Introduction

1.1. GENERAL

The region described extends approximately 4330 km from latitude 26°N to 13°S, and approximately 5570 km from longitude 85°E to 135°E (Fig. 1.1). Its area, approximately 24 million km², is roughly comparable with that of Europe, and somewhat larger than that of Australia. Although geology should recognize no political boundaries, it is useful to be aware of the political subdivisions, for geological explorations have been and are largely restricted to individual countries. More often than not the international boundaries represent the limits of geological study, or changes in terminology.

The region includes all the Association of South-East Asian countries (ASEAN), namely Indonesia, Thailand, Malaysia, Singapore, and the Philippines. In addition, Myanmar and Indochina (Cambodia, Laos, and Vietnam) naturally fall into this region. For completeness, some reference will be made to Taiwan, the southern and eastern regions of China including Tibet and Hong Kong, the Assam area of India, Nepal, the Andaman and Nicobar Islands, and the northern parts of Australia and New Guinea.

About two-thirds of the region is covered by seas, in which there are thousands of islands, ranging in size from Sumatra and Borneo to those which are too small to show on the map. The interwoven network of seas, islands, and the peninsulas of mainland Asia and Australia have allowed a successful synthesis of modern oceanographic research with classical geological studies on land. Our understanding of South-east Asia has been significantly advanced as a result of international research co-ordinated and supported by the Co-ordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP), and the Intergovernmental Oceanographic Commission of UNESCO (IOC), as part of the International Decade of Ocean Exploration (IDOE). The programme came to be recognized as Studies in East Asian Tectonics and Resources (SEATAR), and a progress report was published some years ago (CCOP-IOC 1980).

The impressive amount of oceanographic work carried out in this SEATAR project has made possible the correlation of previously completed geological investigations on land with the submarine topography and its tectonic elements.

South-east Asia provides the world's most outstanding geological laboratory for the study and understanding of active plate tectonics. Deep-sea trenches, marginal seas, and island arcs abound. The region is seismically active and contains many of the world's most active volcanoes. The island arcs, and small intervening seas, are in the process of being compressed by the 8 cm per year northwards movement of cratonic Australia. The immediate effects of the arrival of Australia are to be seen in collision tectonics on the island of Timor and extinction of the volcanic arc to the north of it. As Australia continues to push northwards, the complex of island arcs and seas will be compressed further, eventually forming a major orogenic welt sutured between mainland Asia and Australia. By this time the seas will have been driven out, and the disparate islands and basins will be compressed into a Himalayan-style complex such as can now be seen between India and Tibet. The study and understanding of South-east Asia is therefore important in the development of the geological sciences, for this is a region in which a future mountain or orogenic system can be seen in the early stages of formation. Every orogen is unique, but a study of the sequence of events in the South-east Asian archipelagos and seas will help in the unraveling of older now completed orogens.

The region is also of interest in providing evidence of the relationships between tectonic evolution and economic deposits. Sedimentary basins lying between island arcs and occupying shallow shelf seas on continental margins are important for oil, gas, and coal. The volcanic island arcs are important for porphyry copper and precious metal deposits. Base metal deposits are also of some importance. Uplifted oceanic lithosphere contains chromite and nickel deposits. In the more continental parts of the region, there are spectacular granite-related tin and important tungsten
Fig. 1.1. Outline map of South-east Asia showing the countries and some of the place names. Burma is now known as Myanmar and Kampuchea as Cambodia.
deposits, and antimony and mercury are locally significant. Some of these deposits have been locally worked out.

Environmentally, the region may be divided into a stable cratonic core and an outer island arc system, which is seismically and volcanically active. Some major fault zones, such as the Red River, have high seismic risk. The volcanic arcs of Indonesia and the Philippines offer rich volcanic soils, but at the same time they are regions of high earthquake risk. The archipelagos which face the major oceans are susceptible to tsunami damage. Volcanic eruptions have frequent local effects, but they are more widely felt if the magnitude and frequency of the eruptions increase (Blong and Johnson 1986). Large-scale clearances of jungle and forest result in significant changes in micro-climate, and most certainly result in soil erosion. Urbanization, especially in flat coastal plains and inland valleys, has led to severe air and water pollution, and changes in the micro-climate. Withdrawal of groundwater at excessive rates has led to regional subsidence, which in the case of Bangkok is beginning to result in disastrous flooding and structural collapses (Natalaya and Rau 1981).

1.2. HISTORY OF GEOLOGICAL STUDIES

The majority of the South-east Asian countries benefited from their colonial eras in that established geological surveys, complete with experienced geologists and administrative infrastructure, were established in the territories. Only Thailand was spared the yoke of colonialism, with the drawback that systematic geological study and publication have accordingly been slow to develop.

Geological and mining activities were totally disrupted by the Japanese occupation of the whole region in the early 1940s and valuable records and manuscripts were lost for ever. Continuing insurgency in many South-east Asian countries has until recently prevented systematic geological surveys in parts of the region, and political disputes prevent a proper assessment of the oil potential of the major part of the South China Sea.

1.2.1. Thailand

The first useful geological description was by Hallet (1890). He was a civil engineer in search of a railway route from Moulmein to south China, and he traveled through north Thailand by elephant, describing the geological formations seen on the way.

The Royal Department of Mines and Geology was established in 1891, but little geological work was done. Its principal function was to grant tin mining leases. The second director made several trips through the country and his publications contain some descriptions of the mineral deposits (Smyth 1898).

An Anglo-French convention of 1896 secured the borders with Myanmar (then Burma) and Cambodia, and assured the continuing independence of Thailand. The southern borders with Malaysia (then called the Malay States) were long disputed, but were fixed by a treaty with Britain in 1899. In 1909 Thailand ceded to Britain its rights over the northern states of what is now Peninsular Malaysia.

The first critical geological investigation was made in 1912 by a professor from Uppsala University (Hogbom 1914). Prince Kamphaengbej, who was commissioner of the Royal State Railways, engaged Wallace M. Lee, an American geologist, to investigate the coal and oil resources of Thailand, in an attempt to find fuel for the locomotives. Lee made three investigations between 1921 and 1923, the first to the north, the second to the peninsula, and the third to the Khorat area. The reports are concise and contain useful geological summaries (Lee, W.M. 1923a, b, c). These reports form the important foundations of Thai geology. Lee subsequently summarized the reports and emphasized the oil potential of the country (Lee 1927).

In 1927–9 Wilhelm Credner, from Kiel University, visited many regions of Thailand that had not previously been described, and he published the most comprehensive description of the geology yet written (Credner 1935).

In 1934 the Ministry of Defence engaged two Swiss geologists to study the possibility of petroleum in the north, including the oil shales at Mae Sot and long-known oil seeps at Maung Fang. Accounts of the petrography and structure of the region were published (Heim and Hirschi 1939; Hirschi 1938, 1939; Hirschi and Heim 1938).

In 1941, a geological survey division was established in the Royal Department of Mines, but it was not until the end of the war in 1946 that the division could be staffed and a beginning made on a long-term geological programme. The Royal Department of Mines then asked the United States Government to assist in a reconnaissance study of the mineral deposits of the country. The survey was carried out between 1949 and 1950 and the result was the first authoritative account of the geology and mineral deposits of Thailand (Brown et al. 1951). Since 1951, geological mapping, research, and publication by the Department of Mineral Resources have flourished. The work has been carried
1.2.2. Myanmar

In 1862 Pegu, Arakan, and Tenasserim were amalgamated to form British Burma, and the whole of Burma became incorporated in the British Indian Empire in 1886. Before the association of Burma with India there were a number of geological reports on the mineral deposits and fossil localities. Many of the reports appeared in the Journal of the Asiatic Society of Bengal. However, it was during the Indian administration that systematic surveys and published accounts flourished. These are to be found in the memoirs and records of the Geological Survey of India. The earlier records are too numerous to enumerate here, and the reader is referred to Goossens (1978a, b) for a bibliographic summary. The early work was excellently summarized in outstanding accounts by La Touche (1913) and later by Pascoe (1950, 1959, 1964). Sir Edwin Pascoe's massive 2130-page work was published after his death in 1949. He started writing in 1933 and submitted the complete manuscript in 1939. Most of it was already set in type, but at the beginning of the war in 1939 the 2.5 tons of type were broken up and remelted for munitions. After his death, the manuscript of Volume 4, which consisted of general and geographical indexes, was unfortunately never traced. This massive work is therefore not indexed, but it represents the outstanding introduction to the pre-1933 knowledge of Myanmar.

In 1923 the University of Rangoon set up a new department of geography and geology. Its staff included such famous names as L. Dudley Stamp and H. L. Chhibber. Both were active in the field and made the results of their work widely available; for example Stamp (1927). Chhibber (1934a, b) made a landmark in the geological literature by publishing his two books, one on the geology and the other on the mineral deposits of Myanmar.

Myanmar was administratively separated from India in 1937, and eventually gained independence from Britain in 1948. Since Chhibber's work, many Burmese and other geologists have contributed significantly to our understanding of the country. The publications are summarized by Goossens (1978). A notable summary of the geology and mineral deposits was published by Robertson Research (1973, 1977) at a time when it appeared that the government was opening up the country to international mining companies. Unfortunately this did not take place, and several recent surveys, maps, and reports prepared by overseas investigators have been suppressed. A geology of Burma has been recently published by Bender (1983).

1.2.3. Indochina (Cambodia, Laos, Vietnam)

The various provinces were unified as French Indochina in 1887, but French influence extends back to 1787. The early literature on Indochina was in French. There was only occasional research up to the end of the nineteenth century. Some of it, however, like the study of the rich flora in the coal basins of North Vietnam, was of great importance (Couinillon 1914, Zeiller 1902). Before 1880, the French colonial administration showed little interest in geological research and mining development. Thus, it was that the first general work on the geology of the region (Petiton 1895) was not published until some twenty years after its completion.

The Service Géologique de L'Indochine was founded in Hanoi in 1898. Field mapping and palaeontological studies progressed rapidly, but for many years they were restricted to selected areas, most of the effort being centred on Yunnan and southern China. From 1925 onwards, emphasis was placed on the compilation of a geological map of the whole of Indochina, completed only in 1963. The publications up to 1950 are largely the fruits of the Service Géologique de L'Indochine. Individual works are too numerous to enumerate, but mention should be made of the important summaries by Fromaget (1941) and Saurin (1935, 1944). A detailed bibliography of this and the later period was compiled by Fontaine (1973). French Indochina split up into North Vietnam, South Vietnam, Laos, and Cambodia in 1956, and the newly independent countries formed their independent geological surveys. Since then, North and South Vietnam have unified and Cambodia was renamed Kampuchea before again becoming Cambodia.

The geology of North Vietnam has been extensively re-studied, with assistance from the USSR. To the extent that wartime conditions allowed, South Vietnam and Cambodia continued to perform new mapping, but little new work has been possible in Laos, and little is known still of the geology of that country. A booklet on the geology of North Vietnam was published by Tran et al. (1979), but nothing comparable has come recently from the other countries which formerly
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1.2.4. Indonesia

A very impressive geological programme of mapping, research, and publication flourished under Dutch control, which gradually spread throughout Indonesia. The last territory to be annexed was the northern part of Sumatra as late as 1907. Many significant surveys and publications were made in the latter years of the nineteenth century, but the most important works were published in the first two decades of the twentieth century. Many eminent geologists either worked in Indonesia or took part in well-organized expeditions there. The Geological Survey of the Netherlands Indies lasted from 1850 to 1950, with its headquarters in Bandung and the Bureau of Mines in Jakarta (then Batavia). During that time, the regular publication was the series Jaarboek van het Mijnwezen, published in Batavia. In addition, several books and many articles were published in Europe on the geology of Indonesia. Virtually everything ceased in 1941 with the outbreak of war.

Many famous Dutch geologists wrote about Indonesia, and it would be impossible to do justice to all of them here. I will mention only those authors who synthesized the earlier work and built upon it in their books. The earliest and widest compilation was by Brouwer (1925). Rutten (1927, 1932) gave a series of lectures and his books brought the attention of the world to this fascinating region of South-east Asia. Umbgrove (1949) also did much to summarize the earlier work and built upon it in their book form. Volume 2 of this work is on the mineral resources of these countries.

1.2.5. Philippines

The Philippines was held by Spain until 1898 and geological records of that era are generally now only of historic record. Enrique Abella-y-Casariego, the last chief of the Spanish Mining Bureau, was the ablest of the early investigators. His publications, now hard to find, are listed in Smith (1924).

In 1898 the Philippines was ceded to the United States of America. Soon after this a Mining Bureau was established. A considerable amount of information was published by the United States government, and it summarized all the useful earlier knowledge. Notably, Becker (1901) summarized all that was known to that date. The publication of Smith (1924) was a landmark in Philippine geology. He had been with the Mining Bureau since 1906, becoming chief of the division of mines in 1920. This outstanding book contains a complete bibliography of previous work of the Spanish era. Wallace E. Pratt, also of the Bureau, published extensively; for example, Pratt (1916). Filipinos began publishing; a notable example was Leopoldo A. Faustino, who joined the division of mines around 1920 and has a long list of publications (for example Faustino 1934).

The Philippine Commonwealth was established in 1934, which planned for and led to the independence of the Philippine Republic in 1946. However, no significant geological work was done around that time.

The next landmark was the publication of Corby \textit{et al.} (1951), which contains a comprehensive account of the geology, emphasizing the oil potential. There have since been numerous publications on the geology of the Philippines, too numerous to mention, but summarized by Teves (1953, 1957), and by Aquino and Santos (1971). The most recent landmark is the publication by the Bureau of Mines (1981), summarizing the geology in book form. Volume 2 of this work is on the mineral deposits, published later (Bureau of Mines, 1986).

1.2.6. Peninsular Malaysia and Singapore

Peninsular Malaysia, formerly known as the Federation of Malaya, was under British rule until 1957. With independence it became Malaysia, and eventu-
ally included Sarawak and Sabah (North Borneo), which are jointly now referred to as East Malaysia. Singapore withdrew from Malaysia and is now an independent country.

The earliest and most comprehensive records of the geology of Peninsular Malaysia and Singapore were by Logan (1848). Between 1870 and 1903 Europeans began participating in the mining industry of the peninsula and several authors wrote on the tin deposits. However, until 1903 any geological work had been of a short-term and haphazard nature. It was against this background of the important tin-mining industry that the government appointed its first geologist, J. B. Scrivenor, who set up his office in Batu Gajah, in the foremost tin-mining valley of Kinta. He arrived in 1903 and devoted most of his working life to Malaysian geology. Until his retirement in 1930, most of the geological publications were written by Scrivenor, who laid the foundations of Malaysian geology. His other earlier works were admirably summarized in his two books (Scrivenor 1928, 1931). In 1913, W. R. Jones joined Scrivenor as a geological assistant. He studied the great Kinta Valley tin field and summarized its geology in Jones (1925). The early geological literature of Peninsular Malaysia and Singapore has been compiled by Gobbett (1968).

The Federation of Malaya Geological Survey continued to grow, and the headquarters moved to Ipoh, where the main laboratories are still sited. With independence in 1957, the Geological Survey of Malaysia gradually phased out its expatriate staff. The Survey headquarters moved to Kuala Lumpur, and assumed control of geological work in both Peninsular and East Malaysia. In addition to a large number of reconnaissance memoirs and map bulletins, the Survey continues to map systematically and in detail the geology of the whole of Malaysia.

Geological work in Singapore comes under the Public Works Department, but work is usually limited to site investigations, and no systematic geological mapping is undertaken.

Establishment of a geology department in the University of Malaya in 1956 was an important landmark in the development of the geological sciences in the region. The professors – C. S. Pichamuthu, T. H. F. Klompe, N. S. Haile, K. F. G. Hosking, C. S. Hutchison, and P. H. Stauffer – have all made significant contributions to Asian geology. The Geological Society of Malaysia was founded in 1967 by the academic staff of the department, notably by D. J. Gobbett, and it continues to flourish.

As a successor to Scrivenor (1928, 1931), a book was published under the editorship of Gobbett and Hutchison (1973). It remains the authoritative summary of the geology of Peninsular Malaysia and Singapore. A revised edition is currently under preparation. The Republic of Singapore (1976) has published a summary of its own geology.

1.2.7. Sarawak, Sabah, and Brunei

Accounts of geological explorations in Borneo have been given by Hatton (1886), Posewitz (1892), Schmidt (1904), and Rutter (1922). The early systematic geological studies of Sarawak, Brunei, and Sabah were made primarily by oil companies and also by companies exploring for mineral deposits. But no comprehensive accounts came until a geological survey was established.

The Geological Survey Department, British Territories in Borneo, was first established in 1949, with offices in Kuching and Kota Kinabalu, then known as Jesselton. An important landmark was the publication of Reinhard and Wenk (1951). The Shell Oil Company employed these two Swiss geologists to compile a comprehensive account of the geology of North Borneo (Sabah). The field work was completed before 1942 and the results published by the Geological Survey Department in 1951.

Shell also collaborated with the Geological Survey Department in making available the only regional compilation of the whole territory, including Sarawak, Brunei and West Sabah (Liechti et al. 1960). Since then a large number of reconnaissance memoirs and bulletins have been produced by the Department, and later by the Geological Survey of Malaysia. Independent Brunei is dominated by the Shell Oil Company and its geology has recently been summarized in book form by James (1984). The latest book on North-west Borneo, Sarawak, Brunei and Sabah, is by Hutchison (2005).

1.3. THE MODERN ERA OF GEOLOGICAL CO-OPERATION

Rapid advances in the geological knowledge of Southeast Asia have been made since the early 1970s, as a result of planned international co-operation between oceanographers and land-based geologists within a programme of transect studies across peninsular Southeast Asia and its island arcs. This programme was carried out within the International Decade of Ocean Exploration, and co-ordinated by the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asia Offshore Areas (CCOP) and the Intergovernmental Oceanographic Commission of
UNESCO (IOC) (CCOP-IOC 1974, 1980). From this programme, there has been a rapid flow of papers in international journals and books over the past decade, which has greatly improved our understanding of South-east Asia. Active offshore exploration by petroleum companies also greatly increased our knowledge of the Tertiary basins. The release of some of their data helped, for example, in the compilation of Hamilton (1979). An unnecessary reluctance by national petroleum corporations to make available regional data, has, however, greatly hindered tectonic analysts. Summaries of the Tertiary oil basin geology have been published, for example, by ASCOPE (1981). Oil companies of the region continue to release permitted information through publications of the Indonesian Petroleum Association, Jakarta, the Southeast Asia Petroleum Exploration Society, Singapore, and various regional geological societies, such as the Geological Society of Malaysia, Kuala Lumpur, which holds an annual petroleum geology seminar and publishes the papers in its bulletin series.

In 1972 the Geological Society of Malaysia began an important tradition of holding a regional conference on the geology and mineral resources of South-east Asia (GEOSEA). The proceedings have been published by various societies in the countries of the region: GEOSEA 1 (Tan 1973); GEOSEA II (Wiryosulono and Sudradfat 1978); GEOSEA III (Natalaya 1978); GEOSEA IV (Philippines 1981); and GEOSEA V (Malaysia 1984). The full proceedings of GEOSEA V were published in 1986 and 1988 as bulletins 19 (Teh and Paramananthan, 1986) and 20 of the Geological Society of Malaysia. GEOSEA VI was held in Jakarta in July 1987. The ninth GEOSEA conference proceedings were published as Bulletin 43 of the Geological Society of Malaysia.

Volume 1 of the Journal of Southeast Asian Earth Sciences, published by the Pergamon Press in Oxford and edited by B. K. Tan of the University of Malaya, appeared in 1986. This journal has been superseded by the Journal of Asian Earth Sciences, now published by Elsevier.

The research programmes of the International Decade of Ocean Exploration Studies in East Asian tectonics and resources (SEATAR) have resulted in several special publications, for example Barber and Wiryosulono (1981), Hayes (1980, 1983) and Hamilton (1979). Important new work is in progress in the Philippines, the Timor area, and the South China Sea. Not all SEATAR transects have been published but those across the Banda Sea and Java to Sarawak have been published (Hutchison, 1991a, b).

Three outstanding quality maps of the region have been compiled by Gatinsky (1983), by Ray (1982) and by Pubellier et al. (2005), and the oil and gas map by ESCAP (1985).