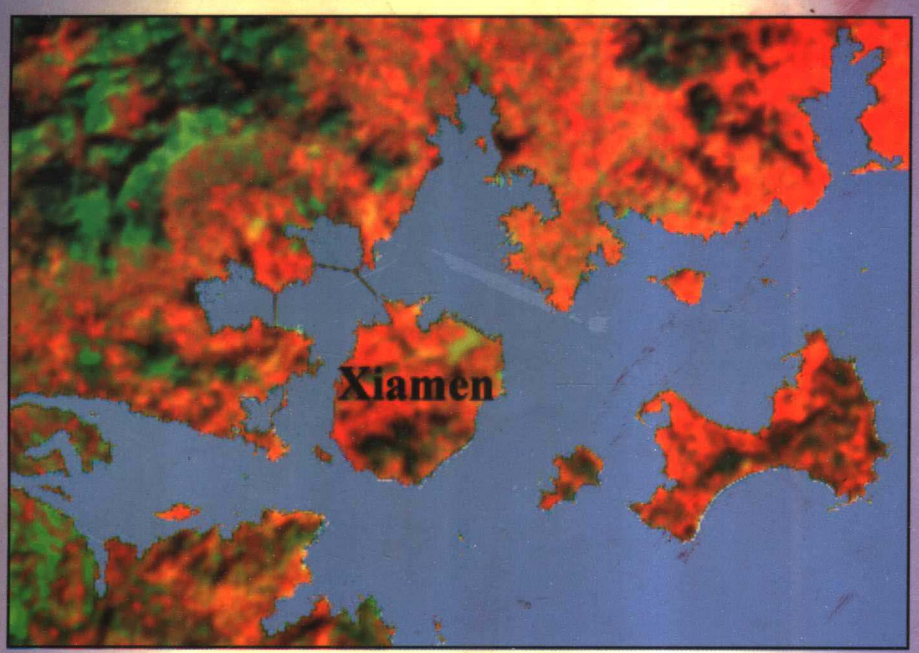
洪华生　徐　立　等著

香港与厦门港湾污染沉积物研究

Study of Contaminated Sediment in Hong Kong and Xiamen Harbours



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内 容 简 介

本书是一部有关港湾污染沉积物研究的论文专集。书中反映了洪华生教授主持的国家自然科学主任基金项目—“香港维多利亚港与厦门西港污染沉积物变化过程的对比研究”(项目编号 49356001)的成果。内容涉及香港维多利亚港和厦门西港沉积物中有机污染物和重金属的分布与变化、生物标记物的指示作用、磷循环模式、碱性磷酸酶活力动态变化、微生物生态、底栖生态等。

本书可供大专院校海洋学科、环境学科师生参考，也可供有关科技人员和环保管理人员阅读。

前 言

沿海是经济发展速度最快的地区，发展所带来的污染问题日益严重。人类所产生的污染物通过不同的途径汇集到河口港湾，许多污染物通过絮凝或吸附于颗粒物质而沉降到海底。过去，往往认为沉积物是污染物的最终归宿。但近年来的研究表明，虽加强了对陆源排污的控制，但河口港湾所累积的污染沉积物可以成为二次污染源，将污染物再次释放进入水体，产生生态毒理效应，还能通过食物链传递和富集，对人类健康构成威胁。因此，污染沉积物的研究已成为人们关注的热点问题。尤其是微量有机污染物性质稳定、毒性大，在环境中易被生物积累，有“三致”(即致癌、致畸、致突变)效应。但它们的化学成分复杂、量微，测试比较困难，因此微量有机污染物的研究在我国尚属薄弱环节。

我们在国家自然科学主任基金的支持下，和香港科技大学研究中心开展合作研究，选择长期接受大量废水排放的香港维多利亚港和近年来经济快速发展的厦门西港沉积物进行对比研究。其主要目的在于比较全面深入地研究沉积污染物的来源、分布特征及变化动力学过程，研究沉积物对上覆水的影响及对生物的效应，并为环境管理、港湾工程提供科学依据。在两地环保部门的配合下，我们收集并综合分析了多年调查的现存资料，在对香港维多利亚港和厦门西港的环境状况有了比较全面了解的基础上，1993 年 11 、12 月和 1994 年 7 月在香港维多利亚港和厦门西港分别进行了现场调查研究，重点放在有机污染物上，对它们的分布、来源及变化过程进行了研究；并且自制模拟装置，在实验室开展了沉积物磷释放模拟研究；采用先进的生物标志物手段来示踪污染物的来源及变化；还用微生物、底栖硅藻和底栖生物等来探讨污染物的生态效应。圆满完成课题预定的研究内容和目标，取得了可喜成果，有所发现，有所创新：

1. 首次全面、系统地研究了香港维多利亚港和厦门西港的有机污染状况，所分析的有机污染物包括饱和烃、长链烷基苯、多环芳烃、含氯农药和多氯联苯等。比较详细地研究了它们在沉积物中的分布特征、来源和变化过程。研究结果证明，香港维多利亚港的有机污染物主要来自当地的输入，而不是珠江口的输入。维多利亚港沉积物含氯农药和多氯联苯的含量较低，但石油烃污染相当严重。厦门西港沉积物中的石油烃污染较轻，但残留农药如 DDT 的含量较高，DDE/DDT 比例表明还有近期输入的残留，必须引起有关部门的重视。

2. 建立沉积物中有机标记物脂肪酸和甾醇的分析鉴定方法，鉴定出 120 种脂肪酸和近 30 种甾醇。用模糊聚类分析法对甾醇的数据进行处理，不同来源的污染物中甾醇的组成特征不同，某些脂肪酸或甾醇可以作为近岸海区有机物来源的示踪剂，利用它们来区别陆源和海源有机物以及海源有机物的具体来源(如浮游动、植物，细菌等)。用粪甾醇来指示生活污水的影响范围和程度。

3. 我们在厦门西港通过不同形态磷的分析以及沉积物释放模拟实验，对沉积物磷循环进行了比较深入的研究，初步建立了磷循环模式。模拟实验结果表明，磷从沉积物向上覆水的扩散通量可高达 2 $mmol/m^2/d$, 沉积物释放是该海域水体中磷的一个重要来源。厦门西港水

体含磷量低，磷又与赤潮发生有密切关系，在估算海域的纳污容量时，必须重视沉积物的再释放量。

4. 首次对香港维多利亚港和厦门西港沉积物碱性磷酸酶活力进行了研究。沉积物碱性磷酸酶活力与水体受污染程度的多项指标均表现出一定的相关性，该指标可作为小区域水体富营养化程度的重要参考指标。维多利亚港沉积物中碱性磷酸酶活力比厦门西港高出一个数量级左右，更说明该港沉积物的污染状况比厦门西港严重。

5. 探讨了微生物生态、大型底栖动物生态和底栖硅藻与沉积物和水体污染的关系。结果表明污染指示菌和异养菌丰度、细菌生物量，大型底栖生物群落结构和底栖硅藻的丰度等与沉积物或海水污染程度有较好的相关性，可以用上述生物指标来指示污染程度。大型底栖生物的结果也表明，维多利亚港底质的污染比厦门港的严重，两个港湾的共同特点是在与外界水域交界的区域底栖生物群落处于平衡状态，指示底质状况良好；而水交换差的区域底栖生物小型化，指示底质污染较重。

6. 我们从港湾的生态环境特点探讨了填海工程的影响。填海工程能引起水动力的改变，使潮流流速和流量减少，降低冲刷能力；能加速港口的航道淤积；也降低了污染物的迁移扩散能力，减少纳污容量，使污染问题加剧，因此，对填海工程必须进行综合环境影响评价，重视其累积性效应。

本书收集 32 篇论文，部分已在国内外学术刊物和学术会议上发表或交流。 1995 年 2 月，本人还应香港特别行政区筹委会之邀赴北京参加“维多利亚港填海问题座谈会”，作了“从香港维多利亚港环境特点看填海可能造成的影响”的报告。 1995 年 1 月本人应邀赴香港参加“海洋污染与生态毒理学国际讨论会”，作大会主旨报告，引起与会者的广泛兴趣，该报告已在 SCI 刊物 Marine Pollution Bulletin 上发表。 1996 年 6 月 25 日至 28 日，在国家自然科学基金的支持下与香港科技大学研究中心在香港联合主办了“亚太沿海环境科学和管理国际会议”，有 24 个国家的 231 位科学家参加，取得了圆满成功。本课题组的 12 篇论文进行了交流，其中一篇作大会特邀报告。这些论文的摘要也一并收集于本书的附录中。

在本书出版之际，我衷心感谢国家自然科学基金会的资助，感谢香港科技大学研究中心的真诚合作和香港、厦门两地环保部门的大力支持以及课题组成员的共同努力。

课题负责人　洪华生
国家教委海洋生态环境开放研究实验室
厦门大学环境科学研究中心

一九九七年十一月

PREFACE

Coastal areas are under increasing pollution pressure as a result of rapidly economic development. Historically, coastal sediment is considered to be the ultimate sink for many classes of anthropogenic contaminants, however, recently studies have shown that although environmental regulation has resulted in a reduction of waste discharged from the terrestrial sources during the last decade, but the coastal sediment could act as a secondary pollution source, it has the potential to release the pollutant which could cause adverse impact to the water column, toxicological effects to the marine organism then transferring through the food web, and ultimately, affect humans. In particular, trace organic pollutants have long term effects and are of potential threat to human health. However, due to their chemical complexity, trace levels of present in the environment and difficulty of detection , trace organic pollutants have not been studied extensively in most of the China coastal areas.

With the support from the National Natural Science Foundation of China, a collaborate research project was developed with the colleague from the Research Centre of the Hong Kong University of Science & Technology. The sediment of Victoria Harbour, Hong Kong which receives substantial amount of untreated waste and the sediment of the Western Harbour, Xiamen which is under great environmental stress owing to rapidly development, are studied for making a comparison.. The aims of the project are to study the sources, distribution characteristic and the dynamic processes of the contaminated sediment, the effects to the over-lying water and their ecotoxicology, and to provide the scientific basis for environmental management and coastal engineering. In November and December of 1993 and in July of 1994, field studies were conducted in the Victoria Harbour and Xiamen Western Harbour, respectively. The sources, distribution and the variation processes of the contaminated sediment with emphasis on trace organic pollutants were studied; the release of P from the sediment was studied in a laboratory simulated experiment; the biomarkers were used to trace the sources and processes; the bacteria, benthic and benthos communities were studied to indicate the ecotoxicology effects. We had fulfilled the tasks planned and have obtained significant outcome from the study:

1. The status of organic pollution in sediment of Victoria Harbour and Xiamen Western Harbour was studied comprehensively for the first time. The sources, distribution characteristic and the fate of organic pollutants such as non-aromatic hydrocarbon, long-chain alkylbenzenes, polycyclic aromatic hydrocarbon, organochlorine pesticides and polychlorinated biphenyls were investigated. Our results indicated that the organic pollutants came from local discharges in both harbours. In comparison, the concentrations of organochlorine pesticides and polychlorinated biphenyls in sediment of Victoria Harbour were low, but the non-aromatic hydrocarbon levels present in Victoria Harbour sediment indicated that there was significant petroleum contamination in the harbour. The concentration of petroleum hydrocarbon in sediment of Xiamen Western Harbour was relatively low, the high level of DDTs and the ratio of DDE/DDT indicated that there was a more recent input of DDT in Xiamen Western Harbour.

2. The analytical method of biomarkers (fatty acids and sterols) was set up in our laboratory. More than 120 kinds of fatty acids and 30 kinds of sterols were identified. A fuzzy classification method was applied to distinguish source indicators of sterols. Some of the fatty acids and sterols could be used as biomarkers for tracing sources of organic matter, they were used to evaluate the relative importance of terrigenious versus marine inputs or from phytoplankton versus zooplankton and microorganisms. Coprostanol was also applied to indicate sewage pollution.

3. Phosphorus speciation and flux at sediment- sea water interface were studied in Xiamen Western Harbour. A preliminary dynamic box model was developed. The results of our simulation experiment showed that the upward benthic phosphorus flux was as high as 2.0 mmol/m^2 /d. the benthic flux might be an important source of phosphorus input to the water. The water in Xiamen Western Harbour had low concentration of phosphorus and it was suggested that red tide in this harbour be closely related with phosphorus. One should emphasize the benthic phosphorus release when considering the environmental capacity.

4. The alkaline phosphatase activity (APA) was studied for the first time in the sediment of Xiamen Western Harbour and Victoria Harbour. The results showed that the APA in sediment was closely related to the degree of water pollution. in sediment and could be regarded as an important index to indicate the water eutrophication in these two harbours. Our data showed that the APA in sediment of Victoria Harbour was at least ten times higher than that of Xiamen Western Harbour. This was consistent with the fact that the sediment in Victoria Harbour was more seriously polluted than in the Xiamen Western Harbour.

5. The relationship between microorganism ecology, macrobenthos, benthic diatoms and the degree of sediment/water pollution was also studied. The results indicated that the bacterial biomass, bacterial production, the structure of benthic community and the abundance of benthic diatoms had good relationship with the degree of sediment/water pollution. These biological index could be used as indicators for pollution. The data of benthos also indicated that the pollution in Victoria Harbour was more serious than that in Xiamen Western Harbour. The common characteristics such as small-sized benthos, fine grain sediment, high organic carbon content and weak water exchange were found in the polluted areas of the two harbours.

6. In addition, we have studied the impact of reclamation based on the ecological environment features of the harbours. It was concluded that reclamation would change the hydrodynamic condition, reduce the tidal flow, accelerate the siltation of navigation channel and reduce the environmental assimilative capacity. All the reclamation projects should be based on integrated environmental impact assessment and the long term accumulated effect carefully considered.

There are 32 papers collected in this book, some papers were already published in the Journals or presented in the international symposium. During 25-28 June 1996, the Asia-Pacific Conference on Science and Management of Coastal Environment was held successfully at the Hong Kong University of Science and Technology. This Conference was organized by the Research Centre of the Hong Kong University of Science and Technology and we served as a co-organizer, with the further support from the National Natural Science Foundation of China. The conference has been an extremely successful event in terms of scientific quality, a total of 231 scientists and scholars from 24 countries and areas attended at the Conference. Twelve papers and one plenary keynote lecture from this study were presented, the abstracts of the papers were also attached in this book.

We greatly appreciate the support from The National Natural Science Foundation of China , the Environmental Protection Agency of Xiamen and The Environmental Protection Department of Hong Kong. We are also grateful and enjoy the sincere collaboration with the colleague of Research Centre, the Hong Kong University of Science and Technology. Sincere thanks to all the team members for their great contributions to the study.

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November, 1997

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香港维多利亚港的环境状况评述*

张珞平　洪华生　庄峙厦

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摘　要　根据实测水文资料、污染源估算以及水质和底质的监测数据对香港维多利亚港的水动力条件、污染负荷以及环境质量状况进行了分析和评价。

关键词　环境状况，评价，香港维多利亚港

香港目前有近600万人口，土地总面积1068 km^2，工业企业有2000多家。每天排放的各类城市和工业污水估计达200多万吨，其中有60%的污水几乎未经处理而直接排入香港周围海域[1]。

维多利亚港位于香港岛和九龙之间，是香港的中心港区。港区周围是香港最繁华的金融、商业贸易区和居民区，旧工业区也分布在港区周围。环绕着维多利亚港居住着400多万人口。由于大量城市和工业污水排入港内，使港内水质逐年下降。尽管近年来加强了污水管制，使维多利亚港水质的下降速率有所减缓，但目前仍呈现下降的趋势。

1　维多利亚港的水动力状况

维多利亚港是一个海峡，而非半封闭的海湾(图1)，东西长约12 km，东部湾口（鲤鱼门）宽约450 m，西部湾口宽约4.5 km，总面积约30 km^2，水深4~40 m，平均水深约为10 m。

香港位于珠江口东部，由于受巴士海峡传来的潮波的影响，加之位于香港岛西北的大屿山岛的天然屏障作用，维多利亚港基本上受海洋潮汐控制，珠江水对它的影响很小。

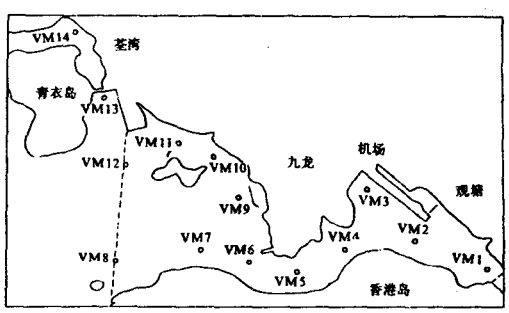

图1 维多利亚港水质监测站位图
Fig. 1 Water quality monitoring in Victoria Harbour

维多利亚港属潮汐控制的港湾，潮波由东部鲤鱼门传入。潮汐属混合潮类型，由小潮时的正规半日潮逐渐变为大潮时的不正规日潮[2]，小潮潮差为1 m，大潮潮差约为2 m。枯水期大潮和小潮的最大涨潮流速分别为0.81和0.77 m/s，最大落潮流速分别为0.5和0.43 m/s[2]。涨潮流速始终大于落潮潮流。余流的方向从东向西，平均流速约为0.12 m/s。涨潮潮流在港口

* 本文原载于海洋通报，1994，13（6）：75～79

西部以西与香港岛西南部北上的潮流汇合，汇合点的高、低平潮潮时均比港东部的鲤鱼门晚1 h左右。港内没有汇流区，也未见明显的环流。

以平均低潮水深10 m计，低潮港容量约为3×10^8 m^3，以潮差计算的纳潮量每日约6×10^7 m^3。由于该港是海峡，潮水从东部进，西部出，实际进潮量远大于由潮差计算的纳潮量。根据鲤鱼门的实测流速[2]和截面积计算得大、小潮通过鲤鱼门进入港内的每日进潮量分别为2.5×10^8 m^3和2.1×10^8 m^3左右。水体交换能力很强，日进潮量约占低潮港容量的80%。

维多利亚港具有独特、优越的水动力条件，有利于污染物的迁移扩散。港内沉积速率极小，平均为1 cm/a。

2 进入维多利亚港的水污染源

目前有400多万人居位在维多利亚港区周围，人口密度达20万/km^2[3]，工业用地275 km^2。每天有近200万吨的工业和城市污水通过19条污水管道和77条排洪沟进入港内及其周围海区。

根据由香港政府环保署 (EPD) 主持进行的“Sewage Strategy Study”中实测和估算的数据[4, 5]，每日直接进入港内的污水量和污染物排放量列于表1。每日直接输入港内的污水量为110万吨，各种污染物源强分别为：COD 639 t，BOD 303 t，悬浮物252 t，总氮44 t，其中氨氮28 t，各种有毒金属共1.9 t，大肠菌数共3.1×10^{18}个。污染源强极大。

表1 输入维多利亚港的水污染源

Tab. 1 Pollution sources to Victoria Harbour

	人口	流量 (m^3/d)	COD (t/d)	BOD (t/d)	S.S. (t/d)	TN (t/d)	NH_4-N (t/d)	TTM (t/d)	E.coli (No)
	3.1×10^6	1.1×10^6	639	303	252	44	28	1.9	3.1×10^{18}
	百分率（%）								
北岸	73.8	68.5	69.9	69.1	70.1	70.0	71.2	87.2	73.2
南岸	26.2	31.5	30.1	30.9	29.9	30.0	28.8	12.8	26.8
东部	56.0	45.6	46.6	45.7	47.2	47.8	50.1	65.6	47.2
中部	10.5	16.8	16.6	17.2	16.1	15.7	14.9	5.5	15.4
西部	33.5	37.6	36.8	37.1	36.7	36.5	35.0	28.9	37.4

注：TN＝总氮；TTM＝总有毒金属；S.S＝悬浮颗粒物质

在污染物的来源中，民用和商业污水占有机污染的90%，工业污水仅占10%；而工业污水占有毒金属污染的80%[4, 5]。氨氮主要来源于土地平整和填方工程的水土流失(占80%~90%)，其次是民用污水[5]；大肠菌群主要来源于民用污水。

从污染源的分布可看出(表1)，由于多数居民和工业企业分布在九龙，北岸九龙一线的排污量占输入维多利亚港污染物总量的70%左右，南岸香港岛仅占30%左右。从接纳水体的分布来看，港区东部接纳了污染物总量的45%~50%，有毒金属占65%，这是由于观塘、东

九龙、土瓜湾和北角一带稠密居民区以及观塘工业区和启德机场等排污所致；港区西部接纳了污染物总量的35%~37%，排污主要来源于旺角，深水埔和上环一带居民区；中部接纳了15%~17%，负荷相对较轻。

3 维多利亚港的污染负荷和净化能力

若以港内低潮港容量$3\times10^8 m^3$计，由每日污水排入的污染物造成的港内水体污染物浓度的增量分别为：COD 2.1，BOD 1.0，S.S. 0.8，总氮0.15，氨氮0.09，重金属0.0006 mg/ dm^3，大肠菌群1.0×10^7个/ dm^3。由浓度增量来看，维多利亚港承受了极大的污染负荷。污染负荷最重的是细菌，其次是营养盐和有机物。

由于维多利亚港是一个海峡，水体交换能力能强，每日的进潮量约占低潮港容量的80%，采用单箱模式估算，以平均余流流速0.12 m/s计，水体净迁移通过12 km长的港区所需时间为27.8h，即水体更新期为1.16d。24h水体更新量约占港内水体总量的86%。由此可见，每日输入港内的污染物约有80%~86%通过水动力作用迁移出港区，加上生物、化学和沉积的去除作用，因此尽管港内承受了极大的污染负荷，污染物仍能基本达到收支平衡，港内水质基本保持稳定，水质下降速率极缓慢。

4 维多利亚港水质状况评价

根据香港EPD 1991年每月一次的监测结果(表2，采样站位见图1)，以我国GB3097-82的《海水水质标准》中的二、三类水质标准对维多利亚港海水质量进行评价。

溶解氧含量2.58~9.09 mg/dm^3，均值5.26 mg/dm^3。按二类水质标准，超标率为20.8%；按三类水质标准则超标率为1.7%。溶解氧饱和率为30.8%~114%，均值67.6%。水质的溶解氧含量偏低，尽管80%测值符合二类水质标准，但多数测值在4~6 mg/dm^3之间。溶氧饱和率最低达30%，均值也仅67.6%。九龙东部和西部溶解氧含量和饱和率最低，目前仍有缓慢下降的趋势。造成溶解氧含量低的原因应归于大量有机污染物的输入。

由于未测定水质COD项目，而海水水质标准未列BOD项，无法进行比较评价，港内BOD含量为0.28~3.10 mg/dm^3，均值1.04 mg/dm^3。除了九龙西部和东部的个别测值含量较高外，多数测值不高。

无机氮含量0.17~1.31 mg/dm^3，均值0.47 mg/dm^3。按二类水质标准，超标率为98%；按三类水质标准则超标率为86%，均值为三类标准的1.57倍。水体无机氮含量严重超标，无机氮中氨氮的比例极大，平均约占70%。

无机磷含量0.025~0.159 mg/dm^3，均值0.059 mg/dm^3。按二类水质标准，超标率为93%；按三类标准则超标率为71%，均值为三类标准的1.3倍。水质无机磷含量也严重超标。

大肠菌群含量为620~979,500个/dm^3，均值104,690个/dm^3。按水质标准，超标率为85.8%，均值超标10倍，港内水体受到细菌的严重污染，九龙西部和东部水体尤为严重。

以上结果表明，维多利亚港内水质受到细菌的严重污染；营养盐含量超过三类水质标准，水体呈高度富营养状态，赤潮发生频繁。7月份监测数据的pH、BOD和叶绿素含量异常