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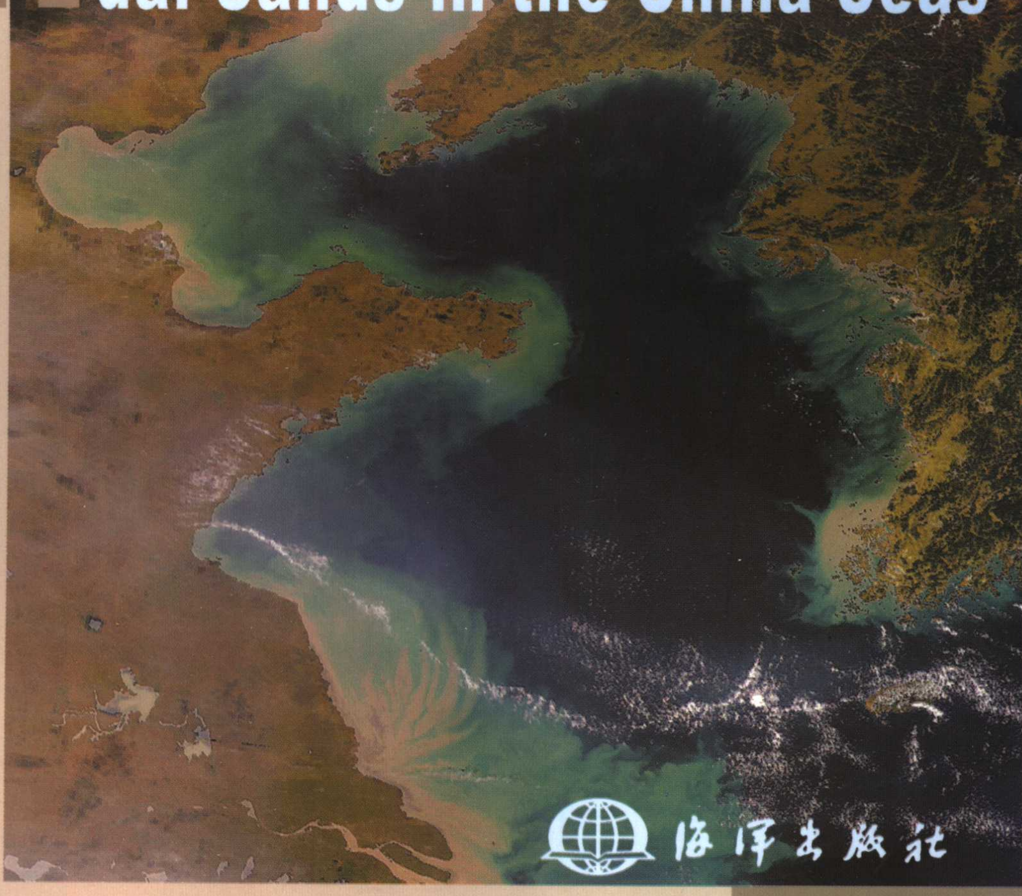
中国近海潮流沉积沙体

刘振夏　夏东兴　著

Tidal Sands in the China Seas



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内 容 提 要

冰后期海侵以来，潮流成为陆架近海最重要和最活跃的海洋动力，对海底沉积和地貌发育起了主导作用。本书基于中国近海的地形、沉积、潮流动力等资料，分析陆架的潮流沉积过程、特征和主导因素，沙脊发育演变与海面变化的关系，以及海洋工程开发与潮流沉积的密切关系，详细叙述了黄海东部、渤海东部、长江口外、台湾海峡、海南岛周边和东海陆架等6个潮流沉积体系。

本书可供海洋学科与地质学科的科研工作者、大专院校师生、海洋开发工程技术人员和政策管理人员参考。

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序

在一个相当长的时期内，海洋地质学家认为中国近海陆架海底主要发育了残留沉积和地貌，尤其那些称为浅滩的海底地貌，几乎无一例外被定为残留沉积。当本书的作者在20世纪80年代初期发表了《潮流脊初步研究》一文后，这种看法慢慢地发生了变化。我一直关注着这一研究工作的进展。通过近20年的工作，现代潮流作用对中国近海陆架的巨大影响渐渐明晰起来。辽东浅滩、苏北浅滩、西朝鲜湾浅滩、台湾浅滩、扬子浅滩、海南岛西南岸外及琼州海峡口门发育的浅滩，以及陆架、河口等发育的其他砂质沉积区几乎都与潮流作用有关，且这些陆架浅滩多为现代潮流作用形成，如辽东浅滩就是涨潮流掘蚀渤海海峡海底物质，并搬运至渤海东北部形成的潮流沙脊。作者在潮流沙脊和潮流沙席与潮流性质的关系方面提出了定量判断标准，探讨了中国陆架和西欧陆架潮流沙脊沉积物分布格局不同的原因，论述了水下沙丘的形成条件及分布区域，总结了中国近海六大潮流沉积体系，将陆架潮流沙体研究向前推进了一大步。该书是作者多年对我国近海潮流沉积研究的总结，这一新的开创性的工作使我们对陆架沉积有了更深层的认识，同时也拓展了新的研究空间。应该说，有关陆架沉积尤其是中国近海陆架沉积地貌的许多课题尚有待进一步深入工作，如海底沙丘和沙脊的动态研究、潮流三角洲发育的研究等均处于起步阶段，但它们对海底管线、航道建设和油气开发有重要的影响，需要研究者投入自己的热情。哪里有需要，哪里就会有科学的突破，古今中外皆同。

陈吉余

前　言

20世纪80年代始，笔者在参加江苏省海岸带与滩涂资源综合调查时开始涉足陆架潮流沉积与地貌的研究工作。规模宏大的江苏岸外潮流沙脊群奇特的辐射状形态，以及它与潮流流场协调一致的关系，犹如天造地设，令人慨叹。对科学的兴趣让我们对辽东浅滩、西朝鲜湾、台湾浅滩及琼州海峡口门等海底沙脊的形态和成因进行了探究，发现原来认为单调的陆架海底，却有着一个由潮流塑造的斑斓世界：切割海底的潮流冲刷沟槽，与潮流流向一致的沙脊、沙条（带），与潮流流向垂直的水下沙丘、沙波，平缓凸起的沙席以及零星散布海底的沙斑等众多沙体。这些丰富多彩的海底地貌却是同宗同源，都是现代潮流作用的产物。

进入90年代，笔者通过中法国际合作、国家自然科学基金和海洋开发等项目，先后对渤海东部、东海陆架、琼西南近岸等潮流沙体开展了地球物理和沉积动力学调查，综合分析了在潮流主导的陆架海中动力、底形和沉积三者之间的关系，划分了中国近海陆架区6个潮流沉积体系，并总结了冰后期潮流沉积模式。

本书所涉海域为渤海、黄海、东海和南海。本书是笔者在国家海洋局第一海洋研究所工作期间完成的，其中第2章由国家海洋局第一海洋研究所汤毓祥研究员完成，第5章中河口湾沙脊部分由华东师范大学刘苍字教授完成，第8章的部分内容由美国北卡罗来纳州州立大学刘敬圃博士完成。在本书的写作过程中得到了美国马里兰大学郑全安教授、厦门大学李炎教授、国家海洋局第一海洋研究所印萍研究员的无私帮助，余华博士处理了全书的图件、校对和部分翻译工作。在此，一并向他们和其他为本书写作提供帮助的同事、朋友表示衷心感谢。同时向支持本项研究的国家自然科学基金委员会、科技部和国家海洋局表示衷心感谢。笔者借此机会向两次中法合作研究的法方首席科学家 S. Berné 博士和法国海洋开发研究院致以谢意。

本书是笔者20余年相关研究工作的总结，书中不仅展示了中法国际合作的部分成果，同时参考了大量相关的国内外文献，希望本书的出版能对从事海洋地质学研究和教学以及从事海洋开发的读者们有所裨益。书中的错漏亦恳请批评指正。

作　者

2004年5月于青岛

Preface

In the early 1980s, we took part in the comprehensive investigations on the Jiangsu coastal zone and tidal flat resources and started to set foot in the studies on the tidal deposition and geomorphology on continental shelf. The radial pattern of the spectacular tidal sand ridges off the Jiangsu coast which being consistent with the tidal current field made a marvelous impression on us. The interest in science aroused our exploration on the pattern and genesis of submarine sand ridges in the Liaodong shoal area, the Western Korea Bay, the Taiwan shoal area and the Qiongzhou Strait entrance area. It is shown that there is a gorgeous submarine scene on the continental shelf, such as the deep tidal scour trough, the sand ridges and ribbons consistent with the tidal current directions, the sand dunes and waves traverse to the tidal current directions, the gentle and raised sand sheet and the sporadically distributed sand patches. These submarine geomorphologies are cogenetic modern tidal current products.

In the 1990s, we took part in the China – France collaborative study projects, the Chinese natural science foundation projects and the marine development project. The hydrographic, geophysical and sedimentary surveys on the tidal sand bodies in the eastern Bohai Sea, the East China Sea continental shelf and the offshore area southwest off Hainan Island coast were made. The relation between dynamic force, bedform, and deposition in continental shelves dominated by tidal current was comprehensively analyzed. Six tidal deposition systems in the continental shelves of China seas have been determined, and the postglacial tidal deposition models are also summarized.

Among a book "Tidal Sands in the China Seas", the China seas include the Bohai Sea, the Huanghai (Yellow) Sea, the East China Sea and the South China Sea. The authors finished this book during working in the First Institute of Oceanography (FIO), State Oceanic Administration. Among the book, Chapter 2 was written by Tang Yuxiang, Senior Research Scientist of FIO, the text of estuarine bay sand ridge in Chapter 5 was written by professor Liu Cangzi, East Normal University, and a part of Chapter 8 was written by Dr. Liu J. Paul, NC State University of USA. Disinterested assistances were given by professor Zheng Quan'an, University of Maryland, USA, professor Li Yan, Xiamen University, and Yin Ping, Senior Research Scientist of FIO during - preparing this book. Dr. Yu Hua has worked on the graphics, a part of translation for this book. We express our heartfelt thanks to them. We are indebted also to the National Natural Science Foundation of China, the Ministry of Science and Technology of China and the State Oceanic Administration of China for their support. Special thanks must be offered to the French chief scientist, Dr. S. Berné participating in two cruises under the China – France collaborative study program and IFREMER France.

This book is a sum - up of relevant studies by authors for more than twenty years that include the achievements of two China - France collaborative study projects and the research results based on many relevant domestic and foreign literatures on tidal deposition. It is hoped that this book will be helpful to the professionals engaged in scientific research, teaching and marine exploitation in this field.

Valuable comments and criticisms on any negligence and mistake in this book are earnestly requested.

Liu Zhenxia and Xia Dongxing
May 2004 in Qingdao

A Summary of *Tidal Sands in the China Seas*

Since the postglacial period, the tidal current has become the most important and active dynamic force in the continental shelves and played a heading role in the submarine deposition process and geomorphology development. In this book, the deposition features, depositional process and geomorphic evolution of tidal sands on the continental shelves and in the estuaries of China are expounded on the basis of topography, deposition, tidal current and other dynamic elements. The topics include the relationship between tidal dynamics and tidal bedforms; the characteristics and material source of tidal deposition; the classification and formation mechanisms of submarine sand ridges; and the offshore tidal deposition models in the postglacial period. 6 tidal deposition systems and sand ridges in tidal deltas and estuaries in the China seas are depicted in detail. Tidal deposition systems are located on the eastern Huanghai (Yellow) Sea, the eastern Bohai Sea, off the Changjiang (Yangtze) River mouth, off the Taiwan coast, around the Hainan Island, and the continental shelf of the East China Sea. The leading role of tidal current in the nearshore and offshore deposition of China since the postglacial sea level rise are emphasized. The close relation of tidal deposition with marine engineering and exploitation is pointed out.

The main conclusions of this book are as follows:

(1) The first leading factor affecting the tidal deposition is the tidal current force. The tidal current nature and the magnitude of current speed directly determine the type of tidal deposition. When the tidal current speed is greater than 3 knots, the predominant tidal current action is erosion to form deep scour channels. When the tidal current speed is in the range of 1 to 3 knots, the predominant tidal current action is accumulation to form tidal shoal deposition. There are two types of tidal shoal deposition, tidal sand ridge and tidal sand sheet. Their formation depends on the tidal current nature, i. e., the former is mainly formed by reciprocating currents with an absolute value of M_2 tidal current ellipticity less than 0.4, and the latter is mainly formed by rotary tidal current with that greater than 0.4. On the other hand, the tidal sand ridge and the tidal sand sheet generally develop jointly.

(2) The second leading factor is material source. The massive fluvial, lacustrine and aeolian sediments formed in the late Pleistocene and early Holocene low sea level period and the massive loose sediments in the modern and old subaqueous delta areas are reserved on the continental shelf. These sediments are in a hydrodynamic field and easy to be eroded, transported, and redeposited and to be moulded into different tidal sand bodies. Both of sandy tidal deposition and wave deposition are generated in marine high - energy environment, therefore their sediments are generally coarse. The offshore tidal deposits in the China seas are composed mainly of well - sorted fine sands. The Holocene tidal deposits originate mainly from the local and neighboring late

Pleistocene submarine sediments and were formed by redeposition after being eroded and transported by the tidal current. Because the modern tidal deposits originate mainly from the late Pleistocene sediments, these deposits are bound to contain many biological fossils inconsistent with the present environment. For example, the spore pollen assemblage reflects an environment cooler than that at present; the shells are broken, lusterless and calcified; and some brackish water and even terrestrial mammal relict bodies are found in the deposits. Another important feature of modern tidal deposition is that the deposits seem to be generally old or the mixture of ancient and modern sediments. It is concluded that the Liaodong shoal, the Bozhong shoal, and the Yangtze shoal are typical modern tidal depositions rather than relict depositions.

(3) The sea level changes are important conditions for the tidal sand ridge development. The sand ridges are reserved in the strata as typical transgressive sequence, and have a close relation with the sea level changes. The subsidence of the East China Sea continental shelf (about 30 cm/ka) and the abundant sediment supplies provide a favorable environment for the sand ridges to be reserved in the area. It is shown from the seismic stratigraphic profiles that the tidal sand ridges formed in the transgression oxygen isotope stages 8 – 7 (U10), stages 6 – 5 (U6. 1) and stages 2 – 1 (U2 and U3. 1) are reserved in the East China Sea. This indicates that their formation period roughly corresponds to the 100 ka period of sea – level equilibrium activity.

(4) The bottom sediment distributions of tidal sand ridge on the continental shelves of the China areas are different from those on the West European continental shelves. The modern tidal deposits originate mainly from the late Pleistocene sediments, which result in the characteristics of the Holocene tidal deposition to a great extent. For example, the late Pleistocene sediments on the northwestern European continental shelf are mainly glacial and glacioaqueous sediments with a coarse grain size, therefore, the tidal sand ridges of coarse bottom material are generally formed. The bottom sediment distributions are characterized by the sediment on the crest finer than that on the swale, i. e., the crest sediments are composed of fine sand, medium – fine sand, and the swale sediments are composed of gravel and grit. However, the late Pleistocene sediments on the continental shelves of China seas are mainly relatively fine fluvial, lacustrine and aeolian deposits which mostly form the tidal sand ridges of fine bottom material. The bottom sediment distributions are characterized by the sediment on the crest coarser than that on the swale, i. e., the crest sediments are composed of fine sand and medium fine sand, and the swale sediments are composed of silty sand and clayey silt. As viewed from the grain threshold velocity, the threshold velocity of fine sand and medium fine sand is the lowest, the essences reflected by the two bottom sediment distributions are the same, although their patterns are opposite to each other. This implies that the current speed is larger on the swale than on the crest, which is consistent with the basic geological theory that the strong tidal current erodes the swale and the weak tidal current aggrades the sand crest.

(5) The genesis and development theory of sand ridge and shoal is still at an exploration and hypothesis stage. The theoretical studies in this field cannot predict the size and evolution of different shoals. Among these theories, the prediction for the linear shoal on the open continental

shelf is the best one. Based on the basic geological theory, some geologists have applied the helical current and the dynamic geomorphologic analysis to qualitative interpretation of the phenomenon that the sediments on both sides of sand ridge are transported to the crest to form a clockwise circulation.

(6) The tidal deposition models on the continental shelves of China seas since the postglacial sea level rise can be classified into two types, the strait – shoal model and the common shoal model. The first type of tidal deposition has deeply extending scour strait or channel due to the tidal current erosion. The eroded materials are brought to the lower reaches with a lower current speed to form tidal shoals, hence this type has obvious material source area, namely, the tidal eroding area. The second type of tidal deposition has all shoals and no strait, i. e., this type has no obvious material source area; and its sediments originate from the local and neighboring continental shelf. The reason for the phenomenon is that the rotation of the tidal current in the material source area is too strong to form narrow and long scour channels.

(7) There are six tidal deposition systems on the continental shelves of China seas. Each system is composed of two to four tidal erosion and deposition geomorphic units. The six systems are (a) the eastern Yellow Sea tidal deposition system composed of the western Korea Bay sand ridges, the Kanghwa Bay sand ridges, the sand ridges off the Keum River mouth, the eastern Yellow Sea offshore sand sheet, and the tidal sand ridges northwest of the Cheju Island; (b) The eastern Bohai Sea tidal deposition system composed of the Laotieshan Channel scour trough, the Liaodong Shoal sand ridges and the Bozhong Shoal sand sheet; (c) the tidal deposition system off the Changjiang Estuary composed of the tidal sand ridges off the Jiangsu coast and the Yangtze Shoal tidal sand sheet; (d) the tidal deposition system off Taiwan coast composed of the Taiwan Strait scour trough, the Taiwan Shoal tidal sand ridges, the Penghu Channel scour trough and the Taizhong Shoal sand ridge; (e) the tidal deposition system around the Hainan Island composed of the Qiongzhou Strait scour trough, the eastern shoal sand ridges and the western shoal sand ridges, and offshore tidal deposition southwest of Hainan Island; and (f) the tidal deposition system of the East China Sea continental shelf composed of the East China Sea tidal sand ridges and the East China Sea sand sheet.

(8) The most complete and typical tidal deposition and dynamical geomorphologic system on the continental shelves of China seas has developed in the eastern Bohai Sea. The maximum surface current speed in the Laotieshan Channel is greater than 5 knots, hence the tidal current has strongly eroded the sea bed of the channel; the maximum tidal current speed in the Liaodong Shoal area is in the range of 1.3 to 2.3 knots. The absolute value of the M_2 tidal current ellipticity is less than 0.4, which indicates that the reciprocating current is predominant in the area, so that the linear submarine sand ridges are formed. The maximum tidal current speed in the Bozhong Shoal area is in the range of 1.2 to 1.6 knots. The absolute value of the M_2 tidal current ellipticity is greater than 0.4, which indicates that the rotary tidal current is predominant in this area, so that the raised sand sheet bedform is formed. The Liaodong shoal and the Bozhong shoal are the evolutionary products of the Holocene flood tidal delta. Their material sources origi-

nate mainly from the Laotieshan Channel, and the two shoals resulted from the tidal current erosion, transportation and redeposition. The Holocene marine sedimentary strata in the two shoal areas are over 20 m thick, and the two shoal areas become the modern depositional areas with the fastest sedimentation rate and the thickest sediment in the Bohai Sea other than the Yellow River mouth area.

(9) The tidal deposition system off the Yangtze River mouth is controlled by the strong Pacific tidal wave system. The tidal wave system travels from the southeast and forms large - scale tidal sand ridges and tidal sand sheets. Among them, the tidal sand ridges off the Jiangsu coast are composed of over one hundred linear sand ridges and inter - ridge channels. The radial tidal sand ridges have a fan apex at Qianggang and cover an area of about 30 000 km^2 with an N - S length of over 260 km and an E - W width of over 150 km. The sand ridge extending direction is consistent with the major axis direction of the M_2 tidal current ellipse. The average spring tidal current speed in the sand ridge area is about 2 knots. The absolute value of M_2 tidal current ellipticity is less than 0.4, so that the tidal current is a strong reciprocating current. The maximum flood and ebb tidal current speed in the Yangtze Shoal sand sheet area are in the range of 1.0 to 2.4 knots. The absolute value of M_2 tidal current ellipticity is greater than 0.7, so that the tidal current ellipse is nearly a circle. This sand sheet area is a large M_2 tidal current ellipticity area of the East China Sea. The Holocene marine sedimentary strata in the sand sheet area are 8 to 25 m thick. The transverse bedforms of varying sizes - submarine sand dunes superimpose on 2/3 of sand sheet area (about 20 000 km^2), which indicates that the sand sheet is the product of modern tidal actions. The Yangtze Shoal tidal sand sheet and the sand ridges off the Jiangsu coast together constitute the modern tidal deposition system off the Yangtze River mouth.

(10) Controlled by the Pacific tidal wave system, the sandy deposition on the East China Sea continental shelf is classified into tidal sand ridge facies and tidal sand sheet facies. The East China Sea sand ridges are large - scale deep water sand ridges on open continental shelf, and are mainly constructed in the postglacial transgression period. When the sea level was lower than that at present and rose slowly or was relatively stable, the original tidal sand ridges were formed in the estuary or offshore area. The sea level then continued to rise, the bottom materials were eroded, transported and redeposited under the tidal current actions. The bedform shapes were constantly adjusted, so that the sand ridges gradually lost their initial features and evolved into open shelf sand ridges in equilibrium with the tidal current force. The East China Sea tidal sand ridges are still affected by the modern tidal current and storm surge and belong to the transitional sand ridge between the active sand ridge and the moribund sand ridge, namely, the quasi - active - sand ridge.

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