EXPERIMENTS AND SIMULATIONS
IN GEOMORPHOLOGY

地貌实验与模拟

金德生 主编

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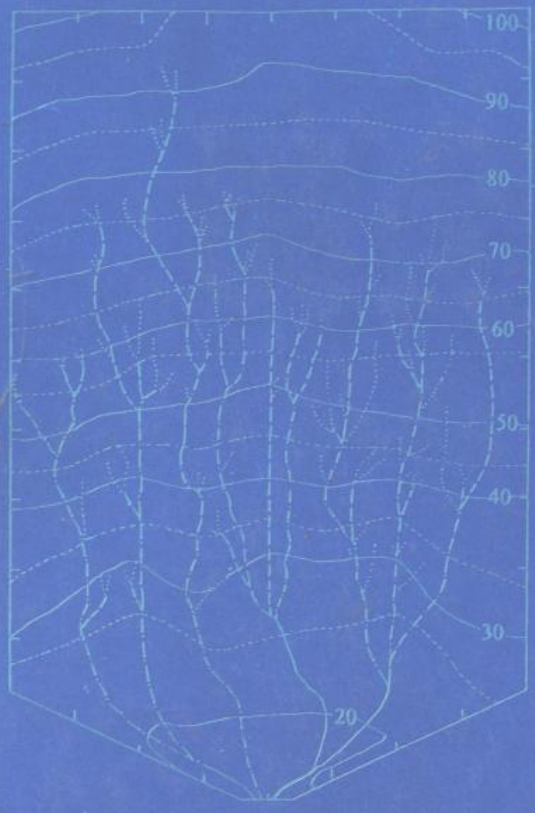

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序

近50年来，结合祖国社会主义建设与科学现代化的需求，我国地貌学的实验与模拟研究获得了巨大的进展和成就。经过前仆后继、坚持不懈地努力，地貌实验与模拟工作现已涉及风沙、冰川、冻土、滑坡、泥石流、喀斯特、黄土、河口海岸、湖泊沼泽等各个新兴地球科学领域。观测系统完善，技术设备先进，成果丰硕，效益显著，不少成果达到了国际一流水平。其中结合水利工程、江河整治、铁路建设、水土保持部门的大型模拟实验与公路网络尤其出色，早已跃居国际先进行列。这些地貌实验、模拟研究工作不仅在工程设计与环境评估方面社会、经济效益十分显著，而且为地球科学理论探索提供了良好的实验基地。意义深远，功不可没。

由于科学技术的进步，地貌实验的观念、理论和方法随之日新月异，彼此相辅相成，相得益彰。地貌学发展的初期，比较侧重于野外实地观察，从地貌学观的现状，以今喻古，由此及彼，建立发育阶段旋回的假设，推导可能的演化规律。后来逐步设置各种人工模拟实验装置，用以表述地貌发育演变的动力学过程和边界条件的变化，以从事微观机理的分析或宏观调控的模拟，藉以满足工程设计和理论研究的需要。但在这些物理模型中，空间与时间的尺度毕竟不可能完全按比例缩小或放大，其仿真程度还有一定的局限性。于是就进一步开拓了野外定位观测台站网络的建设，依托自动化的台站观测记录，通过卫星、微波或光纤通信传输，在全球定位系统(GPS)、地理信息系统(GIS)和卫星遥感数据的支持下，为全球环境变化和区域社会、经济持续发展，提供信息服务。其中地形数字模型(DTM 或 ETM)的模拟和分析对资源探测、环境保护乃至军事指挥，起着十分重要的作用。

我国老一辈地貌学家都非常重视实验、模拟，艰苦创业，勇于开拓。中青年地貌学家继往开来，推陈出新，我是非常敬佩的。有幸奉读了金德生教授等《地貌实验与模拟研究》的初稿。它全面、系统地总结了我国半个世纪以来的实践经验和应用成就；进行了历史的评述和理论的探索。我衷心祝贺作者们没有辜负地貌学界前辈的厚望，本书对未来地貌学的发展深有启迪。本书问世一定会受到地貌学界，乃至地球科学界的欢迎。

中国科学院院士
中国地理学会理事长
陈述彭
1994

此为试读，需要完整PDF请访问：www.ertongbook.com

序

60年代以来，随着地貌学分支科学的细分化，这门科学从宏观走向微观，从定性走向定量，向着广度和深度发展．地貌学本身的发展要求从成因角度对某些地貌现象的机理进行半定量、定量模拟研究，以提高地貌学科的理论水平．另一方面，地貌学和生产实践相结合，各种应用地貌学相继出现，生产实践常常需要地貌学提供一个定量的结论．为此，从生产实践的角度也需要发展地貌学的实验和模拟(包括物理模拟和数学模拟)．

地貌学由于其本身的特点，使得对地貌的成因与定量研究十分困难．各种地貌现象的演化，往往具有长期性，不能复现的特点．对于一个人来说，这种时间尺度和地貌演化时间尺度相比，非常短暂，一个地貌学家通常不可能亲身目睹某一地貌演化的全过程．另一个困难是有些地貌现象，其空间尺度通常很大，存在条件复杂，而且各种影响因素相互制约，野外实地观测很难窥其全貌．而地貌模拟可以通过建立室内的物理模型或数学模型，抓住主要的影响因子，忽略次要因子，在较短时间内复演某一地貌的发育过程和发育趋势，乃至于某一重要因子发生变化，这种地貌将会发生怎样的相应变化．这种方法尤其对研究预测各种极值情况下，灾害性地貌发生、发展具有重要意义．对于地貌演化在成因机制上，这种方法也可以弥补时间尺度和空间尺度上的不足．

虽然室内模拟有上述的优点，但它毕竟只是对野外实地各种地貌演化的模拟．由于目前科学技术水平所限，室内模拟不可能完全真实地代表实际地貌的演化，这就要求我们对某些地貌演化在野外建立定位观测站，以对各种室内模型实验进行验证，并弥补其不足之处．从某种意义上讲，现场就是天然实验室，在这个实验室中，我们可以通过对各种地貌演化进行系统详细的观测和分析，为研究地貌演化提供系统的资料，也为模拟提供依据．因此，地貌的室内模拟和野外观测是地貌实验和模拟研究不可缺少的两个方面，也是地貌研究从定性走向定量不可缺少的方法，这是当前地貌学发展的一个重要研究方向．

我国自五六十年代起，先后对流水、风沙、冰川、冻土、滑坡、泥石流、岩溶、河口海岸地貌等进行了野外观测和系统调查，并进行了一些室内模拟试验和数值模拟研究，建立了多个部门地貌实验室和实验站，形成了一支相当规模的研究队伍．在这种情况下，第一届地貌实验和模拟会议的召开，对我国地貌研究来说是一个新的里程碑．它标志着我国的地貌模拟、实验研究有了自己的学术组织，也为我国地貌模拟实验研究走向系统化、深入化打下了坚实的基础，它将为提高我国地貌学的理论水平和解决生产实践能力发挥更大的作用．出席这次会议的很多是年轻同志，他们是我国地貌学研究队伍的中坚力量和新生力量，体现了我国地貌研究的希望所在．我相信，通过地貌学者共同努力，我国地貌模拟与实验研究会更上一个新台阶，促进我国以及世界地貌学的新发展．

华东师范大学河口海岸所名誉所长
陈 吉 余
1994

前　言

近代地貌学在19世纪中叶以后才发展起来，出现"地貌学"或"新地质学"概念并成为一门新兴学科不过百余年．从以构造、作用、阶段为标志的台维斯"侵蚀循环学说"到以系统、地貌临界、复杂响应为特征的乔莱-夏姆系统地貌学思想，地貌研究由定性的描述向定量表达发展；由演释性地貌形态研究向地貌作用过程研究过渡．随着地貌学研究向广度和深度发展，现代地貌研究以定量、过程和微观机制分析为特征，已离不开实验和模拟手段的运用，其中包括野外实地的定位、半定位观测，实地试验，室内物理模型实验、借助计算机建立的数学模型及进行的仿真模拟，等等．实验模拟已逐渐成为地貌学研究的重要手段和不可分割的组成部分，实验地貌学正在成为一门跨界于地貌学与技术科学之间的边缘学科．

在我国，60年代初，作为自然地理学主要组成部分之一的地貌学，要获得前进和发展，正如竺可桢先生早先指出的那样，应当加强新技术、新方法的应用，包括定位观测及实验模拟等．30多年来，经过老、中、青几代地貌科研工作者的努力，地貌实验与模拟事业获得了蓬勃发展．到目前为止，我国已建立了30多个定位站和实验室，研究领域遍及流水、坡地、沙漠、冰川、冰缘、泥石流、滑坡、河口海岸、喀斯特、湖泊及沼泽地貌等各个分支．从事地貌观测、实验与模拟的科技人员有250余人，在基础理论、实际应用及技术方法诸方面均取得了丰硕成果．80年代中期以来，地貌模拟及数据库建立方面也逐步得到发展．1993年4月5—8日，中国地理学会地貌与第四纪专业委员会"第一届地貌实验与模拟研讨会"于江苏无锡召开，来自全国各地11个科研系统和5所大学的32位代表出席了会议，其中1／3以上为青年科技工作者．会上正式宣布成立"地貌实验与模拟组"，并成为地貌与第四纪专业委员会下属的最活跃的专业组之一．会议的召开和专业组的成立，是我国地貌学研究发展过程中的里程碑，标志着实验地貌学不仅已填补了我国在这一领域的空白，而且标志着我国实验地貌学已发展到了一个新的阶段，说明我国的地貌学研究，从宏观向微观，定性向定量，理论与实践相结合等方面取得了新的进展．

研讨会内容涉及地貌实验与模拟各个方面的有关学术问题．一方面回顾了多年以来，尤其是近年来取得的成果，探讨一些共同关心的问题，如地貌实验与模拟的特色及其在地貌研究中的地位和作用，地貌实验模拟中的相似性问题，GIS与地貌数学模拟，实验模拟技术的自动化程度的提高等；另一方面磋商了加强联合搞活科研、酝酿和组织共同攻关课题，以适应市场经济发展的需要．研讨会强调室内实验与室外实验的互补性，模型实验与数学模拟的关联性与互促性．因此，(1)在实验与模拟内容上，应当为解决生产问题更上一层楼；(2)在实验理论上，在相似性、可比性、推延性研究方面应当有新突破；(3)在实验方法和技术上，高科技自动化程度当跨出一大步；(4)在实验组织形式上，在国内不同部门不同学科之间的联合及与国际同行合作方面应当有一个新发展．

研讨会前后共收到论文约40篇，根据内容划分四个部分．

Ⅰ．地貌实验、模拟研究综述．该部分共8篇论文，对实验地貌学研究进展、现代地貌学数学模拟、地理信息系统与地貌模拟的关系，并对若干地貌学分支，如流水地貌的室内外

实验研究、河流地貌研究若干问题、泥石流、喀斯特地貌等实验研究的进展做了回顾和评述。明确指出，70年代末以来，国际上复又重视以流域地貌系统为主要内容的定位观测，实验地貌内容向构造地貌和空间星体地貌实验扩展。在国内，地貌实验由常态过程向非常态过程发展，特别是泥石流、风沙、冰缘块体运动及喀斯特作用过程发展。对于常态过程，特别强调了河床演变研究中，运用野外第一手观测资料及室内实体模型模拟实验，深入揭示河床过程内在机理的重要性；在深度上，由平衡态向非平衡态，由线性向非线性，由均变向突变地貌过程发展。

Ⅱ. 地貌实验与定位观测。该部分收录论文10篇，反映近年来有关地貌分支，如流水地貌、坡面发育、土壤侵蚀、航道建设、冰缘、风沙、喀斯特地貌过程等方面的具体研究成果。通过研究，认识到均匀物质流域中产沙的非均匀性，水系发育过程中河长临界值的存在；首次定量地确定了梁峁坡水流下沟时的沟坡侵蚀产沙增量，获得了红土坡地产沙来源于泥化及溅蚀，人类活动促进细沟发育；大风浪对茅家港航道的骤淤作用，天山冰缘块体运动速度、特征及分布规律；认识到主风场决定沙山基本形态及其前缘的沙丘形成和主体分布，次主风导致沙脊线摆动及金字塔状沙丘的形成；提出了喀斯特地区白云岩水具有惰性溶蚀作用等新观点。该部分还介绍了尾矿砂及防护林环境沙风洞的实验观测成果。

Ⅲ. 地貌数学模型与模拟。本部分编入7篇论文，反映运用系统论、信息论、熵模型及耗散结构研究流域地貌、河流地貌系统及泥沙问题；运用数学方法研究沉积盆地埋藏过程、潮滩演化、风沙流结构及喀斯特地貌形态组合自动分类等方面的部分成果。研究表明，由非线性理论出发，蜿蜒、分汊、游荡是河道的耗散结构形式，河道形式的随机性来自系统内部的浑沌运动及系统外部的随机干扰；含沙水流中泥沙悬浮熵模式的研究，基于远离平衡态的稳定态认识，提出了扩散理论与重力理论间存在某种仲裁性认识；EOF谱分析表明，潮滩变化是不同时、空尺度的波动合成所致，第一、二、三特征函数分别代表潮滩的淤积趋势、风浪导致的潮滩季节变动、海平面季节变化造成的潮滩各部分之间的泥沙交换等；揭示了苏北海岸带沉积物运动与动力机制的协调一致性；提出了起跃沙粒在风沙流结构中呈对数分布的理论认识，流域系统中广义力和广义流的存在，确定了流域系统中熵产生和超熵产生的表达式。同时，本部分介绍了喀斯特地貌形态组合的自动分类，初步进行了模糊定量分析。

Ⅳ. 地貌实验理论、方法与技术。本部分收集论文10篇，介绍了地貌学研究的三个新动向，探讨了流域地貌、坡地水沙运移、沙风洞研究中的相似性问题，坡面侵蚀研究方法、泥石流研究方法及研究入渗、径流与土壤侵蚀产沙过程的模拟降雨装置。本部分还着重介绍了湖泊沉积物磁性研究与环境应用，矿物鉴定数据库及其在泥沙来源分析中的应用等论文。

上述研究成果，不仅提高了地貌学理论水平，也为大坝上、下游河道规划，入海航道减淤工程择优方案，潮滩合理开发利用，黄土地区水土保持，喀斯特地区旅游资源开发，西昌卫星发射中心的泥石流防治工程，西藏、塔克拉玛干、敦煌地区治沙工程提供了有价值的科学依据。

在本书编辑出版过程中，得到中国地理学会、地貌与第四纪专业委员会、兄弟专业组、中国科学院地理研究所科研处、地貌研究室、南京地理与湖泊所、湖泊沉积开发实验室、太湖湖泊实验站、水电部、交通部南京水科院河港所等单位领导及同志们的支持和帮助，特别是老一辈地貌学家指导和关怀。中国科学院院士、中国地理学会理事长陈述彭先生及华东师大

河口海岸所名誉所长陈吉余先生在百忙中为本书热情洋溢地作序；地貌与第四纪专业委员会主任、中国科学院院士李吉均教授对会议及本书出版极为关切．对于他们的支持、关怀及帮助，我谨代表地貌实验与模拟组及本书编委会致以衷心的感谢．本书存在的不足及疏漏之处，敬请作者和读者见谅，并希不吝指出．

金德生

1994 年于北京

Introductory Note

Modern geomorphology has been developed since the middle of 19century, while the concepts of "Geomorphology" or "New geology" occurred and geomorphology became a new scientific branch only about one hundred years. From "Cycle of erosion" characterized by structure, process and stages to Chorley–Schumm systematic geomorphic idea with feature of system, geomorphic threshold and complex response, research methods in geomorphology develop from qualitative description to quantitative expression, and transfer from deductive study on geomorphic figure to process research. As widely and deeply developing, contemporary geomorphology has grown up and characterized by quantitative, processes and microscopic analyses. It is very closely connected for geomorphic study to use experiments and simulations, including observation at station or semi–station, field test, laboratory experiment with hardway model , mathematical model and real–simulation by computer, etc. Experiments and simulations have been gradually becoming not only very useful tool of study on geomorphology, but also a part, which could not be separated from geomorphological field. Experimental geomorphology tends to be a new frontier scientific branch between geomorphology and technology.

At the beginning of the 1960's, as Prof. Zhu Kezhen, who was an academician of CAS pointed out, geomorphology is one of the main branches in physiography, new technique and method, including station observation and experiment applied to study of geomorphology would be emphasized on. In recent 30 years experiments and simulations in geomorphology have been flourished by efforts of several generations of geomorphologists. Till now, more than 30 stations and laboratories have been established, including that of fluvial, slope, desert, glacial, pre–glacial, debris flow, land–sliding, estuary–coast, karst, lacustrine and swamp geomorphology, etc. More than 250 researchers are engaged in observation, experiment and simulation in geomorphology. It is made that a big progress in fundamental study, practical application and techniques, etc. In the middle of the 1980's simulation and data base in geomorphology started to grow up. The First Symposium on Experiment and Simulation in Geomorphology, sponsored by Commission of Geomorphology and Quaternary, Chinese Society of Geography was held on April 4–8, 1993, Wuxi, Jiangsu Province. The 32 representatives from 11 institutions and 5 universities attended the symposium. Of them about one third was young geomorphologists. At the meeting the Chinese Research Group of Experiments and Simulations in Geomorphology (CRGESG) was announced to be established and becomes one of the most active groups in the Commission of Geomorphology and Quaternary, CSG. Symposium opened and group established show the achievements in experiments and simulations by several generations of

geomorphologists, and a milestone in geomorphology developing in China. Those mean that not only the gap about experimental study on geomorphology has been fitted, but also a new stage is coming, e.g. a recently promoting in aspects of macroscopic to microscopic, qualitative to quantitative, and combination of theory with practice in geomorphology.

At the symposium, many scientific topics, related to experiments and simulations were presented and discussed. On the one hand, it looked back on some achievements for years, especially in recent years and some common problems were discussed, such as characteristics of experiments and simulations, and their role in geomorphic study, relationship between GIS and mathematical simulation, and automatic techniques in experiments, etc. On the other hand, emphasizing on cooperation, flourishing scientific research and proposal of key subjects were also mentioned in order to fit with market economic development. It should be focused on compensation of laboratory study for station observation, relation and promotion of physical model to mathematical simulation. Therefore, (1) in contents of experiments and simulations it should be raised a new level to solve productive problem; (2) in aspect of theoretical study, similarity, comparability and spreading ability should be made a new breakthrough; (3) in aspect of technique and method high level of automatics should have a long march; (4) in organization of experiments, cooperation among different scientific branches at home, and with colleagues abroad, should be newly developed.

Before and after the symposium about 40 articles have been received and divided into 4 parts to be published as follows.

Part I. Review and Prospect in Experiments and Simulations

In this part there are together 8 papers, in which it is reviewed and prospected that general experimental geomorphology, mathematical simulation in modern geomorphology, relation of GIS to geomorphology, and achievements of such branches as fluvial, river, debris flow and karst geomorphology. It is indicated that since the end of the 1970's it has been again paid more attention to station observation with main content of drainage geomorphic system, and in aspect of experimental geomorphology developing to structure morphology and space–planet morphology abroad. In China experimental geomorphology is transferred from normal processes into unnormal ones, especially that of debris flow, desertification, pre–glacial mass movement and karst geomorphology, etc. In normal processes, it is very important to reveal mechanism in channel processes in combination of station observation with hardway model in lab. Also, it is deeply developed from equilibrium, linear and uniforminism processes to unequilibrium, nonlinear and catastrophic ones.

Part II. Experimental Study and Station Observations

In this part 10 articles are collected and dealt with experimental results in some geomorphic branches, for example, fluvial, slope, soil erosion, outlet channel, pre–glacial, wind tunnel and karst processes, etc. in recent years. In accordance with studies, it is understood that there are non–uniformity in sediment yield through time and in space and

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threshold of channel length in network developing even though a drainage basin covers uniform material. The concept of increment of sediment yield on slope exists as coming water drainages from slope of "Liang– Mao" into the gully. In red soil area, sediment is caused by pudding and rainsplash on slope and man's activity accelerates to rill developing. Big wave storm leads sudden deposit of the Maojiagang Port. The rate, characteristics and distribution law of pre–glacial mass movement in the Tianshan Mountain is also obtained. It is recognized that basic form of sand dune, and formation and distribution in front of it in Takla Makan are dominated by main prevailing wind, while vibration of sand dune peak and formation of pyrimad–shaped sand dune are controlled by second prevailing wind. It is newly provided that in karst area the saturated dolomitic water has inertia solution. In this part some experimental studies on tailing in mining and smelting, and shelter belts in environmental wind tunnel are introduced.

Part III. Mathematical Model and Simulation in Geomorphology

In recent years, mathematical model and simulation in geomorphology has been quickly growing up because of introduction of new concepts of mathematics and physics and fast renewal of home computer. When geomorphic phenomena and processes could be simulated, it is necessary to construct mathematical model in geomorphology. In this part there is total of 7 papers, in which it is dealt with studies on fluvial geomorphology, river system and sediment suspending by systematic theory, information, entropy model and dissipative structure, mathematically analyzing evolution of subsidence burial history, tidal flat, blown sand flow structure, and automatic classification for karst type, etc. It is indicated that in accordance with nonlinear theory, meandering, island braided and wandering are regarded as a kind of dissipative structure in channel pattern, and stochastic in channel pattern comes from the two reasons, one is choas in the system, and another is turbulence outside the system. Based on stability far from balance in a system, an arbitration between theories of diffusional and gravitational in sediment motion, because of establishment of entropy model in sediment suspending. With analysis of EOF, it is explained that combination of different wave in time and space changes tidal flat. The first eigenfunction means tendency of tidal flat depositing, the second one does seasonal changes of the tidal profile caused by wind–wave, while the third one indicates exchanging of sediment in different parts of tidal flat by seasonal fluctuation of sea level. Coordination between deposition motion and dynamic mechanics has been revealed. Theoretically, it is understood that jumping sand grain is shown as function of exponent distribution. There are generalized force and flux in a drainage system and expressions of entropy production and super entropy production have been determined. By the way, in this part it is introduced that automatic classification to karst form types with fuzzy quantitatively analysing.

Part IV. Theory, Technique and Method in Geomorphic Experiments

In this part there are 10 articles. It is introduced that there are three new developing tendencies in theoretical study on geomorphology. Similarities in model of drainage

geomorphic system, water and sediment running on slope, and in wind tunnel, research methods of slope erosion and debris flow, and artificial rainfall facilities for study on infiltration, runoff, soil erosion and sediment yield are also explained. It is introduced that magnetic study on lacustrine deposition is applied into environment, and mineral appraisal data base and its application are used to material source analysis.

Achievements mentioned above, it is not only raise theoretical level, but also provided valuable scientific basis for planning channel upstream and downstream a dam, development and use of tidal flat, water and soil conservancy on the Loess Plateau, developing trip source in karst area, debris flow protecting engineering in the Xichang Center of Satellite Launch, and desert realignment engineering in Tibet, Takla Makan and Dunhuang areas, etc.

During editing this book many institutes and organizations, such as Chinese Society of Geography, Commission of Geomorphology and Quaternary, Institute of Geography, CAS, Nanjing Institute of Geography and Lacustrine, CAS, Division of Science & Technology IG, CAS, Division of Geomorphology IG, CAS, Opening Laboratory of Lacustrine Deposition, NIGL, CAS, Ecology Research Station at Taihu, NIGL, CAS, etc. and many geomorphologists provided a lot of useful opinions and enthusiastic supports. It should be specially mentioned that Prof. Chen Shupeng, geoscience academician of CAS and Chairman of Chinese Society of Geography, and Prof. Che Jiyu, Honorary Director of Institute of Esturine and Coastal Research, East China Normal University warmly and in the midst of pressing affairs wrote prefaces for this document, and Prof. Li Jijun, geoscience academician of CAS and chairman of the Commission of Geomorphology and Quaternary, CSG, paid more attention to this symposium and publication. Editorial Board and all of authors also contributed to effort a lot. On behalf of the Chinese Research Group of Experiments and Simulations in Geomorphology I would like to thank them for their significant contribution. In editing and publishing, undoubtedly, there exists some lacks and errors, for which I relay apologize to authors and readers, and sincerely hope to be pointed out at all.

Jin Desheng
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