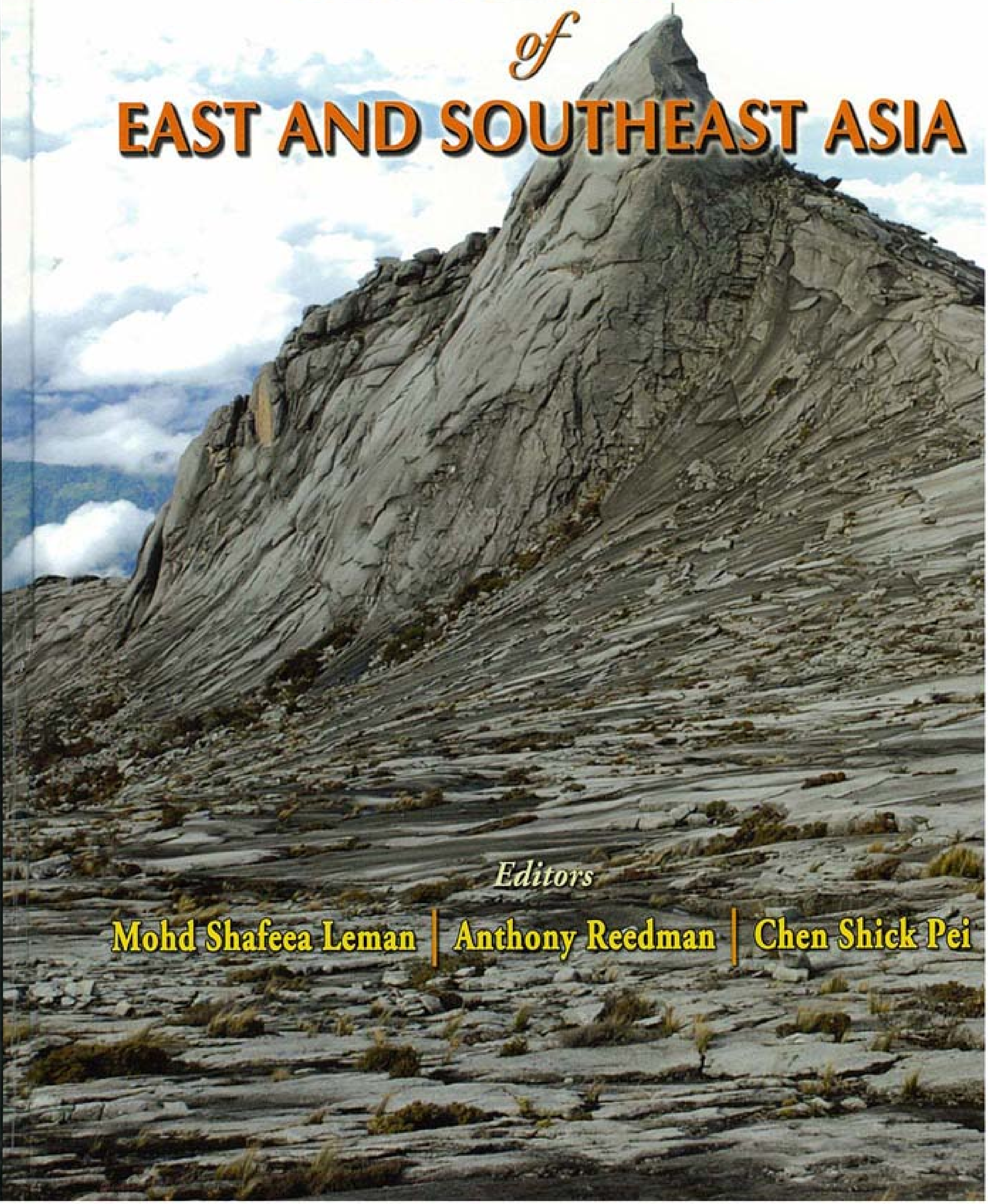
GEOHERITAGE *of* EAST AND SOUTHEAST ASIA



Editors

Mohd Shafeea Leman | Anthony Reedman | Chen Shick Pei

Front cover photograph:- Granite at Low's Peak, Kinabalu Mountain, Malaysia.

Back cover photographs:- (anti-clockwise from top left)

1. Peak clusters at Yuntaishan Geopark, China.
2. Merapi Volcano, Indonesia.
3. Columnar basalts at San-in Coast, Japan.
4. Lava Tube at Jeju Island, Korea.
5. Limestone pinnacles at Mulu, Malaysia.
6. Limestone of Chocolate Hills, Philippines.
7. Natural pillar at Phu Phra Baht, Thailand.
8. Karst Islands at Ha Long, Vietnam.

GEOHERITAGE
of
EAST AND SOUTHEAST ASIA

Geoheritage of East and Southeast Asia

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GEOHERITAGE
of
EAST AND SOUTHEAST ASIA

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Message from IYPE

It is a great privilege introducing this book on the Geoheritage of East and Southeast Asia as a contribution to the **International Year of Planet Earth (IYPE)** by the Coordination Committee for Geoscience Programmes in East and Southeast Asia (CCOP). This book greatly supports the aims and objectives of the International Year of Planet Earth as proclaimed by the General Assembly of the United Nations for 2008 and extended by the IYPE Corporation to 2007 and 2009. These aims and ambitions focus on raising awareness for the great importance of the geosciences for the daily life of citizens to arrive at safer, healthier and more prosperous societies on this planet. They are also geared at convincing politicians and decision makers to effectively apply the knowledge accumulated in the minds of and through the publications by the about 400,000 active geoscientists in the world, among which, rapidly growing numbers are serving in East and Southeast Asian region. Moreover, the IYPE aims to excite people and in particular youth in gaining interest in the world surrounding them and to be captured by the stories stones and landscapes can tell us about how our planet has developed to its present state.

The Geoheritage of East and Southeast Asia is incredibly rich but has not yet gained the attention by the public at large that it deserves. Therefore, IYPE Corporation is very happy that the initiators for this book selected geoheritage as the topic for their contribution to the International Year of Planet Earth. By distributing this beautiful book widely throughout the region we hope and expect that it will enhance the appreciation for the beauty of the Earth and interest of the public in the exciting science behind it.

The International Year of Planet Earth is being celebrated in 74 nations around the globe including China, Indonesia, Japan, Korea, Malaysia, Philippines, Thailand and Vietnam. The IYPE Corporation is very pleased that all these countries in East and Southeast Asia have contributed to this book. Our gratitude also extends to LESTARI and UKM for their generous financial contribution to realize this book. This is a fine example of the successful and effective cooperation among the geoscientific communities in the region which is an extra asset to the legacy of the IYPE. We are most thankful, therefore, to CCOP and the persons behind this great initiative and we wish them that this accessible book will be read and appreciated by the numerous citizens that populate this region.

Eduardo de Mulder
Executive Director
IYPE Corporation

Message from CCOP

The year 2008 was declared by the 60th United Nations General Assembly to be the **International Year of Planet Earth.** It was agreed that "the Assembly would encourage Member States, the United Nations system and other actors to use the Year to increase awareness of the importance of Earth sciences in achieving sustainable development and promoting local, national, regional and international action"

To this end the International Year of Planet Earth aims not only to organize wide ranging geoscientific programmes but also a programme of outreach activities appropriate to audiences from all sectors of society. It is the biggest ever international effort to promote the Earth sciences as sources of knowledge that are vital to mankind's future survival.

The principal target groups for the Year's broader messages are:

- **Decision makers** and politicians who need to be better informed about how Earth scientific knowledge can be used to achieve sustainable development.
- **The public** who need to know how Earth scientific knowledge can contribute to a better society; a safer and wealthier society.
- **Geoscientists**, who are very knowledgeable about various aspects of the Earth but who need help in applying their knowledge for the benefit of the world's population today and tomorrow.

The **Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP)** strongly supports the aims of the International Year of Planet Earth. CCOP is an inter-governmental organization with eleven Member Countries from the region: Cambodia, China, Indonesia, Japan, Malaysia, Papua New Guinea, the Philippines, Republic of Korea, Singapore, Thailand and Vietnam. Its mission is to facilitate and coordinate the implementation of applied geoscience programmes in order to contribute to the economic development and an improved quality of life within the region. This is achieved through the promotion of capacity building, technology transfer, exchange of information and institutional linkages focused on sustainable resource development, management of geoinformation, geohazard mitigation and protection of the environment.

The suggestion that CCOP should produce a book on geoheritage in the CCOP region to mark the International Year of Planet Earth was first put forward by two senior Honorary Advisers of CCOP, Dr Anthony Reedman and Dr Yoshihiko Shimazaki. This suggestion was endorsed by the CCOP Steering Committee in October, 2006. In the following Steering Committee meeting in March 2007, Dr Anthony Reedman, Prof Dr Mohd Shafeea Leman and Chen Shick Pei were named as co-editors of the proposed book and were given the task of guiding it through to publication and launch in 2008.

A book production team comprising a National Coordinator from each CCOP Member Country, the Geo-information Coordinator of the CCOP Technical Secretariat, and the three co-editors was officially formed at the first Coordinators' meeting held in Bangi, Malaysia in July 2007. During the meeting, the guidelines for Member Countries' contributions were clarified, and agreed. Other overall aspects of the book were also discussed. Each Member Country was requested to prepare a chapter for the book following guidelines prepared by the co-editors and agreed in the Coordinators' meeting. Member Countries were also encouraged to prepare a more detailed version of their chapter that could be published in their own language by their own IYPE National Committee. Subsequently, a further informal coordination meeting for the book was held in Langkawi in November 2007 attended by those national coordinators, or their representatives, who were participating in the Asia Pacific Geoparks Conference. Further communication to discuss issues and problems encountered and review progress on individual chapters of the book was undertaken through e-mail exchanges.

The Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia generously offered to provide full financial support for the publication of the book as well as hosting the Coordinators' meetings in Bangi and Langkawi. In addition, it offered to undertake the arduous task of formatting, proof reading, and liaising with the printers in the publication of the book. This generous offer was gratefully acknowledged by the CCOP Steering Committee.

Eight Member Countries of CCOP contributed chapters to the book. They display different approaches to conserving, protecting and promoting their important geological sites as tangible examples of their geoheritage. Taken together they demonstrate the growing importance that is being given to placing each nation's geological heritage in its rightful place as the foundation upon which the nation and its society has developed. This effort is being greatly strengthened by the establishment of numerous modern and imaginative geological museums throughout the CCOP region and it is hoped that a further publication highlighting their role in educating and informing the public of their geoheritage will be published for the CCOP region in the future.

Dato' Yunus Abd Razak
Chaiman
CCOP Steering Committee

Message from Vice-Chancellor

Universiti Kebangsaan Malaysia (UKM) is proud to be involved in the production of a book on Geoheritage of East and Southeast Asia in commemoration of the ongoing **International Year of Planet Earth** (IYPE) 2007-2009.

IYPE's agenda to raise awareness of the great importance of geosciences in our daily lives and in building a safer, healthier and more prosperous society is very timely. The rapid depletion of the global stock of geological resources reminds us of the urgent need to address the serious challenges in implementing sustainable development. The global economic crisis and regional political instability have also hampered geoheritage conservation efforts by geoscientists, particularly those in the developing countries.

Since its establishment in 1970, UKM has been at the forefront in sustainable development research. Following the 1992 United Nations Conference on Environment and Development (UNCED) Rio Summit, UKM established the Institute for Environment and Development (LESTARI) in 1994. One of its research areas is sustainable development of geological resources, with a focus on geoheritage conservation. This research focus has received support from geoscientists in UKM and other universities as well as government agencies and the private sector. Consequently the Malaysian Geological Heritage Group (MGHG), spearheaded by LESTARI, was established in 1996. It assumed the formidable tasks of establishing national inventories on geoheritage resources and persuading relevant authorities to conserve these invaluable geoheritage sites.

Changing the mindset from an economic exploitation of geological resources towards a more innovative, sustainable development-oriented research for geotourism and geoheritage conservation is not an easy task. However, with substantial funding from the Ministry of Science, Technology and Innovation (MOSTI), the Ministry of Higher Education (MOHE) and the Ministry of Natural Resources and Environment (MONRE) and strong support from the Department of Mineral and Geosciences, Forestry Department, Langkawi Development Authority (LADA) and Sabah Parks, MGHG has succeeded in placing geoheritage at par with other natural heritage of Malaysia. To date, the group has managed to develop the Malaysian geoheritage database, established the theoretical research framework and Malaysian evaluation criteria. Most importantly, the Langkawi Geopark was declared as Malaysia's and Southeast Asia's first global geopark.

In UKM we believe in *Inspiring Futures, Nurturing Possibilities.* UKM has given full support to its scholars in establishing and promoting geoheritage and geopark at the regional and international arena. We are proud that Prof.

Dato' Dr. Ibrahim Komoo, the founder of MGHG, has been appointed a Geopark Expert and Bureau Member of the UNESCO Global Geoparks Network (GGN) as well as a Founder Member of the Asia Pacific Geoheritage and Geopark Network (APGGN). MGHG members have been actively organizing and participating in international conferences on geoheritage and geopark. The signing of the MoU between UKM and Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) in 2007 is another great milestone achieved by MGHG and LESTARI, and a great international recognition to this research group on geoheritage conservation. UKM is also pleased that Prof. Dr. Mohd Shafeea Leman, the present leader of MGHG is the lead editor of the CCOP Geoheritage of East and Southeast Asia book.

This book would not materialize without the strong support of the Geo-information Coordinator of the CCOP Technical Secretariat hosted in Bangkok, the three co-editors Dr. Anthony Reedman, Prof. Dr. Mohd Shafeea Leman and Mr. Chen Shick Pei and, most importantly, the National Coordinator of each of the CCOP Member Countries who contributed the chapters in this book. With encouraging support from various organizations as well as individuals, it is hoped that this effort would lead to closer collaboration between UKM and CCOP in the ongoing promotion of geoheritage conservation. We must promote geoheritage conservation and geotourism. They complement each other in providing a *safer, healthier and wealthier* environment for the future generations.

Prof. Dato' Dr. Sharifah Hapsah Syed Hasan Shahabudin
Vice-Chancellor
Universiti Kebangsaan Malaysia

Preface from Editors

The Earth that we lived in has evolved dynamically since its birth some 4.6 billion years ago. Various geological processes acting in the interior of the earth and on its surface as well as impact from the extra-terrestrial regime have continuously and repeatedly modified the composition of earth material and transformed the natural landform of the earth. As a consequence, our wonderful earth today is well endowed with marvels of landscape and invaluable resources both of intrinsic and extrinsic value. These together constitute geoheritage resources that should not only be appreciated by all walks of life, but also for us to safeguard them from large scale man-made destruction, so that the future generations can continue to enjoy the use of these geoheritage resources.

Geological studies have revealed that the earth today was formed as a result of very long and complicated processes of both rock and landscape formation. In this perspective, any earth material that is extracted for various human needs would be almost impossible to be naturally reproduced again within our lifetime. This implies that earth material are non-renewable resources; hence they should be exploited wisely without depriving the local community of their socio-economic benefit while at the same time promising the future generation of their rights to continue to be able to enjoy the use of these resources. For this purpose it is very important for us to first recognize the heritage value of our geological resources before making any plan to conserve them.

This book is primarily aimed at highlighting the various initiatives taken by CCOP Member Countries in promoting geoheritage resources both for development and conservation. At the same time, it provides the best platform to showcase some of the amazing geoheritage resources found in the East and Southeast Asian countries, a region that has undergone a very long and complex geological history. Information compiled in this book will be useful to relevant authorities in each country that share the same aspiration in protecting geoheritage resources under their helm. This book is unique as it compiles geoheritage chapters provided by geoscientists from eight different countries. Perhaps through the networking that developed in this book project, countries with aspired geoparks should be able to seek assistance from those countries which already have experiences in establishing national as well as global geoparks.

This book contains nine chapters including eight chapters on geoheritage resources contributed by eight Member Countries of CCOP and one invited chapter on general issues related to the UNESCO Global Geoparks Network's role and contribution in geoheritage conservation. The eight chapters in this book are contributed by National Coordinators of Member Countries including China, Indonesia, Japan, Korea, Malaysia, Philippines, Thailand and Vietnam.

Each country's chapter is organized in three main sections; the introduction, description of geoheritage sites and the future for geoheritage conservation. In the introductory section, each chapter reports the current status of geoheritage conservation in the respective country. This includes the country's history of geoheritage research and initiatives played by various authorities, agencies and institutions in promoting sustainable use and conserving geoheritage resources, disseminating information and enhancing public awareness on the importance of geoheritage.

This book shows that there is a considerable diversity between different CCOP Member Countries, particularly in the amount of effort given for conservation of geoheritage resources. China, for example, has a long history of geoheritage research and long list of well established national and global geoparks specially dedicated for promoting and conserving geoheritage resources. On the other hand, initiative in geoheritage conservation in several other CCOP Member Countries is still in its early stage although substantial amount of research and public awareness campaigns have been carried out by various responsible parties.

Description of geoheritage resources for each of the contributing countries constitutes the main section of the book. As this book is intended for the general reader, it is very important that this part is written in a language that is friendly to common reader. The contributors are also given some flexibility in organizing their descriptive section to best suit the different ways that tangible geoheritage resources are identified, classified and protected in their respective country.

There are 139 geoparks, 7 aspiring geoparks and 116 geoheritage sites described or mentioned in this book. For the description of these geoheritage sites, attention was specially given on the scientific value of the sites, but many sites were also chosen for their additional aesthetic as well as cultural values. Although many of these geoheritage sites are apparently large enough to be considered for a future geopark, only Japan specifically acknowledged that their geoheritage sites are aspiring geoparks. Others are described either as part of UNESCO World Natural Heritage Sites, National Parks, National Geological Monuments or just as ordinary geoheritage sites. Meanwhile, out of the 139 geoparks developed in the East and Southeast Asian region, 138 of them are all in China, while Malaysia has the only other geopark outside China.

In the respective concluding remarks, there seem to be a growing concerns among all contributing countries on the importance of placing their nation's geological heritage in its rightful place as the foundation upon which the nation and its society develop. There is also a general consensus on the necessity of establishing a national body to be held responsible for matters pertaining to geoheritage conservation more seriously. Last but not least is the importance of building closer regional collaboration in promoting geoheritage conservation.

A book of this nature would not have been possible without the help of many people. We would especially like to thank all the National Coordinators and their colleagues who were responsible for their countries' contribution to the book for their hard work, dedication and cooperation for this CCOP geoheritage book project. We also like to extend our deepest appreciation to the Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia for the generous technical and financial support for the publication of this book. We also thank the CCOP Technical Secretariat, particularly Ms Marivic Uzarraga, GeoInformation Coordinator, for the excellent coordination with Member Countries that contributed much to the smooth preparation of this book. We express special thanks to the Chairman and Members of the CCOP Steering Committee for their unwavering support for this geoheritage book project.

Mohd Shafeea Leman
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GLOBAL GEOPARKS
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Separator Photo:
Incised valley, Wanghushan-Daimeishan Global Geopark, China.

1

GLOBAL GEOPARKS NETWORK: AN INTEGRATED APPROACH FOR HERITAGE CONSERVATION AND SUSTAINABLE USE

Ibrahim Komoo and Margarete Patzak

INTRODUCTION

Geoheritage conservation idea arose mainly from the need to protect geological resources for its intrinsic, heritage and ecological values. The primary focus is the protection of geodiversity in order to not only protect features of direct scientific or inspirational value to humans, but also in order to maintain the natural ecological processes which are essential for most nature conservation concerns (Ibrahim Komoo 2003). However, several geoheritage resources are found in an area where development has already occurred and substantial economic activities are being carried out. In such an area, alienating particular geoheritage resources for protection or conservation alone is not an easy task, hence, the focus should be placed on integrating the conservation and to ensure sustainable use of resources within the existing governance framework. This innovative approach has been promoted by UNESCO under its initiative called geopark.

The initial concept as promoted by UNESCO indicated that geopark should become a tool for a better understanding of the geoheritage and wise use of the earth resources by sensitizing the broad public to a balanced relationship between people and the environment. Geopark should be capable of acting as a focus for economic activity, particularly through geotourism. As the concept evolved, geopark is defined as nationally protected area containing a number of geological heritage sites of particular importance, rarity or aesthetic appeal which can be developed as part of an integrated concept of conservation, education and local socio-economic development (UNESCO 2006).

This chapter highlights the brief history of the geopark, criteria for the development of national geopark, and nomination and assessment procedures to be included as a member of Global Geoparks Network. Geopark concept is also an innovative tool to enhance the effectiveness of the initiative for geoheritage protection and conservation while promoting the sustainable use of the geological resources.

HISTORY OF GEOPARK

UNESCO's General Conference in 1997 approved an initiative to promote a global network of geosites having special geological features to be actively nurtured as a vehicle to encourage conservation and geoheritage promotion globally. Consequently, in 2000, the Division of Earth Sciences submitted the feasibility study report on 'Developing a UNESCO Geoparks Programme' for the UNESCO's Executive Board approval. Unfortunately, as the timing was not appropriate, the programme was not to be pursued, but instead, the UNESCO will support any efforts by member states to establish their own national geoparks (Eder 2002). Based on this decision, UNESCO with the help of International Advisory Group of Experts will assist the development of National Geoparks through the concept of global networking.

Under the auspices of UNESCO, the European Geoparks Network (EGN) has been established in June 2000 by four territories, in France, Germany, Spain and Greece. The main objective of this initiative is the cooperation in the protection of geoheritage and the promotion of sustainable development of regions with less economic opportunities. European Geoparks Network has been very active in promoting the concept of geopark through various activities such as innovative projects based on cultural, geological and natural heritages. Until September 2007, the network consists of 32 Geoparks in 13 European countries (EGN 2008).

The landmark of the global geoparks movement was achieved when in February 2004, the UNESCO Advisory Committee on Geoparks agreed to establish a Global Network of National Geoparks or commonly referred to as Global Geoparks Network (GGN) with 25 geoparks from Europe and China to be the initial members of the network (Figure 1). The coordinating office for the GGN was established in Beijing on June 2004, followed by the First International Conference on Geoparks held on the 27-29 June 2004 also in Beijing, China (World Geoparks Newsletter 2005). Since then the GGN was administered by the Bureau, Global Geoparks Network under the auspices of the Division of Ecological and Earth Sciences, UNESCO. In 2005, through the Madonie Declaration the European Geoparks Network has become an integrating organization for the members of the Global Geoparks Network in Europe. Currently, GGN consists of 56 Geoparks representing 17 countries from four different continents. The interest is still growing as regions in all part of the world are continuously applying to become a member of the network.

Figure 1. Yuntaishan Global Geopark, China is amongst the first Chinese geoparks to be included in Global Geoparks Network in 2004. This outstanding geological landscape of scenic beauty is a landmark of the geopark. *(Photograph©Ibrahim Komoo 2008).*

The latest development of the Global Geoparks Network initiative is a proposal for an establishment of Asia Pacific Geoheritage and Geoparks Network (APGGN) during the first Regional Conference on Asia Pacific Geoparks held on the 13-15 November 2007 in Langkawi Malaysia. This proposal was subsequently endorsed by Global Geoparks Network Bureau Meeting held on the 21st June 2008 in Osnabruck, Germany.

CRITERIA FOR GLOBAL GEOPARKS

Unlike most nature conservation or protection entities where focus is given to the protection of diversity and heritage value, geopark concept was introduced based on the following criteria:

Size and Setting

The area must have a well-defined limit and a large enough surface area for it to serve as local economic and cultural development. It must also comprise a number of internationally important geological heritage sites or a mosaic of geological entities of special scientific importance, rarity and beauty. Apart from geoheritage, the non-geological themes or heritage are integrated part of geopark. For this reason, it is necessary to include sites of ecological, archeological, historical and cultural values as equally important aspects of conservation.

Management and Local Environment

Pre-requisite to any successful geopark proposal is the establishment of a management body and a comprehensive development plan. The management approaches normally in the form of coordination committee which acts to bring together major stakeholders responsible for the development of their own sector, work as a team in a more integrated manner. In addition, the geological features within the geopark area must be accessible to visitors, linked to one another and conserved in a formally managed manner. One of the key success factors in the initiative to create a geopark is involvement of the local authorities or communities with strong commitment from state or federal government.

Economic Development

One of the main strategic objectives of the establishment of geopark is to stimulate economic activities and promote sustainable development. For this reason, geopark shall stimulate, amongst other things, the creation of innovative local enterprises, small businesses, cottage industries and high quality training courses and new jobs to support local socio-economic development, particularly through geotourism activities.

Public Education

Geopark must provide and organise support, tools and activities to communicate science, particularly the geoscientific knowledge and environmental concepts to the public. Some of the basic infrastructures, such as, information center, museum of natural history and geotrails are crucial to support public education. Others include regular communication and promotion through popular publication and use of modern communication media.

Protection and conservation

It is important to note that geopark is not specifically a new category of protected area or landscape. It is also quite different from what is mostly an entirely protected and regulated National Park. Geopark is a development tool where conservation of existing protected areas can be enhanced while opportunity for socio-economic development of the local community can be further improved. The responsible geopark authority should ensure that the protections of the geological and other heritages are being implemented in accordance with local traditions and legislative obligations.

Global network

As a member of Global Geoparks Network, geopark has an advantage to be part of the global network which provides a platform of cooperation and exchange between experts and practitioners in geological heritage matters. Therefore, the mechanism for national and international cooperation must be put in place to take maximum opportunity. Under the UNESCO umbrella, local and national geological sites can gain worldwide recognition and profit through the exchange of knowledge and expertise between members of global geoparks.

NOMINATION PROCEDURE AND ASSESSMENT

UNESCO has prepared draft operational guidelines for member states to propose national geoparks to be included in the Global Geoparks Network since 1999 (UNESCO, 2000). These guidelines have been regularly updated and are used by aspiring geoparks for the preparation of a dossier for their application as a member of Global Geoparks Network. In general the application dossier should include the following items:

- Identification of the area;
- Scientific description of the international and national geosites;
- General information on the area;
- Management plan and structure;
- Sustainable development policy strategy; and
- Arguments for nomination for Global Geoparks Network.

It is advisable during the preparatory phase to seek cooperation from national geological-based agencies, local geoheritage research groups or even regional members of the UNESCO International Advisory group for the conceptualization of the geopark approach. This will help to establish a feasible development concept for the geopark, and to get a broad perspective in identifying possible plans of action. It is also advisable that the main stakeholders within the community be consulted before the dossier is submitted to the Division of Ecological and Earth Sciences, UNESCO.

Figure 2. Young generation from the local community showing their support to the members of International Advisory Group during the validation mission at the Funiushan Global Geopark, China in 2006. *(Photograph©Ibrahim Komoo 2006)*.

The dossier will normally be assessed by designated members of the International Advisory Group before they proceed with the field verification or validation mission (Figure 2). Because of the time constraint, aspects that are normally being given more priority during several days of validation mission are management structure, conservation of geosites, infrastructure development, public education, socio-economic opportunity for local community and international networking. Management structure in term of its strategy and action plan is crucial because this will determine the long term sustainability of the geopark. An emphasis is also given to the local community recognition and participation, particularly in relation to conservation efforts and tourism-based economic enterprise. Finally, the report from the validation mission will be deliberated before Global Geoparks Network Bureau endorses a particular application to join as GGN member.

GEOPARK AND CONSERVATION

One of the most important building blocks for geopark development is geoheritage protection and conservation programme. Therefore aspiring geoparks must first undertake the activity to identify, evaluate and protect several geoheritage sites of international and national importance (Figure 3). In some countries where legal instruments for geoheritage conservation are already available, this activity can be carried out relatively easily. However, for many countries where specific legal instruments are still not in place, efforts toward promoting geoheritage development can be used as the initial momentum for research, policy advocacy and public awareness which lead to the establishment of the policy and legal instruments. For the short and medium-term measures, other indirect legal instruments for conservation, such as forest reserves, national parks or even cultural heritage protection can be used for some geoheritage sites.

Figure 3. Kilim Karst Geoforest Park, Langkawi Global Geopark, Malaysia not only exhibit an outstanding geological landscape of scenic beauty but also contains several important geoheritage sites of international and national value. *(Photograph©Ibrahim Komoo 2008)*.

The geopark concept recognizes the relationship between people and geology and the ability of the geoheritage resources to serve as a focus for socio-economic development. This concept promotes the integration of natural science, particularly biological resources, and culture whilst recognizing the unique importance of the geological landscape. Therefore, promoting the biological and cultural heritage conservation and sustainable use is equally significant for the balanced development of the geopark. The comprehensive geopark should make an attempt to enhance an integrated approach for natural and cultural heritage conservation and a holistic use of these resources for socio-economic development. While developing geoheritage sites for conservation and geotourism activities, some biological reserves and protected historical or archeological sites can be further enhanced and promoted together for the sustainability and balanced development of the geopark.

Even though the conservation movement in general take into account the need to conserve both natural (biological and geological) and cultural heritage (UNESCO 1988), in actual practice these three main components of conservation have been developed, promoted and conserved separately. Cultural and biological heritage are the most advanced and many countries have put in place some legal instruments for protection and conservation. The weakest component has been the geoheritage conservation. Geopark not only provides an accelerated geological conservation effort, but equally important, it will inculcate through public education and awareness, the importance of implementing a meaningful integrated conservation system.

GEOPARK AND SUSTAINABLE USE

One of the most crucial aspect of geopark development is the need to integrate various major stakeholders in its management structure. This is important because geopark usually covers an area where few existing authorities – park managers, local governments, head of local community – are in place and have to work together in developing and promoting their geopark. Since geopark, in actual fact is just a development approach, major stakeholders involved had to work as partners from the conceptualization of the idea to the development until to the implementing stage. The most effective management approach is usually in the form of a coordinating committee led by the key stakeholder and supported by the geopark manager. Geopark in essence is a pragmatic sustainable development programme where there is a need to balance between conservation and economic development and managed by major stakeholders in an integrated manner.

Geopark concept gives great emphasis on the need for socio-economic development of the local community. Unlike most of the existing parks which focus on conservation of nature, geopark provides a balanced development between conservation and the economic opportunity for the local people. Based on the concept of geotourism, many geoheritage sites within the geopark area can be developed as tourism products. In addition, this will also encourage the development of innovative local enterprises, small businesses, cottage industries and creation of new jobs by generating new sources of revenue.

Another strategic purpose of geopark development is to enhance the public awareness towards the science of natural landscape. Usually, the general public visits the parks and wilderness areas because they would like to appreciate the beauty of the scenery and landscape. Geopark programmes intend to increase public knowledge on the way in which the landscape has developed over geological time. This can be done through well planned tourism activities, particularly geotourism (Figure 4). Geotourism is based on the concept of utilization without distruction which places a greater emphasis on the intrinsic value of geological features and encourages the development of education-based tourism. Geotourism supports the objectives of sustainable tourism which enhances local tourism

Figure 4. Most geological landscapes of scenic beauty not only important in terms of geoheritage value but have great potential to be developed as geotourism destinations. Ha Long Bay World Heritage Site, Vietnam. ***(Photograph©Ibrahim Komoo 2008).***

products and activities. It is also a tool for releasing and diverting the pressure of tourism away from highly frequented sites and objects towards new geoheritage sites in the vicinity (UNESCO 2000).

CONCLUDING REMARKS

Two important features of the geopark concept are the opportunity to build the governance for sustainable development, and to provide balance between socio-economic development and environmental protection. Intergrating idea and aspiration of major stakeholders through coordination committee of geopark is a beginning of a more holistic and informal approach for land use management. Integrating the concept of conservation and active participation of local community for geopark development will enhance a sense of belonging towards local heritage, while at the same time, provide more opportunity for developing local economic activities.

Geoheritage conservation and geoparks network are two important instruments for conservation and sustainable use of geological resources with heritage value set Ibrahim Komoo 2005). While geoheritage approach can be applied to enhance research and development toward geoheritage conservation, the geopark concept is a practical mechanism to promote and utilize geoheritage resources for socio-economic development of the local community.

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GEOHERITAGE OF CHINA

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Separator Photo:
Sandstone peaks controlled by verticle joints, Longtanxia, Henan, China.

2

GEOHERITAGE OF CHINA

Zhao Ting and Zhao Xun

GEOHERITAGE RESEARCH SCENARIO

Geological heritage or geoheritage is considered as one of the most important elements of natural heritage in China (Zhao Ting & Zhao Xun 2004). It is the manifestation of geological processes acting through millions or even billions of years. Research on geoheritage is fundamental in gaining a better understanding of Earth's evolutionary progress and trends (Eder 1999; Cowie & Wimbledon 1993). These types of research projects have been carried out in China since the mid 1970s, producing a lengthy list of geoheritage sites based on current scientific knowledge.

The evaluation of the scientific significance and classification of geoheritage type are two most important foundations for geoheritage research. A better understanding of these foundations is crucial in planning for more detailed scientific research and for the development and conservation of geoheritage sites. In this matter, Chinese geoheritage researchers are not only studying the scientific value and the classification of geoheritage, but are also actively pursuing a methodology for a more comprehensive classification of geoheritage (Zhao Ting & Zhao Xun 2007).

In China, geoheritage research and geoheritage conservation initiatives are boosted by the strong and continuous support from the Ministry of Land and Resources and Chinese Academy of Geological Sciences. With such support China very successfully hosted the First International Conference on Geoparks in Beijing in 2004 and also hosted the Office of Global Geoparks Network which was established in the same year. They are also responsible in promoting the geopark concept for geoheritage conservation, for which China had already established 138 national geoparks, 20 of which have already been accepted as global geoparks (Zhao Ting & Zhao Xun 2004). With strong support from the government, China had also very successfully hosted the First and Second International Symposia on Development within Geoparks, in Jiaozhuo in 2006 (Wang Zhe 2006) and Lushan in 2007, respectively. Chinese geoparks that have already attained the UNESCO Global Geopark status are encouraged and supported by the government in participating actively in networking activities organized by the UNESCO Global Network of National Geoparks (GGN) and the Asia Pacific Geoheritage and Geopark Network (APGGN).

GEOHERITAGE RESOURCES DISTRIBUTION

Geotourism resources, mainly represented by geoheritage sites are abundant in China. The distribution of geoheritage sites is determined by such factors as geological and geotectonic evolution, weather (rainfall, temperature, etc.), neotectonic movement and topomorphology. Based on these factors, China can generally be divided into four regions that are East, Northwest, Southwest and West Pacific Coast regions (Wang Hongzhen & Mo Xianxue 1995).

The widely varying geoheritage resources of China can be grouped into several clusters according to their geological and climatic characteristics. For example, geoheritage sites related to volcanoes and volcanic rocks are chiefly found in the West Pacific coastal and Southwest China regions, while those related to palaeontology and archaeology are mainly concentrated in the East China region. The Huangshan landforms with granite peaks, peak-clusters and spheroidal-weathering are common in the East China region, while Yuntai landforms of stepped valleys are concentrated on the second geomorphographic level in the same region. Karst landforms are mostly found in the southwest and north part of the East China region, while Danxia landforms are scattered rather densely in the southern part of the same region. Meanwhile, hydrogeologically related geoheritage occurs in the south part of East China region and the Southwest China region, whereas glacial landforms can be seen in both the Southwest China region and the mountain ranges of the Northwest China region (Zhao Ting & Zhao Xun 2007).

GEOPARK INITIATIVE

In the middle of 1990s, through Professor Zhao Xun, China had joined several other countries across the globe in undertaking feasibility studies on the establishment of UNESCO geoparks. In 2000, organized and led by the Ministry of Land and Resources, the first batch of 11 Chinese national geoparks were established based on their outstanding histories of investigation, research and conservation of geoheritage. This was followed later by the second batch of 33 national geoparks in 2002, and then 41 and 53 national geoparks in 2003 and 2005, respectively, so that by 2005 a total of 138 national geoparks were already established in China (Figure 1). These geoparks are well dispersed throughout all provinces on the Chinese mainland. Internationally, therefore, China is perhaps the most aggressive of all countries in promoting national geoparks such that currently China has the largest

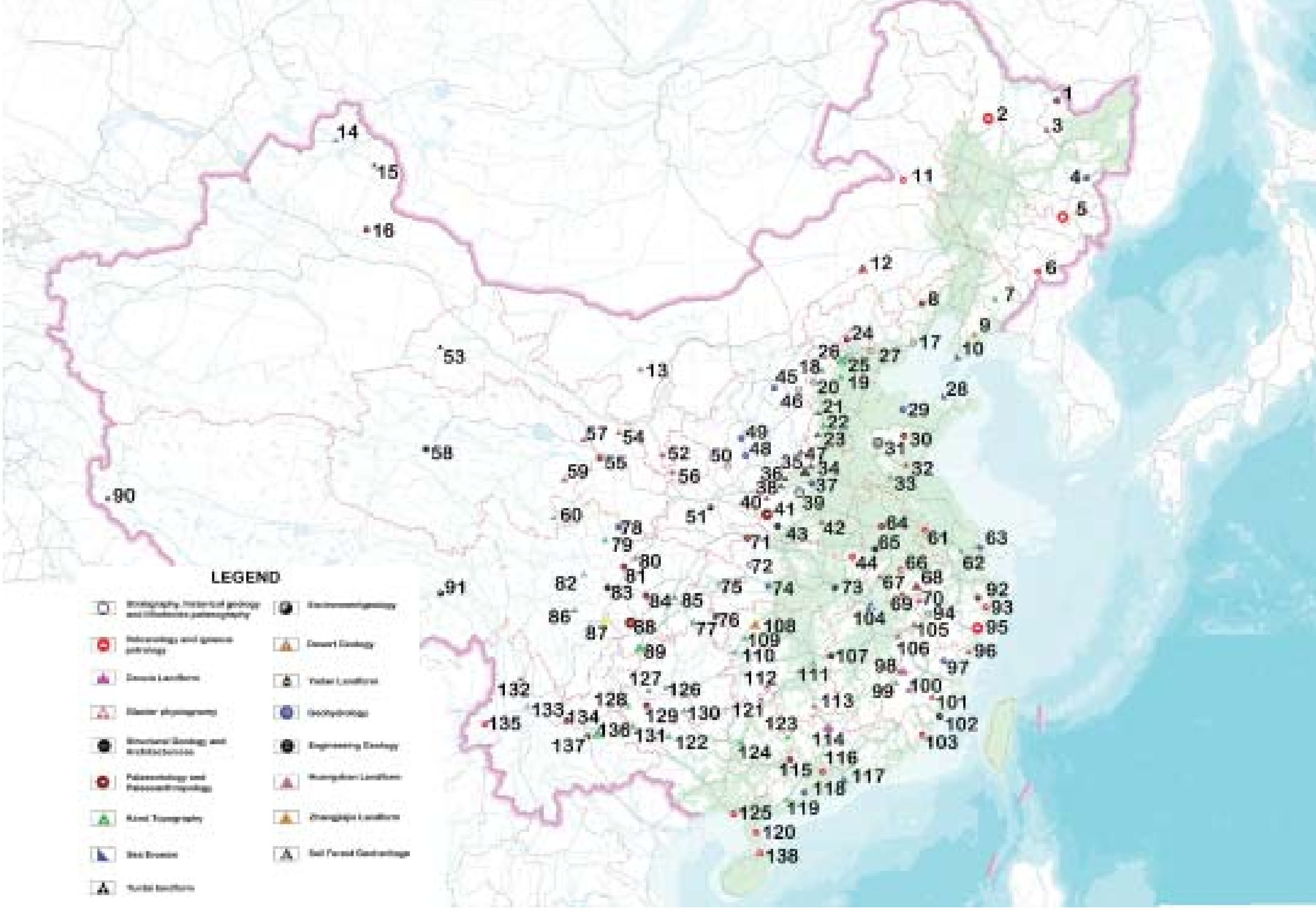

Figure 1. Distribution of 138 Chinese National Geoparks.

1. Dinosaurs National Geopark in Jiayin Heilongjiang
2. Wudalianchi Volcanoes Global Geopark in Heilongjiang
3. Yichun Granitic Forest National Geopark, Heilongjiang
4. Xiaoxinhu National Geopark, Mudanjiang, Heilongjiang
5. Jingpohu Global Geopark, Mudanjiang, Heilongjiang
6. Jinyu Volcanoes and Mineral Springs National Geopark, Jilin
7. Shuidong National Geopark, Liaoning
8. Chaoyang Bird Fossil National Geopark, Liaoning
9. Binyugou National Geopark, Liaoning
10. Dalian coastal region National Geopark, Liaoning
11. Aershan National Geopark, Inner Mongolia
12. Keshiketeng Global Geopark, Inner Mongolia
13. Alashan desert National Geopark, Inner Mongolia
14. Kanasi National Geopark, Buerjin, Xinjiang
15. Keketuhai National Geopark, Fuyun, Xinjiang
16. Qitai silicified wood and Dinosaurs National Geopark, Xinjiang
17. Liujiang National Geopark, Qinghuangdao, Hebei
18. Baishishan Laiyuan National Geopark, Hebei
19. Yeshanpo National Geopark, Laishui, Hebei
20. Peping Tianshengqiao National Geopark, Hebei
21. Zanhuang Zhangshiyan National Geopark, Hebei
22. Jingcheng National Geopark, Hebei
23. Wuan National Geopark, Hebei
24. Yanqing Silicified wood National Geopark, Beijing
25. Shihuadong National Geopark, Beijing
26. Shidu Global Geopark, Fangshan, Beijing
27. Jixian National Geopark, Tianjing
28. Changshanliedao National Geopark, Shandong
29. Yellow river Delta National Geopark, Dongying, Shandong
30. Shanwang National Geopark, Shandong
31. Taishan Global Geopark, Shandong
32. Yimengshan National Geopark, Shandong
33. Xiongershan Baoduzhai National Geopark, Zaozhuang, Shandong
34. Guanshan National Geopark, Huixian, Henan
35. Jiaozuo Yuntaishan Global Geopark, Henan
36. Wangwushan National Geopark, Henan
37. Zhengzhou Yellow river National Geopark, Henan
38. Daimeishan National Geopark, Luoyang, Henan
39. Songshan Global Geopark, Henan
40. Luanning Shenlingzhai National Geopark, Henan
41. Xixia Funiushan Global Geopark, Henan
42. Chayashan National Geopark, Henan
43. Baotianman National Geopark, Henan
44. Jinganghai National Geopark, Xinyang, Henan
45. Ningwu ice cave National Geopark, Shanxi
46. Wutaishan National Geopark, Shanxi
47. Hugkou Grand Canyon National Geopark, Shanxi
48. Hukou waterfall National Geopark, Huanghe
49. Yanchuan yellow river National Geopark, Shanxi
50. Luochuan loess National Geopark, Shanxi
51. Cuihuashan landslide National Geopark, Shanxi
52. Huoshizhai National Geopark, Xiji, Ningxia
53. Dunhuang Yadan National Geopark, Gansu
54. Jingtai Yellow river Stone Forest National Geopark, Gansu
55. Liujiaxia Dinosaurs National Geopark, Gansu
56. Kongtongshan National Geopark, Pingliang, Gansu
57. Jiading National Geopark, Huzhu, Qinghai
58. Kunlunshan National Geopark, Geermu, Qinghai
59. Kanbula National Geopark, Qinghai
60. Nianbaoyuze National Geopark, Jiuzhi, Qinghai
61. Liuhe National Geopark, Nanjing, Jiangsu
62. Taihu Xishan National Geopark, Suzhou, Jiangsu
63. Chongmingdao National Geopark, Shanghai
64. Bagongshan National Geopark, Huainan, Anhui
65. Dabieshan Liuhe National Geopark, Anhui
66. Fushan National Geopark, Anhui
67. Tianzhushan National Geopark, Qianshan, Anhui
68. Huangshan Global Geopark, Anhui
69. Guniujiang National Geopark, Qimen, Anhui
70. Qiyunshan National Geopark, Anhui
71. Yunxian Dinosaurs eggs fossil National Geopark, Hubei
72. Shennongjia National Geopark, Hubei
73. Mulanshan National Geopark, Wuhan, Hubei
74. Three Gorges National Geopark
75. Longgang National Geopark, Yunyang, Chongqing
76. Xiaonanhai National Geopark, Qianjiang, Chongqing
77. Wulong Karst National Geopark, Chongqing
78. Jiuzhaigou National Geopark, Sichuan
79. Huanglong National Geopark, Songpan, Sichuan
80. JiangYou National Geopark, Sichuan
81. Anxian National Geopark, Sichuan
82. Siguniangshan National Geopark, Aba, Sichuan
83. Longmenshan National Geopark, Sichuan
84. Shehong silicified wood National Geopark, Sichuan
85. Huayingshan National Geopark, Guangan, Sichuan
86. Hailuogou National Geopark, Sichuan
87. Daduhe Canyon National Geopark, Sichuan
88. Zigong Dinosaurs Global Geopark, Sichuan
89. Xingwen stone sea Global Geopark, Sichuan
90. Zhada Soil Forest National Geopark, Xizang
91. Yigong National Geopark, Xizang
92. Xinchang silicified wood National Geopark, Zhejiang
93. Linhai National Geopark, Zhejiang
94. Changshan National Geopark, Zhejiang
95. Yandangshan Global Geopark, Zhejiang
96. Fuding Taimushan National Geopark, Fujian
97. Pingnan Baishuiyang National Geopark, Fujian
98. Taining Global Geopark, Fujian
99. Tianxiadong National Geopark, Ninghua, Fujian
100. Yongan National Geopark, Fujian
101. Shiniushan National Geopark, Dehua, Fujian
102. Shenhuwan National Geopark, Jingjiang, Fujian
103. Zhangzhou coastal region Volcanoes National Geopark, Fujian
104. Lushan Global Geopark, Jiangxi
105. Sanqingshan National Geopark, Jiangxi
106. Longhushan National Geopark, Jiangxi
107. Wugongshan National Geopark, Jiangxi
108. Zhangjiajie sandstone forest Global Geopark, Hunan
109. Guzhang red stone forest National Geopark, Hunan
110. Fenghuang National Geopark, Hunan
111. Jiuhuijiang National Geopark, Youxian, Hunan
112. Langshan National Geopark, Hunan
113. Feitianshan National Geopark, Binzhou, Hunan
114. Danxiashan Global Geopark, Renhua, Guangdong
115. Fengkai National Geopark, Guangdong
116. Xiqiaoshan National Geopark, Guangdong
117. Dapeng Peninsula National Geopark, Shenzhen, Guangdong
118. Enping Underground Heat National Geopark, Guangdong
119. Lingxiaoyan National Geopark, Yangchun, Guangdong
120. Huguangyan National Geopark, Guangdong
121. Ziyuan National Geopark, Guangxi
122. Leye Dashiwei Tiankeng National Geopark, Baise, Guangxi
123. Fengshan National Geopark, Guangxi
124. Luodianxiangjiao Karst National Geopark, Guangxi
125. Weizhoudao Volcanoes National Geopark, Beihai, Guangxi
126. Shuanghedong National Geopark, Suiyang, Guizhou
127. Zhijingdong National Geopark, Zhijing, Guizhou
128. Wumengshan National Geopark, Liupanshui, Guizhou
129. Guanling Fossil National Geopark, Guizhou
130. Pingtang National Geopark, Guizhou
131 Xingyi National Geopark, Guizhou
132. Yulong Liming-Laojunshan National Geopark, Yunnan
133. Dali Cangshan National Geopark, Yunnan
134 Lufeng Dinosaurs National Geopark, Yunnan
135. Tengchong Volcanoes National Geopark, Yunan
136. Yunnan Stone Forest Global Geopark
137. Chengjiang Paleospecies fossil National Geopark, Yunan
138. Shishan Volcanoes National Geopark, Haikou, Hainan

number of national geoparks included in the list of the UNESCO assisted Global Geoparks Network (GGN). Since the GGN was established in 2004 China has managed to upgrade 20 of its national geoparks to become members of the UNESCO Global Network of National Geoparks. Other national geoparks of China seem already very well prepared to be nominated as candidate global geoparks and it is anticipated that more Chinese national geoparks will soon join this list.

NATIONAL GEOPARK CLASSIFICATION

Since the inception of the geopark concept at the beginning of the 21st century, China has seen a rapidly growing demand for geoheritage protection under this concept. Up till now, China has established 138 national geoparks that differ from one another because of their contrasting geological background, geological history and geotectonic evolution. These differences have directly influenced the required protection and development plan of each geopark.

As mentioned above, Chinese national geoparks constitute a very big family displaying various geoheritage categories although no single geopark contains all categories of geoheritage. In normal practice, emphasis is placed on only the most important geoheritage characteristics when identifying the geoheritage category of individual geoparks. In coping with such highly diverse geoheritage, a better scientific and more elaborate classification system of geoheritage, geoheritage sites and geoparks is required to replace the old classification system which is somewhat superficial in nature. A new classification of geoparks has been created based on the conventional division of geoscientific disciplines such as stratigraphy, palaeontology, geomorphology, volcanology and engineering geology (Zhao Ting & Zhao Xun 2007). According to this new classification system, the 138 national geoparks in China can generally be subdivided into the following categories:

1. Stratigraphy, geological history and palaeolithofacies (8 national geoparks)
2. Palaeontology and palaeoanthropology (18 national geoparks)
3. Volcanic and other igneous rocks (15 national geoparks)
4. Tectonic structure (7 national geoparks)
5. Geomorphology and landscape – which can be subdivided further into:
    - Danxia landform (represented by 14 national geoparks)
    - Karst landform (represented by 27 national geoparks)
    - Yuntai landform (represented by 7 national geoparks)
    - Huangshan landform (represented by 12 national geoparks)
    - Glacial landform (represented by 6 national geoparks)
    - Yardan landform (represented by 3 national geopark)
    - Zhangjiajie landform (represented by 3 national geoparks)
    - Marine erosion landform (represented by 3 national geoparks)

6. Hydrogeology (in 11 national geoparks)
7. Environmental geology and geohazards (3 national geoparks)
8. Engineering geology (in 1 national geopark)
9. Metamorphism and metamorphic rocks (in several national geoparks such as Taishan, Songshan, etc.)

Apart from these categories, some Chinese national geoparks could also be included in categories such as mineralogy and mining. The definitions of the various Chinese Geopark categories, with examples of geoparks that represent them, are discussed in the following sections.

Stratigraphy, Geological History and Palaeolithofacies

This category of geoheritage includes type sequences and index stratigraphic cross-sections, some of which have been recognized as global standards for geochronological classification. This category also includes significant events recording geological evolution and processes, such as in palaeotectonics, palaeogeography and palaeoenvironments, studied since the early years of geological investigation. These includes type sections of stratigraphic units and systems, type localities for special sedimentary structures and textures that have become cradles for geological training, or a basis for the creation of new theories or modification of old concepts. Most geoheritage sites under this category are distributed in East and South China, because of their easy access and long histories of geological investigation. Geoheritage features related to this category of geopark are briefly described in Table 1 of Appendix 1 (Figures 2a, b).

Figure 2. Taishan Geopark in Shandong Province; a) blocks from collapsed granite peaks, b) metamorphosed Proterozoic rocks.

Palaeontology and Palaeoanthropology

This category of geoheritage is represented by important fossil sites, such as palaeobotanical sites, assorted palaeofauna, dinosaurs, birds, silicified trees and other crucial fossils for taxonomic classification and stratigraphic correlation. However, more attention has been paid to palaeofaunas for their significance in geochronology, the origin of life, evolution and paleontological development. As such, palaeofaunas can be used to differentiate one stratum from the another even though they are lithologically identical. Geoheritage sites under this category are mostly located in East and South China as this is where basic geological research was developed relatively early, and most importantly where abundant fossils were discovered in sedimentary basins within the tectonic belts. Geoheritage features related to this category of geopark are briefly described in Table 3 of Appendix 1 (Figures 3a, b, c).

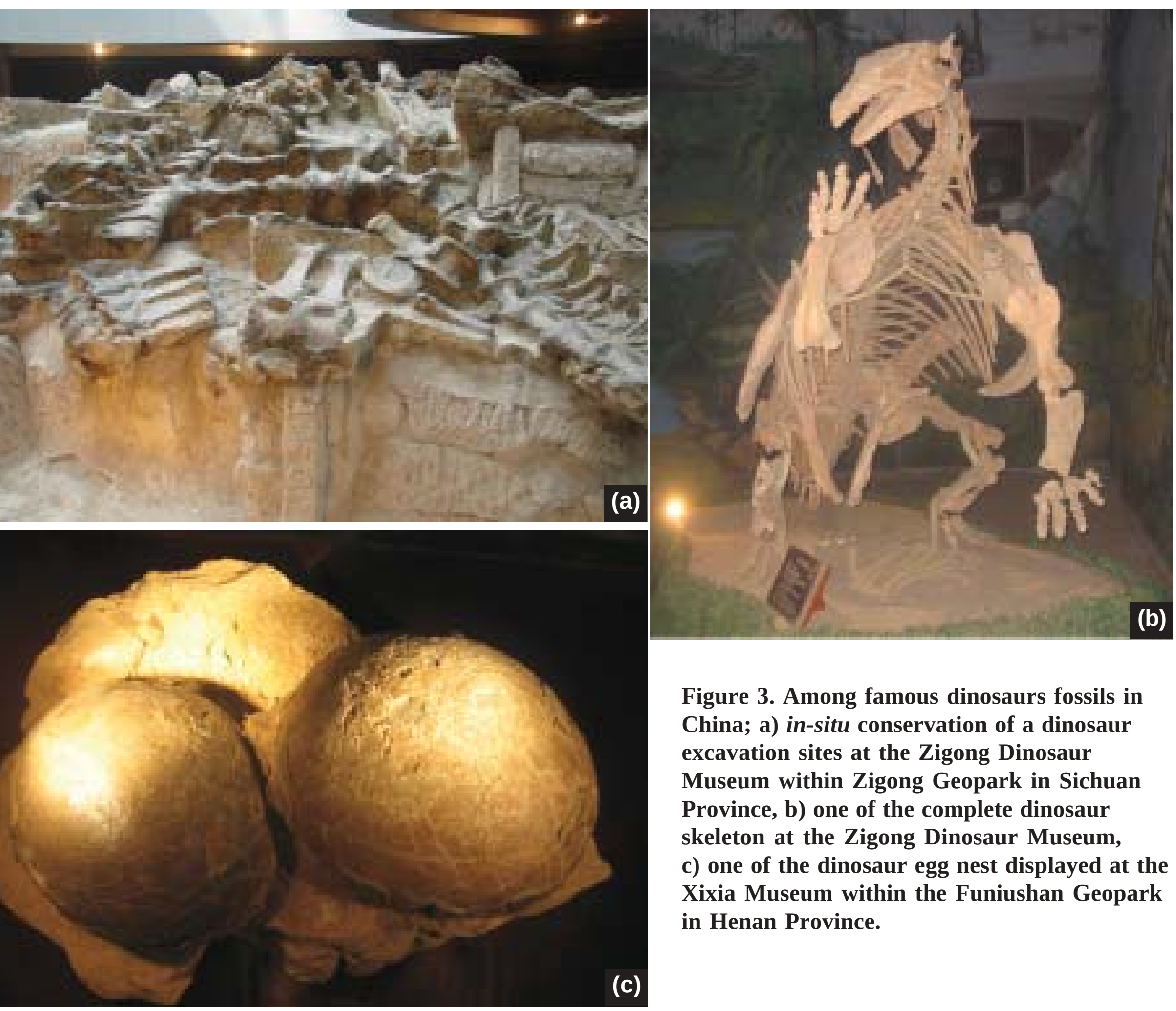

Figure 3. Among famous dinosaurs fossils in China; a) *in-situ* conservation of a dinosaur excavation sites at the Zigong Dinosaur Museum within Zigong Geopark in Sichuan Province, b) one of the complete dinosaur skeleton at the Zigong Dinosaur Museum, c) one of the dinosaur egg nest displayed at the Xixia Museum within the Funiushan Geopark in Henan Province.

Volcanic and Igneous Rock

Geoheritage sites related to volcanoes are mainly located in the East China, along the Pacific coastal zone and along the active tectonic belts in the southwest region. They are characterized by various geomorphological features such as craters, crater lakes, barrier lakes, maars, volcanic cones clusters and chains, volcanic hot springs, volcanic vents and pipes, calderas, lava plains and lava tubes, lava domes and fumerolic cone in cones. They are also characterized by various volcanic products such as pyroclastic deposits, lava flows, cinders and pumice, glasses, volcanic gases, pahoehoe, ropy, aa and pillow lavas, lava spines, lava stalactites, effusive domes, bombs and balls. Geoheritage resources in volcanic belt are extremely abundant. It is necessary to preserve these resources and make good use of them for the benefit of future generations. Geoheritage features related to this category of geopark are briefly described in Table 3 of Appendix 1 (Figure 4).

Figure 4. Mount Fengluling ancient volcanic crater.

Tectonic Structure

Geoheritage sites featuring tectonic structure are chiefly distributed in accordance with tectonic boundaries such as suture zones, orogenic belts and subduction zones, where strong tectonic deformation and metamorphism and related tectonic structures are spectacular. In China, this category of geoheritage site is commonly found along the margin of the Qinghai-Tibet plateau, in the Qinling-Dabie orogenic belt and along the east coast zone (Zhang Yueqiao et al. 2003). Geoheritage features related to this category of geopark are briefly described in Table 4 of Appendix 1.

Geomorphology and Landscape

The following are descriptions of various sub-categories of geomorphology and landscape widespread in China.

Danxia Landform

Danxia landform is widespread all over China marked by Jurassic to Palaeogene downwarped graben basins where red terrestrial clastic sediments were deposited. These basins are widely distributed along NNE-NE and WNW-NNW trending active faults in East China and Northwest China, respectively. Subsequent crustal uplift generated rolling hills with well developed faults, fissures and joints, through which rainfall penetrated and in combination with hot weather, eroded, abraded and scoured the rocks, resulting in the formation of flat-topped hills, precipitous cliffs, gentle foot slopes, deep gorges, pillars, columns, natural bridges and caves. Danxia landforms are usually covered with dense vegetation. Geoheritage features related to this category of geopark are briefly described in Table 5 of Appendix 1 (Figures 5a, b, c, d).

Figure 5. Some of the typical danxia landform in China; a) typical clusters of red rock columns and domes within Liangshan Geopark in Hunan Province, b) red rock column within Longhushan Geopark in Jiangshi Province, c) Strange natural sculpture within Longhushan Geopark, d) Water scouring within Longhushan Geopark.

Karst Landform

Karst landforms (Figures 6a, b, c) are strongly developed in southwest China, and north part of northern China because of the wide occurrence of carbonate rocks containing well developed cracks and joints. The formation of karst is controlled partially by uneven rainfall and differential daily or seasonal temperatures. This category of geoheritage is not only seen on the surface, but also underground. Among the main features are deep valleys, clusters of peaks, columns, stone forests, natural bridges, karst windows, funnels, sinkholes, dolines, ponds or lakes, springs, underground streams, wadi, blind valleys and caves. The latter contains mud and pebble accumulations, chemical deposits such as stalactites, stalagmites and sinters with strange shapes sometimes resembling human and animal sculptures that have become important geotourism resources. Rich archaeological and cultural relics are also found in some caves. Geoheritage features related to this category of geopark are briefly described in Table 6 of Appendix 1.

Figure 6. Several karstic features within geoparks of China; a) karst peak from Shilin Stone Forest Park within Shilin Geopark in Yunnan Province, b) Spectacular limestone cave formation within Laiyuan Geopark in Hebei Province, c) cone-shaped karst peaks found in Guizhou Province.

Yuntai landform

The amazing Yuntai landform is well developed chiefly along the second geotomographic terrane from northeast to southwest of China, (i.e. from the Xinganling, Yanshan, Taihangshan, West Henan and Hubei mountain ranges, to the east margin of the Yun-Gui Plateau as well as in the Yellow River valley and the Hexi corridor closed to the Qilian mountains). The second geotomographic terrain was formed due to the differential crustal uplift between the east China plain and the central Chinese plateau and the mountains. The geomorphological features are almost identical to those of Grand Canyon in the U.S.A. From the top of the plateau, various groups of geomorphological features can be distuingished including the plateau surface with hill remnants, long cliffs, narrow but precipitous walls, steps of terraces clinging to the cliffs and walls, scattered clusters of peaks, columns and pillars. Meanwhile from the bottom of the valleys, prominent geomorphological features include broad valley with ‘valley in valley’ formed due to late crustal uplift. More recent water erosion forms waterfalls and cascades, while torrential currents have generated fantastic geoheritage features such as scoured troughs, potholes, knick points, shoals and river terraces. The intercalation of carbonate and clastic rocks in some sequence has sometimes resulted in some karst features to accompany the main Yuntai geoheritage relics which formed in clastic rocks sequences. Geoheritage features related to this category of geopark are briefly described in Table 7 of Appendix 1 (Figures 7a, b, c).

Huangshan Landform

The Huangshan landform was formed in granite areas where vertical joints and fissures developed in patches, and where precipitation is abundant. In such places, mountain slopes are steep, weathering and erosion are strong and vegetation is vergent. This geoheritage category is characterized by fantastic pillars, peak columns, deep gorges and gullies, but interspersed with domes and cones in less jointed patches, together forming strange rocks naturally shaped to imitate human and animal figures. Geoheritage sites of this category differ in appearance in various climate zones. In northern China, they are characterized by columns and pillars like splitting fish fans because of the stronger wind and frost effects. In the south, where water erosion prevails, pillars, steep peaks and gorges, domes and cones are commonly developed in addition to columns. Geoheritage features related to this category of geopark are briefly described in Table 8 of Appendix 1 (Figures 8a, b, c).

Figure 7. Several characteristic features of Yuntai landscape in China;. a) peak clusters in a stepped valley within Yuntaishan Geopark in Henan Province, b) collapsed sandstone bed at Daimeishan Geopark in Henan Province, c) peak clusters in a stepped valley within Huguan Geopark in Shanxi Province.

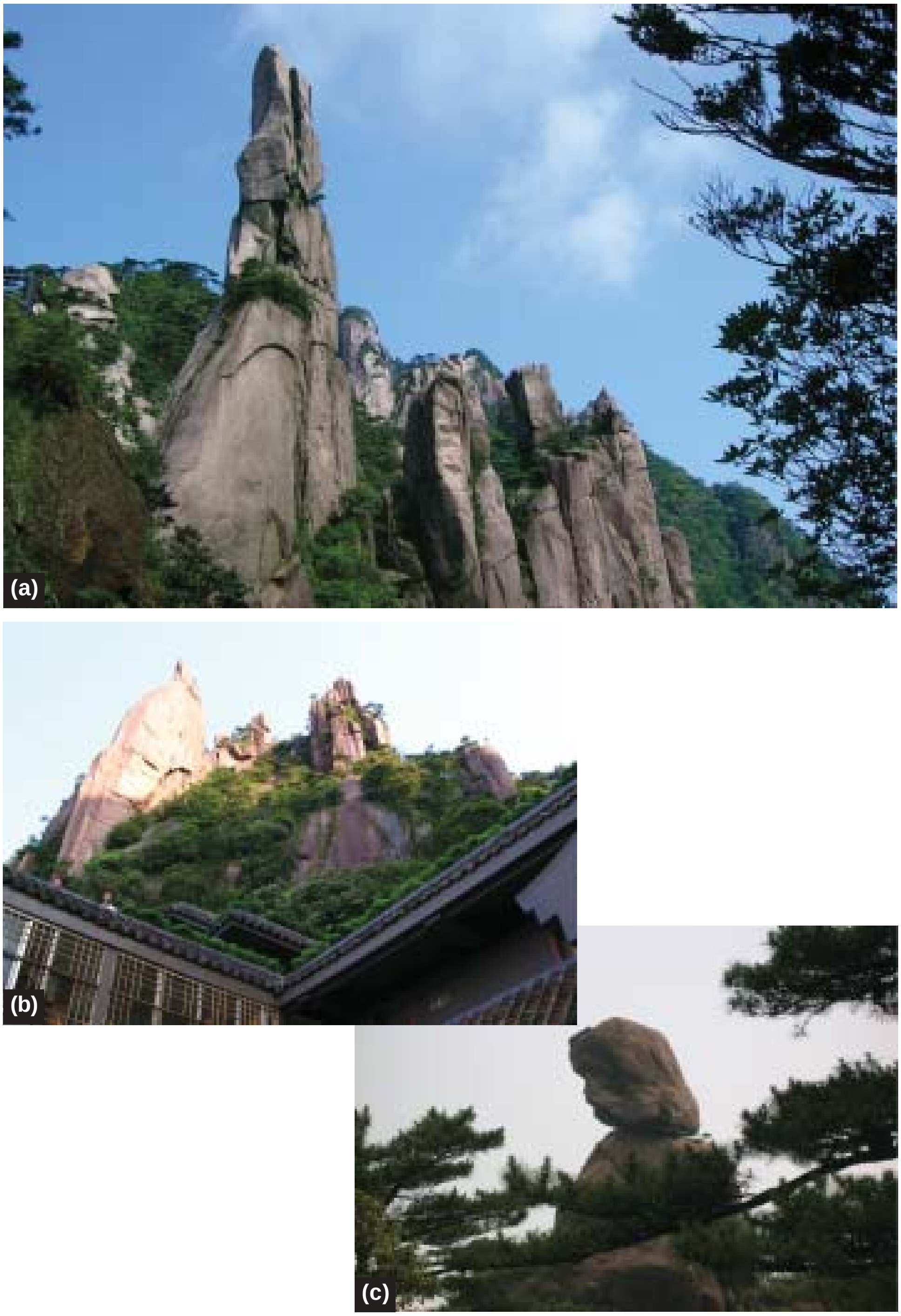

Figure 8. Some of the amazing geomorphological features of Huangshan landform; a,b) granite peak clusters within Sanqingshan Geopark in Jiangxi Province, c) Natural statue of Buddha within Sanqingshan Geopark (*Photographs courtesy of Mohd Shafeea Leman*).

Glacial Landform

Contemporary glaciation is a fairly common phenomenon in southwest and northwest China, such as on the Qinghai-Tibet Plateau and in several other huge mountain ranges where glacial landforms are still being formed. In addition, ancient glacial features from the Quaternary glaciation in China are also common, though identification of some is still controversial. Most Chinese geologists believe that the Quaternary glaciation existed in most Chinese territories, even in east China. These glacial geoheritage sites can be affirmed with the presence of U-shaped valleys and glacial hanging valleys, fish fan crests, cross-walls, roche moutonnees, moulins, moraines, glacial boulders and laminated clay deposits. Geoheritage features related to this category of geopark are briefly described in Table 9 of Appendix 1 (Figure 9).

Figure 9. Beautiful scenery of glacial erosion landform from Kanasi Lake Geopark in Xinjiang Province.

Assorted Landforms

Yardang landform, also known as *Yuanmeng* or earth forest landform (Table 10a, Appendix 1) is characterized by red earth forming a muddy crust with well developed vertical joints, occurring within regions with hot and wet weather condition. This geoheritage category is common in the southern part of China, with rare occurrences in the northwestern part of China. In these regions where the sediments are poorly cemented and the weather is typically dry with uneven and seasonally distributed rainfall, the loose sediments are washed away by torrential flow during the summer storms, then wind reforms the features in dry seasons. This category of geoheritage is usually characterized by clusters of earth peaks and pillars, columns, earth forests, castle-shaped hills, various figures resembling humans and animals, wind-eroded rocks with many blowholes, mushroom rocks, *tafoni*, rocky deserts, desert varnishes and incised gullies or troughs.

Zhangjiajie landform (Table 10b, Appendix 1) is chiefly composed of gently bedded quartz sandstone with well developed vertical joints, within regions with a wide range of temperatures and abundant precipitation. This category of landform is not common but is highly appreciated for its beauty and geoscientific significance. Several isolated geoheritage sites under this category have been formed at scattered locations in east and southwest China (Figures 10a, b).

Figure 10. Some of the breathtaking landscape of Zhangjiajie landform; a) sandstone peak clusters in one of the valleys within Zhangjiajie Geopark in Hunan Province, b) among the sandstone peaks within Zhangjiajie Geopark.

Coastal erosion landform (Table 10c, Appendix 1) consist predominantly of erosion features on coastal and island karst (Figures 11a, b) and volcanic rocks.

Figure 11. Among geomorphic features resulting from marine erosion; a) sea-eroded carbonate peak within Dalian Seashore Geopark in Liaoning Province, b) sea-eroded carbonate column within Dalian Seashore Geopark.

Hydrology

Water is very dynamic agent and a very important factor in external geological processes that produce geoheritage sites characterised by springs, waterfalls, cascades, rivers, lakes and seas, and even underground rivers. In this context, not only the physical forces of water, but also their chemical functions play a crucial role in the formation of geoheritage resources. The mechanical functions of water generates such features as valleys, dividing crests, river beds, rills, gullies, pools, troughs, sand bars, flood plains, shoals, alluvial sand waves, ripples, potholes, knick points, meanders, meander necks and cores, ox-bow lakes, natural levees, incised meanders, alluvial cones and fans, stream captures, reversed rivers, valley in valleys, valley terraces and intermountain plains. This category of geoheritage is widespread throughout China, but the types of geoheritage vary according to the rainfall and topographic patterns. Geoheritage features related to this category of geopark are briefly described in Table 11 of Appendix 1.

Engineering Geology, Environmental Geology and Geohazard

From 3000 years ago, the Chinese people began to tame the rivers in order to protect their agricultural land, its harvest and their villages from floods, and also to use them for irrigation and transportation. Since then, Chinese people have built dams and channels all over the country, from east to west, and from south to north, to support their socio-economy and protect their livelihoods. In recent years, several deep continental scientific drilling projects have been carried out nationwide and the project sites are kept as long term observatories and field laboratories for enhancing geoscientific knowledge.

In another aspect, geohazards are a serious problem in some parts of China such as the Henduan mountain range in west Sichuan and Yunnan Provinces and the coastal zone along the Pacific neo-tectonic belts, close to fault rift grabens. Such geohazards as earthquakes have long been affecting the social and economical development in China. Various historical rock-falls, collapses, landslides, mud flows and debris slides that have taken place on mountain slopes and valley sides have caused serious geoenvironmental problems in the country. Some of these sites have subsequently been developed into very useful geoheritage sites for public education in order to make the people understand the various aspects of geoenvironmental hazards and ways to tackle them (Zhang Yueqiao et al. 2003). Geoheritage features related to this category of geopark are briefly described in Table 12 of Appendix 1.

GEOHERITAGE CONSERVATION AND GEOPARK DEVELOPMENT

Since the year 2000, Chinese geopark initiatives have been accelerating rapidly after a lengthy preparation for geoheritage conservation, shoulder to shoulder with the European geopark counterparts. The Ministry of Land and Resources of China (MLR) was appointed to undertake the responsibility for geoheritage protection. For this the MLR has selected 23 scientists from various disciplines together with technicians and administrative officers to create a national lead group and expert evaluation committee. A blueprint for long term development of geoparks has been formulated to be used as a master plan for geoheritage conservation and geopark construction in China. To futher accelerate the tempo, a series of laws and regulations for administration, management and evaluation were formulated and put into operation. The on-site evaluation of all Chinese national geoparks has urged the local government and managing bodies to improve their work to fulfill the demands of GGN guidelines and criteria for scientific research, information databases, interpretation panels, training programs, technical and administrative personnel exchanges as well as cultural and social activities.

Cooperation between scientists and government officers is crucial for sustaining the success of Chinese national geoparks in undertaking geoenvironment and geoheritage conservation and geotourism promotion. In order to support the national geoparks in protecting geoheritage sites, restoring the geoenvironment, studying and popularizing scientific knowledge, developing geotourism, supporting the local economy and promoting social progress the governments at various levels have allocated some funds in addition to the fixed proportion of paid-back benefits from geotourism income. The expert group, on the other hand, provides expert opinion based on sound scientific foundations and advanced technology in order to improve the conservation concept, infrastructural development, museum and explanation board designs, tour route arrangements, training of guides, as well as strengthening cooperation among the geoparks. They are also responsible for evaluating the progress of geopark construction.

For the purpose of networking, 138 national geoparks, including 20 GGN members and some 80 provincial geoparks have been consolidated to form a national network. Once a year, the managers and geoscientists from all national geoparks will gather to discuss some common problems. Most proposals about geoheritage conservation and geopark construction from this annual meeting will be scrutinized by the MLR to be used as a guide in directing national geoparks to follow certain laws and regulations in order to improve their administration. Once every two years, one of the GGN members in China should volunteer to organize an International Symposium on Sciences and Development within Geoparks, during which several well known geopark researchers are invited to deliver speeches on special topics such as geoheritage and conservation concepts, interpretations and conservation techniques to the geopark administrators, geoscientists and tourism operators. This meeting also provides opportunities to create liaison between one geopark and another. Personnel exchanges between geoparks and ranger training programs have been carried out regularly for several years in order to enhance their capacity to manage and protect geoheritage resources and ensure that the public gain more knowledge of the harmony between human beings and nature through Earth environmental conservation.

Both the Chinese geopark network and GGN have been playing a very important roles in supporting geoheritage conservation, geoenvironment restoration, scientific data popularization, information exchange, billboard improvement and museum establishment and also in implementing evaluation methodologies, organizing training courses for public and rangers and inviting prominent scholars from home and abroad to share their experiences on various aspects of geopark management and development (Zhao Ting & Zhao Xun 2003). Participation in the UNESCO supported GGN Geopark Conference has given Chinese geopark officials good opportunities to learn and improve their geopark conservation and interpretation skills together with various other aspects of geopark development.

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Appendix 1

Table 1. China's National Geoparks that fall within the category of stratigraphy, geological history and palaeolithofacies.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1.	Taishan Geopark, Shandong Province (**Figure 2**).	Stratigraphic sections of the Neo-Archeozoic to Paleo-Proterozoic, Cambrian and Early Ordovician; Early Paleozoic fossils; neotectonism and geomorphology.	Cenozoic uplifting of the Jiao-Liao old massif on the Sino-Korean plate.	Temperate monsoon climate with marked vertical micro-climate variation; numerous waterfalls; over 1000 years old trees.	A place where previous emperors worshipped Heaven; Buddhist and Taoist temples, steles of engravings on cliffs.
2.	Shennongjia Geopark, Hubei Province	Folded metamorphic basement; Pleistocene palaeoanthropic relics, mountainous glacial, fluvial and karst landforms.	Fault-dome structure; two tiered peneplain surfaces (at 2800-3100 metres and 2400-2600 metres).	Tropical monsoon with distinct multi-level micro-climate.	Stationing troops in ancient times, ancient temples, stone inscriptions, wood carvings, the old Sichuan-Hubei Salt-transport Road.
3.	Wutaishan Geopark, Shanxi Province.	Stratigraphic units and tectonic events.	Peneplanation surface; well developed typical peri-glacial geomorphology.	Warm temperate monsoon-type continental climate with vertical variation in temperature.	The Five Table Mountains, Upward-Facing Buddha, temples.
4.	Fuping Geopark, Hebei Province	Standard Longquanguan Formation.	Piedmont fault system; Taihang Mountains.	Waterfalls and hot springs.	Site of early geologists' activities in China.
5.	Songshan Geopark in Henan Province	Three clear unconformities: three tectonic movements.	Differential uplift caused by block faulting.	Dense forest.	Shaolin Monastery, clusters of Pagoda Forest.
6.	Jixian Geopark, Tianjin Province	Stratigraphic section of the Middle-Upper Proterozoic (1.8-0.8 Ga).	Old gently-dipping strata on the North China Platform	Geomorphology of carbonate peak clusters.	Huangya Pass, ancient battlefield.
7.	Changshan Geopark, Zhejiang Province.	Stratotype profile (GSSP) of the Darriwilian Stage reef limestone.	Stable neritic carbonate deposits of the Yangtze Platform.	Karst, low mountain and hilly terrains.	Adjacent to Taihu Lake scenic spot.
8.	Luochuan Geopark, Shanxi Province.	Standard section of loess deposits; loess landform.	Loess deposition area in the western part of the North China Platform	Loess gullies, terraces, tablelands and ridges; sparse dry vegetation.	Loess folk culture; site of Luochuan Meeting.

Table 2. China's National Geoparks from the category of palaeontology and palaeoanthropology.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
	Palaeobotany				
1.	Yanqing Geopark, Beijing Province.	Swarms of *in-situ* buried silicified wood fossils.	Northern margin of the North China Platform; Mesozoic inland basin.	Medium- to low-mountain land.	Historical sites of human being.
2.	Qitai Geopark, Xinjiang Province.	Silicified wood fossil, swarm of dinosaur fossils, yardang.	Southern part of the Junggar Basin.	Margin of the Gurbantunggut Desert.	Ancient Silk Road; cultures and customs of ethnic minorities.
3.	Xinchang Geopark, Zhejiang Province.	Silicified wood occurring in six layers; Danxia landform.	Mesozoic red volcanic terrigenous clastic sediments of rift basin	Low mountains, hills, and dense vegetation of Cathaysian massif.	Bhuddist temples; local operas.
4.	Shehong Geopark, Sichuan Province.	Silicified wood and paleontological fossils.	Grayish yellow calcareous lithic arkose of Penglaizhen Formation.	Predominantly subtropical humid monsoon climate.	China's "Dead Sea"; temples, Tartar caves.
	Dinosaur				
1.	Zigong Geopark, Sichuan Province.	Dinosaur fossils complete skeletons. (**FigureS 3a, b**).	Yangtze Platform; Mesozoic inland lakes and swamps.	Hills of red-bed in central Sichuan.	Guilds; ancient salt wells.
2.	Liujiaxia Geopark, Gansu Province.	Large dinosaur footprints (longer than 1 metre).	Mesozoic inland lakes in the west North China Platform.	Canyons in the upper reaches of the Yellow River.	Liujiaxia Power Station and Liujiaxia Reservoir.
3.	Jiayin Geopark, Heilongjiang Province.	Dinosaur fossils of the latest Cretaceous in China.	Wandashan Massif.	Natural landscape in northernmost China.	Three-river holiday resort.
4.	Xixia/Funiushan Geopark, Henan Province.	Dinosaur egg fossils (**Figure 3c**), Qinling orogenic belt.	Boundary between the north China Platform and the Qinling tectonic belt.	Border between China's northern and southern climate zones and biotic provinces.	Relics of historical interest.
5.	Yunxian Geopark, Hubei Province.	Fossils of Cretaceous dinosaur eggs.	Middle Proterozoic Wudang Group, the Upper Cretaceous and the Quaternary.	Mild climate with four distinct seasons.	Ape cave at Meipu; *Australopithecus*; the Fairy Maiden Cave.

(*Continued*)

(*Continue Table 2*)

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
	Palaeoanthropology				
1.	Fengkai Geopark, Guangdong Province.	Relics and fossils of ancient human-being since 0.14 Ma; geological and geomorphological features.	Northern margin of Yunkai belt of the South China fold system; multi-level river terraces; karst caves.	Tropical-subtropical monsoon climate.	Ancient capital of Lingnan (the Guangdong-Guangxi region).
	Assorted palaeofauna				
1.	Chengjiang Geopark, Yunnan Province.	Early Cambrian (530 Ma) biotic explosion; synchronous appearance of tens of biotic taxa.	Stable neritic environment.	Hills and lakes (faulted).	Fuxian Lake tourist area.
2.	Huainan Geopark, Anhui Province.	Huainan biota (700-800 Ma); stratigraphic section.	Southern margin of North China Platform.	Border between China's northern and southern climatic zones.	Ancient (383 AD) famous battlefield.
3.	Anxian Geopark, Sichuan Province.	Devonian siliceous sponge reef.	Western margin of Yangtze Platform.	Medium- to low-mountain landform and forest.	Ancient temples, stockaded villages and fortresses.
4.	Shanwang Geopark, Shandong Province.	Abundant and perfectly preserved Miocene biota.	Volcanic fault basin.	Volcanic cones, craters and caldera lakes.	Museum lake.
5.	Guanling Geopark, Guizhou Province.	Perfectly preserved Late Triassic marine reptile and crinoid fossils.	Neritic bay in the south-western part of Yangtze Platform.	Karst landform; flourishing vegetation.	Huangguoshu Waterfall.
6.	Changshan Geopark, Zhejiang Province.	Middle Orodovician Darriwilian Stage of GSSP; graptolites and conodonts; karst geomorphology.	Southeastern margin of Yangtze Platform; tectonic boundary of Cathaysian massif.	Karst hills; luxuriant vegetation.	Ancient temples and pagodas.
7.	Lufeng Geopark, Yunnan Province.	Middle Jurassic Lufeng dinosaur and Miocene ape fauna.	Western margin of Yangtze Platform; Xikang-Yunnan fault.	Mesozoic and Cenozoic red sedimentary basins.	Silk Road of Southwest China; 24 ethnic minorities.
8.	Chaoyang Geopark, Liaoning Province.	Rehe fauna with abundant birds, dinosaurs, primitive mammals, earliest flower and fruit and various insects.	Northern margin of North China Platform; Yanshanian laccustrine basin; Volcanic eruption.	Vegetation and hills peculiar to semi-arid zone.	Holy Land of Bhuddism in Liao Dynasty; relics of Hongshan Culture.

Table 3. China's National Geoparks that are based on volcanic rocks.

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1. Wudalianchi Geopark, Heilongjiang Province.	Volcanic geomorphology. 14 volcanoes, typical lakes.	Affected by the circum-Pacific tectonism; east Asia rift system.	Plains, hills and vegetation are well-developed.	Temples and monasteries; ore sludge and medical springs.
2. Zhangzhou Geopark, Fujian Province.	Littoral volcanics; columnar joints of basalt; volcanic fumaroles and cones.	Affected by circum-Pacific tectonic activities.	Seashore hills, sand beaches, islands, marine erosion landform.	Ancient forts, castles, temples.
3. Tengchong Geopark, Yunnan Province.	Volcanoes, biodiversity, various types of hot springs and sinter.	Hengduan Mountains fold belt; strong neotectonic movement.	Low mountains, hills, springs, lakes and luxuriant vegetation.	Ancient frontier city; cultures and customs of ethnic minorities.
4. Huguangyan Geopark, Guangdong Province.	Volcanic landform, Maar Lake.	Circum-Pacific volcanic rocks.	Hills, a lake and flourishing vegetation.	Temples and engravings on cliffs.
5. Fushan Geopark, Anhui Province.	Volcanic rocks (weathered) volcanic cones, craters, cinder and lava flows.	A fault basin in the east Asia rift system.	Hills and luxuriant forest.	Temples and engravings on cliffs.
6. Linhai Geopark, Zhejiang Province.	Late Cretaceous volcanoes, columnar joints, pterosaurd bird fossils.	Circum-Pacific tectonic volcanic belt.	Littoral hills.	Ancient architectures.
7. Yandang Mountain Geopark in Zhejiang	Early Cretaceous large calderas, processes of volcanic eruption, caldera collapse, resurgence and re-eruption, waterfalls.	Volcanic zone on the west side of the circum-Pacific belt; mobile zone on the margin of Eurasia.	Flourishing vegetation, 4 scenes: peak, cliff, cave and waterfall.	Ancient poets and stone inscriptions since 1500 years.
8. Xiqiao Mountain Geopark, Guangdong Province.	Volcanic cones, trachytic rocks canyons, waterfalls, mining relics, and sites of paleoanthropologic activities.	Eurasia margin; Cenozoic belt of volcanism.	Unique volcanic landform on the Pearl River delta. vegetation and water landscape.	Ancient celebrities' activities; cultural relics.

(*Continued*)

(*Continue Table 3*)

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
9.	Weizhou Island Geopark, Guangxi Province.	Volcanic crater, volcano sedimentary profile	Eurasia margin; Cenozoic belt of volcanism.	Vegetation; sea beaches; and coral reefs.	Ancient churches, fishing village.
10.	Shishan Geopark in Haikou, Hainan Province. (**Figure. 4**)	Basic volcanic rocks volcanic cones; lava tunnels mineral springs.	Eurasia margin; Holocene graben-rift volcanism. Activities.	Island tropical rain forest.	Temples; cultures & customs of ethnic minorities.
11.	Jingyu Geopark, Jilin Province.	Volcanoes, lava platform, cones, Ma'ar Lake and mineral springs.	A belt of volcanic activities on the circum-Pacific margin.	Primitive forest, mineral spring swarm, and Ma'ar Lakes.	Cultural heritage sites of Bohai, Gaojuli, site of anti Japanese guerrilla.
12.	Alxan Geopark in Inner Mongolia	Volcanic landform, granite peak forest stone mortar.	Circum-Pacific mobile belt on the east margin of Eurasia.	Primitive forest; swarm of hot springs; plateau lakes and trenches; prairie.	Border port; cultures and customs of ethnic minorities.
13.	Jingpo Lake Geopark in Mudangjiang, Heilongjiang Province.	Volcanic and granite geomorphology; water body landscape.	Situated between the Siberian and Sino-Korean plates, on the southwest margin of the Bulieya-Jiamusi microplate.	Temperate continental climate. Barrier lake	Ruins of the ancient Bohai Kingdom (618-907); Ancient Monastery; Temple; Jingpo Korean.
14.	Jingangtai Geopark in Xinyang, Henan Province.	Ultra-high pressure metamorphism; magmatic intrusion; volcanic processes.	Junction between Yangtze and North China plates and in the east segment of the Qinling-Dabie orogenic belt.	Climate, vegetation belongs to the transitional area from a northern subtropical to a warm temperate zone.	Cultural relics and historic sites.
15.	Liuhe Geopark in Nanjing, Jiangsu Province.	Shield volcano cluster, columnar joints and hoodoo swarms.	East margin of the Liuhe Tianchang uplift, adjacent to the uplift-depression junction of the Jinhu sag.	Subtropical monsoon warm and wet climatic zone layers of Colorful pebbles on terrains.	Cultural Relics Confucian Temple (618-907); Yeshan Iron (-copper) Mine.

Table 4. China's National Geoparks highlighting highly significant tectonic structure.

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1. Baotianman Geopark, Henan Province.	Tectonism, metamorphism and various geological traces	Central orogenic belt (Qinling orogenic belt) of China continent.	Transitional zone of China's northern and southern climatic zones; biodiversity.	Nature reserve.
2. Longmenshan Geopark, Sichuan Province.	Long-distance nappe structure.	Border between Qinghai Tibet Plateau and west margin of Yangtze Platform.	Medium-mountain forest.	Temples and castles.
3. Shenhu Bay Geopark in Jinjiang, Fujian Province.	Landform, Changle-Nan'ao ductile shear belt.	Mesozoic subduction collision zone between the Eurasia and Pacific plates.	Lagoons and marine-erosion landform of coastal zone.	Temples, ancient bridges, facilities of ancient coastal defence.
4. Dabie Mountain Geopark, Anhui Province.	Tectonic geomorphologic features, granulite-facies rocks, granite peak cluster, caves, canyons, volcanic cones, craters, silicified wood and neo-tectonism relics.	Suture line between the Yangtze and North China plates ultra-high pressure metamorphic zone.	Divide between Yangtze and Huaihe river systems. Northern subtropical humid monsoon climatic zone. Junction between North, Central and East China floral provinces. 96.5% vegetation coverage.	The Tiantang (Heaven) Village (1127-1279); the Wanfo Lake; relics of ancient culture.
5. Kunlun Mountains Geopark in Golmud, Qinghai Province.	Ice hummocks; tectonic earthquake relics, six glaciations and leaving ancient glacier remnants.	Main ridge of the eastern Kunlun Mountains, complex geological structures. Quaternary tectonism, strong uplift of mountains.	at the elevation of 5000-6000 metres on average, the divide between the inland water system of the Qaidam Basin and the Yangtze river system, grasslands and meadows of a alpine rigid climate.	Human remnants, religions and cultures of the Middle Stone Age; cliff carvings.
6. Wugong Mountain Geopark, Jiangxi Province.	Structures metamorphic of core complex; granite peaks and cliffs.	South side of the convergence belt of the Yangtze and Cathaysian plates, superimposition and reworking by multi-stage tectonic movement.	Climate monsoon-type, subtropical, warm and humid. subtropical evergreen broadleaf forest.	Cliff engravings, temples, and mountain paths relics of ancient culture.
7. Mulan Mountain Geopark in Wuhan, Hubei Province.	Plate collisional high pressure belt, structures of metamorphic zone geological features.	Indosinian collisional orogenic belt and the high-to ultra-high pressure metamorphic zone.	Transitional zone humid northern subtropical monsoon climate, subtropical mixed evergreen.	Ancient Mulan Village; Dayuwan Village of folk customs.

Table 5. China's National Geoparks featuring extensive Danxia landforms.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1.	Danxiashan Geopark, Guangdong Province.	Typical Danxia-type landform, where this type of landform is named.	Fault basin on the South China para-platform.	Low mountains, hills and flourishing vegetation. Subtropical climate	Cliff engravings temples, Taoism.
2.	Longhushan Geopark, Jiangxi Province (**Figures 5b, c, d**)	Danxia-type landform and grotesquely shaped rocks and hills.	Fault basin on the South China Paraplatform.	Low green mountains and hills with clear waters.	Cliff engravings, suspended coffins, and birthplace of Taoism.
3.	Chenzhou Geopark, Hunan Province.	Danxia-type landform, cavities, valleys, natural bridges and precipices	Fault basin on the South China Paraplatform.	Low mountains and hills.	Temples, tablet inscriptions, and suspended coffins.
4.	Liangshan Geopark, Hunan Province. (**Figure 5a**)	Danxia-type landform, tafelbergs, peak pillars, canyons and precipices.	Mesozoic fault basin on the South China Paraplatform	Valley flats along Zijiang River.	Graves of ancient celebrities; ancient battleground.
5.	Ziyuan Geopark, Guangxi Province.	Danxia-type landform, tafelbergs, peak pillars, sheer precipices and overhanging rocks.	Mesozoic fault basin on the South China Paraplatform.	Valley flats along upper reaches of Zijiang River; clear waters and dense forest.	Culture and customs of the Miao nationality.
6.	Taining Geopark, Fujian Province.	Various peak pillars, prisms, precipices and overhanging rocks mirrored on lake water, queer rocks caves, valleys.	Mesozoic volcanic fault basin in the South China mobile belt.	Clear waters and thick forest, subtropical climate.	Culture and customs of the She nationality, ancient civil houses.
7.	Qiyun Mountain Geopark, Anhui Province.	Danxia-type landform, long walls of red cliffs, flat caves, natural bridges, and valleys. There are also dinosaur fossils.	Mesozoic volcano-sedimentary basin controlled by a fault belt on the South China Paraplatform.	Low mountains and hilly land with dense forest.	Numerous cliff engravings, Taoist culture, stockade villages and castles.

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(*Continue Table 5*)

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
8. Kanbula Geopark, Qinghai Province.	Danxia-type landform, complete sequence since Tertiary, periglacial landform.	Rapidly uplifted area of the Qinghai-Tibet Plateau.	River valley landscape and alpine forest belt.	Tibetan cultures, folk customs, and religions.
9. Huoshi Chai Geopark, Ningxia Province.	Danxia-type landform and Loess Plateau.	Northern and southern tectonic belts of the Liupan Mountain; west margin of the North China Platform.	Loess special landscape belt with dense vegetation.	Taoism, Buddhism and Islam coexist harmonically.
10. Kungdongshan Geopark, Gansu Province.	Danxia-type landform structures formed in Himalayan movement.	West margin of the North China Platform.	The north-south middle ridge of the Loess Plateau, a special landscape belt.	Taoism, Confucianism and Buddhism coexist.
11. Laojun Mountain Geopark, Yunnan Province.	Alpine Danxia-type landform, glacial relics, modern glacial canyon geo morphology.	Located on the west margin of the Yangtze Platform and close to the collision zone of the India plate.	Close to three rivers, high mountains and deep valleys in Hengduan Mountains.	Many ethnic minorities, folk customs and cultures.
12. Yong'an Geopark, Fujian Province.	Karst and Danxia-type landforms, stratigraphic type sections.	Northern part of the Yongmei depression in the south of the Cathaysian old land.	Middle subtropical climate.	Remnants of cultures, ancient architectures.
13. Huzhu, Beishan Geopark, Qinghai Province.	Karst, glacier, with three order cirques canyon and other geological relics.	Snow line. Northeast margin of Qinghai-Tibet plateau, strong active.	Plateau rigid and temperate climate.	Ancient religions, cultures and relics, temple, monastery.
14. Jiangyou Geopark, Sichuan Province.	Karst and collapse landforms, standard Devonian stratigraphic profile.	North-south tectonic belt of the Yangtze platform margin, Himalayan Longmenshan nappe structure belt.	Subtropical humid monsoon climate, fog on the Guanwu Mountain.	Famous poet Li Bai (701 762)'s hometown, Taoist and Buddhist cultures, earliest gunpowder manufacturing site.

Table 6. China's karstic National Geoparks.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1.	Tian'edong Geopark in Ninghua, Fujian Province.	Four layers of karst cave fish fossils, vertebrate fossils, paleoanthropologic relics.	Yanshanian Fault basin northeast-trending faults in the Cathaysian plate.	Middle-mountain and hilly terrains; tropical and sub tropical climate, lakes in caves.	Ancestral home of Hakka people, Red Army Soviet Area (1927-1937).
2.	Dashiwei Geopark in Longlin, Guangxi Province.	Funnels, valleys, under ground streams, peak clusters and natural bridges formed by collapse of karst caves. Karst landscape.	Southwest marginal area of the Yangtze Platform	Primitive vegetation in huge deep doline, margin of Yunnan Guizhou Plateau, subtropical climate	Cultures and customs of Zhuang nationality.
3.	Shuanghe Cave Geopark in Suiyang, Guizhou Province.	Gypsum crystal flowers and springs in karst caves of dolomites.	Southwest part of the Yangtze Platform.	Plateau, primitive forest, precious and rare tree species, subtropical climate	Ancient bridges and waterfalls.
4.	Lingxiaoyan Geopark in Yangjiang, Guangdong Province.	Karst landform and caves, underground streams, paleoanthropologic relics.	Northeast-trending fold-fault belt of the Cathaysian massif.	Hilly land, subtropical climate and vegetation	Paleoanthropologic site, ruins of ancient smelting and casting.
5.	Zhijin Cave Geopark in Zhijin, Guizhou Province.	Karst landform, peak clusters and forest, buttes, caves, valleys, karst lakes, springs.	Southwestern part of the Yangtze Platform.	Yunnan-Guizhou Plateau, subtropic climate and vegetation	Ancient Zhijin Town
6.	Huanglong Geopark in Songpan, Sichuan Province.	Travertines, waterfalls, rimstone dams, colorful pools, caves, karst landscape.	Border between west margin of Yangtze Platform and Qinghai-Tibet Plateau, Hengduan Mountains	Flourish vegetation, plentiful precipitation.	Tibetan Folk customs, cultures and religions.
7.	Xishan Geopark in the Taihu Lake, Jiangsu Province.	Karst, nappe and lake bank landform.	Southeast margin of the Yangtze Platform, tectonic depression belt.	Yangtze Delta area, small islands in the Taihu Lake.	Ancient resort area, engravings on cliffs.

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(*Continue Table 6*)

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
8. Wulong Geopark, Chongqing Province.	Karst landform, hoodoos, valleys, natural bridges, caves, deep dolinen.	Yangtze Platform, faults.	Valley of the Wujiang River, dense vegetation, forest and alpine meadows.	A summer resort of Chongqing City.
9. Shidu Geopark in Fangshan, Beijing Province.	Karst landscape valley, peak clusters, and caves.	Junction between Yanshan orogenic belt Taihang Mountains uplift belt.	Border of west hills and North China Plain, forest park.	Religious Holy Land of Shijing Mountain.
10. Yesanpo Geopark in Laishui, Hebei Province.	Karst valley and peak clusters, granite peaks and cliffs, caves.	Junction of Taihang uplift and Yanshan orogenic belt.	East slope of the Taihang Mountains, flourish vegetation.	Ancient pass and castle, stone engravings.
11. Xingwen Geopark, Sichuan Province.	Karst peak clusters, hoodoos, huge cavities, big deep dolinen, valley and waterfall.	Yangtze Platform, south margin of the Sichuan basin.	Slope south margin of the Sichuan Basin, a sea of bamboo forest.	Cultures of Miao and ancient Bo nationalities.
12. Xingyi Geopark, Guizhou Province.	Karst peak clusters, hoodoos and valley, waterfalls, *Kueichowsaurus* fossils.	Southwest margin of the Yangtze Platform.	Margin of the Yunnan Plateau, subtropical climate, reservoir.	Ancient town, folk customs and cultures.
13. Shihuadong Geopark, Beijing Province.	Seven layers of limestone karst caves, stalactites, stone flowers, prisms and stalag mites, underground streams.	During the neo-tectonic movement block uplifting and downwarping of North China Platform.	Low mountains, valleys and karst area, changeable climate.	Temples.
14. Xiong'ershan Geopark, Shandong Province.	Karst landscape, queer rocks, valleys, fantastic caves.	Carbonate rocks on the North China Platform cut by Cenozoic faults.	Low mountains and hills, typical karst landform in North China.	Holiday resort.
15. Shilin Geopark, Yunnan Province (**Figure 6a**).	Karst landform, sword shaped stone pinnacles 20-50 metres-high peak forest and cluster, caves, waterfalls.	Southwest margin of the Yangtze Platform, limestone suffered fluctuations and water dissolution repeatedly.	Hilly land and peak forest plain, water ponds.	Cultures and customs of Sani nationality.

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(*Continue Table 6*)

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
16. Laiyuan Geopark, Hebei Province (**Figure 6b**).	Dolomite and marble peaks, columns and cliffs, springs, source of the Laishui River.	North China Platform, Cenozoic differential block ascent and descent, vertical faults and joints, collapse.	Medium to low-mountain terrain, green mountains and clear waters, gushing springs.	Great Wall, ancient passes, temples.
17. Fenghuang Geopark, Hunan Province.	Karst canyons, peak forest, tablelands, caves and waterfalls.	Second topomorphological terrains on Yangtze platform, intermittent uplift.	Middle subtropical humid climate seasonal variation biodiversity.	Miao cultural relics, Great Wall of southern China, ancient Fenghuang Town.
18. Lincheng Geopark, Hebei Province.	Karst caves and stepped landform in valleys.	Warm temperate continental monsoon climate, natural secondary forest.		Ciyun (Mercy) Nunnery (618-907), Puli Temple and Pagoda Xibo Pavilion of the Ming Dynasty.
19. Fengshan Geopark, Guangxi Province.	High peak forest, deep depression karst landform.	Located in the Youjiang geosyncline at the southwest end of the Yangtze Plate, characterized by strong tectonism.	Subtropical monsoon climate much cloud and fog and a high humidity, distinct microclimate.	Culture of longevity, ancient Bagang stockade, cultures and customs of Zhuang and Yao.
20. Huaying Shan Geopark in Guang'an, Sichuan Province.	Middle to low mountain karst landform, structures, stratigraphic profiles.	Huaying Mountain fault important regional basement faults in Sichuan Basin.	Subtropical humid monsoon climate flourishing vegetation and numerous wild animals	Hometown of Deng Xiaoping, ancient plank roas, monasteries.
21. Wumeng Shan Geopark in Liupanshui, Guizhou Province.	Karst plateau, valleys, caves, natural bridge, fossil sites.	Yangtze platform, neo tectonic strike slip faults, tensional rifts.	Subtropical plateau warm and humid climate mild weather, vegetation flourishing.	Relics of ancient human being, cultures and customs of ethnic minorities.
22. Hongshilin Geopark in Guzhang, Hunan Province.	Red carbonate rock forest and karst landform, valley, caves, columns, pinnacle peak clusters.	Second topomorphological terraine on Yangtze platform, x-type NW and NE trending joints.	Middle subtropical moun tainous monsoon climate, warm and humid, 73% forest cover.	Cultures and customs of Tujia nationality.

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(*Continue Table 6*)

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
23. Xiangqiao Geopark in Luzhai, Guangxi Province.	Karst landform, valley peak forest and cluster, natural bridge, sinter waterfall.	Transitional zone between a karst peak cluster and a pyramidal peak forest.	Southern subtropical warm and humid climate, flourishing vegetation.	Ancient Zhongdu Town, old residential houses, engravings on cliff.
24. Jiubujiang Geopark in Youxian, Hunan Province.	Karst landform, peak cluster, valley caves, natural bridges, waterfalls, lakes, fossil sites.	Border close to Yangtze platform and Cathyan fold zone, Yanshanian NNE trending folds and faults.	Middle subtropical monsoon humid climate.	Revolutionary Dongchong arsenal, ancient monasteries.
25. Pingtang Geopark, Guizhou Province.	Plateau karst landform, valley, peaks, cliffs caves, underground stream.	South margin of the Upper Yangtze platform, folded mountain.	Middle subtropical monsoon humid climate, subtropical plant species.	Gumei Bridge, stockade villages of Buyei Shuilong Festival.
26. Shuidong Geopark in Benxi, Liaoning Province.	Solution depressions and dolines, cave and under ground stream, standard cross-section of strata.	Extensive carbonate rocks deposited in the Paleozoic, north margin of North China Plate carbonate shelf.	Temperate monsoon climate, middle to low mountain terrain and hilly land.	Great Wall (1368-1644), ancient temples and Taoist sites.
27. Longgang Geopark in Yunyang, Chongqing Province.	Karst landscape, big deep dolines, caves, valley, reservoirs.	Fold belt between Huaying Mountain and Qiyao Mountain Faults, southeast corner of the parallel ridge and-valley terrain in eastern Sichuan.	Monsoon circulation, little sunshine, high humidity, much fog and a long frost-free period, mixed coniferous and broadleaf forest, clear vertical zoning.	Ancient buildings, Confucianism and Taoism, Qiyang Pass, cultures and customs of Tujia.

Table 7. China's National Geoparks with amazing development of Yuntai landform.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1.	Yuntaishan Geopark, Henan Province (**Figure 7a**).	Barrier valley, canyon, jar shaped valley, waterfall, red cliff and long wall, karst, caves, peaks.	North China Platform, southwest segment of Taihang Mountains uplift, second terrace of China's topogeomorphology.	Warm, wet monsoon climate, dense forest.	Sages in bamboo forest, temples, cliff engravings, pagodas.
2.	Wangwushan Geopark in Jiyuan, Henan Province.	Red cliff and long wall, valleys, unconformity ancient and modern water conservancy works.	North China Platform, southwest segment of Taihang Mountains uplift.	Warm wet monsoon climate forest dense.	Legend of the "Yugong Yisharl", temples and mosques, old trees.
3.	Zhangshiyan Geopark, Hebei Province.	Red cliff and long wall, sedimentary structures.	North China Platform, east side of Taihang Mountains uplift.	Junction between the east piedmont of the Taihang Mountains and the subsidence belt of the North China Plain, semi-arid monsoon climate.	Ancient architecture and military works, temple cliff inscriptions.
4.	Guanshan Geopark in Huixian, Henan Province.	Yuntai landform, fault scarps, peak cluster, peak forest, three-step platform, stepped valley.	North China plate, typical platform-type sediments and the binary structure of basement and cover.	Warm temperate continental monsoon climate, complete biologic chain.	Bi Gan's Temple, King Lu's Tomb, Great Wall of State of Zhao (475-221 BC).
5.	Wu'an Geopark, Hebei Province.	Yuntai landform, valleys, peak clasters and stepped valley basalts.	North China plate, Taihang uplift order planation surfaces including Beitaian (1500-1700 m), Taihang (1100-1200metres) and Tangxian (600-800metres) surfaces.	Warm temperate continental monsoon climate, plants belong to semi-arid forest steppe system.	Cishan Culture revolutionary historical sites.
6.	Daimeishan Geopark in Luoyang, Henan Province (**Figure 7b**).	Stepped valley, peak cluster, water body, Yuntai landform.	Transitional zone of the Taihang Mountains uplift belt, continental nucleus of the North China landmass.	Northern warm continental monsoon climate, distinct vertical and regional variation from northwest to southeast.	Xiaolangdi Dam.
7.	Huguan Geopark, Shanxi Province (**Figure 7c**).	Yuntai landform, stepped valley, water body, barrier valley.	North China Plate, Taihang uplift intermittent intense intermontane flood currents downcut along tensional joints, producing a landform of valley the since about 150,000 years ago.	Warm temperate monsoon climate and four clear-cut seasons, 74.9% vegetation cover.	Grottoes, temples, palaces and mosques, historical battlefield.

Table 8. China's National Geoparks based on unique Huangshan landforms.

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1. Huangshan Geopark, Anhui Province.	Granite peak forest, rock pillars, grotesque peaks, queer rocks, deep and secluded valleys, hot springs.	South Chinaplatform, Cenozoic faulting, differential uplift caused by flowing water and glacial action.	Middle mountain land with widespread fantastic pine trees and dense foggy forest.	Cultural relics of Literati, ancient residential houses and rock grottoes.
2. Hexigten Geopark in Inner Mongolia.	Granites with horizontal joints, granite pillars and peaks ice splitting, eolian erosion.	Junction between Da Hinggan-Inner Mongolia fold belt, Yanshan tectonic magmatic belt at the north margin of the North China Platform.	Da Hinggan Mountains primitive forest, Hunshandake Desert, Horqin Grassland, Dali lake.	Cultural relics of Liao (907 1125) and Jin (1115-1234), cliff engravings and paintings.
3. Yichun Geopark, Heilongjiang Province.	Indosinian granites with joints and fissures, peaks and pillars formed by gravity collapse, ice splitting, running water.	Northeast-trending faults of the Inner Mongolia geosyncline.	Middle mountains with a primitive forest; wetland ecology, biodiversity.	Forestry based industry.
4. Chaya Mountain Geopark, Henan Province.	Granite peak forest and stone egg landform, gravity collapse, water erosion, weathering.	Junction between the south margin of the north China Platform and the Qinling Dabie orogenic belt.	Transitional climate and vegetation between China's northern and southern zones, biodiversity, mixed broadleaf and conifer forest.	Office buildings of previous People's Commune.
5. Taimushan Geopark in Fuding, Fujian Province.	Granite with potassic vugs and fissures, gravity collapse, hoodoo, peak cluster and cavities, marine erosion.	Circum-Pacific continental marginal mobile belt.	Sea shore and beach, flourishing and dense island vegetation.	Ancient temples and battlefield.
6. Tianzhushan Geopark, Anhui Province.	Granite peak cluster landform and ultra-high pressure metamorphic belt, vertebrate fossils.	Tancheng-Lujiang fault, Yanshanian granites, grotesque granite landform peaks, pillars, caves, odd rocks.	Northern subtropical monsoon climate, plant and wild animal resources are abundant, unique pine trees.	Remnants of Xuejiagang Culture, Buddhist temple.

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(*Continue Table 8*)

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
7. Shiniushan Geopark in Dehua, Fujian Province.	Granite peak cluster landform, volcanic geology, odd rocks, strong water erosion.	The last cycle of Cretaceous volcanic eruption. Revived caldera at the margin of the Eura-Asia continent. Paleo Pacific plate and Asia continent plate.	Middle subtropical mountain climate, warm humid and foggy, 95% forest cover, middle mountain wetland, vast Huangshan pines.	Porcelain City of China, Shilu Temple, Buddhist Monk Tomb of Qing Dynasty (1644-1911), ancient porch and bridge, Santonggu folk art.
8. Guniujiang Geopark, Anhui Province.	Granite peak cluster and forest landform, valley, odd rocks.	Cretaceous porphyroid granites, regional crustal uplift.	Middle mountains; luxuriant vegetation, fantastic water bodies, ponds, waterfalls and springs, forest.	Ancient villages, and residential houses, ancient camping sites.
9. Yimengshan Geopark, Shandong Province.	Gems and jade.	A volcano-sedimentary sequence of Taishan Group (2.8-2.75 Ga ago), basement of north China platform.	Warm temperate continental monsoon climate, percentage of forest 85-95%, biodiversity.	Red tourism, Neolithic Age sites, Longshan and Yueshi Cultures.
10. Sanqingshan Geopark, Jiangxi Province (**Figures 8a,b,c**).	Granite peak forest landform.	Border between Yangtze and Cathaysian plates large ENE-, NNE- and NW-trending faults. Controlled Himalayan intrusion three forming a typical triangular fault-block.	Middle subtropical monsoon climate, forest coverage 88%, biodiversity.	Taoist culture, Sanqing Palace.
11. Shenlingzhai Geopark in Luoning, Henan Province.	Granite landscape, cone shaped peaks spheroidal weathering.	Northern slope of the Xiong'er Mountain at the south margin of the North China plate and adjacent to the Qinling-Dabie central orogenic belt.	Warm temperate continental monsoon climate and four clear seasons every year.	Relics of Yangshao and Longshan Cultures.
12. Koktohay Geopark in Fuyun, Xinjiang Province.	Relics of mining for granite pegmatite-type rare metal deposit, earthquake deposit, earthquake landform, granite landform.	Xin-Meng geosyncline on south margin of Siberian plate, typical structures of granite pegmatite veins.	Typical continental cold temperate dry climate. The Ertix River of the water system of the Arctic Ocean, two faults lake.	Cliff paintings at Temeke, ancient graves of Kazak nationality.

Table 9. China's National Geoparks with glacial geomorphology.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1.	Cangshan National Geopark in Dali, Yunnan Province.	Relics of Quaternary glaciers, precipitous high mountains, tectonic orogeny, horn peaks, cirques.	Junction between Hengduan Mountains gigantic composite orogenic belt and south margin of the Yangtze massif. Ocean to continent evolution of Paleo-Tethys and Neo-Tethys stages. Qinghai-Tibet Plateau and Yunnan-Guizhou Plateau.	Southeastern and south western monsoons, distinct dry and wet seasons vertical climatic zonation numerous rare and endangered wild animals. and most complete biodiversity world over.	Ancient Dali City; Culture and local civilian residential houses of Bai nationality
2.	Lushan Geopark, Jiangxi Province.	Birthplace of research on China's Quaternary glaciers, glacial relics and naming place, fault-block mountain.	Old continental nucleus of the South China platform; differential ascent and descent of Meso-Cenozoic block movement.	Co-existing Lushan Mountain, Boyang Lake and Yangtze River, forest is luxuriant.	Ancient academy of classical learning, engravings on cliffs, monasteries, multi-style architectures.
3.	Kanasi Lake Geopark in Burqin, Xinjiang Province (**Figure 9**).	Quaternary glacial relics, glacial barrier lake, cirque, terminal moraine, U-shaped valleys, boulders, pyramidal peaks, knife-edge crests, glacial scratches.	Xinjiang-Inner Mongolia geosynclinal folding belt, Altay tectonic belt.	Altay primitive forest, grassland, and clear rivers and lake.	Tuwa Culture of Mongolian nationality, cliff carvings.
4.	Hailuogou Geopark, Sichuan Province.	A modern glacier on the east side of the Gongga Mountain. It is 29 kilometres long, ice tongue extending down to 2750 metres, hot springs.	Junction between the west margin of the Yangtze Platform and the Hengduan Mountains fold belt, Cenozoic intense uplift.	A vast primitive forest coexists with the glacier and hot spings.	Culture of Tibetan nationality, ancient Moxi Town.
5.	Siguniangshan Geopark in Aba, Sichuan Province.	Quaternary glacial landform. Pyramid peak, cirque, fin-crested U shaped valleys.	Intra-continental deformation among Changdu, Yangtze and North China landmass uplift of the Qinghai-Tibet Plateau.	Qinghai-Tibet high cold climatic zone, vertical climatic zonation, permafrost zone above 5000 metres.	Historical relics, local culture conditions and customs of Tibetan nationality at Jiarong.
6.	Nyainbo Yuze (Golog) Mountain Geopark in Jiuzhi, Qinghai Province.	Modern glaciers, glacial relics and landform.	Himalayan movement and the collision-compression between the Indian and Eurasian plates, block uplift and depression in the interior of the plateau.	Plateau continental climate, Yangtze or Yellow River system and lakes.	Culture of Tibetan Buddhism, cultures and customs of Tibetan nationality.

Table 10. China's National Geoparks with assorted geomorphological/landform types.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
a)	Yardang landform (Yuanmeng or earth forest landform)				
1.	Dunhuang Geopark, Gansu Province.	Grotesquely shaped geomorphologic features, roaring winds at night.	Fluvio-lacustrine sediments in Cenozoic fault basin in northeast corner of the Tarim massif.	Desert landscape; stretches of desert varnish.	Mogao Grottoes in Dunhuang, abundant cultural relics.
2.	Alashan Geopark in Inner Mongolia	Desert; lakes and wind scoured eolian landforms.	Granite bodies and Ordovician Silurian sedimentary rocks transitional area of North China and Tarim plates.	Middle temperate continental climate, dry, little rainfall long frost season, abundant solar and wind energy resources.	Ancient mosques and temples, rock paintings, Mongolian cultures and customs.
3.	Zanda Geopark, Tibet	Earth forest landform.	Incised Mesozoic lake-basin sedimentary beds in Himalayan movement and climatic change.	Tibetan plateau temperate monsoon arid climate region.	Ruins of the ancient Guge Kingdom, grottoes, frescoes, Tibetan cultures and customs.
b)	Zhangjiajie landform				
1.	Zhangjiajie Geopark, Hunan Province (**Figures 10a,b**).	Quartz sandstone peak forest. Over 3000 peak pillars, highest 400 metres, gorges, mesa karst, caves.	South China platform, Cenozoic faults; horizontal beds.	Middle mountain land, green mountains and clear waters; curly pine trees on peak pillars.	Folk customs of Tujia nationality.
2.	Jingtai, (Yellow River-Hoodoo) Geopark, Gansu Province.	Stone forest landform of sandy conglomerate, Yellow River valley and neo-tectonism.	Western margin of north China Platform, neo tectonism uplift of the Qinghai-Tibet Plateau.	Yellow River valley; Loess Plateau, arid climate.	Buddhism and Islamism.
3.	Bingyuguo Geopark in Dalian, Liaoning Province	Sandstone peak cluster.	Glaciation of Dali glacial period. Rock cave (pocket- or sack-like) structures related to glaciation. North China plate.	Warm temperate humid climate zone under the effect of marine climate, percentage of vegetation is up to 75%.	Buddhism and Taoism Temple (907-1125) and (1115 1234), temples of the Bore Caves (1271-1368).

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(*Continue Table 10*)

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
c)	Marine erosion landform				
1.	Dapeng Peninsula Geopark in Shenzhen, Guangdong Province.	Palaeo-volcanic relics, marine erosion and deposit landscape.	Pacific plate subducted beneath Eurasian plate, large scale volcanic eruption grotesque, marine deposition and marine erosion, geomorphologic landscapes.	Subtropical monsoon climate, forest and vegetation luxuriant.	Xiantouling Culture, Dapeng City, General's Mansion, Dongshan Monastery.
2.	Changshan Islands Geopark, Shandong Province.	Marine erosion and deposition landforms (sea stacks, caves and viaducts, cliffs, arches).	Chain of islands Jiao-Liao uplift-fold belt of north China plate situated in the east part of the Tancheng-Lujiang fault belt.	Beautiful scenery, fresh air, pleasant climate, the 54% forest cover, migratory birds, marine organisms include mainly fishes, shrimps and crabs, conches and shellfishes, algae.	Site of Longshan Culture (of late Neolithic Age), ancient tombs Tuoji inkstones.
3.	Seashore Geopark in Dalian, Liaoning Province (**Figures 11a,b**).	Geologic and structural profiles, locality of trilobite fossils, marine erosion landform, sedimentary structures, ductile shear zones, natural boundary between Yellow Sea and Bohai Sea.	East wall of the Tancheng-Lujiang Fault, stretching and contracting structures multiphase tectonic deformation, ductile shear structures, marine erosion.	Temperate continental monsoon climate under the effect of oceanic climate.	Old Japanese and Russian jails, island of snakes, ancient architectural complex, Taoist temples, monasteries.

Table 11. China's National Geoparks from the category of hydrology.

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
1.	Yellow River Hukou Falls Geopark in Shanxi, Shaanxi Province.	The largest cascade on the main Yellow River, narrow and deep valley, headward erosion.	North China Platform, a set of "X" joint controlling the river erosion formed under the influence of Indosinian movement.	Valley of the Yellow River; incision, arid to semi-arid climate, waterfall frozen in winter.	Inscriptions of poems of ancient poets, battlefield of World War II.
2.	Yellow River Delta Geopark in Dongying, Shandong Province.	Water bodies of the Yellow River Delta, sedi mentological features, ancient coast relics, shell dykes.	Worth China Platform. Abundant sediments were deposited at the river mouth in a swinging-branching form, producing a broad flower bud shaped delta. Reeds are well developed. Biodiversity is remarkable.	Flower bud-shaped delta has changed its course several times since 1855, with its eight "buds" being superimposed successively.	Oilfield development history, army horse pasture, reservoir on plain.
3.	Three Gorges Geopark in Hubei and Chongqing Provinces.	Valley landform, karst and gravity collapse, landslides, travertine deposits in karst caves, peak cluster, old stratigraphic and classic structural profiles, fossil sites.	Yangtze Platform and fault structures.	The formation of the Yangtze River valley and the development of terraces, Three Gorges Dam project, hazard control project.	Wushan People relics, site of Three Kingdoms (220-280), Culture of Ba and Chu Principalities (c. 11th century 256 BC), coffins on cliffs, water conservancy project.
4.	Jiuzhaigou Geopark in Sichuan Province.	Alpine lakes, springs, waterfalls and torrents, karst, stratigraphic profiles, fossils.	Junction between the east margin of the uplift belt of the Qinghai-Tibet Plateau and the west margin of the Yangtze Platform, Hengduan Mountain region.	Snow mountains, primitive forest, alpine lake swarm, travertine dam.	Cultures and customs of Tibetan and Qiang nationalities, civilian residential houses.
5.	Yellow River Geopark in Zhengzhou, Henan Province.	Loess profile at the top of the Yellow River Delta, geomorphologic features and geologic engineering projects.	Neotectonic uplift and incision of the Yellow River table land at the southeasternmost margin of the Loess Plateau, thick loess-paleosol succession.	Mangshan wetland within 1-2 km of the Yellow River, plenty of water and lush grass, natural habitat for water fowls, wetland ecologic system.	relics of Dahe Village; iron smelting site of Han Dynasty (206BC-220AD) in Guxing, site of ancient Yangshao City, Yellow River Dike.

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(*Continue Table 11*)

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
6.	Baishuiyang Geopark in Pingnan, Fujian Province.	Flat-bottomed river bed of bedrock, valleys, waterfalls, columnar joints.	Volcanic geologic evolution nearly 100 Ma ago created the relics of structures, typical volcanic rocks, volcanic land form and water body landscape.	Middle subtropical monsoon climate, dense streams, nature reserve of mandarin ducks and rhesus monkeys.	Red tourism resources, ancient buildings, wood archtopped bridge.
7.	Yellow River Meander Geopark in Yanchuan, Shaanxi Province.	Remainder loess hilly and valley landform.	Two sets of vertical joints within Triassic bedrock with chessboard-like pattern, meanders developed along two sets of joints. Neotectonism caused continuous rapid regional uplift and river incision, forming the valley along the original basic meander pattern.	Temperate continental monsoon climate with frequent thunder storm.	Huifeng Stockade, ancient ecologic civilian residential houses at Nianpan, Xiaocheng Village of folk arts, red tourism resources
8.	Xingkai Lake Geopark in Mudanjiang, Heilongjiang Province.	Tectonic lake, lake mounds and wetlands.	Xingkai massif of the Pacific mobile belt on the east margin of Eurasia plate, NNW trending collision and subduction.	Cold temperate continental monsoon climate, abundant plant resources with some rare and endangered plants.	Site of Ancient Xinkailiu Culture, Tingtao Pavilion flood gate, border town boundary bridge.

(*Continued*)

(*Continue Table 11*)

	Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
9.	Permanent Ice Cave Geopark in Ningwu, Shanxi Province.	Glacial relics and ice caves spherifer weathering granite landscape.	Old continent splitting and collision took place in the Precambrian. The third uplift belt of the Neo-Cathaysian tecontic system in the Meso Cenozoic, the Fen-Wei continental rift system.	Northern margin of a warm temperate zone. Alpine meadow and forest are well developed, many natural lakes distributed on a planation surface.	Temple or other houses on wooden stilts on precipices, Ningwu Pass, Drum Tower, ancient Ninghua City
10.	Geothermal Geopark in Enping, Guangdong Province.	Geothermal landscape, granite geology and landform.	Neotectonic faults, down seepage of precipitated water was heated to form convection and produce hot springs. Multi-phases faults along shattered zones.	Subtropical marine climate with plentiful rainfall.	Yunli Stone Village, Didu Hot Spring Village, Museum of Hot Spring.
11.	Chongming Island Geopark in Shanghai Province.	Tidal mud flat landform.	Influence of the Himalayan orogenic movement about 25 Ma ago, re-activated crust, basaltic magmas in fluvio lacustrine sediments, rise and fall of the sea level since about 2.6 Ma influenced by 6 glacial and interglacial events.	The climate is warm and wet and aquatic plants are flourishing. Wetland birds, amphibians and other aquatic animals abundant.	Ecologic Village, windmills on tidal banks, Dongtan Beach, Tide-Aoiding Blocks, Jin'ao Mountain, Hanshan Temple, Danyuan Garden.

Table 12. China's National Geoparks related to engineering geology, environmental geology and geohazard.

Representative national geoparks	Major geological and geomorphological features	Controlling geological setting	Related physiographic conditions	Main cultural interest
Engineering Geology				
1. Dadu River Valley National Geopark in Sichuan Province.	Dadu River valley the Dawa Mountain, Quaternary glaciers. The large scale, formidable engineering project – Cheng-Kun Railway, bridges, culverts and tunnels, passes.	West margin of the Yangtze Platform, the north-south Sichuan- Yunnan tectonic belt, intense neotectonism.	Middle and high mountains, deep valleys, luxuriant forest.	Cultures and customs of Yi nationality, Cheng-Kun Railway
Geohazard				
1. Cuihua Mountain National Geopark in Shaanxi Province.	Mountain collapse and accumulation, earthquake relics, barrier lake course.	Piedmont fault activities on the north side of Qinling Mountains, metamorphic and granite landscape.	Middle mountain, boulder talus, superimposed rock caves.	Engravings on cliffs, stone inscriptions by ancient celebrities
2. Qianjiang National Geopark in Chongqing Province.	Earthquake relics, collapse and slump blocks, talus, barrier lake, karst landform, fossils sites.	Yangtze Platform, fold belt on the margin of the Sichuan syncline.	Middle mountain landform and flourishing vegetation.	Ancient temples, ancient inscriptions engravings site of revolutionary war.
Environmental Geology and Geohazard				
1. Yi'gong National Geopark in Tibet.	Modern glaciers, high mountains and valleys, extensive slump slides of mountain mass, vertical zonation of vegetation.	Uplift belt of the Qinghai Tibet Plateau.	High mountains, valleys and glaciers, torrential river, vegetation zonation.	Cultures and customs of Tibetan nationality, folkways and folklores.

GEOHERITAGE OF INDONESIA

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Separator Photo:
Bromo-Tenger Valcano, Indonesia.

3

GEOHERITAGE OF INDONESIA

Yunus Kusumahbrata

INTRODUCTION

Situated within the triple junction of mega-plates where complex geological processes are actively taken place, Indonesia possesses numerous outstanding geological heritage or geoheritage resources (Bambang Dwiyanto 2006). Unfortunately, until recently, there were no serious efforts in conserving these geoheritage resources hence many Indonesian geoheritage sites are now facing danger from unsustainable resource utilization and other anthropogenic activities (Sukhyar Kartakusumah 1990). At present, nature heritage conservation in Indonesia is focused more on protection of flora and fauna or living heritage, whereas the non-living geodiversity or geoheritage such as rocks, minerals, fossils, soils, geological structures, and landscapes are not recognized. The general perception is that all geological features are highly resistant and thus are not requiring any protection. In reality, however, many valuable geoheritage resources are as sensitive to disturbance as that of bioheritage (Ibrahim Komoo 2003). Any destruction to geoheritage resources like particular types of fossils or rocks/minerals can be considered as a permanent loss because it is impossible to be reproduced during one's lifespan.

Geological features of high heritage value are well distributed across the nation (Figure 1). For the obvious reason mentioned earlier the most important and highly significant geoheritage resources of Indonesia are active volcanoes as well as their landscape remains. For centuries, active volcanoes have continuously drawn researchers of various backgrounds and general observers to Indonesia. Other geoheritage features include karst landscapes, fossils, geohazards and mining sites as well as the sites of ancient subduction complex. This chapter will highlight some of Indonesian geoheritage resources, grouped and described on the basis of the main island where they were located.

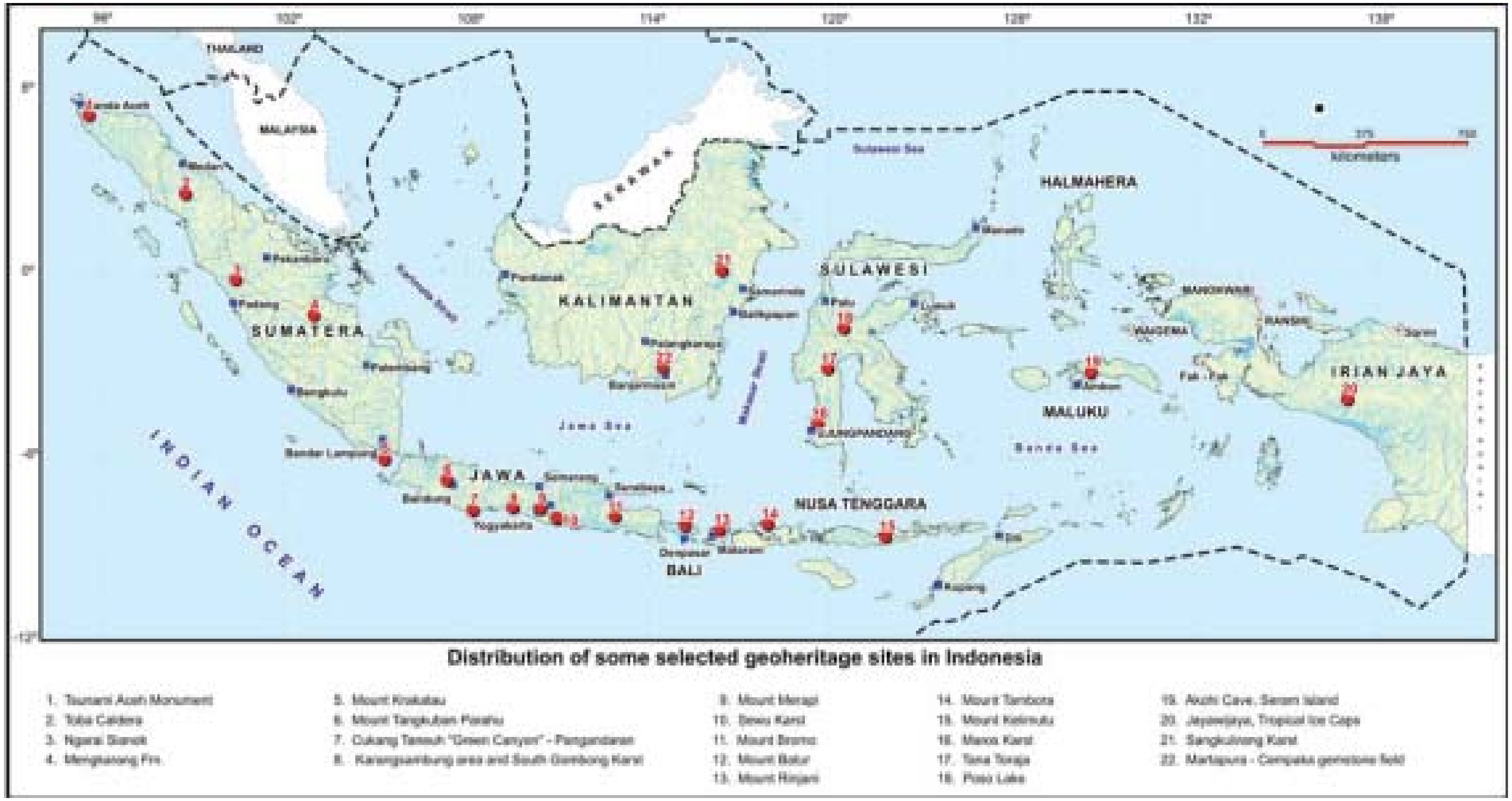


Figure 1. Distribution of selected geoheritage sites in Indonesia described in this chapter.

GEOHERITAGE OF SUMATERA

Covering an area of approximately 473,481 square kilometres, Sumatera is the western-most and the third-largest island of the Indonesian Archipelago (Figure 1). Its west coast faces the Indian Ocean, the southeast coast faces the Karimata Strait, while the northeast coast faces the Straits of Malacca and Andaman Sea. Geographically, Sumatera possesses two contrasting landscapes; the nearly 3,000 kilometres long Barisan Range that occupies the western part of the island and the vast swampy lowland that dominates the eastern part. Sumatera offers a great variety of scenic attractions ranging from extensive rainforests, rivers, gleaming white beaches and volcanic landscapes which are among the most spectacular in the world. Amongst the many spectacular geoheritage sites found in Sumatera are the Aceh Tsunami Monuments, Toba Lake, Ngarai Sianok, the type area of the Mengkarang Formation with its rich fossil flora and Kakatau Volcano, each of which is briefly described below.

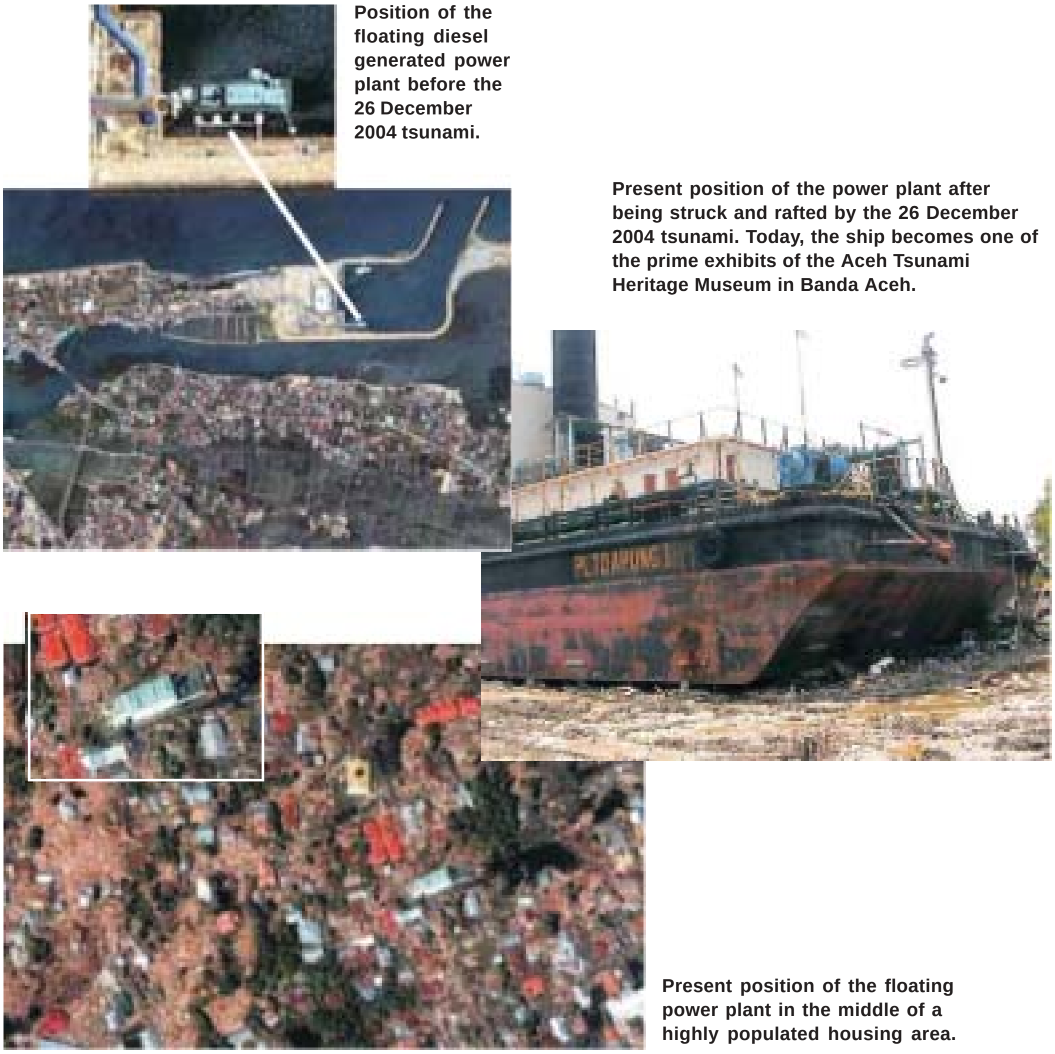
Aceh Tsunami Monument, Aceh Province

In remembrance of the devastating tsunami of 26 December 2004, several monuments have been built in Aceh Province. The wreck of a floating diesel power plant (Figure 2) is one of the most striking demonstrations of how tremendous was the tsunami power that caused the catastrophic destruction of much of Aceh's west coastal area. The tsunami waves moved the 30,000 DWT floating ship for several kilometres and dumped it on to dry land.

Toba Lake, North Sumatera Province

Toba Lake (Figure 3) or *Danau Toba* is the most popular tourist destination in Sumatera with Parapat as its centre of tourism development. Located in North Sumatera Province, this biggest lake in Southeast Asia covers an area of approximately 1146 square kilometres, with depth of more than 450 metres. Toba Lake occupies the caldera remnant of an immense volcano which exploded about 100,000 years ago in what was probably the most powerful eruption yet known in human history (Yunus Kusumahbrata 1998).

The eruption of the Toba Volcano is categorized by volcanologists under the mega-colossal category and possibly the largest explosive volcanic eruption to have occurred within the last twenty-five million years. The 100 - 300 metres thick deposits of pyroclastic material spread over 30,000 square kilometres and known as Toba tuff, is evidence of the massive eruption of the ancient Toba super volcano. This eruption resulted in the largest ever volume of volcanically erupted fragmental material, estimated at around 2800 cubic kilometres (670 cubic miles), compared to a mere 100 cubic kilometres spewn by the famous Tambora 1815 eruption. Because



Position of the floating diesel generated power plant before the 26 December 2004 tsunami.

Present position of the power plant after being struck and rafted by the 26 December 2004 tsunami. Today, the ship becomes one of the prime exhibits of the Aceh Tsunami Heritage Museum in Banda Aceh.

Present position of the floating power plant in the middle of a highly populated housing area.

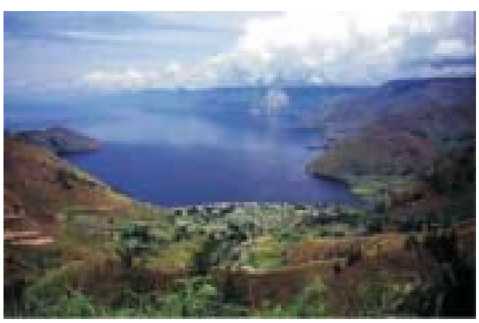
Figure 2. Aceh Tsunami Monument.

of the huge withdrawal of material from beneath the volcano, the cone collapsed downwards and the world's biggest caldera was formed. Soon after, a huge caldera lake was formed. But 70,000 years later most of the lake was disturbed by another smaller eruption forming the Samosir Island and other geological landscape on the eastern shore of the lake.

Ngarai Sianok, West Sumatera Province

Sianok Gorge, locally called Ngarai Sianok (Figure 4), is a deep incised valley located in the vicinity of Bukit Tinggi City, West Sumatera Province. This approximately NW-SE

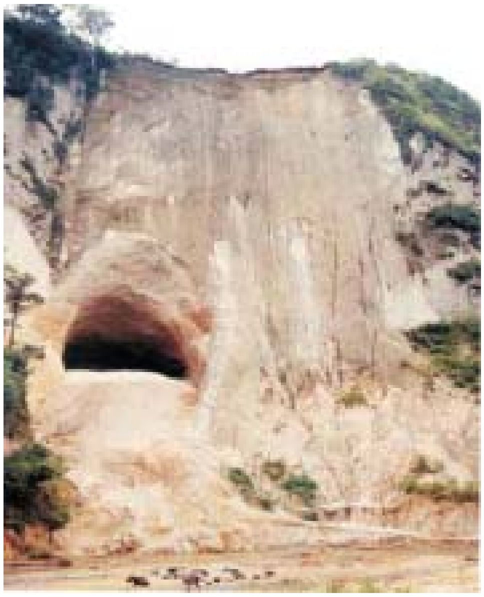
Satellite Image of Toba Lake, North Sumatera.



Magnificent views of Toba Lake.

Figure 3. Toba Lake.

oriented sinuous valley, approximately 15 kilometres long and 200 metres wide, stretches from the south of Koto Gadang to Sianok Enam Suku and ends near Palupuh. The 100 - 150 metres deep Sianok Gorge was formed by extension of the Earth's crust in conjunction with movement of the Great Sumatera Fault during the last two million years (Quaternary Period). The fault can easily be recognized from satellite images as a continuous gigantic crack across Sumatera extending more than 3,000 kilometres from Semangko Bay to Banda Aceh (Yunus Kusumahbrata 1998). Sianok Gorge exhibits outstanding view of landscapes represented by huge vertical cliffs on both sides of the valley, the Sianok River incising the floor of the valley and lush green tropical forest surrounding the valley.



Beside its colorful cultural diversity, West Sumatera's other attraction is the historical 1,400 metres long Japanese tunnel built beneath the Bukit Tinggi City. This tunnel network was dug by forced labour, so called romusha, and was mainly intended for defensive purposes during World War II.

During the 1930's this valley was a playground for a huge number of wild water buffalo, the so-called Kerbau Sanget.

Figure 4. Several geoheritage features related to Ngarai Sianok.

Mengkarang Formation, Jambi Province

The type locality of Mengkarang Formation in Mengkarang River, Jambi Province is proposed to be conserved as an important geoheritage site due to its rare and important plant fossils (Figure 5). Based on its stratigraphic position and its fossil content, the Permian Mengkarang Formation is interpreted as having been deposited within a lake environment during the Permian Period. Permian fossils found in the Mengkarang Formation are evidence for the existence of a micro-continent with Cathaysian affinity in east and southeast of Sumatera that amalgamated with another micro-continent with Gondwana affinity to form Sumatera during Late Triassic time.

Krakatao Volcano, Sunda Straits

Indonesia contains over 130 active volcanoes, more than any other country on earth. Most of them are concentrated along the axis of the Indonesian island arc system, which is formed by the northeastward subduction of the Indo-Australian oceanic plate beneath the thick and rigid Eurasian

Well preserved Permian fossil flora of Cathaysian affinity within mudstone of the Mengkarang Formation.

The gigantic size of certain Permian vegetation within well bedded mudstone of the Mengkarang Formation indicated by nearly complete tree trunk and roots preserved in its life position.

Figure 5. Several geoheritage features related to type locality of the Mengkarang Formation.

continental plate. Located in the middle of Sunda Straits, the Krakatau complex (Figure 6) consists of four small volcanic islands, Rakata, Panjang, Sertung and Anak Krakatau, respectively. Although relatively small, Mount Anak Krakatau is considered to be the most active volcano to threaten the populated shoreline along both sides of the Sunda Strait (Suharto et al. 2000, Yunus Kusumahbrata et al. 2006).

Figure 6. Scenic views of Krakatao Volcano and its active minor eruptions.

1893 Krakatao Eruption Event (Sukhyar Kartakusumah 1990)

Before the famous eruption of 1893, the ancient Krakatau volcano consisted of three active craters known as Rakata, Danan and Perboewatan. From May 20, 1883, Krakatau generated series of mild detonations from Perboewatan. By mid-June the summit crater of Perboewatan had been largely destroyed and the centre of eruption widened to include several new vents near Danan. By mid-July, banks of pumice were found floating across the Sunda Straits. The climax came suddenly on August 26, 1883 at 12:53 pm, when Krakatau delivered the opening salvo of a catastrophic eruption that last throughout the evening of August 27. The initial blast generated an ear-shattering fusillade accompanied by black churning cloud of volcanic debris that rose quickly to 25 kilometres above the island. Over the next several hours, the cloud widened dramatically to the northeast, rising to a height of at least 36 kilometres. This frightening display of volcanic power culminated in a series of at least four stupendous eruptions that began at 5:30 a.m., climaxing in a colossal blast that literally blew Krakatau apart. The noise was heard over 4600 kilometres away, throughout the Indian Ocean, from Rodriguez Island and Sri Lanka in the west, to Australia in the east. Two-thirds of the island collapsed beneath the sea into the underlying, partially vacated magma chamber. About 23 square kilometres of the island, including all of Perboewatan and Danan, subsided into a caldera about 6 kilometres across. From an original height of 450 metres , Danan had collapsed to a depth of 250 metres below sea level.

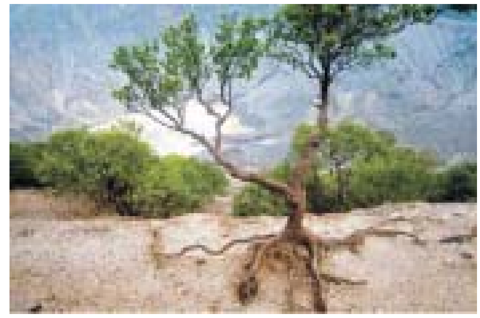
GEOHERITAGE OF JAVA

Java Island is the most populated island in Indonesia. This mountainous island possesses many outstanding natural phenomena as well as a rich cultural heritage. Among important geoheritage sites of Java Island are the Tangkuban Parahu volcano, Karangsambung Complex, South Gombong Karst, Merapi Volcano, Gunung Sewu Karst Complex, and Bromo - Tengger Volcano (Yunus Kusumahbrata 1998).

Tangkuban Parahu Volcano, West Java Province

Situated about 25 kilometres to the north of Bandung, the famous Mount Tangkuban Parahu (Figure 7) is an active volcano with spectacular views of craters and many other kinds of volcanic phenomena including fumaroles and hot springs which are distributed around the volcano. The shape of this volcano as seen from the south resembles an upturned boat, hence it was named as Tangkuban Parahu and was believed to be associated with the old folk myth of Sangkuriang. Being upset by the trickery of Dayang Sumbi, his beloved Queen, Sangkuriang angrily kicked a giant boat and this became a mountain, Tangkuban Parahu. Scientifically,

Panoramic view of Ratu crater.



Endemic plant grows on coarse-grained sulphuric soil around the crater.

Domas crater with one of its high-discharge hot springs.

Waterfall at a fault near the volcano.

Figure 7. Several geoheritage features related to Tangkuban Parahu Volcano.

the upturned boat shape of Tangkuban Parahu volcano was formed due to the east-west migration of its eruption center. The lateral migration caused the formation of an elongate, rather than a conical volcano.

Cukang Taneuh, West Java Province

Cukang Taneuh (Figure 8) or Green Canyon is a popular geotourism destination located about 20 kilometres to the west of the well known Pangandaran Beach in South Ciamis, West Java Province. Situated in Cijulang River, this locality offers different tourism attractions compared to beaches along the Southern Jawa coast. Cukang Taneuh is a lush green river valley formed by the deep incision of the Cijulang River into a limestone formation which displays many distinctive karst phenomena. The canyon can be accessed either by boats provided by local people, or by trekking along the footpath which passes Karang Paci Village. During the dry season many tourists prefer to get to Cukang Taneuh by rafting downstream along the Cijulang River from Bantar Kawung Village (Yunus Kusumahbrata 2003).

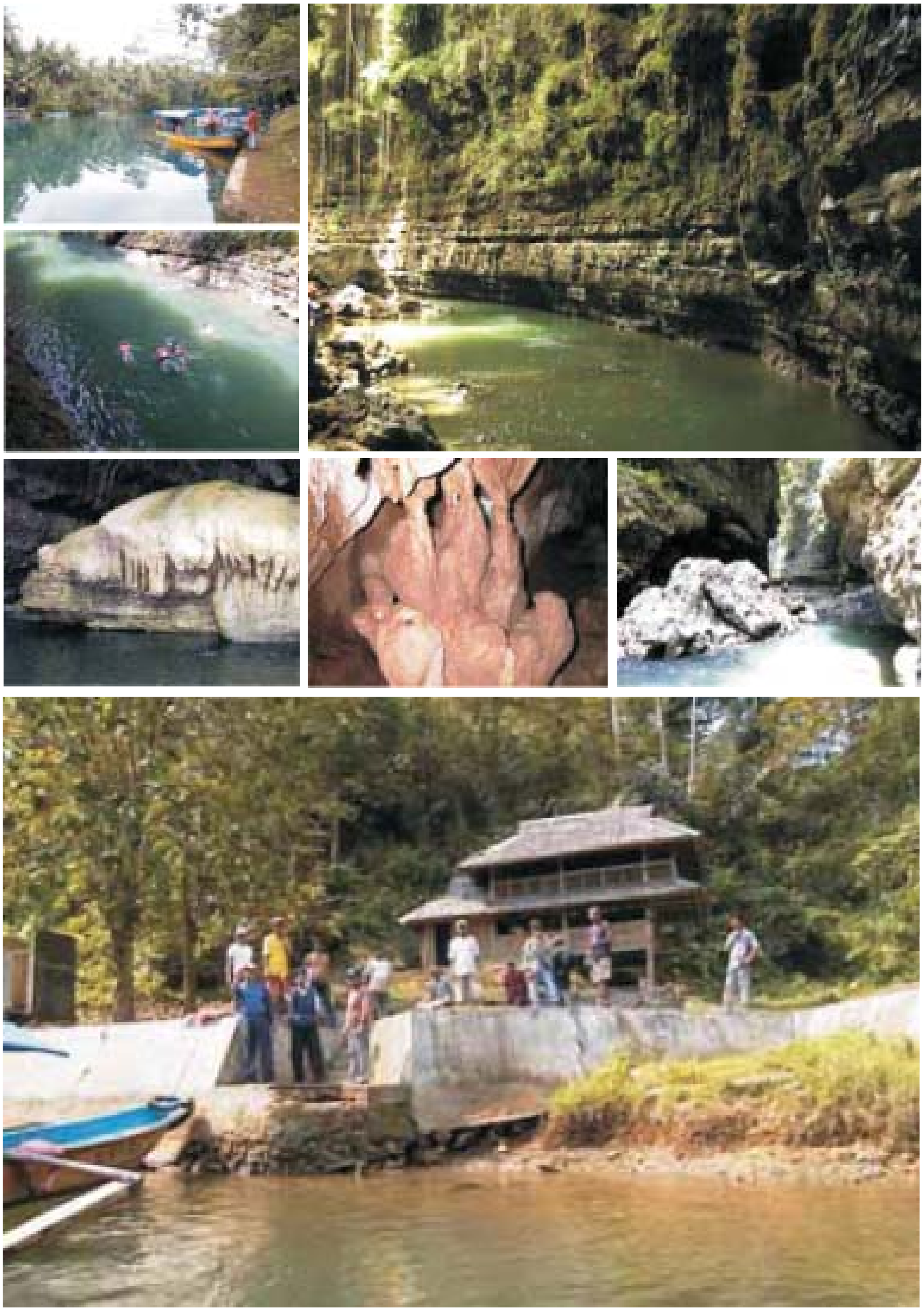


Figure 8. Several geoheritage features related to Cukang Taneuh.

Besides offering experience on the flora and fauna of lowland tropical rainforest while cruising along the river, tourists can also observe many spectacular speleothems or secondary carbonate deposits formed by crystallization from calcium carbonate saturated water. Local people are actively participating in tourism activities as boat operators, tour guides and guardians for conservation.

South Gombong Cockpit Karst, Central Java Province

Located approximately 12 kilometres south of Gombong in Central Java, a relatively small karst area, the so called South Gombong Karst is recognized as an outstanding conical-type karst landscape with its typical dolines or bowl like depressions, caves and clear spring water. Banyumudal spring water, emerging from an underground river, has been used as a source for domestic water for Gombong City and also for agriculture. Spectacular caves containing many types of beautiful speleothem include Jatijajar, Petruk, Simbar and Barat caves. The first two caves have been developed as tourist attractions, while the latter two are popular for cave adventure activities (Yunus Kusumahbrata et al. 2006). The South Gombong Cockpit Karst and its outstanding geoheritage features (Figure 9) are now under the threat from traditional limestone mining and prospecting for minerals associated with the underlying rocks.

Karangsambung, Central Java Province

The ampitheatre-shaped Karangsambung area is located approximately 20 kilometres to the north of Kebumen Regency, Central Java Province and can be accessed easily through Kebumen or Banjarnegara. This geoheritage site (Figure 10) had been declared as a geoconservation area with various outstanding features associated with the subduction of the Indo-Australian plate beneath the Asian plate around 120 million years ago. For the geoscientistst, these features include many outcrops of rarely found rocks, such as fragments of serpentinite and gabbro of oceanic crust origin, mica- and blue-schists of continental crust origin, red chert of deep-sea sediments and basaltic pillow lava of spreading sea-floor or mid-oceanic ridge origin. These exotic rocks are mixed tectonically to form a mélange unit. All these rocks are exposed in a relatively small area and thus can be regarded as an outstanding field laboratory for studying plate tectonic model associated with subduction process (Yunus Kusumahbrata 1998). There are a total of 30 protected geosites in Karangsambung area, within an area of around 22.15 hectares (Yunus Kusumahbrata et al. 2006). Community development programmes implemented by the local government in Karangsambung and surrounding areas, are mainly directed towards hand crafting river-floating stones as souvenirs.

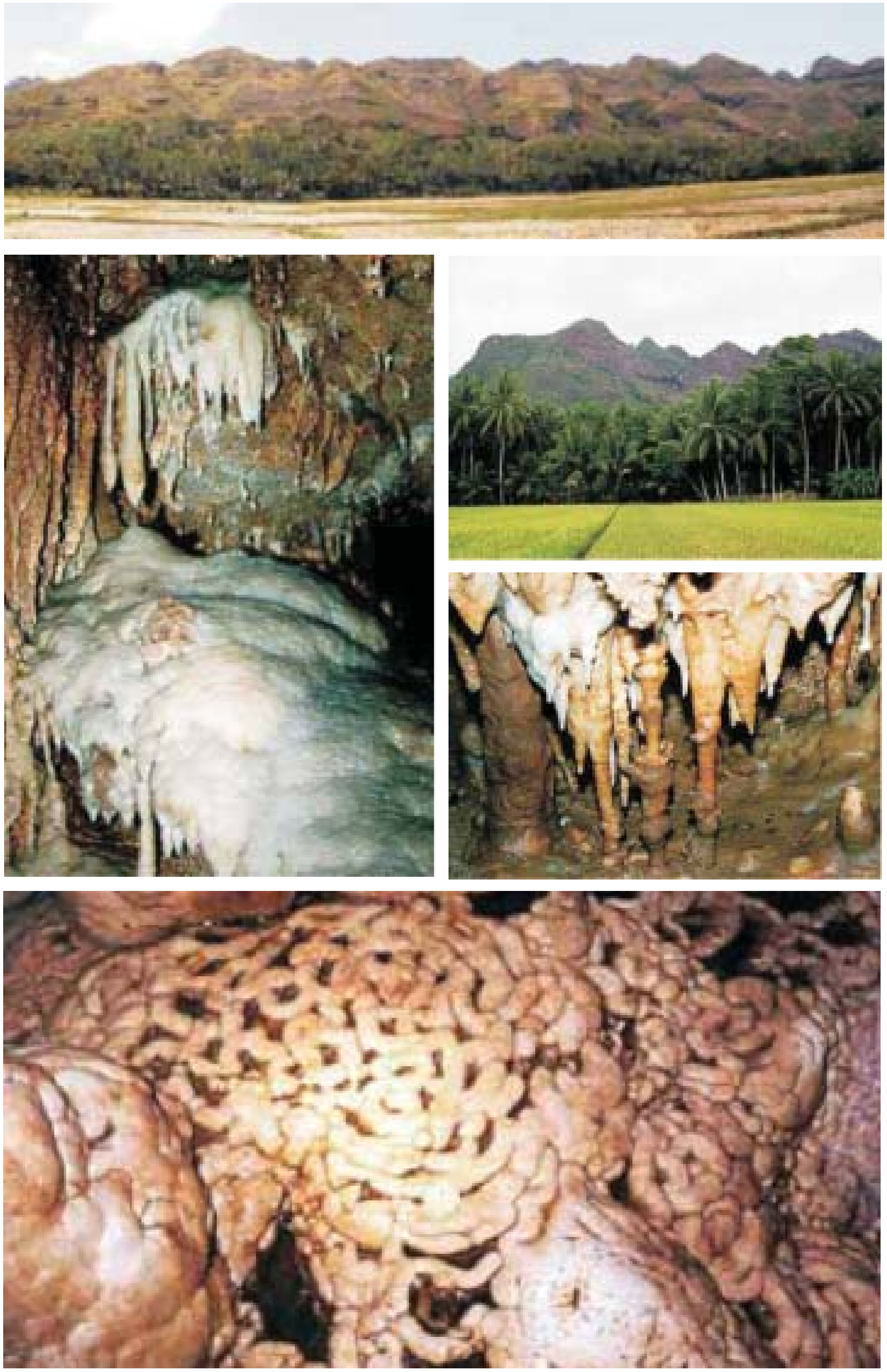
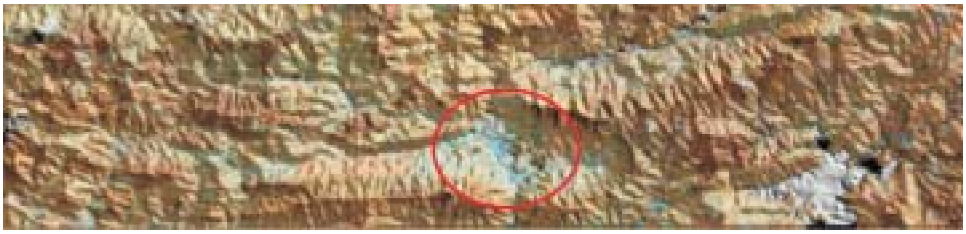
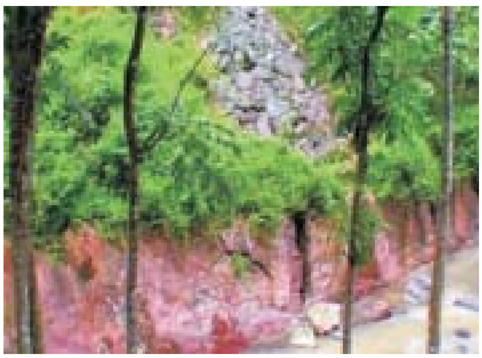


Figure 9. Panoramic view of South Gombong karst landscape and several cave deposits within the caves.





Red chert overlain by pillow lava exposed in Muncar River.

Serpentinite as part of oceanic crust fragments.

Well exposed gabbro as oceanic crust fragment.

Figure 10. Aerial view and the various features of Karangsambung geoheritage.

Merapi Volcano, Central Java Province

Mount Merapi (Figure 11), locally called Gunung Merapi, is one of the most active volcanoes in Indonesia. This conical shaped volcano is located several kilometres north of Yogyakarta, forming a beautiful towering landscape (Bambang Dwiyanto 2006). Thousands of people live on the flanks of the volcano, developing villages as high as 1700 metres above the sea level.

Figure 11. The various images of the fearsome Merapi, one of the most active volcano in the world.

Historically, Mount Merapi possesses a unique character with its pattern of periodic eruption that caused a number of fatalities. Until about 10,000 years ago, eruptions were typically effusive and the outflowing lava emitted was basaltic. Since then, eruptions have become more explosive, with viscous andesitic lavas often generating voluminous lava domes.

During periods of active eruption, ruptured domes often generated pyroclastic flows due to strong explosions. The most notorious type of eruption is characterized by pyroclastic flows consisting of volcanic gas and hot debris that travel at great speed along river valleys on the flank of the volcano. These pyroclastic flows are locally called wedhus gembel (Yunus Kusumahbrata 1998).

The last (2006) Merapi eruption was characterised by the destruction of the 2004 lava dome and the collapse of the Geger Buaya wall, ended with the formation of a new gigantic lava dome.

During the wet season, huge accumulations of volcanic debris on the slope of Merapi can turn into laharic floods that flow rapidly downstream, destroying bridges, rice fields and villages. On the other hand, such laharic floods are a natural source of construction materials, such as sand, gravel and rock boulders.

Sewu Cockpit Karst, East Java – Yogyakarta Provinces

The Sewu Karst region spreads over a vast area of about 1,400 square kilometres situated between Teleng Ria Beach in Pacitan Regency, East Java, and Parang Tritis Beach, Yogyakarta. This region can be accessed easily as it is served by many public roads. The Sewu Karst (Figure 12) is characterized by thousands of 100 - 150 metres high hills of limestone separated from one another by dolines, hence it was locally named as Gunung Sewu or Thousand Mountains. This results in a spectacular landscape characterised by its conical to dome-shaped hills.

Gong and Jaran caves, two of the most beautiful caves within the Sewu Karst area, present an outstanding display of varieties of speleothem including stalacites, stalagmites, flowstones, gourdam and cave pearls.

Figure 12. Amazing landscape and cave features of the Sewu Cockpit Karst.

Apart from the surface landscape, subterranean processes have created an extensive network of caves. Over 500 caves have been documented and mapped. Most of the caves are poorly known due to their remoteness, but several caves including Gong, Tabuhan, Serpeng, Jaran, Bribin, Suci, Jomblang, Sadeng, Sapan, Gupuh, Ngantap, Cerme and Maling Caves can be accessed and a few have even been developed as popular tourism attractions (Hanang Samodra 2002).

Cave fauna that can be identified includes various bats, birds (swifts), crickets and fresh water prawns. Collecting the swift's nests contributes significantly to the local government economy.

Due to the increasing demand for limestone as raw industrial mineral, many highly important areas in the Sewu Karst are currently under direct threat from mining activities.

Mount Bromo – Tenger, East Java Province

Mount Bromo (Figure 13), situated within the Tengger Caldera is one of the most popular tourist attractions in East Java Province. It is an active volcano rising to 2,330 metres above sea level and forms part of the Tengger Mountain Range. This outstanding geoheritage site reveals not only a beautiful volcanic landscape but also the richness of the cultural diversity of the people living around the mountain (Yunus Kusumahbrata 1998).

Figure 13. Scenery, culture and volcanic activities around Mount Bromo-Tenger.

After the last eruption in 2004, the Bromo crater has consistently produced columns of white volcanic steam accompanied by strong noises of gas outburst.

Trekking around the vast sandy volcanic desert in the cool air, observing the sunrise and sunset, and attending local festivals held annually to worship Princess Roro Anteng are among the attractions for great numbers of tourists.

Mount Batur, Bali Island

Bali Province has long been recognized as a world class tourist destination due to its unique socio-cultural and natural heritages. Mount Batur, Batur caldera lake and other associated features surrounding the volcano (Figure 14) are among prime attractions for visitors to the Bali highland area (Yunus Kusumahbrata 1998). Mount Batur is located in the center of two concentric calderas northwest of Mount Agung, Bali. The southeast side of the larger (10 x 13 square kilometres) caldera contains a caldera lake. A 700 metres high, active volcano rising above the surface of Batur Lake creates a beautiful landscape.

Just like many other natural objects in Bali, Lake Batur has been developed as a popular tourist destination along with its well known Balinese cultural heritage.

Historical eruptions have been documented since 1804 and the volcano has been active frequently since then. The eruptions are characterized by mild to moderate explosive activity and sometimes accompanied by lava emission.

GEOHERITAGE OF NUSA TENGGARA

Nusa Tenggara Province is geographically known as the Lesser Sunda Islands that together stretch over a distance of 1,300 kilometres and consists of over five hundred islands. It connects the bigger Sunda Island in the west with Maluku Island and Papua in the east. The Lesser Sunda Islands form two distinct arcs. The longer nothern arc consists of Lombok, Sumbawa, Komodo, Flores and Lembata Islands is an arc of volcanic origin. The islands of the shorter southern arc such as Sumba, Sawu, Roti and Timor consist of raised coral reef.

Mount Rinjani, Lombok Island

Mount Rinjani (Figure 15) is an active volcano on Lombok Island. It rises to 3,726 metres above sea level, making it the second highest volcano in Indonesia after Mount Semeru in East Jawa. The volcano and spectacular Segara Anak crater lake are protected by a National Park established since 1997 (Hanang Samodra & Yunus Kusumahbrata 1998). The 6 kilometres by 8.5 kilometres oval-shaped caldera is partially filled by a 230 metres deep lake known as Segara Anak and displays many volcanic phenomena such as hot springs, fumaroles and solfatara.

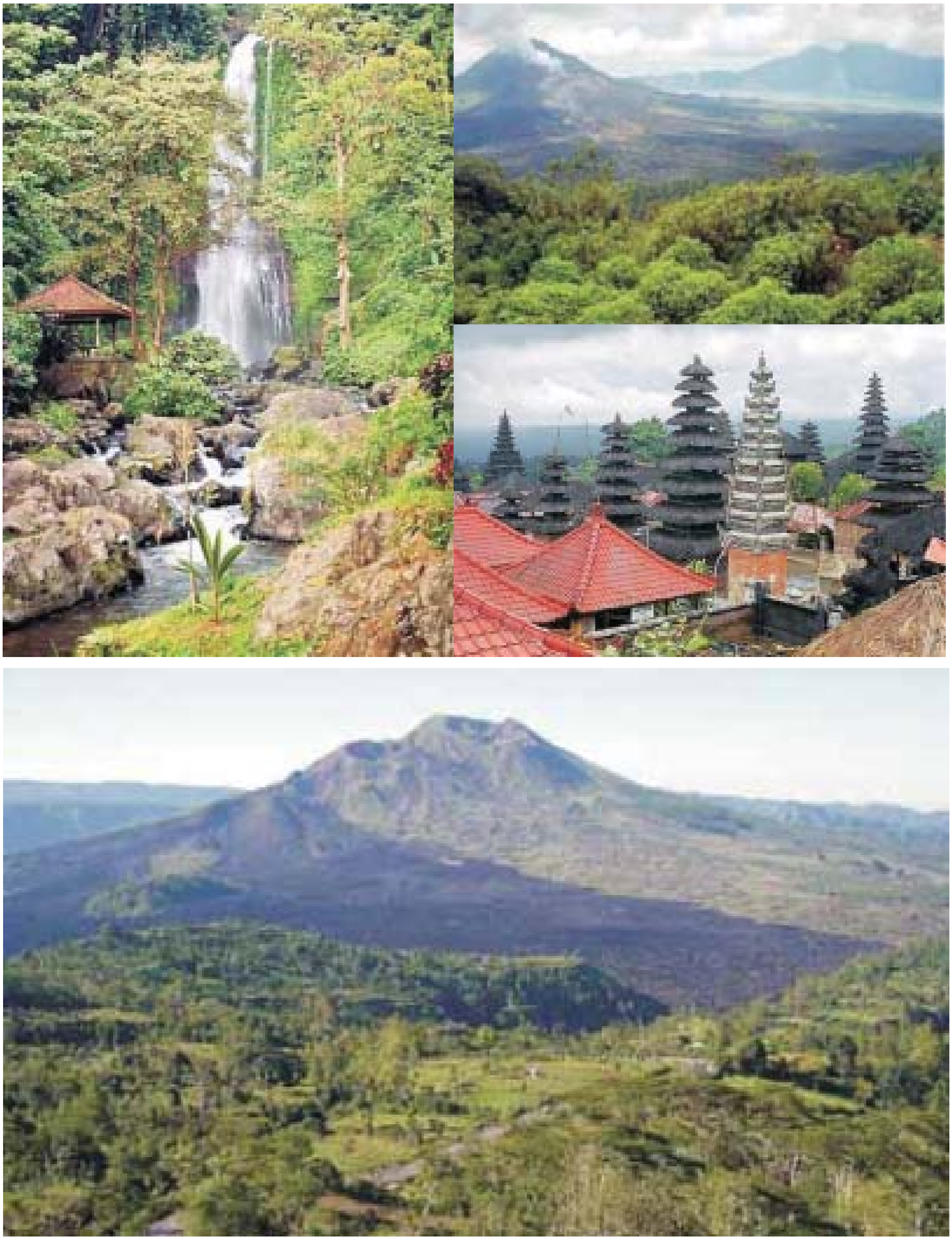


Figure 14. Mount Batur and its surroundings, one of the tourist attractions in Bali.

Consecutive eruptions of 1994, 1995 and 1996 have formed a small volcanic cone called Gunung Barujari which rises to 2,300 metres above sea level at the center of the caldera. Lava flows from these eruptions have entered the crater lake and resulted in a distinctive landscape around the volcano. Being located close to Mataram, the capital city of Nusa Tenggara Barat Province, Mount Rinjani has become a popular tourist destination. Under the supervision of the New Zealand Government, the local community have established well managed ecotourism activities around Mount Rinjani.

Figure 15. Satellite image and panoramic view of Mount Rinjani, the most prominent landscape in the north of Lombok Island.

Mount Tambora, Sumbawa Island, West Nusa Tenggara

Mount Tambora (Figure 16) is located on Sumbawa Island, part of the Lesser Sunda Islands. It forms its own peninsula on Sumbawa, known as Sanggar Peninsula. To the north and south of the peninsula, Mount Tambora is bordered by the Flores Sea and Saleh Bay respectively.

The 2,850 metres high Mount Tambora is an active stratovolcano which recorded the greatest eruptions in history. The Tambora 1815 eruption caused climatic anomalies around the world. The worst famine of the 19th century in the Northern Hemisphere was said to be due to the effect of the global spread of Tambora volcanic dust veil within the stratosphere. This led to the ‘Year Without Summer’ in North American and Europe and caused a global agricultural disaster.

The gigantic eruption of this super volcano in 1815 is estimated to have generated four times the energy of the 1883 Mount Krakatau eruption. An estimated 100 cubic kilometres of fragmental volcanic material was ejected forming a caldera measuring 6 - 7 kilometres across and 600 - 700 metres deep. Before the explosion, the height of ancient Mount Tambora was estimated at 4,300 metres compared to 2,850 metres at the present time (Hanang Samodra & Yunus Kusumahbrata 1998).

The casualities totalled at least 71,000 people, of which only 11,000 - 12,000 were directly killed by the eruption. During an excavation in 2004, a team of archeologists discovered cultural remains buried by the 1815 eruption kept intact beneath a 3 metres thick pyroclastic deposit.

Figure 16. Aerial and panoramic views of Mount Tambora, the most devastating volcano in Human History.

Mount Kelimutu, Flores Island, East Nusa Tenggara

Mount Kelimutu (Figure 17) is a volcano in central Flores Island with three summit crater lakes, each with its own unique colour of water. Water of the Tiwu Ata Mbupu or Lake of Old People, the westernmost lakes is blue, while waters in the other two lakes, the Tiwu Nuwa Muri Koo Fai or Lake of Young Men and Maidens and Tiwu Ata Polo or Bewitched or Enchanted Lake are typically green and red in colour, respectively. The level of acidity in the lakes, the growth of different types of algae and the activity of subaqueous fumaroles are probable causes of upwelling that occurs at the two eastern lakes (Hanang Samodra & Yunus Kusumahbrata 1998).

In historical times, the lakes have been the sites of minor phreatic eruptions. The summit of the compound Kelimutu volcano is elongated in a north-northwest – south-southeast direction. Older cones of Kelido and Kelibara are located three and two kilometres to the north and south, respectively.

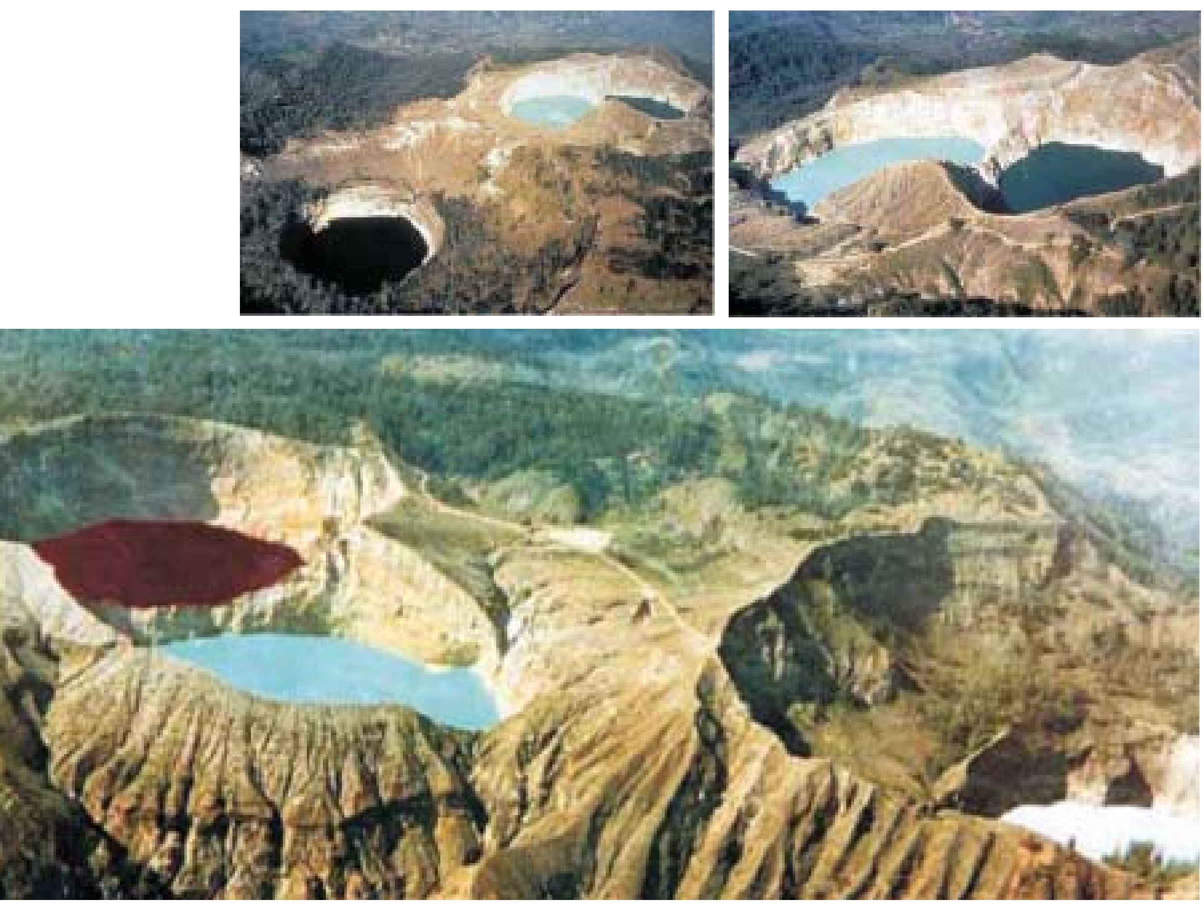


Figure 17. Mount Kelimutu and its colourful volcanic crater.

GEOHERITAGE OF SULAWESI (CELEBES)

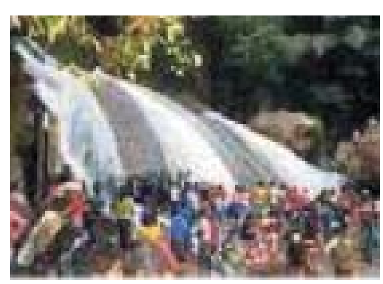
The 17,600 square kilometres, K-shaped Sulawesi or Celebes Island is the fourth largest island in the Indonesian Archipelago after Papua, Kalimantan and Sumatera. Geological evolution of this island is rather complicated because it is placed at the junction between three major tectonic plates. As a result, many distinctive geological phenomena of great scientific value can be observed on Sulawesi Island. The islands cultural heritage is also of great interest to anthropologists and tourists.

Maros Karst, Bantimurung National Park, South Sulawesi

A prime example of geoheritage in Maros Regency, South Sulawesi Province is the geomorphological expression of the Tonasa Limestone that forms typical tower and table karst hills (Figure 18). Because of their distinctive shapes as compared to other karst landscapes in Indonesia, these towering hills are specially classified as the 'Maros Type' karst.

There are many caves in Bantimurung National park and Gua Mimpi is probably the best cave for tourist.

The cave consists of a passage, about 500 metres long, full with stalactites and stalagmites, some are white in colour, others with varying shades of cream, yellow and brown. Some of them look like large chandeliers hanging on to the ceiling.



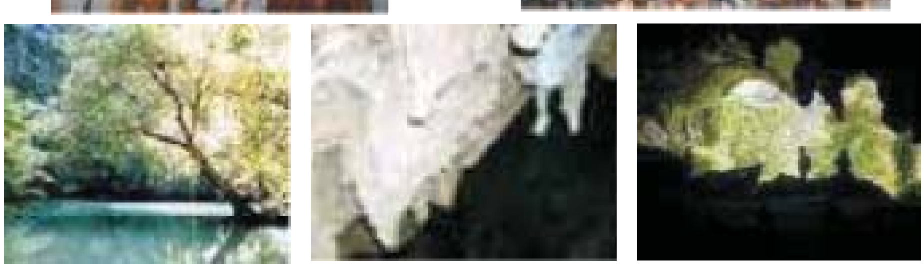


Figure 18. Typical Maros Type karst and cave feature within the caves.

The 1,000 hectares Bantimurung National Park is located about 45 kilometres north of Makassar which was previously known as Ujung Pandang and includes the Maros Karst landscape. Inside the park, there are many striking karstic phenomena including Bantimurung waterfalls and several caves (Sahat Tobing et al. 2000). Bantimurung lies at the southern end of a limestone outcrop which houses a series of caves and rock shelters. Bantimurung waterfalls are set amid lushly vegetated limestone cliffs. Bantimurung National Park is usually crowded with local tourists during weekends and public holidays, but at other times the park is a wonderful retreat from the congestion of Makasar, the capital of the octopus-shaped island of South Sulawesi.

Apart from its spectacular scenery, Bantimurung is also famous for its beautiful butterflies. The best time to see this living parade is when the sun appears after a rain shower when they form a riot of colours.

Tana Toraja, South Sulawesi

Tana Toraja is a regency situated approximatelly 300 kilometres to the north of Makassar. This area can easily be accessed by road through the Trans Sulawesi regional roadway interconnecting South Sulawesi with the West and Central Sulawesi Provinces. It is situated within a mountainous area underlain mostly by 15-20 million years old limestone units called the Toraja Formation. Tana Toraja is famous for its majestic scenery, captivating villages and dramatic ceremonies of the Torajan community traditional way of life (Sahat Tobing et al. 2000 – Figure 19).

One the most interesting aspects of Torajan culture is how they respect and treat their ancestors. The Torajan believed that by burying the dead in man-made tombs chiseled into the hard limestone hills one would be able to keep his/her ancestor's spirit close to the family and protect them from any misfortune. Slaughtering animals to be distributed amongst the community is one way of showing family respect to their dead. This ceremony can last for several days depending on family status and wealth.

Lokomata is situated on the side of Mt. Sesean, approximately 1400 metres above sea level and hosted one of the most spectacular burial sites. The burial caves here have been hand chiseled into a huge block of limestone. Today, the Torajan have reverted to their traditional way of burying the dead in either natural graves (*liang*) or man-made tombs (*patane*). For the Torajan people, land is too precious to be used for burying the dead. Up till now, more than 60 stone tombs have been produced and this had caused the rock to rapidly change its appearance as more and more tombs are being made. Each completed tomb requires between six and twelve months of hard work.

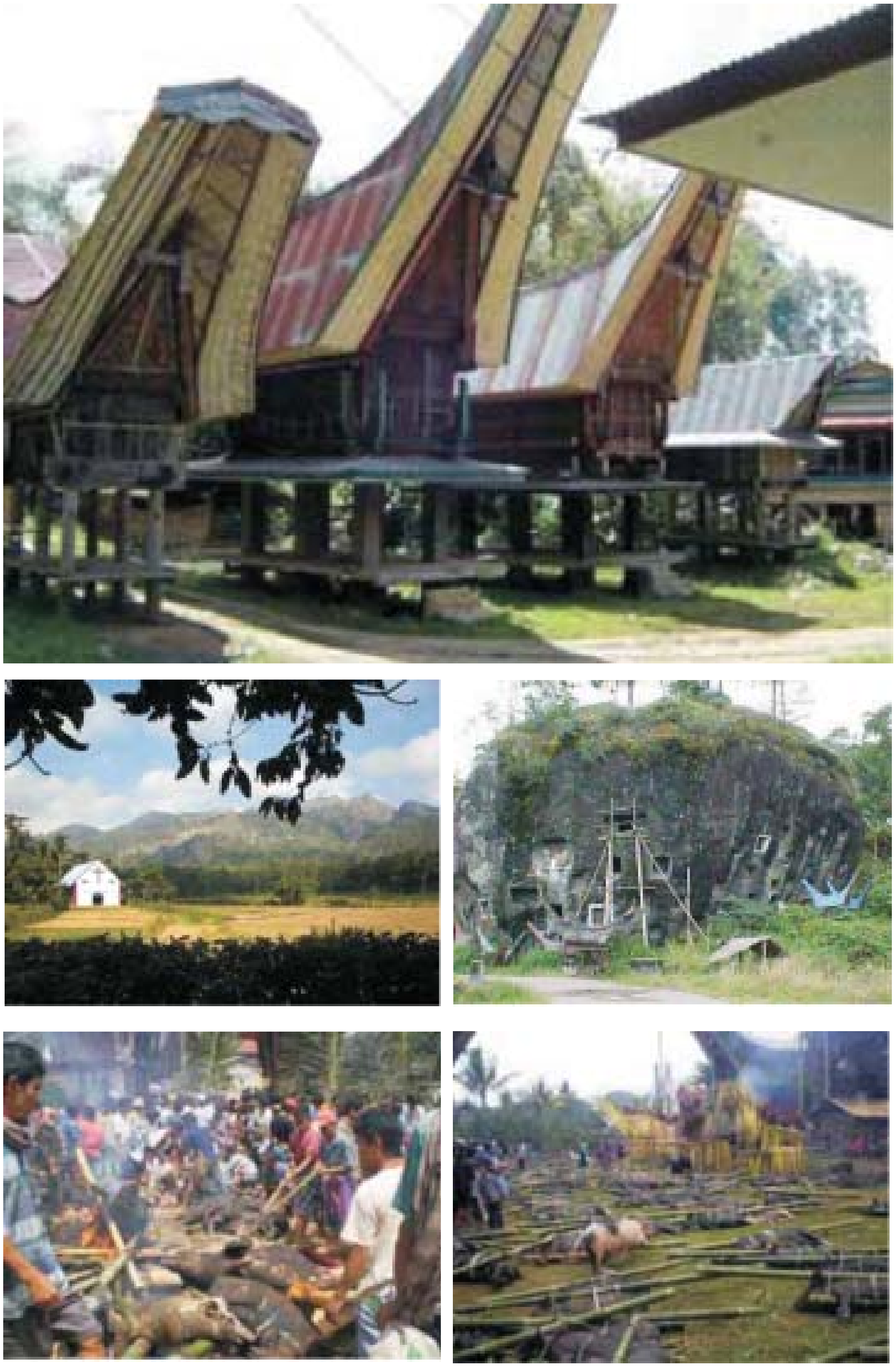


Figure 19. Landscape and the various cultural aspects related to geoheritage of Tana Toraja.

Poso Lake, Central Sulawesi

Poso Lake (Figure 20), 32 kilometres long, 16 kilometres wide and up to 450 metres deep, is the third largest lake in Indonesia. The Lake is placed at a height of about 600 metres above sea level and is believed to be formed by earth movements associated with the northwest trending Palu-Koro Fault Zone.

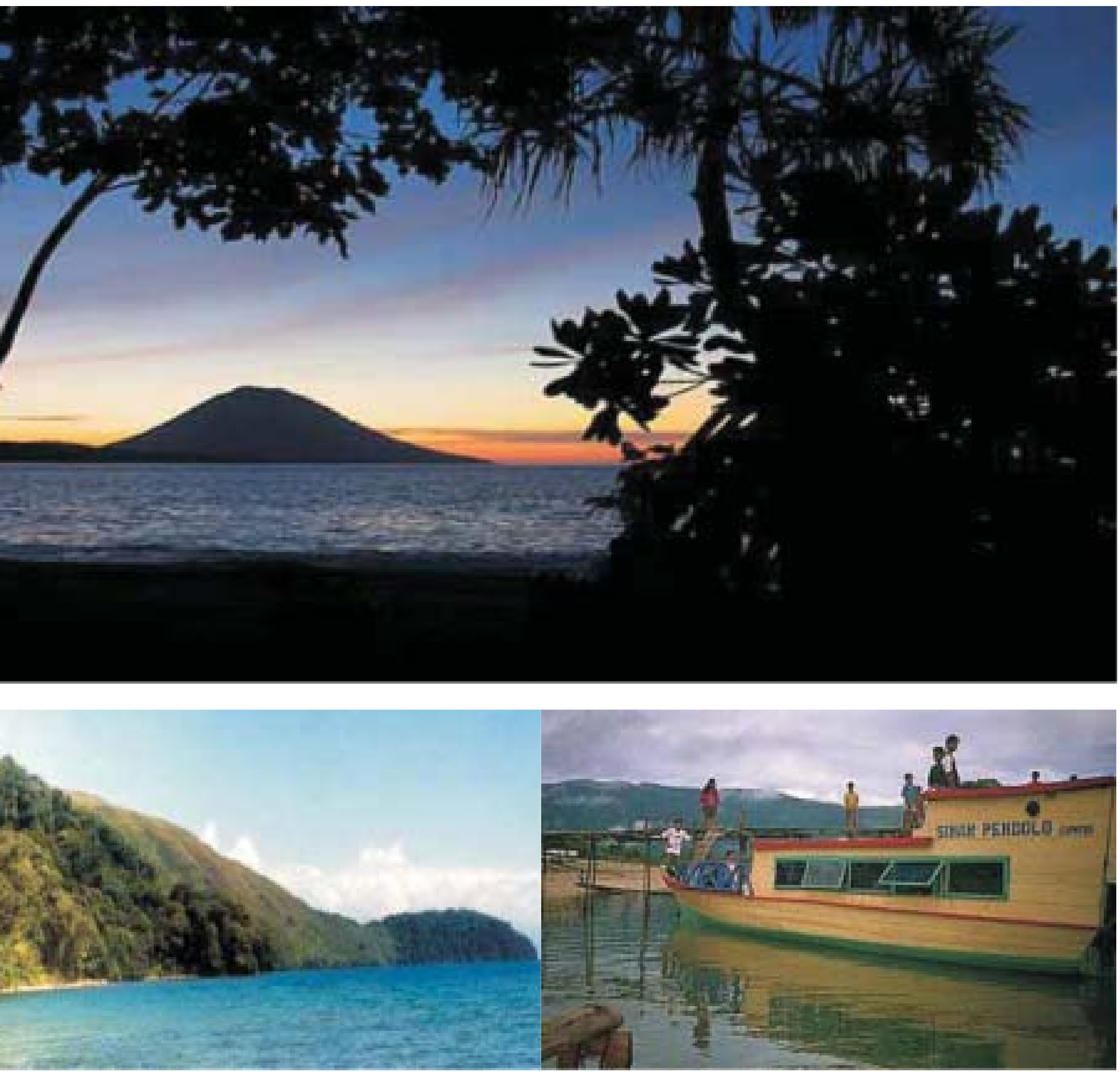


Figure 20. Geoheritage and geotourism at Poso Lake.

The main reason for people to visit Poso Lake is to enjoy its natural beauty. The nearby Tentena District in the north and Pendolo District in the south of Poso Lake have been developed into tourist districts, both with adequate supporting facilities for regular lake-based recreation. Tourists can walk to the rural areas fringing the lake or rent a boat to roam the lake. Poso Lake is also famous for its orchid gardens including the Bancea Orchid Garden in Taripa, where many varieties of wild orchids are exhibited.

Another tourist attraction is the Salopa Waterfall that is located in a forest close to Tentena, where a waterfall and a number of rapids and pools with crystal-clear fresh water are there to be enjoyed.

GEOHERITAGE OF MALUKU

The Maluku Islands form an archipelago lying to the east of Sulawesi, west of Papua and north of Timor. The archipelago was popularly known as the Spice Islands. Most of the islands are mountainous and some are made up of active volcanoes. Due to their complex geodynamic evolution, these islands reveal many interesting geoheritage features and magnificent geological landscapes.

Akoh Cave, Seram Island

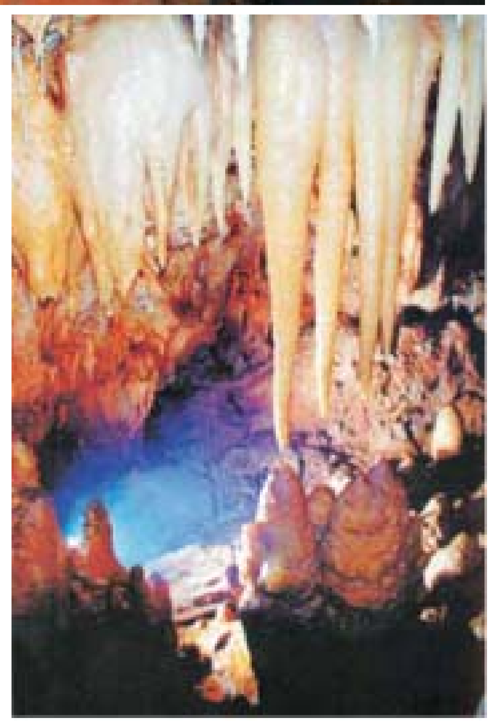
The beauty of Maluku's hidden underground treasures have been recognized as one of the most spectacular in Indonesia. Amongst them is the Akoh Cave (Figure 21) in Temilouw Village, 40 kilometres east of Masohi Town in South Seram. This cave displays spectacular arrays of speleothems including stalactites, stalagmites, flowstones, gypsum needles, helictites, and angel's hair abundant with sparkling clear calcite crystals (Hanang Samodra 2002).

The cave is located adjacent to the roadside and is managed by Dinas Pariwisata or Tourism Office. The caretaker can arrange your cave tour at any time, but for convenience it is advisable that you pre-book your tour with the Dinas Pariwisata in Masohi before visiting.

GEOHERITAGE OF PAPUA

Papua Province, the western half of New Guinea, is Indonesia's largest province covering 410,000 square kilometres or almost 21 percent of Indonesia's total land area. More than 75 percent of the land is covered by dense forest and its jungles are among the wildest and most impenetrable in the world. With a total population of 2.5 million, Papua has the lowest population density of any province in Indonesia. Morphologically, Papua consists of three major types of landscapes, i.e. the Central Mountain Range, the North and West Lesser Mountain Ranges, and the vast Southern and Northern Lowlands.

Abundant growth of helictites on a stalactite in Akoh Cave, indicating the relatively stable temperature and humidity of the cave.



Spectacular growth of speleothem within Akoh Cave showing calcite crystal with superb clarity.

Figure 21. Akoh Cave and among its amazing cave features.

Tropical Glacier of Puncak Jaya, Papua

Puncak Jaya Glacier (Figure 22) is a tropical glacier located in the Papua Central Range. After being reported by a Dutch explorer in 1623, the snow field of Puncak Jaya was first reached in 1909 by another Dutch explorer, Hendrik Albert Lorentz together with six indigenous Dayak Kenyah porters recruited from the Apokayan in Borneo. The peak of Puncak Jaya was climbed in 1962 by Heinrich Harrer, the Austrian mountaineer.

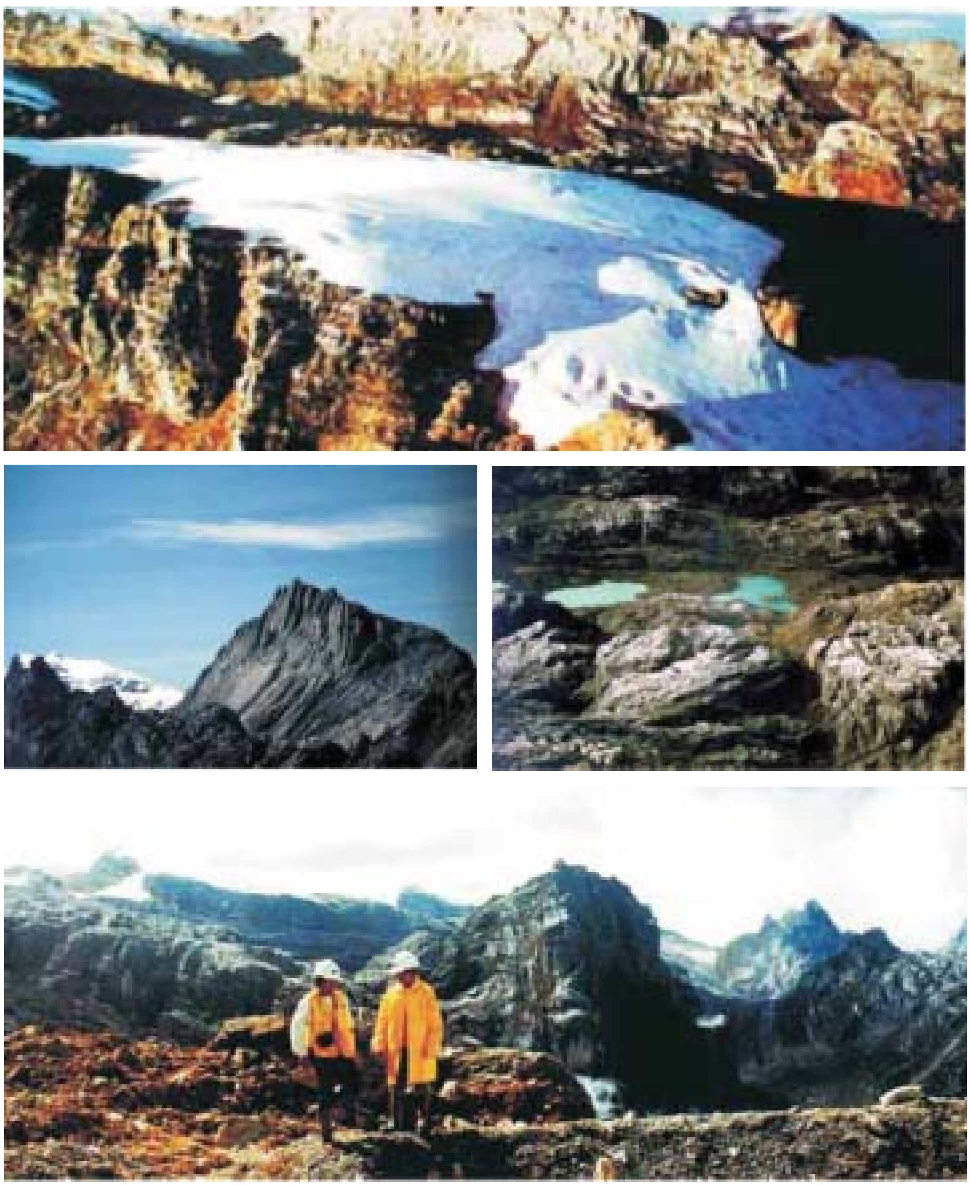


Figure 22. Tropical glacier and various other glacial landforms at Puncak Jaya.

Prior to 2000, tropical glaciers of Puncak Jaya complex were presented by the Cartenz, Meren and Northwall Firn glaciers. By the year 2000, the Meren Glacier had completely disappeared, and the rest are degrading rapidly. This rapid melting of Puncak Jaya's tropical glacier is probably due to continuous global warming as indicated by the regional increase in temperature of around 0.6 degrees per century between 1850 and 1972 (Hanang Samodra & Yunus Kusumahbrata 2000).

GEOHERITAGE OF KALIMANTAN

Borneo is the second biggest island in Indonesia after Papua. Geologically, Borneo is regarded as part of a stable continent referred to geologically as Sunda Land. The island consists of a vast flat lying swampy outer area surrounding an undulating, hilly to mountainous, rugged interior. The interior uplands are the source of many large river systems including those of the 1,143 kilometres long Kapuas River and 880 kilometres long Barito River. Borneo is also known for its extensive cave systems found in several karst terrains including that of Sangkulirang.

Sangkulirang Karst Landscape, East Kalimantan

A spectacular karst landscape is located on the Mangkalihat Peninsula on the border between Kabupaten Kutai and Kabupaten Berau. This is the so-called pinnacle karst, characterised by the intensive development of needle-shaped peaks (Yunus Kusumahbrata 1998). This area contains many caves with spectacular cave features (Figure 23). Many caves containing evidence of prehistoric human habitation can be found in this area. Apart from its display of outstanding geological phenomena, the karst ecosystem also plays an important role as a habitat for many important flora and fauna.

Martapura – Cempaka Gemstone Field, South Kalimantan

Kalimantan Selatan (South Kalimantan) or Kalsel is often nick-named as the Land of a Thousand Rivers. It is a swampy province, particularly in the southeast coast of Kalimantan. Banjarmasin, the capital city of South Kalimantan is famous for its colourful floating markets and bustling canals. The majority of local people are Banjarese, who are largely Muslim, with a sprinkling of Protestants and Catholics. The Banjarese are strict adherents to their religion, with thousands making the pilgrimage to Mecca each year.

Close to Banjarmarsin, Martapura or the Barito is another good place to experience riverside life at its best. Due to its famous gemstone market, Martapura is known as gemstone city. Using both traditional and modern equipment for cutting and polishing gemstones of many kinds, the local people have been involved in this handcrafting industry for many years.

Growth termination of stalactite groups indicating a decrease in the water supply dripping from the roof.

A sump indicating the development of an active passage-way.

Figure 23. Some of the cave features within Sangkulirang Karst.

Cempaka is a small village 10 kilometres from Banjarbaru, and 45 kilometres from Banjarmasin. It is an old site of traditional diamond mining (Figure 24), using very simple equipment. In 1965 a large raw diamond of 166.75 carats was found. Martapura is the centre of diamond and precious stone polishing (Yunus Kusumahbrata 1998).

At Cempaka, male workers usually dig 10-15 metres shafts, shored up with bamboo scaffolders fitted with steps to draw up baskets of soil, clay and gravel from underground in search for precious and semi precious gems. Most of them are hoping to duplicate the illustrious 1965's finding of the 100-plus carat trisakti diamond. Female workers puddle the dirt, sift it through a screen, pan it, and watching with their experienced eyes for even the smallest of diamonds, sapphires, amethysts, garnets or gold. The discovered gemstones, locally called *galuh* that means princess, will be traded in the nearby town of Martapura, where they will be cut and polished. Some gemstones of Cempaka have been appraised in the west at a much higher value than the price paid locally, but nevertheless, prospective buyers are advised to shop with reputable dealers, who usually pay particular attention to quality.

Figure 24. Martapura and various aspects of Cempaka gemstone mining.

The Trisakti diamond is the largest and most expensive diamond ever found in this region. About the size of a bird's egg it weighed 166.75 carats and belonged to the pink diamond category. Haji Sukri, the man who found the diamond from a 12 metres deep trench in Cempaka on 26 August 1965, was not very fortunate as he never saw the diamond again in his life after surrendering it to one of the high level officials in Jakarta. He only got just enough payment to build a house and to make a pilgrimage to Mecca with his wife.

FUTURE OF GEOHERITAGE CONSERVATION

Geotourism industry has been developed steadily in Indonesia since the late 1990s. Since then, more and more interesting geological features were identified to support the growing industries. Consequently, these features were gradually being accepted as part of geoheritage sites though there has not yet been any systematic effort made in order to conserve them as part of geoheritage conservation.

In the past, conservation of Indonesian geoheritage resources was mere coincidental. Geoheritage was conserved either as part of National Parks, World Heritage Sites or protected for the interest of culture and tradition. It is anticipated that with a much better understanding of the heritage value of geoheritage resources and higher awareness among various stakeholders on the fragility of these resources, the need to protect them will be realized by the government in the near future.

The conventional geoheritage concept adopted in Indonesia has often viewed goeheritage resources as separate entities that are only useful for the purpose of scientific research and education. Indonesians are now gradually adopting new geoheritage concepts that take into consideration the value of geoheritage features in assuring sustainability of particular ecosystems. Hence, protecting geoheritage resources is vital for integrated or holistic nature conservation and in long term comprehensive land management planning in Indonesia.

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GEOHERITAGE OF JAPAN

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Separator Photo:
Fumaroles at Owakudani, Hakone, Japan.

4

GEOHERITAGE OF JAPAN

Mahito Watanabe and Yoshihiko Shimazaki

INTRODUCTION

Japan's geoheritage aptly illustrates the restless character, past and present, of this earth we inhabit. The outer part of the sphere that we call earth, the so-called lithosphere, is divided into a number of relatively rigid segments or plates. These plates are not static but through much of geological time have moved about the globe, have sometimes split or amalgamated and collided with each other in complex processes known to geologists as plate tectonics. This interaction, particularly at plate edges, is the fundamental cause of much volcanic activity and of seismic disturbance, better known as earthquakes. The Japanese Archipelago is situated where four of these tectonic plates converge and thus currently constitutes one of the most seismically and volcanically active areas on the globe. Japanese geology records much of the movement history and present status of four great plates, the North American, Pacific, Philippine Sea and Eurasian Plates.

The earth's dynamic past is further reflected in the fact that the islands that now constitute the Japanese Archipelago were once an integral part of the Eurasian Continent. However, about 25 million years ago, a narrow part of the eastern margin of that continent split away and then slowly drifted to its present location. The geologic units that constitute present day Japan together record around five hundred million years of earth history and this, added to the still unstable geological environment, have endowed the Japanese Islands with many geoheritage sites of both national and international significance.

The islands are generally mountainous and the topography is rugged. High mountains were formed by the volcanic activities and uplifting events associated with the movements of tectonic plates. The climate of the islands is humid with high precipitation that has resulted in the formation of deep valleys dissecting the mountains and many scenic ravines throughout the country. Reflecting the diverse geology and topography, equally diverse ecosystems comprising a wide variety of fauna and flora have developed. Thus the scenic beauty of the Japanese Islands and the diverse ecology were formed, either directly or indirectly, as a result of fundamental geologic conditions, namely the converging tectonic plates.

This chapter describes examples of Japan's geoheritage at seven sites where proposals for the establishment of geoparks are being prepared (Figure 1). Many of the geoheritage sites in Japan are protected as Natural Monuments. This involves designation by the national or local governments of scientifically important natural products and features of an area, such as its fauna, flora and geology. At present, 975 items have been designated, of which 221 items are related to geosciences. Information regarding geoheritage designated as Natural Monuments is available at the website of the Commissioner for Cultural Affairs.

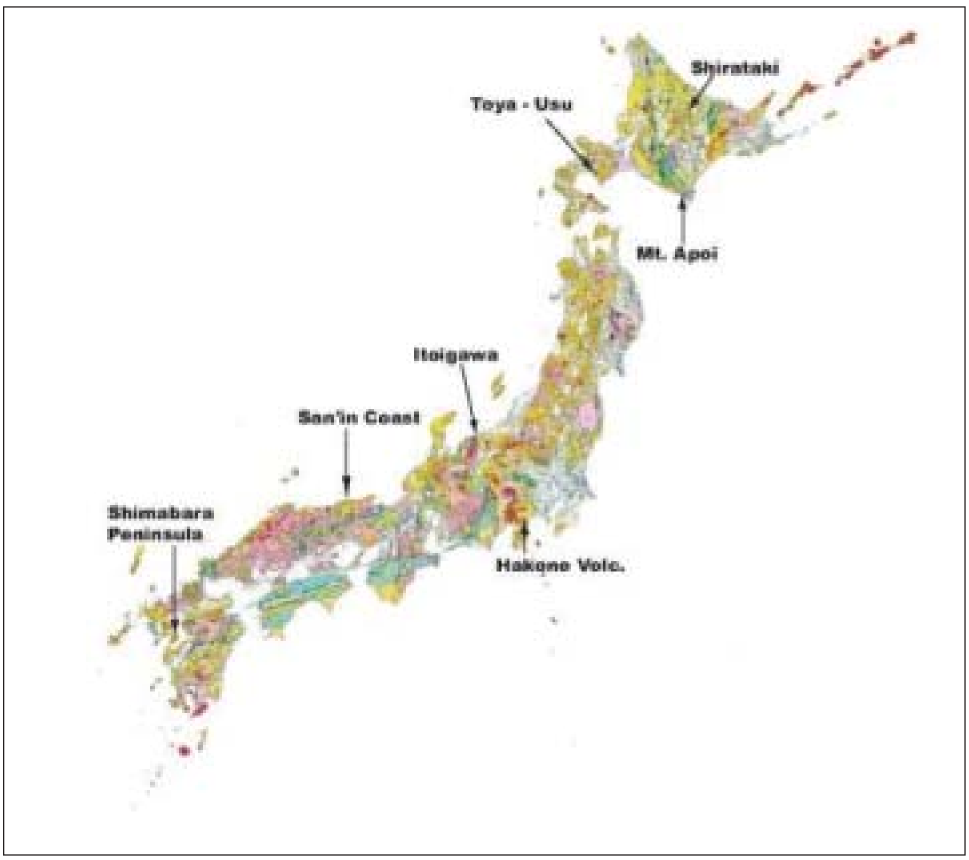

Figure 1. Locations of the areas described in this chapter. Geological map is after 1/1,000,000 Geological map of Japan published by Geological Survey of Japan.

In addition to these Natural Monuments, there are about two hundred museums in Japan which have geoscientific displays. Some of them are volcano related and one, unusually or even uniquely, preserves an active fault with a house built over it, whilst others are centered on field activities and call themselves field museums, eco-museums and other names as deemed fit.

Shirataki Palaeolithic Obsidian Stoneware Sites

The township of Shirataki is located in the mountains northeast of the northern island of Hokkaido. A large body of obsidian and remains of ancient sites for large-scale stone tools production constitute the central theme of this geopark. Obsidian is a natural glass formed by quenching of magma emitted from volcanoes. A large amount of obsidian, the product of a volcanic eruption several million years ago, was found to be suitable for the production of ancient stone tools by a pre-historic community residing near Mount Akaishi of Shirataki Town. There are more than a hundred sites of Palaeolithic remains near the confluence of a river flowing from Akashi and a larger Yubetsu River, and excavation is still going on. Several hundred thousand stone tools and fragments were gathered from these sites (Figure 2). These large numbers of stone tools and fragments indicate that the sites represent ancient factories for the production of stone equipment during the Palaeolithic time.

Figure 2. Palaeolithic obsidian stoneware excavated from the Shirataki area.

Recent progress in analytical methods have now enabled us to pinpoint the origin of the material of old stone tools and it has become clearer that the obsidian from this town was used for tools not only in Hokkaido, but was also used abroad as far as Sakhalin and the Amur River area in Siberia. This is a proof that the range of trading activities of the people in the Palaeolithic age could extend as far as several hundred kilometres. In those days people used obsidian as a measure in trade in a fashion similar to money in subsequent civilizations. Therefore, Shirataki obsidian is a precious geoheritage in Japan which shows the interrelation between georesources and humans ever since pre-historic time.

In the Shirataki Township, there are also many examples of geoheritage other than the obsidian and Palaeolithic remains. Among them are the first geologic units formed by the accretion of submarine mud by plate motion when Hokkaido was a part of the Eurasian Continent and also periglacial relics such as topography and alpine plants. Thus Shirataki is a very important area for the observation of various phenomena of natural history.

Apoi-dake Area

Apoi-dake or Mount Apoi is located in the southern part of Hokkaido, the northern island of Japan. This mountain is made of rocks known as peridotite that was originally formed several tens of kilometers below the earth's surface. Although Apoi is only a small mountain rising to 810 metres above sea level, it is well known internationally among geologists because of its peridotite occurrence.

Peridotite

The upper 10-40 kilometres of the earth is called the earth's crust and it is made of rocks similar to those we see on the surface. Below the crust is a thick layer called the mantle and it is made of rocks different from those of the crust. These rocks are named peridotite. Partial melting of this peridotite produces magma. Therefore, in order to understand the genesis of magma, study of peridotite is of utmost importance. Many types of peridotite occur at Apoi, such as those which remained after parts of it had melted and the rocks along the conduit in which the molten magma moved. Thus, these rocks provide the most important clues in understanding the conditions in the deeper subsurface zones of the earth.

How can we observe the rocks which were born several tens of kilometres below the surface? The answer to this question has its roots in the manner of the birth of Hokkaido. This island was formed by the collision of two island arcs (chains of islands along the boundary of a tectonic plate). The Hidaka Range where Apoi is located was formed at the place where the two island arcs collided around 15 million years ago. During the collision, the frontal part of one plate was pushed up and placed on to the other plate hence the rocks that was originally located at great depth came to rest near the earth surface, and eventually become exposed on the surface of the overridden plate.

At the Outdoor Museum for Peridotites at Samani Town, many types of peridotites are exhibited with explanatory boards. Large blocks of the rocks have been cut and polished and the beautiful minerals constituting the green peridotites can be observed.

Rocks and flora of Mount Apoi

Peridotite rock is exposed at the surface on Mount Apoi and can be seen as outcrops along the mountain routes. Weathering of these rocks has produced soil in this area containing relatively large amounts of magnesium and iron. This favours the growth of a particular type of flora and many beautiful flowers bloom along the mountain route from May through to October.

There is a Visitor Center in Samani Town at the foot of the mountain providing information concerning the geology, flora and fauna and also for climbing activities at Mount Apoi (Figure 3).

Figure 3. Mount Apoi Visitor Center.

Toya - Usu Area

Toya - Usu area is located in the southern part of Hokkaido Island in northern Japan. This site covers a relatively wide area where various volcanic features can be observed (Figure 4). These include Usu Volcano which last erupted in the year 2000, Showa-Shinzan Volcano which first erupted in the years of 1943-45 and Lake Toya which is a caldera lake formed by huge intensive eruption around 100 thousand years ago. The area is known for its many hot springs situated in scenic localities a reminder that although volcanic activities can cause human disasters, they can also provide us with benefits such as hot springs and beautiful scenery.

Figure 4. Guided tour for children in Toya - Usu area.

Lake Toya

Toya is a caldera lake born by a series of gigantic eruptions around 100 thousand years ago. Calderas are depressions formed through processes of effusion of large amount of magma during volcanic eruptions and the subsequent collapse of the summit of the volcano into the subterranean space left vacant by the emission of magma. At Toya, rocks formed from pyroclastic flows that were extruded during the eruption are piled several tens of meters thick around the lake and they can also be observed along the river south of the lake. Tens of thousand years later, eruption occurred again in the middle of the lake forming an island. Usu and Showa-Shinzan which will be mentioned later are volcanoes which were formed by later eruption at the southern foot of the volcanic complex.

Toya Caldera

Lake Toya hot spring occurs at the southern bank of the lake, where many hotels and hostels beautified the landscape in this well known resort area. In July 2008, the political leaders of the world gathered here for a summit meeting. There are also a Volcano Science Museum and a Visitor Center in this area providing useful information to visitors regarding the geology of the area.

Usu Volcano

Usu began its volcanic activity about 20 thousand years ago and has erupted eight times since 1663, including four eruptions during the past 100 years and the most recent in 2000. During the 2000 eruption, the residents of the area were evacuated most opportunely by extremely well-coordinated cooperation between volcanologists and the local administration. There was no loss of life in spite of the close proximity of the volcano and sites of human activities.

There is a rope guided track leading from the eastern foot of the mountain up to the crater of the 1977 eruption along which Toya Lake and Showa-Shinzan Volcano can be observed (Figure 4). A promenade is constructed around the 2000 eruption crater where one can see the fearsome forces of nature such as the presently steaming crater, buildings destroyed by the eruption and roads torn by the uplift of the land surface associated with eruption.

Showa-Shinzan Volcano

In December 1943, earthquakes occurred repeatedly in the vicinity of the active Usu Volcano. Subsequently the tremors became more frequent, and in June 1945 a steam explosion took place in a wheat field at the foot of Usu and a new volcano began to form accompanied by violent eruptions. The eruptions continued until the end of 1945. The activity ceased with the rise of the volcano to 407 metres above sea level in a field with elevation of about 100 metres (Figure 5). These events represented the birth of the Showa-Shinzan volcano. They were recorded and sketched in detail by Mr. Mimatsu Masao who was the local postmaster at that time. As they occurred at the height of World War II, geologists could not be diverted from the war effort. Thus these sketches became extremely valuable scientific data which subsequently came to be called the Mimatsu Diagram and are well known among volcanologists. Later, Mr. Mimatsu bought the area around the Showa-Shinzan in order to preserve this volcano as a monument. After Mr. Mimatsu died, his family founded a museum named Masao Mimatsu Memorial Museum and they have been managing it very well ever since.

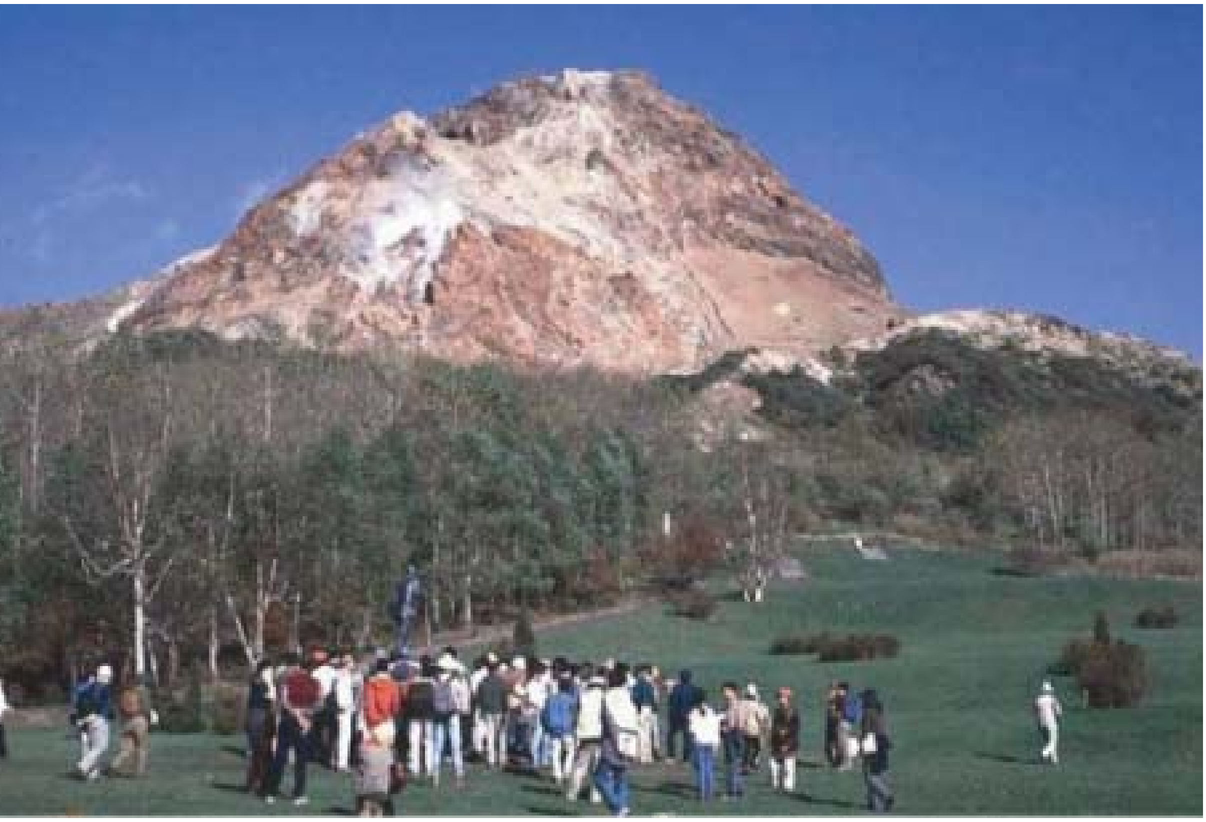

Figure 5. Showa-Shinzan Volcano today.

People and volcanoes

In this geopark, the visitors should be able to feel and understand the enormous natural energy of volcanoes and the disasters and ruin that these volcanic activities can cause. At the same time, however, it is also seen here that these volcanoes can bring benefits to humanity.

It will be clear from the exhibits that volcanic eruptions cause intense and severe damage, but at the same time, it should be noted that geoscientific research on volcanism and the dissemination of the results of these studies will enable significant mitigating action to be taken in potentially threatened areas. Also the blessings such as beautiful scenery, hot springs and other benefits of these natural phenomena will become evident from a visits to this park. The main theme of the geopark is to enable visitors to understand natural earth processes and to reflect on living in harmony with nature.

Itoigawa Area

Itoigawa City faces the Sea of Japan in the central part of Honshu. The so-called Itoigawa - Shizuoka Tectonic Line (ISTL) which divides Japan into Northeast and Southwest Japan, cuts through this city and is named after it. This line drawn on the geological map is very significant as it is considered by most geologists to mark the boundary between the North American Plate and the Eurasian Plate, two of the important crustal plates that together built Japan. To the east of the ISTL lies a graben (large topographic depression) formed some time later than 20 million years ago. Known as the Fossa Magna this graben was subsequently filled by geologic formations including those from the active volcanoes that were also situated here. In marked contrast, the area to the west of the ISTL is occupied by much older geologic formations comprising rocks of the Palaeozoic Era (400 to 250 million years ago) and Mesozoic Era (about 250 million to 65 million years ago).

Fossa Magna and Itoigawa - Shizuoka Tectonic Line (ISTL)

When a narrow strip from the eastern margin of the Eurasian Continent broke apart and drifted to its present position forming the archetype of the Japanese Islands some 15 million years ago, a N-S trending trough, 10 kilometres wide and more than 5000 metres deep was developed and separated these islands in two. This is the Fossa Magna. The trough or graben is bounded to the west by a large fault situated at the contact between the North American Plate to the northeast and the Eurasian Plate to the southwest. This is the Itoigawa - Shizuoka Tectonic Line. At the Fossa Magna Park in Itoigawa City, exposures of the ISTL can be observed along well maintained paths. The fault contact between 260 million years old rocks known as meta-gabbro to the west and 16 million years old basaltic andesite to the east represents the boundary between the North American and Eurasian Plates. This is a very rare location where the contact of two large tectonic plates can actually be observed. ISTL as the boundary of two plates was formed rather recently in terms of geological time. The two plates on both sides of the ISTL began to collide and push against each other around 3 million years ago, and as a result, a mountain chain exceeding 3,000m in elevation was formed in the central part of Honshu Island. Prior to the collision, the Fossa Magna region was below the sea where pillow lava, formed 14 million years ago by the extrusion of molten lava from submarine volcanoes and its subsequent quenching by sea water, can be seen along the observation path.

Hisui-Kyo (Jade Gorge) of the Kotaki River

Precious gemstone known as jade occurs naturally as either one of two different minerals and one of them is the mineral known as jadeite. Many loose fragments of jadeite are found within the Hisui-Kyo or Jade Gorge (Figure 6) and these fragments record a long and complex geological history that stretches back in time for about 400 million years. They appear in the gorge as part of the debris or blocks (Figure 7) eroded and fallen from the sandstones that form the cliffs bounding the river. Ornaments made from these jades are found in 5000 year old archeological remains in Itoigawa City and vicinity. These are the oldest jade ornaments in the world. Jade ornaments are found from many ancient sites in Japan and they are all made from Itoigawa jade. People in Japan, however, lost interest in jade around the 8th Century and since then such ornaments were not made. Thus, the Itoigawa jade was completely forgotten until it was re-discovered in the 20th Century.

Figure 6. Hisui-Kyo (Jade Gorge) with jade boulders.

Figure 7. Boulder of jadeite from Hoigawa.

There are high mountains to the south of Itoigawa such that one may think that accessibility to the south would have been almost impossible in pre-historic times. However, there is a continuous topographic depression along the ISTL that would have allowed traffic access to the Pacific side of Honshu through this route. The Itoigawa jade and its trade to other parts of Japan are further examples of both the use of georesources by humans since very old times and of the relationship between our culture and geological heritage.

Fossa Magna Museum

This museum is located in Itoigawa City, and its exhibits are focused on the geology of Fossa Magna region as well as fossils and minerals from various parts of the world. This institution is the center of activities regarding the establishment of a geopark in the Itoigawa area. The preparatory activities include construction of an observation promenade, with explanatory boards highlighting important geological exposures. Some of the major items to be seen include limestone of Palaeozoic age, dinosaur foot prints in Mesozoic rocks, landslide topography, active volcanoes and exposures of rocks deposited by pyroclastic flows. All information on the geology of this area can be acquired at this museum.

Hakone Volcano and Vicinity

Hakone Volcano is located in the central part of Japan, at a distance of about 80 kilometres southwest of Tokyo. This volcano formed a bowl-like depression or caldera when its central part subsided after a large-scale eruption. A lake named Ashinoko occupies part of the floor of the caldera and there are also some volcanic cones within in the caldera.

Hakone Volcano

Hakone area displays a complex topography that reflects repeated episodes of volcanic activity. The first volcanic activity at Hakone began around 650 thousand years ago, and subsequently more than 10 volcanoes erupted intermittently over a period of more than 400 thousand years until about 230 thousand years before the present. Between 230 thousand to 130 thousand years ago, the character of the magma beneath Hakone became more viscous resulting in the occurrence of many large-scale explosive eruptions. These eruptions caused the expulsion of huge amounts of fragmental material as pyroclastic flows from the volcano. The result of the loss of so much material from beneath the volcano created a void in the mouth of volcano into which the overlying central part of the volcano collapsed and formed a large circular depression or caldera. Subsequently intermittent small eruptions occurred within the caldera and a number of new central volcanic cones were formed. Then, between 80 and 60 thousand years ago, more explosive eruptions emitted large amounts of pyroclastic material. Sixty thousand years ago a further collapse occurred and a new caldera was formed. Several further eruptions followed in the center of the caldera resulting in the formation of a new generation of central volcanic cones completing the topographic complexity seen today.

The scenic beauty of Hakone Volcano resulted from its volcanic activity evolving over the past several hundred thousand years. Some of the volcanic cones are still active where fumaroles and with hot springs exceeding 90ºC in temperature can be observed at Owakudani (Figure 8). Eggs boiled in these hot waters have become a novel specialty of the area. There are many hot springs within the Hakone Caldera and these together with the weather, scenery and the relative proximity to highly populated areas such as Tokyo and Yokohama have made Hakone a very popular resort area with many hotels and villas provided. Yugawara, on the southern side of Hakone is also a well-known and long established hot spring area. The summit of Hakone is well-established as the scenic spot for viewing the beautiful Mount Fuji.

Figure 8. Fumaroles at Owakudani.

Manazuru Peninsula

One of the products of Hakone eruptions is andesite, a hard and durable volcanic rock that is widely distributed in the Manazuru Peninsula some fifteen kilometres southeast of Hakone. These rocks gained fame by their use as the material of the stone walls of the moat when Yedo Castle (the present Imperial Palace) was constructed between late 16th and early 17th centuries. These rocks are still quarried for use in construction.

San-in Coast

San-in coast is located in western Japan, bordering with the Sea of Japan. Rocks which were formed by volcanic activities at the time of the birth of the Japanese Islands, some 15 million years ago, are widely distributed along the coast. These rocks have been eroded by very strong waves and seasonal winds caused by development of high pressure zones over Siberia during the winter months. These have resulted in formation of unique and spectacularly beautiful scenery. Seasonal wind and waves also deposited sand at the western end of the coast and produced the sand dunes of Tottori.

The birth of the Japanese Archipelago and the Sea of Japan

The Japanese Islands were originally a part of the Eurasian continent. About 25 million years ago, near to its eastern margin, the continent began to split and pull apart. It was this large-scale rift that became the Sea of Japan while the eastern border of the rift became the Japanese Islands which migrated to the present location around 15 million years ago. During this process of separation, many rifts and fractures developed and magma rose to the surface through these fractures and produced abundant volcanic rocks. Many geological features that reflect processes of the birth of the Japanese Islands, particularly the volcanic activities, can be best observed along the San-in coast.

Volcanic and sedimentary rocks of the San-in Coast

Volcanic rocks occur widely along the San-in coast and can be observed from tour boats travelling near to the shore. These rocks reveal many of the phenomena that occur when molten lava cools and solidifies. For example, regular vertical cracks in the rocks called columnar joints form bundles of vertical hexagonal pillars about a metre in diameter (Figure 9). Striking views of columnar joints can be seen from the sea at several localities. Severe erosion of volcanic rocks by the waves and wind form many interesting sea-caves and sea-tunnels along the rocky coast.

Not only volcanic rocks, but also sedimentary rocks such as sandstone and mudstone occur in the area. At some localities, fossils of the footmarks of animals

Figure 9. Columnar joints along the San-in Coast.

and birds that lived along the shore of lakes at the time when the Japanese Islands began to separate from the Eurasian continent, can be observed on the surface of sandstone formations.

Tottori Sand Dune

The accumulation of large amounts of sand at the Tottori Sand Dune (Figure 10) is the result of various natural processes. These involve the transportation of large amounts of sand to the coastal areas by the flow of Sendai River, followed by the westward movement of the sands along the coast driven by coastal currents and waves, and finally the landward transport of the sand influenced by the strong seasonal sea winds. The resulting dune, the largest in Japan, extends for 2.4 kilometres from north to south and 16 kilometres from the east to west with maximum relative height of 90 metres. These sand dunes have frequently been blown and scattered over the nearby farms causing significant damage to the agricultural product. To avoid more damage lines of trees were planted in order to break the wind. This resulted in the shrinking of the dunes and caused changes

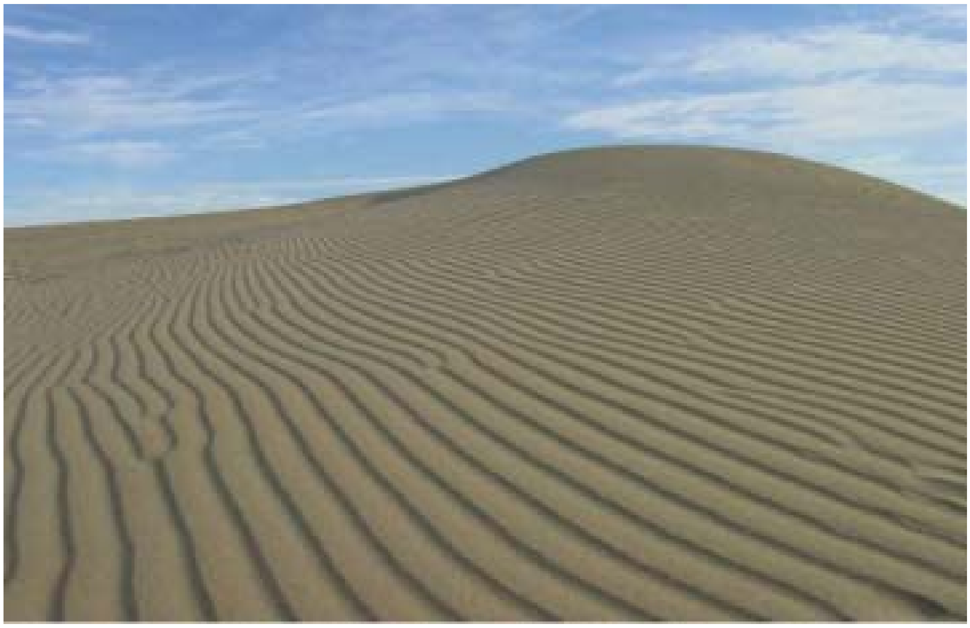

Figure 10. Tottori Sand Dune.

in the ecosystem. In response, the wind breaker trees were reduced and efforts are now made to protect and preserve the dunes as well as the farms.

Shimabara Peninsula

The Shimabara Peninsula is located in Kyushu in the western part of the Japanese Islands. Unzen Volcano, which erupted from 1990 to 1995, is located in the central part of the peninsula. This is the first area designated as a national park in Japan together with the Inland Sea and Kirishima areas.

Unzen Volcano

The most recent eruption of this volcano took place from 1990 to 1995. There are also records of eruptions in 1663 and 1792. As a result of the 1792 eruption, part of the volcano collapsed forming an extremely large landslide that overwhelmed Shimabara Town before cascading into the sea beyond, causing catastrophic tsunamis that flooded Amakusa, the island across the strait. The landslide caused 5,000 deaths and the tsunami took a further 10,000 lives. The total of 15,000 deaths is the largest volcanic disaster in the history of Japan.

The 1990-1995 eruption formed lava domes near the summit (Figure 11), and their collapse generated many violent and destructive pyroclastic flows. The largest flow occurred on 3 June 1991 when 43 people were killed, many of them news reporters. Two well-known volcanologists, Dr. Kraft and his wife also lost their lives whilst observing the eruption. Following the termination of the eruption in 1995, extensive engineering work was planned and is currently undertaken aimed at controlling erosion in order to prevent further slope collapse. In this area, two museums and three visitor centres were built to educate the public in relation to volcanic and other geohazards. The ruins of an elementary school building which was destroyed by these flows is preserved as a vivid testimony to the power of volcanoes and the danger they pose. All these facilities are well maintained and are planned to be the core of the proposed geopark.

Figure 11. Unzen Volcano.

FUTURE PLANS FOR JAPANESE GEOPARKS

Since 2005, the Geological Survey of Japan (GSJ) has been collaborating with the Geological Society of Japan in promoting the geopark initiative in Japan. In 2008, a Japan Geopark Committee was founded which will evaluate the aspiring Japanese geoparks and prepare recommendations to the Global Geoparks Network (GGN). The secretariat of this committee is placed in GSJ. The committee is presently selecting areas and plans to finalize the recommendation particulars to be submitted to the GGN within the near future. Preparations are also under way for completing Japanese domestic geoparks. The plan calls for the establishment of at least 10 geoparks in the global network and several tens of geoparks in the Japanese network.

FURTHER READING

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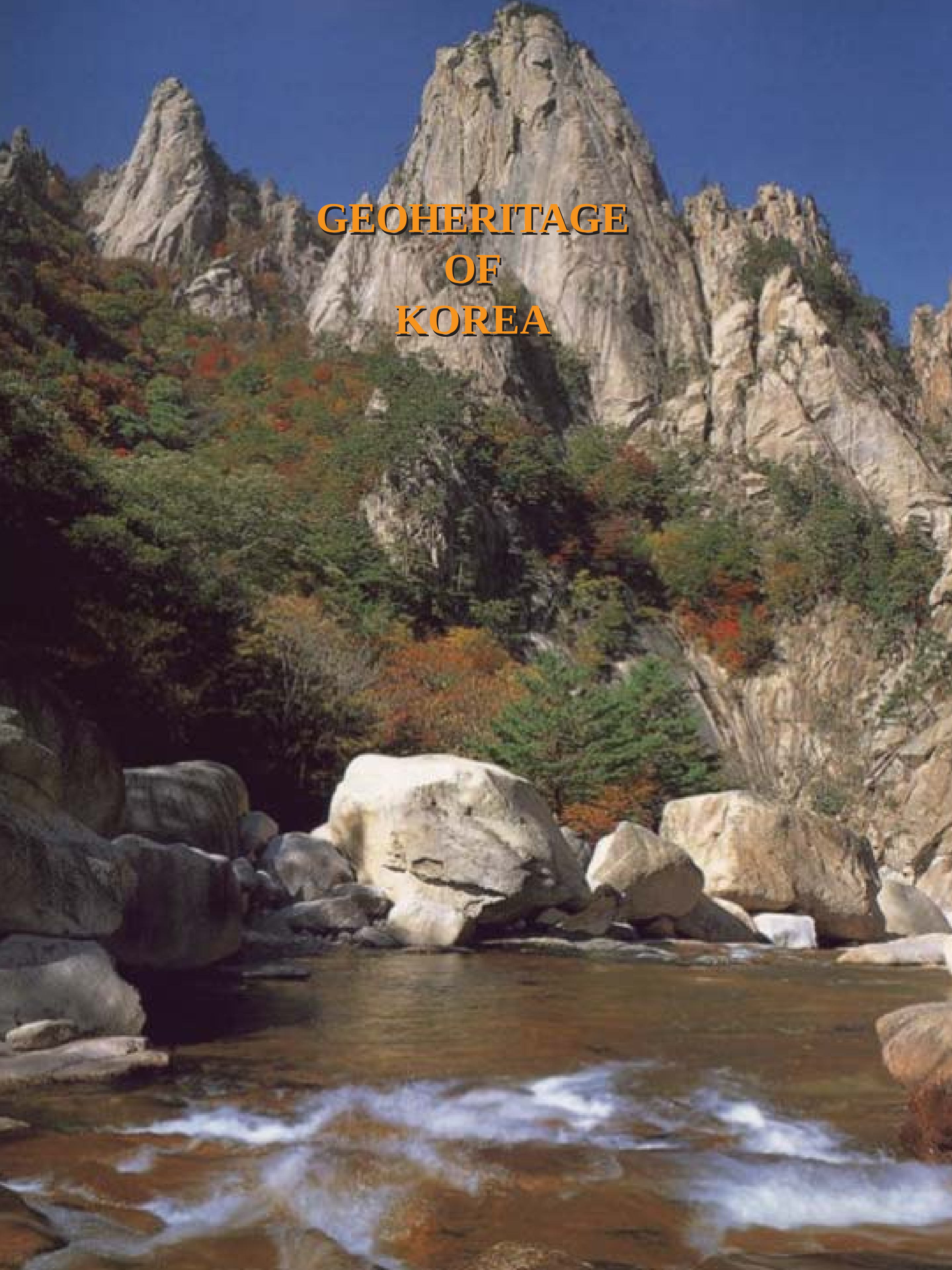
GEOHERITAGE
OF
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Separator Photo:
Cheonbuldong Valley of Soraksan, South Korea.

5

GEOHERITAGE OF KOREA

You Bong Kim

DEVELOPMENT OF GEOHERITAGE

The Republic of Korea forms the southern part of the Korean Peninsula which lies in the northeastern section of the Asian continent (Figure 1). The country covers a total area of 222,154 square kilometres of which two-thirds are mountainous. A mountain range stretches the length of the east coast and plunges steeply into the East Sea, while along the southern and western coasts, the mountains descend gradually to the coastal plains where the bulk of Korea's agricultural crops are produced.

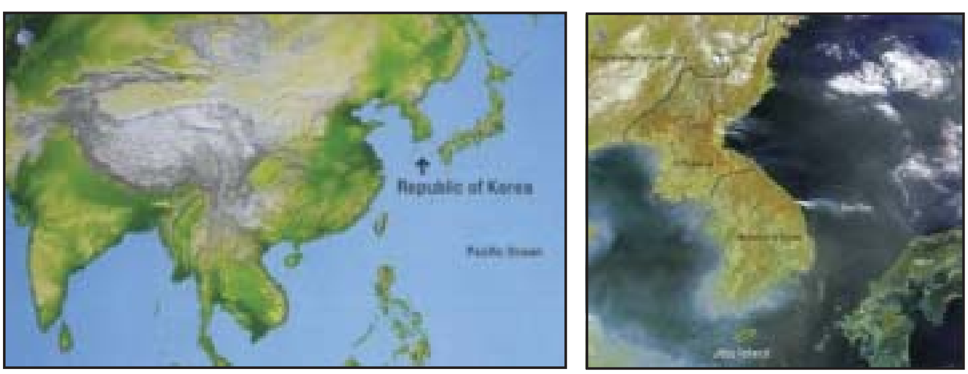


Figure 1. Location of Republic of Korea.

Although the territory of Korea is relatively small, its geological heritage is extremely rich and varied (Reedman & Chun 2005). Many areas displaying important features of this heritage have been protected under different categories, such as National Parks and Natural Monuments. The Korean government designates important landscapes representative of Korea's natural beauty as Natural Parks which can be classified into 3 categories: national parks, provincial parks and county parks. Natural parks are freely accessible, though certain activities are restricted or prohibited in order to preserve them. All facilities within the parks are planned and operated by responsible park authorities. Recent development in providing visitor-friendly services has transformed natural parks into prominent tourist attractions. Currently, Korea administers a total of seventy-three natural parks consisting of twenty national parks, twenty-two provincial parks and thirty-one county parks.

National Parks of Korea are designated for the purpose of preservation of the natural environment and for promotion of public health, leisure and recreation (Article 1 of the Natural Park Act, 1995). They consist of preserved parcels of public land on which most forms of development are prohibited. Together they cover a total of 6.6% of the country's area, and are typically located in mountainous or coastal regions. Some of them have been internationally recognized as UNESCO Natural Biosphere Reserves.

The national parks, except Gyeongju National Park and Hallasan National Park which are managed by provincial governments, are overseen by the Korea National Park Authority (NPA), established in 1987. The Authority operates its own police force, and since 1998 has been under the jurisdiction of the Ministry of Environment. Since the designation of Jirisan as the first national park in December 1967, in accordance with the Natural Park Act 20, many other areas including Gyeongju, Gyeryongsan, Hallyeohaesang, Soraksan, Songnisan, Hallasan, Naejangsan, Gayasan, Deogyusan, Odaesan, Juwangsan, Taeanhaean, Dadohaesang, Bukhansan, Chiaksan, Woraksan, Sobaeksan, Byeonsan Bando and Wolchulsan have been designated as national parks (Figure 2). The largest mountain park is the Jirisan National Park in the southwest of the country, while the largest marine park is Dadohaesang with an area of more than 2,200 square kilometres. The smallest park is Wolchulsan, with an area of only 56.1 square kilometres (Kim 2004).

Provincial Parks are natural parks designated by the natural park law to preserve and utilize natural resources. Municipal and provincial authorities manage the parks, and activities in the parks require the approval of the governor of the province. Since the designation of Mt. Gumosan in Gyeongsangbukdo as a provincial park in June1970, twenty-two areas including Naksan, Gyeongpo and Taebaeksan in Kangwondo, Namhansansung in Gyeonggido, Kajisan and Yeonwhasan in Gyeongsangnamdo, Gumosan, Palgongsan, Mungyeongsaejae and Chungryangsan in Gyeongsangbukdo, Mudeungsan, Jogyesan, Duryunsan, Palyoungsan and Chungwansan in Chullanamdo, Moaksan, Daedunsan, Maisan and Sunwoonsan in Chullabukdo, Duksan, Chilgapsan and Daedunsan in Choongchungnamdo have all been designated as provincial parks.

* The suffix “san” indicates a mountain in Korea.

Figure 2. Index map of National Parks of Korea.

In order to preserve and maintain Korea's cultural heritage in its original condition, to tap tourism resources through promoting the value of cultural properties, to enhance people's enjoyment of their cultural heritage and to publicize Korean traditional culture to the world, the Korean Government established the Cultural Properties Administration under the jurisdiction of the Ministry of Culture and Tourism.

There are several schemes of heritage classification managed by the Cultural Properties Administration including National Treasures, Historic and Scenic Sites, Natural Monuments, Important Intangible Cultural Heritages, Important Folklore Materials and several other categories. They are also classified into categories such as State-Designated Heritage, City/Province-Designated Heritage, Cultural Heritage Materials and Registered Cultural Heritages.

Most nationally important examples of Korean geoheritage belonged to the category of Natural Monument which can include rocks, minerals, caves and other geologic features. At present, of the 396 sites that have been designated as Natural Monuments, 60 are related to geoscience. These geological monuments are distinguished by their outstanding geology, and their scientific and educational value.

Dinosaur fossils are treated as national properties that are protected by law in Korea. Among a total of 13 national fossil monuments, nine were designated by dinosaur bones and footprints and the rest consist of Paleozoic trilobites and mollusks, Mesozoic bird footprints and Cenozoic mollusks. The fact that dinosaur fossils occupy 70% of all designated national fossil monuments clearly indicates their importance as national fossil properties in Korea. As the public come to recognize the high value of natural properties through special interest such as in dinosaur fossils, the Cultural Heritage Administration is developing an integrated network system for proper management of fossil properties through the Research Center of National Monument Preservation.

GEOHERITAGE SITES

Among geoheritage sites in Korea are the Jeju World Natural Heritage Sites, some National Parks, Provincial Parks and natural monuments. The following are selected geoheritage sites in Korea with superb value from the aesthetic and geological points of view.

Jeju Island: World Natural Heritage Site

Jeju Island is a volcanic island, located 130 kilometres south from the Korean Peninsula. It is the largest island in Korea, elliptical in shape with its major axis aligned in an east-northeast direction and an area of 1,846 square kilometres (Figure 3). Volcanic activity commenced on the sea-floor at the end of the Tertiary Period, approximately 1.2 million years ago. As volcanic activity continued, a volcanic edifice was gradually developed above sea-level to eventually form the present Jeju Island. Mt. Hallasan, the main and the highest volcanic cone, rises to 1,950 metres above sea level. The Baengnokdam crater at the peak of Mt. Hallasan was formed 25 thousand years ago. About 360 other smaller volcanic cones, known as parasitic cones, were also developed throughout the island.

Jeju Island composed mainly of basaltic lava and tuffs, displays diverse volcanic landscapes, some of which are still developing. Among the most spectacular landscapes are the shield-shaped volcano of Mt. Hallasan, numerous parasitic cones, extensive lava tubes, trachyte domes and numerous outcrops with

Figure 3. Satellite image of Jeju Island.

spectacular columnar joints (Park et al. 2005). Fossilized avian and hominid footprints are also found on the island, the latter dating from the Old Stone Age and amongst the oldest known in Asia.

In addition, owing to the peculiarities of the volcanic ecosystem and the islands isolation after the last glaciation, there are many plant and animal species which are endemic to the island, especially to Mt. Hallasan. The ecological characteristics of Mt. Hallasan include the clear vertical variation of its diverse flora with the formation of the subalpine evergreen coniferous forest of Korean fir (Abies koreana) at the top of the mountain and the presence of arctic or alpine plants which have migrated to the highest slopes due to climatic warming during the Holocene Epoch. With many endemic plants and animals, as well as spectacular volcanic landscapes, Jeju Island attracts not only experts in geology, biology and speleology, but also over five million tourists and visitors each year. It is a very popular vacation island and one of the top honeymoon destinations for Korean newlyweds.

In 2007, the 31st UNESCO World Heritage Committee designated Jeju volcanic island and lava tubes as a World Natural Heritage consisting of three sites that together make up 18,846 hactres, 10.3% of the surface area of Jeju Island (Figure 4). The designated sites include Mt. Hallasan, the highest mountain in the Republic of Korea, with its waterfalls, multi-shaped rock formations and lake-filled crater, the Geomunoreum Lava Tube System, regarded as one of the finest lava tube system of caves anywhere with its multi-coloured carbonate deposits and dark-coloured flow-striated lava walls and finally the fortress-like Seongsan Ilchulbong tuff-cone, rising dramatically out of the ocean.

Figure 4. Location of the World Heritage sites on Jeju Island.

Hallasan

Mt. Hallasan is a typical large shield volcano with a crater lake at its summit and numerous smaller parasitic volcanic cones on its flanks. The pristine state of Mt. Hallasan is preserved in the Hallasan Natural Reserve. In and around the Reserve a wide variety of volcanic features can be observed (Figure 5). At the summit of Mt. Hallasan, a prominent trachyte dome was emplaced 25,000-30,000 years ago. In addition, a crater-lake was developed at the summit, bordered by basalt to the west and rocks of the trachyte dome to the east. The crater (1.6 hectares) is about 108 metres deep and about 550 metres in diameter. Since 1970 Hallasan Natural Reserve covering an area of approximately 15,338.6 hectares has been designated a National Park. Mt Hallasan at the center of the park was identified as a Natural Monument (Natural Monument No. 182) with an area of 9,093 hectares. As such, a large part of the park was placed under careful management so as to prevent damage from human activities.

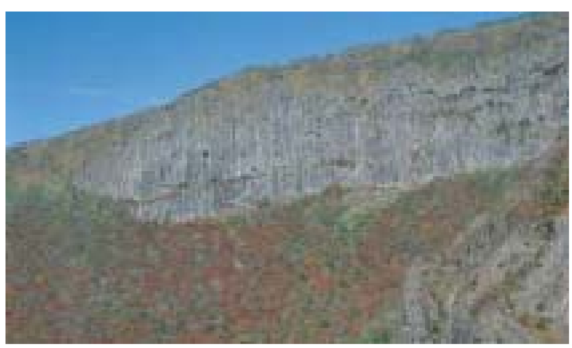
The Geomunoreum Lava Tube System

More than 120 lava tubes are sporadically distributed throughout Jeju Island. The Geomunoreum Lava Tube System refers to a series of lava tubes which were formed when large amount of basaltic lava were poured out of Geomunoreum volcano (456.6 metres high) during its eruption. The lava that erupted from the Geomunoreum volcano flowed down the slope of Mt. Hallasan in a north-northeast direction down to the coastline. Throughout the flow numerous lava tubes, such as

Crater Lake (Baeknokdam) at the summit of Mt. Hallasan.

Scenic view of the peak of Mt. Hallasan.

Scenic view of Yeongsil.



Columnar joints, in Mt. Hallasan.

Figure 5. Geoheritage features around Mt Hallasan.

Manjanggul, Bengdwigul, Gimnyeonggul, Yongcheondonggul and Dangcheomuldonggul lava tubes were created. The tubes were formed when much of the lava flow cooled and solidified but parts of the hotter interior continued to flow downhill, eventually leaving behind an empty tube which the hot lava had previously occupied. With the exception of Bengdwigul lava tube, the others (i.e. Manjang, Gimnyeong, Yongcheon and Dangcheomul) are distributed along the same extended line of tubes. Each tube has its own unique attributes regarding its form, size and the content and diversity of speleothems (Figure 6).

Main passage of Manjanggul Lava Tube with numerous lava flow lines.

Narrow passage in Bengdwigul Lava Tube.

Main passage of Gimnyeonggul Lava Tube.

Figure 6. Various features of Yongcheondonggul Lava Tube System.

Passage of Dangcheomuldonggul Lava Tube with secondary carbonate deposits.

Lake of Yongcheondonggul Lava Tube.

Stalactites and curtains of Yongcheondonggul Lava Tube.

From a global perspective, given its spectacular geological phenomena, the system of tubes deserves worldwide recognition. This is particularly true of Yongcheondonggul and Dangcheomuldonggul which are worthy rivals of the world's most spectacular lava tubes.

Seongsan Ilchulbong Tuff Cone

Seongsan Ilchulbong Tuff Cone is located in Seongsan-ri, Seongsaneup, Namjeju-gun, Jeju-do. The summit of the Ilchulbong Cone is at an altitude of 179 metres with the lowest point in the accompanying crater at 89 metres (Figure 7). The major axis of the bowl-shaped crater is about 570 metres long.

In the late Pleistocene Epoch (approximately 40,000 - 120,000 years ago), an underwater eruption resulted in a tuff cone being built up above sea-level. The cone is made up of a composite mixture of various types of volcanic tuffs including breccia, massive lapilli tuff, stratified lapilli tuff, bedded tuff and tuffite. Through repeated eruption and deposition, the slopes of the cone and crater developed a virtual museum of volcanic structures. For geologists interested in such detail, examples of base surge bedding, internal cross laminations, graded bedding, pyroclastic flow lamination, slumping, ripple marks, bedding sags, ballistic blocks, channel systems and local unconformities can all be seen on the eroded flanks of the cone (Figure 7). Three sides of the original cone have been eroded by wave action, creating cliffs which display the internal structure of the tuff cone in cross section. On the northeastern side, the cliffs almost reach the summit of the crater. Only the northwestern slope remains relatively unaffected by erosion from the sea, and serves to indicate the original morphology of this spectacularly eroded and dissected volcanic cone.

Sanbangsan

Sanbangsan is a prominent bell-shaped hill adjacent to the Dragon Head Beach in the coastal area of Sagye-ri, Andeok-myeon. Viewed from all directions, it forms a conspicuous landmark in the southwestern corner of Jeju Island (Figure 8).

The mountain was formed as a 345 metres high volcanic dome of trachyte lava some 700,000-800,000 years ago. Sanbangsan, which means cave in the mountain, describes the presence of a sea cave at a height of 150 metres above sea-level. The cave, approximately 10 metres long and 5 metres high, provides a natural viewpoint overlooking the ocean, and is one of the 10 most beautiful scenic views in Jeju Island. Sanbang sea cave and the nearby cliffs and tallus covered slopes indicate that the sea-level was at one time much higher than today. Sanbangsan also provides a unique habitat for plants and is an important site to be protected in terms of its botany. On top of the mountain, there is a thick evergreen forest with *Machilus*

Aerial views of the eroded Seongsan Ilchulbong Tuff Cone.

Stratification of basaltic tuff at Seongsan Ilchulbong Tuff Cone.

Internal structure of basaltic tuffs of Seongsan Ilchulbong Tuff Cone.

Figure 7. Morphology and bedding features of Seongsan Ilchulbong Tuff Cone.

Figure 8. Scenic views of Sanbangsan.

thunbergii, *Castanopsis cuspidata* var. *sieboldii*, *Litsea japonica* and *Neolitsea sericea*. In particular, on the rocky walls, rare rock wall plants such as *Sarcanthus scolopendrifolius* grow.

Jisagae Columnar Joints

Along a 3.5 kilometres-long stretch of the coast, from Seongcheonpo to Weolpyeongdong, spectacular columnar joints can be seen within the upper part of a basaltic lava flow. These columnar joints were formed when liquid lava from Mt. Hallasan flowing down to the sea at Jungmun began to cool and crystallize to form solid rock. Most columns are straight with diameters up to a maximum of about 140 centimetres. The length of the column may extend up to 20 metres and most tend to have 5 or 6 sides but sometimes have as few as 3 or as many as 8 sides. The Jisagae columnar joints constitute Natural Monument

No. 443 (Figure 9). The administration of the district has named them Jisatgae Rocks from their old name Jisatgae. The locality is also famous for its 20 metres high cliffs, a popular place for sea angling during the high tide.

Scenic view of Jisagae columnar joints.

Hexagonal shapes of columnar joints.

Figure 9. Jisagae columnar joints.

Soraksan National Park

Located in the eastern part of the central Korean peninsula, this national park covers an area of 398 square kilometres. Soraksan is the third highest mountain after Mt. Hallasan and Mt. Jirisan and its magnificent scenery is second to none in the Republic of Korea. Soraksan extends from Kumgangsan in the north to Odaesan in the south. Its dramatic peaks and cliffs reflect the underlying geology of the park (Figure 10). The oldest rocks of the area are the metamorphic rocks of Precambrian age found in the vicinity of the highest peaks. Mesozoic sedimentary rocks cover these older metamorphic rocks and both were subsequently intruded by a granite batholith which covers most of the area. From the aspect of landscape development, Soraksan landscape resulted from differential erosion of the various texturally contrasting rock-types (Lee 1982).

Differential erosion has created a magnificent landscape of tall peaks or locally called bong. These peaks have various shapes, sizes and heights, but almost all have sheer cliffs representing steep joint planes. There are 28 peaks, including the highest peaks of Daecheongbong, Hwachaebong, Hangyeryeong and Madeungnyeong that clustered together to form the magnificent scenery of Soraksan. The main peak, Daecheongbong is 1,708 metres in altitude is also named as Sorak because it is covered with snow for 5-6 months of each year. Daecheongbong is located in the southeast of the park area and from there ridges radiate in all directions. The eastern ridge running to the north is called Oe (Outer) Sorak, while the western one is called Nae (Inner) Sorak. Oe Sorak is regarded as masculine since there are many rugged peaks such as Chyeonbuldong, Cheonwhadae, Chihyeongjebong, Beombong and Janggunbong. The most popular attraction of Oe Sorak is the Ulsanbawi, a huge mass composed of six individual peaks. Ulsanbawi rises to a maximum height of 873 metres and is 4 kilometres in circumference.

In contrast, Nae Sorak has female features of beautiful valleys and gentle mountain ranges. Among the valleys are Cheonbuldong, Suryeomdong, Baekdam, Seonyeotang, Huksundong, Jujyeongol and Santubawaigol Valleys. The Cheonbuldong valley, the main valley of Mt. Soraksan, is 12 kilometres long and extends from Biseondae to Daecheongbong. The rock shapes of the Cheonbuldong valley are said to resemble one thousand statues of Buddha. There are many waterfalls in Soraksan National Park including the Towangseong Fall, the tallest falls in Korea, Daeseung, Soseung, Biryong, Oryeon, Sang, Yongso and Sibee Falls.

Animals inhabiting the area include 116 species of mammals, 19 species of amphibians and reptiles, 28 species of freshwater fish and 1,600 species of insect. There are also about 1,000 species of vascular plants growing in the park. In 1965 Soraksan became the 171st natural monument of Korea. It was subsequently designated as the 5th national park in 1970, and in 1982 the United Nations Educational, Scientific and Cultural Organization (UNESCO) designated it as a district for conservation of the biosphere.

Peaks of Soraksan shrouded by cloud.

Cheonbuldong valley at Soraksan.

Dissected granite and gneiss.

Winter at Soraksan.

Waterfall at Soraksan in autumn

Figure 10. Magnificent peaks and valleys within the Soraksan National Park.

Jirisan National Park

Mt. Jirisan rises to a height of 1,915 metres and is the second highest mountain in Korea and one of the most magnificent peaks in the country. The exceptional scenery make it one of the three most important mountains in South Korea together with Hallasan and Soraksan. The Jirisan National Park, occupying an area of 471.58 square kilometres, covers parts of the three provinces of North Cheolla, South Jeolla and South Gyeongsang. Jirisan is located at the southern end of the Sobaek Mountain Range which itself forms the south-western branch of the Baekdudaegan mountain range, the spine of the Korean Peninsula. The rocks of the area comprise mainly metasedimentary rocks and various gneisses including porphyroblastic, granitic and migmatitic gneiss, all of Precambrian age (Son et al. 1964; Kim et al. 1964).

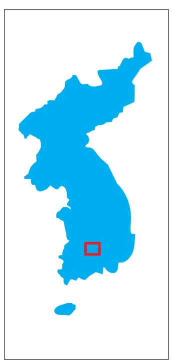
Cheonwangbong (1,915 metres) forms the summit of Jirisan but Jirisan National Park embraces many other high peaks such as Jeseokbong (1,806 metres), Banyabong (1,732 metres) and Nogodan (1,507 metres). It also contains valleys of Baemsagol, Chilseon and Daewonsa and boasts excellent views of the impressive Guryong, Buril and Yongchu waterfalls (Figure 11).

As this is the location of the most well-preserved virgin forest and wild life in Korea, the majestic and mystical mountain is always regarded with great respect. It is the place where tea was first cultivated in Korea, and where herbal medicine cultivation still flourishes. Jirisan is also an historic area where Buddhist culture prospered, and there are many cultural assets preserved in the vicinity such as Silsangsa Temple (National Treasure No.7), Hwaeomsa, the largest and best-known temple, Baekjangam and the Three-Storey Stone Pagoda (National Treasure No. 26). The mountain is also home to the Cheonghak-dong (Azure Crane Village) alpine valley, which includes the Samseong-gung (Three Stages Palace), which is a recently developed site that celebrates one of Korea's foundation myths.

Bukhansan National Park

Bukhansan National Park is a rare national park in Korea in that it lies partly within a city boundary. It became Korea's 15th National Park on April 2, 1983. It extends from Seoul into Kyonggi Province and covers a total of 79.916 square kilometres or 13% of the Seoul metropolitan area. The name Bukhansan means big mountain in the north and it is also known as Samgaksan. Since the park is surrounded by the Seoul metropolitan area, it is ecologically isolated. However, it plays an important role as a green lung for Seoul City. Bukhansan National Park has many mountain tourist attractions with beautiful scenery. It has the honour of being included in the Guinness Book of World Records for being the national park with the highest number of visitors per square foot.

Spring at Jirisan, with blooming azaleas.



Baemsagol valley, Jirisan.

Winter at Jirisan.

Figure 11. Mountain and valleys of Jirisan National Park.

The Bukhansan scenery is dominated by the harmoniously curving outlines of Jurassic granite outcrops, the towering granite peaks contrasting with the dozens of deep valleys and rivers flowing below (Figure 12). The mountain's main summit is Baekundae (836.5 metres), and it displays many spectacular granite outcrops (Hong et al. 1982). Among them are the world famous Insubong which is over 200 metres above sea level with about 100 seperate mountain paths leading to the rock.

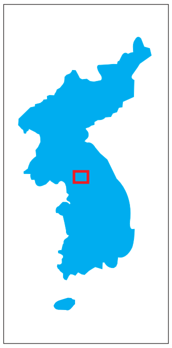
Bukhansan has a rich history and possesses many cultural treasures including King Jinheung's Sunsubi on Bibong Peak, the Bukhansan Seong Fortress built along the ridges, Sangunsa Temple built by monk Won-Hyo, and numerous other temples. Bukhansan Seong Fortress has an approximately 8,500 metres long wall, built specifically to stop foreign invasion, and is one of the representative mountain fortresses of the Joseon Era. In spite of its many visitors, Bukhansan remains a natural sanctuary for plant and animal life.

Byeonsanbando National Park

Byeonsanbando National Park is located on a small peninsula along 35 kilometres stretch of the western coast of Korea, covering a total area of only 155 square kilometres. It was designated as the 19th National Park in June 1988. The park is appreciated as a multifunctional park with an excellent harmony between mountain and sea. The park is divided in two large sections i.e. the Oe Byeonsan (outer Byeonsan) in the shore area and the Nae Byeonsan (inner Byeonsan) in the inland area.

Among popular tourist attractions at Oe Byeonsan are the Chaeseokgang and the nearby Byeonsan Beach. Chaeseokgang is an eroded coastal cliff and was named after sedimentary rocks that were eroded by the ocean waves over thousands of years to resemble hundreds of thousands of stacked papers or books (Figure 13). Here, within the Cretaceous sedimentary rocks, amateur and professional geoscientists alike can examine a host of sedimentary structures, joints, faults and igneous intrusions. Nearby, the Byeonsan Beach is one of the three most beautiful beaches on the west coast of Korea. Many tourists are also attracted to the pine forest along the beach perimeter.

Nae Byeonsan on the other hand is famous for its valleys, lush woodlands and waterfalls. Here there are about ten peaks, each over 400 metres in height, including Uisangbong (508 metres, the highest peak), Sinseonbong (486 metres) and Ssangseonbong (459 metres). Curiously shaped rocks abound and historic ancient temples like Gaeamsa, Naesosa, and Wolmyeongam are found in the area. Places with superb scenery such as Jiksopokpo falls, Bongnaegugok and Nakjodae are scattered here and there together with historic remains such as the ancient Yucheolli ceramic ware site, Guamni dolmen site, Hobeolchi and Ugeumsanseong mountain fortress walls. An additional attraction is the spectacular sunset view where many visitors gather on the last day of each year to see the final sunset of old year.

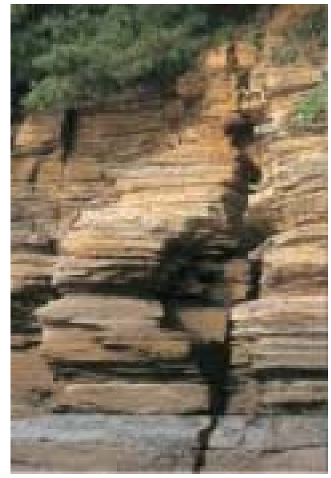


A view of Bukhansan from the Han River in Seoul.

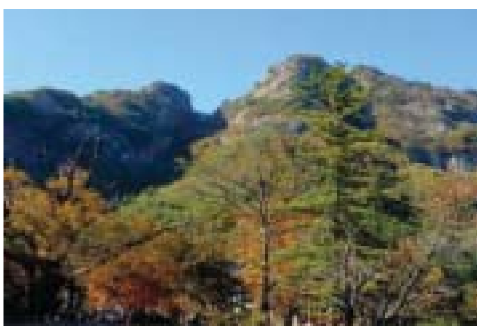
Insubong peak of Bukhansan.

Wall of Bukhansan Seong Fortress.

Figure 12. Granite peaks at Bukhansan National Park.

Sedimentary rock outcrops at Oe Byeonsan (Chaeseokgang).




Scenic views of Nae Byeonsan.

Figure 13. Mountains and bedded sedimentary rocks within Byeonsanbando National Park.

Byeonsanbando National Park is characterised by its well preserved natural ecosystem. A variety of rare animals and plants are distributed within the park and many of them are designated as natural monuments (e.g. Ilex Cornuta, Silver Magnolia, Holm Oak and Abeliophyllum Distichum). Geologically, the local sedimentary basin was formed during the Mesozoic Era and was successively filled by sequences of volcanic tuffs and related river and lake sediments. The Cretaceous Kyokpori Formation rests unconformably on Jurassic granite and conformably overlies thick deposits of volcanic tuff (Heo 2007).

Deogyusan National Park

Designated as National Park in 1975, Deogyusan National Park extends over Geochang-gun of Gyeongsangnam-do and Muju-gun of Jeollabuk-do. From the main peak of Deogyusan, also known as Hyangjeokbong, the 1,300 metres high mountain ridge stretches southwestward for about 18 kilometres branching out in various directions to create an extensive network of ridges. For every branch of the ridge, there are matching valleys and the most famous valley is the Mujugucheondong Valley that stretch for 25 kilometres from the Deogyu peak to Seolcheon River in the north. This valley dissects various rocks including Precambrian granitic gneiss, sediments of the Deogyusan Formation and Cretaceous dacite (Lee & Nam 1969). In the valley, there are 33 scenic vistas called the Gucheondong 33 Kyeong, with the 12th Kyeong, known as Susimdae, regarded as the most beautiful. Susimdae, sometimes called Suhwa is a 400 metres deep valley with free flowing greenish water, resembling jade.

Mt. Deogyusan has three valleys, the Chilyeon, Jeoksang and Munan valleys that are grouped together. Chilyeon Valley is famous for its Chilyeon Waterfall, where clear water flows through thick pine forest and passes between rocks of many contrasting shapes. The stream has created seven ponds. The clear stream water dropped successively from pond to pond to create seven segmented waterfalls (Figure 14). Mt. Deogyusan is a popular tourist site with its fantastic scenery, temples and other cultural relics representative of Korea. It is also a ski resort. Baekryeonsa Temple is located at the end of Mujugucheondong Valley. It is famous for the Stone Samjon Buddha, created during the reign of the Goryeo Dynasty. Jeoksangsan Seong Fortress, Anguksa Temple, Guebul and many other relics are scattered throughout the park. Approximately 250 animal and 600 plant species are found within the Deogyusan National Park.

Sobaeksan National Park

Designated as the national park in December 1987, Sobaeksan is one of the famous mountains of the Baekdudaegan Mountain System with a total area of 322.383 square kilometres crossing Danyang-gun of Chungbuk, and Yeongju-si and Bonghwa-gun of Gyeongbuk Province. Sobaeksan National Park extends southwestwards out of the Taebaek Mountain Range to the border between Chungcheongbuk-do and Gyeongsangnam-do. The word 'so' in Sobaeksan may be misleading as it means small in Korean. With a total area of over 300 square kilometres, it is actually the third most extensive of Korea's national parks after Jirisan and Seoraksan. The geology of the park area is mainly composed of Precambrian metamorphic rocks of the Sobaeksan gneiss complex (Won & Lee 1967). Sobaeksan owes it mountainous topography and striking scenery to the high resistivity of these ancient metamorphic rocks against erosion. As a result, extensive mountain ridges are formed, extending for over 20 kilometres and interconnected to one another, started from the peak of Gungmangbong (1,421 metres) in the east, Birobong (1,439 metres), the first Yeonhwabong (1,394 metres), second Yeonhwabong (1,357 metres) and Dosolbong (1,314 metres) across the Jungnyeong pass. Group of peaks, higher than 1,000 metres set in a sea of clouds provides one of the greatest sights in this park. In this

Mountain ridge of Mt. Deogyusan.

Mujugucheondong Valley.

Figure 14. Mountain ridges and streams within Deogyusan National Park.

instance, the lower slopes of these peaks are veiled in cloud, while the summits seemingly floating over the clouds in variety of shapes as if they were islands in a white sea.

Between Birobong and Gungmangbong, the Jukgye and Huibang Valleys continue from Yeonhwabong to create a superb landscape. On the other hand, the northward flowing valleys become a scenic masterpiece of the Eight Danyang Sceneries, while the Huibang Waterfall (30 metres) portrays its magnificent posture between these rocky cliffs.

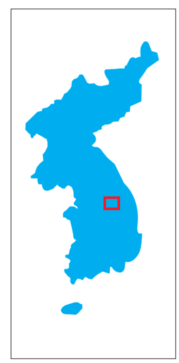
Situated on a natural watershed, Sobaeksan is the source of Korea's two most important rivers, the Han and Nagdong Rivers. It also formed the border between two administrative districts and, historically formed a natural obstacle that separated two unique cultural zones in terms of the local lifestyles, dialects and the spiritual beliefs. In Korean history, Mt. Sobaeksan is an important maternity ward for the birth of Korea's Confucianism and Buddhism where temple of Buseoksa built roughly a thousand years ago, and Sosuseowon, the first institute named after a King are still preserved intact.

The main peak, Birobong, contains numerous wild plants including edelweiss. In spring, royal azaleas in full bloom create graceful scenery, while a yew tree community flourishes on gentle slopes (Figure 15). Sobaeksan’s yew trees are best seen on the northwest slope at height between 1,200-1,350 metres in between the 1st Yeonhwabong and Birobong. This yew tree community contains a total of 3,798 trees including 1,999 of Natural Monument No. 244 with an average life of 350 years (200-800 years), standing as the largest yew tree community in Korea.

Mudeungsan Provincial Park

Mudeungsan is a mountain at the border between Hwasun-gun, Damyang-gun and Gwangju, and became a Provincial Park in 1972. It is also known as Mudeungsan jusang jeollidae or pillar-shaped points of Mt. Mudeungsan. Mt. Mudeungsan rises to 1,186 metres above sea level, and its top consists of three rocky peaks called Cheonwongbong, Jiwongbong and Inwonbong, collectively known as the Jeongsang Three. Mudeungsan is composed of rocks that were produced by volcanic activity during the Cretaceous Period (Kim et al. 1990). They were formed through the cooling of molten dacitic lava near the earth's surface. As the lava cooled, columnar joints were developed, forming rows of natural rock pillars rising vertically and arranged in rows, a geological feature of great beauty (Figure 16). At the base of the mountain, there are famous temples such as Yaksa-am, Jeungsimsa and Wonhyosa Temples.

Spring at Sobaeksan with azaleas in bloom.



Winter at Sobaeksan.

Yew tree community at Sobaeksan.

Summer at Sobaeksan.

Figure 15. Scenery in Sobaeksan National Park.

Figure 16. Columnar joints at Mudeungsan Provincial Park.

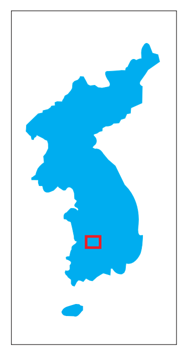
Maisan Provincial Park

Maisan was designated as a Provincial Park in October 1979. Although the park only covers an area of 17.22 square kilometres, it includes 5 ris (towns) of Jinan-eup and 4 ris of Maryeong-myeon, many cultural sites and natural attractions. It was known as Seodasan during the Shilla Dynasty and Yongchulsan in the Goryeo Dynasty, but since the time of the Joseon Dynasty it has been called Maisan because of the spectacular mountains with its twin peaks resembling horse's ears (Figure 17). The two peaks are known as the female Maibong (673 metres) and male Maibong (667 metres).

During the Cretaceous Period the Maisan area was a fresh water lake into which sands and pebbles were washed down from nearby mountains. As the sands and pebbles became more deeply buried they solidified to form sandstone and conglomerate, respectively. Upheaval of these rocks by earth movements about 60~70 million years ago formed new mountains and subsequent erosion produced the horse-ear shapes of Maisan. Due to weathering, the rocky surface of Maisan is covered with countless honeycomb structures known as tafoni. Fossils of fresh water fish that lived in the lake where the rocks were originally formed are occasionally found in these ancient lake deposits.

Due to its different appearance through various seasons, Maisan is called Dotdaebong in the spring, Yonggakbong in summer, Maibong in autumn and Munpilbong in winter time. Nowadays the mountain also boasts a high diversity of plant life, with groves of Chinese fringe trees (Natural Monument No. 214) near Pyeongji-ri, Jinan, and a grove of winter creeper (Natural Monument No. 380).

Horse's ear shape mountain peak.



A temple in front of the peak.

Aerial view of Mt. Maisan.

Figure 17. Scenic views of Mt. Maisan.

Gossi Cave

Gossi Cave is located at a height of 210 metres near the northeastern foot of Sobaeksan, about 10 kilometres to the southeast of Youngwol Bridge, across the Jinpyul-ri River. Designated as a Natural Monument No. 219 in 1969, the cave was opened to the public in 1974. Its whole length is about 6.3 kilometres, but only about 620 metres are accessible to tourists. The cave is shaped like the letter ‘W’ and contains four lakes and three waterfalls. Gossi Cave was formed within limestone of the Lower Paleozoic Maggol Formation. Based on the evidence of its lithology, sedimentary structures and fossil content, the limestone that made up the Maggol Formation appears to have been deposited in a tidal flat environment during the Ordovician Period. The main passage of the cave was developed along the northeasterly bedding strike of the Maggol Formation, whereas branches from the main passage follow the directions of joint planes.

Numerous beautiful and interestingly shaped mineral deposits (speleothems) with a variety of names such as soda straws, stalactites and stalagmites, cave corals, flowstones, curtains, cave pearls, cave pisolites, cave shields, helictites, heligmites and moonmilk can be seen in the cave (Figure 18). These speleothems are usually composed of either calcite or aragonite. Several speleothems that were originally composed of aragonite have apparently been partially altered to calcite. Of great interest is the black cave coral developed on stalactites and stalagmites. The black colour is due to organic matter derived from the soil through which cave water percolated.

Various animals inhabit the Gossi Cave, where a total of 67 species are known, dominated by 27 species of insects and 26 species of spiders. Additionally, the fact that Grylloblattodea, a fossil of an ancient insect, inhabited this cave 4-5 hundred million years ago, has aroused great interest from experts and the general public.

Dinosaur Fossil Sites

There is abundant evidence that reflects the presence of dinosaurs on Korean soil during the Cretaceous Period, over sixty five million years ago. This includes fossilized dinosaur footprints, eggs and nests, teeth and bones that were preserved in freshwater sedimentary rocks. Among them, dinosaur footprints forming distinctive tracks are the most common including some world famous track sites. Until now, 27 dinosaur track localities have been discovered from Cretaceous strata in Korea. Scattered sites along the southern coast of Korea are among the largest sites for various fossilized eggs and footprints of Cretaceous dinosaurs in the world. At some of these sites fossilized dinosaur eggs are widely distributed and are in a particularly well-preserved condition. In addition, there are also various fossil footprints of birds with webbed feet, probably the oldest of their kind in the world.

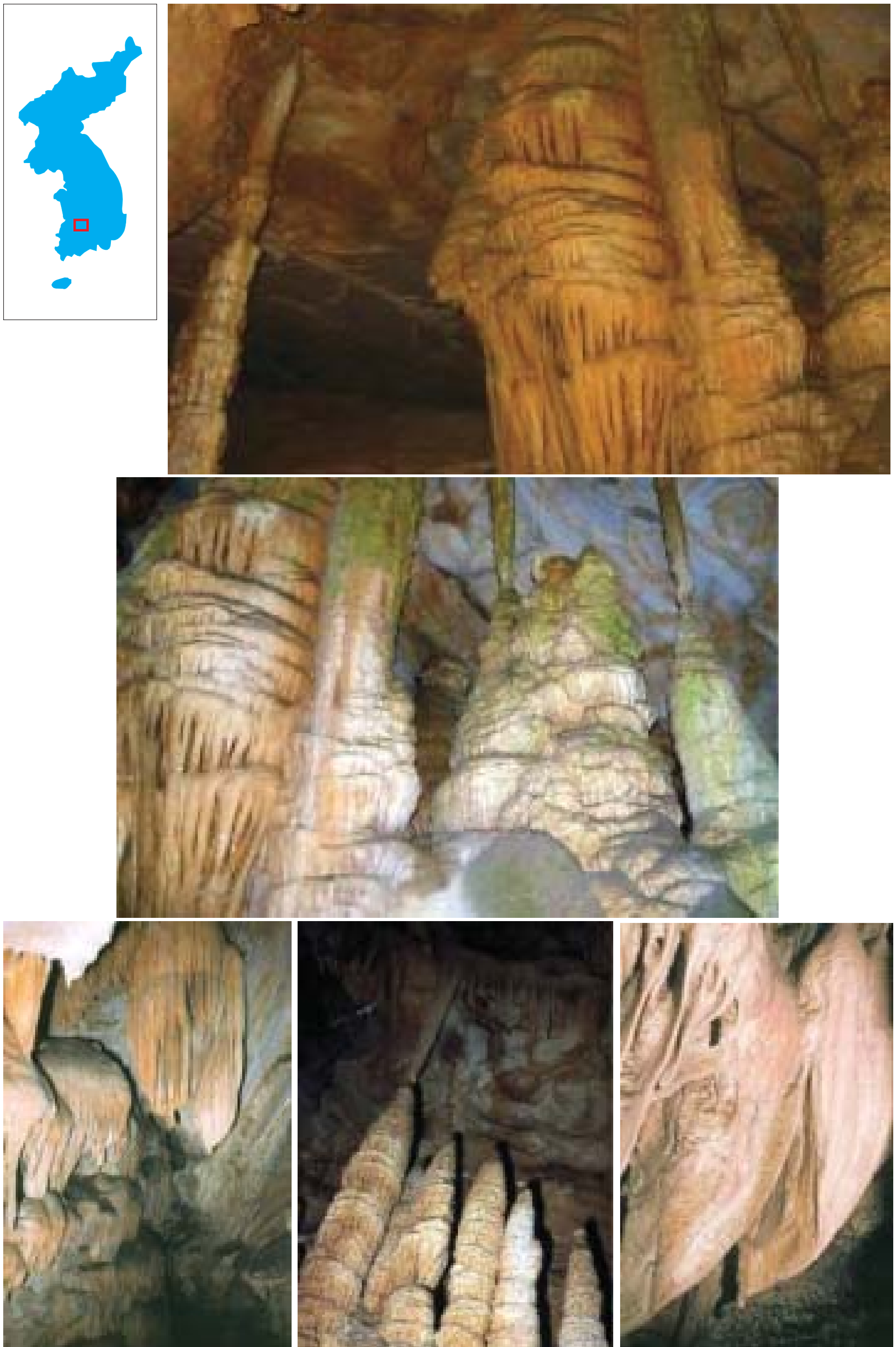


Figure 18. Among spectacular carbonate speleothems in Gossi Cave.

Haenam

The Haenam site is located on the southern shore of Geumhoho near Uhang-ri, in the southwestern part of Cheollannamdo Province. At this site, sedimentary rocks of the Uhangri Formation crop out and expose many fossils of dinosaur footprints and other animal footprints (Figure 19). The Uhangri Formation is interpreted to have been deposited in a shallow lake some one hundred to seventy million years ago.

At the site, a total of over five hundred dinosaur footprints, including some unusually large prints have been found. In addition, numerous pterosaur tracks, pterosaur bones together with thousands of tracks from web-footed birds testify the rich fauna that lived around the Haenam ancient freshwater lake (Huh & Hwang 2004). The pterosaur tracks have been assigned to a new genus, Haenamichnus uhangriensis, named for its geographic location. The web-footed bird tracks, which are the oldest ones in the world, were previously identified as Uhangrichnus chuni and Hwangsannipes choughi. It was here that bird's footprints and pterosaur's footprints were discovered together on the same rock stratum for the first time in Asia, proving that pterosaurs and birds might have shared the same habitat.

The Haenam fossil site was designated as Natural Monuments No. 394 and a fine museum and attractive gardens with realistic sculptures of various dinosaur species have been created within the vicinity.

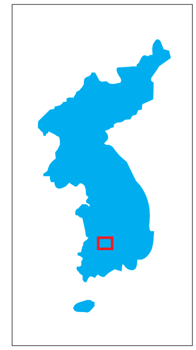
Goseong

Goseong site, near Deokmyeong-ri, Goseong-gun, in southwestern Gyeongsangnam-do Province, is one of the largest dinosaur track sites in the world (Figure 20). The first discovery of dinosaur footprints in Korea was reported from the Goseong area where they were found in strata of the Jidong Formation of Cretaceous age.

At this site a total of 412 mapped dinosaur trackways (249 ornithopod, 139 sauropod and 24 theropod trackways) were found. Along with dinosaur tracks, numerous bird tracks were also found in the area including a new bird, Jindongornipes kimi, together with the previously known Koreanaornis, first reported from similar rocks of Cretaceous age elsewhere in Korea. The Goseong site has been designated and protected as a Natural Monument No. 411.

Hwaseong

Among the central districts of Korea, only this area has outcrops of sedimentary rocks of Cretaceous age. It was in these rocks that the fossilized shells of dinosaur eggs were discovered (Lee et al. 2005). Over 200 fossils of dinosaur's eggs have now been found in about 30 nests, with a maximum of 12 eggs found in a single nest (Figure 21).



Pterosaur footprint.

Web-footed bird footprint.

Large Sauropod footprint.

Ornithopod footprints.

Figure 19. Various footprint fossils at Haenam Fossil Site.

Figure 20. Among dinosaur tracks at Goesong Site.

It is rare for so many fossilised dinosaur eggs to be discovered in close proximity and this area is thought to have been a dinosaur's group breeding ground during the Cretaceous Period, about one hundred million years ago. The fossils of various plants, such as a swamp reed, found at the same site gives a clue to the type of habitat that the dinosaurs inhabited.

The area is also rich in contemporary birds and animals. One hundred and twenty different kinds of migratory bird, together numbering about 90-150 thousand individuals, including the black-haired seagull and long-legged plover, both under the international protection, visit the area. Some large animals including about 300 roe deer and elks also inhabit the area which is designated as Natural Monument No. 414.

Fossilized dinosaur egg.

Fossilized dinosaur eggs.

Figure 21. Some of the dinosaur eggs from Hwaseong Site.

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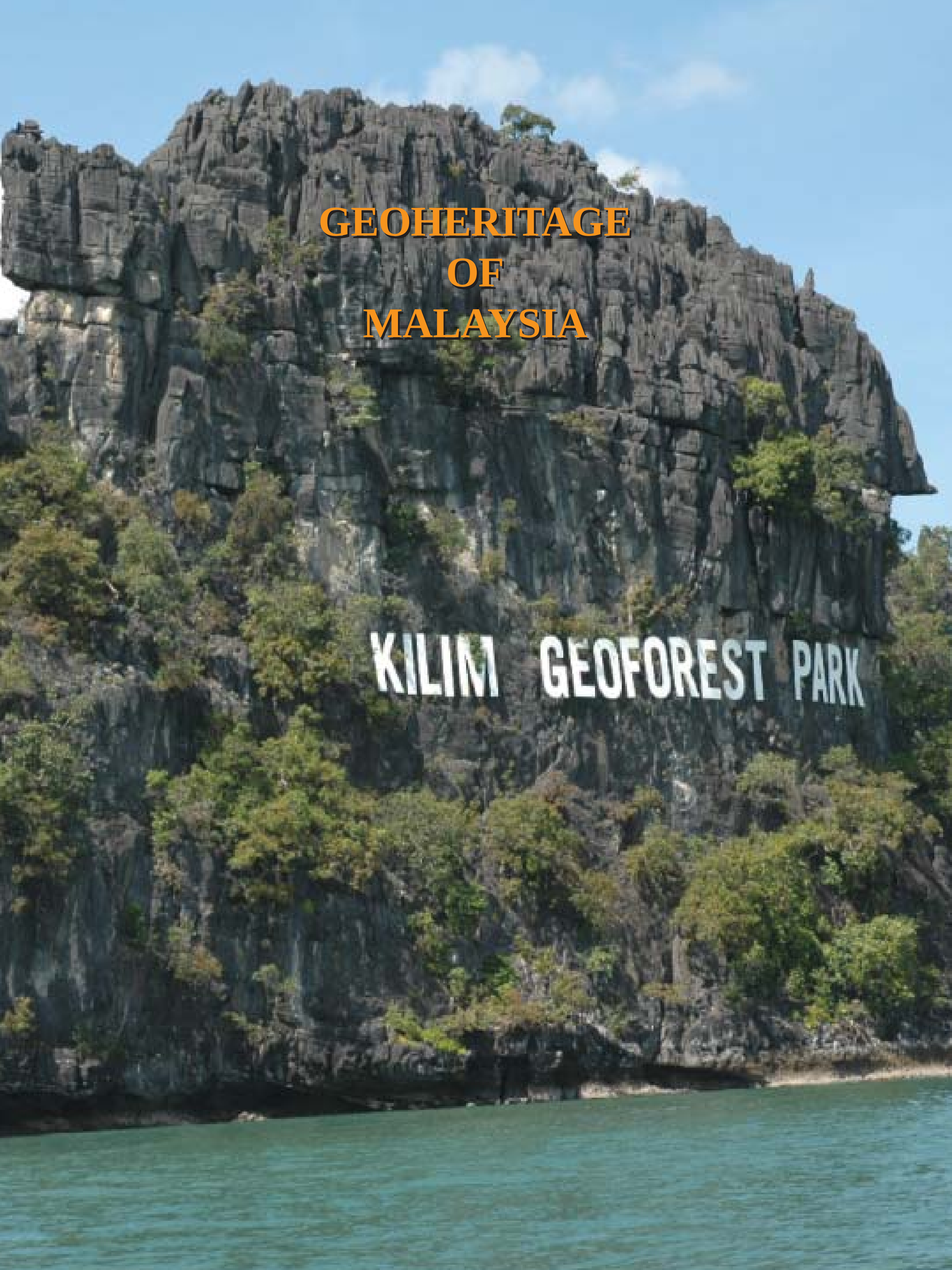
GEOHERITAGE OF MALAYSIA



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Separator Photo:
Limestone peaks within the Kilim Karst Geoforest Park, Langkawi, Malaysia.

6

GEOHERITAGE OF MALAYSIA

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INTRODUCTION

Geological heritage, or geoheritage, is acknowledged to be an important heritage resource in many countries including Malaysia. For this reason, extensive geoheritage research has been carried out for decades in this country. Significant sites illustrative of Malaysia's geoheritage have been identified, protected and utilized by various parties for education and geotourism purposes. To help to ensure the sustainable development of these heritage resources, various geoheritage conservation initiatives have been exercised in Malaysia. In addition, Malaysia is actively involved in promoting geoheritage conservation at regional and global levels. The inauguration of Langkawi Geopark as the first global geopark in Southeast Asia is a testimony to Malaysia's strong support for global initiatives to protect valuable Earth's heritage and to consume geological resources in a more sustainable manner. This chapter will highlight activities related to geoheritage development in Malaysia and will showcase selected geoheritage resources in the country.

GEOHERITAGE RESEARCH DEVELOPMENT

The significance of geoheritage has been recognized since the 1970s in Malaysia. Early work was mainly focused on identifying sites of geological interest. Several lists of geologically interesting sites in Malaysia have been produced by individuals such as Aw (1977), Yong (1989), Tjia (1991), among others. Though these authors indicated the importance of conserving their listed geoheritage sites, none of them provided any proposals on concepts or mechanisms for conservation of the sites. It was not until mid 1990s that more comprehensive geoheritage research and more effective geoheritage conservation was really initiated in Malaysia. These initiatives were undertaken by a group of researchers known as the Malaysian Geological

Heritage Group, which was established as an informal research group of enthusiasts in 1996. They took a lead in establishing methodologies for a geoheritage research framework and concepts for geoheritage development and conservation. Progress was achieved through various meetings, dialogues, seminars and conferences, the results of which were disseminated in various forms of publication including the *Geological Heritage of Malaysia* book series (see Ibrahim Komoo et al. 1997, 2001; Ibrahim Kommo & Tjia 2000; Ibrahim Komoo & Mohd Shafeea Leman 1999, 2002; Mohd Shafeea Leman & Ibrahim Komoo 2004 and Mohd Shafeea Leman et al. 2007a), newsletters, proceedings, scientific journals, etc.

GEOHERITAGE SITES

For a tropical country like Malaysia, warm and wet weather all year round accelerates chemical weathering, resulting in the formation of a thick ground cover of weathered rocks and soils. A combination between sunny-wet weather and thick fertile soils is the main reason why we always see a thick canopy of rainforest developed in tropical countries, depriving them of extensive areas of rock, free of soil and vegetation cover. For this reason, most of Malaysian geoheritage sites are located within forested areas and are protected together with other forest resources by the Forestry Department under the 1984's Forestry Act.

For geoheritage researchers and rock lovers, having good rock exposure is truly a luxury in Malaysia, hence good rock exposure becomes a very important criterion in searching for geoheritage resources. For that matter, highly resistant rocks against deep chemical weathering such as quartz dykes, some limestones and other highly siliceous igneous, sedimentary and metamorphic rocks are the most commonly exposed (Mohd Shafeea Leman et al. 2007b) and most likely to become geoheritage resources.

Systematic compilation work on geoheritage resources and geoheritage sites has been carried out between the mid 1990s and early 2000s. This work involved every state office of the Department of Minerals and Geoscience in collaboration with researchers from higher learning institutions. A comprehensive list of geoheritage sites was published in the fourth issue of the *Geological Heritage of Malaysia* book edited by Ibrahim Komoo et al. (2001). From this list, Malaysian geoheritage resources can be grouped into seven major categories such as mineral, rock, fossil, primary structure, secondary structure, landform and geological process categories, based on the Malaysian Geological Heritage Group's classification published by Ibrahim Komoo (2003) and Ibrahim Komoo et al. (2004). Following are the various geoheritage categories with several examples of relevant geoheritage sites. The distribution of these geoheritage sites is shown in Figures 1a, b.

Figure 1a. Location of selected geoheritage sites in Peninsular Malaysia described in this chapter.

Figure 1b. Location of selected geoheritage sites in East Malaysia described in this chapter.

Mineral Diversity

Malaysia is richly endowed with minerals ranging from rock forming minerals to economically valuable industrial and metallic minerals. At this moment, none of the Malaysian geoheritage sites are based solely on mineral diversity. The tangible mineral heritage of the country is conserved mainly as mineral collections in several geological museums managed by the Department of Minerals and Geoscience and local Universities as well as in several rock galleries managed by local authorities. However, as Malaysia was historically a well known producer of minerals such as tin, iron, copper, gold, coal and bauxite, certain geoheritage sites have also been developed on old or abandoned mines. Such sites include the Sungai Lembing underground tin mine in Pahang, Bukit Besi open cast iron mine in Terengganu and Tanjung Batu underground coal mine in Labuan Federal Territory.

Rock Diversity

A great diversity of rock types charaterises the geology of Malaysia. These range from basic to acidic igneous rocks, low to high grade metamorphic rocks as well as sedimentary rocks of various origins and composition. Study of the distribution and relationships of these various types of rocks allows us to unravel their geological history such as their palaeo-depositional environment and tectonic setting, both closely associated with the broader geological and tectonic history of Peninsular Malaysia, Borneo and the adjacent Southeast Asian region. The following are selected examples of Malaysian geoheritage sites that could be classified under the category of rock diversity.

***Conglomerate of Bukit Keluang, Terengganu (R1)* – Figures 2a, b.**
Bukit Keluang, Bukit Bubus and Bukit Dendong formed three isolated hills along the coastline of northern Terengganu. These hills are made up of various sedimentary

Figure 2a. Conglomerate of Bukit Keluang Formation representing best Permian continental deposit in Malaysia.

Figure 2b. Permian fossil flora from the Bukit Keluang Formation.

rocks such as conglomerate, sandstone, siltstone and red shale that comprise the Bukit Keluang Formation. Conglomerate is predominant at Bukit Keluang exhibiting various sedimentary structures indicating that it was deposited in an ancient river. Meanwhile, red shale at Bukit Bubus and Bukit Dendong contains plant fossils. Together these outcrops represent the best example of Middle to Late Permian (approximately 260 million years old) terrestrial deposit in the country (Kamal Roslan Mohamed et al. 2000). This geoheritage site also features a beautiful sandy beach and various coastal erosion features.

Granite of Pulau Tioman, Pahang (R2) **– Figure 3.**
The rocks which make up the island are predominantly granite, with minor volcanic and metasedimentary rocks. The granite is of Jurassic age and intruded both volcanic and metasedimentary rocks more than 150 million years ago. Prolonged erosion of the granite has created undulating hills, occasionally with steep slopes forming among others the beautiful twin-peaks of Bukit Nenek Semukut (695 metres). Along Tioman coastline, the occurrence of many rocky granite outcrops as granite tors adds beauty to the coastal scenery.

Figure 3. The Bukit Nenek Semukut (695m) twin granite peaks.

Igneous complex of Mersing Islands, Johor (R3) **– Figures 4a, b.**
A cluster of islands off Mersing coast is mainly made up of granitic and volcanic rocks. Granitic rocks are more dominant in northern islands while volcanic rocks made up most of the southern islands including Pulau Tinggi and Pulau Sibu. The

Figure 4a. Unconsolidated interbedded tuffs at Pulau Sibu – the tuffs range from ash to sand-sized with occasional thin-sheets of felsic lava flow.

Figure 4b. Pulau Tinggi that is made up of dacite and andecite tuffs.

composition of volcanic rocks ranges from dacite to andesite. The southeastern islands are formed by intermediate to more mafic igneous rocks.

***Volcanic Complex of Tawau, Sabah (R4)* – Figures 5a, b.**

Pliocene-Pleistocene volcanic rocks that were erupted a few tens of thousands up to a few million years ago dominate the geology and landscape of the area southeast of Sabah. Conical hills such as Mt. Tiger, Mt. Andrassy and Quoin Hill are remnants of this old volcanic activity. Columnar joints are prominent features exhibited by andesitic rocks of Sungai Balung area (Che Ibrahim Mat Saman 2000). Apart from these, this area is also very rich in geothermal activity.

Figure 5a. Columnar joints in basalt (hexagonal prism) exposed along Balung River, Tawau.

Figure 5b. Cones of hot spring vent in Apas Kiri, Tawau.

Fossil Diversity

Malaysia's sedimentary rocks yield rich and diverse fossil assemblages, preserved within strata of different ages from Cambrian (540 million years ago) to recent times. The bulk of Malaysian fossils are shells of marine invertebrates, ranging from shallow to deep marine faunas. Fossil flora are also found. The distribution of the different fossil groups is strongly controlled by the palaeo-depositional environment and palaeo-tectonic setting of fossil-bearing strata, which in turn closely related to the tectonic evolution of the country. Malaysian fossil heritage are mostly subjected to *ex-situ* conservation within local museums and rock galleries. However, several natural outcrops of highly fossilliferous sedimentary rocks are recognized as national geoheritage sites to be protected under various mechanisms of conservation.

Brachiopod of Bukit Buchu, Terengganu (F1) **– Figure 6.**
Sedimentary rocks in Terengganu, formed from marine sediments deposited in a shallow sea in early Carboniferous times, are often very rich in both fossil fauna and flora. At Bukit Buchu, a rich fossil assemblage of brachiopods, trilobites, cephalopods, bivalves, bryozoas, crinoids, echinoids and plant fragments are all well preserved within vertically bedded light grey shale and light brown sandstone (Idris & Zaki 1986; Che Aziz Ali & Kamal Roslan Mohamed 2001). Cross bedding and ripple marks are also very well preserved in the sandstone.

Figure 6. Well preserved brachiopods at Bukit Buchu fossil bed.

Foraminifera and coral of Bukit Biwah, Terengganu (F2) **– Figure 7.**
Bukit Biwah and Bukit Taat are notable not only as two limestone hills with beautifully shaped karst landforms at the fringe of Kenyir Lake, but also because they contain a rich fossil fauna of Middle Permian age. This fauna consists predominantly of large and small foraminiferas and corals with some bivalves, cephalopods, alga, brachiopods and crinoids (Kamal Roslan Mohamed et al. 2001). Bukit Biwah and Bukit Taat are also rich in archaeological artefacts, for which both hills are protected by the Heritage

Figure 7. Well preserved corals from Bukit Bewah limestone.

Department. As they are located within the National Park, they are also protected by the Department of Wildlife and National Park.

***Ammonoid and bivalve of Aring, Kelantan (F3)* – Figures 8a, b.**
A large assemblage of ammonoid fossils can be observed within dark grey tuffaceous mudstone in the vicinity of Aring. The mudstone was formed from mud deposited in a deep-water marine environment. The ammonoid assemblage is indicative of a Middle – Late Triassic age (240-220 million years ago) and belonged to the Tethyan Province. Other fossil fauna found together with these cephalopods include some bivalves and crinoids.

Figure 8a. Triassic cephalopods from one of the fossil beds within Telong Foprmation in Aring area.

Figure 8b. Triassic bivalves from one of the Aring fossil beds.

Primary Structure Diversity

Primary structure diversity refers to sedimentary as well as igneous emplacement structures. In Malaysia, most well known primary structures are of sedimentary origin particularly those within Cenozoic (up to 65 million years old) sedimentary rocks of Sarawak and Sabah. In older sedimentary rocks, most primary structures have undergone various degrees of metamorphisms, thus have often been overprinted by deformation structures as seen in most Palaeozoic sedimentary rocks of Peninsular Malaysia. Meanwhile, primary structures in igneous rocks are not very well known in Malaysia apart from some examples of magmatic flow structures in volcanic and epizonal or shallow intrusive igneous rocks.

***Sedimentary Structure of Bako, Sarawak (SP1)* – Figures 9a, b.**

Bako National Park of Sarawak is mainly underlain by sedimentary rocks of the Plateau Sandstone Formation deposited during the Miocene (5-23 million years old) Epoch (Johansson 1999; Kamal Roslan Mohamed et al. 2004). Sandstone in this area contains a great diversity of sedimentary structures including large scale trough and tabular cross beds, ripples marks and convolute laminations. The coastlines of Bako exhibit excellent coastal erosional features such as sea stacks, sea notches, abrasion platforms, pot holes, *tafoni* and various other honeycomb structures.

Figure 9a. Cross-bedded sandstone of Plateau Sandstone Formation at Bako National Park *(Photograph courtesy of Kamal Roslan Mohamed).*

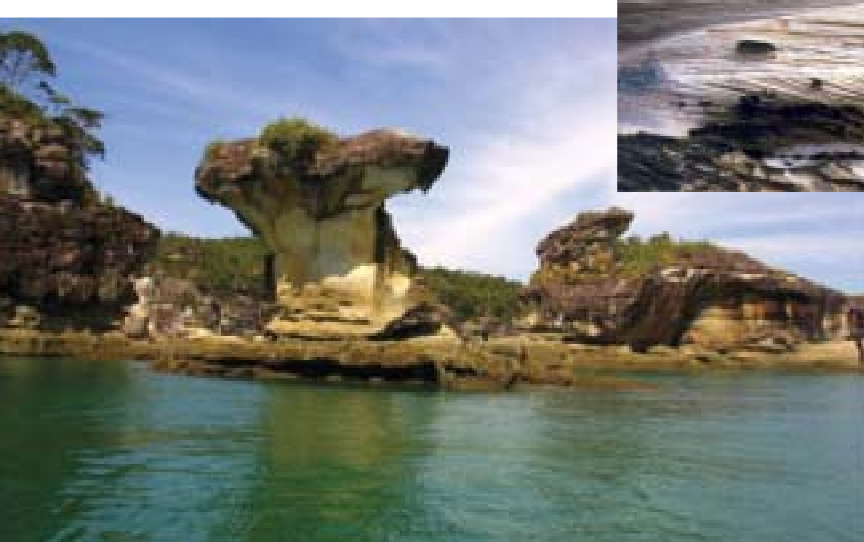

Figure 9b. Amazing geological landscape at Bako National Park as a result of differential weathering and erosion of massive sandstone *(Photograph courtesy of Kamal Roslan Mohamed).*

Volcanic Flow Structure of Tandek, Sabah (SP2) **– Figure 10.**

Volcanic flow structures such as pillow lava are not uncommon in Sabah particularly in north and central Sabah. Pillow structures are best preserved in basaltic rocks associated with chert in Tandek area in northern Sabah (Tongkul 1999). This so-called chert-spillite association is very important evidence for the presence of ancient oceanic crust in Sabah during the Cretaceous Period.

Figure 10.
Well preserved pillow structures within basaltic rocks of Tandek, near Kota Marudu, Sabah.

Secondary Structure Diversity

Throughout its geological history, both Peninsular Malaysia and North Borneo were located within a tectonically active region. The oldest tectonic events are recorded in Late Palaeozoic rocks of Peninsular Malaysia and several younger tectonic episodes are recorded within younger rocks. These events have transformed and deformed the affected sedimentary rocks into various types of metamorphic rocks with rich diversity of secondary or deformation structures. Deformation is generally more intense within the established suture zones as compared to the neighbouring areas (Hutchison 1989).

***Deformed Rocks of Pantai Chendering, Terengganu (SS1)* – Figures 11a, b.** Highly deformed metasedimentary rocks of Carboniferous age are exposed as patches of rocky coast along the Terengganu coastline particularly in central and southern Terengganu. At a resort beach of Pantai Chendering in central Terengganu, the metamorphosed sedimentary strata (meta-argillite and meta-arenite) exhibited well-preserved isoclinal, recumbent and overturned folds and various types of faults as well as several micro-structures such as crenulation cleavage and chevron folds (Ibrahim Abdullah et al. 2001).

Figure 11a. One of the many recumbent folds exposed at Pantai Chendering, Terengganu.

Figure 11b. Chevron fold and crenulation cleavage on the flank of larger recumbent folds.

***Deformation Structures of Tanjung Balau, Johor (SS3)* – Figure 12.**

A distinguished record of tectonic events is presented by deformation structures in metasedimentary rocks of Tanjung Balau, Southeast Johor. Exposed at this coastal outcrop are metasandstone, phyllite and slate of possibly Carboniferous age with excellent secondary structures such as tight isoclinal folds, refolded folds, periclinal folds, crenulation cleavage, mullions, boudinage and various other deformation structures (Tajul Anuar Jamaluddin 2000).

Figure 12. Tanjung Balau coastal exposure showing part of the tightly folded metasedimentary sequence of the Mersing Formation.

***Faults of Miri Anticline, Sarawak (SS4)* – Figures 13a, b.**

Part of the Miri Anticline is clearly vissible in outcrops at kilometre 2 Miri-Airport Road where varieties of primary and secondary structures can be observed (Lesslar & Lee 2001). Primary structures include hummocky cross-beds and bioturbation structures including *Orphiomorpha*. Secondary deformation structures at this outcrop are represented by various types of closely spaced faults and an open anticline. The outcrop is part of a protected geoheritage site managed by the Miri City Council.

Figure 13a. Outcrop of the Miri Formation showing part of the Miri Anticline at the Miri Airport Road.

Figure 13b. A close-up view of some of the faults on the flank of the Miri Anticline.

Landforms Diversity

Landform and geomorphic features are manifestation of the different physical and chemical properties of rocks, their structures and their interaction with erosion and other geological processes throughout geological history. Current Malaysian landforms are mostly a final product of erosion by surface running water and underground water under the strong influence of a tropical to sub-tropical climate. Due to a variety of controlling factors, Malaysian landforms can be further subdivided into various sub-categories such as waterfalls, beaches, mountain peaks, lakes and caves. The distribution of these various types of landforms in Malaysia is closely related to the geology of the country.

Waterfall Landform Diversity

Most waterfalls in Malaysia are located where highly resistant bedrocks, such as granite, sandstone and other highly siliceous sedimentary and metamorphic rocks, crop out. Some strategically located waterfalls have been developed as Recreational Forest managed by the Forestry Department.

***Lata Iskandar Waterfall, Perak (LW1)* – Figure 14.**
The Lata Iskandar waterfall is located at the western flank of the Main Range of Peninsular Malaysia, along the road in between Tapah and Cameron Highlands. The underlying rock here is granite (coarse-grained porphyritic biotite granite) and constitutes part of the Main Range Granite. This waterfall has been developed into recreational forest and is popularly visited by local and foreign tourists.

Figure 14. Lata Iskandar Waterfall in Tapah, Perak.

***Tembakah Waterfall, Besut, Terengganu (LW2)* – Figure 15.**
The waterfall is developed on Sungai Tenang, which is located at the eastern limb of the boundary range in Besut District, Terengganu. The geology of the site is made up of monotonous granitic rocks displaying very little lithological variation. The site has seven stages of waterfalls, naturally shaped by faults that intersect the stream. The waterfall and surrounding area has also been developed as a recreational forest.

***Sagil Waterfall, Gunung Ledang, Johor (LW3)* – Figure 16.**
Standing at 1,267 metres, Gunung Ledang is the highest mountain in Johor. The mountain is more popular for its mystical legend rather than the beauty of its enchanted landscapes. The mountain is mainly made up of granite (biotite-muscovite granite), representing the southernmost extension of the Main Range Granite. Sagil Waterfall is the best developed and most popularly visited waterfall along the foothill of the Gunung Ledang.

Figure 15. Tembakah Waterfall in Besut, Terengganu.

Figure 16. Gunung Ledang Waterfall in Sagil area of Tangkak, Johor.

Buaya Sangkut Waterfall, Johor (W4) **– Figures 17a, b.**
Endau-Rompin National Park is a large national park that is located within Pahang and Johor States. In the Johor part of the park, the geology is predominantly made up of the Jasin volcanic rocks of Permian age. The rock sequence consists of various types of volcanic tuffs which were erupted explosively and deposited in a sub-aerial environment some 280 million years ago. The horizontal layers of volcanic rocks create platforms over which several vertical waterfalls cascade down successive plateaux. Erosion along the many vertical faults has formed steep-sided cliffs and deep gorges. Buaya Sangkut Waterfall is the largest waterfall known within the Johor Endau-Rompin National Park.

Figure 17a. Buaya Sangkut Waterfall at Jasin River, Endau-Rompin National Park, Johor.

Figure 17b. Rapids at Buaya Sangkut Waterfall.

Cave Landform Diversity

Throughout its long geological history, calcareous sediments were deposited in various part of Malaysia forming several calcareous rock formations. These formations consist mainly of limestone and dolomite, some of which were subsequently transformed into good quality marble due to metamorphism. Chemical reaction and dissolution of limestone and other calcareous rocks occurs both on the land surface and in fractures and pores within the rock. Prolonged internal dissolution that started merely within tiny cracks eventually forms huge caves. Continuous dissolution is followed by precipitation of carbonates known as cave deposits or cave speleothems. The shape, size and direction of the cave deposits are highly variables and are controlled by various physical and biological factors. Collectively, these processes created the amazing beauty of limestone caves. Some caves of Malaysia contain archaeological artefacts, while some others are made into cultural and religious sites.

***Gua Kelam, Perlis (LC1)* – Figures 18a, b.**

Gua Kelam or Dark Cave is located near the Kaki Bukit Town, in the north of Perlis State, not very far from the Malaysia-Thai border. It is actually a natural tunnel with subterranean stream flowing from Wang Burma to Kaki Bukit. This tunnel cut across limestone hills of the Nakawan Range, a part of Thai-Malaysia boundary. This range is essentially underlain by the Setul Limestone Formation of Ordovician age. In the cave, one can observe various spectacular forms of stalactites, stalagmites, limestone columns and stacking rimmed pools. On fresher, unaltered limestone walls, various types of fossils that formed part of the limestone are clearly vissible. Gua Kelam is part of the Perlis State Park, which is protected and managed by the state Forestry Department. A platform has been built to facilitate access for tourists to explore the cave and forest amenities provided for the recreational forest in the wang on the western side of the hill.

Figure 18a. Some basic infrastructures built in Gua Kelam to support tourism industry.

Figure 18b. Stacked giant rim-pools; one of the main tourist attraction within the Gua Kelam.

Gua Tempurung, Perak (LC2) **– Figure 19.**

Gua Tempurung or Cocconut Shell Cave is a very large cave located in Kampung Gunung Panjang not very far to the south of Ipoh City, the capital of Perak State. The length of the cave is about 1.9 kilometres and part of it merged with a subterranean stream. The cave cut across a large hill typical of a well defined mogote karst topography consisting of isolated hills with steep to overhanging walls and rounded tops. This hill belonged to the Kinta Limestone (Devonian to Permian in age), and is essentially made up of marble as a result of metamorphism due to granite intrusion during the Late Triassic time. Gua Tempurung has 5 gigantic chambers with a gallery of stalagmites, stalactites, curtains, flowstones and pillars. In recent history, it was the hideout for the guerrillas fighting against the British governing regimes. At present, this cave is managed by the State's authorised agency and is popularly visited by local and foreign tourists.

Figure 19. Perak State government provides facilities such as spotlights, hanging bridges, tourist guides, adventure package and souvenir/information kiosks to attract tourists to Gua Tempurung.

Batu Cave, Selangor (LC3) **– Figures 20a, b.**

Though the Kuala Lumpur Limestone (Silurian in age) formed a large part of the Kelang Valley, there are only two limestone hills found around Kuala Lumpur City, the Batu Cave and Takun Hills. The Batu Cave Hill is the largest limestone hill and is located just northwest of the capital city. It covers an area of about 1 square kilometre. Batu Cave or Stone Cave, is also the largest natural cave in this area. The elevated main chamber of Batu Cave, exhibits various types of speleothems. Despite its prominent geological features, Batu Cave is most famous for its Hindu Temples and the Thaipusm Ritual that draws millions of people to visit the cave every year. The cave is currently protected by the Heritage Department of Malaysia whereas the Thaipusm Ritual has been put in the Calendar of National Events.

Figure 20a. The entrance, sunrays beaming into the cave create a pleasant scene at Batu Cave.

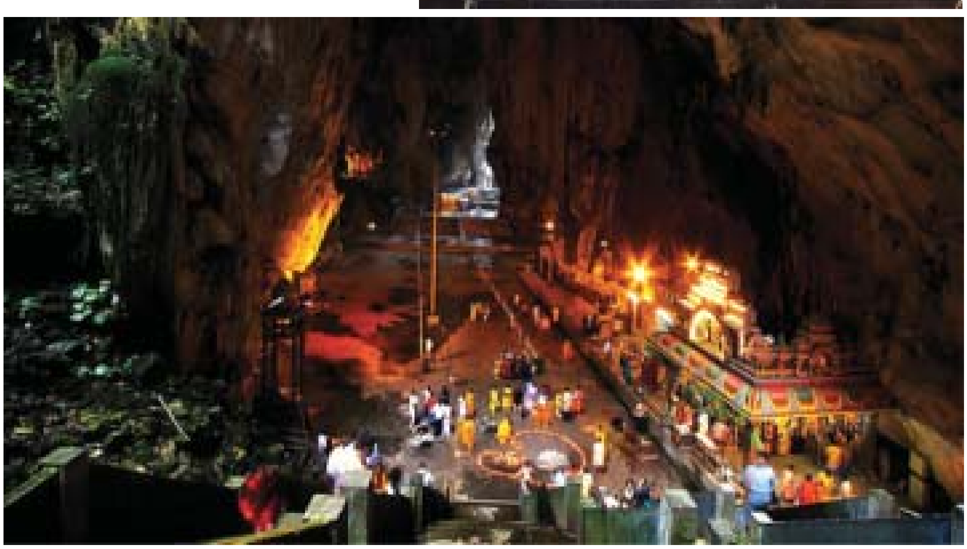

Figure 20b. Batu Cave during the preparation of the Hindu Thaiphusm Festival.

***Caves of Gunung Senyum, Pahang (LC4)* – Figures 21a, b, c.**

Gunung Senyum and Gunung Jebak Puyuh are two limestone hills of Late Permian – Early Triassic age. These hills are located on the eastern side of Pahang River about 40 kilometres north of Temerloh Town. Standing at a height of 550 metres, Gunung Senyum contains more than 20 large and small caves and several well confined dolines. These caves and dolines possess various unique speleothems, particularly some remarkable stalagmites that resemble certain figures. The local people believed that these figures and other cave features such as stacking rimmed pools and swallow holes are closely linked with an old folk myth of a fairy king (Mohd Shafeea Leman et al. 2001). Some caves also contain important archaeological artefacts. Gunung Senyum has been conserved by the Pahang State Forestry Department and managed as a Recreational Forest, while some of the caves have also been gazetted as archaeological research sites.

Figure 21a. Gunung Senyum is a Permian - Triassic limestone hill with over 20 caves recorded.

Figure 21b. Enlarged swallow-hole due to the collapse of the roof of Gua Taman Dua at Gunung Senyum.

Figure 21c. One of the unique stalagmites at Gua Taman Dua.

***Gua Niah, Sarawak (LC5)* – Figures 22a, b.**

Bukit Subis is a very large limestone hill covering an area of around 54 square kilometres with a height around 370 metres. It is located within the Niah National Park in Northern Sarawak Division. The entire hill is made up of highly fossiliferous bioclastic limestone belonging to the Subis Limestone Member of the Sibuti Formation of Early Miocene age (Banda et al. 2000). Subis Hill contains many caves, one of which is the world renowned Gua Niah or Niah Cave. Gua Niah is a very important archaeological site where remains of a 40,000 years old human skeleton and a large burial site of Palaeolithic humans were discovered by archaeologists. The cave which also contains many cave paintings has now been gazetted as a national heritage site and became one of the most popularly visited sites in Sarawak today.

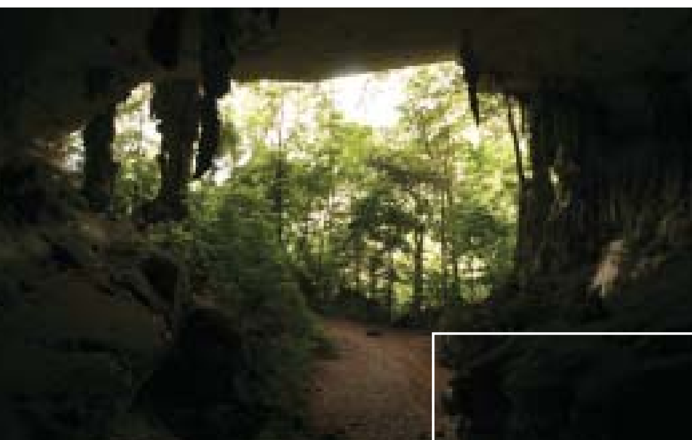

Figure 22a.
Niah Cave is one of the most famous archaeological sites in Malaysia.

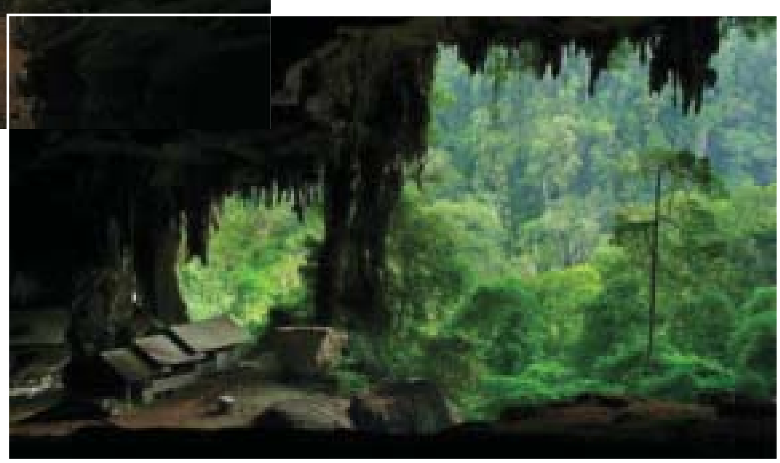

Figure 22b. One of the cave chamber that contains archaeological artefacts.

Mountain Peak Landscape Diversity

As mentioned earlier, rocks which are highly resistant to deep chemical weathering such as quartz dykes, pure limestone and other highly siliceous igneous, sedimentary and metamorphic rocks do not favour the formation of thick soils and thus are not likely to be heavily vegetated. In Malaysia, only Kinabalu Peak (4,095 metres) reaches higher than 3,500 metres height, the roughly estimated upper vegetation line. The amount of exposures of rock on other peaks is mostly controlled by the rock types as shown in the following examples.

***Klang Gate Quartz Reef, Selangor (LL1)* – Figures 23a, b.**

The Klang Gate Quartz Ridge is the longest quartz ridge in Malaysia with total length of up to 14 kilometres and maximum width of nearly 200 metres. This ridge formed the northeastern boundary of Malaysia's capital city Kuala Lumpur. The name Klang Gate came from a narrow gap between the ridges through which the Klang River flows. It is here that the Klang River was turned into the oldest and most important domestic water reservoir in the history of Kuala Lumpur. The quartz ridge was formed by alteration of granitic country rocks, where emplacement of quartz in the form of a dyke along the Kuala Lumpur Fault is believed to have taken place during post-Triassic time, possibly between Jurassic and Mid-Cretaceous time. Through millions years of weathering and erosion, the hard and highly resistant quartz minerals formed the upstanding ridge, creating a stunning picturesque background to the bustling Kuala Lumpur city below. At this quartz ridge, one can find many quartz veins and veinlets crossing one another and sometimes appearing as hieroglyphs. This quartz ridge has been included into the Selangor State Park for protection of the rocks and several endangered species of fauna and flora in the area.

Figure 23a. The Klang Gate Quartz Ridge standing at 367 metres above sea level, with its highest peak at 534 metres.

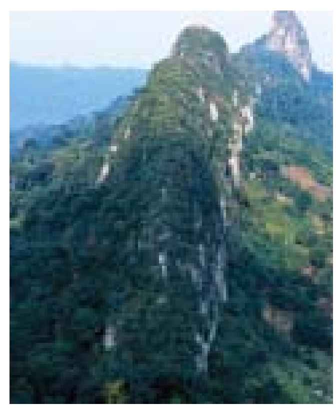

Figure 23b. From the top view, the Klang Gate Quartz Ridge is rather undulating and looks like the back of a serpent.

***Kinabalu Peak, Sabah (LL2)* – Figures 24a, b, c.**

Sabah has several world-class nature heritage sites such as Sipadan Island, Maliau Basin, Danum Valley and Mount Kinabalu. Mount Kinabalu (4,095 metres), the highest mountain in Southeast Asia is a flat-topped granite block that sits some 113 kilometres to south-southwest of the northern tips of Borneo. It has significant elements of interesting geological history, rock formation, rock types and the natural

Figure 24a. Panoramic view of the Kinabalu Mountain as seen from the Kinabalu Park Headquarters.

**Figure 24b.
The jagged peak of Donkey's Ears (right) and the Ugly Sisters (back left) at the western part of Kinabalu Plateau.**

**Figure 24c.
Sharp-conical shaped of Kinabalu South Peak and glacial erosion features at the western part of Kinabalu Plateau.**

beauty of its unique and enchanting landscapes. The main rock types are the igneous rocks (adamellite and granodiorite in composition) of late Miocene age that intrude the Crocker Formation to the north and ultrabasic rocks and Trusmadi Formation to the south. The peak landform is of particular interest for its clear display of the effects of glacial erosion and deposition during the maximum Pleistocene glaciation some tens of thousands years ago. As the glacier sheet moved downward due to gravitational force, it scoured and broke the rocks beneath it, and dragged the loose rock lower down the mountain. This created several unique glacial features such as *cirques*, jagged peaks, glacial striation and groove marks, U-shaped valleys and *roche moutonnees*. Kinabalu Mountain has been accepted as one of the UNESCO World Natural Heritage Sites. The Kinabalu Park Authority is now preparing documentation and infrastructure to enable it to become a national geopark.

***Gunung Api Pinnacle, Mulu, Sarawak (LL3)* – Figures 25a, b.**

The largest limestone cave in Malaysia, the Sarawak Chamber is also the largest cave in the world. This and several other unique caves are part of the karst landscape of Melinau Formation comprising limestone of Late Eocene–Early Miocene age. The Melinau Limestone, covering an area of about 300 square kilometres, occupies the biggest national park of Sarawak, the Mulu National Park. Beside its spectacular caves, Mulu National Park is also famous for the spectacular limestone peaks of Gunung Api. These pinnacles create a vast field of tall standing needle- and sharp blade-like outcrops that cling to the flanks of Gunung Api or Fire Mountain. An aerial view reveals, a dense green mountain rainforest encircling these sharp silver-blue limestone pinnacles. The pinnacles were formed due to the virtually constant rainfall that has penetrated and dissolved the limestone along vertical joints in the rock thus eroding and shaping it into sharp pinnacles with narrow crevices and intersecting ravines. The limestone itself is also of great interest for its rich and diverse fossil fauna including larger foraminifera (*Nummulites*), red algae, hermatipic corals, echinoids and molluscs. Though it is remotely located, the Mulu National Park, which is also a UNESCO World Natural Heritage Site, attracts thousands of local and foreign tourists every year.

Figure 25a. The razor- and blade-shaped pinnacles of Gunung Api that constitute part of the Mulu Nature World Heritage Site.

Figure 25b. A closed-up view on some of the pinnacles.

***Batu Lawi Peak, Bario, Sarawak (LL4)* – Figure 26a, b.**

Sarawak Plateau is located within Miri and Limbang Divisions in the interior of Sarawak. The Kelabit Highland in Bario area consists of several ridges and

Figure 26a. Panoramic view of Batu Lawi twin peak in the heart of Borneo jungle.

peaks including the Tama Abu Range, Gunung Murud and Batu Lawi. Gunung Murud, the highest peak of Sarawak, Gunung Tamado and Batu Lawi are made up of thick to massive sandstone of the Meligan Formation of Miocene age. Perhaps the most striking geoheritage feature of the Sarawak Plateau is the formation of rock columns known as the Batu Lawi twin peak, the tallest of which stands at 2045 metres with vertical cliffs on all sides. Currently, due to its remoteness, Batu Lawi is not yet open for mass tourism.

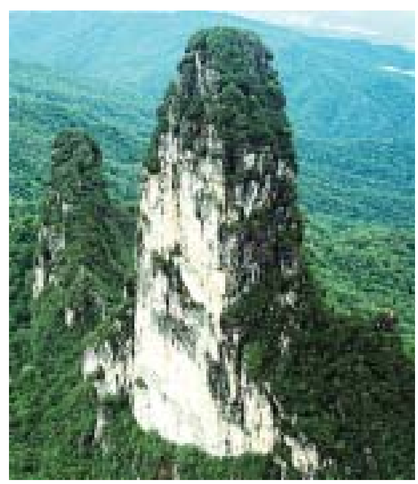

Figure 26b. Batu Lawi Peak is a column of massive sandstone.

***Kilim Karst Pinnacle, Langkawi, Kedah (LL5)* – Figures 27a, b, c.**

Kilim Valley in the northeast of Langkawi Island is predominantly made of Ordovician limestone of Setul Formation. Prolonged erosion on limestone has formed isolated hills and ridges separated by narrow and incised valleys on which a unique mangrove ecosystem is developed. The limestone peaks were etched into highly variable shapes, controlled by the nature and attitude of the bedding planes, the fracture and fault patterns and the position of the hills upon the directions of prevailing win and wave.

Figure 27a. Panoramic view of karst hills of Kilim Valley within Kilim karst Geoforest Park of Langkawi.

Figure 27b. Limestone peaks of various shapes along the Kilim River.

Figure 27c. Razor-sharp pinnacles near the Kilim River Mouth as an icon for the Kilim Geoforest Park.

The peaks that are directly facing the easterly wind are apparently less vegetated and thus form more dramatic pinnacles than those are protected against the seasonal monsoon. The combination of a picturesque island karst landscape and a rare limestone-hosted mangrove ecosystem, merited the Kilim Valley to be adopted as one of the geoforest parks by the Kedah State Forestry Department. Kilim Karst Geoforest Park became one of the most important geoheritage conservation components of the Langkawi Global Geopark (Mohd Shafeea Leman et al. 2007c).

***Machinchang Peak, Langkawi, Kedah (LL6)* – Figures 28a, b.**

Lying in the northwestern corner of Peninsular Malaysia are the oldest rocks of the country comprising the Machinchang Formation of Cambrian age. The formation consists mainly of moderate to thick beds of pure quartz sandstone together with subordinate amounts of siltstone and shale. Though it is over half a billion years old, the Machinchang sandstones are only very weakly metamorphosed, and generally display their original sedimentary structures. The resistant sandstone beds formed prominent ridges known as the Machinchang Mountains. Deformation has created numerous sets of intersecting fractures in these brittle hard sandstones and prolonged erosion along these fractures have turned the Machinchang peaks into numerous chopped- up blocks, hence it was named as Mat Chinchang or Chopping Mat. Like Kilim valley, the entire Machinchang Mountains has been designated as a geoforest park, the Machinchang Cambrian Geoforest Park, another geoheritage conservation component of the Langkawi Global Geopark (Mohd Shafeea Leman et al. 2007c).

Figure 28a. Panoramic view of Machinchang mountains within Machinchang Cambrian Geoforest Park of Langkawi.

Figure 28b. Strike ridges formed by Cambrian sandstone of Machinchang Formation.

Geological Process Diversity

As in other heritage resources, geoheritage resources can be divided into the tangible and intangible resources. The intangible geoheritage resources are mostly related to the geological history and the prevailing geological process of such sites. Most of the time, it is the tangible final product of the geological process that is being considered as the geoheritage resource, but occasionally the final product is not very obvious and tangible enough to be considered as a geoheritage resources. Some active coastal erosion and hot springs, for examples, do not reveal enough end products to be appreciated as a heritage. However, the scientific value of the prevailing process can sometimes be considered as a very important geoheritage resource.

Hot Springs Diversity

Hot springs are not so common in Malaysia as the geological terrains are mostly very old in geological terms, particularly in Peninsular Malaysia, and lacking in relatively recent volcanic activity. Most of them are related to deep fractures tapping the heat source from the deep crust. Most hot springs in Malaysia are located along the west and east of the Main Range Granite, with some isolated ones occur in close association with other granite bodies.

Sungai Klah Hot Spring, Perak (H1) **– Figure 29a, b.**
The hottest hot spring ever discovered in Malaysia is located at Sungai Klah, near Sungkai Town, where the spring water temperature reaches 98^{o}C. The site is located along the contact between granite and sedimentary rocks, probably situated within a major fault or shear zone. This thermal spring is therefore considered to be structurally controlled with heat source derived from ancient magmatic activities. The spring points are spread for about 50 metres along the stream and cover an area of about 16.6 hectares. Local people have traditionally used these geothermal springs for bathing and other recreational purposes. Some basic facilities have been developed by the State Government's recognised authority in this area including five-star chalets, food stalls and souvenir shops. The geothermal spring is believed to contain chemical ingredients that are beneficial to sufferers from rheumatism, arthritis, insomnia and various types of skin problems.

Kampung La Hot Spring (H2) **– Figure 30.**
The La Hot Spring is located at Kampung La, near Besut, Terengganu and is accessible by road. The geothermal source is believed to be associated with the northerly trending Terengganu Fault. The site has beautiful scenery and potential to be developed and promoted as a tourist destination and for geothermal resources study.

Figure 29a. Several hot springs developed along the fault-controlled stream at Sungai Klah.

Figure 29b. One of the hottest spot where rocks were encrusted near the spring.

Figure 30. La Hot Spring in Terengganu which has been developed into a popular tourist spot.

GEOHERITAGE CONSERVATION

Geoheritage conservation initiatives in Malaysia are a multi-institutional effort involving various government agencies, higher learning institutions, local authorities and NGOs. Important government agencies include the Department of Minerals and Geoscience, Department of Heritage, Department of Museum, Forestry Department, Marine Park Department, Wildlife Department and Department of Drainage and Irrigation. Among higher learning institutions actively involved in pursuing geoheritage conservation are the Universiti Kebangsaan Malaysia, Universiti Malaya, Universiti Malaysia Sabah, Universiti Sains Malaysia and Universiti Utara Malaysia. Local authorities are perhaps the most important players in conservation as land matters fall under their jurisdiction. Among the most active local authorities are the Langkawi Development Authority, Sabah Park Authority, Johor and Sarawak National Park Authorities and other state parks authorities.

Geoheritage sites in Malaysia are protected under various mechanisms and concepts, managed by respective local authorities and related government agencies (Ibrahim Komoo 2003). Thus they are conserved either as part of national parks, state parks, geoforest parks, recreational forests, heritage sites or forest reserves. Following recent development of UNESCO geopark concept, some of these conservation areas would served perfectly as the required geoheritage conservation component of a geopark.

At this moment, Malaysia has successfully developed one national geopark that is the Langkawi Geopark. This geopark has been accepted in June 2007 as the 52nd member of Global Network of National Geoparks under the auspices of UNESCO (Mohd Shafeea Leman et al. 2007c). Langkawi Geopark is managed by the Langkawi Development Authority (LADA), but the plan and development concept of this geopark were built together by LADA, Universiti Kebangsaan Malaysia (UKM) and Forestry Department of Peninsular Malaysia. The management structure of Langkawi Geopark is organized under one advisory committee and four subcommittees including Technical, Conservation, Promotion and Development Subcommittees. While promotion and development of Langkawi Geopark is handled by LADA, geoheritage conservation within Langkawi Geopark is organized by the Kedah State Forestry Department. Three major geoheritage conservation components of Langkawi Geopark are the Machinchang Cambrian, Kilim Karst and Dayang Bunting Marble Geoforest Parks, respectively, highlighting Cambrian sandstone of Machinchang Formation, island karst of Ordovician-Devonian Setul Formation and marble of Permian Chuping Formation (Shaharuddin Mohamad Ismail et al. 2005). The technical committee of Langkawi Geopark is led by UKM researchers under the Langkawi Research Centre.

Up till now, the planning and monitoring of geoparks in this country is organised by the Malaysian Geological Heritage Group, but a plan has been put forward to establish a National Geopark Unit under the Department of Minerals and Geoscience of Malaysia. So far, eleven potential national geoparks have been identified by this research group and efforts are being made to develop these potential geoparks. However, a special focus is given to the establishment of Kinabalu World Heritage Site as part of Kinabalu Geopark.

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Separator Photo:
View of Taal Volcano and Taal Lake as seen from Tagaytay Ridge, the Philippines
(*Photograph courtesy of Simplicio Caluyong*).

7

GEOHERITAGE OF THE PHILIPPINES

Yolanda Maac-Aguilar

INTRODUCTION

The Philippine Government, recognizing that some outstanding geological features in the country need to be protected and conserved for future generations, formed the National Committee on Geological Sciences (NCGS) through Executive Order No. 625 on October 8, 1980. This Committee, assigned under the office of the President, is tasked to look into various geological issues and concerns, such as the search for mineral and energy resources, as well as matters regarding environmental protection and conservation. The Committee is made up of twenty one government agencies headed by the Mines and Geosciences Bureau (MGB).

National Geological Monuments

The NCGS had so far declared six important or threatened geoheritage sites as national geological monuments in order to ensure their preservation and to promote awareness on geology among the public and decision makers. These areas were selected according to criteria such as their scientific significance and high aesthetic value. The six geological monuments of the Philippines are:

1. Montalban Gorge in Rizal
2. Taal Volcano in Batangas
3. Chocolate Hills in Bohol
4. Ilocos Norte Sand Dunes
5. Hundred Islands in Pangasinan
6. Saint Paul Formation in Palawan

Before the declaration of these sites as national geological monuments, detailed geological mapping and field investigations were conducted by the Mines and Geoscience Bureau and other member agencies in order to study the geology, geomorphology and evolutionary development of each site. A geological monument marker was installed explaining the geological value, the evolutionary development and other features of each site. Maintenance of the geological monument is the responsibility of the Tourism Office of the concerned municipality.

Geoparks and Inventory of Geoheritage Sites

With the introduction of the UNESCO Geopark Network Program, the Mines and Geosciences Bureau had proposed a project on the *Development of National Geoparks in the Philippines*. The project, commenced in 2008, aimed at establishing Philippine Geoparks with UNESCO recognition. The project is also one of the geoscience activities of the Philippines in support of the International Year of Planet Earth (IYPE). The aim is not only to ensure protection and preservation of geoheritage sites, but also to promote socio-economic and sustainable developments of particular landscape, a criteria required by the UNESCO Geopark Network Program. Three of the proclaimed national geological monuments have been proposed as National Geoparks for 2008, namely the Chocolate Hills, Puerto Princesa Subterranean River Park (St. Paul Limestone) and the Hundred Islands. This will be accomplished in coordination with the Local Government Units and the Philippines Tourism Authority. Comprehensive field guidebooks and pamphlets for the tourism industry and promotional programs will be prepared for these geological monuments.

Previously, beside the establishment of geological monuments, no further inventory works on geoheritage sites were conducted. Pertinent studies relating to the cultural, educational and scientific values (e.g. biodiversity) of potential geopark areas were only to be conducted when the sites had been proposed, or were declared, as UNESCO World Heritage Sites. However, under the national geopark project, further systematic inventory work will be conducted to cover interesting geological and geomorphological terrains, landscapes or sites such as fossil localities, stratigraphic features, mineral sites, karst areas, volcanoes and lakes. The inventory work will cover both small and large geoheritage sites.

As part of the Philippine contribution to this book, six sites which have been declared as National Geological Monuments and some other key tourist destinations with geological significance are described in the following pages.

NATIONAL GEOLOGICAL MONUMENTS

Montalban Gorge in Rizal Province

The Montalban Gorge (Figure 1) is located in the town of Rodriguez (Montalban), Rizal Province, east of Manila. It lies between two limestone mountains near the foot of the Sierra Madre Mountain Range. The limestone formation was formed during

Early Miocene time (about 20-25 million years ago) from the accumulation of calcareous precipitates and remains of marine organisms in shallow marine environment. Because of its beauty, the karst area attracts tourists, picnickers and nature trekkers. In the gorge, there is a dam, constructed in 1908, which had been used to supply water to Metro Manila residents until the Angat Dam was completed in 1924.

In recognition of its scientific value as the type locality of the Montalban Limestone Formation and as a natural laboratory for the study of geological processes, the gorge was declared as the first National Geological Monument in the Philippines on September 10, 1983. Another geological feature that adds to the historical value of the Montalban Gorge is the Pamitinan Cave or the "Cave of Bernardo Carpio", which has an important place in Philippine history. This is the site where Andres Bonifacio, a Filipino revolutionary hero, and seven other men declared independence from Spain on April 12, 1895. This cave and a few others are also said to have been used by Japanese soldiers during the Second World War. A memorial was erected at the entrance of one of the caves in memory of the dead Japanese soldiers. According to folklore, the cliffs in the gorge were separated by Bernardo Carpio, the Filipino hero who was said to be gifted with special strength, comparable to Samson in ancient mythology.

Figure 1. The Montalban Gorge with the Wawa dam. (*Photograph courtesy of Lorna Habal*).

Taal Volcano in Batangas Province

Taal Volcano (Figure 2) is one of the world's smallest but deadliest volcanoes. It is located in the municipalities of Taal, San Nicolas and Talisay, in the province of Batangas. It covers an area of about 23 square kilometres and rises to a height of about 400 metres and is classified as a stratotype volcano within a fresh water caldera lake known as Taal Lake. It is unique in that the island volcano encircles its own 2 kilometres wide crater lake. During the evolution of the area, 50,000-100,000 years ago, repeated eruptions had caused the collapse of a much larger ancient volcano and the formation of a lake and then the formation of new volcanic cone within the lake. The volcano is very active, with thirty three eruptions having been recorded since its earliest known outburst in 1572. The most violent and catastrophic events occurred in 1754, 1911 and 1965, which caused the loss of 6,000 lives and much property around the area.

Taal Lake which is approximately 30 kilometres accross at its widest part and covers an area of about 243 square kilometres is the third largest lake in the country. The best view of both the lake and the volcano is from the Tagaytay Ridge (Figure 3). The lake water is drained by the Pansipit River into Balayan Bay. The volcano and the lake is a natural laboratory for the study of volcanic hazards and the processes of our dynamic earth. The site was declared as the second National Geological Monument by the NCGS on November 25, 1985. Because of its unique beauty, the volcano and the lake is frequented by volcanologists, other scientists, media persons and tourists. Tourists usually explore the volcanic island either on foot or on horseback, and they can also enjoy rowing and kayaking on the lake.

Beside its scenic beauty, Taal Lake holds some rare and endemic species that used to live in salt water but have survived and evolved in fresh water. Examples are "tawilis", the world's only fresh water sardine fish; trevally, *Caranx ignobilis* or "maliputo", an endemic fish and *Hydrophis semperi*, a rare sea snake. Sightings of the bull shark *Carcharhinus leucas* were also reported in the lake prior to the 1930s.

Figure 2. Aerial view of the island volcano and crater lake of Taal. (*Photograph courtesy of Mike Gonzales*)

Figure 3. View of Taal Volcano and Taal Lake as seen from Tagaytay Ridge. (*Photograph courtesy of Simplicio Caluyong*).

Chocolate Hills in Bohol Province

Chocolate Hills of Bohol is one of the most unique geologic features in the Philippines. These hills consist of a total of more than one thousand symmetrical cone-shaped hills of almost uniform size (Figure 4), in clusters that spread over an area of more than 50 square kilometres in the towns of Carmen, Batuan, Sagbayan and Valencia. Its name was derived from the grass cover of the hills that turns brown during summer giving an appearance of large drops of chocolate. The height of each mound varies from 30 to 50 metres, the highest reaching 120 metres. The hills are composed dominantly of thin to medium bedded sandy to rubbly limestone containing fossils of foraminifera, corals, mollusks and algae indicating that the sediments from which the rocks were formed, originally accumulated in a shallow sea during Late Pliocene to Early Pleistocene time, about 2 million years ago. After the area was uplifted from the sea, fracturing of the rocks and the further processes of erosion and dissolution by acidic rain water resulted in the limestone forming the spectacular hummocky landscape dotted with haystack-like mounds.

Figure 4. Chocolate Hills viewed from Mt. Buenos Aires, Carmen municipality.
(Photograph courtesy of the Provincial Tourism Office, Tagbilaran, Bohol).

Beside its scenic beauty, Chocolate Hills offer a host of other interesting geological and geomorphological features such as the flat plains in between the hills, caves, springs and tunnels. Some of the caves are also noted for their archaeological and historical values. In recognition of its scientific importance, uniqueness and high aesthetic value, and also to ensure its protection and preservation, the Chocolate Hills area was declared as the third National Geological Monument in the Philippines by the NCGS on June 18, 1988. A memorial was erected in a government owned viewing deck at Buenos Aires Hill about 55 kilometres northeast of Tagbilaran City and 5 kilometres south of Carmen Town. Despite the proclamation, the hills still face the perils of exploitation. Three of the hills have been quarried for construction material since the date of the proclamation. In order to provide more protection for the hills, a further proclamation (Proclamation No. 1037) was signed by President Fidel Ramos on July 1, 1997 based on the recommendation from the Department of Environment and Natural Resources (DENR). This has established the Chocolate Hills and the areas around them in the municipalities of Carmen, Batuan, Sagbayan, Bilar, Valencia and Sierra Bullones as a natural monument. With this proclamation, the Chocolate Hills are protected by the National Integrated Protected Areas System (NIPAS) Law, with the DENR as the lead implementing agency. At present, maintenance and protection of the hills are within the jurisdiction of the provincial government through the Protected Areas Management Board (PAMB).

Ilocos Norte Sand Dune

The Ilocos Norte Sand Dunes (Figure 5) constitute a unique landform in the Philippines. They are low-lying or gently rolling elongated hills of loose sand formed in a 4 kilometres wide zone that extends for about 40 kilometres along the coast of Ilocos Norte, from Currimao in the south to Pasuquin in the north. These hills, which sometimes reach a height of 30 metres, are believed to have been formed by erosion and deposition by the combined actions of wind and sea (waves and shoreline currents) a few thousand years ago. Based on its unique landform, the area was designated the fourth National Geological Monument on November 26, 1993. It provides a natural laboratory for the study of coastal erosion and sedimentation. A marker was installed at Barangay Calayab, Laoag City.

Figure 5. The Sand Dune of Ilocos Norte. (*Photograph courtesy of Alaric Magnus A. Yanos*).

Hundred Islands in Pangasinan Province

The area known as the Hundred Islands is located about 250 kilometres north of Manila in Barangay Lucap, Alaminos City, Pangasinan Province. It consists of 124 islets (123 at high tide) of varying sizes (Figure 6) scattered over 18.5 square kilometres of the Lingayen Gulf. These islets are mainly composed of coralline limestone deposited about two million years ago in a shallow marine environment. Through a combination of various geological processes such as uplift, erosion and karstification, the area evolved to its present landscape. Karstification is the process of landform development in limestone or other soluble rock areas where acidic surface water percolates underground, reacting with underground solutions and dissolving the limestone along cracks and fissures.

Figure 6. Some of the islets of the Hundred Islands. (*Photograph courtesy of Ed Garcia*).

Thirty of these islets are bordered by white sandy beaches and surrounded by wide coral reef flats. Others crop out as mere limestone promontories. Crystal clear waters around these islands are favourite recreational sites visited by sea sport enthusiasts and other tourists, for swimming, picnicking, scuba diving, snorkeling and island hopping. Access to these islands is from the Lucap Wharf (Figure 7) from where one can go around the area using a motor banca or kayak. Most of these islets are uninhabited and only three of them, the Governor, Quezon and Children's Islands have been developed for tourism. Beside its beautiful scenery, the Hundred Islands area also has a highly diverse ecosystem that supports a variety of marine and terrestrial flora and fauna. Marine resources such as sea grasses, corals, shellfish and numerous fish species abound in the waters around these islands. The land area consists of forest and fruit trees that provide habitats for birds such as the tree sparrow, Philippine bulbul, brahminy kite, little egret and oriole. The surface and submarine caves around the area, especially Urduja and Cathedral Caves have attracted speleologists and other scientists. Because of the natural wonders of the region, many legends and myths have been told and written about the origin of the Hundred Islands.

For the benefit and enjoyment of the people of the Philippines, the Hundred Islands was established as a national park on January 18, 1940 under Proclamation No. 667 issued by the late President Manuel Quezon. With the enactment of the

Figure 7. A view from Lucap Wharf, Alaminos City showing some of the islets.

NIPAS Act of 1992, this national park was considered as an initial component of the protected areas system. The system was established to ensure the maintenance of ecology, preservation of biodiversity and sustainability of an area. In recognition of its special characteristics, scientific importance and high scenic value, the NCGS also declared the Hundred Islands of Pangasinan as the fifth National Geological Monument on September 14, 2001. All these proclamations provided a balance between the sometimes conflicting demands of providing access and opportunities for carrying out recreational and research programs in the park and assuring the preservation of the area.

Saint Paul Limestone Formation and Peurto Princesa Subterreanean River National Park

The Saint Paul Limestone Formation forms the Saint Paul mountain range (Figure 8), located about 81 kilometres northwest of Puerto Princesa City, Island of Palawan. This limestone formation is located in a tectonically stable zone which is believed to have become detached from mainland Asia about 25-30 million years ago and to have drifted to its current position by about 15 million years ago. Diverse landforms such as towering pinnacles, plains, rolling hinterlands, sinkholes, multi-level caves, cliff notches, surface and underground river systems, white beaches, sinking creeks and the impressive karstic mountain landscape are characteristics of the scenic beauty of the Saint Paul mountain range.

Figure 8. The Saint Paul Range. (*Photograph Courtesy of HoboTraveler.com*).

The highest point of the mountain range is about 1,028 metres above sea level. The main feature within the national park is a 12 kilometre long cave occupied by a subterranean river, reputed to be the longest in the world, and navigable for about 8.2 kilometres within the cave. The cave winds through a snaky tunnel that is enhanced at every turn by spectacular stalactite, pillar and stalagmite formations (Figure 9), and cathedral-like domed amphitheaters. The river originates at least 2 kilometres southwest of Mount Saint Paul, flows underground throughout the entire length of the cave and meets the sea at Saint Paul Bay (Figure 10). The underground river is accessible by pump boat ride from Barangay Sabang or Bahile, or a hike through a monkey trail. In the northern part is the marine component of the park consisting of the Saint Paul Bay and a rich mangrove forest. The Babuyan River flows along the eastern side of the park.

Figure 9. Mushroom stalactite inside the Subterranean Cave. (*Photograph courtesy of John Ryan Cordova*).

Figure 10. The entrance of the Puerto Princesa Subterranean River National Park.

The forests around the Saint Paul Range are exceptional for their biodiversity, containing flora and fauna of terrestrial karst, lowland forest and marine ecosystems. Hard wood and other typical karst plant species were found in their natural form. Several species of coastal and mangrove trees and also mossy forests, sea grass beds and coral reefs abound in the Saint Paul Bay and Sabang areas. Endemic and rare mammals were identified in the forests around Saint Paul Range including the Palawan tree shrew, Palawan porcupine, Palawan stink badger, binturong, anteater, oriental small-clawed otter, palm civet, oriental civet and crab-eating macaque. The park is also popular for bird watchers as many rare and threatened species are found in the area, including herons, stork-billed kingfisher, collared scoops owl, white bellied swiftlet, pygmy swiftlet, scrub-hen, Palawan pheasant peacock, Philippine cockatoo and sea eagle. Monitor lizards and marine turtles are also common in the park. Swiftlets and bats are usually found in abundance in the caves. Sightings of endangered species of dugong, a sea cow, have also been recorded. Saint Paul Bay area is also home for groups of indigenous natives called the Palaweños, Bataks and Tagbanuas.

The Puerto Princesa Subterranean River was established as a national park in March, 1971 under Presidential Proclamation No. 835 and is managed by the Philippine Department of Environment and Natural Resources. In 1992, the boundaries of the site were the subject of a Presidential Proclamation under Republic Act 7586 (NIPAS Act of 1992). Due to its spectacular natural landscape, and its educational and scientific significance, the Puerto Princesa Subterranean River Park (Saint Paul Limestone Formation) was listed as a UNESCO World Heritage Site in 1999. In December, 2003 it was declared by NCGS as the sixth National Geological Monument. Like other protected areas, the Puerto Princesa Subterranean River National Park is now under the jurisdiction of the PAMB headed by the City Government of Puerto Princesa, with the Palawan Council for Sustainable Development (PCSD) as a member of the Board. Tourism at the underground river was originally centered on the main cave, but after its declaration as a UNESCO World Heritage Site, other areas of interests, such as the mangrove forest, beach and river areas in the park are also now being promoted to visitors.

Puerto Princesa Subterranean River Park originally covered an area of 20,202 hectares, with the main park covering 5,753 hectares and the buffer zone 14,449 hectares. In 1993, the PAMB of Puerto Princesa extended the park’s area to 86,000 hectares before its declaration as a UNESCO World Heritage Site.

OTHER SIGNIFICANT GEOHERITAGE SITES

Apart from these established National Geological Monuments, the Philippines also enjoys a score of other geoheritage sites with high scientific, aesthetic as well as historical values. These geoheritage sites are commonly related with volcanoes, caves, limestone karst and waterfalls.

Volcanoes

Being located along the ***Pacific ring of fire***, the Philippines is a country of many volcanoes, 22 of which are still active and a number that are dormant. Among active volcanoes are Babuyan Claro, Banahaw, Biliran, Bud Dajo, Bulusan, Cagua, Camiguin de Babuyanes, Didicas, Iraya, Iriga, Kanlaon, Hibok-hibok, Makaturing, Matutum, Mayon, Musuan, Parker, Pinatubo, Ragang, Smith, Bulusan and Taal. Mount Apo, which is dormant, is the highest of all the volcanoes and possesses the most diverse flora and fauna in the country. The following volcanoes are described based on information provided by the Philippine Institute of Volcanology and Seismology (PHILVOCS) and the Smithsonian Institution Global Volcanism Program.

Mayon Volcano

Mount Mayon, the most active volcano in the Philippines, is located about 553 kilometres southeast of Manila in the Province of Albay. It is a classic example of a stratovolcano formed by an alternation of pyroclastic deposits and lava flows. The peak is famous for its symmetrical profile (Figure 11), having an almost perfect cone rising to a height of 2,462 metres above sea level from a base that has a radius of about 62.8 kilometres. The upper slopes are rather steep, averaging about 35°-40°. The volcano is located within six municipalities (Daraga, Bacacay, Camalig, Guinobatan, Santo Domingo and Malilipot) and three cities (Ligao, Legaspi, Tabaco) having a total area of 5,775.70 hectares.

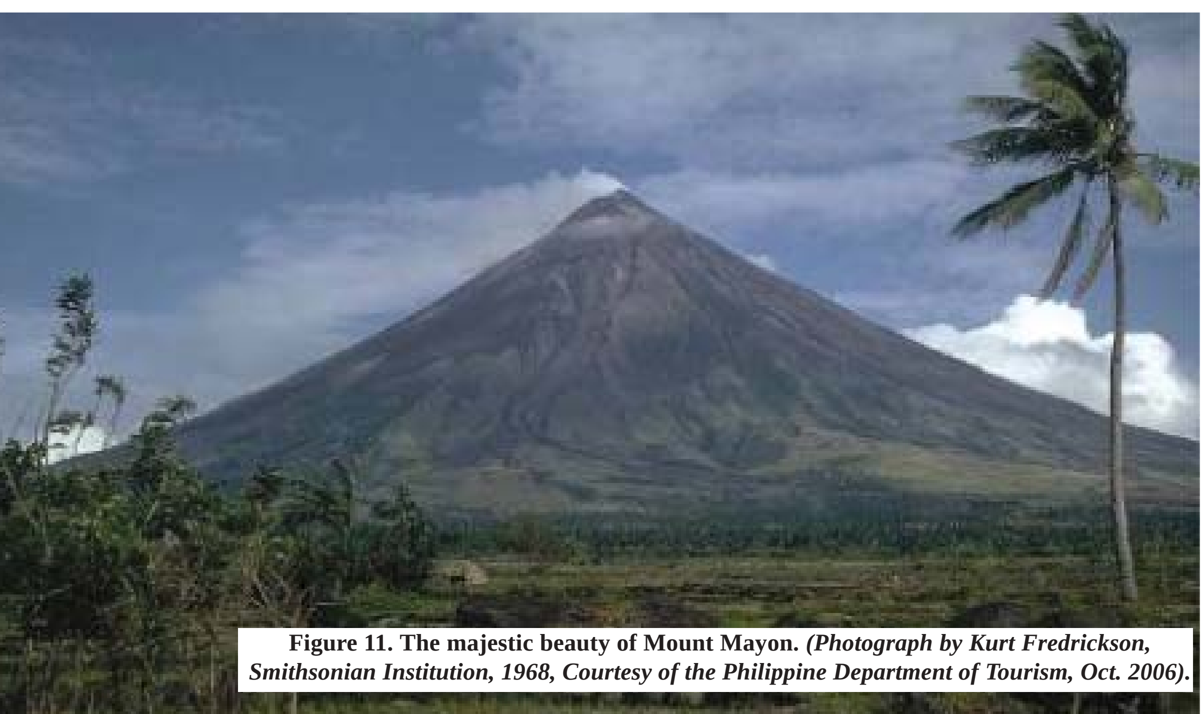

Figure 11. The majestic beauty of Mount Mayon. ***(Photograph by Kurt Fredrickson, Smithsonian Institution, 1968, Courtesy of the Philippine Department of Tourism, Oct. 2006).***

Records show that the volcano has erupted at least 48 times during the past 323 years. Historical eruptions of the volcano dated back to 1616 and, in volcanological terms, they range in eruptive style from strombolian and vulcanian to plinian, with cyclical activity commencing with basaltic eruptions, followed by more prolonged andesitic lava flows. Eruptions occur predominately from the central conduit from where lava flows far down the flanks of the volcano. Pyroclastic flows and mudflows have swept down 40 ravines that radiate from the summit and often devastated the populated lowland areas. Mount Mayon's most violent eruption in 1814 killed more than 1,200 people and destroyed properties in several towns. The eruption almost completely buried the Cagsawa Church in mud, boulders and ash. Only the belfry of the church remains above the ground today. The latest major eruptions of Mount Mayon were in 2001 and 2006 (Figure 12).

Figure 12. The 2006 eruption of Mayon Volcano. (*Photograph courtesy of US Geological Survey*).

Because of its grandeur, Mount Mayon had inspired many legends and myths regarding its origin. It is famous among local and foreign mountaineers and campers. Mayon Volcano Ecological Campsite located at its foot in Barangay Lidong, Santo Domingo, features the interesting Philippine Civil Service Centennial Forest, established in 1996, the rattan plantation and the dry creek sites where campers can visit. It is also a good place to observe endemic species of birds. Though often exposed to violent volcanic activity, Mount Mayon provides habitats for many rare and endangered plants, among them are the dipterocarp species *Hopea philippinensis*, pitcher plant *Nepenthes rajahi* and the tree fern *Cyatheaceae* spp. Fifty seven species of birds including *Otus megalotis* (Philippine scoops owl), *Gallus gallus* (Red jungle fowl), *Ptilinopus merrily* (Merrill's fruit dove), *Loriculus philippinensis* (Philippine hanging parakeet) and *Bubo philippinensis* (Philippine horned owl). More than 34 herpetofaunal and 13 mammalian species have been recorded around the volcano. In consideration of the beauty and scientific value of Mount Mayon, the area was established as a National Park on July 20, 1938 under Presidential Proclamation No. 292 of President Manuel Quezon. On November 21, 2001, Presidential Proclamation No. 413 was signed by then President Joseph Ejercito Estrada declaring Mount Mayon Volcano as a Natural Park.

Pinatubo Volcano

Mount Pinatubo (Figure 13) is another active stratovolcano located in the island of Luzon at the common border of the provinces of Zambales, Tarlac and Pampanga. It is one of the composite volcanoes in the chain of the Luzon volcanic arc that runs parallel to the western Luzon coastline. The ancestral Pinatubo Volcano, composed of andesite and dacite volcanic rock types, may have reached a height of 2,300 metres above sea level, as estimated from the present remnants of the volcano. However, following the 1991 eruption, a new summit was established at 1,745 metres above sea level, considerably lower than the old summit. Until the 1991 eruption, Pinatubo Volcano was virtually unknown to most people, mainly due to the absence of any notable volcanic activity, and also its location in the center of a mountainous area, encircled by other mountain peaks. Though it is the highest mountain in west-central Luzon, it is neverthless largely obscured from view as it is only about 200 metres higher than other nearby mountains and is covered by dense forest. Several thousand indigenous people called the Aeta, the aboriginal people of the Philippines, inhabit the area.

Figure 13. Mount Pinatubo before the major eruption of 1991.
(*Photograph courtesy of US Geological Survey*).

After more than 490 years of lying dormant, Mount Pinatubo suddenly awakened the world in 1991, in what was the second most violent eruption ever recorded in the 20th Century. The eruption, with worldwide repercussions, ejected roughly 25 cubic kilometres of pyroclastic materials which led to the formation of a 2.5 kilometres wide caldera (Figure 14). The ash cloud from the volcano covered an area of about 125,000 square kilometres, brought total darkness to almost the whole of central Luzon and ash falls to the whole of the Philippines and to several other Southeast Asian countries such as Vietnam, Cambodia and Malaysia. Tephra fell over most of the South China Sea. Deposits of pyroclastic materials, up to 1,000 metres thick, accumulated on the volcano's slopes. During the climactic eruption, material was hurled upwards into the air above the volcano to heights of 19-24 kilometres (Figure 15). Several mountains found near Pinatubo today are believed to be the volcanic plugs and lava domes of old satellite vents of a previously existing, even larger volcano.

Some seventeen years after the eruption, the area has gradually become a well-known destination for tourists in Central Luzon. Some popular tours include a jeep ride that starts from Capas, Tarlac, to the end of the barren plains, followed by a 2-3 hours trek that leads to the crater lake. Near the lake are a viewing deck and some cottages. Kayaking and swimming are allowed here only in certain restricted areas.

Figure 14. The 2.5 kilometres diameter caldera lake formed by the 1991 eruption. (*Photograph courtesy of US Geological Survey*).

Figure 15. Mount Pinatubo during its climactic eruption in 1991. (*Photograph courtesy of US Geological Survey*).

Bulusan Volcano

Bulusan volcano (Figure 16) is another active stratovolcano situated within a caldera. Its location is about 250 kilometres southeast of Manila and 70 kilometres southeast of Mount Mayon in the extreme southeastern part of Bicol Peninsula in Sorsogon Province. It rises to about 1,559 metres above sea level and its base covers an area of approximately 400 square kilometres. The summit crater is 300 metres in diameter with numerous lava flows on the flanks. It is dominantly composed of andesite with lesser amounts of dacite. Bulusan volcano has erupted at least 13 times since 1886 and the most recent eruption was in the later part of 2007. Various eruptive styles have been recognised including phreatic (1918-1922, 1980), strombolian (1918-1919) and caldera-forming eruptions (40,000 years before present).

Lake Bulusan is a crater lake situated at an elevation of 635 metres on the southeast flank of Bulusan volcano and surrounded by lush forest. The mountain has two peaks, the eastern rugged mound that is probably the remnant of a vast, pre-existing circular crater, and the active bell-shaped western summit of the volcano.

Figure 16. Bulusan Volcano. ***(Photograph Coutesy of Roland Empleo)*****.**

Mount Hibok-Hibok and Other Camiguin Volcanoes

Hibok-Hibok, formerly called Catarman, is one of the seven volcanoes of Camiguin Island. It is an active stratovolcano, rising to a height of 1,332 metres above sea-level, and with a basal diameter of about 1,000 metres. The volcanic rocks consist of a variety of andesite (hornblende andesite) and dacite. It has six hot springs (Ardent, Tangob, Bugong, Tagdo, Naasag and Kiyab Springs) and three crater lakes (Kanangkaan Crater, site of the 1948 eruption; Ilihan Crater, site of the 1950 eruption and Itum Crater, site of the 1949 eruption). It also has a volcanic maar, the Taguines Lagoon, between Binone and Maac. Adjacent volcanic edifices are Mount Vulcan at 671 metres above sea level to the northwest of Hibok-Hibok, Mount Mambajao in the center of Camiguin, Mount Ginsiliban at 581 metres above sea level in the southernmost part of Camiguin and Mount Uhay to the north of Mount Ginsiliban. There are also volcanic domes and cones at Campana Hill, Minokol Hill, Tres Marias Hill, Mount Carling, Mount Tibane, and Piyakong Hill. The volcanoes of Camiguin Island are considered as part of the Central Mindanao Arc.

Mount Hibok-Hibok has experienced five historical eruptions since the Spanish era. The first of the five was in 1862 and the last was from September 1952 to July 1953. Eruptions are classified into pelean (1948-1952), dome building with *nuee ardente* (1871, 1949-1953) and solfataric (1897-1902). The explosive eruption of Hibok-Hibok in 1951 killed nearly 2,000 Camigueños.

Mount Hibok-Hibok is a popular hiking destination. From the foot of the mountain it normally takes 3-5 hours to reach the summit. The usual starting point is at Ardent Hot Springs in Mambajao. Since the island is endowed with beautiful volcanic landscapes, beaches, hot springs and lush forest, it is a well known ecotourism site in northern Mindanao.

Kanlaon Volcano

Mount Kanlaon (Figure 17), also spelled Canlaon, in Negros Island is another stratovolcano in the Philippines. It is located 36 kilometres southeast of Bacolod City in the provinces of Negros Occidental and Negros Oriental in central Visayan region. It has an elevation of 2,435 metres and a base diameter of 30 kilometres. It is dotted with pyroclastic cones and craters. The summit of Kanlaon is made up of a broad elongated northern caldera with a crater lake. It has three hot springs on its slopes, the Mambucal, Bucalan and Bungol Springs. Its adjacent volcanic edifices are Mount Silay and Mount Mandalagan. Mount Kanlaon is part of the forest reserve of the Mount Kanlaon National Park that has tracts of rainforest and a variety of wildlife. Various species of ferns, lichens and orchids are found. It is a home for endemic and endangered birds like Negros fruit doves, barblers, warblers and other species of doves, bulbuls, flycatchers and woodpeckers.

Mount Kanlaon, the most active volcano in central Philippines has recorded 25 phreatic eruptions since 1886. In 1996, it erupted without warning, killing six mountain climbers and injuring several others.

Mount Apo

Mount Apo (Figure 18), the highest peak in the Philippines, is located within the boundaries of Davao City, Davao del Sur and North Cotabato. It is a large stratovolcano that reaches a height of 2,954 metres, capped by a 500 metres wide volcanic crater containing a small crater lake. Though it is currently a source of geothermal energy, it has no recorded history of eruption in modern times. It has the highest diversity of land-based flora and fauna in Mindanao and provides a habitat for more than 270 bird species, about half being endemic. The most famous, but considered an endangered species, is the Philippine monkey-eating eagle, *Pithecophaga jefferyi*.

Figure 17. Kanlaon Volcano in Negros Island. (*Photograph courtesy of Dana Barcelona*).

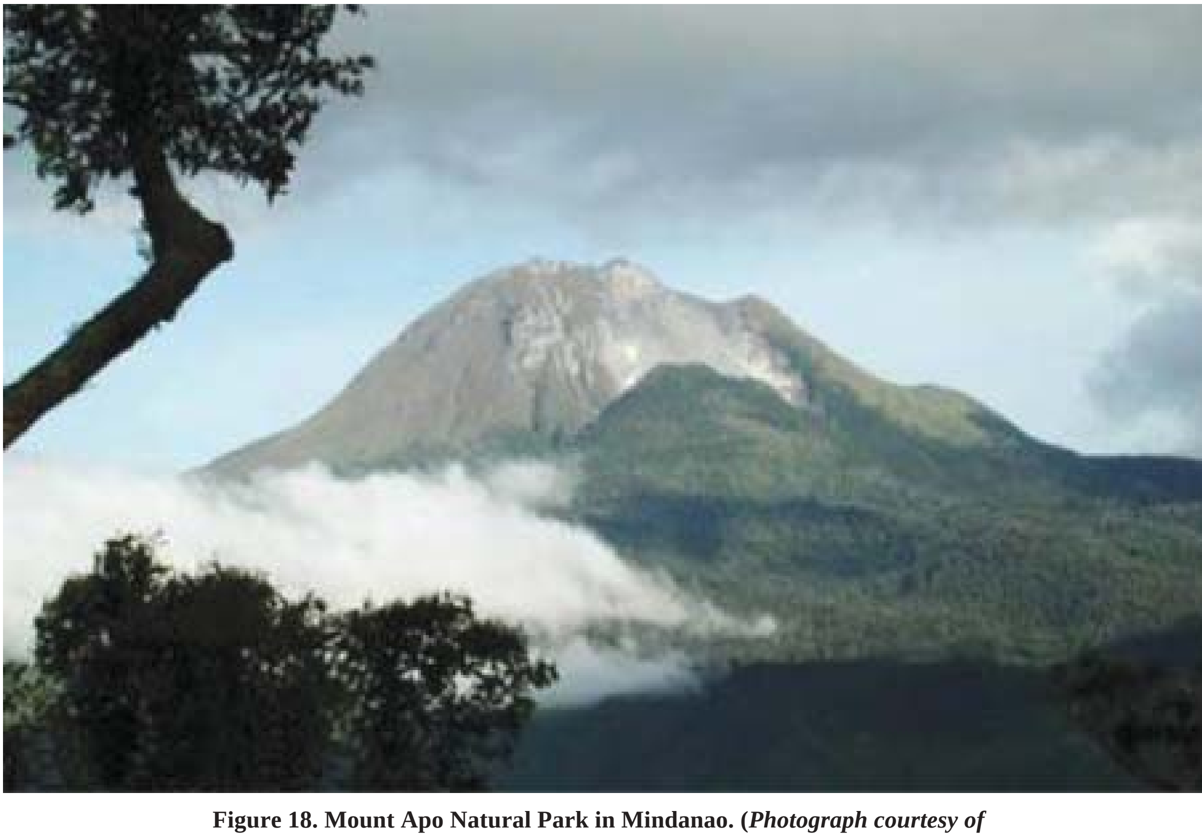

Figure 18. Mount Apo Natural Park in Mindanao. (*Photograph courtesy of Chin William L. 2004*).

Of the 629 species of vascular and non-vascular plants found in Mount Apo Natural Park, 572 species belong to the fern and angiosperm families, and 57 species belong to 24 families of bryophytes or mosses. Ficus, a common food of many birds and mammals, has the most number of species. Orchids are also common, but the world famous *Vanda sanderiana* or waling-waling and the rattan species *Plectocomia elmiri* that used to abound in the primary forests of Mount Apo are no longer found in their natural habitats because of over collection. Sixty nine families of amphibians, reptiles, birds and mammals, 118 species of butterflies belonging to 69 families have been recorded in Mount Apo. Wild mammalian species identified in this mountain include shrews and gymnures, bats, rats, squirrels, ungulates, civet cats and deers. Common and endemic frogs also inhabit some niches in the park. Because of its unique beauty and highly diverse flora and fauna, the mountain was declared as a national park by President Manuel Quezon on May 9, 1936. It is now one of the most popular climbing destinations in the Philippines.

Caves and Karst

Significant tropical karst landscapes are found in different parts of the Philippines. They vary considerably in terms of landforms and ages of the limestone host rocks. The limestone ranges in age from Permian (about 290 million years old) to the most recent uplifted reefs. Some of the most striking of these karst areas are described in the following sections.

Tabon Cave

Tabon Cave (Figure 19) is famous for the excavated remains of the earliest man in the Philippines, dated around 22,000 to 23,000 years old (Detroit et al. 2004). Stone tools and artifacts found in the caves dated back to 30,000 B.C. These were found in a series of cave chambers (Tabon, Guri, Manunggul, Igang and Diwata Caves) located about 155 kilometres south of Puerto Princesa at Lipuun Point, Quezon, Palawan. Of the 200 caves in the area, only 29 have been explored and confirmed to have been shelter and burial sites of ancient Filipinos. Out of the 29 caves, only three caves are open to visitors.

The Tabon Cave complex is within the Alfonso XIII Limestone formation which is about two million years old. Because of its importance to Philippine history and heritage, the site was declared as a Museum Reservation Site by virtue of Presidential Proclamation No. 996 in 1972. The site is currently being maintained and managed by the National Museum.

Figure 19. Tabon Cave, the site of an important Philippine Archaeological discovery. (*Photograph courtesy of Palawan Council for Sustainable Development*).

Callao Cave

Callao Cave is one of the best known tourist attractions in the province of Cagayan located in Barangay Parabba and Quibal, Peñablanca, near Tuguegarao, the capital town of the province. It has seven chambers developed in the limestone formation of Middle Miocene age (15 million years old). The cave is 9 kilometres long and contains an actively flowing stream. The first chamber is a natural domed cathedral (Figure 20) that serves as a chapel for tourists. It contains beautiful stalagmites, flowstones and stalactites. Every chamber has natural crevices, which permit light into the cave. Adjacent to Callao Cave are many other caves that contain interesting geological and archaeological features.

Sohoton National Park

Sohoton National Park is located in Barangay Rawis, Guirang, Basey and Samar. The area was designated as a national park on July 19, 1935 through Proclamation No. 831 in order to protect the unique rock formations, caves and rainforest along the Sohoton River in southwestern Samar. Interesting geological features include caves, sinkholes, weathered rock formation and underground rivers adorned with beautiful natural forms such as stalactites, stalagmites and flowstones. The park is located inland and can be reached by a 2½ hours boat ride from Basey Proper. Amongst the most prominent sites in the park are the Sohoton, Panhulugan I, Panhulugan II, Bugasan and Capigtan Caves.

Figure 20. The cathedral chamber of the Callao Cave. (*Photograph courtesy of WOW Philippines, Department of Tourism Reg. 2*).

The Sohoton Cave is a cathedral-like dome with a 50 metres high parabolic arch at the entrance. Spike-shaped crystalline stalactites, a pool, window and balcony are some of the features of the cave. Panhulugan Cave I is the largest and most spectacular endogenic cave that displays a cathedral dome, about 15 metres high with multi-level chambers and a variety of speleothem and other cave structures. Directly across this cave is the Panhulugan Cliff, a towering and steep rock formation that was an ambush area of the Filipino rebels during the Spanish-American war. The Panhulugan cave II is a scar-like rock that cuts into the face of Panhulugan Cliff. It served as burial sites during the 13th century. Another interesting feature of the park is the Sohoton Natural Bridge (Figure 21), a huge arch-shaped rock that connects two mountain ridges spanning the Sohoton River which flows towards a waterfall. The natural stone bridge which is 40 metres in length has a vertical clearance of about 8 metres. It is forested at the sides and above the bridge, while on its underside hangs giant stalactites resembling swords and rockets. The Bugasan and Kapigtan Caves are smaller but are important archaeological sites where ancient remains dating back to the Stone and Iron Age periods were found. These caves had earlier served as burial sites for the natives and were once the center of ancient cult practices. All these caves were used as hideouts by the Filipino rebels during the Spanish-American War.

Adding to its enchanting beauty and geological wonders, the park is endowed with a rich stock of forest vegetation which serves as home to varied forms of endemic, rare and endangered Philippine fauna. Mammals and reptiles abound in the park. Freshwater fish, crabs and shrimps can also be found.

Figure 21. The Sohoton Natural Bridge. (*Photograph courtesy of Samar Provincial Tourism*).

Coron Protected Areas

Coron Island (Figure 22) is located in the municipality of Coron in northern Palawan. The island is composed of a gray limestone formation of Jurassic-Triassic age (150-250 million years old). The area is famous for its towering pinnacles of rock, craggy cliffs, white beaches and its seven lakes. The most popular among the lakes is the Kayangan Lake (Figure 23), claimed to be the cleanest in the Philippines. Coron Island is generally the best known of the Calamian Group of Islands in the North Palawan Block, a cluster of islands formed from a continental sliver believed to have been detached from mainland Asia about 40 million years ago. This block drifted southeastward to arrive at its present position some 15 million years ago. It is a home for a group of indigenous Tagbanua tribes.

As well as being an endemic bird habitat, it is also home to distinct assemblages of mammals, reptiles and amphibians. The cliffs of the island provide shelter for small Philippine swifts that are the source of edible bird's nests (Nido), the main ingredient of a famous Chinese soup. The sea around the island is popular among divers exploring for World War II Japanese shipwrecks. The lakes and waters of Coron are also excellent sites for swimming, snorkeling and scientific research.

Coron Island was declared as the first National Reserve on July 2, 1967 and further designated as a Tourist Zone and Marine Reserve in 1978 and a prioritized protected area under the 1992 NIPAS Act, managed and protected under the PAMB.

Figure 22. Coron Island (*Photograph courtesy of Hans Neukomm*).

Figure 23. Kayangan Lake in Coron Island (*Photograph courtesy of China Pajarillo*).

El Nido Landscape and Seascape

El Nido municipality is located at the northern tip of Palawan Island, about 430 kilometres southwest of Manila, and 238 kilometres north of Puerto Princesa. It is one of the Philippine's premier tourist destinations and occupies an area of 96,000 hectares. It got its name from the edible nests of swiftlets *Collocalia fuciphaga*, locally called nido, found in the crevices of the limestone cliffs. The most striking feature of El Nido is its scenery. It is considered as a showcase of Palawan's geology and wildlife, boasting a diverse ecosystem of rainforests, mangrove swamps, white sand beaches, coral reefs and limestone cliffs. Several geosites, mostly limestone peaks with unique shapes and of various sizes are located here. The geological ages of the island's rocks are Permian to Cretaceous (280-100 million years old). The geological development of the El Nido area, as part of the North Palawan Block is similar to that of Coron Island. The geological formations of El Nido can be seen in the town and in 45 other islands and islets, such as those of Cadlao (Figure 24), Lagen, Minilog, Dilumacad, Tapuitan and Pinagbuyutan (Figure 25) dotting the Bacuit Bay. Among the islands, Cadlao is the highest, rising to 609 metres above sea level.

Figure 24. Lagen Islands is one of the most outstanding El Nido landscapes. (*Photograph courtesy of Ms. Vina Mataganas of El Nido Resorts*).

Figure 25. Pinagbuyutan Islands is one of the most outstanding El Nido landscapes. (*Photograph courtesy of Ms. Apple Lina of El Nido Resorts*).

Minilog Island is the site of the first established resort in the area, opened in 1983 as a great place for snorkeling, scuba diving and kayaking. The sea is home to dugongs, turtles, rays, numerous species of fishes and of coral reefs. On land, its lush forests are host to more than 100 species of birds, a large number of which are endemic to Palawan. Lagen Island has the most luxurious and exclusive resort in the area. It is famous for its coves, lush forest and sheer limestone cliffs. The Leta Leta Cave, discovered by Dr. Robert Fox in 1965, was an important burial site during the Neolithic Age, from where stones, pottery and shell artifacts were recovered. Matinloc Island, the longest island, has a secret beach surrounded by steep rock walls. Pangalusian Island has the widest stretches of powdery white beaches, ideal sites for sunbathing, sunset viewing and other beach activities. Cudogmon Point is an important anthropological site where jewellery and pottery dating back to the Sung Dynasty (960-1279 BC) were excavated.

Waterfalls

Maria Cristina Falls

The Maria Cristina Falls (Figure 26) is a majestic waterfall near Iligan City on the island of Mindanao. It is located about 8.5 kilometres southwest of the city. Well-known for its natural beauty and grandeur, the 100 metres high waterfall is also a primary source of power for the city's industries and the whole Mindanao region.

Figure 26. The Maria Cristina Falls, near Iligan City of Mindanao Island.

Pagsanjan Falls

The Pagsanjan Falls (Figure 27) or Magdapio Falls are located in the rugged highlands of Barangay Anglas, about 102 kilometres southeast of Manila. It is one of the most visited tourist destinations in Laguna Province. The main waterfall is on the Cavinti River where water pours over the falls in a drop of about 90 metres. A trip to this spectacular waterfall, approaching along the main river gorge, starts in Pagsanjan Town from where tourists are ferried in banca, a wooden canoe. On the upstream journey, there are fine views of verdant forest adorned with wild orchids, ferns and vines, inhabited by monkeys and multi-colored

Figure 27. The bamboo raft-ride at Pagsanjan Falls. (*Photograph courtesy of Mary Ann Raya*).

birds. The first stop is at Talahib Falls followed by several smaller falls which number more than nineteen during the rainy season. At the main falls, a bamboo raft takes tourists through the waterfalls to reach the Devil's Cave. On the way back is the enthralling adventure of rapid shooting, where the skillfull boatman steer the boat through fourteen roaring rapids on curves and bends of the river. Management of the resort is under the PAMB, Department of Enviroment and Natural Resources.

ISSUES OF GEOHERITAGE IN THE PHILIPPINES

Despite the declarations made by the National Committee on Geological Sciences (NCGS) and the Department of Environment and Natural Resources (DENR), many of the Philippine geoheritage sites have been plundered or neglected, not maintained or ineffectively utilized in promoting geotourism. The following are some of the issues faced in the Philippines.

1. In the case of the Chocolate Hills of Bohol, three of the hills were quarried for construction stone. Furthermore, as a response to the threat of climate change, the Government, under its reforestation program, planted trees that masked the natural beauty of some of the haycock hills.
2. Before the declaration of the Republic Act No. 9072, which is also known as the "National Caves and Cave Resources Management and Protection Act", some of the caves were plundered and vandalized. Important stalactites and stalagmites in the caves have been extracted for commercial purpose. Others were utilized for cult activities.
3. Some of the conflicting land-use demands faced in geoheritage areas include logging, mining, forest produce collection, cultural and agricultural activities of local residents.
4. Some of the important fossil-bearing rock formations may also be opened to exploitation for coal or as a raw material for cement manufacture.
5. The Puerto Princesa Subterranean River Park has a well organized conservation management programme with due regard for the indigenous inhabitants of the area. Such concerns as protection of the watershed and water supplies, protection of ecosystems and biodiversity, the livelihood of the local communities and support for ecotourism are all addressed in the management program. However, still of concern is the lack of well-paved roads leading to the park together with other supporting infrastructure and amenities, all of which hinder the growth of tourism in the area.

These problems could be due partly to the lack of geological knowledge and understanding of its importance to conservation by both the public and the management organizations and administrators. Greater dissemination of geological information in a form easily understood by all is a pre-requisite to improve the situation.

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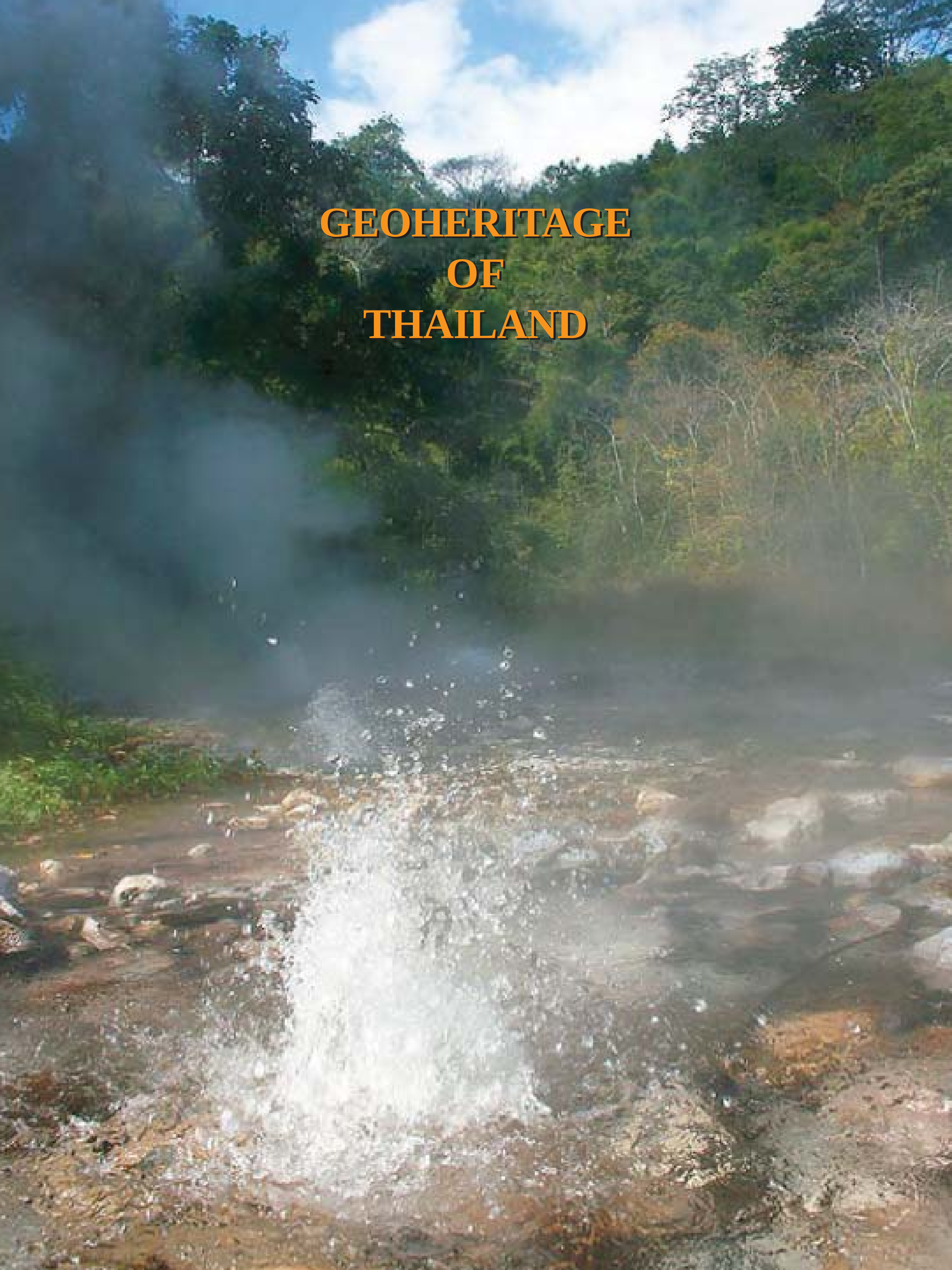
GEOHERITAGE
OF
THAILAND

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Separator Photo:
Geyser of Pong Duead Pa Pae Hot Spring, Chiang Mai Province, Thailand.

8

GEOHERITAGE OF THAILAND

Pracha Kuttikul

GEOHERITAGE DEVELOPMENT

The conservation of Thailand's geoheritage and the raising of its public awareness was initiated by a natural heritage program more than twenty years ago. The success of geoheritage conservation and management depends largely on readily available geological information and knowledge coupled with the interest, support and cooperation of everybody concerned. Therefore, public education is the most important tool to achieve success. Legislation may also be required as an additional tool in order to fulfill the mission.

Natural Heritage

Geoheritage protection in Thailand was first developed as a part of a Natural Site Selection Project initiated in 1983 by the Office of Natural Resources and Environmental Policy and Planning (ONEP). More than two thousand important natural sites were identified and inventorised based on five criteria as follow:

- Uniqueness
- Natural structure and aesthetic value
- Historical significance including local folklore
- Holy place, and
- Scientific, geographic and archaeological value

Six years later, the Thai Government declared 1989 as the Year of Natural and Environmental Protection. Within that year, 263 sites were selected from a total of 2,362 candidates and these were endorsed by the Thai Cabinet as **Natural Conservation Sites**. They have been classified in 6 categories as follow:

- Island and islet
- Mountain, cave, waterfall and hot spring
- Lake and swamp
- Seashore
- Fossil site, and
- Geomorphological site

During 1999-2001, the Department of Environmental Quality Promotion (DEQP) in collaboration with ONEP published four Natural Conservation Site Books (Figure 1) in Thai which introduced the endorsed sites in each of the four regions; the northern, northeastern, central and southern Thailand. These books contain many illustrations and maps and describe the locality, status and problems encountered for each of the sites.

Geoheritage Publication

Most of the natural conservation sites endorsed by the cabinet are predominantly of geological value. They are therefore, illustrative of the geoheritage of the country. During geological surveying, the Department of Mineral Resources (DMR) routinely collect information on Thailand's geoheritage. Selected geoheritage sites are described and the information is published and widely disseminated.

Figure 1. Books on natural conservation sites.

Thai Geological Heritage Book

This is a semi-technical book published in 2001 by the Department of Mineral Resources in Thai. The book (Figure 2) introduced 32 geological heritage sites located in four regions of Thailand. The book gives more technical information than a normal tourist guide book. It contains many illustrations, location maps, geological maps and drawings of geological models which are easy for general readers to understand.

Figure 2. The Thai Geological Heritage book.

Geotourist Site Illustration Book

This book was published in 2004, describing 59 geotourist sites in the four regions. This book contains more illustrations with simple explanations for non-geologist readers. Moreover, a glossary of geological terminology is also appended.

Figure 3. Geotourist Site Illustration Book.

Geological Heritage Education

In addition to publications, websites and museums are important and effective media for geological information dissemination. Moreover, DMR also carries out special activities such as exhibitions and a dinosaur (dino)-camp (Figure 4) and fossil-camp (Figure 5) for students to learn to respect and to live with Thailand's non-renewable resources.

Figure 4. School children enjoying activities in a Dino-Camp.

Website

The website of DMR (Figure 6) includes knowledge and service pages, frequently asked questions and a web board. The knowledge page contains information on geology, geological resources, geoheritage, fossils, minerals, geohazards and geoenvironment. The service page includes information on the library, museum, geo-resources identification services, publications and maps in hard and digital copies, videos and compact discs.

Figure 5. School children enjoying fossil preparation in a Fossil-Camp.

Figure 6. DMR website contains geological information, news, activities and a web board.

Geological Museum

A museum can be one of the most effective mediums for knowledge dissemination (Figure 7). The advantage of a museum over other media is that it presents tangible objects that give lasting impressions and memories to the visitors. There are three geological museums managed by DMR in Thailand, located in Bangkok, Kalasin and Khon Kaen Provinces.

Figure 7. School children enjoying hands-on experience in Geological Museum at DMR Head Office, Bangkok.

DMR Geological Museum

The museum at DMR head office in Bangkok (Figure 8) presents nine topics including history of the museum, historical geology, mineralogy, rocks, groundwater, natural fuels, evolution of life, geology of Thailand and applied geology.

Figure 8. Geological Museum in Bangkok.

Sirindhorne Museum

The presentation at the Sirindhorne Museum (Figure 9, 10, 11) in Sahas Sakhan, Kalasin Province is arranged by time into eight zones as follows:

- The universe and the earth
- The first life
- Paleozoic: The era of life evolution
- Mesozoic: The era of reptiles and dinosaurs
- Dinosaur livelihoods
- Awakened dinosaur
- Cenozoic: The era of mammals
- The Story of human life

Figure 9. Dinosauria at the main entrance of the Sirindhorne Museum – the largest dinosaur museum in Southeast Asia.

Figure 10. The theropod *Tyrannosarus rex* welcomes visitors at the entrance of the exhibition hall.

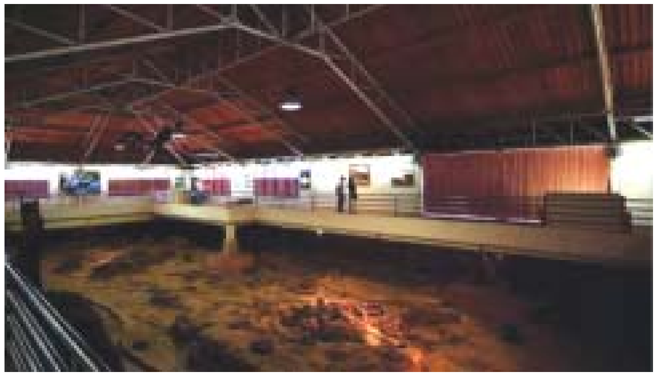


Figure 11. The most complete *Phuwiangosaurus sirindhornae*, named in honour of Her Royal Highness Princess Maha Chakri Sirindhorn

Phuwiang Museum

Presentations at the Phuwiang Museum (Figure 12) in Phuwiang, Khon Kaen Province are arranged according to the following themes:

- The Origin of the Earth
- Rocks and Minerals
- Evolution of Life
- The Nine Dinosaur (Figure 13, 14) Excavation Sites
- Khon Kaen's Historical, Geological and Natural Heritage

Figure 12. Special exhibition in front of Phuwiang Dinosaur Museum.

Figure 13. The first piece of sauropod bone found in Thailand in 1976, displayed in Phuwiang Museum.

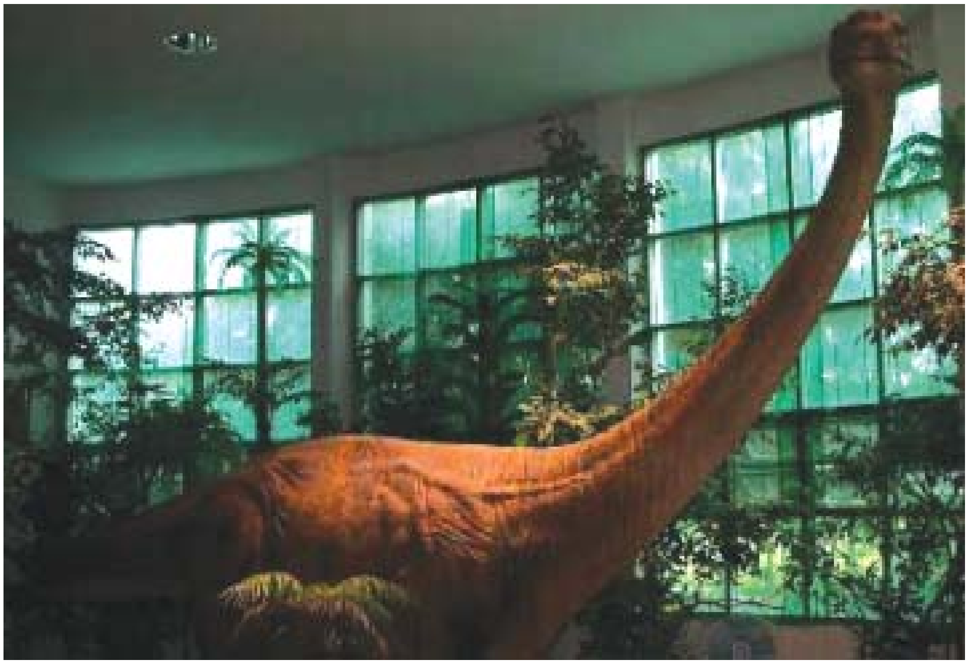


Figure 14. The model of *Phuwiangosaurus sirindhornae.*

GEOHERITAGE MANAGEMENT

As part of a study for the Geological Resources Management Master Plan conducted in 2005 by DMR, more than eight hundred geological sites were identified and listed in 7 categories as shown in Table 1.

Table 1: Categories of geological site

Category	number
1. Geological type section	32
2. Rock type	4
3. Mineral deposit	5
4. Structural geology	4
5. Geological morphology	475
6. Hot spring	111
7. Fossil site	208

In 2006, DMR started work on a provincial geological resources zoning program. Under the program, significant geological sites in every province are identified and systematically recorded. DMR also provides this geological information to the local government and encourages them to manage their geological sites with a people-oriented approach. This program will be completed in 2011 by which time the geological site inventory will be comprehensive and up-to-date.

Legislation

DMR has been instrumental in introducing and helping to develop criteria for legislation as an additional instrument for the protection and conservation of important geological sites. Among the currently available laws, bills and acts with regards of geoheritage are:

Geological Resources Management Bill

A Geological Resources Management Bill was prepared in 2007 and is in the process of being enacted. There are twelve chapters covering topics such as an organizational committee, funding, management, management area, reporting, inspection, government officer, surcharge, participation, liability, penalties and transitory provisions. The bill must be approved by the Thai cabinet before submission for parliamentary consideration.

Fossil Act B.E. 2551

In early 2008, the Fossil Protection Act (B.E.2551) was promulgated. Its various clauses cover topics such as the organizational committees, fossil sites, fossils, museums, fossil funds, cancellation of licenses, government officers, penalties and transitory provisions.

Criteria for Geological Conservation Site Selection

In 2007, the Criteria for Geological Conservation Site Selection were established by the DMR. The objectives are to protect areas of geological value, to classify and facilitate development of conservation sites, and promote tourism and recreation of these sites. Six characteristics which are the basis for geological conservation site selection have been defined as follows:-

1. **Geological values**
   - Geological Type Section
   - Rock Types
   - Mineral Deposits
   - Structural Geology
   - Geological Morphology
   - Hot Springs
   - Fossils
2. **Potential for conservation**
   - Conservable and in danger of damage by natural and/or human activity

3. **Technical values**
   - Geological diversity
   - Geological source of information and research
   - Geological reference
   - Geological correlation
4. **Uniqueness**
   - National single or rare
   - Representative
5. **Potential for future**
   - Potential for sustainable conservation
   - Potential for development
6. **Aesthetic and recreational values**
   - Attractive scenery
   - Bio diversity
   - Historical and/or cultural site
   - Tourism

Based on these characteristics, three criteria have been set for the selection of a geological conservation site, and these criteria are:

- The site must have at least one item from each of the first four characteristics defined above.
- The 4th to 6th characteristics classify a geological site as either a provincial or a national geological conservation site.
- The 6th characteristic specifies a geological conservation site as a recreational area and geotourism site.

These criteria will be used by a national committee appointed to select known geological sites all over the country to be designated as geological conservation sites. Some of the more important and prominent geological sites according to the categories defined above are described in the following sections.

GEOLOGICAL CONSERVATION SITES

Described in the following pages are examples of geological conservation sites in Thailand, classified under various geological values such as geological type sections, rock types, mineral deposits, structural geology, geological morphology, hot springs and fossils.

Geological Type Sections

Phu Tok Noi (Sri Wilai, Nong Khai Province)

Phu Tok Noi is the geological type section for the Khorat Group, a sequence of sedimentary rocks of late Cretaceous age. The section is 140 metres thick, comprising alternating beds of variously fine- to coarse-grained sandstone. Phu Tok Noi is surrounded by cliffs that display the differing resistance of the various sandstone beds to weathering (Figure 15). At the cliffs, many sedimentary features such as ripple marks, mud cracks and sun cracks can be observed in the fine-grained sandstone beds and provide clues as to the environmental conditions that prevailed at the time the sediments were deposited many tens of millions of years ago (Figure 16).

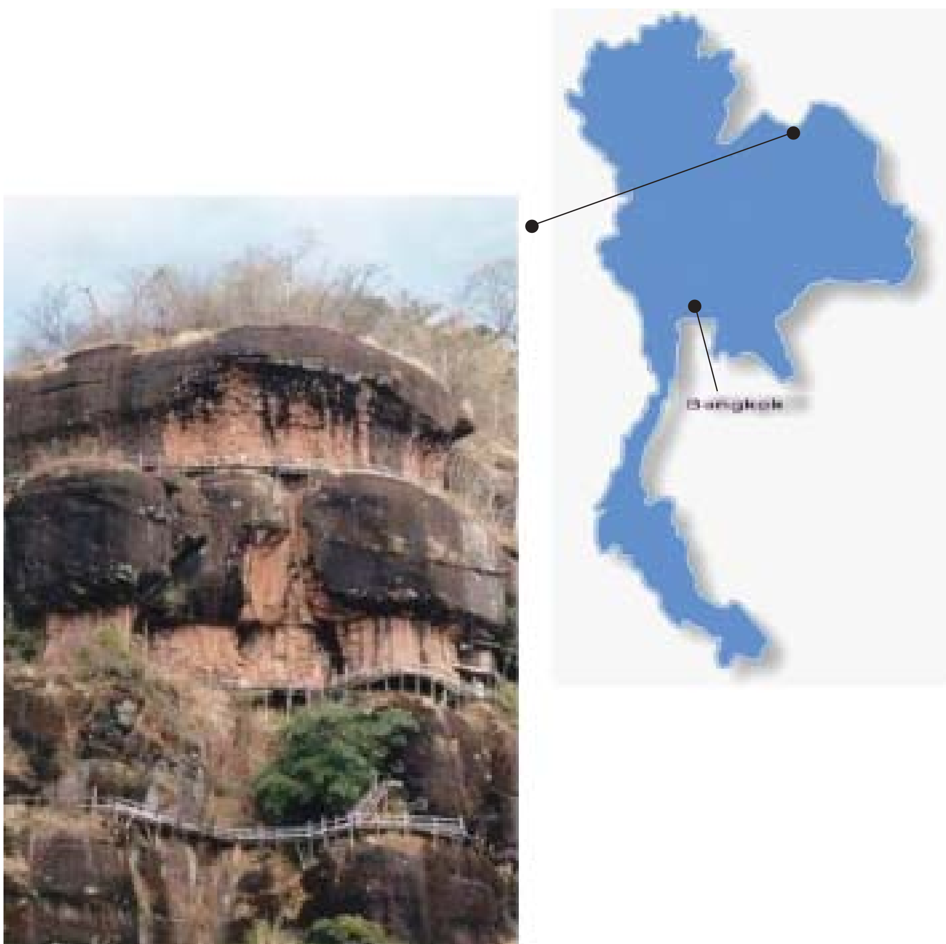


Figure 15. Location map and Phu Tok Noi outcrop exhibiting different lithologies with different degree of resistance against weathering.

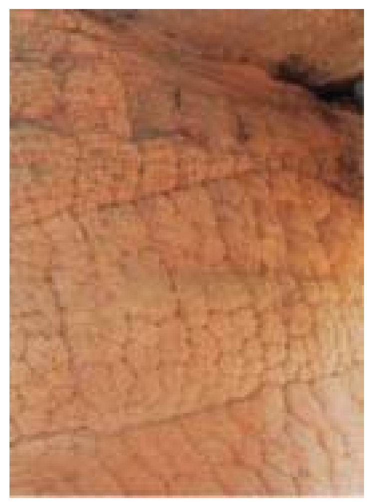
UNIT D
Thick beds of medium to fine grained sandstone with cross bedding, interbedded with siltstone with ripple marks and mud cracks.

UNIT C
Thick beds of coarse to fine grained reddish brown sandstone with large-scale cross bedding, interbedded with ripple marked siltstone.

UNIT B
Medium to thick beds of medium to fine grained yellowish orange sandstone with ripple marks and large-scale cross bedding, inter-bedded with ripple marked siltstone.

UNIT A
Thick beds of very fine grained purplish red sandstone and siltstone with ripple marks and some cross bedding.

Ripple marks in fine sandstone.



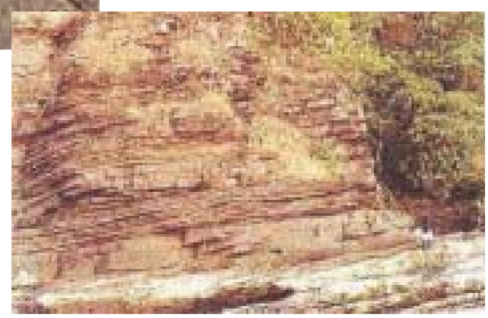
Sun crack in siltstone.

Figure 16. Lithological log of Phu Tok Noi section showing various lithologies and sedimentary structures (inset).

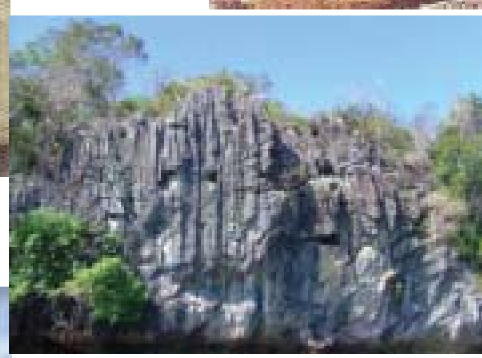
Tarutao Group, Tarutao Island, Satul Province

The Tarutao Group, first described and named in 1969, is a succession of Cambrian sedimentary rock units comprising sandstone and shale with a total thickness of more than 1 kilometre. The Tarutao geological type section, about 700 metres thick, is located in Talotopo Bay and was mapped by Bunopas in 1981. Cross-bedding is present in the upper part of the sequence and indicates that the sediments were deposited from water in which easterly currents predominated. Figure 17 shows the various aspects of the Tarutao Formation.

Interbedded sandstone – shale of Middle Unit at Talotopo Bay.

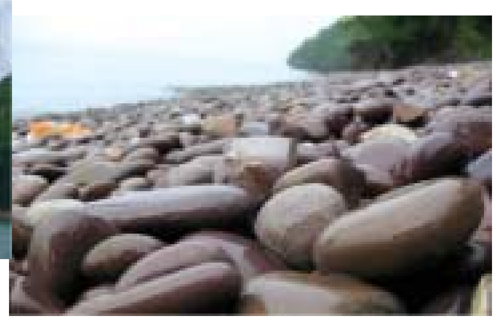


Cambrian trilobite fossil found in the Middle Unit of Tarutao Group.



Ordovician limestone overlain the Tarutao sandstone of Cambrian Age.

Easterly dipping beds on the ridge of Tarutao sandstone hill.



Gravel beach, southwest of Tarutao island. These beautiful gravels were derived from Tarutao sandstones.

Figure 17. The location, fossils, sedimentary structures and various other aspects of the Tarutao Formation.

Tarutao Group can be devided into three units as follows:

Upper Unit	Thin to medium beds of brown to grayish brown sandstone interbedded with siltstone and shale (300 metres)
Middle Unit	Thick beds of brown sandstone and medium beds of sandstone interbedded with thin beds of shale (180 metres) Thick to very thick beds of brown orthoquartzite with cross-bedding interbedded with thin beds of green shale (240 metres)
Lower Unit	Thick beds of coarse-grained brown to grayish brown sandstone with some gravels. (100 metres)

Rock Types

Phu Phra Angkharn (Chalearm Prakhieat, Burirum Province)

Phu Phra Angkharn is a basalt lava dome, surmounted by a small crater. The dome is located inside an older volcanic caldera with a diameter of 1 kilometre (Figure 18). The volcano is hosted in Cretaceous sandstone and siltstone. The last eruption here took place about one million years ago, and vesicular basalt, together with scoria and bombs with sizes of 1 - 2 centimetres up to 50 centimetres are found within the crater. Figure 19 shows some of the geoheritage features at Phu Phra Angkharn.

Figure 18. Location and sketch of the Phu Phra Angkharn basalt lava dome.

Rapid cooling of basaltic lava caused shrinkage and the development of hexagonal columnar joints.

Sheet joint structure on the surface of basaltic lava.

Figure 19. Columnar and sheet joints in basaltic rocks at Phu Phra Angkharn.

Haew Suwat Waterfall, Khao Yai National Park

The Lam Ta-khong stream runs through a knick point in Permian-Triassic volcanic breccia and agglomerate to form an impressive waterfall called Haew Suwat (Figure 20). The agglomerate contains abundant rounded to subrounded volcanic rock fragments and boulders mainly of rhyolitic composition (Figure 21). The agglomerate, pink in colour, is very coherent and resistant to weathering. Graded bedding and stratification can commonly be seen within these volcanic rocks.

Figure 20. Haew Suwat Waterfall and its location within the Khao Yai National Park.

Agglomerate or volcanic breccia at Haew Suwat Waterfall.

The knick point on agglomerate.

Sub-rounded to sub-angular volcanic rock fragments.

Figure 21. Volcanic rocks at Haew Suwat Waterfall.

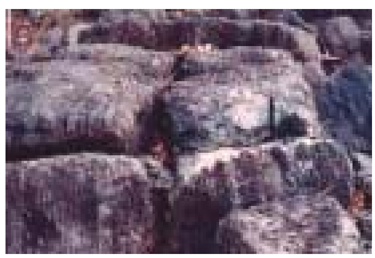
Mineral Deposits

Khao Falami Perlite, Sra Bot, Lop Buri Province

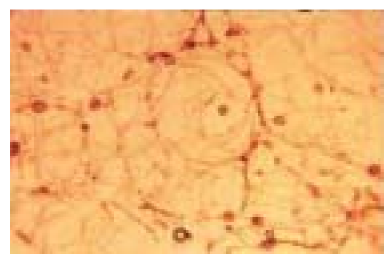
Khao Falami is a hill of volcanic rocks (Figure 22) located about 6 kilometres northeast of Ban Kaka Pho, Sra Bot, Lopburi Province. These 22-24 million years old volcanic rocks, comprise four layers i.e. rhyolite, upper perlite, tuff and lower perlite layers. The total thickness is 135 metres. Perlite is a grey lustrous volcanic glass, often with minute crescentic fractures, and at this locality three different types of perlite can be recognized. They are:

- Classical perlite comprising dense perlite with feldspar spots and crescentic perlite cracks
- Banded perlite comprising dense perlite with feldspar spots and red bands of alteration products
- Pumicious perlite or vesicular fibrous perlite.

Flow structure in perlite.



Black perlite.



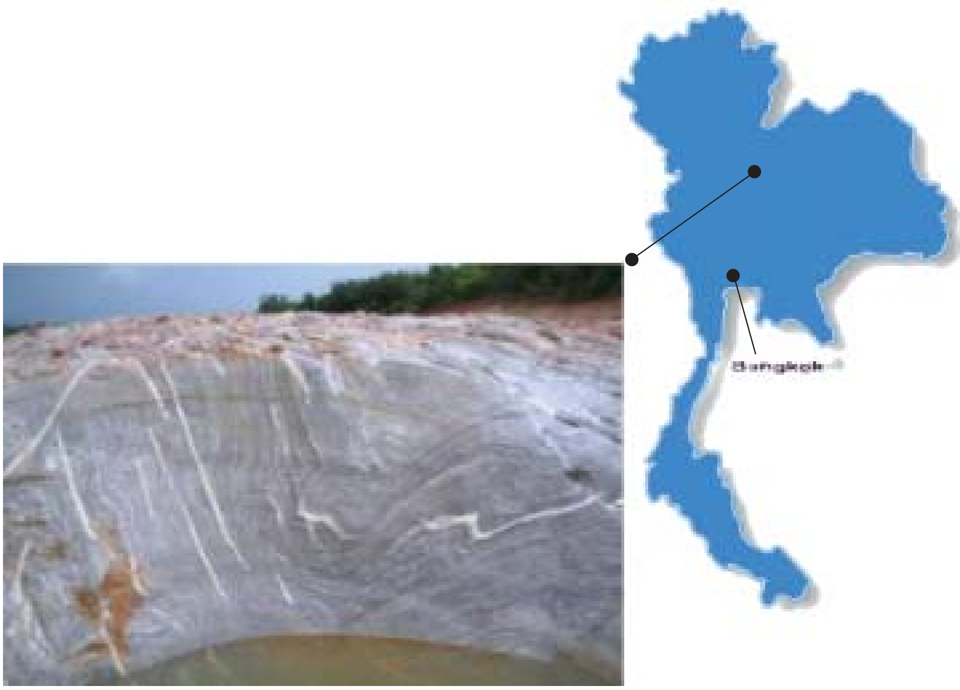
Perlitic (onion like) texture under microscope.

Figure 22. Location of Khao Falami volcanic hills and various features of perlite.

Nakhon Sawan – Phiat Gypsum (Figure 23), Nong Ba, Nakhon Sawan Province – Dong Charoen, Phichit Province

In 1956, gypsum mineral was discovered in Bang Mun Nak District of Phichit. The related mineral, anhydrite is composed of calcium sulphate, which when hydrated becomes the mineral gypsum. The gypsum deposit here is the hydrated top of an anhydrite unit that is intercalated with other sedimentary rocks ranging in age from Middle Carboniferous to Lower Permian.

The nature of the gypsum/anhydrite deposit indicates that it was originally deposited as beds of selenite (a form of crystalline gypsum) by the evaporation of confined sea water in shallow lagoons. Selenite was subsequently transformed to anhydrite after burial beneath other accumulating sediment. The anhydrite was then uplifted, either by tectonic movements or granite intrusions during the Triassic-Jurassic period after which rehydration by meteoric water converted the top part of the anhydrite deposit back to gypsum, leaving the deeper part unaffected. Studies within the mine and of drill cores revealed that there is a transition between gypsum to anhydrite at depths of 25 to 35 metres beneath the current ground surface.



Gypsum has prominent laminae, composed mainly of carbonate mud and clay.

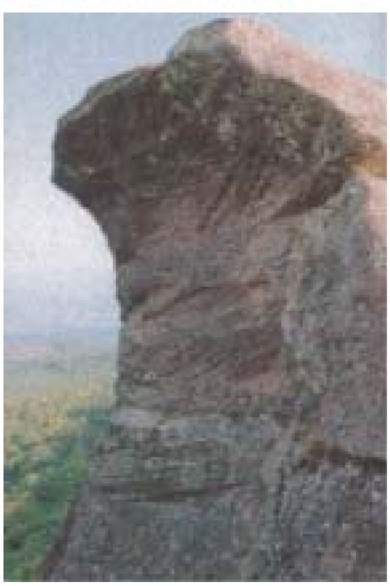
Karstification: The uppermost part of the gypsum is not a depositional top but an erosional surface.

Mining stopped at depths of 25 to 35 metres where gypsum changed to anhydrite.

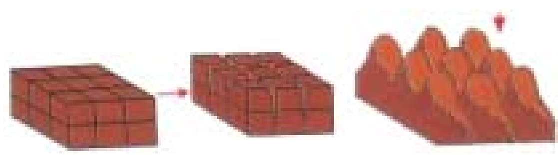
Figure 23. Location of the Nakhon Sawan – Phiat Gypsum and various other aspects of gypsum-anhydrite occurrence in the area.

Geological Structure

Lan Hin Pum, Phu Hin Rong Kla National Park, Nakhorn Thai, Pitsanulok Province. Phu Hin Rong Kla National Park is underlain by sandstones of the Phu Phan Formation of Cretaceous age, a part of the Khorat Group. Three attractive, strange looking landscapes, Lan Hin Pum, Lan Hin Taek and Mon Hin Sorn are the favourite tourist destinations in this national park (Figure 24).



Cross bedding in Phu Pan Formation.



Schematic diagram showing the formation of Lan Hin Pum structure.

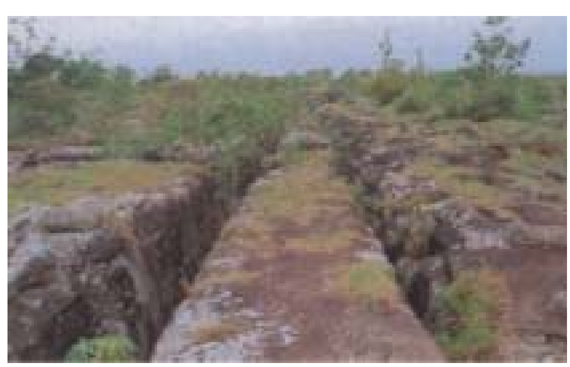
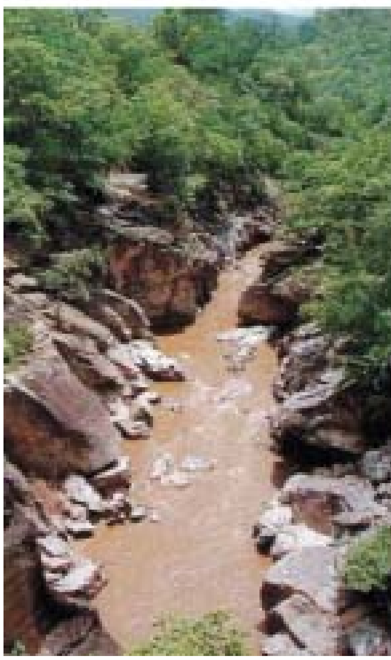
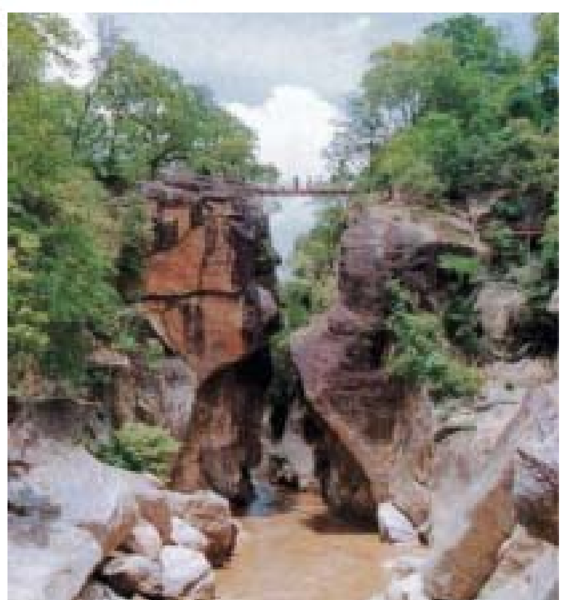


Figure 24. Various strange looking landscapes within Phu Hin Rong Kla National Park.

Ob Loung, Hod, Chiang Mai Province

Ob Loung, the grand gorge (Figure 25), cuts through a type of metamorphic rock known as anatexite, a rock formed when a pre-existing rock was raised to such high temperatures that it became partially melted. At Ob Loung, about 250 million years ago, intense heating from regional metamorphism caused older rocks of pre-Cambrian age to recrystalize to anatexite. Much more recently, during the Quaternary Period, this terrain was uplifted, and Mae Jam River started to incise the Ob Loung gorge, a process that is still continuing.



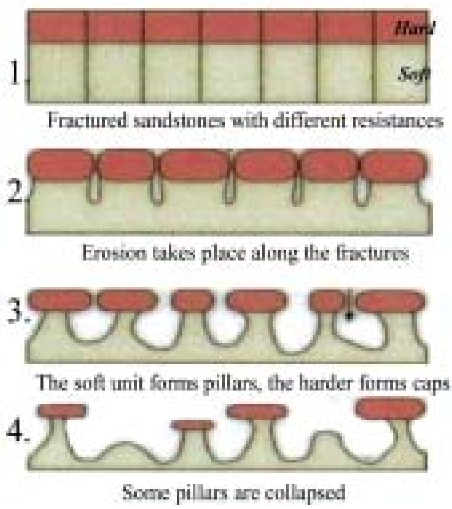


The bridge is 32 metres above Mae Jam River and the narrowest part of the gorge is only 2 metres wide.

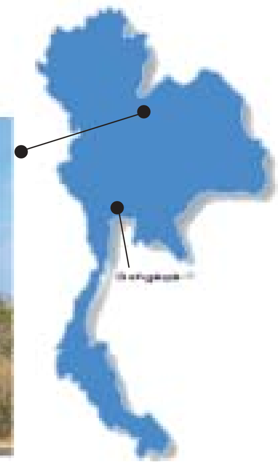
Figure 25. Beautiful scenery at Ob Loung, the grand gorge.

Phu Phra Baht Ban Phue, Udon Thani Province

The Phu Phra Baht Historical Park is sited on the Cretaceous Phu Phan sandstone formation of the Khorat Group. Differential erosion due to the high resistance of sandstones compared with other rock types of the formation has created many unique natural geological sculptures such as caps and pillars (Figure 26). The remains of ancient wall painting, Nang Eusa's hall and Buddha carvings found here indicate that the site was a residential and religious place in the past.



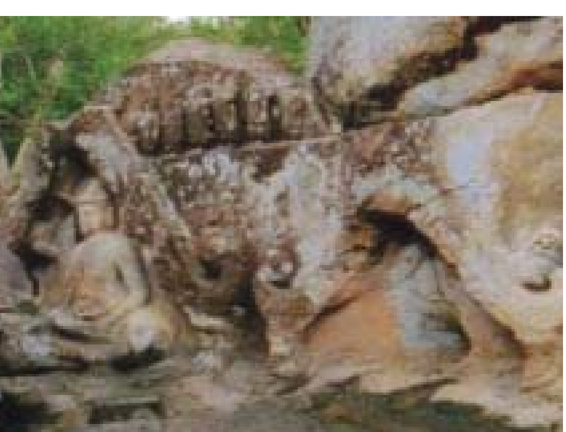
Cap and pillar forming process.



Natural pillar called Nang Eusa's hall was used for shelter by ancient people.

Ancient painting in "Tham Khon – Human's cave".

Natural pillar called Nang Eusa's monument placed on a cross-bedded sandstone.



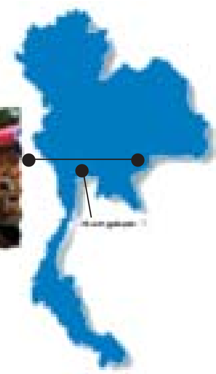
Buddha carvings on a Phu Pan sandstone outcrop.

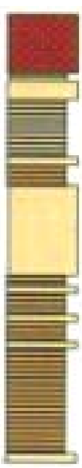
Figure 26. Various natural geological landscape and ancient archaeological remains within Phu Phra Baht Historical Park.

Geomorphology

LaLu, Ta Prmaya, Sra Kaew Province

Lalu, an area of natural sculpture (Figure 27), is located close to the Thai – Cambodian border. Lalu which is named after a Cambodian subsided ground is a 3 square kilometres basin of semi-consolidated Quaternary sediments. The sedimentary sequence comprises four units of clayey fine sand and silt interbedded with coarse sand, gravel and lateritic soil. Natural earth walls and posts seen at Lalu were carved by vertical and horizontal erosion. During the rainy season, the areas between the earth posts and walls turn green when cultivated with rice. Tourists can travel around Lalu by E-Taek, a locally made car.





Various natural earth posts and walls with flat ground in between.

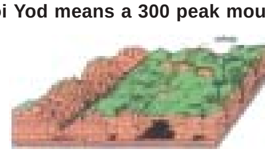
Figure 27. Some of the amazing natural sculptures within the Lalu basin.

Khao Sam Roi Yod, Kui Buri, Prachuab Khirikhan Province

Khao Sam Roi Yod (Figure 28) is a north-south trending limestone range, located in a 75 square kilometres National Park. Its distinctive landforms were shaped by the dissolving action of water on limestone. The limestone was formed in a warm shallow ocean about 250 million years ago. The limestone contains fossils of sea creatures such as algae and foraminifera.

Khao Sam Roi Yod means a 300 peak mountain range.

Karst features are formed when rain water combines with carbon dioxide to make a weak carbonic acid solution. This acidic water finds its way down through cracks and joints in the bedrock and dissolves the surrounding rocks.



Karst features such as sinkholes, underground streams, caves and springs are formed.

Higher terrains are dissolved, a large limestone plain is formed and stream sediment is deposited.

Tham Sai Cave is a collapsed solution feature in limestone.

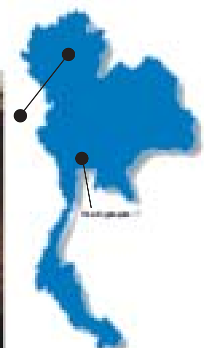
A sea cave carved by rain and sea waves.

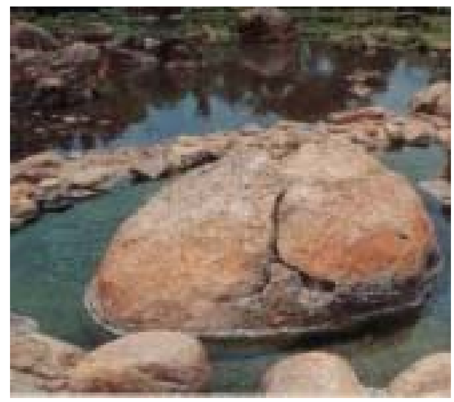
Figure 28. Beautiful landscape of Khao Sam Roi Yod and the formation of limestone karst features.

Hot Springs

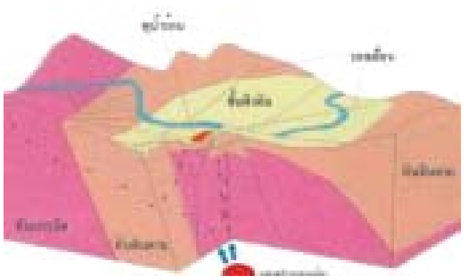
Jae Sorn Hot Spring, Muang Pan, Lampang Province

Jae Sorn Hot Spring (Figure 29) is found in Silurian-Devonian metamorphic rocks. Northerly and northwesterly trending faults and fractures cutting the rocks in the area deliver hot ground water to the surface. Triassic granite which intruded the older Silurian-Devonian rocks is believed to be the source of heat. The hot ground water here is either of hot pool or seep type, with water temperatures of up to 82° Celsius.





Exfoliated granitic boulder confirms a nearby granite heat source.



A simple hot spring model showing country rocks with faults, fractures and a source of heat.

It takes ten minutes to boil an egg here.

Large feldspar phenocrysts in porphyritic biotite granite.

Figure 29. Jae Sorn Hot Spring in Lampang Province.

Pong Duead Pa Pae, Mae Taeng, Chiang Mai Province

Pong Duead Pa Pae Hot Spring (Figure 30) is located within sandstone close to an intrusion of Triassic granite. The hot spring is closely related to a northwesterly trending fault. The hot spring comprises one geyser and ten hot pools within an area of about 100 square metres. The temperature of the water is between 90-99° Celsius.

Open air natural sauna by hot pools.

Porphyritic granite, with large crystals of feldspar in a fine groundmass.

Mineral water from the hot spring flows over fractured granite.

It takes five minutes to boil an egg here.

Figure 30. Pong Duead Pa Pae Hot Spring in Chiang Mai Province.

Fossil Sites

Phu Faek, Na Khu, Kalasin Province

More than 150 million years ago, many theropod dinosaurs were hunting on a sand bed along a braided stream. In the slightly humid conditions, their foot prints on the sand were not destroyed. Younger sediment subsequently covered the foot prints and they were preserved in the Phra Wihan sandstone formation. Three traces of these foot prints are now preserved at a small stream in Phu Faek, Kalasin Province (Figure 31). Three traces of theropods footprints are now preserved in Phra Wihan sandstone formation at a small stream in Phu Faek, Kalasin Province. The 110-120 centimetres long steps indicate that the rumps of these theropods are about 2 metres tall. Footprints are about 45 centimetres long, 40 centimetres wide.

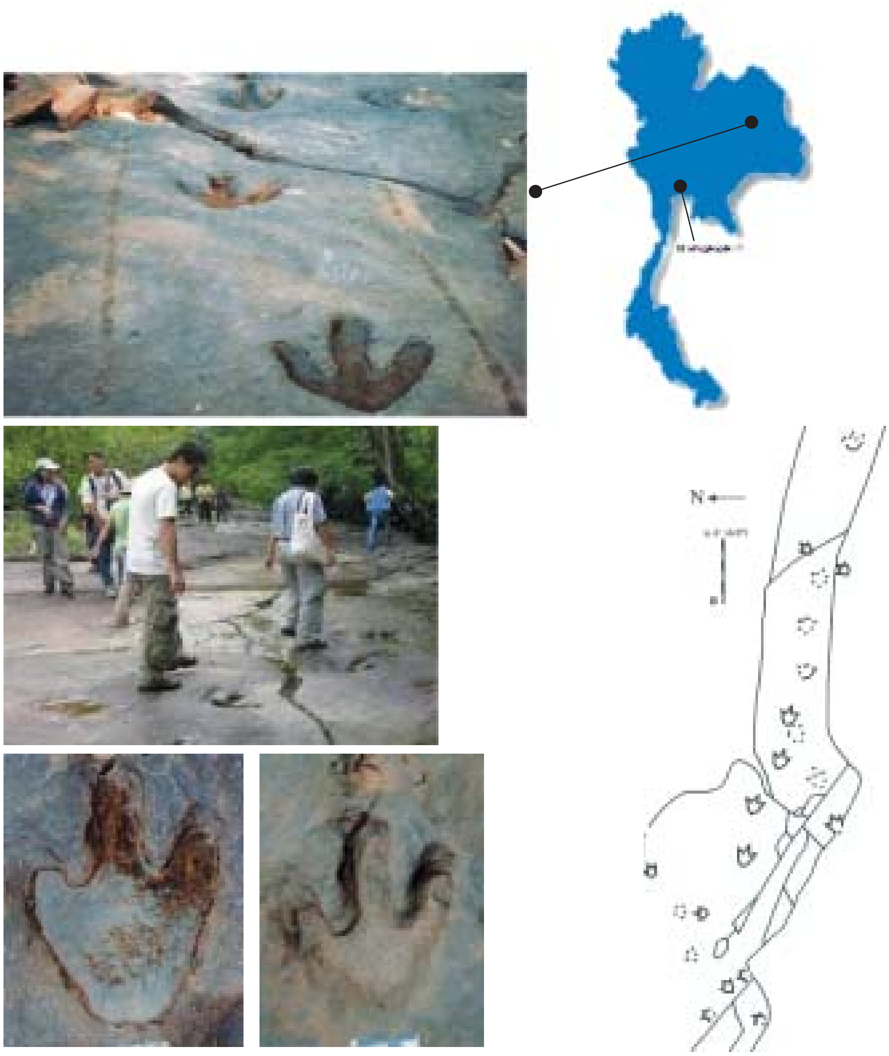
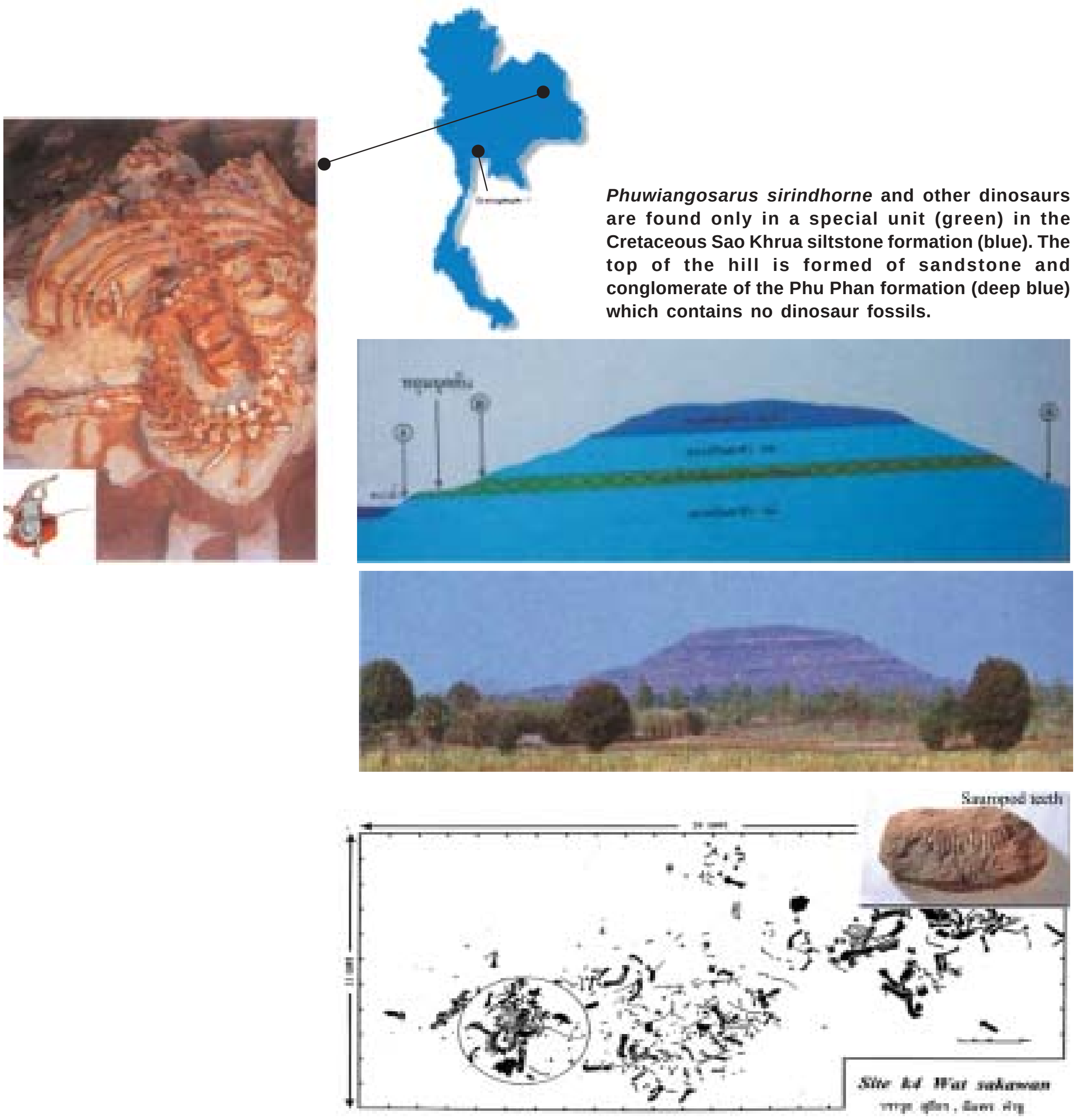


Figure 31. Preserved fossil footprints of theropod dinosaurs.

Phu Khum Khao, Sahas Sakhan, Kalasin Province

In Kalasin Province, at the foot of a 300 metres high sandstone hill, the first piece of dinosaur fossil was discovered by a monk of Wat Sakawan in 1994. Systematic exploration was subsequently carried out that resulted in the discovery of more than 700 pieces of bones from 6 individual dinasour *Phuwiangosarus sirindhorne* in one excavation site (Figure 32). Moreover, many teeth of theropod and Sauropod dinosaurs have also been found at the same site.



Phuwiangosarus sirindhorne **and other dinosaurs are found only in a special unit (green) in the Cretaceous Sao Khrua siltstone formation (blue). The top of the hill is formed of sandstone and conglomerate of the Phu Phan formation (deep blue) which contains no dinosaur fossils.**

Figure 32. Dinosaurs of Phu Khum Khao.

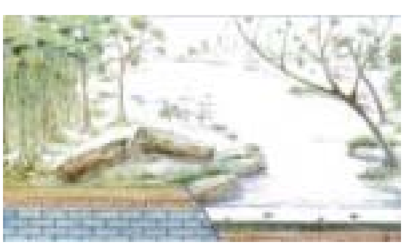
Laem Pho Gastropod Site, Muang, Krabi Province

Laem Pho is a small cape located in Had Nopparat Thara National Park, Krabi Province. Snail-like gastropod fossils are found here in a carbonaceous clay bed underlain by a 10-15 centimetres thick lignite seam (Figure 33). The 1.5 to 2 metres thick fossil bed is exposed to the sea and easily eroded by sea waves. Referring to the gastropod Viviparidae, the bed was thought to be 75 million years old. The more accurate age was obtained later by referring to vertebrate fossils from the same area which gives an age of about 40 million years.

Laem Pho gastropod fossil bed, broken by sea waves, looks like man-made concrete slabs.

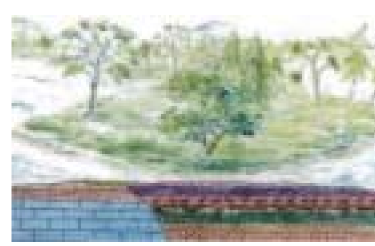
There are 3 fossil sites along the 3 kilometres beach of Laem Pho cape.

***Viviparus*, Tertiary gastropod fossils cemented by calcium carbonate.**



Laem Pho was a big fresh water swamp surrounded by tropical forest, 40 million years ago. Gastropods, pelecypods and other aquatic animals were abundant.

Abrupt climate change disrupted the life system in the swamp. It became shallower with dead creatures and sediments. Finally, it was covered with younger sediments and lithified.



During the last Ice Age, the area was uplifted. At the end of the Ice Age, sea water level rose up to its present level. Subsequently, the gastropod beds have been exposed and eroded.

Figure 33. Laem Pho Tertiary gastropod bed.

FUTURE OF GEOHERITAGE CONSERVATION IN THAILAND

The Department of Mineral Resources (DMR) is the main government agency in charge of geological site management in Thailand. The Department, in cooperation with local governments, has been developing geological sites all over Thailand using a people oriented approach. DMR has continuously disseminated geological information and knowledge on the sustainable utilization of geological resources using various media, because education is the key to geological site conservation.

Geological heritage conservation is an integrated task, since all geological sites are closely related to other natural resources such as forest, wild life, surface and ground water and the sea coast. Therefore, DMR acts as the initiator and a focal point in collaboration with other relevant agencies.

In 2008, the Fossil Act B.E. 2551 was promulgated and the Geological Resources Management Bill has also been prepared. These will be important additional tools for DMR to assist protection of Thailand's geological heritage. Establishing geological conservation sites and national geoparks are two of DMR's main goals and these will obviously enhance public awareness of Thailand's rich geological heritage.

NATIONAL GEOPARK DEVELOPMENT

A set of key criteria for geological conservation site selection was established by DMR in 2007. The criteria will be used by a national committee appointed to select geological sites to be promoted as geological heritage conservation sites. Subsequently, national geoparks will be established from among those geological conservation sites that are suited to sustainable geotourism.

Although Thai geological conservation site establishment task is not yet fully completed, the national geopark program is simultaneously executed. For sustainable use of its non-renewable resources, Thailand also aims to develop world geoparks in this region with the cooperation and support of the Asia Pacific Geoheritage and Geoparks Network (APGGN) and the Global Geoparks Network (GGN).

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GEOHERITAGE OF VIETNAM

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Separator Photo:
Ha Long Bay World Heritage Site, Vietnam. (*Photograph courtesy of Ibrahim Komoo*).

9

GEOHERITAGE OF VIETNAM

La The Phuc

GEOHERITAGE RESEARCH

For many years Vietnamese geoscientists have been accumulating knowledge of the country's geoheritage through their routine investigations on geology and mineral resources of the nation. Many areas recognised as having outstanding value in terms of deciphering the geological history of Vietnam have been identified and continued to provide topics for further research by both local and foreign geoscientists. Some areas of spectacular topography in Vietnam, such as the beautiful karst landscapes with their extensive systems of limestone caves, have become popular tourist destinations. A systematic research programme aimed at ensuring the conservation, management and rational exploitation of geoheritage sites for sustainable socio-economic development has recently been initiated, after first being proposed in 1996 by staff of the Geological Museum of Vietnam.

In accordance with a growing international trend towards a greater recognition of the importance of conserving and protecting natural heritage, Vietnamese geoscientists are now carrying out studies of national geoheritage sites with the aim of establishing geo-conservation sites and developing geoparks. Prominent in this new field of research are the geoscientists of the Department of Geology and Minerals of Vietnam (including the Geological Museum), the Institute of Oceanology, the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) and the University of Science under Hanoi National University. Several important international collaborative research projects with geoscientists from various foreign geoscientific institutions have been conducted. Several important outcomes of these researches will be mentioned below and will be further elaborated in descriptions of individual geoheritage sites in later sections of this chapter.

Some early research leading towards the recognition and future conservation of geoheritage sites in different areas of Vietnam had been carried out by geoscientists of the Geological Museum of Vietnam, in cooperation with the

Colorado University at Boulder and the United States Geological Survey (USGS). One project in particular, led by Trinh Dzanh entitled *Research on Geoconservation sites in Vietnam (2001 – 2004)*, was the first project specifically oriented towards geoheritage conservation. Preliminary results of this project have confirmed that Vietnam possesses geoheritage sites representative of each of the ten geoheritage categories listed in UNESCO's temporary classification scheme of *Global Indicative List of Geological Sites* (GILGES). Such sites were reported to be widely distributed in eight regions of Vietnam, the Eastern Bac Bo, Western Bac Bo, Red River, Northern and Central Trung Bo, Southern Trung Bo Plateau, Southern Trung Bo Coastal, Western Nam Bo and Bay of Thailand regions (Figure 1). Over three hundred sites of geological interest were listed and over half of them can be classified according to the ten geoheritage categories of the UNESCO indicative list.

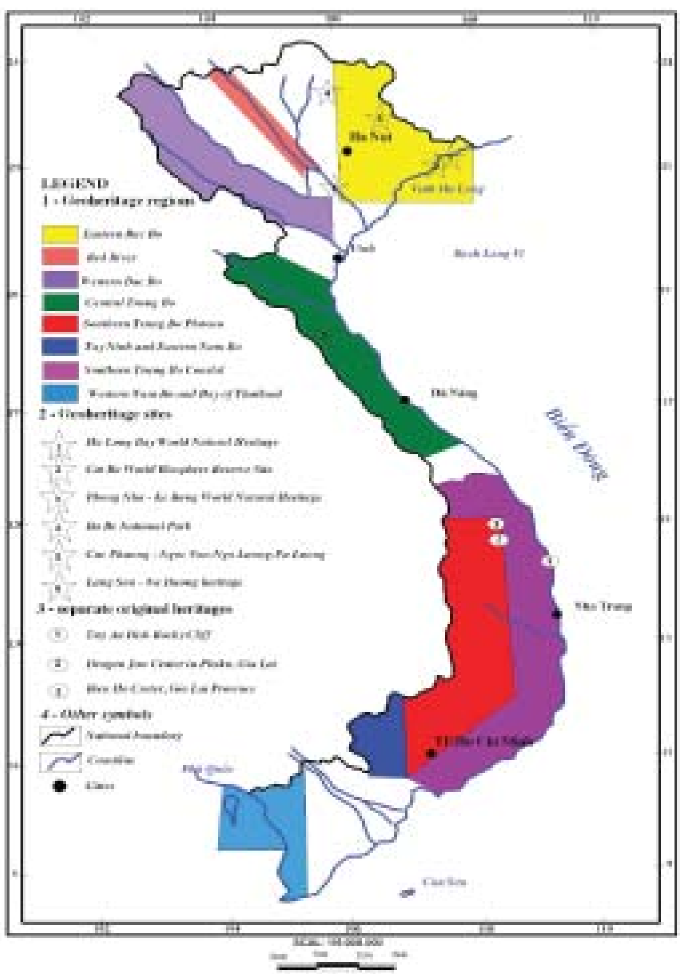


Figure 1. Distribution map of some important geoheritage sites in Vietnam.

Geoscientists of the VIGMR have also made specific contributions to geoheritage research in Vietnam. From 1991 to the present, they, together with Belgian speleologists have carried out eight speleological and karst surveys during which they investigated nearly three hundred caves in a variety of locations. As a result, many caves with geological, archaeological and touristic value have been discovered, including the Culvert Cave in Tam Duong, Lai Chau, reported to be the deepest cave in Southeast Asia, the Flower Cave (Tua Chua, Lai Chau), the Queen Cave (Son La) and the Dragon Cave (Tan Lac, Hoa Binh). The results of each survey have been published in English by Berliner Höhlenkundliche Berichte Publishing House (http://www.speleo-berlin. de/d_publikationen.php, volume 22; 2006).

Together with specialists from the Belgian Universities of Brussels, Leuven, Antwerp, Ghent and Liege, and from the Belgian Geological Survey, VIGMR geoscientists have also implemented two collaborative projects on conservation and sustainable development relevant to limestone regions. These are *Development of rural limestone areas in North West Vietnam through sustainable management measures of land, water and community education (VIBEKAP, 1998-2003)* and *Intensifying the exchange among participators in conservation of Pu Luong - Cuc Phuong limestone landscapes (2002-2006)*.

Areas of karst landscape within limestone terrains, a common feature in Vietnam, pose particular problems of conservation. In 2004, VIGMR, with support from Belgian partners, the Hanoi UNESCO office and the Vietnam National Committee for UNESCO, successfully held an *International Interdisciplinary Conference on Conservation and Sustainable Development of Karst Areas (TRANSKARST, 2004)*. The results of this conference were summarized in the book entitled *Sustainable Development of Karst Regions in Vietnam* which was published by UNESCO in Vietnam.

GEOPARK PROGRAM

In December 2007, VIGMR and the Vietnam Geological Museum signed a memorandum of understanding concerning research cooperation related to geoheritage by establishing the *Research and Development Team for a Geopark Network in Vietnam*. This is expected to develop into a national focal point for geopark development. Also in 2007, VIGMR together with Vietnamese Institute of Ethnology, Vietnamese Academy of Social Sciences and People's Committees of Ha Giang, Cao Bang, Bac Kan Provinces and with Belgian partners (Leuven, Brussels, Ghent, Antwerp Universities and the Belgian Geological Survey) have started the project on *Integrated capacity building through research-based geopark development in Northeast Vietnam*. This project is supported by the Interscholastic Council for 5 years with the main aim of enhancing Vietnamese capacity in the development of geoparks.

Although geoheritage research started only relatively recently in Vietnam, it has already made good progress. Vietnamese geoscientists have systematically identified, described and classified many geoheritage sites and based on these endeavors, the establishment of various geoparks has been proposed. Nevertheless, progress on the formal establishment of geoheritage sites and geoparks has been quite limited compared with those on landscape and biodiversity conservation. Since 1962, in order to conserve landscape and biodiversity, the Vietnamese Government has made decisions in establishing 128 special-use forests, 28 national parks and 62 nature conservation areas (which include 13 species and habitat conservation areas, 49 nature reserves, and 38 protected landscape areas). Ha Long Bay and Phong Nha - Ke Bang have been established as UNESCO Natural Heritage sites, while Ba Be Lake is an established Asean Heritage Park. Although there are no established conservation areas where geological values are specifically emphasized, recognition of the Ha Long Bay and Phong Nha - Ke Bang natural heritage sites (see descriptions below) were tacitly based not only on biodiversity, but also on their outstanding geological and geomorphological values. The same is true for the Ba Be Asean Heritage Park. However without the assessment of geologically important sites by the competent bodies, no specific geoconservation sites are likely to be established. To date, geoheritage sites that happen to be located in national parks are obviously protected, while other geoheritage sites not belonging to national parks, historical sites or cultural conservation areas are not protected and are being freely encroached upon.

In summary, it can be said that the first stages of geoheritage research work in Vietnam have been conducted on a scientific basis and in accordance with internationally accepted criteria. However, the establishment of geoconservation sites and geoparks though proposed, has not yet been fully accomplished. This may be partly attributed to economic constraints and the lack of investment in this new field together with the absence of the necessary legal framework and a lack of awareness among the community.

IMPORTANT GEOHERITAGE SITES

At the moment, there are 348 geoheritage sites described in eight regions of Vietnam, 80 sites in Eastern Bac Bo Region, 83 in Western Bac Bo Region, 38 in Central Trung Bo Region, 61 in Southern Trung Bo Plateau Region, 22 in Tay Minh and Eastern Nam Bo Region, 44 in Trung Bo Coastal Region and 20 sites in Southern Trung Bo and Western Trung Bo-Bay of Thailand Region. Based on the outstanding values of all these geoheritage sites, geoscientists of the

Geological Museum are planning to establish at least fifteen distinct geo-conservation areas in Vietnam. For this chapter, only the the most important geoheritage sites of Vietnam are described. These include sites such as the geomorphologic landscapes of Ha Long Bay, caves of Phong Nha - Ke Bang, the Ba Be Lake, and the Reptile Fossil Site (*Placodontia)* in the Cuc Phuong National Garden (Figure 1), each of which displays unique characteristics that are of high significance for the Southeast Asian region. The complex geological history of each described geoheritage site is summarized in Appendix I at the end of this chapter.

Ha Long Bay World Natural Heritage Site

Ha Long Bay, located between longitudes 106°58′E and 107°22′E and latitudes 20°45′N and 21°50′N in Quang Ninh Province (Figure 1) is currently considered as one of the best known sites for international tourism in Vietnam. The bay covers an area of 1,553 square kilometres and has 120 kilometres of coastline. Within the bay there are around two thousand islands of various shapes and sizes, almost half of which are nameless. Ha Long Bay is deemed to have outstanding value for its geological history and structure, its spectacular aesthetic landscape (Figure 2,3), its Quaternary marine geological development and its diversity of geological resources. The area represents an outstanding example of a mature limestone plain that evolved into a karstic landscape prior to becoming partially submerged by marine encroachment. Taken together its many geomorphological and geological phenomena indicate that Ha Long Bay can be turned into a huge open air museum of natural history.

Three decades ago, geoscientists of Hanoi National University, the Department of Geology and Minerals of Vietnam and the Institute of Oceanology, in cooperation with their colleagues from the British Geological Survey (BGS), carried out various studies in Ha Long Bay which led to its recognition as a UNESCO World Natural Heritage Site in 1994. The initial recognition was given for the bay’s universal aesthetic value, and this was supplemented with recognition of its universal geological value in 2000. Since 2005, VIGMR have cooperated with Italian experts in further surveying the geology of the Ha Long Bay area in preparation for an application to UNESCO for further expansion of the Ha Long Bay World Natural Heritage Site.

Figure 2.
Some of the outstanding karst landscapes of Ha Long Bay World Natural Heritage Site.
(Photographs courtesy of Ha Long Bay Natural Heritage Management).

(a) (b)

Figure 3. Undulating beds of limestone of Song Da Isle that enhanced the beauty of Ha Long Bay landscape. ***(Photographs courtesy of Tranh Duc Than (a) and Ha Long Bay Natural Heritage Management (b)).***

Geological History and Landscape Development

The geological history of Ha Long Bay area spans more than three billion years of geological time and is closely connected with that of the adjacent areas in the Bac Bo Gulf and Southeast China. In terms of its geological history it is considered as a part of the Vietnam – South China continents which have undergone complex processes of fragmentation, drifting, collision and alteration as summarized in Table 1 (Appendix 1).

Distinctive landscapes and seascapes of Ha Long Bay represent a well developed karst topography that has been partially submerged by the sea. Residual limestone hills of once coastal mountain topography remain today as numerous small islands. Originally a mature karst landscape developed when hot, wet climatic conditions interacted with the 1,000 metres thick sequence of homogenous limestone strata that underlay the area. The evolution of the landscape to its present state (Figure 4) took place over a period of about twenty million years. It happened in five stages (from oldest – stage 1, to youngest – stage 5), as follows:

Stage 1 - Formation of a limestone plain.
Stage 2 - Formation of karstic sinkholes and valleys.
Stage 3 - Formation of groups of conical-shaped limestone hills.
Stage 4 - Erosion into individual high limestone towers.
Stage 5 - Invasion and partial submergence of the limestone karst by the sea.

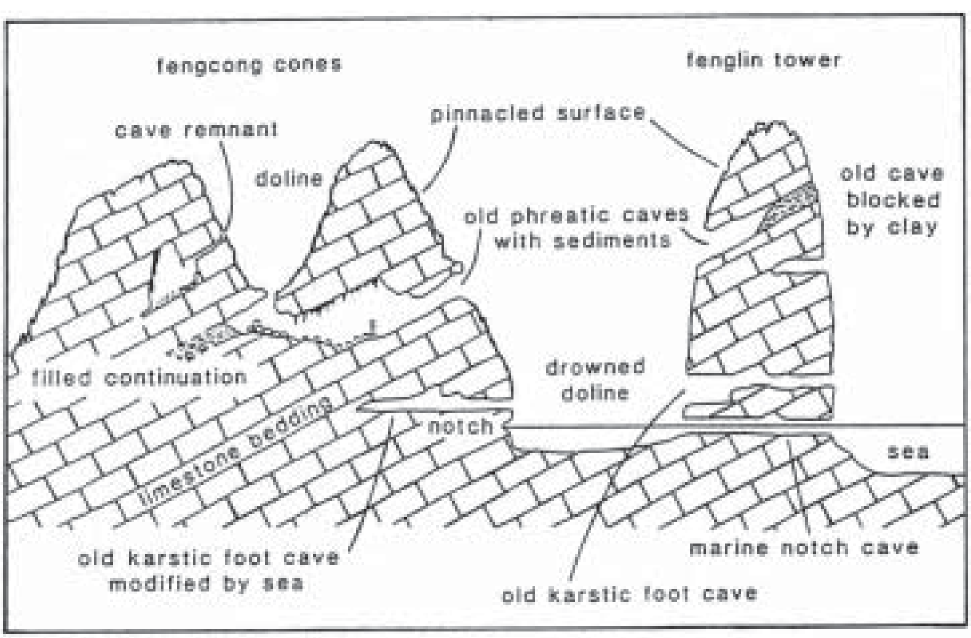


Figure 4. Types of landforms and caves in Ha Long Bay.

There are around two thousand islands in Ha Long Bay area but small islands and extremely small isles (0.1-0.01 and <0.01 square kilometres, respectively) constitute over ninety percent of the total number. There are only seven islands with an area larger then 1 square kilometre, the largest of which is the Hang Trai Island. Although they are so many in number, when taken together, the islands account for only ten percent of the total area of the bay.

The islands from Dau Go to Dau Be form three distinct groups according to their elevations. Those with elevation between 140 – 220 metres correspond to Pliocene (5.3-1.8 million years old) planation surface, the tallest group of islands. Islands with heights between 50 – 130 metres correspond to an early Quaternary (1.6-1.0 million years old) development stage. More than 50% of the islands in Ha Long Bay fall within this group. Meanwhile, the lowest islands, with heights of 10 – 14 metres, were subjected to the direct impact of the sea in the late Pleistocene and the Holocene Epochs (125,000-10,000 years ago).

In the terrain around bays and on islands' negative landforms such as depression surfaces, sinkholes and blind valleys form topographic features that are often highly attractive to the many visitors. These landforms are of various shapes and sizes, generally less than 5 metres deep, and most of them have been partly submerged, becoming lakes and lagoons. The local people call them *Ang* and *Tung*. *Ang* refers to a temporary lake within a blind valley on a limestone island and is usually 1-3 metres deep, while *Tung* is a small embayment incised into a limestone island and is usually a drowned valley, ravine or sinkhole into which the sea has encroached. In the Ha Long Bay and Cat Ba karstic areas there are fifty-seven *Tung*, the largest being *Tung Gau* (220 hectares) and the smallest *Tung May Den* (1.5 hectares). Of the sixty-two *Ang*, the largest is *Ang Vem* (28.8 hectares) and the smallest *Ang Tre Mo* (0.7 hectares).

Caves

Caves are common karst features of Ha Long Bay, extending from tens up to hundreds of metres in length. They fall into three groups according to their respective elevations of 3-4, 5-15 and 25-50 metres above current mean sea-level. In general, the higher caves are the older ones whereas most of the caves in the 3-4 and 5-15 metres elevations were formed in the Pleistocene Epoch, some as little as ten thousand years ago. These caves can further be grouped into three geomorphological types, i.e. the underground, horizontally floored and recess caves.

Underground caves. Underground caves mostly represented old drainage tunnels in the karst. They usually have a steeply sloping floor and high roof. For example, the Amazing Cave has an entrance that is more than 10 metres high and Tam Cung Grotto has three chambers at a height of 20 metres developed along bedding planes of the enclosing limestone. Lau Dai Grotto in Co Ngua Island is a 300 metres long cave with complex outlets. Thien Cung Grotto and Dau Go Cave are remains of large old caves located at a height of 20-50 metres. Thien Cung and Dao Guo Caves, each have a more than 100 metres long chamber, divided into many smaller chamberlets by stalagmites and stalactites.

Horizontal Floor Caves. Horizontal floor caves were formed as a result of erosion by the sea at the base of an island. As the name implies, they have nearly horizontal passages that are related to marine erosion and to the development of marine terraces. For example, the Trinh Nu Cave is 80 metres long with the roof 12 metres above the sea level, and 70 metres long Bo Nau Cave is adorned by numerous old stalactites and stalagmites.

Recess Caves. Recess caves were formed by combined actions of sea water dissolution, waves and tides. They often have a flat roof and were created by marine erosion during periods of transgression in the Holocene Epoch (up to 11,000 years ago) and also in the Pleistocene Epoch (hundreds of thousands of years ago). Some caves in the Ba Ham Lake area are part of a complex of three tunnels that connect three salt lakes and open to the sea. Luon Cave (on Bo Hon Island) is 50 metres long and its roof is only 2 metres above the present maximum tide level.

Sea Notches

Sea notches are formed by the action of waves and the erosion of sea-water cutting into the cliffs, diminishing the size of the limestone tower-shaped isles at their base and creating tunnels through them contributing to some of the most spectacular karst landscapes of the bay. They are commonly found at heights of 2-2.5, 3-5, 7-8 and 9-12 metres and many still display attached ancient oyster shells as evidence of higher ancient sea level that prevailed when they were formed.

Partially Submerged Karst Plain

Ha Long Bay sea bed, 3-20 metres deep, comprises a submerged old karst plain. Consequently, the sea bed is not flat and is characterised by the presence of numerous residual mounds, rivulets and ditches, grouped at water depths of 1-4, 6-11 and 12-20 metres, each of which indicates a significant episode of denudation and abrasion of the original karst plain before its final submergence. The present impact of direct waves upon the sea-bed is minimised by the presence of numerous surrounding barrier islands, but the high tidal amplitude in Ha Long Bay had permitted substantial accretion and erosion within the bay.

Frequent fluctuations in the relative levels of land and sea have dominated the recent geological history of Ha Long Bay. Evidence for this is seen in the relics of raised marine terraces at different elevations above current sea-level and the many ancient sea notches that can be found cutting into the limestone cliffs. Many of the latter were only revealed in the cliffs when the sea level last dropped in middle to late Holocene times, less than ten thousand years ago. Oyster shells, borings of marine worms, teredos and marine snail shell remains in some of the notches gave radiocarbon (C^{14}) dates of between 2,300 to 5,000 years old, although a few samples gave ages of up to 40,000 years.

Changes in human development and cultural history were also taking place in the area of Ha Long Bay during the last 25,000 years. Evidence for the Soi Nhu Culture (25,000-7,000 BC) have been discovered in several caves and on several isles of Ha Long and Bai Tu Long Bays, and to a lesser extent in Hoa Binh-Bac Son. Evidences for the Cai Beo Culture (7,000-5,000BC) have been found on the shore of Airtight Bay in Ha Long and in the Trang Kenh area in the Bach Dang Estuary.

Geological Resources

Ha Long Bay and its adjacent areas are rich in geological resources, especially minerals such as coal (10 billion tonnes), construction and industrial materials such as limestone, clays, sand, gravel, fertilizer minerals in phosphorite and peat, both surface and underground water including thermal and mineral waters and some metallic minerals. This poses the challenge of achieving a balance between the exploitation of such resources for immediate revenue and conservation of Ha Long Bay's natural resources such as its spectacular landscape, biodiversity of island ecosystems, coral reefs, mangrove forests archaeological relics and communities of local inhabitants. The economic potential of ecotourism has recently been accepted by the local authority, business community and local public as incentives for managing this balance in a more constructive and sustainable manner.

Natural Attractions of Ha Long Bay

Ha Long Bay forms an extensive island karst landscape where many of the limestone islands contain caves of outstanding beauty. There are more than twenty well known caves and the most famous caves are usually closely connected with old folk tale of particular legend, history, culture, tradition or spiritual and religious beliefs. Below are descriptions of some of the more spectacular caves in Ha Long Bay.

Amazing Cave. Amazing Cave is located on Bo Hon Island at the center of Ha Long Bay. Besides the Amazing Cave, there are many other caves in Bo Hon Island such as the Bo Nau, Luon, and Me Cung Grottos. The Amazing Cave was discovered by the French in 1901. Because of its surprising natural beauty it was given the name *Grotte des surprises*. It is considered to be one of the most beautiful caves in Vietnam. It covers an area of 12,200 square metres and it has two chambers with many stalactites. The cave entrance is more than 25 metres above sea level and is hidden by luxuriant tree canopies. The main cave (Figure 5) has an extensive

Figure 5. Dripstones in Amazing Cave, Ha Long Bay ***(Photograph courtesy of Nguyen Viet Hung).***

area with an appearance of a huge opera theatre, which never fails to impress visitors when they first enter. The roof is a curved dome with regular and smooth depressions and many beautiful stalactites hanging down from the ceiling. Further examples of nature's sculptural artwork are the various stalagmite formations resembling elephants, seals, birds and flowers. At the centre of the cave, a massive column of rock stretches from the floor to the roof.

From the first chamber, a small passage leads into the second chamber where light floods in and illuminates the various strange scenes. The stalactites in this chamber resemble an old tree with a luxuriant canopy. Another stone formation that looks like a horse and a long sword is found at the entrance. The legend associated with the cave relates how Saint Giong, after defeating the An invaders, helped the local people to drive away the ghosts. He returned to Heaven but left behind his sword and his horse in order to reassure the local people of his spiritual presence.

Reaching the highest point of the cave, a so-called *Royal Garden* becomes visible. The garden contains a limpid pond surrounded by many trees such as weeping figs**,** cycads and banyan trees with many species of birds. Sometimes group of monkeys descend from the nearby mountain, seeking for abundant fruits in the garden. Amazing Cave is also a habitat for many rare species of cave snails. Fourteen of the 86 known species have been found together with other endangered species of invertebrate creatures that need to be protected.

Golden Turtle Grotto. The Golden Turtle Grotto is located on Dam Nam Isle. In front of the Golden Turtle Grotto lies Dam Bac Isle and behind it, Soi Sim Isle. The grotto is about 100 metres long and 5-10 metres wide. There is one small path leading to the top part of the cave where the murmur of water issuing from a small spring can be heard throughout the year. Soft, newly fomed, white stalactites hang down from the ceiling of the grotto. The last chamber of the grotto exhibits a fantastic view, often said resemble to the Bach Dang battlefield of the General Tran Hung Dao period, with densely aligned stalagmites appearing like the wooden stakes that were driven to the bottom of the Bach Dang River for defence against the enemy.

The Golden Turtle Grotto has a legend which says that the Golden Turtle gave King Le Loi a sword that helped him defeat the invaders. Afterwards, the turtle took back the sword and swam to the East Sea. On reaching Ha Long Bay, the Golden Turtle found that there were many spirits within the area and he was allowed by Neptune to stay back in Ha Long Bay to exterminate the spirits. After finishing his task, the exhausted Golden Turtle found himself a grotto to rest, where he was turned into stone. From a certain angle, the Golden Turtle resembles the half-closed sleepy eyes of a turtle with wounds all over its body.

Heavenly Palace Grotto. Heavenly Palace Grotto (Figure 6) is located on Dau Go Island in the southwestern part of Ha Long Bay. The Island is located about 4 kilometres from the mainland tourist wharf. The cave entrance is sited about 25 metres above sea level. Luxuriant trees are growing on both sides of the adventurous cliff pathway that leads to the grotto. The cave can be accessed through a narrow cleft in the rock that opens into a large chamber over 130 metres wide. The magnificent stalactites in the grotto, particularly on its east side, resemble a monumental painting of characters from popular fairy tales. The Grotto is also closely connected with the legend of the King Dragon.

There are four big columns in the center of the grotto holding up Heaven, and on these columns are carved many strange creature-like forms including fishes, birds and flowers as well as scenes representing the daily activities of people. Many clusters of stalactites adorn the arch of the grotto including a blue stalactite that resembles a pearl-inlaid ornament. At the last chamber of the grotto, a mixture of colorful lights illuminates the beautiful scene where a natural rivulet is flowing down to three limpid pools. On leaving the magnificent Heavenly Palace Grotto, visitors can justly feel that they have visited a unique natural art gallery.

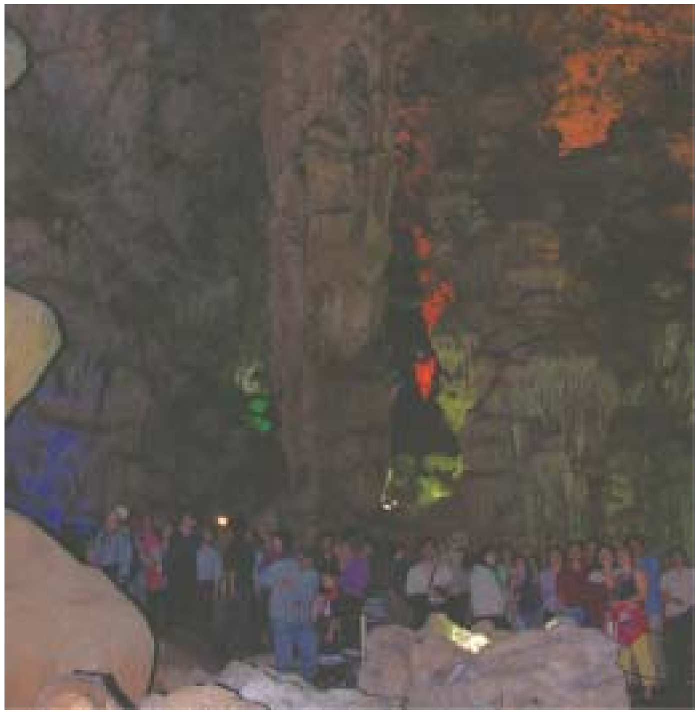


Figure 6. Some of the colourful cave features within Heavenly Palace Grotto (*Photograph courtesy of Ha Long Bay Natural Heritage Management*).

Dau Go Cave. Dau Go Cave (Figure 7) is located in Dau Go Isle where a climb up ninety rocky steps leads to the cave entrance. The cave dome is about 25 metres high, where hundreds of huge stalactites hang down resembling the rapids in a fast-flowing river. The cave has three main chambers. The outer one is dome-shaped and is flooded with natural light. Forests of colourful stalactites and stalagmites create natural sculptures that have been visualised as herds of elephants seeking food, deers, sleeping lions and a tortoise swimming in a vast sea, but they can also be related to many other things, according to one's imagination. In 1917, when visiting Dau Go Cave, Khai Dinh King was astonished at the extraordinary beauty of the cave. He erected a monument with inscriptions praising the natural beauty of Ha Long Bay and Dau Go Cave. In the book entitled *Merveille de Monde* (or World's Wonders) published in 1938, the Dau Go Cave was called a G*rotte des Merveilles* (or Grotto of Wonders).

Passing through a narrow passage, a second chamber is reached. Here, in the misty light, the cave takes on a mystical atmosphere but the cave is abruptly enlarged into the third chamber. At the end of the cave there is a *Fairy Well* overflowing with fresh water all year round.

Figure 7. Dau Go Cave added more beautiful cave features for Ha Long World Natural Heritage Site *(Photograph courtesy of Ha Long Bay Natural Heritage Management).*

Trinh Nu Cave (The Maiden Cave). Trinh Nu Cave (Figure 8) is located in Bo Hon Island about 15 kilometres south of Bai Chay, near the Amazing, Fairy and Luon Cave systems. The French named this cave as *La Vierge* (the Maiden). The cave is a favourite retreat for young couples in love. At the entrance of the cave there is a stone statue resembling a girl with long hair, lying down with her eyes looking out to the sea waiting as if she is in desperation. Opposite the Trinh Nu Cave is the Trong Cave (or Male Cave) with another natural stone statue, resembling a male with his face looking to the Trinh Nu Cave.

Figure 8. Beautiful view overlooking Ha Long Bay from Trinh Nu Cave or the Maiden Cave. (*Photograph courtesy of Ha Long Bay Natural Heritage Management*).

Ba Ham Lake. Ba Ham Lake area offers some of the most fascinating scenery of Ha Long Bay (Figure 9). It is located on Dau Be Island in the southwestern part of Ha Long Bay. Dau Be is one of the outer islands of Ha Long Bay and lies in the centre of a narrow rectangular sea surrounded by high mountains. Ba Ham Lake is a complex of three sea water lakes connected by a narrow winding cave that opens to the sea. The surrounding island provides a natural habitat for abundant flora including wild orchids, banyans and cycads. Flowers can be found blossoming throughout the year and this is also the home of yellow monkeys, various birds, flying squirrels and bats.

Figure 9. Various scenic views of Ba Ham Lake (*Photographs courtesy of Ha Long Bay Natural Heritage Management*).

Although Ba Ham Lake is located about 25 kilometres from the mainland, it has attracted tourists for many years. The entrance to the lake is located at the cliff to the northwest of the island at 4-5 metres above sea level. Visitors entering the cave on approaching the first lake, will see a forest of stalactites of various colours, like the roots of a banyan tree hanging from the roof. The cave's bottom is very deep but the water is clear enough to see schools of fish swimming in the water. Visitors can also see many wild orchids, cycads and chicken tail bamboos growing on the mountain wall. There is a century-old thistle located to the southeast of the second lake which is the habitat of many herds of yellow monkeys, flying squirrels and silver-headed parrots. The third lake is separated from the second lake by a cliff but they are connected by a small tunnel.

Cat Ba World Biosphere Reserve Site

The Cat Ba Archipelago, occupying an area of 300 square kilometres, is located in Quang Ninh Province between longitudes 106°52′E and 107°07′E and latitudes 20°42′N and 20°54′N in northeastern Vietnam. Cat Ba Island (Figure 10) is a very

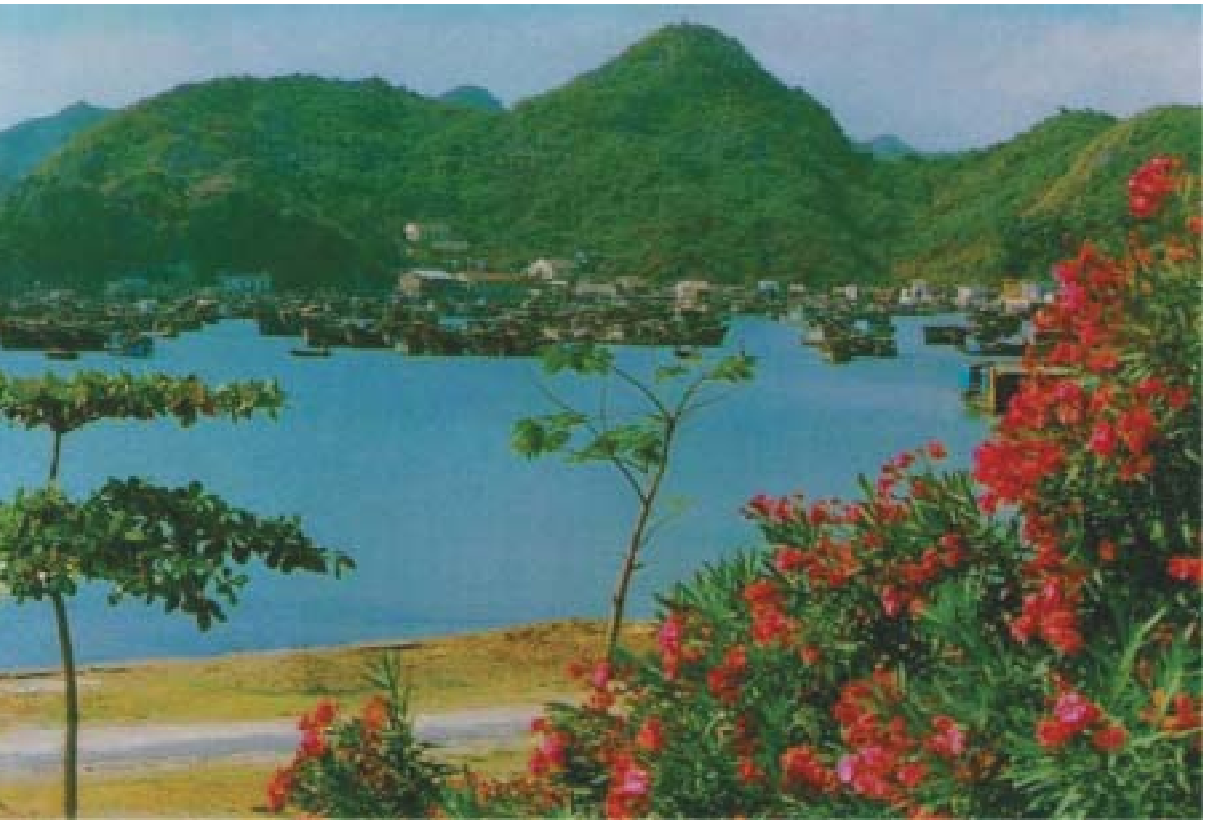


Figure 10. Road built along the coast and through Cat Ba Island
(*Photograph courtesy of Cat Ba Archipelago Biosphere Reserve Management*).

beautiful island. It is the largest of the group, rising to an elevation of about 70 metres. It is also known as *Ngoc* or Jasper Island. Other smaller islands include Cat Ong, Cat Duoi, May, Quai Xanh and Tai Ke.

Geological History and Structure

The Cat Ba archipelago forms part of a large area of folded rocks known as the Quang Ninh anticlinorium. The area has a long and varied geological history (see Table 2, Appendix 1) with rocks ranging in age from about 400 million years old up to a few thousand years old. The discovery of the boundary marking the transition from rocks of Late Devonian age to those of Early Carboniferous age, dated at 359 million years before present, is of considerable geological importance. VIGMR is currently collaborating with the Management Board of the Cat Ba Biosphere Reserve, Hai Phong, to develop a project for its establishment as a geopark.

Special Natural Attractions

Like Ha Long Bay the main morphological features of the Cat Ba archipelago reflect its origin as an area of karst that has been partly submerged. The beautiful landscape of Cat Ba features various landforms of typical karst, such as the elongate valleys along geological faults, numerous caves and intricately shaped limestone hills. The latter emerge above the current sea-level as small islands, together make up the interesting and beautiful landscape. There are about one hundred beaches of various sizes in this area including many (e.g. Cat Tien, Cat Co 2, Cat Co 3, Cat Dua) that are justifiably famous. The main cave systems such as Trung Trang, Thien Long, Hoa Cuong and Quan Y, the lagoons or *Tung* such as as Vung Tung, Dinh Tung and Cai Beo Landing, and the abundant plant cover of the primary forests found in Kim Giao and Ao Ec are either of special geomorphological or biological value.

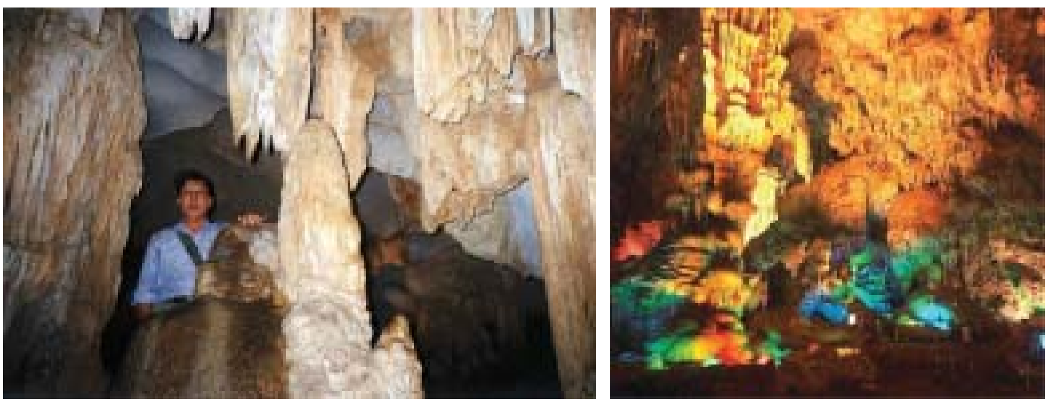
Beaches

Though their sizes are small, Cat Co I, Cat Co 2, Cat Dua, Cat Ong and Duong Danh Beaches are very beautiful with white sand and crystal clear sea water (Figure 11). The construction of aquatic galleries is planned in order to allow easy observation of marine life in its natural environment.

Figure 11. White sandy beach on Monkey Island, Cat Ba area (*Photograph courtesy of Cat Ba Archipelago Biosphere Reserve Management*).

Caves

As in Ha Long Bay, the various caves of the Cat Ba Archipelago (Figure 12) can also be divided into three groups, each of which is found at different altitudes. The first group of caves comprises those with floors at the current sea level, and is the most numerous and the most popular. The second group, with cave elevation about 15 metres above sea-level is usually found surrounding the small isles. These caves usually penetrate deeply into the isles with many beautiful stalactites, cave dwelling snails and the fossilised bones of various animals. The third group of caves is distributed at an altitude of 40 metres. Some of the caves in Cat Ba archipelago are also archaeological relic sites of the Cai Beo Culture.



(a) (b)

Figure 12. Among beautiful stalactites and stalagmites of, a) Phi Long Cave (*Photograph courtesy of Nguyen Viet Hung*), and b) Hoa Cuong Cave (*Photograph courtesy of Cat Ba Archipelago Biosphere Reserve Management*).

Trung Trang Cavern – Trung Trang cavern is 279 metres in length, located about 15 kilometres from Cat Ba Town, containing many beautiful stalactites. The cavern is wide enough to accommodate hundreds of people.

Hung Son Cavern – Hung Son cavern is located 13 kilometres from Cat Ba Town. It is a rather wide cave with a 100 metres long passage. This cave is also known as Quan Y, which refers to its role as a hospital, with hundreds of beds which was built in the cave during the patriotic war of the Vietnamese people.

Biodiversity

Cat Ba Archipelago is highly significant for its biodiversity. There are 2,320 animal and plant species, about 60 of these species, including the Cat Ba Langur (*Trachypithecus poliocephalus*) are considered to be endemic and are classified as rare species threatened by extinction in Vietnam. With its great value in biological diversity, UNESCO recognized Cat Ba Archipelago as a World Biosphere Reserve in December 2004.

Phong Nha-Ke Bang World Natural Heritage Site

Phong Nha - Ke Bang is an area of karst located within latitudes 17°21′N and 17°39′N and longitudes 105°57′E and 106°24′E in the Bo Trach District, Quang Binh Province. It has outstanding value for its geological history, geomorphology and special aesthetic landscape.

Geoscientists from Hanoi National University in cooperation with speleologists from the Royal United Kingdom Geographical Association and geoscientists from the Department of Geology and Minerals of Vietnam have carried out research activities on geology and caves in order to help the Phong Nha - Ke Bang National Park to be recognized as a World Natural Heritage Site. It was formally recognised by UNESCO for its geologic and geomorphic values in 2003. Besides the caves found in the Phong Nha-Ke Bang area, there are fourteen other caves found in the adjacent Quang Binh Province with a total length of 7,410 metres.

Geological History

Phong Nha - Ke Bang old karst area is one of the most important geoheritage sites in the World where many different rock types were formed during its long geological history which extended from the Ordovician Period (450 Million years ago) to the present. During this long history, the area experienced repeated cycles of subsidence, volcanism, sedimentary basin formation, metamorphism and uplift (Table 3, Appendix 1). Sedimentary rocks of various ages, including limestones, are common within the region forming the foundations of its present-day karst landscape.

The formation of the Phong Nha-Ke Bang karst began over sixty-five million years ago and developed through various tectonic events of differing ages including the Oligocene, Miocene, Pliocene, Early Pleistocene, Middle-Late Pleistocene, Late Pleistocene and Early-Middle Holocene events (see Table 3, Appendix 1). These events are reflected in the different episodes of cave development and of planation surfaces during the evolution of the landscape that we see today. The wide varieties of cave types such as river, dry, stepped, hanging and dendritic caves which are famous features of this karst area, are related to the various episodes of cave development influenced by different tectonic cycles, either crustal uplift or subsidence.

Features of the Phong Nha-Ke Bang landscape are typical of karst formed in damp tropical conditions where the mechanical and chemical erosion rates are very high. Extensive limestone dissolution on cave walls and ceilings, sandy-grit beaches, terraced and alluvial flats, terrigenous sediments in underground rivers and the alluvial fans of tunnel caves are among evidence of the wet tropical environment in which the Phong Nha-Ke Bang karst was developed.

Caves

In the Phong Nha - Ke Bang area there are well developed underground streams in the cave system and these are called *river caves*. Three cave systems have been found in this area. They are Phong Nha Cave System (about 45 kilometres long); Vom Cave System (about 30 kilometres long) and Ruc Mon Cave System. Vom and Phong Nha Cave Systems are located in Bo Trach District, whereas the Ruc Mon Cave System is located in Minh Hoa District.

Vom Cave System. This system comprises modern river caves of considerable size extending from Ruc Ca Roong Cave at about 360 metres above sea level. The general trend of the cave system, which was developed along a main fault, is north-south. The Ruc Ca Roong River flows into Chay River at the Vom Cave entrance. After disappearing underground in places, the river then joins the Son River and finally the Gianh River before flowing into the sea. The total length of the river system is about 50 kilometres.

Phong Nha Cave System (Figure 13). The system begins in the southern part of the Ke Bang limestone massif. Access to the cave system is through the Khe Ry and En Caves at about 300 metres above sea level. En Cave has two entrances:

Figure 13. various features of the Phong Nha cave system. a) Phong Nha Cave entrance in the south of Ke bang limestone massif, viewed from helicopter, b) underground river flowing between cliffs in Phong Nha, c) one of the tunnels in Phong Nha Cave, d) Tunnel in Phong Nha Cave. (*Figure 13a – courtesy of Lee Huy Cuong; Figures 13b,c,d – courtesy of Limbert H.*)

the lower entrance is 15 metres high and 70 metres wide, and the higher entrance is 70 metres high and 100 metres wide. The exit of this cave is 170 metres wide and about 100 metres high. The general direction of these caves is northeast-southwest.

Both Vom and Phong Nha cave systems are developed along fractures within limestone massifs, with all of their entrances and exits positioned at the present day stream level. They are considered as the biggest river cave systems in Asia. In terms of morphology, most of the caves are high and wide with many tunnels and wide galleries. Almost all the caves are connected with one another with a rather complicated network. Multiple cycles of cave formation are expressed in the different levels of the floors. At least four levels of cave floors have been identified. The 0 level is the present stream level and the others are at 20±5, 40±10 and 90±10 metres above the 0 level. All the four levels (at 0, 24, 43 and 93 metres) can be observed at Vuot Cave of the Vom Cave System. In these caves there exist many dripstones, creating colourful stalactites, stalagmites and various other limestone solution features. Meanwhile, underground river sediments such as pebbles, gravels and sand are found deposited on the floor of the En, Khe Ry (Figure 14) and Dai Cao caves, most of which were consolidated by calcareous cement.

(a) (b)

(c)

Figure 14. Several more cave features and river deposited sediments within the Phong Nha Cave System. a) Gravel accumulations on the bed of an underground river in Khe Ry Cave, b) Puddle in Labyrinth Cave (in dry season), c) Ceiling and floor of Dai Cao Cave entrance also composed of conglomerate. (*All photographs are courtesy of Limbert, H.*)

The river caves described above are also known locally as active caves. There are other caves which once contained ancient water courses such as the Fairy and Dry Phong Nha Caves, and these caves contain many beautiful stalactites, relics of animal remains and Terracotta pottery fragments showing that they were once a Pre-historic places of abode. Some of the dry caves such as Chay (Soap) and Wine Plant Caves do not contain any dripstones.

Figure 15. Dripstones in dry Phong Nha Cave (*Photograph courtesy of Limbert, H.*)

Diversity of Mineral and Other Geological Resources

Various metallic mineral resources were found in the area including iron, hydrothermal pyrite, manganese, vanadium, copper, lead, arsenic and gold. Non-metallic mineral resources include fertilizer materials, phosphorite, clay, kaolin, peat, combustible shale, while construction materials such as limestone, clay, kaolin and sand are also abundant. Thermal and mineral water sources are found at two places near a fault at No Bo and Dong Nghen. Some of these resources apparently have the potential for economic exploitation, a fact that could cause conservation problems in the future.

Ba Be National Park

Ba Be National Park, highly regarded for its biodiversity, is located in Ba Be District in the northwest of Bac Can Province (Figure 1). The Vietnam Institute of Geology and Mineral Resources (VIGMR) is currently assisting the People's Committee of Bac Kan Province in its application for Ba Be National Park to be recognized as a World Natural Heritage Site because of its geological, geomorphic and aesthetic values.

The park is covering an area of 10,080 hectares, and was first established in 1992 in order to preserve the forest ecosystems found on mountainous limestone terrain of northeast Vietnam. It was recognized in 2004 as one of twenty-seven ASEAN Heritage areas. It is important because of its geological history, its special natural phenomena and aesthetic landscapes.

Geological History and Structure

The varied rocks and complex geological structures of the area are the result of a long and complicated geological history (Table 4, Appendix 1). The Park is located at the junction of the major NW-SE and NE-SW trending fault systems of NE Vietnam. These fault systems were developed several hundreds of million years ago and have occasionally reactivated from time to time. The activity was especially strong at the end of the Triassic Period and during the Cenozoic Era (tens of millions of years ago and ten thousand years ago respectively). In its early stages, these faults were influential in controlling the formation of Ba Be sedimentary basin in the north and east of Vietnam, thus facilitating the deposition of the Ba Be limestone more than 300 million years ago. Subsequently, the whole area was uplifted and became continental when karstification of limestone terrain commenced. Metamorphism of the Ba Be limestone caused by granitic intrusion at the end of Triassic Era (about two hundred million years ago), is another significant natural factor as it has locally impeded further karstification and contributed to the preservation of the older karst landscape.

Landscape Development

The present day topographic expression from movements of various faults is apparent in the strong dissection of the Ba Be area resulting in the formation of stepped topography with very well developed river system. This area has the highest density of water courses in the country (2-2.5 kilometres per square kilometres). The faults in the Ba Be Lake area are typical representatives of the sub-longitudinal fault system which was very active during the Cenozoic Era, related to movement along the famous Red River deep-seated fault. The Ba Be, Pe Leng, Pe Lu and Pe Lam Lakes were all formed at the intersections of the NW-SE and NE-SW fault systems. Movements upon faults caused a block of the crust, namely the Ba Be Limestone Block, to be lifted up, separating it from the surrounding formations. Eventually this resulted in a number of outstanding topographic features within the uplifted limestone area. These included the ‘cut-off’ of river meanders which then became oxbow lakes with high river terrace levels in Ban Vai (in the East), the Nang River ravine which is narrow and straight, the Dau Dang Waterfall, the blind valley (Mu Valley) in Coc Lung and the Cho Leng river ravine. Block uplifts also created the stepped relief of the landscape with several planation surfaces, plateaus, pediment valleys, river terraces and especially cave systems at six or seven different altitudes.

Geological factors also prevented Ba Be Lake from losing water by draining through the cavities and fractures that are typical in many other karst areas. The lake was formed in a tectonic depression, or basin, where impervious clayey sediments accumulated, acting as effective water tight liners. Besides, the underlying Ba Be limestone has also been strongly metamorphosed into marble.

Old Alluvial Fan Series

The formation of a giant alluvial fan series in Quang Khe, along a NE-SW fault, is illustrative of the influence of strong tectonic activity combined with high storm rainfall simultaneously affecting the area. Subsequently the alluvial fans became the main source of material contributing to the Ba Be lake sedimentation.

The old alluvial fan series in Quang Khe forms a special landscape consisting of many alluvial fans connected together and extending for as much as seven kilometres from the the Cho Leng River to Ban Pian. They are composed of blocks and boulders of granite and of weathered materials rich in kaolin and clay minerals. Each fan is 1-2 kilometres wide, extending in a northeasternly direction towards the top of Phia Bioc Mountain, about 100-200 metres above the Cho Leng River valley. The lower parts of the fans have partially been reworked by the overflowing Cho Leng River and forms flat terraces. Some granite blocks as large as houses are found either on the fan slopes or lying at the foot of limestone cliffs on the left bank of Cho Leng River (Figure 16). They are relics of the old alluvial fans that have been partially eroded by the Cho Leng River. The fans might have been formed during periods of high storm rainfall causing high surface run-off, combined with the added effects of earthquakes during the Middle Pleistocene Epoch, several hundred thousand years ago. Material derived from weathering of the granite boulders was the main source of the clay-rich sediments filling the bottom of the Ba Be valley before the lake was formed.

Karst Plateau

The karst plateau in the Ba Be area exhibits a unique plateau landscape at two different elevations. Both the higher and lower karst plateau are composed of marble of the Ba Be and Pia Phuong formations forming surface residual karst landscapes. On marble of the Ba Be Formation, towers and pyramids of different heights are developed surrounding sinkholes and deep dolines. Among typical high karst plateau in Ba Be formation are the Nam Mau, Cot Co, West Na Co, Na Poong and Pu Luong massifs, while lower ones are represented by the East Ban Cam, Khau Qua, Doc Cum and North Cot Co massifs. Interconnected conical hills with thick alluvial cover, rising from long and wide karst valleys, were developed in limestone of the

Figure 16. Large granite boulders on the limestone slope on the left side of Cho Leng River. (*Photograph courtesy of Tran Tan Van*).

Pia Phuong Formation. Typical high karst plateau in Pia Phuong formation is the Tam Tat massif, whereas the better-known low karst plateaux are the Cao Tri and Xuan Lac massifs.

Nang River Karst Ravine

The formation of the Nang River ravine (Figure 17) and Ba Be Lake, about ten thousand years ago, are examples of crustal instability in this area. A strong earthquake caused the collapse of the roof of a cave, many kilometres long, extending from Puong Cave to the present site of Dau Dang Waterfall. The collapse exposed an underground river and formed a massive ravine with precipitous sides. The river channel became infilled and locally uplifted to form a natural dam, creating the Ba Be Lake (see below).

The Nang River karst ravine consists of WNW and NE branches that join together in a V-shape, one kilometre to the west of the Nang River outlet from the Ba Be Lake. The ravine extends for more than ten kilometres. The WNW branch has walls about 400 metres high where the Dau Dang Waterfall is located, whereas the walls of the NE branch of the ravine are roughly 150 metres in height. The Nang River, which flows in the ravine has created a 2.5 to 3 metres high flood plain due to the accumulation of thick sand layers. Consequently, no

Figure 17. Scene from Nang River Karst Ravine. (*Photograph courtesy of Tran Tan Van*).

bedrock outcrops are seen in the river bed. On the vertical ravine walls, remnants of cave entrances with collapsed roofs are found. Some remaining small stalagmites are still be seen. Located at the end of the NE branch is the Puong Cave, where Nang River flows underground for 150-200 metres before re-surfacing. Over the roof of Puong Cave two rather flat terraces at elevations of 60 and 100-120 metres are found, proving that in the past the old Nang River used to flow on the surface above the roof of the cave.

Dau Dang Waterfall

The 85 metres high Dau Dang Waterfall on the Nang River forms a magnificent cascade of water amidst primary forest. The waterfall was not formed by travertine terraces as commonly occurred in other areas. Here, following the collapse of the caves that created the Nang River ravine, the river had to find a new course by negotiating its way over huge piles of fallen limestone blocks at the base of the ravine and the Dau Dang Waterfall was one spectacular outcome. Specimens of the rare giant devil catfish (*Bagarius yarrelli),* some weighing more than 10 kilograms, can be found at the Dau Dang Waterfall.

Ba Be Karst Lake

Ba Be Lake (Figure 18) is a unique lacustrine phenomenon, comprising three interconnected lakes, the Pe Leng, Pe Lu and Pe Lam. It is 9 kilometres long, 0.2

Figure 18. Ba Be Lake in the middle of the limestone plateaux. (*Photograph courtesy of Tran Tan Van*).

kilometres to 1.7 kilometres wide, with a total perimetre of 22 kilometres. Its maximum depth is 29 metres. The total water surface area is about 4.5 square kilometers, with total water volume of about 90 million cubic metres. The lake receives water from two main surface sources; the Ta Dieng and Cho Leng Rivers. In the North, the lake narrows into a small and shallow stream called Pe Cam which flows into the Nang River during the dry season, but when flood occur in the rainy season, the water flow is reversed back into the lake. The lake lies at an elevation of 150 metres above sea level, between 800-900 metres high limestone hills. This situation creates a natural landscape of exceptional beauty.

Before the formation of the lake, the Ba Be valley used to be a normal river channel, a fact indicated by evidence provided by relics of the second river terrace found on An Ma Isle, twenty metres above the present lake water level, and alluvial deposits in the Fairy Cave ten metres above the present lake water level. Moreover, recent geomorphological studies indicate that limestone isles in the lake, such as the An Ma Widow Isle, are the products of ancient landslides that descended the neighboring limestone slopes.

Some researchers considered that current sites of the Pe Leng, Pe Lu and Pe Lam lakes used to be normal karst plains with numerous funnels and sinkholes as well as other karst features. The lowest cave level in the lake area is found at the elevation of 8-10 metres above the lake surface and 30-40 metres above the lake bottom. It is highly probable that there are more caves at lower levels that have been submerged or filled by sediments. In the past, together with karst funnels and sinkholes these might have served as underground water drainage from the valley and the lake. On cliffs to the east of Cho Leng River in Bac Ngoi, there are remnants of cave entrances which were covered by collapsed roof material and subsequently cemented by travertine. This indicates that along the Cho Leng valley, there are collapsed caves similar to those along the Nang River.

It is to be noted that the Ba Be valley was already populated in prehistoric times by people who left many tools identified as belonging to the Early Neolithic period. The formation of Ba Be Lake appears to have interrupted habitation by ancient people in the area. These archaeological findings have contributed to our understanding of the formation of Ba Be Lake as a unique event in ancient history of Vietnam.

In summary, Ba Be Lake is a beautiful large natural fresh water mountain lake. Such lakes in limestone mountain areas formed by the combined effects of fault movements and natural blockage of rivers, are extremely rare. Therefore, in 1995, Ba Be Lake was recognized by the Conference on World’s Fresh Water Lakes as one of the twenty special fresh water lakes of the world that needed to be protected.

Caves

Like other karst areas of Vietnam many spectacular caves are found in the Ba Be National Park and several of them are briefly described below.

Dong Troi Cave. Located in Cho Leng Hamlet, Dong Troi Cave (Figure 19) is is one of the most beautiful caves in Ba Be National Park. It is an inclined fossil cave with waterfalls. In the deeper parts of the cave, its floor becomes flat, and stalagmites and other speleothems form pillars that divide the cave into many chambers. Glazed Terracotta ceramic fragments of the Le Dynasty have been found in the cave.

Bup Lom Cave. Located in Pian Hamlet, this cave extends for over five hundred metres. It is a fossil cave that used to connect a small valley with the Cho Leng River. Numerous speleothems in the cave are of various shapes and colours. There are some small bodies of water hemmed in by travertine and near the end of the cave there is a chamber of about 3,000 square metres.

Figure 19. Among dripstones in Dong Troi Cave. (*Photograph courtesy of Tran Tan Van*).

Ban Piac Cave. Ban Piac Cave (Figure 20) is the year round source of water for cultivation in the karst valley surrounding Piac Hamlet. The cave system consists of a series of interconnected caves and has three water discharge points, flowing into a stream which later joins the Cho Leng River. The cave has two different water sources from the Ban Lum karstic valley to the northwest and from the Na Co Hamlet karstic valley.

Figure 20. Some stalactites, curtain rocks and various other cave deposits within Ban Piac Cave. (*Photograph courtesy of Tran Tan Van*).

Pac Chan Cave. The Pac Chan Cave (Figure 21) is located to the south of Com Poong Hamlet in Nam Cuong Commune. It is a very large (~100 metres wide and 50 metres high), airy and beautiful fossil cave with great potential for tourism. The large entrance to the cave (31 metres wide and 41 metres high) is semi-circular in shape. Inside, the cave has many huge stone pillars reaching to the roof. As the cave becomes deeper the stalactites become more variable in form, but remain the same size. The lowest part of the cave is a large fissure formed by erosion. The cave ends at a spectacular gallery with numerous different types of stalactite.

Figure 21. Pac Chan Cave entrance. (*Photograph courtesy of Tran Tan Van*).

Na Phong Cave. The Na Phong Cave is located in the Bo Lu Hamlet of Nam Mau Commune. There is an underground river, the Na Phong River, in this cave and it is the largest river in Ba Be National Park. The cave, with a passage 8-26 metres wide is not steep, and some sandy dunes have formed along its two sides, reaching a height of several metres. The cave also contains some beautiful stalactites.

Puong Cave. Puong Cave is located where the Nang River flows through the Ba Be National Park after passing different geological formations from the east of Cho Ra region. The cave is 200 metres long and 25-30 metres high on average, with imposing stone pillars of various shapes. The walls are almost vertical and the roof is dome-shaped. The cave is also the home of thousands of bats and has two exits where visiting tourists can stop and take a rest. Puong Cave is an attractive and unique ecotourism site.

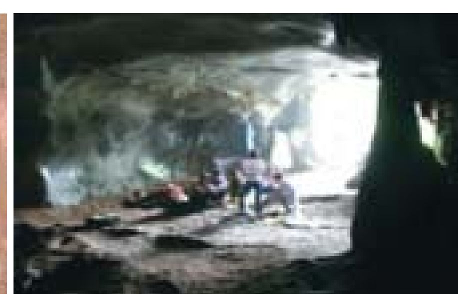
Cuc Phuong National Garden Heritage Site, Ngoc Son-Ngo Luong Natural Conservation Site and Pu Luong Natural Conservation Site

From 2003 to 2004, VIGMR carried out a research on the geology, geomorphology and landscape values of Pu Luong, Thanh Hoa Province and assisted the People's Committee of Hoa Binh province in establishing Ngoc Son - Ngo Luong Natural Conservation Site.

Placodontia Reptile Fossil Site (Figure 22)
Placodontia reptile fossil site is located at E 105°39'46" and N 20°16'50" in Cuc Phuong, Ninh Binh. The fossils are found on a cliff made of dark grey thinly-bedded limestone of the Dong Giao Formation (Middle Triassic, over two hundred million years old). The exposed fossiliferous section of the formation contained eighteen fossil vertebrae, twelve of which are undamaged. Because no head, pelvis or limb bones have yet been found, the specific identity of the Placodontia still awaits confirmation.

There are two types of Placodontia reptiles at this site. The first is a relatively big reptile with no scales, long tail and long slender body, while the second type includes reptiles such as tortoises that had a heavy carapace. Both types had strong teeth. Placodontia was an animal living in shallow water marine conditions. The earliest discovery of Placodontia was in rocks of Lower to Middle Triassic age in Israel. Placodontia development reached its peak during the Middle Triassic Period and they entirely disappeared at the end of the Triassic Period. If the preliminary identification of the Cuc Phuong fossil is confirmed, it represents the first discovery of Placodontia in Southeast Asia.

(a)



(b)

Figure 22. Some geoheritage features within Cuc Phuong National Garden Heritage Site,
a) Placodontia (reptile) fossil ***(photograph courtesy of Nguyen Viet Hung)*****,**
b) pre-historic People's Cave ***(photograph courtesy of Cuc Phuong National Garden Management).***

Caves in Hoa Binh Province

Several interesting caves are found in the Tan Lac District of Hoa Binh Province including the Dragon and High Wave Caves. Dragon Cave (Figure 23) contains a 50 metres long and 40 metres wide lake containing crystal-clear water. This lake is a perfectly natural cave with many stalactites suspended from the 15-20 metres high roof and stalagmites rising from the floor of the lake. High Wave Cave, a short walk from Dragon Cave, is another very large cave with attractive stalactites and containing another, deeper lake (Figure 24).

Figure 23. Calcite precipitation in Dragon Lake. (*Photograph courtesy of Tran Tan Van*).

Figure 24. Deckenkarrens, stalagmites in Swan Lake. (*Photograph courtesy of Tran Tan Van*).

Lang Son and Na Duong Heritage Sites, Lang Son Province

Tam Than Cave System

The very beautiful Tam Thanh Cave System, including the Nhat Thanh, Nhi Thanh and Tam Thanh caves is found in the Lang Son area. The most famous is the Tam Thanh Cave (Figure 25) that is located on the slope of a mountain range. The cave has stalagmites resembling herd of elephants kneeling on a green pasture. The cave entrance is a passage of 30 steps, about 8 metres high, chiseled into the mountain side. A poem by Ngo Thi Si praising the beauty of nature was carved on the right wall of the cave when he was the Governor of Lang Son Province.

Figure 25. Some tourism infrastructures built in the beautiful Tam Thanh Cave. (*Photograph courtesy of Lang Son Department of Culture, Sport and Tourism*).

Tam Thanh Cave with its numerous stalactities and stalagmites was discovered in the time of the Le Dynasty. In a book entitled *Dai Nam Nhat Thong Chi*, there is a note that records that Tam Thanh Pagoda was in the mountain cave of Vinh Trai commune, Thoat Lang Chau (an old administrative unit in the highlands), now known as Tam Thanh Ward, Lang Son City. A statue of Buddha Amitabha, which was carved on the cave wall during the XV Century, is a work of art of great value. Am Ti Lake or the Underworld Lake is also situated in the cave and is notable for its clear water that is never depleted throughout the year.

In Nhi Thanh Cave, there are many statues of saints arranged in a variety of ways for worshipping. The cave is associated with a famous man, Ngo Thi Sy, who served as Lang Son Governor from 1777 to 1780. During a short period of time, he transformed Lang Son to become prominent in politics, economics and national defense. Especially in culture, he is merited as discovering the eight beautiful sites of the Lang Son area and one of these is the Nhi Thanh Cave. In May 1779, he hired workers to develop the cave area and to build the pagoda there. The Tam Giao Pagoda was built in the higher Tam Giao Cave**,** honouring three Saints, Confucius, Laozi and Buddha Sakyamuni. Nhi Thanh Cave, below Tam Giao Cave, is a natural rock shelter, extending for 500 metres from the front entrance to the rear exit. Inscriptions of famous poets and other personalities are still preserved on some of the cave walls. The figure of Ngo Thi Sy was also carved here in 1779. These are a valuable source of historical information about Lang Son.

Fairy Pagoda Cave and Fairy Well

The Fairy Pagoda Cave and Fairy Well are located in Dai Tuong Mountain about 500 metres from the Ky Cung Bridge on the road to Mai Pha. Fairy Pagoda Cave (Figure 26) is one of the eight beautiful landscapes noted by Ngo Thi Sy. It is found on the slope of the mountain, with 64 steps climbing up to the entrance. In the cave are many dripstones taking the appearance of old men, elephants or flying bats. The Fairy Pagoda, also known as Song Tien Pagoda, was erected in the cave during Hong Duc's time (1460-1497). Many tombstones of writers and famous people can be seen in this pagoda. On a flat rock platform, half way up the slope behind Dai Tuong Mountain, is the Fairy Well, a 20 centimetres diameter well through which groundwater flows all the year round.

Figure 26. "Fairy Field" in Wind Cave, Lang Son Province. (*Photograph courtesy of Nguyen Viet Hung*).

Mau Son Tourist Area

The Mau Son tourist area, located about 15 kilometres northeast of Lang Son City, is a high mountain range extending in an east-west direction. In this range, there are many mountain peaks that resemble standing people. The highest mountain, called Mother Mountain, rises to 1,541 metres above sea level. The average temperature here is 15.5°C and the mountains are shrouded in clouds throughout the year, making this area ideal as mountain resort. In 1935, the French built numerous resort houses here and nowadays, Lang Son Province is building facilities to serve holiday makers and tourists. Visitors can learn of the culture, tradition and the music and songs of the ethnic minority people such as the Dao, Nung, Tay and others.

Na Duong-Rinh Chua Botanic Fossil Heritage Sites

The Na Duong fossil site is located at E 106°57’34”and N 21°42’16” and the Rinh Chua fossil site is at E 106°58’36” and N 21°44’57” both in the Loc Binh District of Lang Son Province. Na Duong is a favorite area for the study of Neogene paleontology and stratigraphy because of the abundant and diverse and known distribution of the fossil types in the area.

Sedimentary rocks that make up the Na Duong and Rhin Chua Formations (Miocene to Pliocene Epochs) contain an abundance of plant fossils including leaves, fruits, seed imprints, spores, pollen and silicified woods as well as fossils of molluscs and insects (Figure 27a). The changing environments in which the various floral assemblages thrived between 11 and 3.5 million years ago can be interpreted in detail from its rich fossil heritage.

Fossil wood is found at Na Duong Coal Mine and two very large, well-preserved cones of Pinophyta (Figure 27b) have been extracted from the the mine waste and are now exhibited at the Vietnam Geological Museum in Hanoi. Abundant silicified wood has also been found in this area.

(a) (b)

Figure 27. Various fossils from Na Duong Coal Mine. a) traces of insects’ holes in a fossilized trunk, b) fossilized cones of *Pinophyta* (*Photograph courtesy of Nguyen Viet Hung*).

Molluscs are preserved in sedimentary rocks that were formed some 5 to 11 million years ago. The molluscs here are of fresh water species, mainly bivalves and gastropods. Some very large gastropods are common in slightly younger (approximately 2 to 5 million years old) rocks in the Rhin Chua area. Fossil insects are rare but when found, they are often well preserved. Of the vertebrates**,** fresh water crocodile and bony fish fossils have been collected.

Other Geoheritage Sites

Ba Lang An Columnar Basalt

Ba Lang An Cape is located in the Son Tinh and Binh Son Districts, Quang Ngai Province. Here, columnar basalt of Pliocene age cropped out both along the coast and on some of the islands. During the rapid cooling of liquid magma, the basalt became fractured in many directions, forming numerous five to seven metres long rock pillars or columns with different attitudes. Oblique, horizontal or closely-packed vertical pillars are all abundantly developed. The cross sections of the rock pillars also came in various shapes, from quadrangular to pentagonal or hexagonal, commonly 15-20 centimetres but sometimes up to 30 centimetres across. These and other assemblages of strangely shaped rock pillars form attractive features at coastal cliffs.

Tuy An Dish Rock Cliff

Tuy An Dish rocky cliff (Figure 28) is located at E 109°17’52”and N 13°21’19” in the An Ninh Dong commune, Tuy An District, Phu Yen Province. It is a *National Natural Landscape Monument* and comprises a 300 metres long stretch of coastal outcrop of Pliocene columnar basalt similar to that found at the Ba Lang An site. The vertical columns of basalt have been split by numerous horizontal fractures so they look like stacks of dishes.

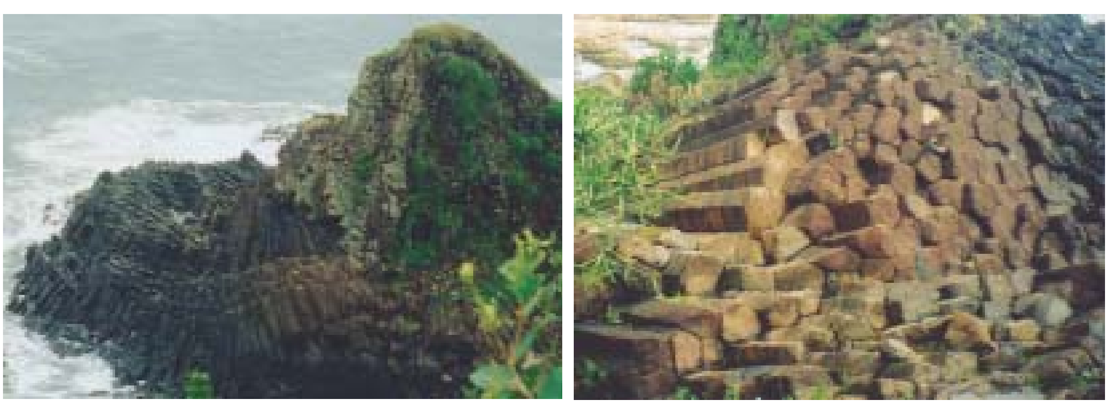


Figure 28. Various attitudes of columnar basalt exposed along Tuy An rocky cliff. (*Photograph courtesy of Nguyen Viet Hung*).

Dragon Jaw Crater

Dragon Jaw Crater is an extinct volcano located at E 108°01'10" and N 13°52'53" in the Bang Commune, Mang Jang District, Gia Lai Province, about 10 kilometres south of Pleiku City. It is composed of basalt between about 1 and 2.5 million years old, and its shape varies according to the direction from which it is viewed. From Pleiku City in the north, the crater exhibits a symmetrical trapezoidal shape (Figure 29), but from the south, the crater has a rounded shape, where a rather wide lava canal can be seen. During eruption of the volcano, lava from the crater cut through the plateau surface and flowed to the south. The plateau is now forested and the local people cultivate their crops inside the Dragon Jaw Crater.

Figure 29. Dragon Jaw volcanic cone crater as seen from Pleiku Town, Gia Lai Province. (*Photograph courtesy of Nguyen Viet Hung*).

Bien Ho Crater

The Bien Ho Crater, actually a composite structure formed from four originally separate craters, is located in the Bien Ho Commune, Pleiku Town, Gia Lai Province. Pleiku Town and the surrounding area lie on a basalt dome with twenty craters of different sizes, in groups of 2-4, are found in various places. At Bien Ho, following the eruption of basaltic magma, the area underlying several craters collapsed and a lake was formed in the resulted depression at an elevation of about 730 metres. A peninsula extending into the middle of the lake indicates an edge of one of the former craters that makes up this composite structure.

Figure 30. Bien Ho volcanic caldera in Gia Lai Province. (*Photograph courtesy of Nguyen Viet Hung*).

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APPENDIX 1
TABLES SUMMARISING GEOLOGICAL HISTORY OF SOME GEOHERITAGE SITES

Table 1. Geological history of Ha Long Bay World Heritage Site

Period	Age	Geological development
Pre-Cambrian	3 - 0.542 Ga	Formation of crystalline basement of ultra-metamorphic rocks (granite, amphibolite), cropping out in several areas around Bac Bo Gulf (Red River, China). One billion years ago, the area was rifted apart, developed into sedimentary basins and volcanic arcs. 550 million years ago, Gondwana mainland was formed; Bac Bo Gulf area drifted and accreted to the continent of Asia.
Cambrian – Silurian	542 - 416 Ma	Deposition of Co To, Tan Mai, Kien An formations. They consist of sericite-quartz schist, siliceous-schist, tuff gritstone, sandstone, and silty-clay. The total thickness is 2,000-3,000 metres.
Devonian – Early Carboniferous	416 - 340 Ma	Deposition of Mia Le, Duong Dong, Do Son, Trang Kenh, Ban Pap, Pho Han, Cat Ba formations. Their composition consists of quartzitic sandstone, clay-shale, calcareous marl, agrillaceous-limestone, calcareous sandstone, limestone, sericite quartz schist and siliceous shale. The total thickness is 2,000-2,500 metres.
Early Carboniferous – Permian	340 - 250 Ma	Deposition of Bac Son limestone formation which crops out mainly in Ha Long Bay littoral islands. The total thickness is up to 1,000 metres.
Triassic – Jurassic	250 - 160 Ma	Deposition of terrigenous sediments (sandstone, siltstone, claystone), intercalated with effusive rocks of Binh Lieu, Na Khuat, Mau Son formations and coal-bearing terrigenous sediment of Van Lang and Hon Gai formations. They are well-known for their abundance and diversity of fora fossils. The total thickness is 2,200-3,800 metres.
Late Jurassic – Cretaceous	160 - 65 Ma	The region was strongly activated. Ban Hang sediment, Ha Coi red coarse-grained clastic continental sediments were deposited. The total thickness is 800-1,000 metres.
Cenozoic	65 Ma - present	Fluvio-lacustrine, deltaic sediments alternate with shallow marine sediments with thickness of 3000-6000 metres. Particularly, these sediments have indications of being petroleum-bearing. Quaternary basalts are present in some places. Since Middle Holocene, the marine island system has been formed in Bac Bo Gulf.

Table 2. Geological history of Cat Ba Archipelago

Stage	Age	Geological development
Devonian-Early Carboniferous	416 - 326 Ma	Deposition of sediments of Pho Han, Cat Ba formations comprising clay-shale, calcareous marl, argillaceous limestone, calcareous sandstone and siltstone and limestone. The total thickness is 2,000-2,500 metres.
Early Carboniferous – Permian	326 - 250 Ma	Deposition of limestone of Bac Son formation, which crops out in many isles and coastal areas of Ha Long Bay region. Total thickness is about 1,000 metres.
Triassic – Jurassic – Permian	250 - 160 Ma	Deposition of terrigenous sediments intercalated with effusive volcanic rocks of Binh Lieu, Na Khuat, Mau Son formations, coal-bearing terrigenous sediment of Van Lang, Hon Gai formations with diverse and abundant plant fossils. The total thickness is 2,200-3,800 metres.
Late Jurassic – Cretaceous	160 - 65 Ma	The area was strongly folded. Sediments of Ban Hang and the red coarse-grained continental sediments of Ha Coi formations were deposited. The total thickness is 300-1,000 metres.
Cenozoic	65 Ma - present	Fluvio-lacustrine, deltaic and littoral sediments were deposited in a 3-6 kilometres deep rift; the sediments are petroleum bearing, In addition, effusive Quaternary basalt occurs in some places. The sea-isle system at Bac Bo Gulf was formed in the Middle Holocene.

Table 3. Geological history of Phong Nha-Ke Bang World Natural Heritage Site

Stage	Age	Geological development
Middle Cambrian – Ordovician	520 - 460 Ma	The underlying continental crust began to break up and sedimentary basins formed in which carbonate-terrigenous sediments of the A Vuong formation, about 1,550 metres thick, were deposited.
Late Ordovician – Silurian	460 - 416 Ma	The Phong Nha-Ke Bang area began to subside and effusive volcanic rocks of the Long Dai formation were deposited. Subsidence continued and metamorphism at deeper levels formed gneiss and sillimanite schist of the Dai Giang formation (thickness about 900 metres).
Devonian	416 - 359 Ma	In Phong Nha-Ke Bang area a new basin developed; sandy-siltstone, and limestone of the Rao Chan formation, quartzitic sandstone, sandy-siltstone, clay-shale of Ban Giang, Muc Bai, Dong Tho and Cat Dang formations were deposited. The thickness of each formation is about 300-1,500 metres.
Carboniferous – Permian	359 - 251 Ma	Tectonic activity was strong; widespread appearance of Dong Hoi magma, forming Phong Nha, La Khe, Bac Son, and Khe Giua formations with sediments comprising sandy-siltstone, argillite, calcareous marble, and limestone. The Thickness of each is 200-1,000 metres.
Triassic – Cretaceous	251 - 65 Ma	Red coarse-grained clastic continental sediment of the Gia formation was formed. The thickness is about 700 metres.
Cenozoic	65 Ma - present	Strong tectonic activity as a turning-point in the geological evolution of the East Sea caused continental orogeny and formation of sedimentary basins in the intermontagne, foreland and marginal regions of Vietnamese continental shelf. Thickness of Cenozoic sediments is commonly some hundreds of metres.

Table 4. Geological history of Ba Be National Park area

Stages	Age	Geological development
Archean	2.5 - 2.6 Ga	Formation of the Song Chay domal microcontinent in the NW of Ba Be National Park, composing mainly of gneissic granite. The main formations formed later embraced this dome.
Ordovician – Silurian	488 - 408 Ma	Deposition of Phu Ngu formation of abyssal facies in the east of Ba Be National Park with rhythmic intercalations of clayey shale, siltstone, sandstone, lenses of limestone, mafic and acid extrusive rocks. Total thickness is about 2,000-2,300 metres.
Early Devonian	408 - 387 Ma	Deposition of Pia Phuong formation which is widely distributed in the north, west and south of the Ba Be National Park comprising shale, calcareous claystone, marble and calcareous siltstone. The total thickness is about 2,000 metres.
Middle – Late Devonian	387 - 360 Ma	Formation of Ba Be basin and limestone deposition with thickness about 500-600 metres. Subsequently the whole area became continental and karstification started.
Late Triassic (Norian)	231 - 213 Ma	Magmatic intrusion of granite of the Phia Bioc complex metamorphosing the rocks in the area, including the Ba Be limestone into marble, thus impeding karstification.
Cenozoic	65.6 Ma - present	Block tectonic movement in combination with climatic factor created diverse modern, specific and clearly stepped landforms.
Paleogene	65.6 - 23 Ma	Formation of the lower Indochina planation surface of 1,200-1,600 metres.
Miocene	23 - 5.3 Ma	Planation surface of 900-1,200 metres and 600-900 metres.
Pliocene	5.3 - 2.6 Ma	Planation surfaces of 400-600 metres and 150-400 metres, hilly denudation plains
Late Pliocene	2.6 - 1.8 Ma	High and low karstic plateau surfaces (600-900 metres and 350-400 metres), high pediment valleys of 350-400 metres.
Late Pliocene – Early Pleistocene	1.8 -1.6 Ma	Sub-longitudinal fault system (including Ba Be valley), effect of the dextral strike slip along the Red River deep-seated fault. Since then, block tectonic movements have up-lifted the Ba Be limestone block, separating it from the surrounding non-karst formations.
Early Pleistocene	1.6 - 0.7 Ma	Formation of 120 metres level river terrace and the corresponding level of the cave floor.
Middle Pleistocene	700 - 125 Ka	Heavy storm rainfall in cold climatic condition caused large landslides along NE-SW faults, forming a giant alluvial fan series in Quang Khe. Formation of the 40-60 metres river terrace and the corresponding level of the cave floors.
Late Pleistocene relics	125 - 10 Ka	Development of the 20-25 metres, 10-15 metres river terraces and corresponding levels of the cave floors. Notable are the of a 20 metres river terrace on An Ma isle in Ba Be lake, proving that here used to be a surface water flow.
Early Holocene	10 Ka - present	Formation of 8-10 metres river terrace and corresponding levels of the cave floor with alluvium found in the 10 metres high Fairy Cave on the eastern bank of Ba Be lake. Strong earthquakes caused cave roof collapse, forming Nang River ravine. The bottom of the ravine was filled up, forming a natural dam, creating the Ba Be lake.

GLOSSARY

Separator Photo:
Hanging Bridge at the Machinchang Cambrian Geoforest Park, Langkawi, Malaysia.

GLOSSARY

Note: This glossary of some of the geological terms used in this book is intended as a guide to the general reader and should not be regarded as definitive. For more precise and complete definitions a more authoritative dictionary of geology should be consulted.

Aa-lava. See lava, below

Agglomerate. A volcanic deposit formed from variously rounded rock fragments which were ejected from a volcano (see also **Bomb**). The fragments (>6.4 cm) were often in a hot, partially molten form when ejected from the volcano, accumulating on the ground as an agglomerate.

Adamellite. An igneous rock which varies from granite (see below) in containing somewhat less quartz and differing proportions of potassium rich feldspar.

Algae. A diverse group of mainly microscopic, sometimes unicellular, aqueous plants. Considered to be primitive but with very varied and complex life cycles.

Ammonoid(s). Animal(s) belonging to a group of **Cephalopods** (see below) of the sub-class Ammonoidea. Fossils of their distinctively coiled shells are particularly common in rocks of the **Mesozoic Era**.

Andesite (andesitic). Fine grained, dark coloured, volcanic rock, particularly common in association with the volcanoes that lie around the rim of the Pacific Ocean including the Andes of South America after which the rock is named. Differs in chemical composition from **basalt** (see below) with which it is commonly associated.

Aragonite. A mineral form of calcium carbonate, $CaCO_3$ (see also **calcite**).

Basalt (basaltic). A dark coloured, fine grained, volcanic rock containing relatively little (43-52%) silica, SiO_2.

Basic. Describes an **igneous rock** containing 45-52% SiO_2 .

Bedding. Layering in sediments and sedimentary rocks, the different layers being characterised by differences in composition and/or texture. The layers **(beds)** are generally parallel to the surface upon which they were deposited.

Bivalve. A member of the Bivalvia class of **Molluscs** (see below). The aquatic animal is characteristically completely enclosed in a shell comprising two saucer shaped halves or 'valves'. Oysters, cockles and mussels are common examples. Bivalve shells are often found as fossils in sedimentary rocks.

Blind valley. A valley in **karst** terrain that ends abruptly where its stream disappears underground.

Bomb. A fist-sized, or larger, piece of rock ejected from a volcano.

Brachiopod. Marine invertebrate animal with a bilaterally symmetrical shell consisting of two saucer shaped parts of unequal size. The shells are common fossils found in many sedimentary rocks originally deposited as sediments on the sea bottom.

Bryozoa. A phylum of aquatic invertebrate animals that tend to grow in colonies and secrete encrusting, often fan-like or branching skeletal structures of calcium carbonate or chitin, found as fossils usually in marine **sedimentary rocks**.

Bioturbation. Disturbance of bedding or layering of a sediment usually by burrowing into the sediment by sea-floor dwelling animals. Bioturbation is sometimes can sometimes be seen in ancient sedimentary rocks formed from sediments originally deposited on the sea floor.

Biotite. A common rock forming mineral of the mica group. It is characterised by its black colour and, like other micas, a platy structure that causes it to split into very thin plates.

Breccia. A coarse grained rock composed of angular broken rock fragments.

Calcite. The stable mineral form of calcium carbonate at all those temperatures and pressures usually found at or near the earth's surface. Other forms of calcium carbonate (e.g. aragonite) often convert to calcite over geological time.

Caldera. A very large bowl-shaped depression at the Earth's surface usually formed by the downward collapse of all or part of a volcanic edifice, usually following a major eruption.

Cephalopod. A member of a class of highly organised marine **molluscs**. Of which squid, octopus and cuttlefish are some representatives alive today. Fossil cephalopods are quite common and extinct forms outnumber living representatives.

Chert. An extremely hard siliceous sedimentary rock, consisting mainly of microcrytalline quartz crystals. It is typically white, black (flint) or grey and sometimes occurs as layered deposits, but is more commonly found as fist-sized, irregular aggregates within limestone.

Cirque. A semi-circular basin with steep walls at the head of a valley once occupied, and eroded, by a glacier.

Clastic. Pertaining to a sediment or rock composed of fragments derived from pre-existing rocks or minerals (see also **pyroclastic**)

Columnar joints. Fractures in igneous rocks that form long parallel columns which are polygonal in cross-section.

Conglomerate. A coarse-grained sedimentary rock consisting of more or less rounded particles (pebbles, cobbles and boulders) greater than 2 mm in diameter.

Crater. A saucer shaped depression on the Earth's surface often caused by the eruption of a volcano (a **volcanic crater**).

Crinoid. A marine animal, popularly known as the sea lily, often living anchored to the sea floor. It is covered by segments made of **calcite** which are found as fossils in some sedimentary rocks.

Cross-bedding/lamination. Structure of a bedding unit in a sedimentary rock in which the internal layering within the unit lies at an angle to the major bedding planes forming the top and bottom of the unit. Usually seen in rocks formed from sediment deposited from a medium (wind or water) where currents were operating, hence often referred to as **current-bedding**.

Crust. The outermost layer of the Earth. Under the continents the **continental crust** is 25 to 90 kilometres thick whilst beneath the oceans **oceanic crust** is only 5-10 kilometres thick.

Dacite. An igneous, commonly volcanic rock.

Dinosaur. An informal term applied to reptiles that belong to either of two formally defined orders (Saurischia and Ornithischia)of reptiles belonging to the Archosauria sub-class. They lived in the Triassic, Jurassic and Cretaceous Periods and became extinct at the end of the Cretaceous Period, approximately 65 million years ago.

Doline. A bowl or cone shaped depression in the a land surface in areas underlain by limestone. A common feature of **karst** landscapes.

Dripstone. A mineral deposit, commonly calcite, formed in caves by dripping water. See also **stalactite, stalagmite and flowstone**.

Echinoid. Any member of the Echinoidea, a class of marine invertebrate animals which includes sea urchins. They characteristically have a hemispherical, spiny test composed of interlocking plates (shell) which can be found as fossil and also in modern seas.

Epoch. Used formally as an interval of geological time (see Table A1).

Era. A major interval of geological time on the Geological Time Scale (see Table A1), larger than a **Period** during each of an individual Geological System was formed.

Fault. A fracture in rocks in which the opposing sides of the fracture have been displaced relative to each other.

Feldspar(s). The most important group of minerals that make up rocks. Feldspars occur in igneous, metamorphic and sedimentary rocks. About 60% of the Earth's **crust** is made up of the feldspar contained in rocks.

Folds. A bend or buckle in any pre-existing structure in a rock. Commonly seen where planar structures such as bedding in sedimentary rocks have been deformed.

Foramanifera. Predominantly very small marine aquatic organisms with a calcium carbonate or chitin test (shell) which are found as fossils in some sedimentary rocks.

Formation. A fundamental unit used in the classification of strata. Formations are usually named for a specific sequence of sedimentary or volcanic strata and are often named after the geographic area in which they occur (see also **type section**).

Flowstone. Mineral deposit formed by water flowing on the floor or down the walls of a cave.

Fluvial. Pertaining to rivers, living or growing in a river or stream, or produced by the action of a river or stream (eg fluvial sediments).

Geological hazard (Geohazard). A geological situation or process that is potentially dangerous to the environment and its inhabitants.

Geomorphology. The study of the surface features of the Earth.

Geomorphography. The description of the Earth's **geomorphic** (surface) features.

Glass. Usually used geologically for an amorphous (non-crystalline) rock) resulting from the very rapid cooling and solidification of **magma**.

Graben. A linear depression or valley bounded at each side by approximately parallel **faults** such that a central area has subsided relative to the areas on both sides, thus forming the depression or graben.

Granite. A coarsely crystalline intrusive igneous rock composed principally of the minerals quartz and feldspar.

Granodiorite. A coarse grained intrusive igneous rock. Similar to granite but containing slightly less alkali feldspar.

Groundwater. Water below the ground surface contained in fractures and pores of rocks.

Gneiss. A metamorphic rock, generally coarsely crystalline and with a banded appearance caused by the segregation of darker and lighter coloured mineral layers.

Gastropod. A snail-like animal, commonly aquatic, and typically with a coiled calcareous shell

Graded Bedding. Bedding in a sediment or sedimentary rock in which the constituent grains decrease in size from the bottom to the top of the bed.

Groundwater. Water below the earth's surface occupying any pores, fractures and cavities within the subsurface rocks.

Holocene. The most recent **epoch** of geological time **(See Table A-1)**

Igneous rock. A rock that has solidified from molten rock material (**magma**, see below). When the magma cools and solidifies beneath the earth's surface it forms an **intrusive igneous rock**, if it reaches the surface before solidifying it forms an **extrusive igneous rock** or **lava**.

Ignimbrite. A fragmental volcanic deposit (or **pyroclastic** deposit, see below) in which all the fragments in the deposit became welded together whilst still very hot.

Joint. A surface fracture in a rock.

Karst (karstic; karstification). A type of topography that usually develops on **limestone** terrain where there is subsurface dissolution of soluble rock. Karst topography is characterised by caves, **dolines**, dry or **blind valleys** and subterranean rivers.

Knick-point. An abrupt break in slope along a river, often marked by a waterfall, and caused by uplift of the area renewing the erosive power of a river in a previously stable and mature river valley.

Lava. Molten rock (**magma**) erupted on to the Earth's surface or the seafloor. It may flow over the surface as a **lava flow** and subsequently cools and solidifies as lava rock. Pahoehoe and aa lavas are basaltic lavas with distinctively different surface features reflecting their different viscosities during flow.

Limestone. A sedimentary rock composed primarily of calcium carbonate.

Maar. A wide but shallow, circular volcanic crater formed during an explosive volcanic eruption often occurring when hot **magma** encounters **groundwater** at shallow depths below the ground surface.

Mafic. Mafic pertains to minerals and igneous rocks with a high contents of iron and magnesium. See also **basic** rocks.

Magma. Molten rock generated deep within the earth's interior (see also igneous rock, above).

Marble. A **metamorphic rock** consisting mainly of recrystallized **calcite** usually formed when **limestone** is subjected to high temperatures and pressures beneath the Earth's surface.

Mesozoic. An **Era** of geological time lasting from approximately 250 million years ago to 65 million years ago (see Table A1).

Metamorphic rock. Any of a class of rocks that have resulted from the recrystallisation in the solid state of a pre-existing rocks under conditions of temperature and pressure which significantly differ from those normally found at the surface of the Earth. **High-grade metamorphic** rocks are those that recrystallized at very high temperatures and/or pressures.

Mollusc. An invertebrate animal of the Phylum Mollusca, most of which secrete an external shell made of calcium carbonate of which many may be preserved as fossils in sedimentary rocks..

Mud cracks also **sun cracks**. Shrinkage cracks, often in a polygonal pattern, formed on the surface of wet muddy sediment as it dries out on exposure to sunlight.

Nuee Ardente. A hot incandescent cloud of rock fragments and gas that can flow rapidly down hill from an erupting volcano.

Orogenic Belt. An arcuate or linear zone of deformed and variously metamorphosed rocks which often form mountains and commonly have resulted from the collision of two of the Earth's **tectonic plates**.

Orthoquartzite. A sedimentary rock composed almost entirely of grains of quartz sand which are cemented together by silica.

Palaeo- A prefix meaning old or ancient. Hence terms such as Palaeoclimates. palaeo environments, palaeogeography

Palaeontology. The study of life forms that existed in the past as represented by fossil plants (palaeobotany, palaeoflora) and animals (palaeofauna).

Paleozoic (or **Palaeozoic**). An **Era** of geological time that lasted from approximately 540 million years ago to 250 million years ago (see Table A1).

Palaeocurrents. Currents of water or wind which were active in the past.

Period. A unit of geological time smaller than an **Era** (see Table A1).

Phreatic. A type of volcanic eruption driven by steam produced when water comes into contact with **magma**.

Pillow, **Pillow lava**. Spherical or ovoid shapes (pillows) typically formed in some lavas when they flow into water. Often found in **basalt** lavas that were erupted under the sea.

Plate (tectonic plate). An extensive part of the Earth's relatively rigid outer layer is referred to as a plate. There are currently seven large plates and several smaller ones making up the outer part of the globe. (see also **tectonics**).

Plinian. A type of explosive volcanic eruption. It is driven by a sustained and powerful jet of gas and produces copious amounts of **ash** derived by the fragmentation of **magma**.

Precambrian. The period of geological time that extends from the birth of the Earth (approximately 4500 million years ago) up to the beginning of the Cambrian period about 540 million years ago (see Table A-1).

Pumice. Solidified frothy magma with a low density often ejected as lumps during the explosive eruption of rhyolite magma from a volcano.

Pyroclastic. A term used to describe a volcanic eruption in which fragments of rock are ejected from a volcano. Following their ejection into the air the fragments settle on to the ground around the volcano to form a **pyroclastic deposit** which may eventually be preserved as a pyroclastic rock (see also **tuff**).

Quartz. A common mineral composed of silica (SiO_2). Found in varying amounts as a constituent of **igneous**, **metamorphic** and **sedimentary** rocks.

Ripple marks. Small (cm scale) ridges and troughs formed by the flow of water or wind over loose sandy sediment and sometimes found preserved in sandstone.

Rhyolite. A fine-grained igneous rock, much richer in silica (>66%) than a basalt. Its composition is similar to granite but it is much finer grained and may be either intrusive or extrusive (**see igneous rock**).

Roche moutonnee. A smooth elongate mound carved out of the bedrock by a glacier moving over the land surface. The long axis of the mound is parallel to the direction of movement of the glacier and the axis slopes gently down in the direction the ice flowed and more steeply in the opposite direction.

Sandstone. A **sedimentary rock** composed of sand-sized grains of rock or mineral particles.

Scoria. Fragments of rock that have solidified from a frothy **basaltic magma** and therefore have a spongy appearance.

Sea stack. A pillar of rock forming a small island in the sea.

Sediment; **sedimentary rock**. Sediment is solid, either inorganic or organic, material that has settled out from suspension in water or the air after transport by water, wind or ice. An accumulation of loose sediment may become consolidated and coherent to form a **sedimentary rock**.

Siliciclastic. Pertaining to fragmental rocks rich in silica (usually quartz) or silicate minerals.

Siltstone. A fine-grained **sedimentary rock** composed mainly of silt-sized grains (see also **sandstone**). Silt grains are intermediate in size between sand (larger) and mud (smaller).

Sinkhole. See **doline** above.

Sinter. Silica deposited as an amorphous white encrustation on rocks around a hot spring.

Solfatara (**solfataric**). A vent at the Earth's surface where sulphur gases and steam are emitted.

Speleothem. A mineral (usually **calcite**) deposit deposited from water within a cave.

Spheroidal Weathering. A form of weathering of rocks that results in the production of concentric shells of weathering products, transforming parts of the original rock body to an onion like appearance. A feature of weathered granite in certain climatic conditions.

Stalactite. A cylindrical mineral deposit that hangs down from the roof a cave, deposited from water dripping from the roof.

Stalagmite. A mineral deposit similar to a **stalactite** but growing upwards from a cave floor.

Stratigraphy. The branch of geology dealing with all the characteristics of rocks that are stratified and their interpretation in terms of their origin and age relative to all the other rocks of the studied area. Usually used of areas of sedimentary and/or volcanic rocks.

Strato-volcano. A type of volcano that, during the course of repeated eruptions, builds a large **volcanic cone** comprising alternation of **lava** and **pyroclastic** material.

Striation (plural **striae**) A thin line or scratch on a rock surface. Glacial striae are caused by the movement of a glacier over bedrock.

Strombolian. A style of volcanic eruption that is characterised by few, relatively small, explosive episodes and therefore produces relatively more lava and less **pyroclastic** material during an eruption.

Subduction. The descent of one of the Earth's **plates** beneath another plate in the zone where the two plates converge and collide. The collision zone is often referred to as a **suture** or **geosuture** and is often the site of volcanoes and earthquakes.

Tafoni. Numerous small cavities caused by weathering of a rock surface to resemble a honey comb. Usually developed on sea cliffs or cliffs in dry areas.

Terrestial Deposit. A sedimentary deposit formed on land. Sometimes used for a sedimentary deposit laid down on land without the involvement of water (for example sand dunes).

Tectonics. A branch of geology that deals with the larger features of earth structure and the processes that caused them, as compared to 'structural geology' a branch of geology that which deals with the geometry of individual rock masses. **Plate tectonics** is a synthesis of many geological observations that describes how the distribution and formation of such major earth features as volcanoes, mountains and earthquakes is dependent on the lateral movement and interaction of the several 'plates' into which the relatively rigid outer part of the earth is divided.

Tephra. A collective term for all fragmental material ejected from a volcano. See also the term **pyroclastic**.

Trachyte. A fine-grained extrusive volcanic rock, containing less silica than **rhyolite**.

Trilobite. An extinct marine animal with a segmented body and chitinous 'shell', the latter often found as a fossil in marine sedimentary rocks deposited after about 540 and before 250 million years ago when they became extinct.

Tuff. A volcanic rock composed of fragments ejected from a volcano (**pyroclastic** material), mainly volcanic ash.

Type locality. A geographic locality at which a particular rock feature or rock type is described or defined and which is used as a point of reference for that geological feature. A **type section** is the particular rock exposure or series of nearby outcrops at which a specific rock unit (normally a **stratigraphic** unit such as a **Formation**) was defined and named.

Ultrabasic. A term used to describe igneous rocks that contain less than 45% by weight of SiO_2.

Vesicle. A small spherical or elliptical void in an igneous rock that was originally a bubble of gas within the molten magma from which the rock originated. A vesicular rock is one containing vesicles.

Vulcanian. A style of volcanic eruption characterised by episodes of intense explosive activity with the production of much **pyroclastic** material.

TABLE A1. Simplified table of Geological Time

ERA	PERIOD	EPOCH	Age (million years before present)
CENOZOIC	Neogene	Pleistocene Pliocene Miocene	0.1-2my 2my-5my 5my-23my
	Paleogene	Not listed	65my-23my
MESOZOIC	Cretaceous	NOT LISTED	145my-65my
	Jurassic		200my-145my
	Triassic		251my-200my
PALAEOZOIC	Permian	NOT LISTED	300my-251my
	Carboniferous		359my-259my
	Devonian		416my-359my
	Silurian		444my-416my
	Ordovician		488my-444my
	Cambrian		542my-444my

NB. Divisions older than the Palaeozoic, traditionally referred to collectively as the Precambrian, are not shown in the above table. Ages are shown to the nearest 1 million years, simplified from more detailed data issued in 2003 by the International Commission on Stratigraphy.

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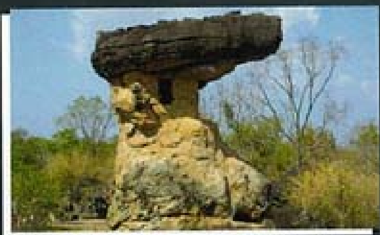
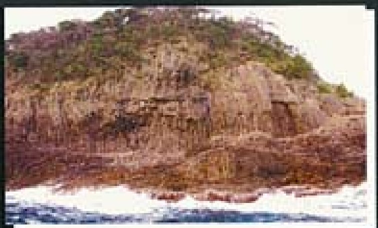
The Geoheritage of East and Southeast Asia is incredibly rich and diverse but somehow has not yet gained the wide attention and appreciation of the public at large. It has great potentials to be utilized in a sustainable manner that can significantly contribute to the development of geotourism, thus bringing the economic benefits to the local community while at the same time protecting the heritage around them. Perhaps the main challenge for geoheritage conservation is to get as many people as possible having different interests to understand and participate in the whole program that include research, knowledge dissemination, development and conservation planning and implementation, and promotion. This beautiful book provides the general public a good introduction to geoheritage in the East and Southeast Asia region. We hope the book can serve to enhance the appreciation for our beautiful Earth and the exciting science behind it while at the same time contribute to the development and promotion of geotourism in the Member Countries of CCOP.





Geoheritage of East and Southeast Asia is currently protected under the different national and global establishments such as the UNESCO Global Network of National Geoparks, UNESCO World Natural Heritage Sites, National Geoparks, National Parks, Provincial Parks, National Geological Monuments, State Parks, Geoforest Parks and as protected geoheritage sites.

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