长江河口动力过程和地貌演变

陈吉余 沈焕庭 恽才兴 等著 上海科学技术出版社

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内 容 简 介

本书由河口发育、河口水文、河口泥沙运动、河口沉积、河口河槽演变、河口治理等六部分组成。采用宏观与微观、历史过程与现代演变、野外观测与实验分析、遥感新技术等研究方法，将河口动力、地貌、沉积等学科紧密结合，全面系统地阐述和总结了长江河口的动力过程与地貌演变，并提出了治理原则和可供选择的治理方案。对河口整治和开发利用有较大的实用价值，同时也丰富了河口学理论。

本书可供水利、航道、水运、海洋、环境、地质、地理和海岸工程等有关科研、生产和教学人员参考应用。

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绪　论

长江全长6300公里，居我国大河首位，世界大河第三位。长江干流先后流经青海、西藏、四川、云南、湖北、湖南、江西、安徽、江苏和上海等十个省（自治区）、市，汇集了大小数百条支流，在黄海与东海的交界处入海；流域面积达180万平方公里，接近全国总面积的五分之一。

长江干流宜昌以上为上游，宜昌至鄱阳湖湖口为中游，湖口以下为下游。自安徽大通（枯季潮区界）向下至水下三角洲前缘（约30～50米等深线）为长达700多公里的河口区。根据动力条件和河槽演变特性的差异，长江河口区可分成三个区段：大通至江阴（洪季潮流界），长400公里，河槽演变受径流和边界条件控制，多江心洲河型，为近口段；江阴至口门（拦门沙滩顶）长220公里，径流与潮流相互消长，河槽分汊多变，为河口段；自口门向外至30～50米等深线附近，以潮流作用为主，水下三角洲发育，为口外海滨。

长江河口是由漏斗状河口演变而成。约在6000～7000年前，长江河口为一溺谷型河口湾。湾顶在镇江、扬州一带。2000多年来，由于大量流域来沙的充填，河口南岸边滩平均以40年1公里的速度向海推进，北岸有许多沙岛相继并岸，口门宽度从180公里束狭到90公里，河槽成形加深，主槽南偏，逐渐演变成一个多级分汊的三角洲河口。

长江河口水量丰沛。据大通站资料，最大流量92600米^3/秒（1954年），最小流量4620米^3/秒（1979年），年平均流量29300米^3/秒，年径流总量9240亿米^3，在世界大河中流量次于亚马孙河、刚果河、奥里诺科河、恒河—布拉马普特拉河，居第五位。径流量有明显的季节性变化，5～10月为洪季，占全年的71.7%，以7月为最大；11～4月为枯季，占28.3%，以2月为最小。

长江的含沙量年平均值0.547公斤/米^3，由于水量大，年平均输沙量达4.86亿吨（实测最大输沙量6.78亿吨，最小输沙量3.41亿吨），在世界上次于恒河—布拉马普特拉河、黄河、亚马孙河，居第四位。沙量在年内的分配比水量更集中，洪季输沙量约占全年的87%，7月输沙量最大，约占全年的21%，2月输沙量最小，不足全年的0.7%。河口段由于受涨落潮流影响，悬沙的年内分配比较均匀，与径流量大小的关系不甚密切，大通站悬沙粒径小于0.1毫米的占94.9%，中值粒径为0.027毫米。河口段悬沙中值粒径约0.019毫米。

长江口是中等强度的潮汐河口。口外为正规半日潮，口内为非正规半日浅海潮。南支潮差由口门往里递减，口门附近的中浚站多年平均潮差为2.66米，最大潮差为4.62米，至黄浦江口的吴淞站多年平均潮差减低为2.21米。北支呈喇叭形，潮差比南支大，由口门往里逐渐递增，在永隆沙至青龙港河段有涌潮现象，涌潮高度可达1米。由于科氏力等因素的作用，北岸潮差要比南岸大，据实测资料，南港北岸潮差一般要比南岸大40～50厘米。

潮流在口内为往复流，一般为落潮流速大于涨潮流速。出口门后逐渐向旋转流过渡，旋转方向多顺时针向。在上游径流接近年平均流量，口外潮差近于平均潮差的情况下，河口进潮量达266300米^3/秒，为年平均流量的8.8倍。进潮量枯季小潮为13亿米^3，洪季大潮达53亿米^3。口门潮波传播方向约305°。受到径流、地形等诸因素影响，潮位与潮流过程线存在一定

的位相差，一个潮周期过程中有涨潮涨潮流、落潮涨潮流、落潮落潮流、涨潮落潮流四个阶段。

长江口盐水入侵距离因各汊道断面形态、径流分流量和潮汐特性不同存在较大差异。北支盐水入侵距离比南支远。盐水入侵界枯季一般可达北支上段和南支中段，洪季一般可达北支中段，南支在拦门沙附近。在特定枯水与大潮组合下，北支盐水入侵可达南北支分流口，在特定洪水与小潮组合下，南支拦门沙以内可全为淡水占据。盐淡水混合类型北支以垂向均匀混合型为主，在南支口门附近，除枯季大潮出现垂向均匀混合型，洪峰流量大又遇特小潮差时出现高度成层型外，全年以部分混合型出现机率最多。

长江口的余流比较复杂。在南支、北支、南港和北港上段，余流流向和强度主要取决于径、潮流的力量对比和潮波变形程度，落潮槽中的余流与落潮流流向一致，涨潮槽中的余流与涨潮流流向一致，导致在平面上产生逆时针向的环流。在南槽、北槽和北港下段，受盐水楔异重流的影响，在纵向上存在上层流净向海，下层流净向陆的河口环流。在滞流点附近，最大浑浊带其范围约25～46公里，含沙量表层变化于0.1～0.7公斤/米^{3}之间，底层变化于1～8公斤/米^{3}间，洪季小潮时常有浮泥出现。口外海滨的余流，上层以东向为主，中层多偏北，底层有偏西趋势，径流是上层余流的重要组成部分，中下层余流则与台湾暖流的顶托与牵引有关。

长江口外流系有台湾暖流、东海沿岸流和苏北沿岸流。台湾暖流具有高温、高盐、透明度大以及夏强冬弱的特点，夏季盐度在34.0～34.7‰、温度在20～28℃之间，冬季盐度在33.0～34.6‰、温度在10～17℃之间。苏北沿岸流具有低温、低盐、透明度小以及冬强夏弱的特点，大约在33°N122°30′E附近，它渗入黄海冷水团范围内，并向东南伸展。夏季，台湾暖流增强，苏北沿岸流减弱，长江冲淡水在口门附近先顺汊道方向流向东南，约在122°30′E左右转向东或东北，冲淡水的影响最远时可达济州岛附近。冬季，台湾暖流减弱，苏北沿岸流增强，长江冲淡水沿岸南下，成为东海沿岸流的主要组成部分。

长江口的波浪以风浪为主，涌浪为次。风浪浪向的季节性变化十分明显，冬季盛行偏北浪，夏季盛行偏南浪，春秋两季为过渡季节，各向频率较为分散。涌浪以偏东浪为主，其他方向很少出现。波高从口门向口内逐渐降低，口门引水船站平均波高0.9米，最大波高6.2米，平均周期3.9秒。口内80公里的高桥站平均波高0.4米，最大波高2.3米，平均周期1.7秒。

长江口自徐六泾以下，河槽出现有规律地分汊。在科氏力作用下，长江口存在明显的落潮流偏南，涨潮流偏北的流路分异现象。在涨落潮流路之间的缓流区，泥沙容易淤积形成心滩沙岛，促使水道分汊。在徐六泾以下先被崇明岛分为南支和北支，南支在浏河口以下又被长兴岛和横沙岛分为南港和北港，南港在九段以下又被水下沙坝——九段沙分为南槽和北槽，从而形成三级分汊四口入海的形势。

在径流与潮流两股强劲动力的作用下，河口段河床冲淤多变，主槽摆荡频繁。18世纪中叶长江主流重归南支后，北支日益淤浅，主槽水深不足5米，已失去大轮通航价值，由于进入北支的径流量减少，潮流作用相应增强，使其成为涨潮流占优势的涨潮槽，在径流量小和潮差大时有水、沙、盐倒灌入南支，影响南支水质和河势稳定。南支是排泄长江径流的主要通道，河面宽阔，多水下沙洲和浅滩通道，在以落潮流占优势的涨落潮流共同作用下，河槽演变复杂，特别是在其下段南北港分流口附近，滩槽演变甚为剧烈。介于南北支之间的崇明

岛是由一系列沙洲合并而成，长期来南坍北涨，有向苏北并岸的趋向。

南、北港的径流分配较为接近，北港径流分配变化在36.6～65.3%之间，南港径流分配变化在34.7～63.4%之间，1958年后，北港的分流量大于南港。南、北槽的径流分配与南、北港大致相似，南槽径流分配变化在35.8～67.6%之间，北槽的径流分配变化在32.4～64.2%之间，1965年以来，北槽的分流量大于南槽。由于南港与北港，南槽与北槽的径流分配较为接近，从而使它们的主次关系易于更迭。1842年南港为上海港的通海航道，1870年后因南港水深恶化，辟北港为主航道，1927年北港上口淤浅，通海航道又被迫走南港。

四条入海汊道均存在航道拦门沙，北支的拦门沙深居口内，南槽、北槽和北港的拦门沙都位于口门附近。拦门沙是长江口主要的泥沙沉降区，滩顶水深除北支外，一般在6米左右，多年来比较稳定。这样的自然水深在世界许多河口拦门沙中尚属优良，但却存在滩长、坡缓、变化复杂的特点。在径流、潮流、盐淡水异重流等多种因素作用下，拦门沙有洪季淤，枯季冲，小潮淤，大潮冲的变化规律。南槽铜沙浅滩是长江河口最大的航道拦门沙、水深不足7米的滩长有25公里左右，不足10米的滩长达60余公里，成为通海航道的天然障碍。长江口通海航道近50多年来取用南港南槽，1975年将南槽拦门沙水深由6米浚深到7米，1979年后挖槽维护日益困难，1983年又改在北槽开挖了7米航槽。

在长江口外有一面积约1万多平方公里的水下三角洲，其上端为拦门沙滩顶，下界水深约30～50米，北面与苏北浅滩相接，南面越大戢、小戢叠复在杭州湾的平缓海底之上。水下三角洲的组成物质，以30°20′N为界，北部较粗，南部较细，前沿与陆架残留沙相接。据100多年来海图对比分析，水下三角洲是在冲淤不断变化过程中逐渐向海推展，1860年至1927年的主要淤积区在崇明东滩外侧，1927年至1976年的主要淤积区在南汇东滩外侧，沉积速率很快。北港口外和横沙东滩外海，淤积速度较慢，相对比较稳定。

长江每年入海离子径流量为14823万吨，占全国入海总离子径流量的43%。长江流域来沙除有50%以上在口门附近沉积外，还有相当数量输向外海。从含沙量分布和悬沙组成看，自122°30′E向东含沙量显见减小，粒径大于50微米的石英和碳酸盐颗粒以及粒径大于60微米的云母、絮凝体和有机体，一般扩散至122°30′E附近，再往东，粒径和数量急剧减小，可见，122°30′～123°E间是长江悬沙向东扩散的一条重要界线，它大致与水下三角洲的前缘相吻合。入海泥沙主要向东偏南向扩散，成为杭州湾和浙江沿海细颗粒泥沙的重要来源之一。

长江是世界上少数几条具有优越通航条件的江河之一，万吨海轮可以自河口直达南京港，素有“黄金水道”之称。长江口扼长江的咽喉，是我国最大的港口——上海港的门户，1985年上海港的年吞吐量达1.1亿万吨。目前在长江口南支下段南岸，除已建的宝山钢铁厂外，尚有许多重要的企业正在或将要兴建。长江自南京港以下尚有镇江港、张家港、南通港等港口均在不断开发扩展。长江口两岸有丰富的滩涂资源，可逐步开发促淤围垦。河口的输出物被带往浩森海域，为鱼类索铒提供丰富的营养盐类，使长江口外及其邻近海域成为我国最大的渔场。由此可见，长江口的开发利用对促进长江流域，特别是上海经济区的工农业生产以及对外贸易，发展江海联营，具有极其重要的意义。

然而，河口发育过程也给建设事业带来一些不利影响。长江河口有拦门沙存在，航槽水深不足，河槽多变与阴沙迁移使航槽稳定性受到威胁，河口水流变异和强浪拍岸引起的侵蚀作用给岸滩防护带来不利影响，为着稳定河槽，增深航道，护岸保滩，围垦土地，就需要对

长江河口进行深入研究。另一方面，河流中上游的大型工程措施往往会改变河口区的自然平衡，从而产生一些自然调节，有时也给河口带来巨大影响，此在世界上其他河口如尼罗河口等已经有所反映，这种现象尤应引起我们的注意。南水北调、三峡工程等一些重大水利建设一旦实施后，长江河口的河槽以至生态与环境将会发生怎样的变化，它对长江河口自然资源有何影响，这些问题也必须通过对长江河口的深入研究，提出预报，采取相应的措施，使河口的生态、环境和资源免遭破坏。

对于水面辽阔、流域来水来沙非常丰富、进出潮量巨大的长江河口，在现代科学发展以前，要进行深入系统的研究是有所困难的。虽然如此，我国丰富的历史记载，还是为长江河口研究提供了有价值的史料。枚乘《七发》和郭璞《江赋》生动地描述了历史时期长江河口水文条件的变化，六朝的历史记载反映了长江河口增水影响的范围，各种史料以及地方志记载着三角洲海岸向海推展与河口缩窄过程的历史事实。19世纪40年代，长江河口有了用近代技术测量水深的水道图件，19世纪50年代开始，长江有了连续的水位记录。20世纪以后，长江河口区陆续设立了水位站和验潮站。1915年长江口进行了首次水文测验，瑞典人海德生根据这些水文资料对长江河口的潮波传播、水文、泥沙运动进行了较系统的然而是初步的研究。此后，直至40年代末，长江河口研究除对水下地形有过一些测量图件外，其他方面的科学研究则很少进展。

新中国成立以后，特别是1956年提出全国自然科学十二年规划后，开始了长江河口研究的新阶段。1957年中国科学院在南京组织了河口学报告会，同年7月，华东师范大学成立了河口研究室。1958年华东师范大学地理系全体师生对长江三角洲进行了全面调查，其中包括南京至吴淞之间河槽演变的调查研究，从而对长江河口发育过程有了一定的认识。同时，由上海航道局（当时称上海河道局）组织了南京水利科学研究所和华东师范大学等单位对长江河口有计划有步骤地进行大规模的水文测验、沙岛调查、河口动力地貌调查、拦门沙地区打钻以及盐淡水混合与河槽演变研究等，此外华东师范大学河口研究所还曾在长江口建立了定位观测站，为长江河口研究积累了大量第一性资料，对长江河口的动力特征、地貌过程、沉积现象、河槽演变特性及河口发育规律等有了比较全面的认识，为进一步深入研究打下了基础。

1972年周总理发出了“三年改变我国港口面貌”的号召，长江口航道治理第一期工程被列为重点建设项目之一，长江河口研究从资料积累阶段上升到规律性的研究并与生产实践密切结合的阶段。1973年起，在交通部上海航道局组织下，围绕拦门沙航道的浚深和深水航道选槽，华东师范大学河口海岸研究所对长江河口的动力条件、泥沙运动、河槽演变、沉积特性等作进一步系统调查和规律性探讨，研究了河口潮波传播、潮流和余流特性、盐淡水混合、最大浑浊带与浮泥运动、河口环流、泥沙输移及其在口外扩散现象，同时对江阴河段、福姜沙河段、南通河段、北支、南支、中央沙河段、北港、南港、北槽和南槽等的河槽演变的过程与规律逐段地进行了分析；对粒度分布、絮凝作用、重矿物和粘土矿物的组成与分布特征、拦门沙的沉积结构以及水下三角洲的发育进行了研究；并对长江河口过程总结出其发育的基本模式。从1981年开始的上海市海岸带和海涂资源综合调查，取得了丰富的调查资料，并应用遥感新技术，使我们对长江河口的认识又向前跨了一大步。

华东师范大学河口海岸研究所和上海航道局、南京水利科学研究院、华东水利学院、杭州大学等单位通过多年的协作研究，已系统掌握长江河口的基本情况，对河口水文、泥沙、沉积和

河槽演变的基本规律已经基本了解。长江河口研究在生产实践中已发挥了作用，如－7米通海航道选槽、上海新港区选址、南支河段治理方案、崇明宝山护岸保滩、排污口选址、南通河段治理、张家港扩建、七二八工程、九五工程和交通部澄西船厂选址、南水北调与三峡工程对长江河口影响等，都离不开长江河口研究提供的科学依据。

现就本所三十年来对长江河口的主要研究成果，按学科体系汇总成《长江河口动力过程和地貌演变》一书，目的是将我们的研究成果作系统汇集，以供水利、水运、海洋、地质和地理等有关部门、专业的科研、生产和教学人员参考应用。全书分六个部分：

第一部分为河口发育，从地质地貌的宏观角度阐述了长江三角洲的地貌发育过程和河口发育的模式；

第二部分为河口水文，对河口潮波、潮流、余流、盐淡水混合、环流、波浪、增减水和海面变化等水文因子逐个进行了分析，并探讨了它们与河槽演变的关系；

第三部分为河口的泥沙运动，着重讨论了悬沙的输移特性、最大浑浊带和浮泥的成因与变化规律、细颗粒泥沙的界面化学、滩槽泥沙交换以及入海悬浮泥沙的扩散；

第四部分为河口沉积，对长江三角洲的第四纪地质和新构造运动、长江口全新世的沉积层序、孢粉组合和微体化石群特征和沉积物粒度分布与水动力的关系等进行了研究；

第五部分为河口河槽演变，对江阴以下的一些河段，如福姜沙河段、南通河段、南支、北港、南北槽分汊口河段等的河槽演变过程与规律逐段进行了分析；

第六部分为河口治理，除阐明长江河口的治理原则和治理中的关键问题外，还对入海航道选槽、南支河段治理等提出了可供选择的方案。

应予指出，河口学是一门新兴科学，目前尚处在一个不很成熟的发展阶段。长江河口又是一个大而复杂的河口，对它的研究无论在深度上和广度上都有待我们进一步努力。

陈吉余　沈焕庭　恽才兴

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Processes of Dynamics and Geomorphology of the Changjiang Estuary

Chen Jiyu Shen Huanting Yu Caixing et al.

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INTRODUCTION

The Changjiang river(Yangtze river) , 6,300 km long, is the largest river in China, and the third largest river of the world. The main stream of the Changjiang river, passed through Qinhai , Xizang , Sichuan, Yunnan, Hubei, Hunan, Jiangxi, Anhui, Jiangsu provinces (including an autonomous region) and Shanghai Municipality etc. and converged hundreds of tributaries big or small, empties into the sea at the junction of the Yellow and East China Seas. The drainage basin covers about 1,800,000 km^2 in area, which is about 1/5 of the total area of the whole nation.

The main stream of the Changjiang can be divided into three sections : the upper reach from Yichang to the river's source, the middle reach from Yichang to the mouth of the Panyang Lake, and the lower reach downstream from the mouth of the lake. The length of the estuary from Datong (the upper limit affected by tides during dry seasons), Anhui Province, to the front of the submerged delta (corresponds to 30~50 m isobath) is about more than 700 km long. The Changjiang estuary also can be divided into three sections : the reach from Datong to Jiangyin (the upper limit of tidal current during flood seasons), about 400 km of its length, where the river channel evolution is controlled by runoff and boundary conditions, and there are many middle-ground sands in the river channel, is called the near-estuarine reach (Jinkouduan in Chinese) ; the reach from Jiangyin to the mouth (at the head of mouth bars), 220 km in length, where the runoff and tidal current interacts with each other, and the river channel and its bifurcations are unstable, is named the estuarine reach (Hekouduan in Chinese); and the reach from mouth to nearby 30~50 m isobath, in which it is controlled mainly by the tidal current and the submerged delta is well developed, is called the offshore area.

The Changjiang estuary is a funnel-shaped estuary. About 6,000~7,000 years ago, the Changjiang estuary was a drowned river valley, and the head of the estuary was situated in the zone of Zhenjiang or/and Yangzhou. The averaged rate of expanding seaward of the south bank is 1 km each 40 years during the last 2,000 years. The sand bars were attached into the north bank, thus the width at the mouth narrowed from 180 km to 90 km. The regular rivermouth was formed and the river channel was deepened, the main channel was deflected southward, and then the deltaic estuary with multi-order bifurcations was formed gradually.

The water discharge of the Changjiang estuary is plentiful. The maximum discharge was 92,600 cubic meters per second (in 1954) and the minimum discharge was 4,620 cubic meters per second (in 1979). The yearly averaged discharge was 29,300 cubic meters per second, and the annual total runoff is 924,000 million cubic meters based on the data at Datong Station, which ranks the fifth in discharge among the largest rivers of the world and is only lower than the rivers of the Amazon, Cango, Orinoco and Ganges-Brahmaputra. The runoff has obvious change with seasons. The period from May to October is the flood seasons when the runoff amouts to 71.7% of the annual total discharge and the maximum occurs in July. The dry seasons are from November to April next year when the runoff amounts to 28.3% of the annual total discharge and the minimum value occurs in Febuary.

The annually averaged value of the suspended sediment concentration is 0.547 kg/m^3, and its annually averaged sediment discharge reaches to 486 million tons (the maximum sediment discharge measured is 678 million tons, and the minimum is 341 million tons), which ranks the fourth after the Ganges-Brahmaputra, Yellow River, and Amazon among the largest rivers of the world. The distribution of sediment discharge is more concentrated than that of the water discharge in a year. The sediment discharge during the flood seasons amounts to 87% of the annual total value. The sediment discharge in July is the largest, which amounts to 21% of the annual total, and the minimum value occurs in Febuary, which is less than 0.7% of the annual total value. The suspended sediments distribute rather homogeneously in the estuarine reach due to effects of the flood and ebb currents, which are related not closely with the runoff. The grain size less than 0.1 mm of the suspended sediments amounts to 94.9%, and the medium size is 0.027 mm at the Station of Datong. The medium size in the estuarine reach is about 0.0086 mm.

The Changjiang estuary is a mesotidal estuary. There exist the regular semi-diurnal tides out of the mouth, and non-regular semi-diurnal tides inside. The tidal range of the South Branch is reduced upstream from the mouth. The average tidal range for years at Zhongjun Station nearby the mouth is 2.66 m, and the maximum is 4.62 m. The tidal range at the Wusong Station nearby the mouth of the Huangpu River is 2.21 m. The channel of the North Branch is trumpet-shaped, the tidal range is larger than that of the South Branch, and trends to be increasing gradually upstream from the mouth. The bore phenomenon occurs at the reach between the Yonglong Sand and Qinglonggang, and the height of the bore can reach 1 m. The tidal range of the north bank is larger than that of the south bank due to the action of the Coriolis force and other factors. In general, the tidal range at the north bank of the South Channel is higher 40~50 cm than that at the south bank according to the measured data.

The tidal current moves back and forth inside of the mouth, and is transformed into the rotary tidal current out of the mouth. The rotary direction is most clockwise. In general, the velocity of the ebb current is larger than that of the flood current. The tidal prism in the estuary reaches 266,300 cubic meters per second, which is 8.8 times of the annual averaged discharge when the tidal range out of the mouth is closed to the averaged tidal range and the runoff from the upper reach approaches to the annual averaged discharge. The tidal prism is 1,300 million cubic meters at neap tides during the dry seasons, and 5,300 million cubic meters at spring tides during the flood seasons. The direction of the tidal wave propagation is about 305° at the mouth. The curves of the tidal level and current have the phase difference under actions of the runoff, the topography and other factors. There are four stages within a tidal period: the flood current of the flood tide, flood current of the ebb tide, ebb current of the ebb tide, and ebb current of the flood tide.

The distances of saltwater intrusion in the Changjiang estuary have great differences due to the section shape, the runoff diversion and the tidal characteristics of the different bifurcations. The saltwater in the North Branch intrudes farther than that in the South Branch. In general, the limit of saltwater intrusion can reach to the upper section of the North Branch and the middle section of the South Branch during the dry seasons, and during the flood seasons it can reach to the middle section of the North Branch and to the mouth bars in the South Branch. Under the special dry water with the spring tide, the saltwater intrusion of the North Branch can reach to the mouth of the current diversion between the South and North Branches. The fresh water is filled within the mouth bars of the South Branch under the special flood water with the neap tide. The mixing of the saltwater and freshwater in the North Branch is quite homogeneous in vertical, and the same phenomenon can not be seen nearby the mouth of the South Branch, except at spring tides during the dry seasons. The probability of partially mixed estuary occurs in the most whole year, and the highly stratified pattern appears when the large discharge of the flood peak occurs and the tidal range is very small.

The residual flow of the Changjiang estuary is quite complicated. The strength and the direction of the residual flow depends mainly upon the comparison of the runoff with the tidal current, and the degrees of the tidal wave distortion in the upper reaches of the South and North Branches and of the Sonth and North Channels. The direction of the residual flow within the ebb channel corresponds to the ebb current and the direction of the residual flow within the flood channel corresponds with the flood tidal current, which results in the counter-clockwise circulation. In the lower reaches of the South and North Passages and of the North Channel, there exists an estuarine circulation with the upper layer flowing seaward and the landward flowing of the lower layer, which is affected by the saltwater wedge in plane. The turbidity maximum lies nearby the null-point and extends about 25~46 km long. The variation of the suspended sediment concentration at surface is 0.1~0.7 kg/m^3, and at the bottom layer is 1~8 kg/m^3. There often appears the fluid mud at neap tides during flood seasons. The direction of the residual flow in the offshore zone is mainly eastward at surface, northward by north in the middle layer, and trends to be westward by west in the bottom layer. The runoff is the major part of the residual flow in the upper layer, and the residual flow in the middle and bottom layers are related to the Taiwan Warm Current and its traction force.

The current systems out of the Changjiang estuary have the Taiwan Warm Current, the East China Sea's longshore current and the northern Jiangsu's longshore current. The features of the Taiwan Warm Current are as follows: high-temperature, high-salinity, good-transparency, and weaker in winter and stronger in summer. The salinity varies in the range of 34.0~34.7‰ and the temperature is 20°~28℃ in summer, and in winter the salinity is 33.0~34.6‰ and temperature is 10°~17℃. The following characteristics of the northern Jiangsu's longshore current are: low-temperature, low-salinity, poor-transparency, and stronger in winter and weaker in summer. It penetrates into the scope of the Yellow Sea cool water mass in latitude 33°N and in longitude 122°30′E, and expands southeastward. In summer, the Taiwan Warm Current strengthens and the northern Jiangsu's longshore current weakens, the diluted water of the Changjiang moves at first southeastward along the bifurcations nearby the mouth, then flows eastward or northeastward at 122°30′E, and the fartherest effects of the diluted water can reach nearby the Jizhou Island (Korea). In winter, the Taiwan Warm Current weakens and the northern Jiangsu's longshore current strengthens, the diluted water of the Changjiang flows southward along the coast, and becomes the major parts along the coasts of the East China Sea.

The waves of the Changjiang estuary are mainly the wind-driven waves, and secondly are swell. The direction of wind-driven waves changes very obviously with seasons, and the wave with the northward direction prevails in winter, and the southward wave prevails in summer. The spring and the autumn are the transition seasons, and the frequency in different directions disperses greatly. The swell is mainly the eastward waves, and seldom appears in other directions

The wave height decreases upstream from the mouth. The averaged wave height of the Yinshuichuan at the mouth is 0.9 m, the maximum height is 6.2 m, and the averaged period is 3.9 seconds. The averaged wave height of the Gaoqiao Station 80 km from the mouth is 0.4 m, the height maximum is 2.3 m, and the averaged period is 1.7 seconds.

The river channel of the Changjiang estuary downstream from Xulujing is characterized by the regular bifurcations. The phenomenon of the route divergence of the flood and ebb currents is obvious in the Changjiang estuary, the direction of the ebb current deflects the south by south, and the flood current deflects the north by north under actions of the Coriolis force. The sediments deposit easily within the zone between the routes of the flood and ebb, and the middle-ground sands are formed, thus promoting the channel bifurcations. Downstream from Xulujing the estuary is divided first into the North and South Branches by the Chongming Island, the South Branch downstream from Liuhe rivermouth is divided into the North and South Channels by Changxin and Hengsha islands, and finally the South Channel is branched into the North and South Passages downstream from Jiuduansha. So the situation of the three-order bifurcations and four outlets into the sea was formed.

The channel bed changes easily and the main channel swings frequently in the estuarine reach under actions of the two forces : the runoff and the tidal current. At the middle of the 18th century when the main stream of the Changjiang returned to the South Branch, the North Branch is shallowed gradually, and the water depth of the main channel is less than 5 m where large ships can not navigate. The North Branch becomes a flood channel dominated by the flood current because the runoff into the North Branch decreases and the tidal current strengthens. The water and sediments return to the South Branch when the runoff is small and tidal range is large, which affects the water quality and the channel stability of the South Branch. The South Branch is the main passage discharging the runoff of the Changjiang river, in which the water surface is wide and there exist many sands as well as shoals underwater. The river channel evolution is complicated under actions of flood and ebb currents with the dominant ebb current, especially nearby the outlet of current diversion of the South and North Channels downstream where the shoals and channels change severely. The Chongming Island between the South and North Branches was formed by a series of sands, and has the tendency of the erosion at south and the growing at north as well as attaching into the northern Jiangsu in future.

The runoff distribution of the South and North Channels approaches to each other, i.e., the North Channel is in the range of 36.6~65.3% and the South Channel is in the range of 34.7~63.4% of the runoff. The discharge diversion of the North Channel is larger than that of the South Channel since 1958. The runoff distribution of the South and North Passages approximates to that of the South and North Channels, i.e., the South Passage is in the range of 35.8~67.6% and the North Passage is in the range of 32.4~64.2% of the runoff. Since 1965, the discharge diversion of the North Passage is larger than that of the South Passage. The relationship of the runoff distribution alternates between the South and North Channels and the South and North Passages due to the approximate quantity. The South Channel was the main waterway for the Shanghai port in 1842, the North Channel became the main waterway due to the depth of the the South Channel shallowed after 1870, and in 1927 when the upper outlet of the North Channel shallowed, the waterway into the sea returned back to the South Channel.

There are mouth bars on the navigable waterway of the four bifurcations. The mouth bars in the North Branch are situated in the inner of it, and the mouth bars in the South and North Passages as well as in the North Channel are situated nearby their mouths. The area of the mouth bars is the major place for the sediment settling in the Changjiang estuary. In general, the water depth to the top of the sands in the mouth bars regions is about 6 m, and it is stable for a long time, except in the North Branch. Such natural depth in the mouth bars regions is rather good conditions in the world. However, it has the following characteristics: the sands is long, the slope is gentle, and its variation is complicated. The mouth bars change with seasons, it is silted during the flood seasons and eroded during the dry seasons as well as it is silted at neap tides and eroded at spring under actions of the runoff, the tidal current, and the density current of the salt- and fresh-water. The Tongsha sand is the largest mouth bar of the waterway in Changjiang estuary. The length less than 7 m in depth is about 25 km, and the length less than 10 m of the water depth is more than 60 km. It is the natural barrier of the waterway into the sea. The South Channel and the South Passage is used as a waterway of the Changjiang estuary into the sea for more than 50 years. The water depth in the mouth bars regions of the South Passage was dredged from 6 m to 7 m in 1975, and since 1979 it has been so difficult to maintain the dredging channel depth that the 7-m deep waterway was dredged in the North Passage in 1983.

There is a submerged delta out of the Changjiang estuary, which is about more than 10,000 square kilometers in area. Its upper end is the apex of the mouth bars and the depth of the lower edge is about 30~50 m. It borders on the northern Jiangsu in the north and superimposes the gentle seabed of the Hangzhou Bay across the Daji and Xiaoji islands. The materials composed of the submerged delta are coarser in the north and finer in the south, and their border is nearby the latitude of 31°20′N. The frontal edge is joined with the residual sands of the shelf. The submerged delta progresses seaward gradually with the variations of the siltation and erosion according to the comparison of the charts during the last 100 years and more. The major siltation area from 1860 to 1927 is situated at the outside of the east bank of the Chongming Island, and from 1927 to 1976 the area is located at the outside of the east bank of Nanhui, and the deposition rate is very fast. However, at the outside of the mouth of the North Channel and of the east bank of Hengsha Island the deposition rate is so slower that it is relatively stable.

The ion discharge of the Changjiang river each year is 148.23 million tons, that amounts to 43% of the total ion discharge. The sediments more than 50% from the Changjiang drainage basin deposited nearby the rivermouth, and a large amount of sediments were transported into the sea. It can be seen, from the sediment concentration distribution and the suspended sediment composition, that the content is reduced obviously eastward from 122°30′E. The quartz more than 50 μ of the grain size, the carbonates and the mica, floc and organism more than 60 μ of grain size are extended in the vicinity of 122°30′E, and farther to the east, the grain size and quantity are reduced rapidly. It can be seen from this that the area between 122°30′E and 123°E is an important border for the eastward diffusion of the suspended sediments from the Changjiang river. It corresponds to the front of the submerged delta. The sediments discharging into the sea diffuse in the direction of the east by south, that is an important source for the fine sediments of the Hangzhou Bay and along the coasts of the Zhejiang province.

The Changjiang river is one of the several rivers with good navigation conditions in the world, namely "Golden waterway", in which 10,000-ton ships can go directly to Nanjing, Jiangsu province. The Changjiang estuary is the throat of the river, and the gate of the Shanghai port — the larest port in our country. The Shanghai port can handle up to 110 million tons of cargoes in 1985. At present, there are many important enterprises underconstructed or to construct in future in the south bank of the lower South Branch except for the completion of the Baoshan Steel and Iron Complex. There are underdeveloping harbors of Zhenjiang, Zhangjiagang, Nantonggang downstream from the Nanjing harbor in the Changjiang river. The abundant beach resources both sides of the river can be developed gradually to be reclaimed into land. The output of the river is carried through the estuary into the open sea, which provides an abundant nutritious materials for fish. For reasons given, the sea regions out of and nearby the Changjiang estuary become the largest fishing areas in China. It may be seen that the development and utilization of the Changjiang estuary have important meaning to promote the production of industries and agriculture, and foreign trade, and the development of the river- and ocean- coordinated transport of the Changjiang drainage basin, especially in the Shanghai economic region.

The construction causes, however, are also affected by the estuarine processes, that is, there are the mouth bars in the Changjiang estuary, the depth of the waterway is insufficient, the river channel changes frequently and shoals underwater migrate, thus threatening the waterway's stablization and resulting in the harmful effects on the protection of the shore and beaches due to the variance of the estuarine flow and erosion by the strong wave. For stablizing the river channel, protecting the shore and beach, and reclaiming the land from the sea, it is necessary to make a thorough investigation and to study comprehensively. In the other hand, the large-scale engineering measures in the middle or/and the upper reaches of the river often reform the natural balance in the estuarine area. The natural adjustment occurs and sometime it may give tremendous effects to the estuary. So, it is worth noticing the phonomenon having occured in other estuaries in the world, such as the Nile estuary. What may be happened about the estuarine channel, ecology and environments as well as natural resources of the Changjiang estuary after construction of some important water conservancy projects, such as the "south-to-north water transfer" and "Three Gorges Dam"? The problems mentioned above all want to propose the situation-forecasts and take the corresponding measures through the deeply study on the Changjiang estuary, so that the estuarine ecology, environments and resources destruction can be avoided.

It would be much trouble to study deeply and systematically such a large estuary as the Changjiang estuary before the modern sciences development because the Changjiang estuary is so wide, the sediments and water from the drainage basin is very abundant and the in- or out-tidal volume is so vast. However, there are some valuable historical records of the Changjiang estuary in the China's history. The variation of the hydrologic conditions of the Changjiang estuary in history was described in the books, namely "Qifa" written by Mei Cheng and "Jiangfu" written by Guo Po. The historic records of the Six-Dynasty showed the extent of the surge in the Changjiang estuary. Many historical facts of the deltaic coasts extanding seaward and narrowing processes of the estuary were recorded in the various historical data and local history (Difangzhi). In the 1840's, the Channel charts of the Changjiang estuary were measured using the modern techniques.