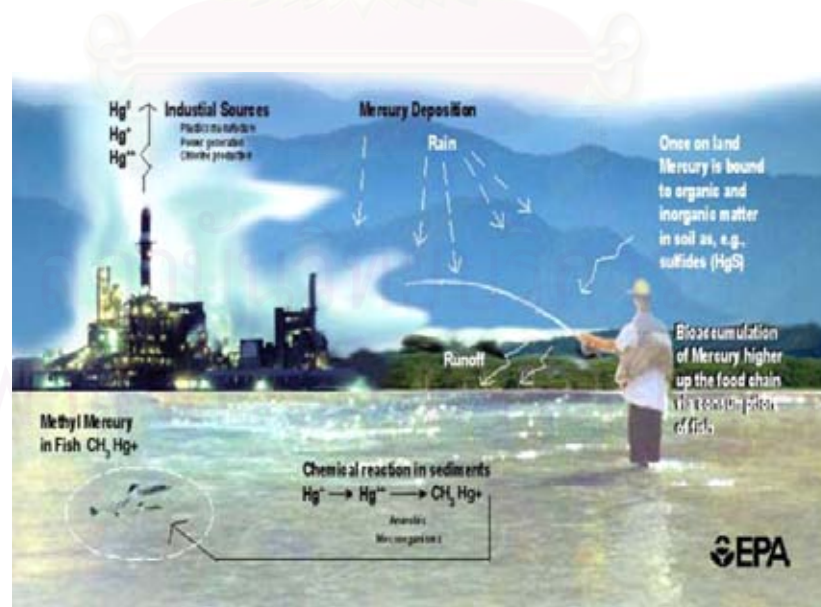


Figure 2-1 Sources and paths of mercury in the environment (source: US-EPA, 2006)

Mercury occurs naturally as the metallic form and/or its sulfide ores such as cinnabar (HgS). Cinnabar is mainly found near the earth surface where volcanic rocks are located. It is a reddish color depending on the purity of the mineral. If there is an underground source, mercury can be found in geothermal hot springs. Certain microorganisms are accustomed to living in high mercury environments such as geothermal springs. These microorganisms in the hot springs easily transform mercury to methylmercury. In general, hot areas with high metal concentration and sulfide content will have a higher concentration of mercury than other areas. Other naturally occurring mercury sources are soils, undersea vents, mercury-rich geological zones such as volcanoes and hot springs, oceans and freshwater, plants, forest fires, sea-salt spray, and meteoric dust (Morita *et al.*, 1998; US-EPA, 2006).

Anthropogenic emissions of mercury are from the use of fossil fuels (especially coal), and other extracted, treated, or recycled mineral materials as well as from mercury used intentionally in products or processes. Mercury has been used in thousands of products and industrial processes including chlorine and caustic soda manufacture; use in laboratories; paint manufactured before 1991; electronic uses such lighting (e.g. fluorescent lamps), wiring devices and switches and batteries; thermometers, thermostats, barometers, and other related instruments; and dental supplies (e.g., dental amalgam fillings) and medical equipment. Historically, and still in developing countries, the chlor-alkali industry is a significant source of atmospheric mercury emissions and direct releases in aquatic systems. Despite the fact that emissions have been drastically reduced in the last decade, the current atmospheric deposition rate still promotes an accumulation of mercury in the nearby environment (Lindqvist *et al.*, 1991; Hintelmann and Wilken, 1995; Ebinghaus *et al.*, 1999; US-EPA, 2006).

The anthropogenic sources of mercury in Thailand include gold refining, pharmaceutical products, hospitals, dentistry, paint industries, fluorescence productions and power plants (PCD, 2001). For gas and oil operations, produced water, and wastewater separated from gasFrankiewicz are likely to contaminate with mercury. Frankiewicz *et al.* (1998) stated that mercury in the Gulf of Thailand gas and

condensate is found in coal and carbonaceous shale in or near the producing reservoirs.

2.1.4 Mercury cycle

Mercury cycles in the environment and undergoes transformation of its chemical forms. In the atmosphere, mercury moves in its volatile forms as well as in particulate-bound forms. In marine and terrestrial environments, inorganic mercury is methylated to methyl mercury species which are readily accumulated in marine organisms. A portion of environmental mercury becomes bound to sulfur, producing insoluble HgS which accumulates in sediments. On land, some plants are known to concentrate Hg as less-toxic chemical forms (Morita *et al.*, 1998).

Mercury cycling in the aquatic environment is shown in Fig. 2-2. With the exception of isolated cases of known point sources, the ultimate source of mercury to most aquatic ecosystems is deposition from the atmosphere, primarily associated with rainfall. Atmospheric deposition contains the three principal forms of mercury, although the majority is as inorganic mercury (Hg^{2+} , ionic mercury). Once in surface water, mercury enters a complex cycle in which one form can be converted to another. It can be brought to the sediments by particle settling and then later released by diffusion or resuspension. It can enter the food chain, or it can be released back to the atmosphere by volatilization.

2.2 Sediment

Sediment are defined as solid fragmental materials, either organic or inorganic, that originate from weathering of rocks and are transported by fluid flow and which eventually is deposited as a layer of solid particles on the bed or bottom of a body of water or other liquid. Sediment is accumulated by other natural agents, such as precipitation from solution or secretion by organisms and that form in layers on the earth's surface at ordinary temperature in loose, unconsolidated forms (Gary *et al.*, 1977). The size of individual particles of sediment varies greatly. They are divided into three groups including sand ($> 63 \mu\text{m}$), silt ($2\text{-}63 \mu\text{m}$) and clay ($< 2 \mu\text{m}$). Clay materials show relatively high metal contents. In the sand fractions the metal concentrations generally decrease as that fraction is dominated by quartz components

with low metal contents. Consequently, metal concentrations tend to increase with decreasing grain size in many types of sediment (Sompongchaiyakul, 1989).

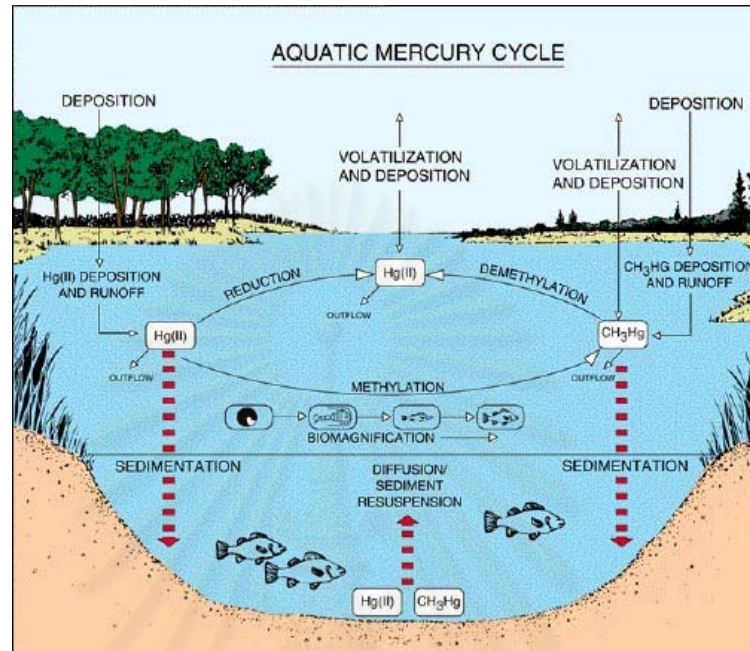


Figure 2-2 Mercury cycling in aquatic environment (source: Wisconsin Water Science Center, 1997)

2.3 Factor controlling mercury contamination in sediment

More than 90% of heavy metals, including mercury, loaded into aquatic systems are bound to suspended particulate matters and sediments (Calmano *et al.*, 1993). Accordingly sediments play a key role as carriers for the heavy metals in hydrological cycle. Sediments can reflect the current quality of the aquatic system as well as the historical development of certain hydrological and chemical parameters (Sompongchaiyakul, 1989; Calmano *et al.*, 1993).

The study of dated sediment cores has proved to be especially useful as it provides a historical record of the background levels and the man-induced accumulation of metal. Sediments are also indicator mediums depending on environmental conditions, sinks or sources for heavy metals in the surface water. They may be recycled via biological and chemical agents between sediments and water column. Distribution and accumulation are influenced by sediment texture, mineralogical composition, reduction/oxidation state, and adsorption and desorption

processes, and physical transport. Moreover, metals can be absorbed from the water column onto fine particles surfaces and move towards sediments; metals participate in various biogeochemical mechanisms having significant mobility can affect the ecosystems through bioaccumulation and biomagnification processes and are potentially toxic for environment and for human life (Sompongchaiyakul, 1989; Manahan, 2000).

Mercury is generally found at very low concentrations and is very reactive in the environment. Total mercury levels are generally less than 10 ng/g in crusted materials such as granites, feldspars and clays and in the range of 40 to 200 ng/g in soils and sediments that are not directly impacted by anthropogenic discharges (Davis *et al.*, 1997). Mercury concentration in sediments in some places of the world is reviewed and summarized in Table 2-2.

Table 2-2 Total mercury concentration in sediment in some places of the world

COUNTRY	LOCATION	TOTAL Hg ($\mu\text{g/g}$ dry weight)	REFERENCES
Italy	Gulf of Venice	0.13	Donazzolo <i>et al.</i> (1981)
India	Indian Ocean	0.004 – 0.008	Sanzgiry <i>et al.</i> (1998)
Russia	Kora Sea	0.03	Loring <i>et al.</i> (1998)
	Ob Estuary	0.035	
	Yennies Estuary	0.05	
Mexico	Lapaz Lagoon	0.018 – 0.023	Kot <i>et al.</i> (1999)
Poland	City of Gdańsk	0.3 – 1.3	Falandysz (1999)
USA.	Enid Lake	0.034	Huggett <i>et al.</i> (2001)
	Sardis Lake	0.031	
Mexico	Gulf of Mexico (near offshore drilling site)	0.025 – 0.558	Trefry <i>et al.</i> (2002)
	Gulf of Mexico (far offshore drilling site)	0.011– 0.092	
USA.	Steamboat Creek, Nevada	0.01 – 21.43	Stamenkovica <i>et al.</i> (2004)
Portugal	Douro Estuary	0.06 – 0.18	Ramalhosa <i>et al.</i> (2005)
Italy	Southern Venice Lagoon	0.1 – 3.4	Berto <i>et al.</i> (2006)
USA.	Guaymas Bay, Gulf of California	0.3 – 2.3	Green-Ruiz <i>et al.</i> (2005)
Canada	Bay of Fundy	0.007 – 0.079	Hung <i>et al.</i> (2006)
Italy	Taranto Gulf, Ionian Sea	0.12	Buccolieri <i>et al.</i> (2006)
Puerto Rico	San Jose´ Lagoon	1.9	Acevedo-Figueroa <i>et al.</i> (2006)
	Joyuda Lagoon	0.17	
Taiwan	Kaohsiung Harbor	0.46 – 3.41	Chen <i>et al.</i> (2007)

Generally, the majority of mercury in the aquatic systems is inorganic forms (about 95 to 99%) and is found in the sediments rather than the dissolved phase. Depending on mercury discharge and ecosystem dynamics, mercury in sediments may be concentrated in hotspots or dispersed over large areas (Hinton and Veiga, 2001; Moreno *et al.*, 2005), mainly associated with organic matter (Mantoura *et al.*, 1978) and/or with sulfur compounds (Drobner *et al.*, 1990).

Main physical and chemical factors controlling mercury accumulation are grain size distribution, organic matter content, hydrology, accretion and erosion rates, salinity and the presence of inorganic components such as carbonates, oxides, and sulfides. Some of the critical factors affecting distribution of mercury in aquatic sediments include (Andersson, 1979; Giblin, 1986; Andersson *et al.*, 1990; Fabbri *et al.*, 1991; Schuster, 1991; Gobeil and Cossa, 1993; Zwolsman *et al.*, 1993; Gambrell, 1994; Williams *et al.*, 1994; Benoit *et al.*, 1998; Spencer *et al.*, 2003):

- a) Ion exchange and adsorption to clay particles — the finer-sized particles such as clay will increase the ability of sediments to retain mercury through ion exchange and adsorption mechanisms due to high cation exchange capacity, large surface area and surface charge in these grain size fractions
- b) Association with organic matter — by chelation bind of mercury with humic fraction in sediments to form metal-organic complexes
- c) Co-precipitation with iron (Fe) and manganese (Mn) oxides — metal-reactive compounds such as oxides of iron and manganese, which are sensitive to diagenesis in sediments subjected to changing oxidation-reduction (redox) status, can adsorb mercury onto their surfaces and influence metal distribution in sediments
- d) Binding to sulfides — the presence of solid sulfides, such as acid volatile sulfur (AVS), is also an important control on mercury in sediments. Precipitation of mercury with sulfide effectively immobilizes mercury in anoxic sediments as the insoluble mercuric sulfide (HgS), however, changes from strongly reduced to

oxidizing conditions in sediments can result in the mobilization of sulfide from sediments and subsequent release of mercury.

The processes affecting retention and mobility of metals in sediments are governed by changes in physio-chemical properties such as redox status, salinity and pH that arise from the system's hydrological regime (Gambrell, 1994; Williams *et al.*, 1994). Diagenetic reactions are important in sediments exposed to transitions between oxidizing to reducing conditions (Shaw *et al.*, 1990). Concentrations of mercury in surface sediments, therefore, may be the result of post-depositional diagenetic processes that remobilize the metal from deeper sediments and cause upward migration in the sediment column (Rasmussen, 1994). Redox conditions can also restrict mobility of mercury from surface sediments, for example, iron and manganese oxides and hydroxides are more stable in surface sediments compared with deeper sediment because of higher redox potential and enrichment of these constituents is likely to reduce mobility of mercury due to the tendency of mercury and mercury-bound organic complexes to adsorb onto these surfaces (Rasmussen, 1994). Oxidic degradation of organic matter can also remobilize metals in sediments (Allen *et al.*, 1990; Valette-Silver, 1993). Tidal inundation can influence the composition of interstitial waters and changes in salinity, for example, can affect the solubility of metals which form strong complexes with chloride ligands, such as mercury (Andersson, 1979; Schuster, 1991; Williams *et al.*, 1994). In the presence of saline waters, metals may be mobilized from the particulate to aqueous phase (Williams *et al.*, 1994).

2.4 Study site

2.4.1 General description

The Gulf of Thailand is a shallow arm of the South China Sea (Pacific Ocean) continental shelf, bordered by Thailand, Cambodia and Vietnam. The boundary of the gulf is defined by the line from Cape Bai Bung in southern Vietnam (just south of the mouth of the Mekong river) to the city Kota Baru on the Malaysian coast. The northern tip of the gulf or so-called inner-Gulf is most shallow and received fresh water from four major rivers namely Chao-Phraya, Tha-Chin, Mae-

Klong and Bangpakong. The Gulf of Thailand is situated between latitudes 5° 00' N and 13° 30' N, and longitudes 99° 00' E and 106° 00' E. It covers about 350,000 km² with average and maximum water depths about 55 and 85 meters, respectively (Sompongchaiyakul, 1989; Chongprasith *et al.*, 1995; Thongra-ar and Parkpian, 2002; Boonyatumanond, 2007). It can be divided into two parts: Upper Gulf (or Inner Gulf) and Lower Gulf. The Upper Gulf located at the innermost area is an inverted-U shape of about 100 × 100 km² (Chongprasith *et al.*, 1995). The Upper Gulf is very shallow with an average depth of 15 meters, while the Lower Gulf includes a relatively deeper part with an average depth of 55 meters (Chongprasith and Srinetr, 1998).

Surface currents in the Gulf of Thailand are generally weak and variable, driven mostly by the light wind of the northeast and southeast monsoons. From October to May, surface currents circulate in an anti-clockwise direction with speeds of < 0.25 m/s for 15-50% of time. From June to September, these currents are reverse and flow in clockwise direction at similar speed for 25% of time. During the two transition periods (April and November), the current is variable and weak. Particularly during the transition period October to December, the northeast monsoon winds have a stronger effect on the surface currents than the other monsoon winds, causing surface currents to flow out of the Gulf (Snidvongs and Sojisuporn, 1997; IEM, 1999).

The Gulf of Thailand is nutrient-rich, shallow waters and confined nature. Its ecosystems are especially vulnerable to human activities (Srisuksawad *et al.*, 1997). However, the rapidly population growth with industrialization has brought about resource decreasing and a decline in environmental quality. Consequently, marine pollution in the Gulf can be a serious problem.

2.4.2 Petroleum exploration in the Gulf of Thailand

Searching for oil in Thailand was first made in 1921. At that time, petroleum activities were solely within the Government sector. In the beginning, exploration of petroleum was conducted by the Military Fuel Division which discovered the first oil field known as Bo Thon Kham in northern Thailand. Subsequently, a number of other oil fields were discovered, but their operations were not very productive. Attempts to attract foreign investors for petroleum exploration

were initiated in 1960. Subsequently, the first foreign oil company was granted a petroleum exploration permit by virtue of the Minerals Act then prevailing as the exploration and mining of minerals included petroleum (Bangkok International Associates, 2006).

The exploration concession in Thailand for oil companies was awarded in 1962 and in 1982, the first gas field of Thailand was started (Unocal, 1995). Since then, natural gas has become the major source of energy for Thailand electricity generation, and it led to the development of the country's petrochemical industry. The petroleum concessions in Thailand were mainly situated in the Gulf of Thailand (Tables 2-3 and 2-4). The petroleum concession areas and current exploration fields in the Gulf of Thailand are shown in Fig. 2-3 and 2-4, respectively.

Table 2-3 Total Petroleum Concessions in Thailand (as of September 21, 2006) (source: DMF, 2007)

AREA	CONCESSIONS	BLOCKS
Onshore	13	16
Gulf of Thailand	20	27
Total	33	43

Table 2-4 Total Concession Areas (km²) (source: DMF, 2007)

AREA	EXPLORATION	PRODUCTION	RESERVE
Onshore	37,903.00	637.85	1,052.54
Gulf of Thailand	54,935.14	12,680.82	8,347.66
Total	92,838.14	13,318.67	9,400.20

2.4.3 Mercury contamination in the Gulf of Thailand

Recently, Thailand has faced the problem of increasing mercury concentrations in the coastal areas as a result of industrial activities and also in the Gulf caused by oil and gas activities (Thongra-ar and Parkpian, 2002). In 1985, Unocal first found mercury as a trace contaminant in natural gas and condensate at Platong field in the Gulf of Thailand. Three years later, mercury was first found at Erawan field to come on stream in the Gulf of Thailand (Unocal, 1996).

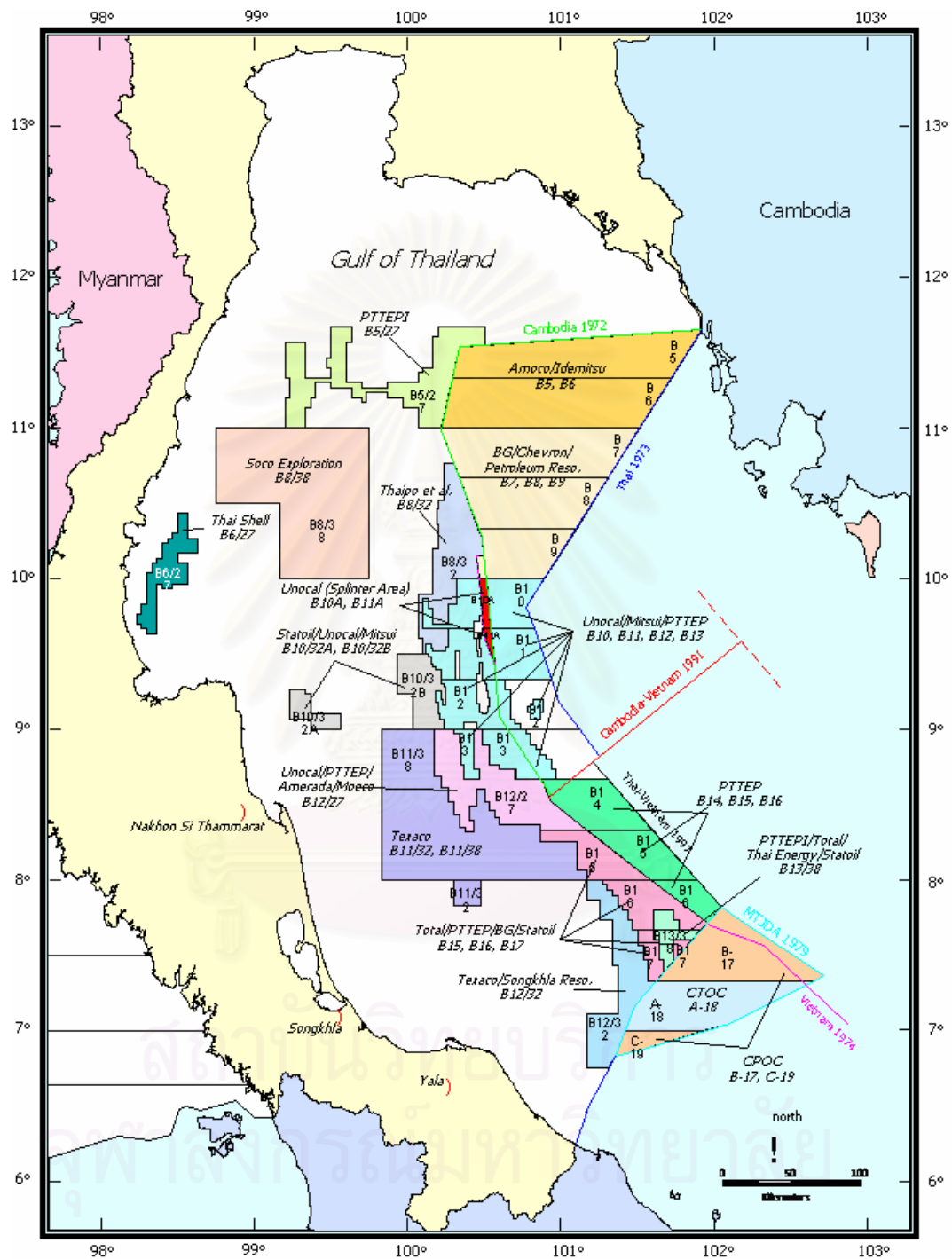


Figure 2-3 Petroleum Concessions in the Gulf of Thailand (DMF, 2007)

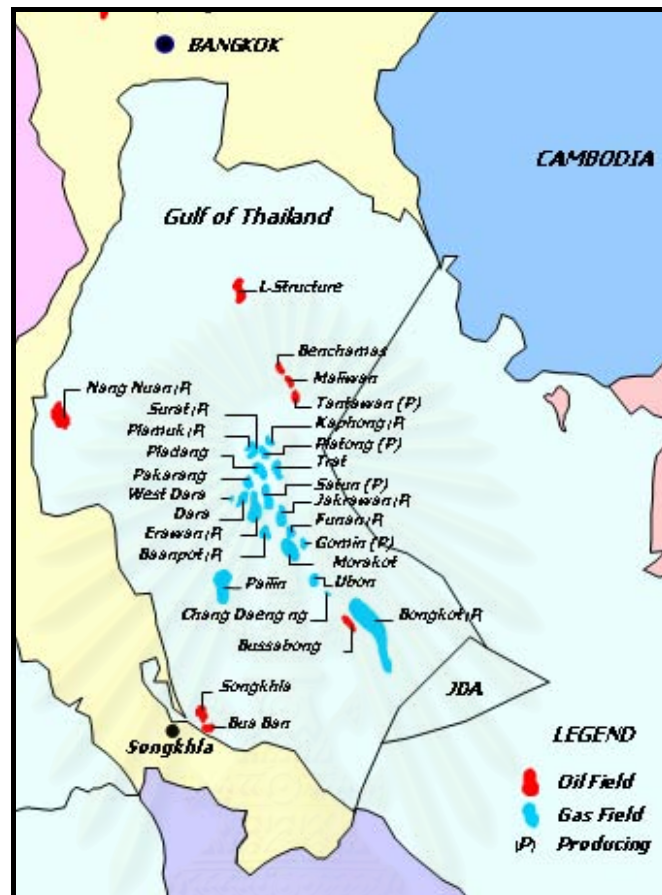


Figure 2-4 Current exploration fields in the Gulf of Thailand (DMF, 2007)

It is now generally accepted that one of mercury sources released to the Gulf of Thailand is offshore oil and gas exploration and exploitation. Petroleum activity contributes mercury and other heavy metals such as copper and zinc contamination. For offshore platforms in the Gulf of Thailand, mercury has been found in natural gas, condensate, produced water and condensate sludge obtained from tank cleaning in the condensate floating storage unit (PCD, 2001). This activity affects the marine environment.

Heavy metal concentrations in seawater reported for the Gulf of Thailand were apparently decreasing by as much as 500 times from 1979 to 1985, which is likely due to improvement in analytical techniques and methodology, rather than a decrease in the discharge of heavy metals into the Gulf (Utoomprurkporn *et al.*, 1987). However, mercury is not interested contaminants during earlier period.

Mercury contamination in the Gulf of Thailand occurs in water, sediment and marine organisms. Between 1995 and 1998, PCD has performed comprehensive monitoring programs in water, sediment and marine tissues in the vulnerable areas of the Gulf affected by the oil and gas operations. The results showed that high total mercury concentrations in seawater were marked only in 1995. In 1996 and 1998, it was found that mercury levels were less than PCD Standard (PCD, 2001).

2.4.3.1 Seawater

PCD (2000) reported total mercury concentrations from the analysis of 296 water samples from 61 stations in the Gulf of Thailand collected in 1995, 1996 and 1998. The mercury concentrations were found ranging from less than 0.01 to 0.69 $\mu\text{g/l}$ with an average of 0.06 $\mu\text{g/l}$.

Chongprasith and Wilairatanadilok (1999) reported that high mercury concentration in the areas around natural gas platforms and in the inner Gulf of Thailand. The concentrations ranged from 0.01 to 0.51 $\mu\text{g/l}$ during the periods from 1995 to 1998 with a peak in 1995, then decreasing in the following years. This was possibly due to the release of mercury from discharged water produced from oil and gas activities. The amount of mercury discharged into the Gulf from oil and gas operations between 1991 and 1996 was estimated monthly sampling of the produced waters at four different platforms (Erawan, Platong, Satun, and Funan production platforms operated by Unocal Thailand, Ltd.). These values ranged between 40 and 330 kg per year, the average value over this period of time was 187 kg per year (Tetra Tech, 1997).

2.4.3.2 Sediment

PCD (2001) revealed the information about mercury in 'Mercury Assessment in Thailand'. The annual loading of mercury to the Gulf of Thailand would be about 5.4 tons per year. In 1996 and 1998, sediment samples in the Gulf of Thailand were taken by PCD for mercury monitoring. Total mercury concentrations were found in a range from 10 to 120 $\mu\text{g/kg}$ (dry weight) with the average of 20 $\mu\text{g/kg}$ (dry weight). Table 2-5 shows the total mercury in coastal sediments of the Gulf of Thailand.

Beside Unocal Thailand that studied by Tetra Tech (1998) reported that the sediment samples were collected at Erawan Platform contained average mercury concentration of $1,404 \times 10^3 \mu\text{g/kg}$ (dry weight) and $863 \times 10^3 \mu\text{g/kg}$ (dry weight) in 1997 and 1998, respectively. The samples around surrounding stations were also taken with the concentrations ranging from 206×10^3 to $292 \times 10^3 \mu\text{g/kg}$ (dry weight).

Table 2-5 Mercury level in coastal sediments of the Gulf of Thailand (after PCD, 2001 and Thongra-ar and Parkpian, 2002)

STUDY PERIOD	LOCATION	TOTAL Hg ($\mu\text{g/kg}$ dry weight)	REFERENCES
1978-1979	Chao Phraya	79 – 1,860	Polprasert <i>et al.</i> , 1979
1979	Upper Gulf	49 – 268	
1980	Chao Phraya	$2,800 \pm 400$	Menasveta and Cheevaparanapiwat (1981)
1981	Upper Gulf	nil – 280	Bamrungrajhira <i>et al.</i> (1984)
1982	Upper Gulf	10 – 260	
1978	Upper Gulf	100 – 130	Idthikasem <i>et al.</i> (1981)
1979	Upper Gulf	nil – 240	
1980	Upper Gulf	nil – 1,200	
1981	Upper Gulf	10 – 140	
1987-1988	Laem Chabang*	100 – 1,400	PCD (1992)
1998	Gulf of Thailand*	50 – 2,800	EVS Environment Consultants (1999)

* Industrial area

Nevertheless, the evidence derived from the three types of analyses (total mercury, particulate mercury, and the relative bioavailability of the mercury) signifies that mercury in the sediments surrounding the Platong and Erawan Platforms is present as metacinnabar (mercuric sulfide). It was also reported that less than 0.2% of the total mercury in the sediments could be considered bioavailability and that between 95% and 98% was present as either crystalline or strongly bound amorphous mercury (Tetra Tech, 1998).

2.4.3.3 Marine organisms

Mercury absorbed into the food chain can adversely affect human health through seafood consumption. There are numerous studies found mercury concentration in marine organisms were elevated. In Thailand, Windom and Cranmer (1998) has studied total and methyl mercury in 100 fishes, 65 'platform' fish and 35 'market' fish. This study reported only a single lizard fish, *Saurida tumbil*, caught

close to Bongkot gas production platform in the Gulf exceeded 0.5 $\mu\text{g/g}$ wet weight action levels adopted by most national authorities regarding mercury levels for food consumption. In the same study also found two grouper had total mercury levels of 0.4 $\mu\text{g/g}$ wet weight or greater. However, the results in this study indicated that mercury in species of snapper and grouper collected near the gas production platform were not significantly different from those of the same species of fish caught from the regional, presumably non-impacted, fishery.

During 1997-1998, Tetra Tech, Inc. was assigned to monitor total mercury concentrations in fishes collected at remote wellhead platforms (reference site) comparing to those in fishes collected from the vicinity of the central production platforms (CPPs) in the Gulf of Thailand. It appeared that the concentrations of total mercury in fish from CPPs were significantly increased compared to mercury concentrations from fishes collected at the reference site (Tetra Tech, 1998).

In addition, Menasveta *et al.* (1995) collected fish from the vicinity of oil and gas operations in the Gulf of Thailand during 1994 to 1995, and found that mercury concentrations ranged from less than 0.01 to 1.27 $\mu\text{g/g}$ dry weight compared with the samples taken from the reference site, Tambon Bangsare, with the range of 0.02 to 0.99 $\mu\text{g/g}$ dry weight.

Among a variety of marine organisms (fish, crab, shrimp and scallop), the average mercury concentrations in fish were low, crabs tended to have higher concentrations than other organisms, while the lowest mercury concentrations were found in scallops (Thongra-ar and Parkpian, 2002).

CHAPTER III

METHODOLOGY

3.1 Sampling

Surface sediment samples were collected from 39 and 51 stations in the upper and lower Gulf of Thailand, respectively, during hydrographic and oceanographic survey of the Hydrographic Department of Royal Thai Navy in October 2003 using a Petersen Grab Sampler (Fig. 3-1). This type of grab sampler consists of a pair of weighted, semi-cylindrical jaws that are held open by a catch bar. The impact with the sediment loosens the tension on the catch bar allowing the jaws to close. Additional weights can be added to the jaws to provide better penetration into harder compacted sediment. As there is no access through the top of the sampler, only bulk samples can be taken. The samplers are restricted to low current conditions and may produce a bow/shock wave that disturbs fine grained sediments. In the presence of cobbles or vegetative debris the jaws may not completely close. Therefore it is suitable for collection of hard bottom material such as sand, marl, gravel, and firm clay. The sample depth is 0-30 cm and sample volume is 9.45 L. The advantages of this sampler are providing large sample and penetrating most substrates. The disadvantages are shock wave from descent may disturb fine-grained sediment, lacks lid cover to permit sub sampling, may not close completely, restricted to low current conditions, and may exceed target penetration depth (Resources Inventory Committee, 1998).

The sampling locations are shown in Fig.3-2 and 3-3, for the Upper and Lower Gulf of Thailand, respectively, details in Appendix A. From each station, a portion of sediments from the middle of the grab, no contact to the sampler's wall, was transferred into labeled plastic bags and immediately kept frozen on board at -20°C until further processes.

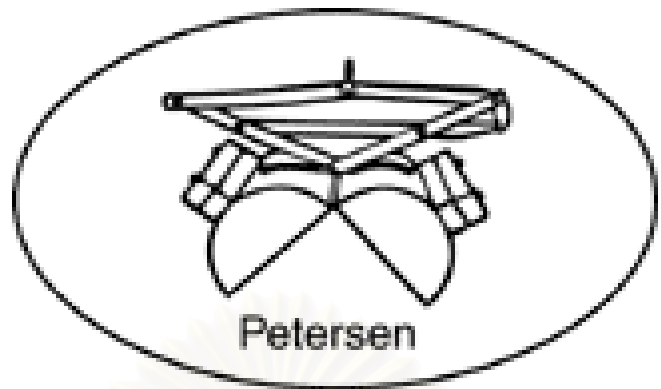


Figure 3-1 Petersen grab sampler (source: US-EPA, 2001)

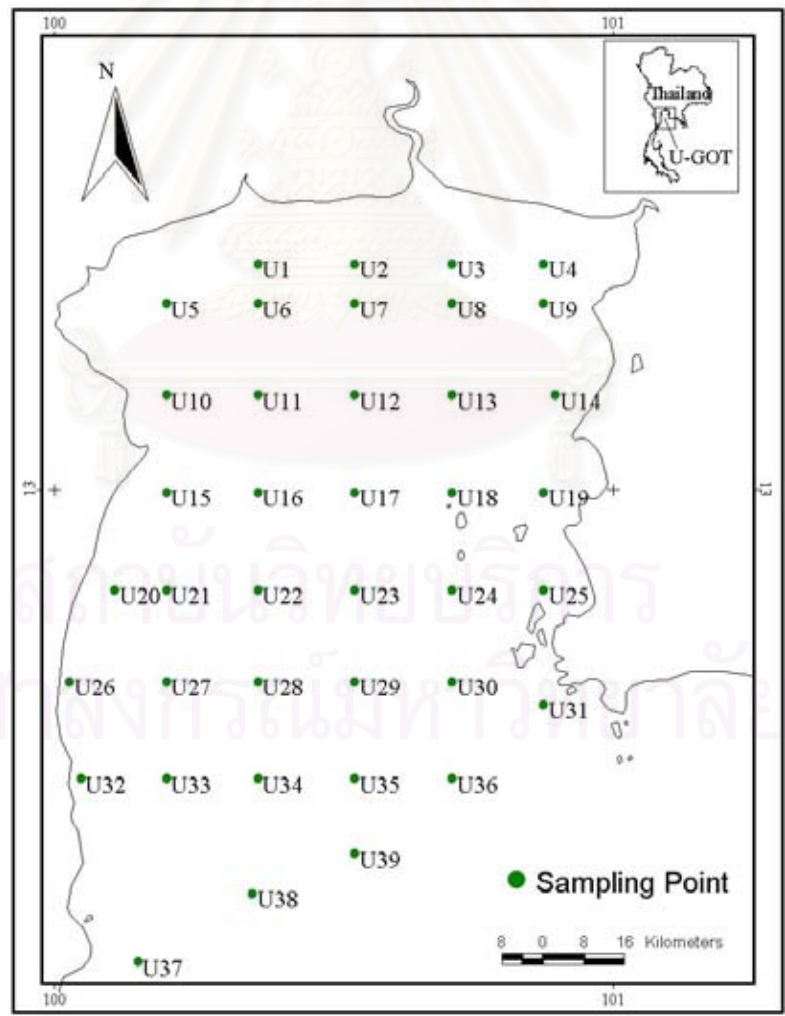


Figure 3-2 Sampling locations in the Upper Gulf of Thailand

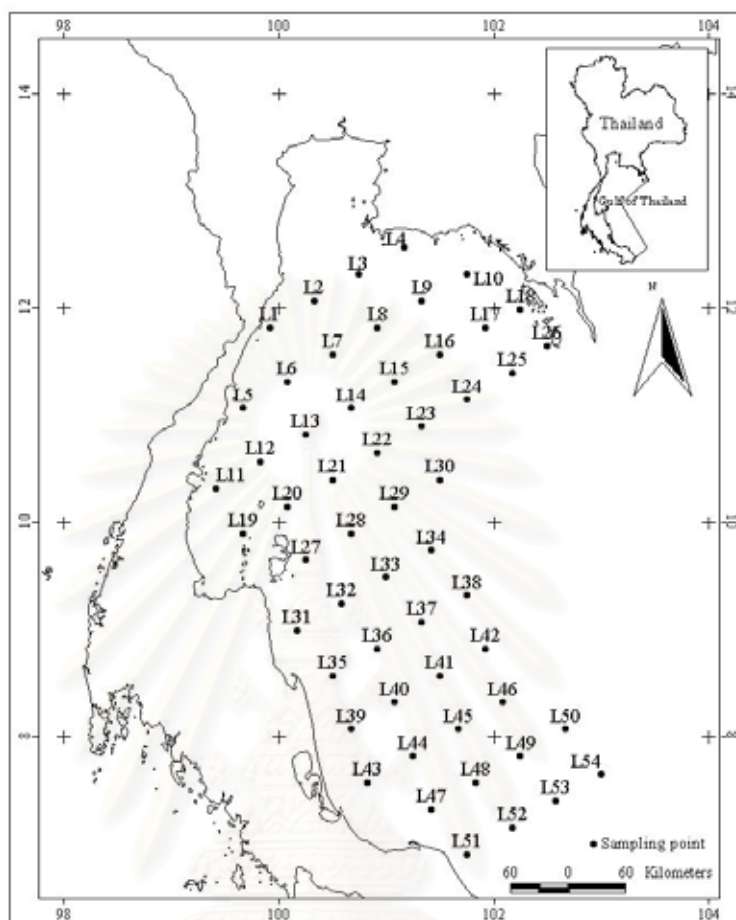


Figure 3-3 Sampling locations in the Lower Gulf of Thailand

3.2 Methods for sample analysis

3.2.1 Sample preparation

Sediment samples were freeze-dried until dryness, approx. 3 days, and kept in acid-cleaned plastic bottles until analyses. Sediment sample of each station was divided into two portions. The untreated portion was used for sedimentological analysis. Another portion was ground to powder using an agate mortar and pestle. The later portion was used for mercury and other geochemical analyses.

3.2.2 Sedimentological analysis

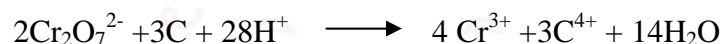
The untreated portion of sediment was accurately weighed and pretreated to remove organic matter using a technique slightly modified from Müller (1967) (Sompongchaiyakul, 1989) (see Appendix B). After removal of organic matter, the sediment was wet-sieved through a 63 µm sieve. The sand size fraction was the portion that remained on the sieve. This portion was transferred to oven dry and weight.

The passed through portion was further analyzed for silt and clay size fractions by Laser Diffraction Particle Size Analyzer (BECKMAN COULTER, model LSTM 13 320 Multi-wavelength Particle Size Analyzer) using 10% sodium hexametaphosphate as a dispersing agent. Analytical precision was determined by analyzing every tenth sample in duplicate.

3.2.3 Readily oxidizable organic carbon analysis

Readily oxidizable organic carbon in sediments was determined by a modified Wallkey-Black method (chromic acid method) as described in Loring and Rantala (1995) (see Appendix C). The readily oxidizable organic matter in sediment was allowed to oxidize by chromic acid and excess chromic acid was reduced by with ferrous solution. Diphenylamine was used as indicator.

The oxidation of carbon by chromic acid is represented as follows:



and the reduction of $\text{Cr}_2\text{O}_7^{2-}$ by ferrous solution is given as:



This method did not interrupt other non-sensitive organic carbon like charcoal, graphite, etc., and proteins also remained unoxidized.

Accuracy of the method was determined by analysis of dextrose. Analytical precision was determined by analyzing every tenth sample in duplicate.

3.2.4 Carbonate (inorganic carbon) analysis

Inorganic carbon, or carbonate content, was measured by an acid-base titration technique of Gross (1971) modified by Sompongchaiyakul (1989) (see Appendix D). The sediment samples were treated with excess amount of standardized hydrochloric acid (0.05N HCl). Complete the reaction between acid and carbonate by heating at temperature of 90°C for 20 minutes. The untreated acid was then back-titrated with sodium hydroxide solution (0.25N NaOH) using phenolphthalein as an indicator. Accuracy was determined by analysis of standard sodium bicarbonate and potassium hydrogen phthalate. Analytical precision was determined by analyzing every tenth sample in duplicate.

3.2.5 Mercury analysis

Sample preparation (sediment digestion) for measuring total mercury were modified from Bloom and Creelius (1987), US-EPA METHOD 7471B (US-EPA, 1998) and US-EPA METHOD 1631(US-EPA, 2001) (see Appendix E). This procedure was intended for coal, ores, sediments, soils, and other geological media. The dried sediment sample was pulverized using an agate mortar prior to digestion. Total mercury in the sediments was measured using cold-vapor spectrophotometry after hot aqua regia digestion following by BrCl oxidation. The addition of BrCl was to ensure that Hg will not re-adsorb to the carbon particles, producing low recoveries. Before measurement, mercury in the solution was reduced to the elemental state using sodium borohydride (NaBH₄) in a closed system. The liberated mercury vapor as Hg⁰ was passes through a cell positioned in the light path of an atomic absorption spectrometer. Its absorbance at a wavelength of 253.7 nm was measured. The absorbance signal is a function of mercury concentration.

Briefly, accurately weight to 4 decimals of 0.4 to 0.6 g of dry sediment was placed in an acid-cleaned digestion tube and was digested in 5 ml aqua regia (HCl : HNO₃ = 3 : 1) in a digestion block at 95±2°C for 30 minutes. After digestion, the solution was diluted to 30 ml with 0.07N BrCl solution; shake the tube to mix thoroughly. After dilution and shaking, allow the sample to settle overnight. Before measuring total mercury, add 3 ml of sodium chloride-hydroxylamine sulfate solution

to reduce the excess BrCl in the solution. All labwares used in the digestion process was acid-washed with 10% HNO₃ and rinsed with deionized water.

In this study, Flow Injection Mercury Analyzer (Perkin-Elmer, model FIMS^{TML}400) was used to measure total mercury in the solution. This instrument based on cold vapor technique using 0.2% NaBH₄ in 0.05% NaOH as reducing agent, 3% (v/v) HCl as carrier solution, and argon stream as an inert carrier to transport mercury vapor into the cell. FIMS provides detection limits of < 0.01 µg/l. Schematic diagram of flow injection is shown in Fig.3-4. Flow Injection systems with two pumps is shown in Fig.3-5.

The relative accuracy for the measuring of mercury was evaluated comparing to the certified values for the National Research Council of Canada (NRCC) sediment reference materials BEST-1 and MESS-1. Analytical precision of all analysis was determined by analyzing every tenth sample in duplicate. All blanks and the certified reference material (CRM) were prepared in the same manure as the samples.

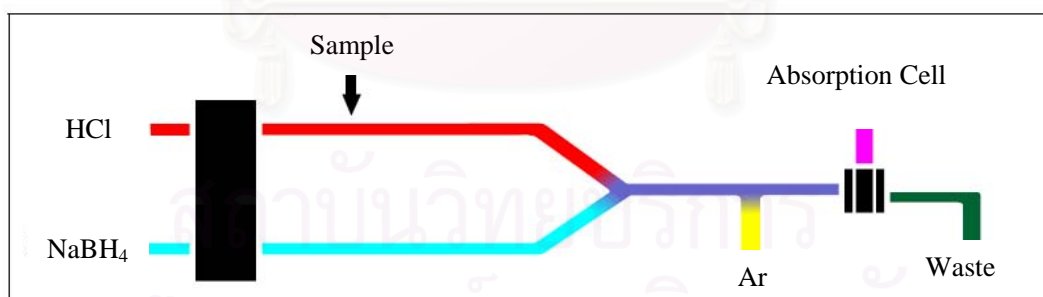


Figure 3-4 General schematic of flow injection

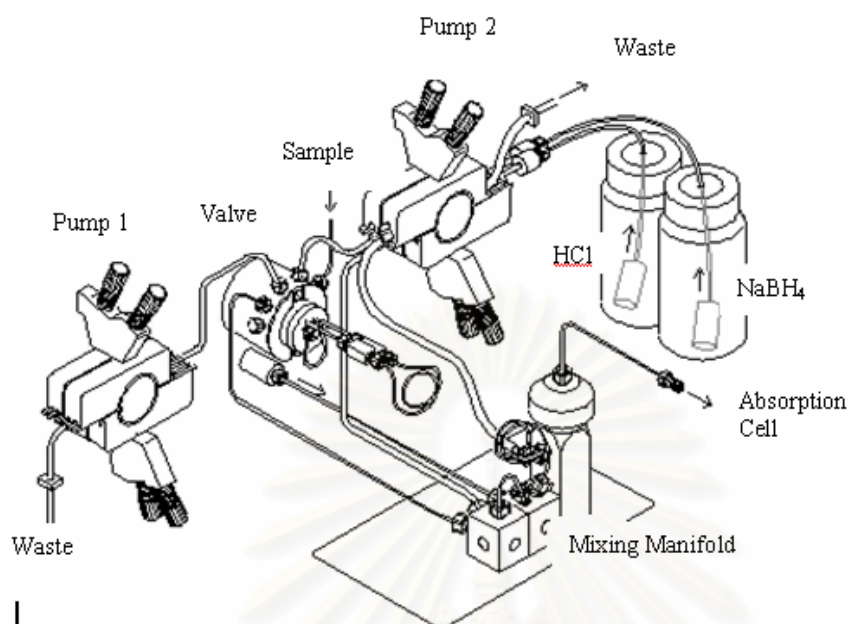


Figure 3-5 Tubing set up for Flow Injection systems with two pumps

3.3 Statistical evaluation and Geo-spatial distribution mapping

The analytical results were compiled to form a multi elemental database using Excel. Descriptive statistics including mean, standard deviation, maximum, and minimum were calculated. Principal Component Analysis (PCA) was used for identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences by MINITAB 14[®]. Cluster analysis was used to discover a system of organizing data and choose hierarchical technique for evaluation by SPSS[®]. Spatial distribution of each parameter was carried out using ArcView[®] Version 3.2a.

NOTE:

PCA is a method that reduces data dimensionality by performing a covariance analysis between factors. This procedure transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The objective of PCA is to reduce the dimensionality (number of variables) of the dataset but retain most of the original variability in the data. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. As such, it is suitable for data sets in multiple dimensions. PCA is a useful statistical technique that has found application in fields such as face recognition and image compression, and is a common technique for finding patterns in data of high dimension. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analyzing data. The other main advantage of PCA is that once you have found these patterns in the data, and you compress the data, such as by reducing the number of dimensions, without much loss of information.

Cluster analysis is a collection of statistical methods, which identifies groups of samples that behave similarly or show similar characteristics. In common parlance it is also called look-a-like groups. The simplest mechanism is to partition the samples using measurements that capture similarity or distance between samples. In this way, clusters and groups are interchangeable words. The clustering algorithms are broadly classified into two namely hierarchical and non-hierarchical algorithms. In the hierarchical procedures, we construct a hierarchy or tree-like structure to see the relationship among entities (observations or individuals). In the non-hierarchical method a position in the measurement is taken as central place and distance is measured from such central point (seed). Identifying a right central position is a big challenge and hence non-hierarchical methods are less popular.

CHAPTER IV

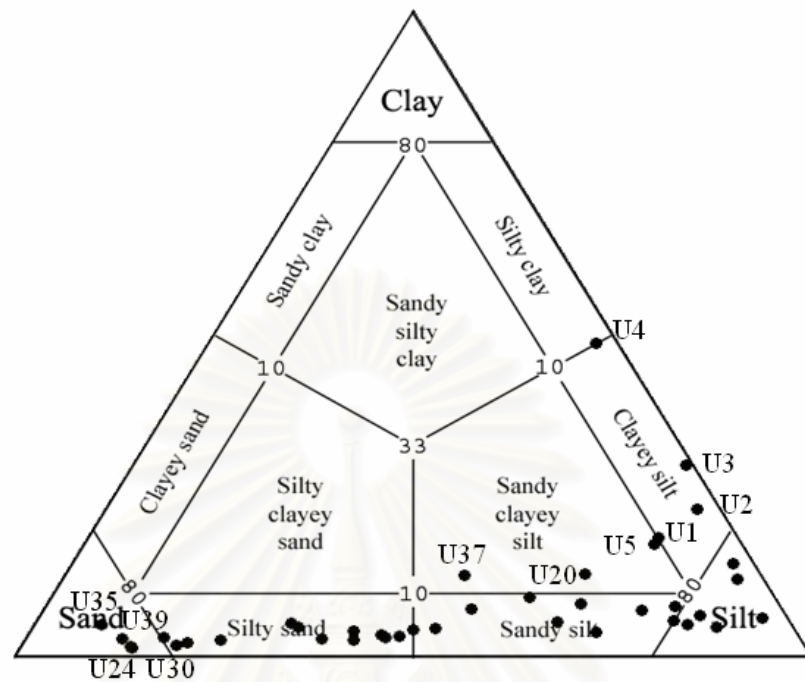
RESULTS AND DISCUSSIONS

4.1 Sedimentological study

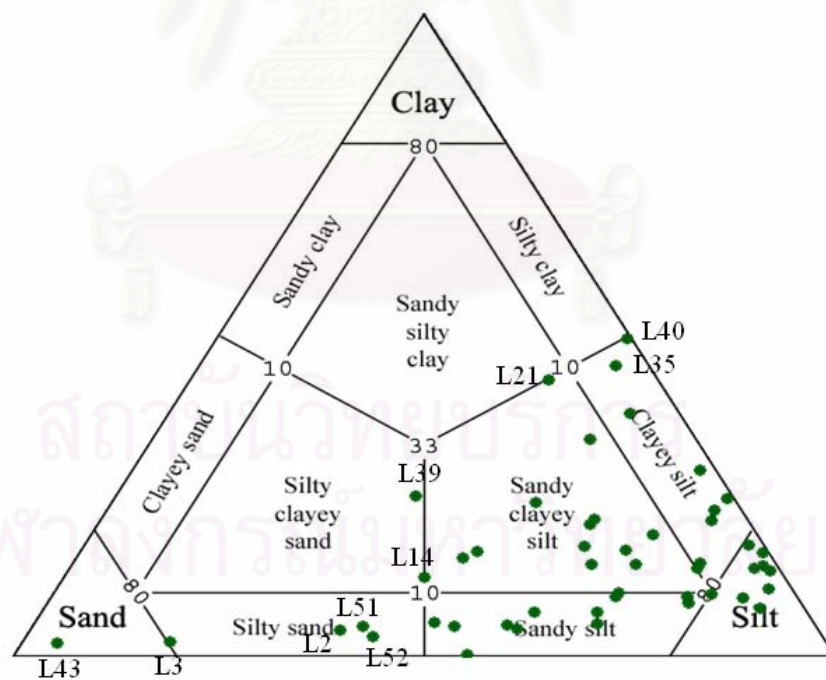
Results of sedimentological study, including size composition and sediment name (following Gorsline (1960)) of sediments in the Gulf of Thailand are shown in Table F-1, Appendix F. The percentage by weight of sand, silt and clay is plotted in ternary diagram proposed by Gorsline (1960) (Fig. 4-1), and the type of each sample is classified accordingly (Table F-1). In general, bottom sediments of the Upper Gulf of Thailand are finer than ones of the Lower Gulf (Fig. 4-2). Figures 4-3, 4-4, 4-5 and 4-6 show the distribution of sand, silt, clay and less than 63 micron (silt + clay) fractions, respectively, in the Gulf sediment.

Sediments from the Upper Gulf of Thailand can be classified to 7 types namely silty sand, sandy silt, silt, sand, sandy clayey silt, clayey silt and silty clay, and are found in a decreasing order of abundance. The percentage of fine grain (< 63 micron) tends to be much higher at the river mouths, and decrease regularly southward with the increase in percentage of sand. For the Lower Gulf of Thailand, 7 types of sediments namely sandy silt, sandy clayey silt, silt, clayey silt, silty sand, silty clayey sand and sand are classified. The percentage of fine grain sediment is the most abundance offshore near Chumporn and Nakhon Si Thammarat provinces. Sand fraction is found to be highest near the mouth of Songkhla Lake.

Size composition and distribution pattern of each fraction are still remains relatively the same as the study done over the last two decades by Sompongchaiyakul (1989). The Upper Gulf sediments are under the direct influence of four major rivers namely Chao-Phraya, Tha-Chin, Mae-Klong, and Bangpakong, while the Lower Gulf sediments are likely to be transported from and deposited under the influence of the South China Sea. Nevertheless, the Songkhla Lake and Tapi River are also influence to the grain size of sediment around that area.



(a)



(b)

Figure 4-1 Triangle diagram of sediment category in the Gulf of Thailand; (a) the Upper Gulf and (b) the Lower Gulf.

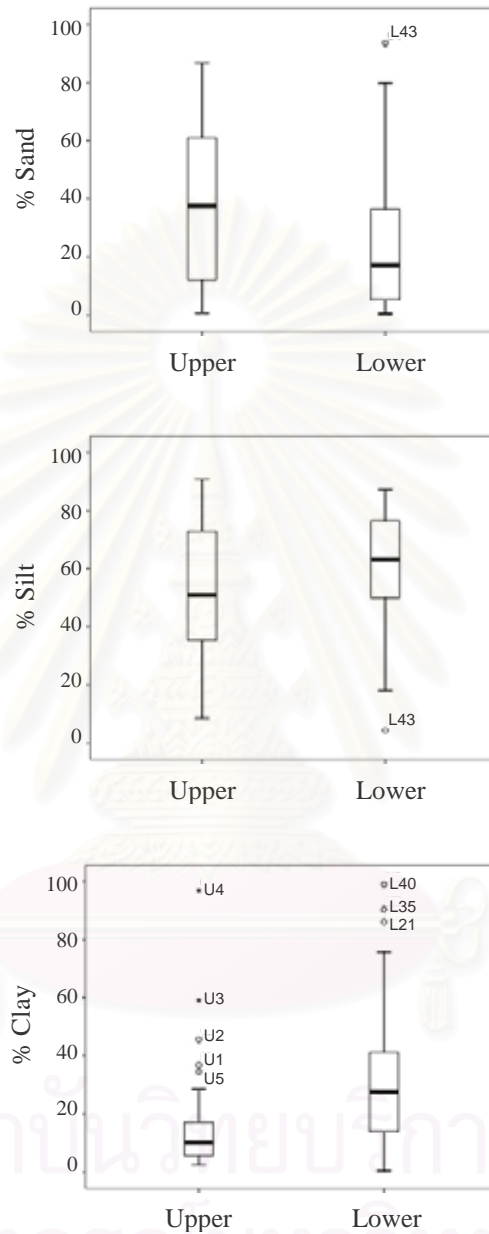


Figure 4-2 Box plot show lower quartile (Q_1), median, upper quartile (Q_3), minimum value and maximum value of percentages of sand, silt and clay fractions in the sediments of the Upper and Lower Gulf of Thailand.

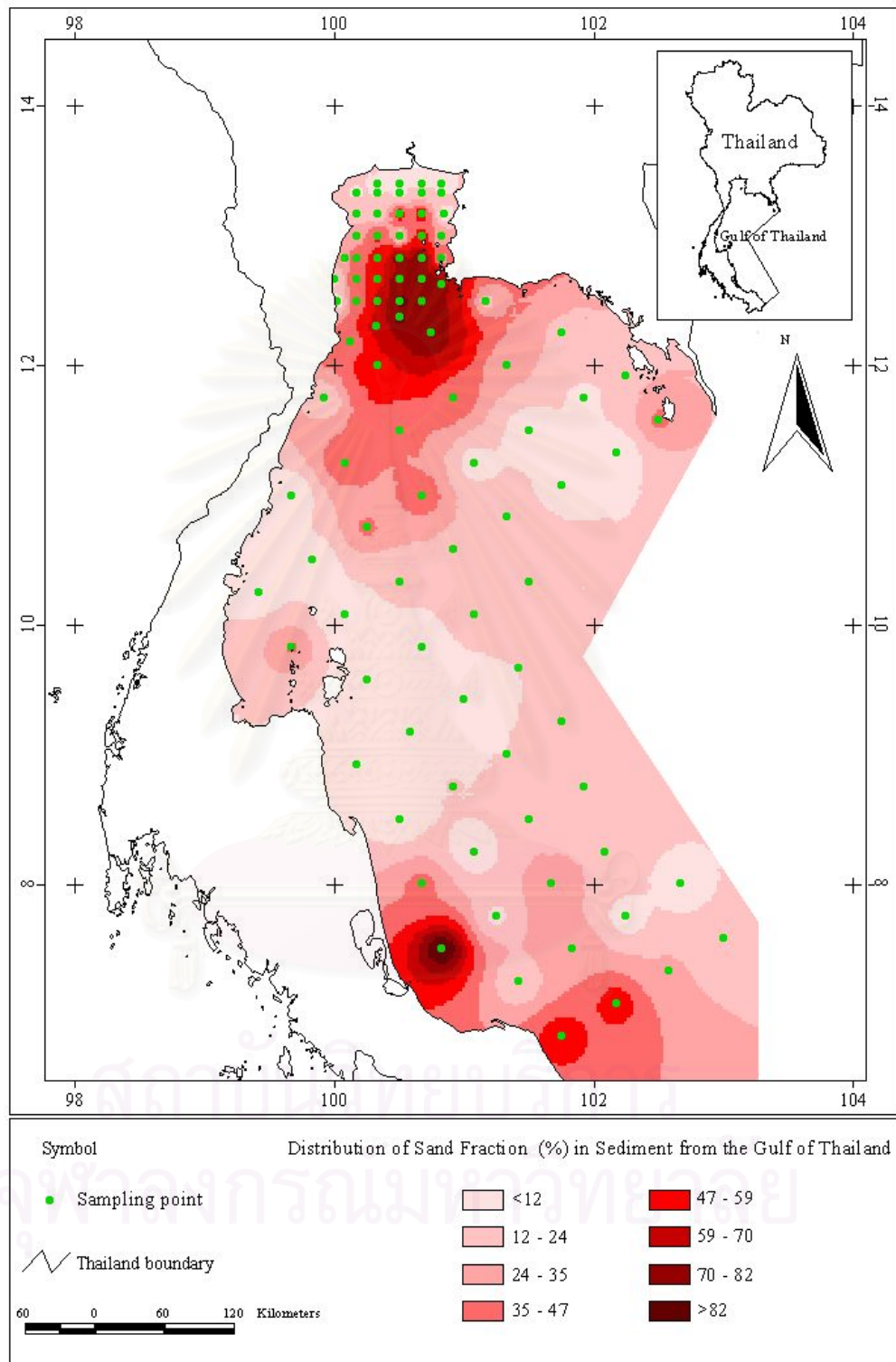


Figure 4-3 Distribution pattern of sand composition in sediment of the Gulf of Thailand

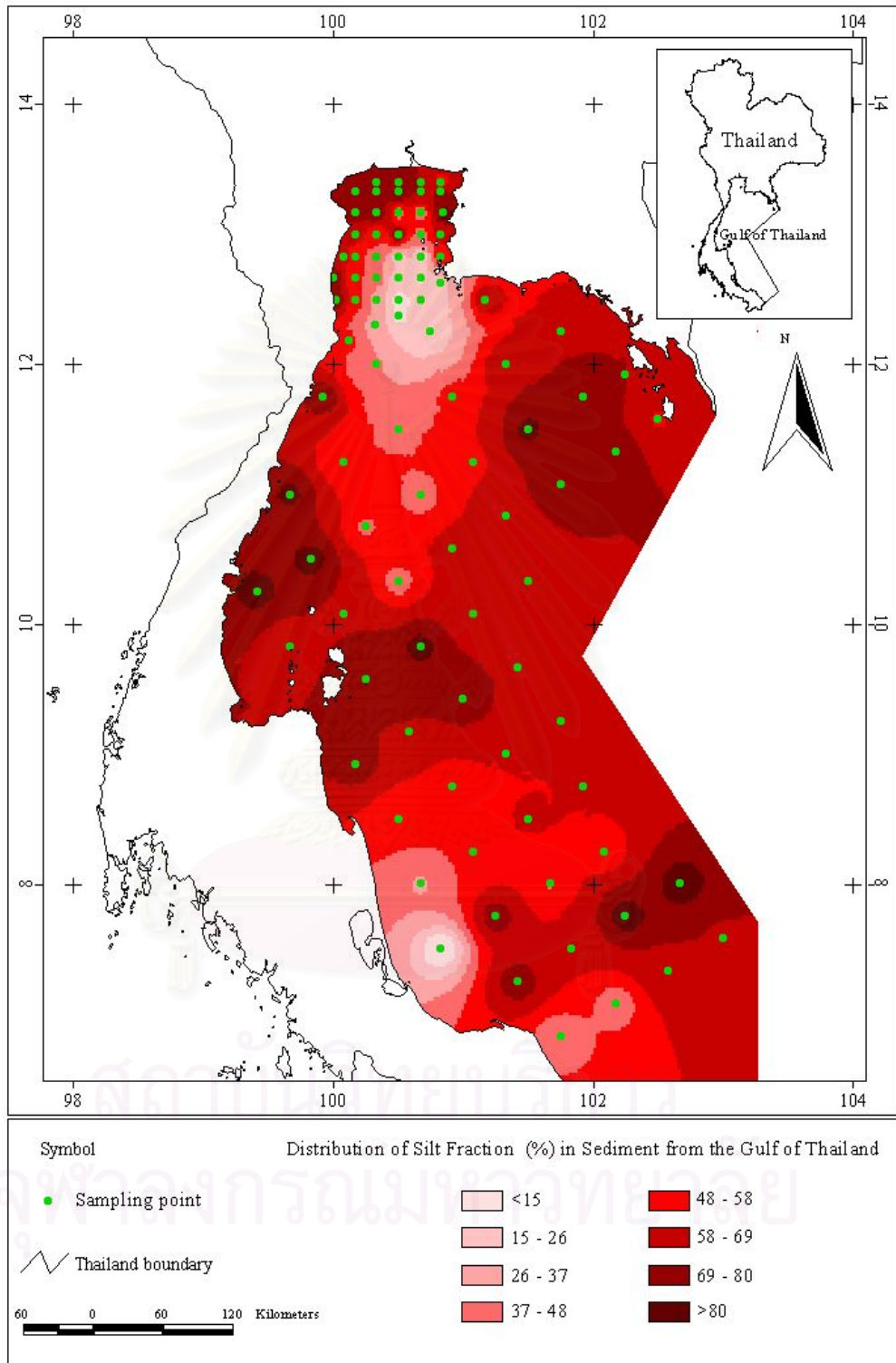


Figure 4-4 Distribution pattern of silt composition in sediment of the Gulf of Thailand

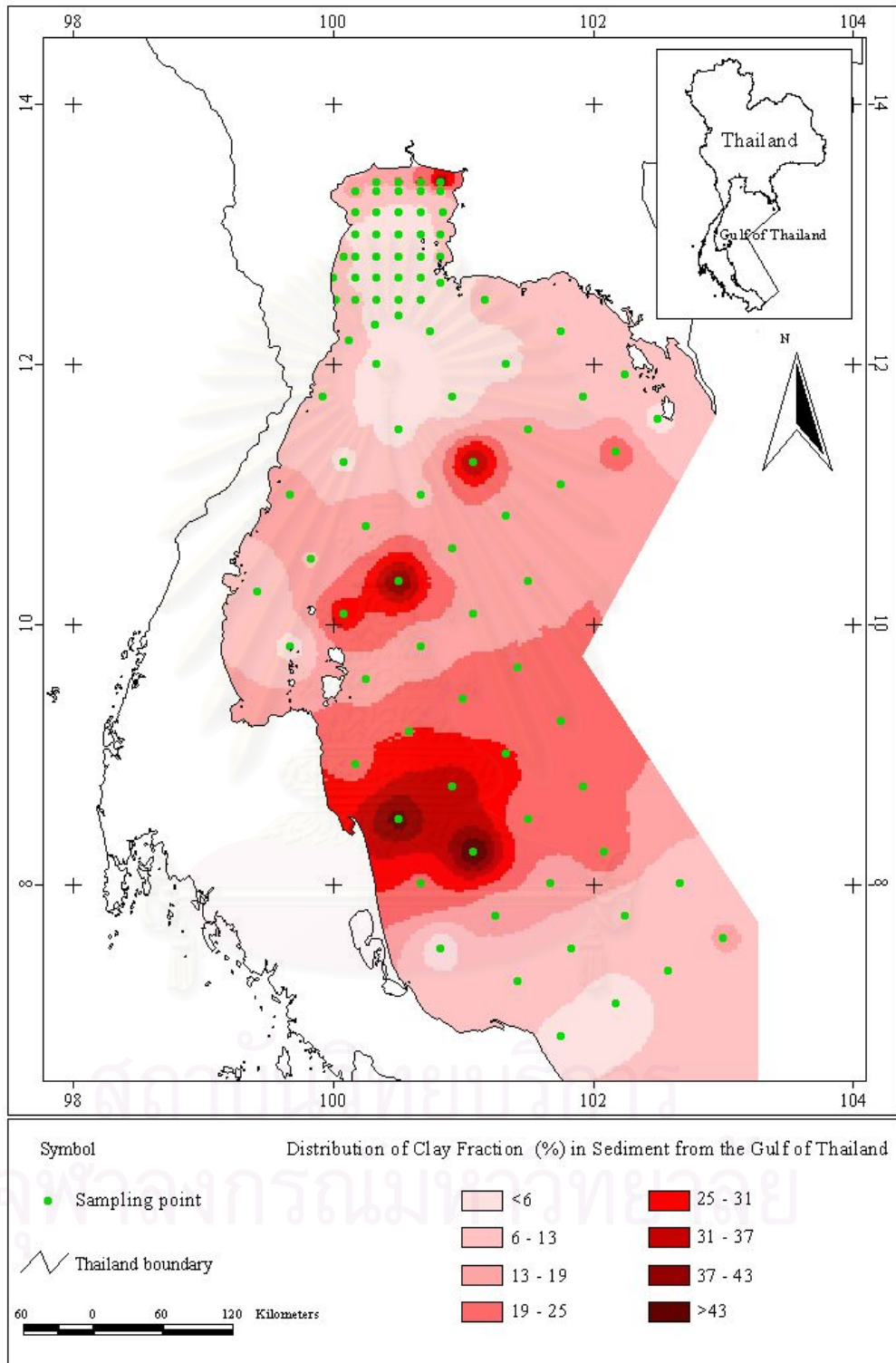


Figure 4-5 Distribution pattern of clay composition in sediment of the Gulf of Thailand

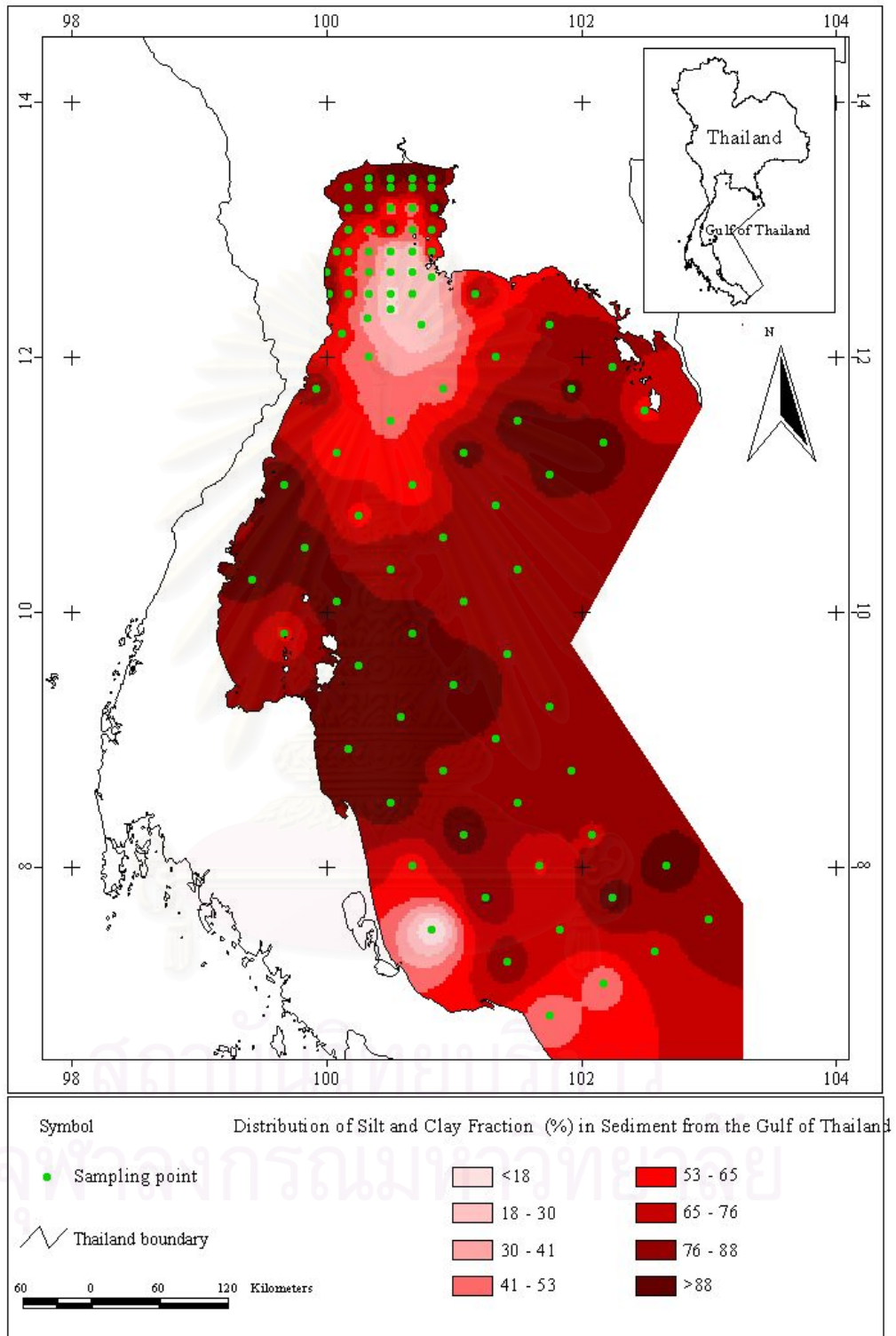


Figure 4-6 Distribution pattern of less than 63 micron (silt + clay) composition in sediment of the Gulf of Thailand

4.2 Readily oxidizable organic carbon content

The values of oxidized organic carbon content analyzed by the chromic acid method are more reliable and are better estimation for organic matter in sediment (Sompongchaiyakul, 1989). The results of percentage of organic carbon in sediment are presented in Table F-2, Appendix F. The average values, range and median of organic carbon in sediment of the Gulf of Thailand of this study in comparison with the results of Sompongchaiyakul (1989) are summarized in Table 4-1; the comparison of oxidized organic carbon between the Upper and Lower Gulf sediments is shown in Figure 4-7. In general, sediments of the Upper Gulf contain higher organic carbon than those of the Lower Gulf. Distribution pattern of organic carbon in content in the seabed of the Gulf of Thailand is illustrated in Fig. 4-8.

Table 4-1 Average, minimum, maximum and median of organic carbon content in percent in sediment of the Gulf of Thailand

PART	N	Average	Minimum	Maximum	Median	References
Upper Gulf	39	0.93 ± 0.61	0.07	2.20	0.77	This study
Lower Gulf	50	0.68 ± 0.37	0.10	1.35	0.56	
Upper Gulf	19	0.68 ± 0.56	0.09	1.89	0.39	Sompongchaiyakul
Lower Gulf	52	0.59 ± 0.37	0.12	1.70	0.48	(1989)

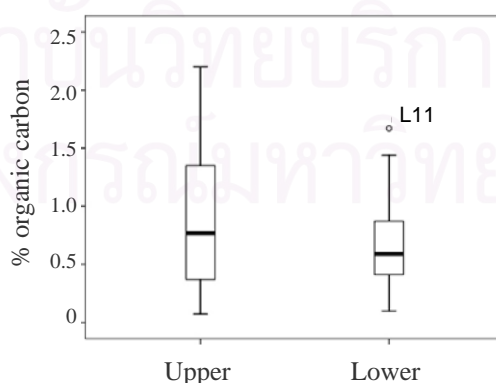


Figure 4-7 Box plot show lower quartile (Q_1), median, upper quartile (Q_3), minimum value and maximum value of organic carbon content in the sediments of the Upper and Lower Gulf of Thailand.

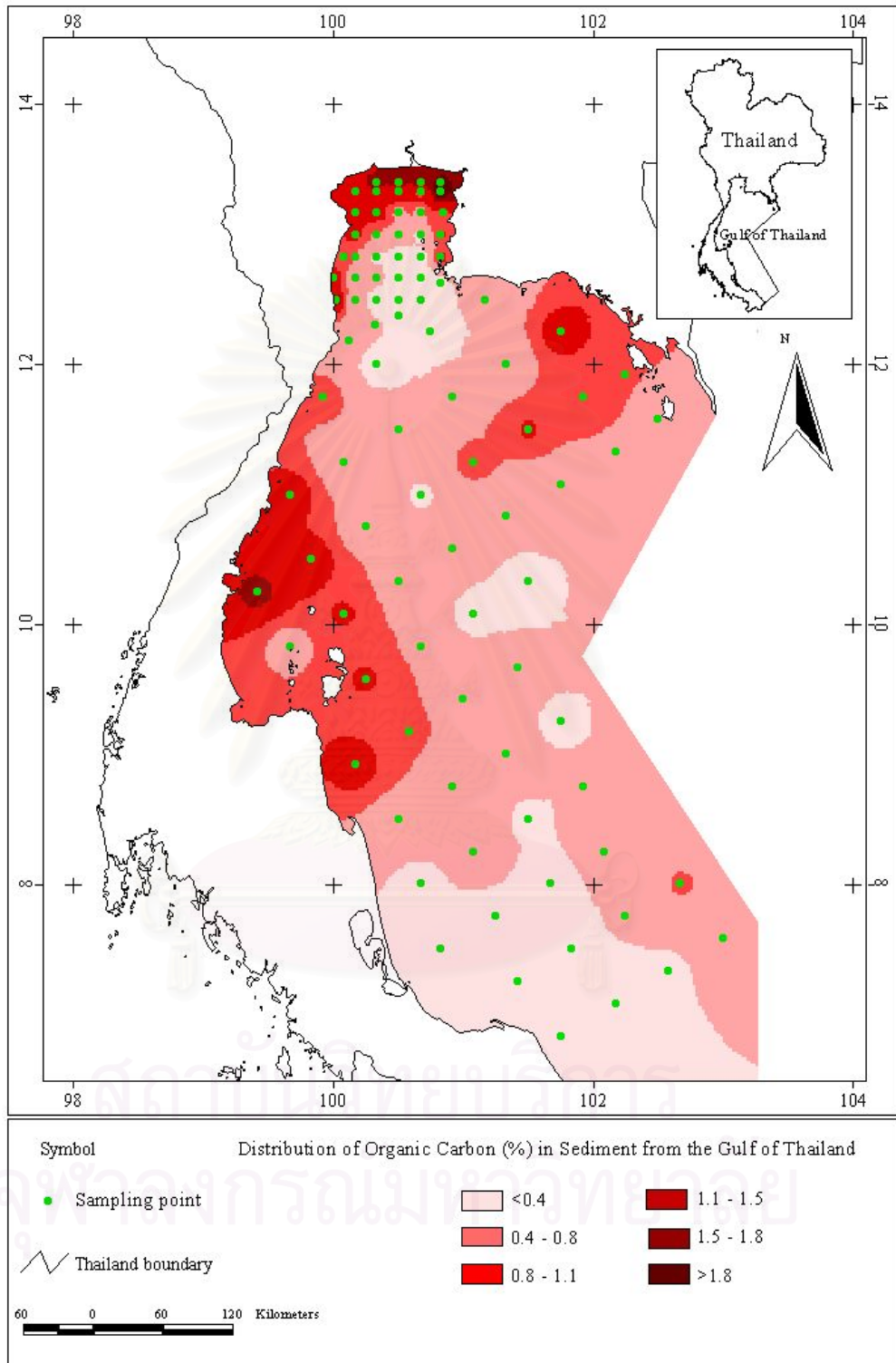


Figure 4-8 Distribution pattern of organic carbon content in sediment of the Gulf of Thailand

In comparison with the previous investigation which done by Sompongchaiyakul (1989) (Table 4-1), there is an accumulation of organic carbon in the sediments of Gulf of Thailand more than the Lower Gulf. The high organic carbon sediments in the Upper Gulf were found near the four major rivers mouth. For the Lower Gulf, the high values found most abundance offshore from Chumporn to Nakhon Si Thammarat provinces, and offshore of Chanthaburi to Trad provinces. Off Songkhla Pattani and Narathiwat, the sediments contain low organic carbon.

The percentage of organic carbon content is found to associate with fine-grained sediment (< 63 micron), silt and clay, rather than coarse-grained sediment as shown in Fig. 4-9. The fine-grained sediment can adsorb more organic carbon than coarse-grained sediment due to its high surface area and contains higher clay minerals (aluminosilicate) composition (Sompongchaiyakul, 1989).

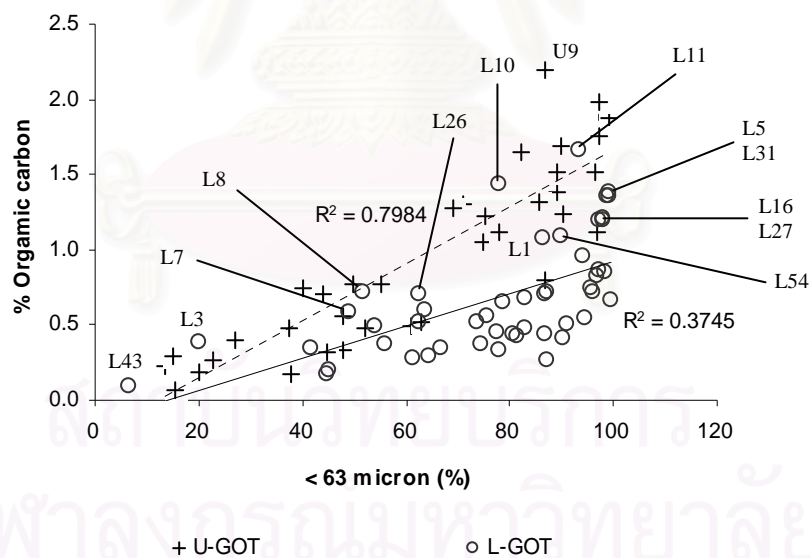


Figure 4-9 Correlation between organic carbon contents and fine-grained fraction in the sediments of the Gulf of Thailand.

4.3 Calcium carbonate content

The results of percentage of calcium carbonate in sediment are presented in Table F-2, Appendix F. The average values, range and median of calcium carbonate in sediment from the Gulf of Thailand in comparison with previous works are summarized in Table 4-2 and the comparison among the Upper and Lower Gulf is shown in Fig. 4-10. The content of calcium carbonate in the sediments of the Gulf of Thailand is found slightly higher than those reported by Sompongchaiyakul (1989) and Nornua (1998). Distribution pattern of calcium carbonate in sediment in the seabed of the Gulf of Thailand is illustrated in Fig. 4-8.

Table 4-2 Average, minimum, maximum and median of carbonate content in percent in sediment of the Gulf of Thailand

PART	N	Average	Minimum	Maximum	Median	References
Upper Gulf	39	15.1 ± 7.9	5.7	36.9	14.7	This study
Lower Gulf	50	16.3 ± 8.6	1.7	39.3	15.3	
Upper Gulf	21	14.4 ± 4.5	8.4	27.1	13.3	Sompongchaiyakul (1989)
Lower Gulf	53	12.2 ± 4.2	4.8	21.4	12.7	
Lower Gulf	51	14.5	–	–	–	Nornua (1998)

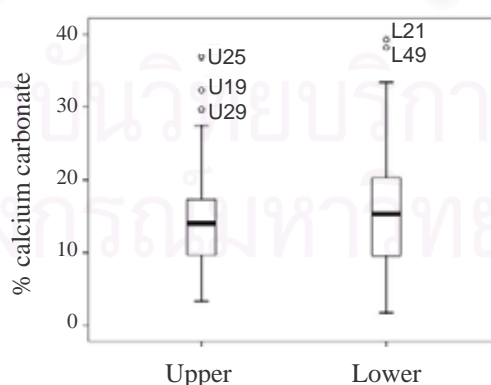


Figure 4-10 Box plot show lower quartile (Q_1), median, upper quartile (Q_3), minimum value and maximum value of carbonate content in the sediments of the Upper and Lower Gulf of Thailand.

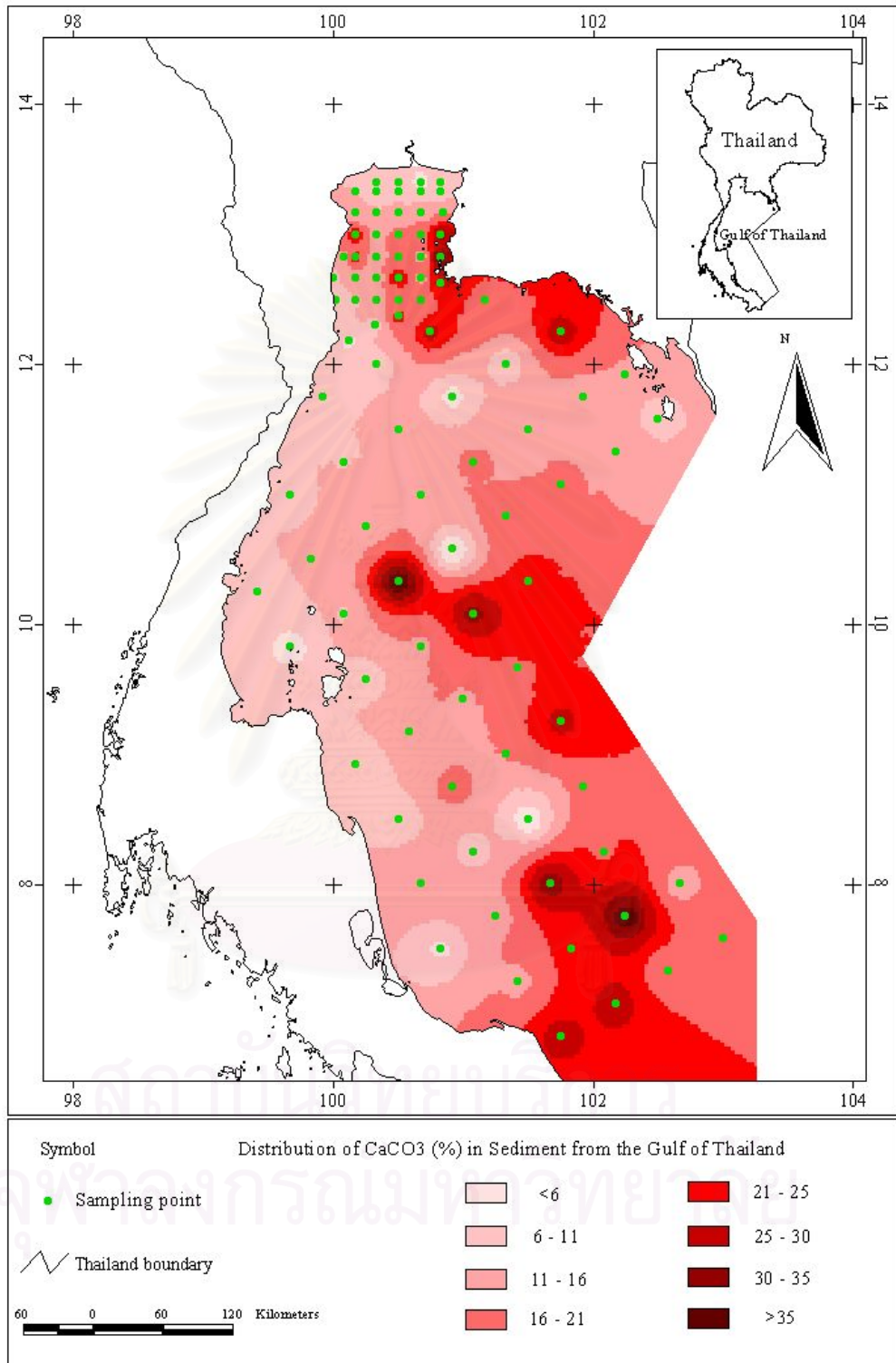


Figure 4-11 Distribution pattern of calcium carbonate content in sediment of the Gulf of Thailand

The results agree with Sompongchaiyakul (1989) and Nornua (1998) that carbonate content in near-shore surface sediment is lower than in the middle of the Gulf which is deeper. High concentrations of calcium carbonate also found along the coast of eastern seaboard area, Chonburi, Rayong and Chanthaburi, and Pattani in the southernmost of the Gulf. The area of high calcium carbonate contents is affected from coral fragmentation or distribution of calcareous, foraminifera and coccolith debris that were found extensive in the Gulf of Thailand. Their structure has calcium carbonate as the constituent (Kengkoom, 1980; Takahashi *et al.*, 1980; Yamamoto, 1982; Pilskaln *et al.*, 1996).

4.4 Mercury contamination in sediments

Accuracy of mercury analysis was performed by analysis of certified reference materials (CRM) obtained from National Research Council of Canada (NRCC). The CRMs were digested and analyzed in the same manure as sediment samples. The values and recovery of both CRMs are shown in Table 4-3.

The results of total mercury ($\mu\text{g}/\text{kg}$ dry weight) accumulated in the surface sediment of the Gulf of Thailand are presented in Table F-2, Appendix F. The average values, range and median of total mercury ($\mu\text{g}/\text{kg}$ dry weight) are summarized in Table 4-4 and the comparison is shown in Fig. 4-12. The limit of detection of the method and instrument for this study is $2 \mu\text{g}/\text{kg}$ which obtained from three times of standard deviation of the blank.

Table 4-3 Mercury concentrations and recovery of NRCC – certified reference materials ($\mu\text{g}/\text{kg}$).

CRM	N	AVERAGE ($\mu\text{g}/\text{kg}$)	CERTIFIED VALUE ($\mu\text{g}/\text{kg}$)	% RECOVERY
BEST-1	8	90.6 ± 1.0	92 ± 9	98.5
MESS-1	3	174.6 ± 13.1	179 ± 6	97.5

Table 4-4 Average, minimum, maximum and median of total mercury ($\mu\text{g}/\text{kg}$ dry weight) in sediment of the Gulf of Thailand

PART	N	Average	Minimum	Maximum	Median
Upper Gulf	39	33.9 \pm 27.4	< 2	92.4	23.5
Lower Gulf	49	24.4 \pm 9.0	6.5	50.1	23.4

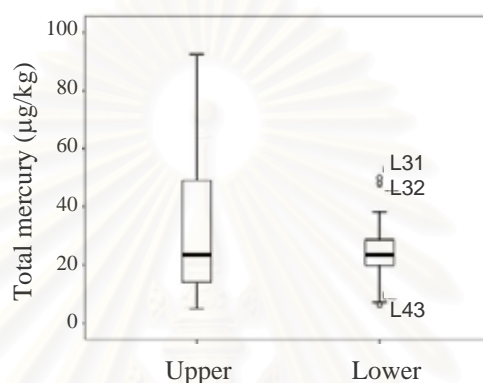


Figure 4-12 Box plot show lower quartile (Q_1), median, upper quartile (Q_3), minimum value and maximum value of total mercury ($\mu\text{g}/\text{kg}$ dry weight) in the sediments of the Upper and Lower Gulf of Thailand.

Although the arithmetic mean (or more commonly, "average") of total mercury in sediment of the Upper Gulf is higher than the Lower Gulf (Table 4-4), the median of the values in both parts is similar. The range of total mercury concentration in the Upper Gulf sediment is much wider than the Lower Gulf as can be seen in Fig. 4-12 and Table 4-4. The maximum values are found near the 4 major rivers drained into the Upper Gulf. Distribution pattern of total mercury ($\mu\text{g}/\text{kg}$ dry weight) contamination in sediment of the Gulf of Thailand is illustrated in Fig. 4-13.

When compare with previous works which mainly interested in the area near industrial sites (Table 2-5, Chapter 2), it can be concluded that sediment of the Gulf of Thailand, in general, is less contaminated from total mercury than those near industrial area; however not in the case of near platform (Fig. 4-14 and see 2.4.3.2 in Chapter 2) (Tetra Tech, 1998). The high concentration of total mercury always found at the river mouths indicated an important of land-based sources. The current pattern affects mercury transportation in the Gulf of Thailand.

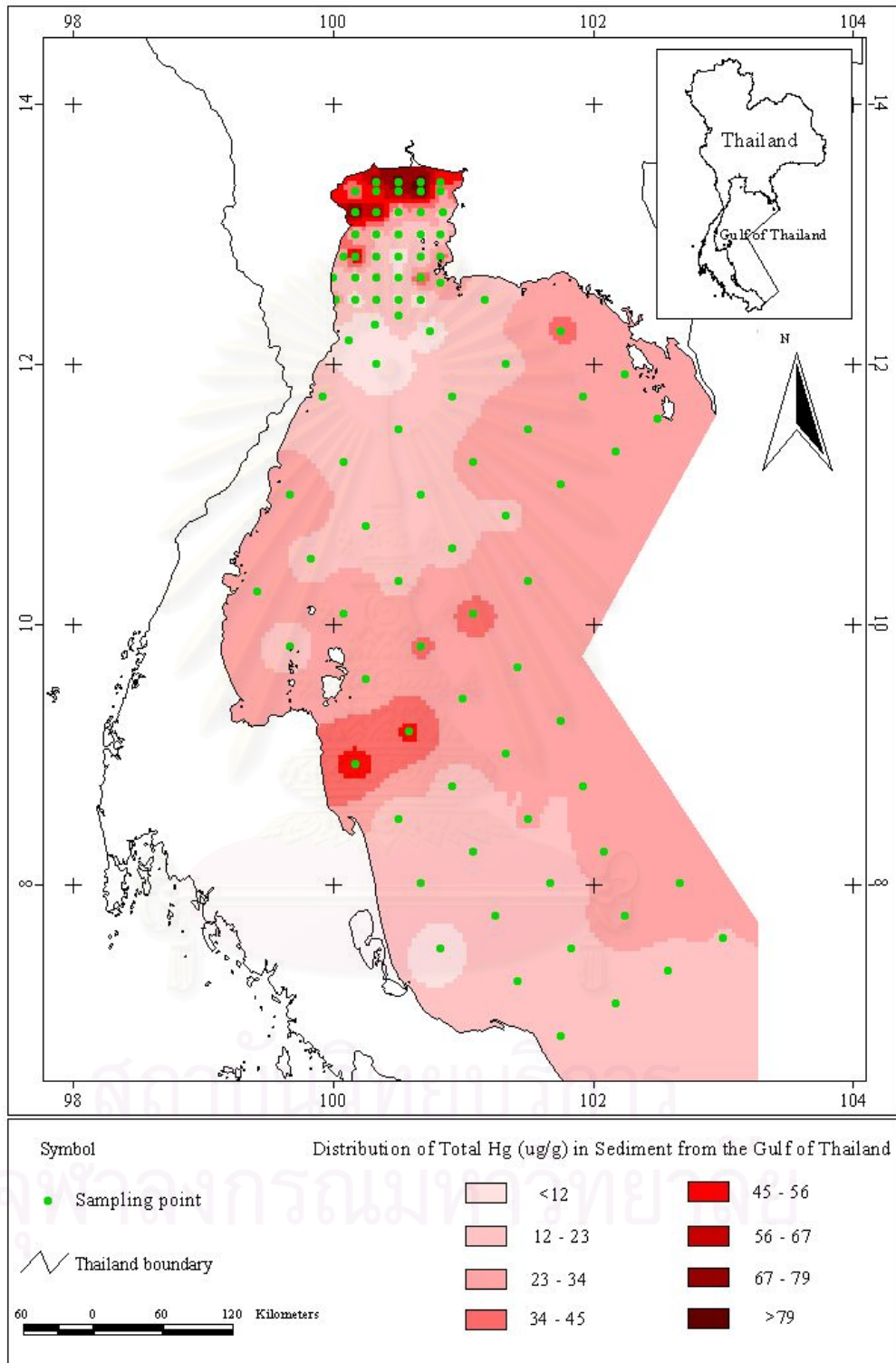


Figure 4-13 Distribution pattern of total mercury ($\mu\text{g/kg}$ dry weight) in sediment of the Gulf of Thailand.

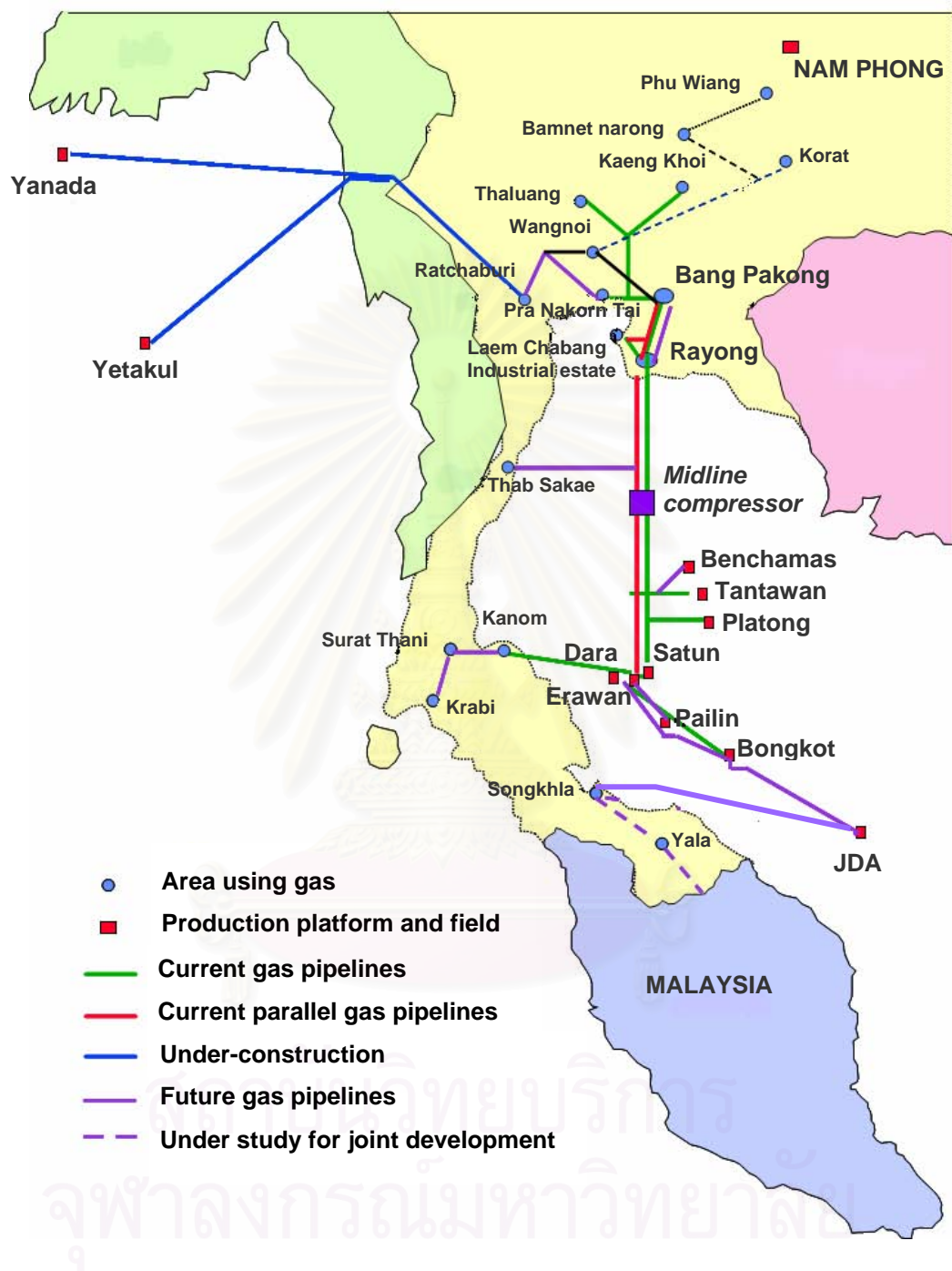


Figure 4-14 Petroleum and gas pipeline network in the Gulf of Thailand (source: DMF, 2007)

High mercury in sediment of the Lower Gulf off Nakorn Si Thammarat province may relate to previous mining activities on land (Fig. 4-13). Total mercury in sediment at some distance away from offshore platforms in the Gulf of Thailand is shown in Table 4-5. Total mercury concentration in sediment from the Lower Gulf is found in a similar range as those studies. Total mercury concentrations in sediment from the Gulf of Thailand found in this study is not yet reaches the limit recommended in sediment quality guidelines (Table 4-6).

Table 4-5 Mercury level in sediment near offshore platforms in the Gulf of Thailand

LOCATION	TOTAL Hg ($\mu\text{g}/\text{kg}$ dry weight)	REFERENCES
Benchamas	10 – 30	IEM, 1997a
Pailin	20 – 40	IEM, 1997b
B6/27*	17 – 37	AEA, 1997
Maliwan	<10 – 30	IEM, 1998a
Jamjuree	<10 – 30	IEM, 1998b
Arthit	≤ 50	IEM, 1999
B8/32*	32 – 61	IEM, 2001
B8/32*	17 – 61	IEM, 2003
Jamjuree	26 – 28	IEM, 2005

* Concession block

Table 4-6 Sediment quality guidelines ($\mu\text{g}/\text{kg}$ dry weight) of Thailand, USA, Australia-New Zealand and Hong Kong (Utoomprukporn, 2006)

Metal	Thailand		USA		Australia - New Zealand		Hong Kong	
	ERL	ERM	ERL	ERM	ISQV-Low	ISQV-High	ISQV-Low	ISQV-High
Hg	150	710	150	710	150	1000	280	1000

ERL = Effect Range Low

ERM = Effect Range Median

ISQV = Interim Sediment Quality Values

Since the kinetics of mercury adsorption depends largely on the physical and chemical characteristic of sediments, amount of fined-grained fraction and organic carbon content should play important roles in controlling mercury content accumulated in the sediments. Figure 4-15 presents the correlation plot of between total mercury ($\mu\text{g}/\text{kg}$ dry weight) with fined-grained fraction, organic carbon content and calcium carbonate content in sediments in the gulf of Thailand.

The figure indicates strong relationship between mercury concentration with fine-grain fraction and organic carbon, but not with calcium carbonate. The results from this study agree with other workers (Ramamoorthy and Rust, 1976; Bartlett and Craig, 1981; Bloom and Crecelius, 1987). Contrary, Armannsson *et al.* (1985) found no correlation between mercury and organic carbon in marine sediments from the Southampton area, and Millward and Herbert (1981) found no correlation between mercury and clay content and organic carbon in the sediments from Plym Estuary in Devon, England.

There are some stations showed high concentrations of mercury, and the values do not follow the trend lines (Fig. 4-15). Most of these stations located near the river mouths in the Upper Gulf (Stations U1, U2, U3, U7, U8, U10, U11, U21 and U30) (Fig. 3-1, 4-13 and 4-15). This indicates the input of mercury from land based-source. In the Lower Gulf, high mercury are found at stations in the middle of the Gulf, especially stations L29, L30, L31 and L32 that the sediment grain is fine and high in organic carbon content. Moreover, there are many activities of gas-petroleum exploration in the area. Therefore, mercury from these activities may cause contamination of mercury in sediment (Fig. 3-2, 4-13 and 4-15).

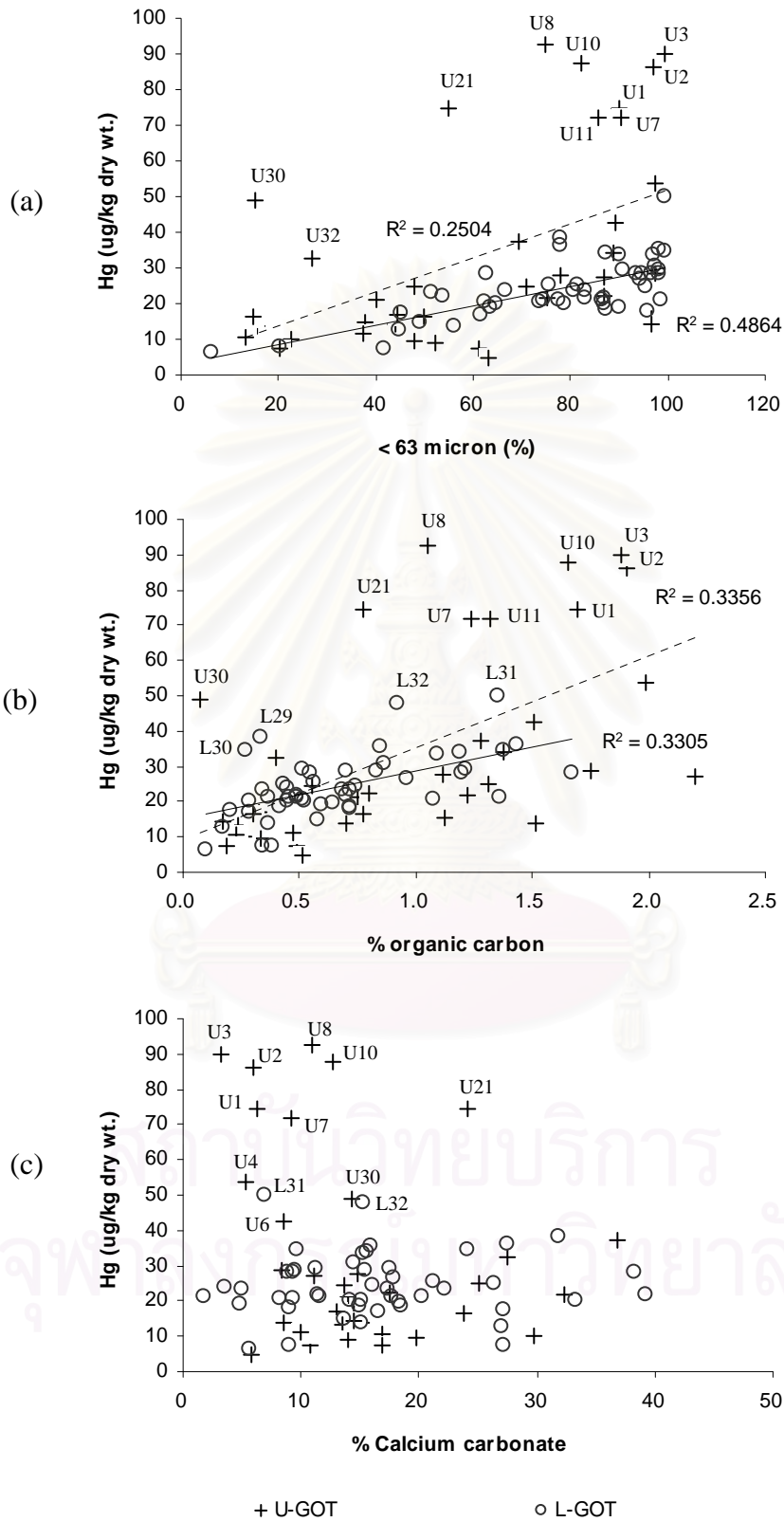


Figure 4-15 Correlation between total mercury and (a) fine-grained fraction, (b) organic carbon, and (c) calcium carbonate in the sediments of the Gulf of Thailand.

4.5 Statistical approaches for analysis of factors controlling mercury distribution in sediments

4.5.1 Cluster Analysis

Hierarchical cluster analysis with distance cluster combine equal 10 indicates that the stations can be clustered into 8 groups as shown in Fig. 4-16 and summarized in Table 4-7.

Cluster I-1Aa comprises of 19 stations: U1, U2, U3, U4, U6, U7, U8, U9, U10, U20, U26, U32, L1, L5, L11, L12, L20, L27 and L31. The sediments of this group have fine texture (low sand and high silt) and contain high organic content and high mercury.

Cluster I-1Ab comprises of 11 stations: U17, L16, L17, L24, L25, L28, L33, L44, L47, L50 and L54. The sediments of this group have fine texture (low sand and high silt), slightly high organic carbon content and low mercury.

Cluster I-1B comprises of 3 stations: L15, L35 and L36. The sediments of this group have fine texture (low sand and high clay), slightly high organic carbon content and low mercury.

Cluster I-2 comprises of 8 stations: U33, U37, L8, L9, L19, L22, L26 and L41. The sediments of this group contain high amount of sand and low mercury.

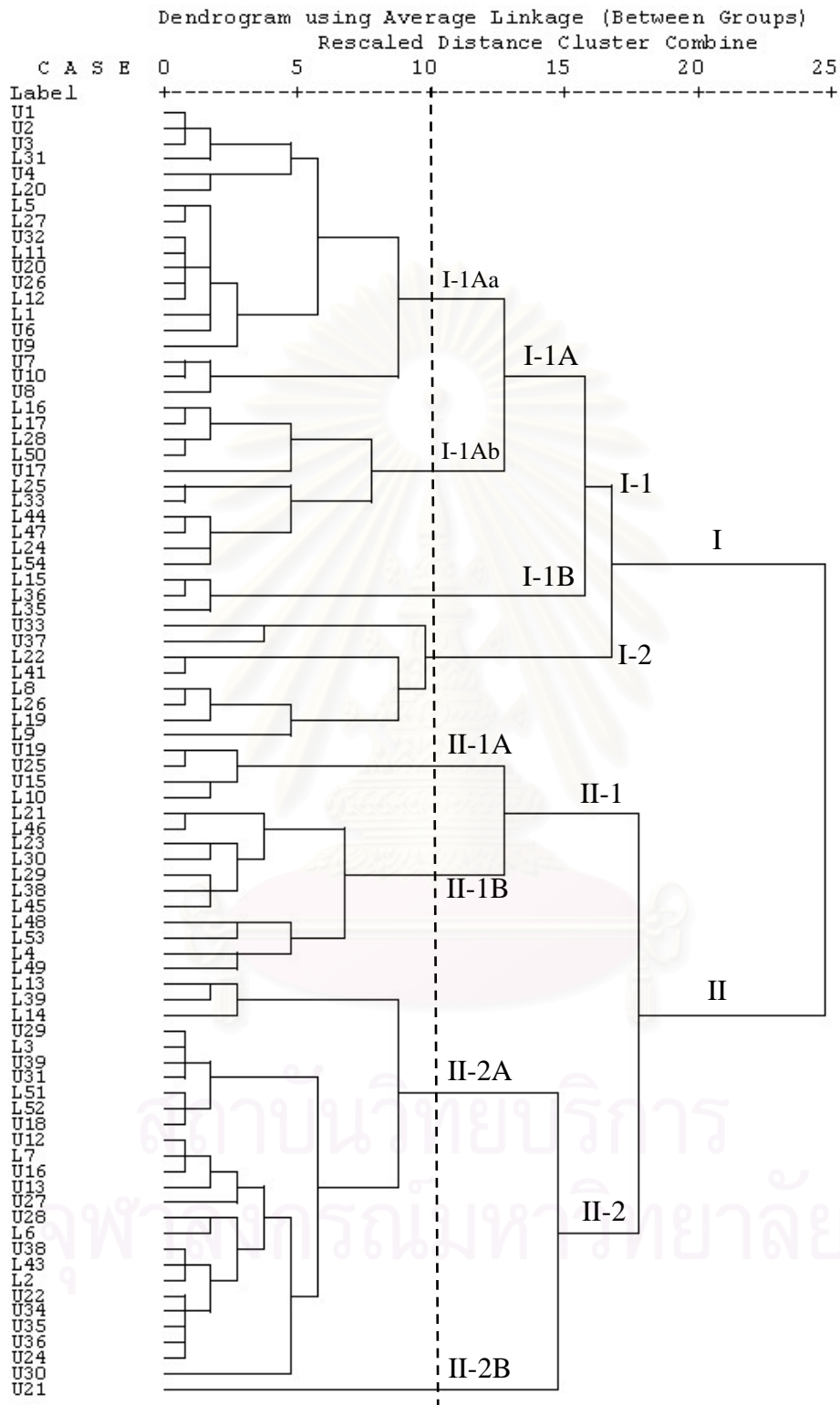


Figure 4-16 Dendrogram show the organizing total mercury data of the sediments from the Gulf of Thailand by Cluster analysis

Table 4-7 Summary of the organizing total mercury data of the sediments from the Gulf of Thailand by Cluster analysis

Cluster	Stations	%CaCO ₃	%sand	%silt	%clay	%Org C	Hg (µg/kg)
I-1Aa	U1, U2, U3, U4, U6, U7, U8, U9, U10, U20, U26, U32, L1, L5, L11, L12, L20, L27, L31	9.0 ± 2.7	7.8 ± 7.4	76.2 ± 8.9	16.0 ± 10.8	1.5 ± 0.3	47.0 ± 26.4
I-1Ab	U17, L16, L17, L24, L25, L28, L33, L44, L47, L50, L54	15.9 ± 1.0	8.4 ± 5.0	78.6 ± 5.1	13.5 ± 4.9	0.8 ± 0.2	27.4 ± 5.6
I-1B	L15, L35, L36	15.1 ± 4.3	7.6 ± 3.8	53.5 ± 2.3	38.9 ± 4.7	0.8 ± 0.1	21.1 ± 4.1
I-2	U33, U37, L8, L9, L19, L22, L26, L41	6.2 ± 2.9	32.5 ± 7.9	58.1 ± 5.2	8.6 ± 6.2	0.6 ± 0.1	18.6 ± 7.7
II-1A	U15, U19, U25, L10	30.5 ± 4.5	26.7 ± 3.5	62.4 ± 3.2	7.9 ± 1.6	1.3 ± 0.1	30.1 ± 7.0
II-1B	L4, L21, L23, L29, L30, L38, L45, L46, L48, L49, L53	26.6 ± 7.4	20.8 ± 8.4	62.1 ± 11.3	17.1 ± 10.0	0.5 ± 0.1	25.4 ± 5.8
II-2A	U12, U13, U16, U18, U22, U24, U27, U28, U29, U30, U31, U34, U35, U36, U38, U39, L2, L3, L6, L7, L13, L14, L39, L43, L51, L52	16.8 ± 6.2	62.1 ± 16.6	32.5 ± 13.8	4.9 ± 5.0	0.4 ± 0.2	16.0 ± 8.9
II-2B	U21	24.1	45.0	50.8	4.2	0.8	74.7
unclassify	U5, U11, U14, U23, L32, L40						

Cluster II-1A comprises of 4 stations: U15, U19, U25 and L10. The sediments of this group have high carbonate content, high silt, high organic, slightly high mercury.

Cluster II-1B comprises of 11 stations: L4, L21, L23, L29, L30, L38, L45, L46, L48, L49 and L53. The sediments of this group have high carbonate content, high clay, low organic and slightly high mercury.

Cluster II-2A comprises of 26 stations: U12, U13, U16, U18, U22, U24, U27, U28, U29, U30, U31, U34, U35, U36, U38, U39, L2, L3, L6, L7, L13, L14, L39, L43, L51 and L52. The sediments of this group have high sand, low organic and low mercury.

Cluster II-2B comprises of only station U21. This station contain slightly high organic carbon and very high mercury.

Stations U5, U11, U14, U23, L32 and L40 are not included in this cluster analysis due to the incomplete of data.

4.5.2 Principal components analysis (PCA)

The distribution patterns of total mercury were analyzed by a principal component analysis (PCA). PCA is a multivariate statistical technique that can simplify large data sets and allow reducing the number of variables to a smaller set of orthogonal factors of easier interpretation by displaying the correlations existing among the original variable (Ashley and Baker, 1999). Total mercury and physicochemical factor including sand, silt, clay, calcium carbonate, and organic carbon are involved. The loading plot of PCA of total mercury in sediment samples from the Gulf of Thailand is illustrated in Fig. 4-17.

First component (PC1) can explain 52.3% of the total variance, with high loading on silt, clay and organic carbon. It can be confirm that high total mercury is affected from the increasing of those factors. Second components (PC2) can explain 17.3% of the total variance. High total mercury would be associated with organic carbon and sand. The summation of variation of both components equal 69.6% that is both components can be explain the factors variation equal 69.6% as shown in Table 4-8.

From the loading plot of PCA results, sediments of the Gulf of Thailand can be divided into 3 main groups (Fig. 4-17 and Fig 4-18): Group A comprises of sediment in cluster I-1A, Group B comprises of sediment in clusters I-1B, I-2 and II-1, and Group C comprises of sediment in cluster II-2.

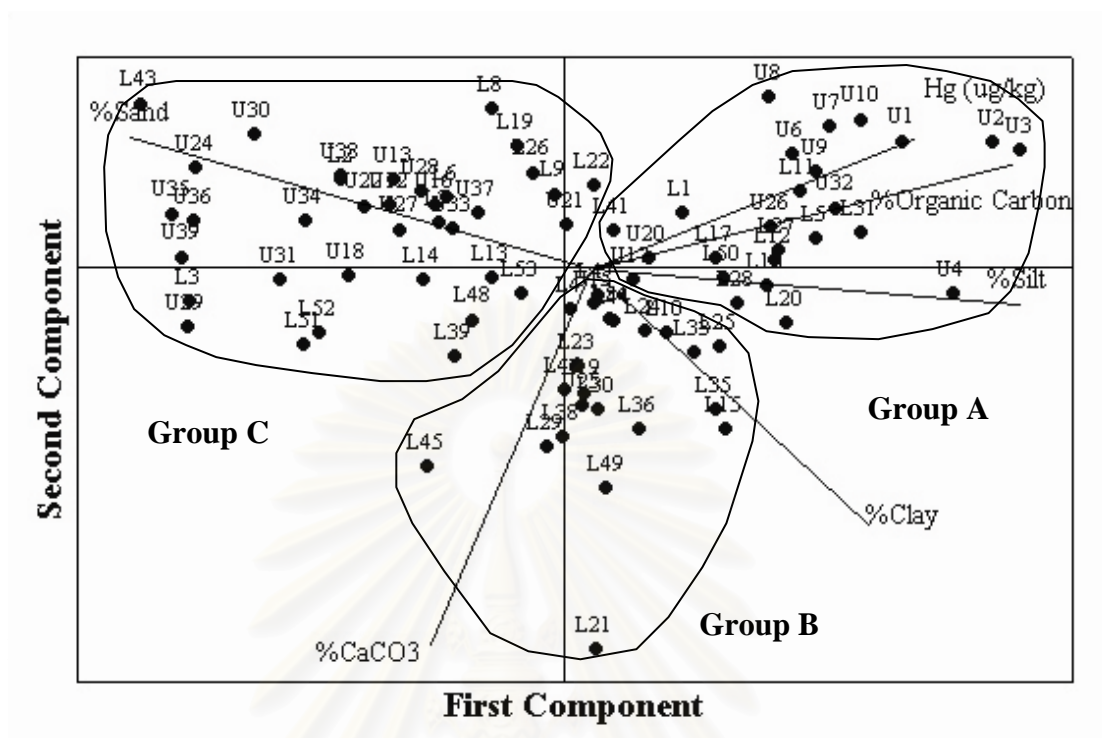


Figure 4-17 Principal component analysis (PCA) results of the two first factors loading plot obtained in the analysis of sediment samples from the Gulf of Thailand.

Table 4-8 Eigenanalysis of the correlation matrix from controlling factors of mercury accumulation in sediments of the Gulf of Thailand.

FACTORS	CORRELATION	
	PC1	PC2
%CaCO ₃	-0.184	-0.747
%Sand	-0.524	0.259
%Silt	0.484	-0.072
%Clay	0.313	-0.510
%Org C	0.475	0.208
Hg (ug/kg)	0.365	0.258
Eigenvalue	3.1356	1.0356
% Variation	52.3	17.3

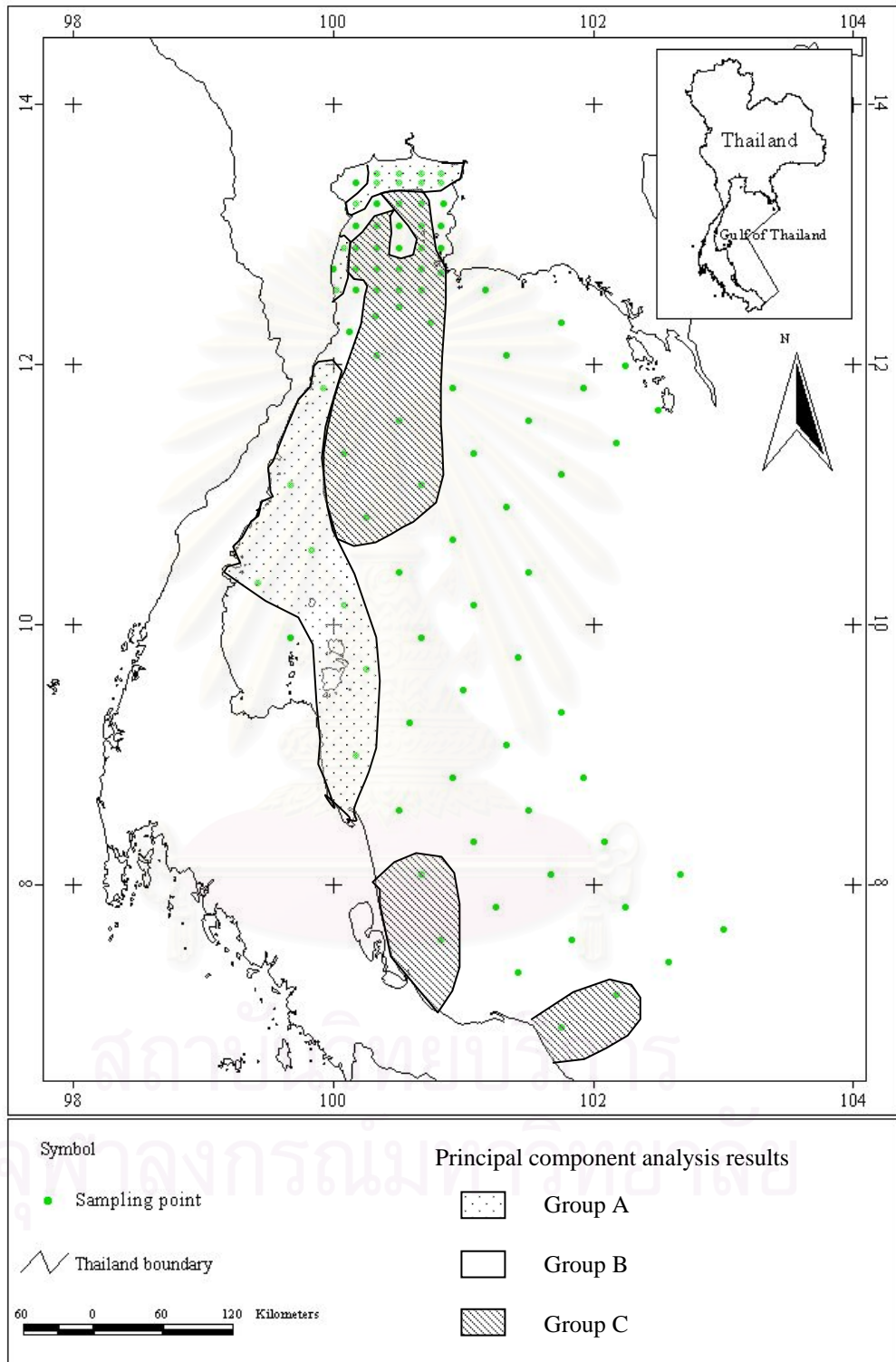


Figure 4-18 Grouping of sediment in the Gulf of Thailand based on Anond Snidvong

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Sediment textures of the Gulf of Thailand are fairly coarse, mainly ranging from sandy silt to clayey silt. Fine-grain sediments found at the four major river mouths drained to the Upper Gulf, namely Chao-Phraya, Tha-Chin, Mae-Klong and Bangpakong. For the Lower Gulf of Thailand, percentage of fine grain sediment is the most abundance offshore near Chumporn and Nakhon Si Thammarat provinces. Sand fraction is found to be highest near the mouth of Songkhla Lake. Size composition and distribution pattern of each fraction are still remains relatively the same as the study done over the last two decades.

The percentage of organic carbon in the Upper Gulf sediments is generally higher than those of the Lower Gulf. The high values of organic carbon found near the four major river mouths. High concentration of organic carbon also found most abundance offshore along Chumporn to Nakhon Si Thammarat provinces and from Chanthaburi to Trad provinces. Organic carbon content in sediments is related to amount of fine-grained particles. High calcium carbonate content in near-shore surface sediment is lower than in the middle of the Gulf which is the deeper. High concentrations of calcium carbonate also found along the coast of eastern seaboard area. In comparison to the last two decade data, slightly higher in organic and carbonate contents in the sediments are found.

For the distribution of total mercury in the Gulf sediment, variation of mercury concentration in the Upper Gulf sediment was much higher than those of the Lower Gulf. High total mercury was found near the mouth of the 4 major rivers of the Upper Gulf, where sediments contained high fine grain particles and organic carbon. The texture of sediment and organic carbon contents in the sediment play important roles in controlling adsorption of mercury onto sediment. Fine grain size tends to increase the ability of mercury adsorption to sediment due to high cation exchange

capacity, large surface area and surface charge in these grain size fractions. According to this study, high mercury in the sediment is direct related to the amount of fine grain fractions. The mercury value decreases when percentage of sand increases. Mercury concentrations in sediment are related to organic carbon content due to mercury can be chelated with humic fraction in sediments to form metal-organic complexes. The current pattern affects the mercury transportation the Gulf of Thailand.

From the distribution pattern, it can be concluded that anthropogenic land-based sources is of important and need to be concerned. Elevated mercury level in Lower Gulf sediments may relate to petroleum exploration activities in the Gulf of Thailand. This study found that total mercury concentration in sediment from the Gulf of Thailand is less than Thailand sediment quality guidelines.

Hierarchical cluster analysis with distance cluster combine equal 10 indicates that the stations can be clustered into 8 groups: *Cluster I -IAa* (U1, U2, U3, U4, U6, U7, U8, U9, U10, U20, U26, U32, L1, L5, L11, L12, L20, L27 and L31), *Cluster I-IAb* (U17, L16, L17, L24, L25, L28, L33, L44, L47, L50 and L54), *Cluster I-IB* (L15, L35 and L36), *Cluster I-2* (U33, U37, L8, L9, L19, L22, L26 and L41), *Cluster II-IA* (U15, U19, U25 and L10), *Cluster II-IB* (L4, L21, L23, L29, L30, L38, L45, L46, L48, L49 and L53), *Cluster II-2A* (U12, U13, U16, U18, U22, U24, U27, U28, U29, U30, U31, U34, U35, U36, U38, U39, L2, L3, L6, L7, L13, L14, L39, L43, L51 and L52), *Cluster II-2B* (U21).

From the loading plot of PCA results, sediments of the Gulf of Thailand can be divided into 3 main groups (Fig. 4-18 in Chapter 4): Group A comprises of sediment in cluster I-1A, Group B comprises of sediment in clusters I-1B, I-2 and II-1, and Group C comprises of sediment in cluster II-2.

5.2 Recommendations

Thailand have benefited from an impressive economical and industrial growth through major industrial development projects along the coast; development in shipping, oil and gas industry; a large and important fishery sector; intensive coastal agriculture and aquaculture; and extensive and intense tourism development. Nevertheless, this partly uncontrolled development focused the attention on the

environmental problems and the pressures and threats to the natural environments of the coastal zone and also offshore. Thus, it is crucially needed to vigil and control marine pollution. A sustainable management of the natural resources in the coastal areas to preserve the resources and its values must be expanded for current and future uses and generation.

According to the study, mercury from land-based sources has higher impact than petroleum exploration in the Gulf. Therefore, pollution control and environmental management measures for land-based pollution should be raised up. Specifically, national and sector policies, laws, regulations, management approaches for controlling the sediment quality are in place and must be coordinated. Moreover, greater authority needs to be extended to local governments combined with policy guidance, law and regulation support from central government agencies. Increasing capacity of local governments and other agencies responsible for the achievement and monitoring of Environmental Impact Assessment process and Environmental Protection Areas should be raised up. At the same time, local communities should participate in the planning and implementation of marine environmental management plans. However, long term monitoring of mercury contamination is required, as long as the petroleum exploration activities still remain, in order to ensure that there is no expansion of the impact.

REFERENCES

- Acevedo-Figueroa, D., Jimenez, B.D. and Rodriguez, S. Trace metals in sediments of two estuarine lagoons from Puerto Rico. Environmental Pollution 141(2006): 336-342.
- AEA. Thai-Shell Environmental Baseline Survey Report for B6/27. Report prepared for IEM. (1997).
- Allen, J.R.L., Rae, J.E. and Zanin, P.E. Metal speciation (Cu, Zn and Pb) and organic matter in an oxic salt marsh, Severn Estuary, Southwest Britain. Marine Pollution Bulletin 21(1990): 574-580.
- Andersson, A. Mercury in soils. In: Nriagu, J.O., editor. The Biogeochemistry of Mercury in the Environment. Elsevier, New York, pp. 79-111. (1979).
- Andersson, I., Parkman, H. and Jernelöv, A. The role of sediments as sink or source for environmental contaminants: a case study of mercury and chlorinated organic compounds. Limnologica 20(1990): 347-359.
- Armannsson, H., Burton, J.D., Jones, G.B. and Knap, A.H. Trace metals and hydrocarbons in sediments from the Southampton Water Region, with particular reference to the influence of oil refinery effluent. Marine Pollution Resource 15(1985): 3-44.
- Ashley, J.T.F. and Baker, J.E. Hydrophobic organic contaminants in surficial sediments of Baltimore harbor: inventories and sources. Environmental Toxicological Chemistry 18(1999): 838-849.
- Bamrungrajhiran, R., Jarach, W. and Chingchit, K. Metals in sea water and marine sediments. In: Proceedings of the Third Seminar on the Water Quality and the Quality of Living Resources in Thai Waters, 26-28 March 1984. National Research Council of Thailand. pp. 222-228. (1984).
- Bangkok International Associates. Petroleum Industry. Available from: <http://www.bia.co.th/015.html>. [2007, September 1]. (2006).

- Bartlett, P.D. and Craig, P.J. Total mercury and methyl mercury levels in British estuarine sediments-II. Water Resource 15(1981): 37-47.
- Benoit, J.M., Gilmour, C.C., Mason, R.P., Riedel, G.S. and Riedel, G.F. Behaviour of mercury in Patuxent River estuary. Biogeochemistry 40(1998): 249-265.
- Berto, D., Giani, M., Covelli, S., Boscolo, R., Cornell, M., Macchia, S., and Massironi, M. Mercury in sediments and *Nassarius reticulatus* (Gastropoda Prosobranchia) in the southern Venice Lagoon. Science of the Total Environment 368(2006): 298– 305.
- Bloom, N.S. and Crecelius, E.A. Distribution of silver, mercury, lead, copper and cadmium in central Puget Sound sediments. Marine Chemistry 21(1987): 377-347.
- Brooks, W.E. Minerals Yearbook - Mercury. In: Minerals Yearbook. United States Geological Survey, Reston. (2003).
- Boonyatumanond, R., Wattayakorn, G., Togo, A. and Hideshige, T. Distribution and origins of polycyclic aromatic hydrocarbons (PAHs) in riverine, estuarine, and marine sediments in Thailand. Marine Pollution Bulletin 52(2006): 942-956.
- Boonyatumanond, R., Wattayakorn, G., Amano, A., Inouchi, Y. and Takada H. Reconstruction of pollution history of organic contaminants in the upper Gulf of Thailand by using sediment cores: First report from Tropical Asia Core (TACO) project. Marine Pollution Bulletin 54(2007): 554–565.
- Bryne, L. Brazil's Mercury Poisoning Disaster. British Medical Journal. Rio de Janeiro: British Medical Association. (1992).
- Buccolieri, A., Buccolieri, G., Cardellicchio, N., Dell'Atti, A., Di, L. and Maci, A. Heavy metals in marine sediments of Toranto Gulf (Ionian Sea, Southern Italy). Marine Chemistry 99(2006): 227-235.
- Calmano, W., Hong, J. and Förstner, U. Binding and mobilization of heavy metals in contaminated sediments affected by pH and redox potential. Water Science and Technology 28(1993): 22-235.

- Catallo, W.J., Schlenker, M., Gambrell, R.P. and Shane, B.S. Toxic chemicals and trace metals from urban and rural Louisiana lakes: recent historical profiles and toxicological significance. Environmental Science and Technology 29(1995): 1439-1446.
- Chen, C.W., Kao, C.M., Chen C.F. and Dong, C.D. Distribution and accumulation of heavy metals in the sediments of Kaohsiung Harbor, Taiwan. Chemosphere 66 (2007): 1431–1440.
- Chongprasith, P., Wilairatanadilok, W. and Rattikhansukha, C. Environmental studies in management of the Upper Gulf of Thailand. In: Watson, D. and Ong, K.S., editors. ASEAN-Canada Marine Environmental Quality Technical Papers and Mission Report. Contributions of the ASEAN-Canada Technical Mission to the Coastal Zone Canada'94 Conference (21-23 September 1994), Halifax, Canada. pp. 62-73. (1995).
- Chongprasith, P. and Srinetr, V. Marine water quality and pollution of the Gulf of Thailand. In: Johnston, D.M., editor. Seapol Integrated Studies of the Gulf of Thailand. Southeast Asian Programme in Ocean Law, Policy and Management. Vol. 1, pp. 138-204. (1998).
- Chongprasith, P. and Wilairatanadilok, W. Are Thai waters really contaminated with mercury?. In: Watson, I., Vigers, G., Ong, K.S., McPherson, C., Millson, N., Tang, A. and Gass, D., editors. ASEAN Marine Environmental Management: Towards Sustainable Development and Integrated Management of the Marine Environment in ASEAN. Proceedings of the Fourth ASEAN-Canada Technical Conference on Marine Science (26-30 October 1998), Langkawi, Malaysia. pp. 11-26. (1999).
- Clark, R.B. Marine Pollution—Third Edition. Oxford University Press, New York. pp. 71-72. (1992).
- Cossa, D.M.C., Gobeil, C. and Martin, J. Mercury Fluxes at the Ocean margins. In: Baeyens, W., Ebinghaus, R. and Vasiliev, O., editors. Regional Mercury Cycles: Sources, Fluxes and Mass Balances. Kluwer Academic Publishers, (Netherlands), pp. 229-248. (1996).

- Dharmvanij, S. Sediment distribution in the Gulf of Thailand. Research Report, Rachadapiseksompoj Research Fund, Chulalongkorn University, Bangkok. 80 p. (1987).
- DMF (Department of Mineral Fuels). Petroleum Concession in Thailand. Available from: [http:// www.dmf.go.th/petro-focus/files/concession.pdf](http://www.dmf.go.th/petro-focus/files/concession.pdf). [2007, September 1]. (2007).
- Donazzolo, R., Merlin, O.H., Menegazzo L V., Orio, A.A., Pavoni, B., Perin, G. and Rabitti, S. Heavy metal contamination in surface sediments from the Gulf of Venice, Italy. Marine Pollution Bulletin 12(1981): 417–425.
- Drobner, E., Huber, H., Wachterhauser, G., Rose, D. and Steller, K. Pyrite formation linked with hydrogen sulphide evolution under anaerobic conditions. Nature 546(1990): 742-744.
- Davis, A., Bloom, B.S. and Que-Hee, S.S. The environmental geochemistry and bioaccessibility of mercury in soils and sediments: A Review. Risk Analysis 17(1997): 557-569.
- Ebinghaus, R., Tripathi, R.M., Wallschaer, D. and Lindberg, S.E. Natural and anthropogenic mercury sources and their impact on the air–surface exchange of mercury on regional and global scale. In: Ebinghaus, R., Turner, R.R., De-Lacerda, L.D., Vasiliev, O. and Salomons, W., editors. Mercury Contaminated Sites. Springer-Verlag, Berlin Heidelberg, Germany, pp. 3–50. (1999).
- EVS Environment Consultants. Heavy Metals and Petroleum Hydrocarbon Contamination in Industrial Areas. A final report prepared for Pollution Control Department. Bangkok, Thailand. (1999).
- Fabrizi, D., Locatelli, C., Snape, C.E. and Tarabusi, S. Sulfur speciation in mercury – contaminated sediments of a coastal lagoon: the role of elemental sulphur. Journal of Environmental Monitoring 3(1991): 483-486.
- Falandysz, J. Mercury in Surface Sediments Associated with Shipyard Activity in the City of Gdańsk. Polish Journal of Environmental Studies 8(1999): 265-267.

- Frankiewicz, T.C., Curiale, J.A. and S. Tussaneyakul. The Geochemistry and Environment Control of Mercury and Arsenic in Gas, Condensate, and Water Produced in the Gulf of Thailand. Abstract: Annual AAPG Convention (Salt Lake City, Utah, 5/17-20/98) No. A209, v.1, p. 3. (1998).
- Gambrell, R.P. Trace and toxic metals in wetlands: a review. Journal of Environmental Quality 23(1994): 88-891.
- Gary, M.R., McAfee, R. and Wolf, C.L. Glossary of Geology—Forth Edition. American Geological Institute, USA. (1977).
- Giblin, A.E. Comparisons of the processing of elements by ecosystems, II: metals. In: Godfrey, P.J., editors. Ecological Considerations in Wetlands Treatment of Municipal Wastewaters. Van Nostrand Reinhold, New York, pp. 158-179. (1986).
- Gobeil, C. and Cossa, D. Mercury in sediments and sediment pore water in Laurentian trough. Canadian Journal of Fisheries and Aquatic Sciences 50(1993): 1794-1800.
- Greenfact. Scientific Facts on Mercury. Available from: <http://www.greenfacts.org/en/mercury-1.htm#2>. [2007, August 4]. (2007).
- Green-Ruiz, C., Ruelas-Inzunza, J. and Páez-Osuna, F. Mercury in surface sediments and benthic organisms from Guaymas Bay, east coast of the Gulf of California. Environmental Geochemistry and Health 27 (2005): 321–329.
- Gross, M.E., Black, J.A., Kalin, R.J., Schramel, J.R. and Smith, R.N. Survey of Marine waste Deposites, New York Metropolitan Region. Marine Science Resource Center State University, New York Tech. Rep. 8. (1971).
- Harada, M. Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. Critical Reviews in Toxicology 25(1995): 1-24.
- Harada M. Neurotoxicity of methylmercury; Minamata and the Amazon. In: Yasui, M., Strong, M.J., Ota, K. and Verity, M.A., editors. Mineral and Metal Neurotoxicology. Boca Raton: CRC Press, pp. 177-188. (1997).

- Hines, M.E., Faganeli, J., Adatto, I. and Horvat, M. Microbial Mercury transformations in marine, estuarine and freshwater sediment downstream of the Idrija Mercury Mine, Slovenia. Geochemistry 21(2006): 1924–1939.
- Hintelmann, H. and Wilken, R.D. Levels of total mercury and methylmercury compounds in sediments of the polluted Elbe River; influence of seasonally and spatially varying environmental factors. Science of the Total Environment 166(1995): 1–10.
- Hinton, J. and Veiga, M. Mercury contaminated sites: A review of remedial solutions. In Proceedings of the NIMD (National Institute for Minamata Disease) Forum Minamata, Japan. (2001).
- Huggett, D.B., Steevens, J.A., Allgood, J.C., Lutken, C.B., Grace, C.A. and Benson, W.H. Mercury in Sediment and Fish from North Mississippi Lakes. Chemosphere 42(2001): 923-929.
- Hung, G.A. and Chmura, G.L. Mercury accumulation in surface sediment of Salt marshes of Bay of Fundy. Environmental Pollution 142(2006): 418-431.
- Hungspreugs, M. and Utoomprurkporn, W. Trace Metal Contamination in Thai Rivers. In: Ittekkot, V., Subramanian, V., and Annadurai, S., editors. Biogeochemistry of Rivers in Tropical South and Southeast Asia. pp. 139-157. (1999).
- Hungspreugs, M., Utoomprurkporn, W., Dharmvanij, S. and Sompongchaiyakul, P. 1989. The present status of the aquatic environment of Thailand. Marine Pollution Bulletin 20(2006): 327-332.
- Hylander, L.D. and Meili, M. 500 years of mercury production: global annual inventory by region until 2000 and associated emissions. Science of the Total Environment 304(2003): 13–27.
- Idthikasem, A., Bamrungrajhira, R., Kaewpakdee, W. and Chingchit, K. Analyses of some trace metals in seawaters and marine sediments. In: Proceedings of the Second Seminar on the Water Quality and the Quality of Living

- Resources in Thai Waters. 26-28 May 1981. National Research Council of Thailand. pp. 166-179. (1981).
- IEM. Benchamas South and Pakakrong Field Block B8/32. EIA-Report prepared for Maersk Oil (Thailand) Ltd. (1997a).
- IEM. Pailin Field Hydrocarbon Development. EIA-Report prepared for Unocal (Thailand) Ltd. (1997b).
- IEM. Maliwan Hydrocarbon Exploration, Gulf of Thailand. EIA-Report prepared for Thaipho Ltd. (1998a).
- IEM. Jamjuree Hydrocarbon Exploration, Gulf of Thailand. EIA-Report prepared for Thaipho Ltd. (1998a).
- IEM. Maliwan Hydrocarbon Exploration, Gulf of Thailand. EIA-Report prepared for Thaipho Ltd. (1998a).
- IEM. Arthit Area Hydrocarbon Exploration, Gulf of Thailand. EIA-Report prepared for PTT Exploration and Production Public Co., Ltd. (1999).
- IEM. Three Year Environmental Monitoring Survey Block B8/32, Gulf of Thailand. Report prepared for Chevron. (2001).
- IEM. Three Year Environmental Monitoring Survey Block B8/32, Gulf of Thailand. Report prepared for Chevron Texaco. (2003).
- IEM. Jamjuree Hydrocarbon Production. EIA-Report prepared for Chevron Offshore (Thailand) Ltd. (2005).
- Ingham County. Mercury: A Fact Sheet for Health Professional. Available from: <http://www.ingham.org/hd/lepc/pamphets/hazwaste/mercuryfacts.html>. [2007, August]. (2007).
- Kengkoom, S. Geological investigation in the Gulf of Thailand. In: Report of the Thai-Japanese-SEAFDEC Joint Oceanographic and Trawling Survey in the Gulf of Thailand on Board Nagasaki-Maru, 15-28 May 1980. pp. 17-40. (1980).

- Kot, F.S., Green-Ruiz C., Páez-Osuna, F., Shumilin E.N. and Rodríguez-Meza, D. Distribution of Mercury in Sediments from La Paz Lagoon, Peninsula of Baja California, Mexico. Bulletin of Environmental Contamination and Toxicology 63(1999): 45-51.
- Kontas, A. Mercury in the Izmir Bay: An assessment of contamination. Journal of Marine Systems 61(2006): 67–78.
- Lindqvist, O., Jernelöv, A., Johansson, K. and Rodhe, R. Mercury in Swedish Environment: Global and Local Source. SOLNA, Swedish National Environmental Protection Board Report No 1816. (1984).
- Lindqvist, O., Johansson, K., Aasrup, M., Andersson, A., Bringmark, L., Hovsenius, G. and Iverfeldt, A.A. Mercury in the Swedish Environment. Recent research on causes, consequences and corrective methods. Water Air Soil Pollution. 55(1991): 261-270.
- Loring, D.H. and Rantala, R.T.T. Manual for the geochemical analyses of marine sediments and suspended particulate matter. Earth Science Reviews 32(1995): 235-283.
- Loring, D.H., Dahle, S., Naes, K., Dos-Santos, J. and Mastishov, G.G. Arsenic and other trace metals in sediment from Kora Sea and Ob and Yennisey Estuaries, Russia. Aquatic Geochemistry 4(1998): 233-252.
- Manahan, S.E. Environmental Chemistry—Seventh Edition. Lewis Publishers, CRC Press LLC. p. 898. (2000).
- Mantoura, R.F.C., Dickson, A. and Riley, J.P. The complexation of metals with humic materials in natural waters. Estuarine and Coastal Marine Science 6(1978):387-408.
- Mason, R. and Fitzgerald, W. The distribution and biogeochemical cycling of mercury in the equatorial Pacific Ocean. Deep Sea Research 40(1993):1897-1924.
- Mason, R. and Fitzgerald, W. Sources, Sinks and Biogeochemical Cycling of Mercury in the Ocean. In: Baeyens, W., Ebinghaus, R. and Vasiliev, O., editors.

- Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances. Kluwer Academic Publishers, (Netherlands), pp. 249-272. (1996).
- Menasveta, P. and Cheevaparanapiwat, V. Heavy metals, organochlorine pesticides and PCBs in green mussels, mullets, and sediments of river mouths of Thailand. Marine Pollution Bulletin 12(1981): 19-25.
- Menasveta, P. Total Mercury in Fishes Caught from Unocal Natural Gas Production Platform in the Gulf of Thailand. A report submitted to Unocal Thailand, Ltd. Aquatic Resources Research Institute. (1995).
- Millward, G.E. and Herbert, I. The distribution of mercury in the sediments of Plym estuary. Environmental Pollution Ser.B. 2(1981): 265-274.
- Moreno, F.N., Anderson, C.W.N., Stewart, R.B. and Robinson, B.H. Mercury volatilization and phytoextraction from base-metal mine tailings. Environmental Pollution 136(2005): 341-352.
- Morita, M., Yoshinaga, J. and Edmondst, J.S. The Determination of Mercury Species in Environmental and Biological Sample (Technical Report). Pure & Applied Chemistry 70(1998): 1585-1615.
- Müller, G. Method in Sedimentary Petrology. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. (1967).
- Nornua, K. Some Physico-chemical Composition of Bottom Sediments in the Gulf of Thailand. M.Sc.Thesis, Graduate Program in Fisheries Science, Kasetsart University, Thailand. (1998). (in Thai)
- Pacyna, E.G., Pacyna, J.M. and Pirrone, M. European emissions of atmospheric mercury from anthropogenic sources in 1995. Atmospheric Environment 35(2001):2987-2996.
- Pacyna E.G. and Pacyna J.M. Global emission of mercury from anthropogenic sources in 1995. Water, Air and Soil Pollution 137(2002): 149–165.
- PCD (Pollution Control Department). Toxic Substances Residues in Seawater in the East Coast of Thailand. Ministry of Science, Technology and Environment. Thailand. (1992).

- PCD (Pollution Control Department). Thailand, Mercury Study in Thai Marine Environment. Ministry of Science, Technology and Environment. Thailand. (2000).
- PCD (Pollution Control Department). Mercury Assessment in Thailand. A Report Submitted to United Nations Environment Programme (UNEP) Chemicals. (2001).
- Pilskaaln, C.M., Paduan, J.B., Chavez, F.P., Anderson, R.Y. and Berelson, W.M. Carbon export and regeneration in the coastal upwelling system of Monterey Bay central California. Journal of Marine Resources 54(1996): 1149-1178.
- Polprasert, C., Vongvisessomjai, S., Lohani, B.N., Muttamara, S., Arbhabhirama, A., Traichaiyaporn, S., Khan, P.A. and Wangsuphachart, S. Heavy Metals, DDT and PCBs in the Upper Gulf of Thailand. Environmental Engineering Division and Water Resources Engineering Division. AIT Research Report No 105. Bangkok. (1979).
- Ram, A., Rokade, M.A., Borole, D.V. and Zingde, M.D. Mercury in sediments of Ulhas estuary. Marine Pollution Bulletin 46(2003): 846–857.
- Ramalhosa, E., Pereira, E., Vale, C., Válega, M., Monterroso, P. and Duarte, A.C. Mercury distribution in Douro estuary (Portugal). Marine Pollution Bulletin 50(2005): 1218–1222.
- Ramamoorthy, S. and Rust, B. R. Mercury sorption and desorption characteristics of some Ottawa River sediments. Canada Journal Earth Science 13(1976): 530-536.
- Rasmussen, P.E. Current methods of estimating atmospheric mercury fluxes in remote areas. Environmental Science and Technology 28(1994): 2233-2241.
- Resources Inventory Committee. Lake and Stream Bottom Sediment Sampling Manual. Province of British Columbia, Canada. 1998.

- Rodrigues, S., Pereira, M.E., Sarabando, L. and Lopes, L. Spatial distribution of total Hg in urban soils from an Atlantic coastal city (Aveiro, Portugal). Science of the Total Environment 368(2006): 40– 46.
- Sanzgiry, S., Mesquita, A. and Kureshy, T.W. Total mercury in water, sediments and animals along the Indian coast. Marine Pollution Bulletin 19(1998): 339-343.
- Schuster, E. The behaviour of mercury in the soil with special emphasis on complexation and adsorption processes: a review of the literature. Water, Air and Soil Pollution 56(1991): 667-680.
- Shaw, T.J., Gieskes, J.M. and Jahnke, R.A. Early diagenesis in differing depositional environments: the response of transition metals in pore water. Geochimica et Cosmochimica Acta 54(1990):1233-1246.
- Snidvongs A. and Sojisuporn P. Numerical simulations of the net current in the Gulf of Thailand under different Monsoon Regimes. In: Proceedings of the First Technical Seminar on Marine Fishery Resources Survey in the South China Sea AREA I. Gulf of Thailand and East Coast of Peninsular Malaysia, 24-26 November 1997, Bangkok, Thailand. (1997).
- Sompongchaiyakul, P. Analysis of Chemical Species for Trace Metals in Near-Shore Sediment by Sequential Leaching Method. M.Sc. Thesis, Chulalongkorn University. (1989).
- Spencer, K.L., Cundy, A.B. and Croudace, I.W. Heavy metal distribution and early diagenesis in salt marsh sediments from the Medway Estuary, Kent, UK. Estuarine, Coastal and Shelf Science 57(2003): 43-54.
- Srisuksawad, K., Porntepkasemsan, B., Nouchpramool, S., Yamkate, P., Carpenter, R., Peterson, M.L. and Hamilton, T. Radionuclide activities, geochemistry, and accumulation rates of sediments in the Gulf of Thailand. Continental Shelf Research 17(1997): 925-965.
- Stamenkovica, J., Gustina M.S., Marvin-DiPasquale M.C., Thomasa B.A. and Agee J.L. Distribution of total and methyl mercury in sediments along

- Steamboat Creek (Nevada, USA). Science of the Total Environment 322 (2004): 167–177.
- Takahashi, K., Masthawe, P. and Ruangsiyakul, N. Preliminary study on the oceanographic conditions of trawl fishing grounds in the Gulf of Thailand. In: Report of the Thai-Japanese-SEAFDEC Joint Oceanographic and Trawling Survey in the Gulf of Thailand on Board Nagasaki-Maru, 15-28 May 1980. pp. 57-80. (1980).
- Tetra Tech Inc. Mercury Investigations in the Central Gulf of Thailand. A Report submitted to Unocal Thailand, Ltd. (1997).
- Tetra Tech Inc. Environmental Studies in the Central Gulf of Thailand. A Report submitted to Unocal Thailand, Ltd. (1998).
- Thongra-ara, W. and Parkpian, P. Total Mercury Concentrations in Coastal Areas of Thailand: A Review. Science Asia 28(2002): 301-312.
- Trefry, J.H., Trocine, R.P., McElvaine M.L. and Rember, R.D. Final Report to the Synthetic Based Muds (SBM) Research Group: Concentrations of Total Mercury and Methylmercury in Sediment Adjacent to Offshore Drilling Sites in the Gulf of Mexico. (2002).
- UNEP (United Nations Environment Programme). Global Mercury Assessment. (2002).
- Unocal. Background Paper, May 1995. (1995).
- Unocal. Development of Water Treatment Technologies on Offshore Platforms in the Gulf Thailand, February, 1996. (1996)
- US-EPA. METHOD 7471B: Mercury in Solid or Semisolid Waste (Manual Cold-Vapor Technique). Available from: <http://www.epa.gov/sw846/pdfs/7471b.pdf>. [2007, July 29]. (1998).
- US-EPA. Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual, EPA/823/B-01/002. Available from:

<http://www.epa.gov/waterscience/cs/collection.html>. [30 April 2008].
(2001).

US-EPA. Appendix to Method 1631. Available from:

<http://www.brooksrand.com/FileLib/app1631.pdf>. [2007, November 28].
(2002).

US-EPA. Mercury Transport and Fate through a Watershed. Synthesis Report of Research from EPA's Science to Achieve Results (STAR) Grant Program.
(2006).

Utoomprukporn, W., Hungspreugs, M., Dharmvanij, S. and Yuangthong, C. Improvement of the processes for the determination of trace elements in seawater and river water. In: Proceedings of the Fourth Seminar on the Water Quality Resources in Thai Waters. 7-9 July 1987. National Research Council of Thailand. pp. 388-393. (1987).

Utoomprukporn, W. Final Report proposed Marine and Coastal Sediment Quality Guidelines, Submitted to Pollution Control Department; under the UNEP GEF Project "Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand". (2006)

Valette-Silver, N.J. The use of sediment cores to reconstruct historical trends in contamination of estuarine and coastal sediments. Estuaries 16(1993): 577-588.

Wattayakorn, G., King, B., Wolanski, E. and Suthanaruk, P. Seasonal dispersion of petroleum contaminants in the Gulf of Thailand. Continental Shelf Research 18(1998): 641-659.

WHO/ICPS. Environmental Health Criteria, 86; Mercury Environmental Aspects. International Programme on Chemical Safety, World Health Organization, Geneva, Switzerland. (1989)

Williams, T.P., Bubb, J.M. and Lester, J.N. Metal accumulation within salt marsh environments: a review. Marine Pollution Bulletin 28(1994): 277-290.

- Windom, H.L. and Cranmer, G. Lack of observed impacts of gas production of Bongkot Field, Thailand on marine biota. Marine Pollution Bulletin 36(1998): 799-807.
- Wisconsin Water Science Center, US Geological Survey. Mercury Contaminaton of Aquatic Ecosystems. Available from: <http://wi.water.usgs.gov/pubs/FS-216-95>. [2007, August 4]. (1997).
- Yamamoto, S. and Yada, S. Bottom deposit and suspended matter in the Gulf of Thailand. Research Number TD/RP/13. Southeast Asian Fishery Development Center. 17 p. (1982).
- Zwolsman, J.G., Berger, G.W. and Van Eck, G.T.M. Sediment accumulation rates, historical input, postdepositional mobility and retention of major elements and trace metals in salt marsh sediments of the Scheldt estuary, SW Netherlands. Marine Chemistry 44(1993): 73-94.



APPENDICES

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Appendix A

Table A-1 Location of sediment sampling stations in the Gulf of Thailand and date of sampling

Station	Latitude (N)	Longitude (E)	Date	Depth (m)
U1	13° 24.0'	100° 20.0'	4/10/03	8
U2	13° 24.0'	100° 30.0'	4/10/03	7
U3	13° 24.0'	100° 40.0'	6/10/03	8
U4	13° 24.0'	100° 50.0'	6/10/03	8
U5	13° 20.0'	100° 10.0'	5/10/03	10
U6	13° 20.0'	100° 20.0'	4/10/03	11
U7	13° 20.0'	100° 30.0'	4/10/03	13
U8	13° 20.0'	100° 40.0'	6/10/03	17
U9	13° 20.0'	100° 50.0'	6/10/03	15
U10	13° 10.0'	100° 10.0'	5/10/03	18
U11	13° 10.0'	100° 20.0'	4/10/03	21
U12	13° 10.0'	100° 30.0'	5/10/03	18
U13	13° 10.0'	100° 40.0'	6/10/03	22
U14	13° 10.0'	100° 50.8'	6/10/03	25
U15	13° 00.0'	100° 10.0'	5/10/03	18
U16	13° 00.0'	100° 20.0'	4/10/03	25
U17	13° 00.0'	100° 30.0'	6/10/03	22
U18	13° 00.0'	100° 40.0'	6/10/03	16
U19	13° 00.0'	100° 50.0'	6/10/03	14
U20	12° 50.0'	100° 05.0'	5/10/03	14
U21	12° 50.0'	100° 10.0'	5/10/03	17
U22	12° 50.0'	100° 20.0'	4/10/03	26
U23	12° 50.0'	100° 30.0'	6/10/03	24
U24	12° 50.0'	100° 40.0'	6/10/03	30
U25	12° 50.0'	100° 50.0'	5/10/03	19
U26	12° 40.0'	100° 00.0'	5/10/03	10
U27	12° 40.0'	100° 10.0'	5/10/03	21
U28	12° 40.0'	100° 20.0'	4/10/03	30
U29	12° 40.0'	100° 30.0'	6/10/03	26
U30	12° 40.0'	100° 40.0'	6/10/03	38
U31	12° 38.0'	100° 50.0'	12/10/03	35
U32	12° 30.0'	100° 01.2'	5/10/03	13
U33	12° 30.0'	100° 10.0'	5/10/03	28
U34	12° 30.0'	100° 20.0'	4/10/03	26
U35	12° 30.0'	100° 30.0'	6/10/03	26
U36	12° 30.0'	100° 40.0'	6/10/03	28
U37	12° 11.0'	100° 07.0'	5/10/03	30
U38	12° 18.0'	100° 19.0'	5/10/03	28
U39	12° 22.0'	100° 30.0'	7/10/03	27
L1	11° 45.0'	099° 55.0'	16/10/2003	28
L2	12° 00.0'	100° 20.0'	16/10/2003	32
L3	12° 15.0'	100° 45.0'	7/10/2003	29
L4	12° 30.0'	101° 10.0'	7/10/2003	22
L5	11° 00.0'	099° 40.0'	18/10/2003	43
L6	11° 15.0'	100° 05.0'	16/10/2003	47

Table A-1 (cont.)

Station	Latitude (N)	Longitude (E)	Date	Depth (m)
L7	11° 30.0'	100° 30.0'	16/10/2003	54
L8	11° 45.0'	100° 55.0'	17/10/2003	45
L9	12° 00.0'	101° 20.0'	7/10/2003	44
L10	12° 15.0'	101° 45.0'	8/10/2003	29
L11	10° 15.0'	099° 25.0'	18/10/2003	33
L12	10° 30.0'	099° 50.0'	18/10/2003	50
L13	10° 45.0'	100° 15.0'	17/10/2003	54
L14	11° 00.0'	100° 40.0'	17/10/2003	56
L15	11° 15.0'	101° 05.0'	17/10/2003	58
L16	11° 30.0'	101° 30.0'	10/10/2003	58
L17	11° 45.0'	101° 55.0'	10/10/2003	53
L18	11° 55.0'	102° 15.0'	—	28
L19	09° 50.0'	099° 40.0'	20/10/2003	26
L20	10° 05.0'	100° 05.0'	18/10/2003	46
L21	10° 20.0'	100° 30.0'	18/10/2003	60
L22	10° 35.0'	100° 55.0'	19/10/2003	62
L23	10° 50.0'	101° 20.0'	19/10/2003	65
L24	11° 05.0'	101° 45.0'	10/10/2003	65
L25	11° 20.0'	102° 10.0'	10/10/2003	61
L26	11° 35.0'	102° 30.0'	9/10/2003	32
L27	09° 35.0'	100° 15.0'	19/10/2003	24
L28	09° 50.0'	100° 40.0'	19/10/2003	60
L29	10° 05.0'	101° 05.0'	19/10/2003	63
L30	10° 20.0'	101° 30.0'	19/10/2003	62
L31	08° 55.0'	100° 10.0'	21/10/2003	24
L32	09° 10.0'	100° 35.0'	27/10/2003	36
L33	09° 25.0'	101° 00.0'	27/10/2003	61
L34	09° 40.0'	101° 25.0'	—	69
L35	08° 30.0'	100° 30.0'	27/10/2003	27
L36	08° 45.0'	100° 55.0'	27/10/2003	40
L37	09° 00.0'	101° 20.0'	—	56
L38	09° 15.0'	101° 45.0'	26/10/2003	75
L39	08° 00.0'	100° 40.0'	28/10/2003	26
L40	08° 15.0'	101° 05.0'	26/10/2003	49
L41	08° 30.0'	101° 30.0'	26/10/2003	57
L42	08° 45.0'	101° 55.0'	—	72
L43	07° 30.0'	100° 50.0'	24/10/2003	20
L44	07° 45.0'	101° 15.0'	24/10/2003	42
L45	08° 00.0'	101° 40.0'	20/10/2003	53
L46	08° 15.0'	102° 05.0'	25/10/2003	72
L47	07° 15.0'	101° 25.0'	26/10/2003	42
L48	07° 30.0'	101° 50.0'	25/10/2003	44
L49	07° 45.0'	102° 15.0'	25/10/2003	69
L50	08° 00.0'	102° 40.0'	25/10/2003	71
L51	06° 50.0'	101° 45.0'	26/10/2003	33
L52	07° 05.0'	102° 10.0'	26/10/2003	46
L53	07° 20.0'	102° 35.0'	25/10/2003	52
L54	07° 35.0'	103° 00.0'	25/10/2003	55

Appendix B

Removal of Organic Matter from Sediment

1. Accurately weigh 5 g of dried homogenized sediment.
2. Add 10% (v/v) hydrogen peroxide (H_2O_2) solution to the sediment in order to oxidize organic matter which binding the particles.
3. Allow the reaction to progress overnight.
4. Heat the mixture to about 60°C for completing the reaction.
5. More 10% (v/v) H_2O_2 may required for some samples which contained high organic matter.
6. Remove the excess H_2O_2 by boiling off.



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Appendix C

Determination of readily oxidizable organic matter

1. Reagents

- 1.1 85% Orthophosphoric acid (H_3PO_4) (sp.gr. = 1.71)
- 1.2 Concentrated sulfuric acid (H_2SO_4) with silver sulfate: dissolve 2.5 g of Ag_2SO_4 in 1 liter of conc. H_2SO_4
- 1.3 Sodium fluoride solid (NaF) (sp.gr. = 1.84)
- 1.4 Diphenylamine indicator : dissolve 0.5 g of diphenylamine in 20 ml of distilled water and 100 ml of conc. H_2SO_4
- 1.5 0.1N Potassium dichromate solution as primary standard: dissolve exactly 49.04 g of $\text{K}_2\text{Cr}_2\text{O}_7$ in 1 liter of distilled water.
- 1.6 0.5N Ferrous ammonium sulfate solution: dissolve 196.1 g of $\text{Fe}(\text{NH}_2)(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ in 800 ml of distilled water containing 20 ml conc. H_2SO_4 then dilute to 1 liter.
- 1.7 Dextrose ($\text{C}_6\text{H}_{12}\text{O}_6$)

2. Procedure

- 2.1 Carefully weigh 0.5 g of freeze-dried sediment sample, ground in an agate mortar, and place in 500 ml Erlenmeyer flask.
- 2.2 Add exactly 10 ml of 0.1N Potassium dichromate solution by 50 ml burette and mixed carefully by gently swirling.
- 2.3 Add 20 ml of conc. H_2SO_4 , mixed carefully by gently rotating the flask of the solution and sample for 1 minute, avoid spattering of the sediment onto the side of the flask.
- 2.4 After 30 minutes, let the chemical reaction complete, dilute the solution to about 200 ml by distilled water.
- 2.5 Add 10 ml of 85% orthophosphoric acid, 0.2 g of sodium fluoride and 15 drops (or 1 ml of indicator), respectively.

- 2.6 The sample is then back titrate with 0.5N ferrous ammonium sulfate solution until the color of the solutions change from dull green to brilliant green. Titration should be made with carefully because the color changed is quite difficult to separate. In the beginning the color of the sample is dull green because of the chromous ions, and then become turbid blue as the titration proceeds before change sharply to brilliant green at the end-point (but not every sample that can be seen the turbid blue color).
- 2.7 If most of dichromate solution is consumed, the analysis should be repeated with smaller sediment sample.
- 2.8 Standardization of blank should be run with each new batch of samples.
3. Standardization
- 3.1 Standardization is run by using a clean 500 ml Erlenmeyer flask without the sediment.
- 3.2 Follow the above procedure.
- 3.3 Three replicate should be done.
4. Calculation of Results

Amount of organic content in the sediment is calculated from the volume in milliliter of used ferrous ammonium sulfate solution using equations below.

$$\% \text{ organic carbon} = 10(1 - T/S) \times F$$

$$\% \text{ organic matter} = \% \text{ organic carbon} \times 1.72$$

where

1.72 = Conversion factor of carbon content of organic carbon

S = Standardization blank titration, ml of ferrous ammonium sulfate solution

T = Sample titration, ml of ferrous ammonium sulfate solution

F = $(1.0N) \times (12/4000) \times 1.72 \times (100/\text{sediment weight})$

where 12/4000 is milli-equivalent weight of carbon

= 1.03 (when sediment weight = 0.5g)

5. Accuracy determination

- 5.1 Carefully weigh 0.01 g of dextrose and place in 500 ml erlenmeyer flask.
- 5.2 Follow the procedure used for sediment analysis.
- 5.3 Calculate the percentage of organic carbon that should be nearly 39.99% (Approximately 1 g of dextrose has 39.99% of organic carbon).

$$\% \text{ organic carbon in dextrose} = 10(1 - T/S) \times F$$

where

$$\begin{aligned} F &= (1.0 N) \times (12/4000) \times 1.72 \times (100/\text{dextrose weight}) \\ &= 30 \text{ (when dextrose weight} = 0.01\text{g)} \end{aligned}$$



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Appendix D

Determination of carbonate content (inorganic carbon)

1. Reagents

- 1.1 0.5N Hydrochloric acid solution (HCl)
- 1.2 0.25N Sodium hydroxide solution (NaOH)
- 1.3 Phenolphthalein indicator: dissolve 100 mg of solid indicator in 100 ml of 80% ethyl alcohol (0.1% in ethyl alcohol).
- 1.4 Sodium carbonate (Na_2CO_3)
- 1.5 Potassium hydrogen phthalate ($\text{KHC}_8\text{H}_4\text{O}_4$)
- 1.6 Bromocresal green solution: dissolve 100 mg of solid indicator in 1.45 ml of 0.1 N NaOH, dilute to 100 ml with distilled water.

2. Procedure

- 2.1 Accurately weigh 1 g of freeze-dried sediment sample, ground in an agate mortar, transfers to a 250 ml Erlenmeyer flask.
- 2.2 Add 10 ml of hydrochloric acid solution
- 2.3 Heat at about 90°C for 20 minutes
- 2.4 Test pH with pH paper, if the pH is > 2 , add another 10 ml of hydrochloric acid solution and resume heating for 20 minutes.
- 2.5 When pH is < 2 after heat, dilute the solution by using distilled water to about half-full of the flask.
- 2.6 Back-titrate with sodium hydroxide solution using phenolphthalein as an indicator. The color of the solution will change sharply from color to purple at the end-point.
- 2.7 Standardization of acid and base solution is made daily.

3. Standardization of Sodium hydroxide solution

- 3.1 Dry potassium hydrogen phthalate at 110°C for 2 hours and cool in a desiccator.
- 3.2 Weigh 0.9-1.0 g of potassium hydrogen phthalate (to the nearest 0.1 mg) into 250 ml Erlenmeyer flask.
- 3.3 Dissolve in 100 ml of distilled water.

- 3.4 Add 3-4 drops of phenolphthalein.
 - 3.5 Titrate with sodium hydroxide solution until the pink color of the indicator persists for 30 seconds.
 - 3.6 Three replicate should be done.
4. Standardization of Hydrochloric acid solution
- 4.1 Dry sodium carbonate at 110°C for 2 hours and cool in a desiccator.
 - 4.2 Weigh 0.6-0.7 g of sodium carbonate (to the nearest 0.1 mg) into 250 ml Erlenmeyer flask.
 - 4.3 Dissolve the solid with about 25-50 ml distilled water.
 - 4.4 Add 3-4 drops of bromocresal green.
 - 4.5 Titrate with hydrochloric acid solution until the solution just begins to change from blue to green.
 - 4.6 Boil the solution for 2-3 minutes, cool at room temperature, and complete the titration if the color is changed back from green to blue.
 - 4.7 Three replicate should be done.
5. Calculation

The reactions during standardization are

Standardization of sodium hydroxide solution:



Standardization of Hydrochloric acid solution:



The results from the acid–base titration for carbonate contents are calculated as follows:

$$\% \text{CO}_3\text{-C} = [(100)(0.006)(\text{ml}_{\text{HCl}})(\text{N}_{\text{HCl}})] - [(\text{ml}_{\text{NaOH}})(\text{N}_{\text{NaOH}})]$$

(This involves no assumptions about the forms of the carbonate phases)

$$\% \text{CaCO}_3 = [(100)(0.05)(\text{ml}_{\text{HCl}})(\text{N}_{\text{HCl}})] - [(\text{ml}_{\text{NaOH}})(\text{N}_{\text{NaOH}})]$$

(This assumes that all the carbonate occurs as CaCO_3)

Appendix E

Sediment digestion for total mercury analysis

1. Reagents

- 1.1 Deionized water
- 1.2 Aqua regia solution: mix conc. HNO_3 with conc. HCl ($\text{HNO}_3 : \text{HCl} = 1:3$).
- 1.3 Sodium chloride-hydroxylamine sulfate solution: dissolve 12 g of sodium chloride and 12 g of hydroxylamine sulfate in reagent water and dilute to 100 ml.
- 1.4 0.2N Bromine monochloride solution (BrCl): in a fume hood, dissolve 27 g of potassium bromide (KBr) in 2.5 l of conc. HCl . Place a clean magnetic stir bar in the bottle and stir for approximately 1 h in the fume hood. Slowly add 38 g potassium bromate (KBrO_3) to the acid while stirring. When all of the KBrO_3 has been added, the solution color should change from yellow to red to orange. Loosely cap the bottle, and allow stirring another hour before tightening the lid.
- 1.5 0.07N BrCl : dilute 300 ml of 0.2N BrCl solution to 1000 ml with deionized water.

2. Procedure

- 2.1 Accurately weigh 0.4 to 0.6 g of freeze-dried sediment sample, ground in an agate mortar, and place in digestion tube.
- 2.2 Add 5 ml of aqua regia to the sediment sample in the digestion tubes, close the cap, and swirl. Allow to digest at 95°C in a heating block.
- 2.3 Add the digestate with 30 ml of 0.07N BrCl and shake the tubes to mix thoroughly. Allow the sample to settle overnight.
- 2.4 Pour slightly the supernatant into the other clean tube and add 3 ml of sodium chloride-hydroxylamine sulfate solution. Measure the total mercury by FIMSTM400.
- 2.5 Method blank should be run with each new batch of samples.

Appendix F

Table F-1 Size composition of sand, silt and clay in the sediment of the Gulf of Thailand

Station	% Sand	% Silt	% Clay	Sediment Name
U1	9.9	71.7	18.4	clayey silt
U2	2.9	74.3	22.8	clayey silt
U3	0.8	69.5	29.6	clayey silt
U4	2.7	48.8	48.5	silty clay
U5	11.0	71.7	17.3	sandy clayey silt
U6	10.9	82.9	6.2	silt
U7	9.6	85.9	4.5	silt
U8	25.1	71.0	3.7	sandy silt
U9	13.2	79.2	7.6	sandy silt
U10	17.7	75.3	7.0	sandy silt
U11	14.4	80.1	5.5	sandy silt
U12	56.1	41.4	2.5	silty sand
U13	60.0	37.3	2.7	silty sand
U14	3.2	90.9	5.9	silt
U15	29.1	65.6	5.3	sandy silt
U16	50.1	46.9	3.0	silty sand
U17	13.1	82.1	4.9	silt
U18	52.3	44.4	3.3	silty sand
U19	24.8	67.2	8.0	sandy silt
U20	22.0	65.2	12.7	sandy clayey silt
U21	45.0	50.8	4.2	sandy silt
U22	55.4	40.7	3.9	silty sand
U23	78.8	19.6	1.7	silty sand
U24	84.5	14.2	1.3	sand
U25	30.8	60.2	9.0	sandy silt
U26	3.3	84.8	11.8	silt
U27	47.8	48.0	4.1	silty sand
U28	52.1	45.2	2.7	silty sand
U29	77.3	20.6	2.1	silty sand
U30	84.6	13.9	1.5	sand
U31	72.9	24.6	2.5	silty sand
U32	2.6	83.2	14.2	silt
U33	39.0	53.8	7.3	sandy silt
U34	62.1	33.5	4.4	silty sand
U35	86.7	8.5	4.8	sand
U36	79.8	17.3	2.8	silty sand
U37	37.5	50.5	12.5	sandy clayey silt
U38	62.7	32.2	5.2	silty sand
U39	85.0	12.2	2.7	sand
L1	13.6	78.1	8.3	sandy silt
L2	58.2	37.7	4.1	silty sand
L3	79.8	18.0	2.2	silty sand
L4	21.3	68.8	9.9	sandy silt
L5	0.7	83.2	16.1	silt
L6	46.1	48.6	5.3	sandy silt

Table x (cont.)

Station	% Sand	% Silt	% Clay	Sediment Name
L7	38.3	44.9	4.1	sandy silt
L8	41.5	51.3	0.3	sandy silt
L9	26.3	68.6	5.1	sandy silt
L10	21.9	68.7	9.3	sandy silt
L11	6.6	84.5	9.0	silt
L12	1.2	85.5	13.2	silt
L13	37.5	47.2	15.3	sandy clayey silt
L14	43.9	43.9	12.2	silty clayey sand
L15	5.9	56.3	37.8	clayey silt
L16	2.9	83.4	13.8	silt
L17	10.1	80.3	9.6	sandy silt
L18	No sample			
L19	36.4	59.3	4.3	sandy silt
L20	1.9	69.0	29.0	clayey silt
L21	13.4	43.7	43.0	sandy clayey silt
L22	22.4	63.4	14.2	sandy clayey silt
L23	17.1	66.3	16.5	sandy clayey silt
L24	9.1	76.5	14.4	clayey silt
L25	3.3	74.0	22.7	clayey silt
L26	37.4	57.8	4.8	sandy silt
L27	1.8	80.9	17.2	silt
L28	1.7	84.2	14.1	silt
L29	21.8	60.8	17.1	sandy clayey silt
L30	12.6	68.4	18.9	sandy clayey silt
L31	0.8	74.7	24.5	clayey silt
L32	—	—	—	—
L33	4.4	74.4	21.2	clayey silt
L34	No sample			
L35	4.0	50.7	45.2	clayey silt
L36	12.8	53.5	33.8	sandy clayey silt
L37	No sample			
L38	18.5	60.1	21.4	sandy clayey silt
L39	38.5	36.6	24.9	silty clayey sand
L40	0.5	50.0	49.5	clayey silt
L41	19.5	59.9	20.6	sandy clayey silt
L42	No sample			
L43	93.5	4.4	2.0	sand
L44	9.9	76.4	13.7	clayey silt
L45	35.4	48.3	16.3	sandy clayey silt
L46	24.3	51.7	24	sandy clayey silt
L47	13.4	77.5	9.2	sandy silt
L48	33.2	60.0	6.8	sandy silt
L49	5.4	87.2	7.4	silt
L50	2.7	86.8	10.5	silt
L51	55.1	40.3	4.6	silty sand
L52	54.3	42.1	3	silty sand
L53	25.5	67.6	6.9	sandy silt
L54	17.1	68.6	14.2	sandy clayey silt

Table F-2 Organic carbon, calcium carbonate and total mercury contents in the sediment of the Gulf of Thailand

Station	%Org C	%CaCO ₃	Hg (µg/kg)	Station	%Org C	%CaCO ₃	Hg (µg/kg)
U1	1.69	6.3	74.6	L9	0.51	8.2	20.7
U2	1.91	5.9	86.2	L10	1.44	27.6	36.4
U3	1.88	3.3	89.9	L11	1.67	9.3	28.3
U4	1.98	5.3	53.7	L12	1.36	11.7	21.1
U5	1.38	nd	34.0	L13	0.52	14.1	20.4
U6	1.51	8.6	42.8	L14	0.37	15.1	13.9
U7	1.23	9.2	71.9	L15	0.96	17.8	26.9
U8	1.05	10.9	92.4	L16	1.19	15.7	33.8
U9	2.20	11.1	27.2	L17	1.09	15.3	33.7
U10	1.65	12.6	87.6	L18		No sample	
U11	1.32	nd	71.9	L19	0.60	4.8	19.0
U12	0.70	15.0	14.0	L20	1.21	11.3	29.3
U13	0.75	14.0	21.2	L21	0.70	39.3	21.8
U14	1.12	nd	15.6	L22	0.45	1.7	21.1
U15	1.31	25.1	24.8	L23	0.48	20.3	21.5
U16	0.77	14.5	16.5	L24	0.51	17.6	29.4
U17	0.80	17.6	22.3	L25	0.83	15.5	28.6
U18	0.34	19.7	9.4	L26	0.70	9.5	28.5
U19	1.22	32.3	21.6	L27	1.19	8.8	28.2
U20	1.12	14.7	27.7	L28	0.85	15.9	35.5
U21	0.77	24.1	74.7	L29	0.34	31.8	38.4
U22	0.32	13.1	17.0	L30	0.27	24.2	34.3
U23	0.19	16.7	< 2	L31	1.35	6.9	50.1
U24	0.24	13.5	13.5	L32	0.92	15.3	48.0
U25	1.28	36.9	37.5	L33	0.74	16.1	24.6
U26	1.51	8.5	14.0	L34		No sample	
U27	0.48	14.0	8.8	L35	0.72	9.0	18.0
U28	0.56	13.7	24.7	L36	0.72	18.5	18.4
U29	0.26	29.7	10.1	L37		No sample	
U30	0.07	14.3	49.0	L38	0.43	26.4	25.0
U31	0.40	27.5	32.6	L39	0.29	16.5	17.0
U32	1.75	8.3	28.7	L40	0.66	9.9	-
U33	0.49	10.8	7.2	L41	0.44	3.5	23.8
U34	0.17	14.4	14.5	L42		No sample	
U35	0.23	16.8	10.5	L43	0.10	5.7	6.5
U36	0.18	16.9	7.6	L44	0.41	14.9	18.8
U37	0.52	5.7	5.0	L45	0.29	33.4	20.2
U38	0.47	10.0	11.3	L46	0.56	21.3	25.5
U39	0.30	23.7	16.3	L47	0.44	15.2	20.0
L1	1.08	9.3	20.8	L48	0.34	22.2	23.6
L2	0.34	9.0	7.2	L49	0.55	38.2	28.2
L3	0.38	27.2	7.7	L50	0.87	14.4	30.7
L4	0.65	18.4	19.8	L51	0.17	27.0	12.5
L5	1.38	9.6	34.6	L52	0.20	27.2	17.3
L6	0.49	11.4	22.0	L53	0.37	17.8	21.2
L7	0.58	13.6	14.8	L54	0.68	17.3	23.5
L8	0.72	4.9	23.4				

BIOGRAPHY

Name: Miss Suchada Buakaew

Date of Birth: June 11, 1983

Nationality: Thai

University Education:

2005 Bachelor Degree of Science (B.Sc.) in Environmental Science and Technology, Faculty of Environment and Resource Studies, Mahidol University, Bangkok, Thailand

Presentation:

Buakaew, S., Sompongchaiyakul, P. and Chanlaeiad, W. Sedimentological characteristics and mercury contamination in surface sediment of the Gulf of Thailand. Presented in IOC/WESTPAC, 7th International Scientific Symposium “Natural Hazards and Changing Marine Environment in the Western Pacific”, 21-25 May 2008, Kota Kinabalu, Sabah, Malaysia. (2008)

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