

Compilation of serial maps on karst geology of China and Southeast Asia

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Abstract: The compilation of serial maps of karst geology in China and Southeast Asia is a project under the “One Belt One Road” geological survey plan granted by China Geological Survey. This paper summarized the research trend of geoscientific mapping in China and Southeast Asia and introduced the significance, contents, technical routes, operating methods and progress of the project. Through bilateral and multilateral cooperation, this project builded an international cooperation platform for mapping and completes the preliminary compilation of related karst geological maps in China and Southeast Asia, thus filling up the blank of karst geological maps in this region.

Keywords: Southeast Asia; Karst geology; Map compilation

Introduction

With the development of global economic integration, China and Southeast Asia have faced greater challenges in terms of energy, resources, environment and disasters, especially karst environment and groundwater resources safety, which directly impact the sustainable development of China and Southeast Asia. The international cooperation project-the compilation of serial maps on karst geology of China and Southeast Asia, is contributable to promoting the geological environment protection, economic development and academic development in China and Southeast

Asian countries, and to building closer relations between China and Southeast Asia. In this paper, we reviewed the previous research results of karst geology in China and South East, analyzed the significance of compiling karst geological serial maps of China and Southeast Asia, and introduced the contents, technical routes and methods as well as the progress we have made.

1 Study on compilation of Geoscientific Maps in China and Southeast Asia

1.1 Current progress of compilation of Geoscientific Maps in China and Southeast Asia

In 1970s, Academician LI Ting-dong compiled the Geological Map of Asia (1/5 000 000), and in 1990s, he prepared the Geological Map of the Asia-Europe (1/5 000 000), a geological map

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covering two continents, which fully expressed the geological characteristics of the Eurasian continent; in 1980s Academician LI Chun-yu compiled the Tectonic Map of Asia (1/8 000 000); in 2006, chaired by the researcher CHEN Zhi-ming from Nanjing Institute of Geography and Limnology, CAS, and under the cooperation of a number of scientists of China and Russia, the draft Topography Map of Asia and the Adjacent Land and Sea (1/8 000 000) was completed (CHEN Zhi-ming, 2010a; CHEN Zhi-ming, 2010b).

In 1990s, Academician REN Ji-shun compiled the Tectonic Map of China and the Adjacent Areas (1/5 000 000), and verified important tectonic boundaries. In 2013, the International Geological Map of Asia (1/5 000 000) with the international standard, whose compilation was led by REN Ji-shun, was published. The compilation of the Map was under the command of the Commission for the Geological Map of the World, led by China and finished by a number of scholars from various countries such as the Philippines, Indonesia, Vietnam, Cambodia, Laos, Myanmar, Malaysia and Thailand. This map is the first international geological map of Asia with its own database to fully demonstrate the geology of Asia and the adjacent sea waters, and it is currently the latest and the most complete geological map of Asia.

In 1996, the Vietnamese Phan Cu Tien compiled the Vietnam, Laos and Cambodia Geological Map (1/1 000 000). Other Southeast Asian countries have also prepared their own geological maps, such as Thai Geological Map (1/1 000 000), Geological Map of the Philippines (1/1 000 000), Geological Map of Myanmar (1/1 000 000) and the like. In the early 21st century, the United States Geological Survey compiled geological maps covering the Southeast Asian countries.

In 2000, the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) and the Circum-Pacific Council on Energy and Mineral Resources (CPCMR) compiled the Tectonic Map of Southeast Asia which covers the Philippines, Vietnam, Malaysia, India and other Southeast Asian region and adjacent areas.

In 2006, Chengdu Geological Survey Center of China Geological Survey (CGS) prepared the Geological Map of Five Southeast Asian Countries (1/1 500 000). In 2003, Professor CHEN Yong-qing compiled and published the Geology and Mineral Resources Map of Southeast Asia Indo-China Peninsula (Five Countries) (1/1 500 000), covering the five countries in the Indo-China Peninsula: Myanmar, Thailand, Laos, Vietnam and Cambodia.

In 2006, Professor CHEN Yu-qi from the Chinese Academy of Geological Sciences led the compilation of Geological Map of China (Second Edition) (1/4 000 000) which presented the general geological situation of China.

1.2 Current progress on the compilation of Karst Environmental Geological Maps of China and Southeast Asia

For groundwater is a crucial part of the geological environment, researches on groundwater resources and groundwater issues and related maps compilation are gaining more and more attention. Under the joint guidance of the UNESCO-International Hydrological Program (UNESCO-IHP), the Commission for the Geological Map of the World (CGMW), the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), the compilation of

the World Groundwater Resources Maps (1/50 000 000 and 1/25 000 000) was initiated in 2002 based on the hydrogeological maps or the groundwater resources maps of all continents and major countries. In addition, the groundwater resources database has been established. The first draft was prepared in March 2003 and has been updated every year. The compilation aims to summarize the groundwater resources information on a global scale with the map (1/25 000 000) as a platform by using the geographic information system. The map will be constantly updated based on the latest data.

Studies of hydrogeological map vary among Southeast Asian countries and regions. Comprehensive hydrogeological maps comprise scales from 1/1 000 000 to 1/5 000 000, some maps of which are in medium scales from 1/200 000 to 1/500 000; national maps include: hydrogeological maps of China, Indonesia, Thailand, and other countries, and such maps include the groundwater runoff map, underground mineral water map and hydrogeochemical maps, main scales for which are 1/1 500 000-1/7 500 000.

The Hydrogeological Map of Asia (1/8 000 000), the compilation of which was led by the Academician ZHANG Zong-hu from the Institute of Hydrogeology and Environmental Geology of Chinese Academy of Geological Sciences (IHEG, formerly known as the Institute of Hydrogeology and Engineering Geology Chinese Academy of Geological Sciences) in 1996, was made from a perspective of the global water cycle. The Map has established the relationship between the groundwater of Asia and the surrounding oceans, geographical latitude, climatic horizontal zoning and topographical vertical zoning. In addition, it analyzed the formation, distribution and migration law of groundwater by based on the <http://gwse.iheg.org.cn>

regional hydrogeological conditions and the mainland water cycle law.

In 2013, the Hydrogeological Map of Asia (1/8 000 000), the Groundwater Resources Map of Asia (1/8 000 000), and the Geothermal Map of Asia (1/8 000 000), compiled by ZHANG Fa-wang *et al.* (2012) from the IHEG, were published (CHENG Yan-pei *et al.* 2010; DONG Hua *et al.* 2011). The abovementioned maps have served as the basic materials for transnational exploitation and utilization of natural resources, water resources planning, geological environmental protection, global climate change research and disaster prevention and mitigation in China and Southeast Asian countries, provided the scientific basis for internationally coordinated economic development, groundwater resources and environmental protection, and have far-reaching scientific and political significance to the strategic needs for addressing the international resources and environment conflicts.

In 1990s, China compiled the China Environmental Geological Maps (1/6 000 000) and published 11 copies. Early this century, China compiled the China Groundwater Resources and Environment Atlas and the China Groundwater Environment Map (1/4 000 000), reflecting that the compilation of Geological Environment Map in China was advanced internationally.

The Institute of Karst Geology, Chinese Academy of Geological Sciences (CAGS) has compiled and published a series of karst geological maps of China, including: Soluble rock types in China (1/4 000 000) compiled and published in 1985, Distribution of Karst Sinkholes in China (1/6 000 000) compiled and published in 1992, China karst hydrogeological map (1/4 000 000) compiled and published in 1993, Karst Environmental Geological Map of China

(1/5 000 000) compiled and published in 2006, Distribution of Underground Rivers and Karst Springs of Eight Provinces (districts, cities) in Southwest China (1/2 000 000) and Rocky desertification distribution of eight provinces (districts, cities) in Southwest China (1/2 000 000) compiled and published in 2007, Karst Collapse of Geohazards in China (1/4 000 000) and Karst Collapse of Geohazards of Eight Provinces (districts, cities) in Southwest China (1/2 000 000) compiled and published in 2010, and Comprehensive Hydrogeological Map in Karst areas of Southwest China (1/2 000 000), Karst landscape in karst areas of Southwest China (1/2 000 000), and Water resources, its development and utilization planning in karst areas of Southwest China (1/2 000 000) compiled and published in 2011. These maps illustrate the main achievements of karst geological research in different periods of China, and also provided important references for the study of karst environmental geology.

2 Significance of the Compilation of Serial Maps on Karst Geology of China and Southeast Asia

1) To carry out the compilation of serial maps on karst geology of China and Southeast Asia is to meet the needs of the implementation of the strategy of “One Belt One Road” and the strategy of “Go Global”. In 2013, Chinese Chairman XI Jin-ping raised the initiative of jointly building the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (hereinafter referred to as the One Belt and One Road). President XI proposed as follows: ASEAN region is an important hub of the “Marine Silk Road” since ancient times. China is

willing to strengthen the maritime cooperation with ASEAN countries to develop sound marine partnership and the 21st-Century Maritime Silk Road together. China is willing to share opportunities and meet challenges together with ASEAN countries through expanding pragmatic cooperation with ASEAN in all fields and complementing each other, thus achieving common development and prosperity with ASEAN countries. Meanwhile, the Ministry of Land and Resources in the Opinions on Promoting Overseas Geological Survey and Mineral Resources Prospection expressed as follows: To implement the “Go Global” strategy, we encourage and support the qualified geological prospecting organizations, mining companies and research institutions to carry out overseas geological survey and mineral resources exploration in accordance with the geological work rules and international practices. This is a major strategic initiative at the new cooperative stage in the field of geology and mineral resources. Therefore, the implementation of overseas geological investigation, research and map compilation of karst geological research is in line with China’s strategy.

2) To carry out the compilation of serial maps on karst geology of China and Southeast Asia is the common demand of the Southeast Asian countries. China and Southeast Asia are one of the three world’s large distribution areas of karst, including Southwest China, and the neighboring countries such as Vietnam, Thailand, Myanmar, Indonesia, Singapore, Malaysia and Cambodia. The unique geological functions of the karst development in karst regions produce a series of environmental and geological issues such as groundwater pollution, shortage of groundwater resources, soil erosion and river siltation, ecological destruction, drought and floods,

collapse, landslide and debris flow, and land subsidence disasters. These geological environment issues increasingly threaten the lives of residents and the development of countries in the region. China and Southeast Asian countries have built comprehensive strategic partnership to carry out cooperation on groundwater resources protection and environmental protection based on the economic and social cooperation. To create a harmonious relationship between water resources has become the common desire of the region.

3) To carry out the compilation of serial maps on karst geology of China and Southeast Asia is the requirement of modern karst subject development. Compilation of karst geological serial maps is one of the most important ways to present the achievements of karst geological investigations, and such maps are also indispensable karst geological data for engineering constructions and economic and social development. The level and quality of the karst geological achievements and their ability to effectively meet the needs of economic and social development are all directly related to the development of karst discipline. Karst geological serial maps are thematic maps in the classification of cartography. Compared with words, the maps are able to show the relationship between various geological bodies more clearly and directly, which directly reflect the temporal and spatial distribution rules of the basic features of karst geology. Through the compilation, the geological study achievements of China and Southeast Asia can be summarized comprehensively, and thus the distribution and features of karst geology at a large scale can be reflected on the maps. By learning the regional distribution features of karst geology directly, summarizing the karst geological information of Southeast Asia and understanding the karst geological structure and

resources distribution in the area, we can provide better support for further studies on karst geology of the area.

3 Main Contents of the Compilation of Serial Maps on Karst Geology of China and Southeast Asia

The serial maps on karst geology of China and Southeast Asia include: the Distribution of Karst in Southern China and Southeast Asia, the Hydrogeological Map of Southern China and Southeast Asia, the Groundwater Resources of Southern China and Southeast Asia and the Environmental Geological Map of Southern China and Southeast Asia on Single Factor. The scales of such maps are all 1/5 000 000.

1) Distribution of Karst in Southern China and Southeast Asia: The Map mainly clarifies the spatial distribution of soluble rocks in Southern China and Southeast Asia, including: carbonate rocks for well-developed karst, carbonate for moderately-developed karst, the carbonate rocks, buried carbonate rocks, red bed karst and non-carbonate rocks for weakly-developed karst, as well as important karst phenomena.

2) Hydrogeological Map of Southern China and Southeast Asia: This Map explains the groundwater storage law in Southern China and Southeast Asia through scientific analysis to the relationship between the groundwater and the surrounding oceans, geographical latitude, climatic horizontal banding and topographical vertical zoning and considering the geological features of the areas in terms of five groundwater reservoir types: (loose rock) pore water, (carbonate rock) karst water, (clastic rocks) fissure pore water, basalt (fissure porewater) and (other rock types)

fissure water, which could be used to illustrate the groundwater occurrence rules.

3) Groundwater Resources of Southern China and Southeast Asia: With the natural groundwater recharge modulus partition as the basic evaluation unit, this map demonstrates the spatial distribution of natural groundwater resources and the distribution of resources under exploitation in Southern China and Southeast Asia. The groundwater resources are divided into five grades according to the topography, climate, hydrology, and the recharge conditions of aquifer media.

4) Environmental Geological Map of Southern China and Southeast Asia on Single Factor: On the basis of analysis of the region's geological environment data, to compile maps on single factors like total dissolved solids (TDS), fluorine, arsenic, ferromanganese, radon and heavy metals; also to compile maps on single factors like constant decline of regional groundwater caused by geological environmental problems, and the subsequent ground subsidence, sinkhole, ground fissures and seawater intrusion; moreover, to compile maps on single factors like land salinization, desertification, shrinking of wetlands and surface waters resulted from climate change and human activities.

4 Technical routes and methods

4.1 Technical routes

By organizing and participating in the international meetings with experts from Southeast Asia, to establish and improve the cooperative mechanism of map compilation with experts from Southeast Asia and prepare the database structure and map compilation plan as required uniformly based on the further cooperation and exchange; to

carry out data collection and analysis on multiple aspects through various channels so as to provide data basis for the map compilation; to carry out remote sensing data processing and interpretation, thus applying the remote sensing technique to karst geological maps in small scales; to verify the collected data through field investigations, thereby improving the mapping quality by combining the fieldwork and indoor analysis; to prepare the karst environmental geological serial maps of China and Southeast Asia based on the abovementioned work; and finally to publish related mapping achievements (Fig. 1).

4.2 Technical methods

1) Remote sensing technology: To use ENVI software with the landsat, MODIS remote sensing satellite data interpretation, including automatic correction, enhancement and classification of satellite images to study the main ecological and geological environment issues relating to groundwater by interpreting the changes in surface waters and vegetation based on the data of a plurality of phases.

2) Geographic information systems (GIS) technology: To use MapGIS and ARCGIS to establish and improve the karst environment geological database of China and Southeast Asia, process digital maps and graphics data and manage the mapping achievements.

3) Scale analogy of map compilation for large-scale regions: The mapping scales of China and Southeast Asia are featured with multi-level, multi-target and multi-factor influence of groundwater environment, so there are a lot of content that cannot be quantitatively categorized into map compilation units. To use analogy method to divide the map compilation units through summarizing and comparing relevant data, for

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example: to determine the groundwater environmental alert areas by judging the impacts of large-scale engineering activities closely relating to the groundwater on the geological environment.

Analogy can be used to balance differences about the groundwater and geological environmental studying degree and information acquired by China and Southeast Asia.

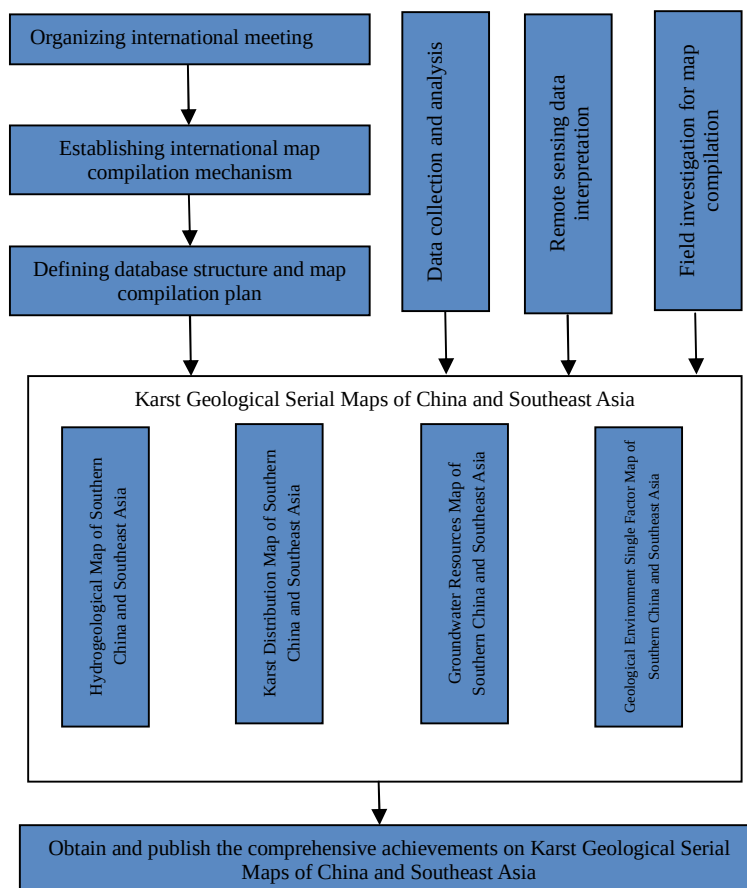


Fig. 1 Technical routes

4) Cartographic generalization method: When compiling maps with smaller scales based on the achievements with larger scales of countries, to use cartographic generalization method to merge the same mapping unit, magnify the contents with rules and features and delete the minor and common map spots.

5) Layers and overlay analysis method: Based on the groundwater quality, geochemical background, human engineering activities, geological environmental impacts in China and Southeast Asia, to use the layers analysis method and overlay analysis method to carry out the map compilation study of systematic combination of the multi-level and multi-factor mapping contents.

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6) Network technology: To share the groundwater and geological environment data of China and Southeast Asia through network technology, which means that based on the current improved groundwater and geological environment database, to collect and update the data in the database and then publish such data through web for data share.

5 Progress on the Compilation of Serial Maps on Karst Geology of China and Southeast Asia

1) The collection, collation and analysis of

relevant information and research results have been carried out. karst geological, hydrogeological and other related maps of China and Asia have been collected; the books of geography, geology, environment, society and economy in Southeast Asian countries have been collected; the geological data and reports of some Southeast Asian countries have been collected through international exchanges, and further translation, collation, analysis of such data and materials have been conducted, providing the data basis for map compilation.

2) The serial maps database structure and mapping outline have been established. The preparation of database structure and mapping outline (first draft) of the karst environment geological serial maps of China and Southeast Asia has defined the objectives and desired outcomes of the map compilation and unified the mapping principles, scale requirements, mapping contents and expressions, and data structure, providing standards for the cooperative compilation.

3) Studied and drafted the Southeast Asian Geological and Humanities Research Report. Through analyzing relevant literature, we studied the geological, humanities, social and economic situation in Southeast Asian countries and drafted the comprehensive study report, providing valuable references for the compilation.

4) Built an international cooperation platform for the map compilation by organizing international seminars. On May 10, 2014, the Sub-forum on Geological Environment Protection of Mines under the China-ASEAN Mining Cooperation Forum was held. Nine guests from China, Thailand, Vietnam, Myanmar, Indonesia and Malaysia respectively delivered speeches and reports on geological environment and geological disasters, karst systematic characteristics, compilation of karst environmental geological serial maps, management of limestone areas, groundwater pollution investigation, sustainable

management of water resources, prospects and history of China-ASEAN cooperation and other issues respectively. They also explained the situation concerning their own country's karst development, geological environment issues and karst protection measures at the project working meetings, and signed the cooperation meeting minutes. On October 25, 2014, at the ASEAN special session of the international karst training course, the project specialist of natural science of UNESCO Beijing Office attended the meeting; meanwhile, the project team signed the meeting minutes with participants from Laos, Myanmar, Cambodia, the Philippines, Malaysia, and Thailand, which deepened the cooperation relationship further. On December 13, 2014, at the project seminar, the team invited experts from Southeast Asian countries to discuss and study the drafted maps, so as to improve the contents of the map.

5) Conducted field investigations and academic exchanges in Southeast Asian countries. The overseas investigation in Thailand mainly includes: Thailand karst geological environment data collection and supplement, field verification of remote sensing interpretation, and communication with Thai experts on map compilation plan. The visit to Thailand received good results. We carried out the overseas investigations and survey in Malaysia and Indonesia and were welcomed and received by the leaders and experts of the National Hydraulic Research Institute during the visits. The project team visited and learnt about the Institute, collected the Malaysian national scale geological maps and hydrogeological maps, conducted field investigation on the coastal karst in Malaysia. During the visits to Indonesia, we were well received by the leaders and experts from the Bureau of Geology of Indonesian Ministry of Energy and Mineral Resource and the University of Indonesia Jakarta. The project team introduced our international cooperation project, investigated the typical karst areas in Indonesia accompanied

by experts, and visited the Indonesian National Karst Museum. Through the visit, the team obtained a better understanding of the karst in Indonesia. At the same time, the project team also collected related geological maps and hydro-geological maps and maps of karst distribution in Indonesia.

6) Carried out the remote sensing interpretation of some Southeast Asian regions. This study is in line with the remote sensing investigation principles of “from points to surface, combining the points and the surface; from the outside to the inside, eliminating the false and reserving the truth”. In this study, we collected the remote sensing, structure and geological data of the research area, studied the characteristics of the remote sensing images of the typical karst areas in Southeast Asia, and carried out a wide range of carbonate rock information extraction based on the remote sensing data (mainly from the landsat8 remote sensing data with Google earth and DEM as supplementary) interpretation by using the analogy theory with human-computer interactive interpretation as main approach and visual interpretation as supporting approach, so as to provide references for Southeast Asia serial maps compilation and explore the feasibility of the application of remote sensing technology to the geographical maps (in small scales) covering large areas.

6 Conclusions

This paper mainly introduced the preparatory work for the Compilation of Serial Maps on Karst Geology of China and Southeast Asia under the CGS. Currently, we have built the international cooperation platform for the map compilation, drafted related karst geological maps of China and Southeast Asia and conducted preliminary study on environment geological issues. Follow-up work <http://gwse.iheg.org.cn>

will also be conducted for realizing the objectives.

Acknowledgements

This Project is supported by Compilation of Karst Geological Series Maps of China and Southeast Asia of China Geological Survey (12120114006301).

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