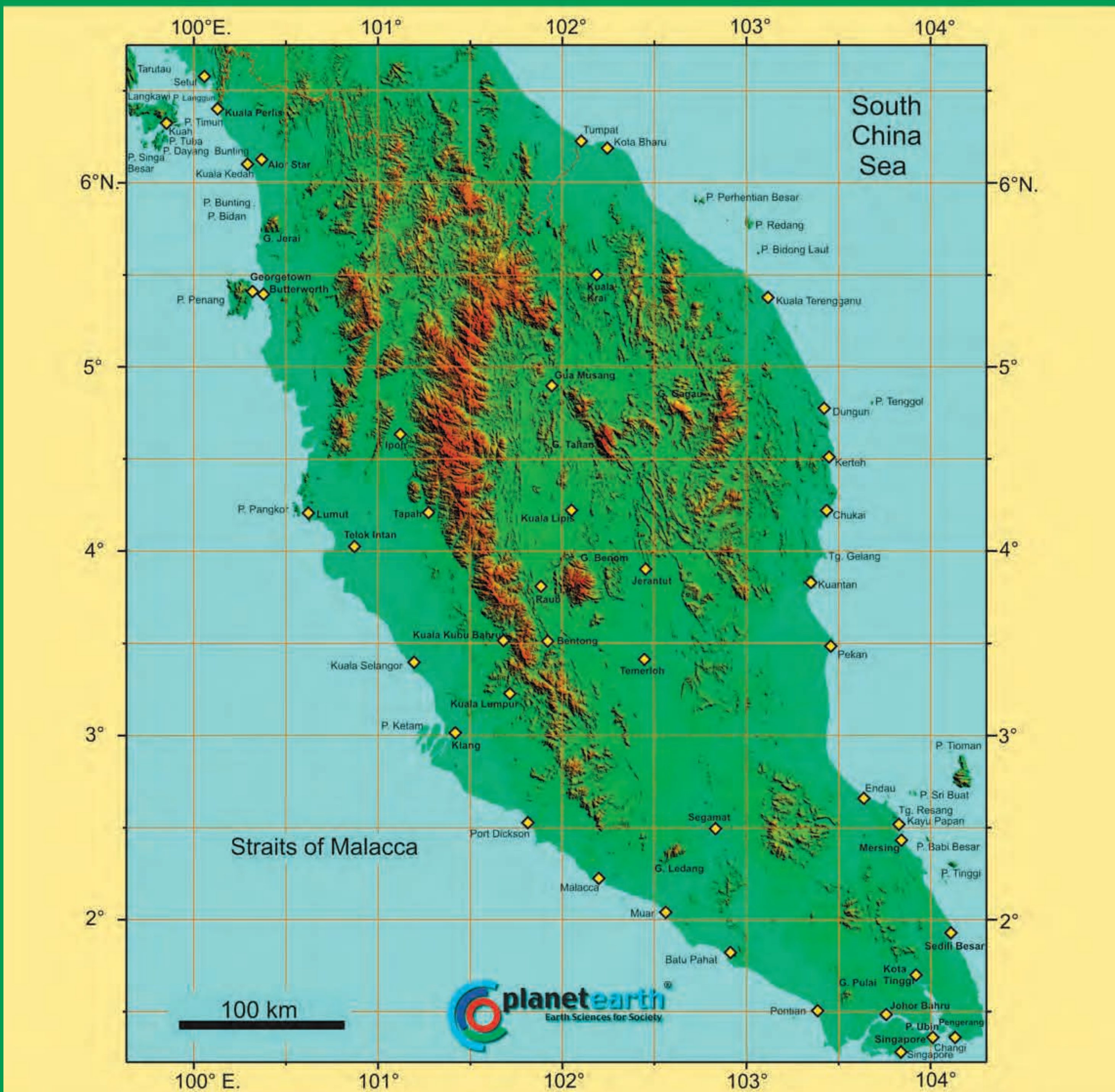
GEOLOGY OF PENINSULAR MALAYSIA

Editors: C. S. Hutchison and D. N. K. Tan



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MURPHY

GEOLOGY OF PENINSULAR MALAYSIA

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The book cover was designed by Robert Tate. The map is a shaded digital elevation model generated from Shuttle Radar Topography Mission (SRTM) datasets. The source of the data is *www2.jpl.nasa.gov/srtm/*

A 1 : 1 000 000 scale geological map of Peninsular Malaysia, compiled by Robert Tate, Denis Tan and Ng Tham Fatt, is included in the back pocket and is an integral part of this book and subject to the same reproduction regulations.

Printed in Malaysia

GEOLOGICAL PUBLICATIONS

This book has drawn extensively on the maps and publications of the Geological Survey of Malaysia, now known as the 'Minerals and Geoscience Department Malaysia'. The 8th edition of the geological map of the whole peninsula, scale 1 : 750,000, was published in 1985. Detailed quadrangle geological maps have been published, the early ones at a scale of 1 : 63,000. Most of the maps are included in a memoir or map bulletin. Most of the peninsula has been mapped on a detailed scale. Details and sales are available from the following address:

Minerals and Geoscience Department Malaysia,
Bangunan Tabung Haji, floor 20,
Jalan Tun Razak,
50658 Kuala Lumpur
e-mail: *imgkl@jmg.gov.my*

Many papers on the offshore areas have been published in the bulletin series of the Geological Society of Malaysia, facilitated by annual meetings of the Society dedicated to Petroleum geology. A great landmark has been 'The Petroleum Geology and Resources of Malaysia', published by PETRONAS (1999), available from

Petroleum Nasional Berhad (PETRONAS),
Tower 1, PETRONAS Twin Towers,
50088 Kuala Lumpur
www.petronas.com.my

Acknowledgements

The editors and authors of this book and the officers of the Geological Society are extremely grateful to Murphy Oil Corporation and the University of Malaya for generous donations to allow this book to be published locally, thereby keeping the selling price within reach of local students and geologists. Ching Yu Hay drafted many of the figures from authors' sketches, where necessary. Special thanks are due to Dr Ng Tham Fatt for compiling maps from satellite and SETM data.

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1

Introduction

C.S. Hutchison

More than 30 years have passed since the John Wiley publication of *Geology of the Malay Peninsula* (Gobbett & Hutchison, 1973). This book was compiled under great hardship by the two editors because it was based on many unpublished manuscript memoirs of the Geological Survey and the editors frequently drove to Ipoh, along the old winding road, to make notes from the draft manuscripts. Readers may be interested to learn the current whereabouts of the authors. Derek Gobbett and Charles Hutchison live in retirement in Yorkshire and Petaling Jaya, respectively. Ken Hosking retired to Spain and then back to England, where he died in 1991 in his hometown of Camborne (Hutchison & Haile, 1992). Peter Herman Stauffer now works for the U.S. Geological Survey in Menlo Park. Professor Emeritus Tjia Hong Djin is retired in Putrajaya and does consultancy work. Clive Roderick Jones lives in retirement in England and Cedric Keith Burton lives in retirement in Jakarta.

Many requests for a second edition have been made over the years but a suitable nucleus of experienced geologists has not, until now, been motivated to undertake a new compilation. This is not a second edition, for too much new information, understanding and updated concepts have necessitated a completely new compilation. The paradigm of plate tectonics requires a totally new approach. Since the publication of the Geology of the Malay Peninsula in 1973, a generation of Malaysian geologists have worked and carried out research on the geology of Peninsular Malaysia. Most of them are graduates of the University of Malaya, and many have reached retirement age. It is felt that the time is right to capture and document the knowledge of these experienced geologists before they fade into the sunset. Thus, the University of Malaya and the Geological Society of Malaysia have agreed to jointly publish this book on the geology of Peninsular Malaysia. Unlike the previous book, this book also includes the geology of the offshore Tertiary basins.

This book and the accompanying map are built predominantly upon the regional mapping programme of the Geological Survey Department of Malaysia that, like many other geological surveys, no longer carries out regional geological quadrangle mapping. Therefore, the areal geology of Peninsular Malaysia may now be considered finalised. A major landmark in the history of the Geological Survey occurred in the middle of 1967. The late Mr. S. K. Chung (Chung Sooi Keong) became its first Malaysian director. He replaced Mr. W. D. Proctor, who retired upon Malaysianization. Proctor was appointed director a year earlier upon the departure of Dr. J.B. Alexander, who left behind an impressive backlog of unpublished memoirs and bulletins extending back as far as 1958.

A publications editor, Mr. Gray Darling, was seconded from Canada under the Colombo Plan. He edited and oversaw into publication most of the draft manuscripts that remained from the directorship of Dr J. B. Alexander. Mr. Darling found the draft memoir on Perlis, Langkawi and North Kedah too long for him to successfully condense and edit. Dr. P. H. Stauffer carried out the task and eventually Memoir 17 was published in 1981 after a long delay. On 1 July 1999, the Geological Survey Department and the Mines Department were merged to form the Minerals and Geoscience Department.

At the time of publication of Gobbett and Hutchison (1973), Peninsular Malaysia was a pre-eminent tin mining country. Petroliam Nasional Berhad (PETRONAS) was established in 1974 and the first oil production from the Malay Basin came only in 1978. Collapse of the international tin price in 1985 resulted in near extinction of the tin industry and recent dramatic increase in metal prices has not revived the industry because many alluvial tin tailings had been reworked, and towns had expanded to cover up former mining areas. The last two placer tin dredges, one in the Kinta Valley, the other near Dengkil, are no longer in operation and are planned to become tourist attractions. There is still a tin smelter in Butterworth and only a very few placer mines in the Kinta Valley. Gold mining has expanded because of the dramatic increase in the metal price.

The earlier book presented a woefully inadequate picture of the ages of the granites. This situation has been dramatically improved beginning with the pioneering work of John Bignell (Bignell & Snelling, 1977), followed by extremely significant work by Liew (1983). The outstanding work of Cobbing *et al*. (1992) later ensured that the granites, their ages and geochemical signatures, became well known. Arising from this great body of work, the Main Range Granite of Peninsular Malaysia became the world standard for collisional S-type granite (Pearce *et al*., 1984).

The collision was identified as the Upper Triassic Indosinian Orogeny that resulted from closure of the Palaeo-Tethys Ocean and much research has been carried out to describe and refine the age of the Bentong–Raub suture. The accurate identification of the radiolaria contained in the ribbon cherts proved to be invaluable (Metcalfe *et al*., 1999). The recognition of the suture led to the realisation of the stratigraphical differences between that part of the peninsula west of the suture and that lying east.

The terrain lying west of the suture has similarities with Sumatra and western Thailand and has come to be referred to as “Sibumasu”. Its stratigraphy contains undeniable Carboniferous–Permian Gondwanaland affinities, notably marine pebbly mudstones of glacial origin. The terrain lying east of the suture has undeniable similarities with eastern Thailand in having affinities with Indochina and southern China. It is said therefore to have Cathaysian affinities. No generally acceptable name has been coined for it. “Indochina” is unsuitable because that is a political entity. In this book we refer to it as “East Malaya”.

AUTHORS AND CONTRIBUTORS

Charles S. Hutchison

spent most of his academic career at the University of Malaya (1957–1992), where he obtained his Ph.D. in 1967. In 2005 he was conferred the title of professor emeritus by the University. He is a recognised authority on the geology and tectonics of Southeast Asia through his books and papers. He recently taught courses part-time at the Universiti Brunei Darussalam and continues to teach part-time at the University of Malaya. He has been visiting professor at Kansas and Cornell universities. He worked for ESRI at the University of South Carolina, for CCOP in Bangkok, and for an oil company in Trinidad. He received the *Special* Commendation Award in 1994 from the AAPG. He was president of the Geological Society of Malaysia from 1969 to 1970 and was awarded its honorary membership in 1986.

Denis N. K. Tan

worked as a geologist in the Geological Survey of Malaysia in Kuching from 1972 to 1984. During this time, he was involved in regional mapping and published two reports. In late 1984, he joined Sarawak Shell Berhad where he worked mainly in regional geological review and exploration geology. In addition to Miri, he had assignments for Shell in The Hague (1990 to 1993), Kuala Lumpur (1999 to 2001), and Houston (2002 to 2004). He retired from Shell in November 2004, and joined the University of Malaya as a Professor in Petroleum Geology in September 2005. He retired from the University in August 2008, and is enjoying his retirement in travelling.

Lee Chai Peng

started his academic career as a tutor in the Department of Geology, University of Malaya in 1977. He was appointed a lecturer on completion of his M.Sc. on the Cambrian of the Machincang and Tarutao Formations. He obtained a Ph.D. from Liverpool University on the Macrobiostratigraphy of the North Downs Chalk in 1988 under a Commonwealth Academic Staff Scholarship. He was promoted to Associate Professor in 1992 and Professor in 2005. His research interests include Upper Palaeozoic glacial marine deposits, scyphocrinoid loboliths, Palaeozoic stratigraphy, regional tectonics, Miocene trace fossils, geohazards in limestones, reclamation of ex-tin mining lands, geo-conservation and geo-art. He was President of the Geological Society of Malaysia from 2004 to 2007. He was appointed Deputy Dean of the Science Faculty in September 2007.

Mustaffa Kamal Shuib

is an associate professor in structural geology and tectonics at the University of Malaya. He graduated from the University of Malaya and did his post-graduate studies at Imperial College, University of London. He has been actively involved in teaching and research at the University of Malaya since 1987. His current research interest is on the tectonic evolution of Peninsular Malaysia. He has published papers on structural geology, tectonics and engineering geology.

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is an associate professor in the Department of Geology, University of Malaya. He graduated from the University of Malaya in 1979 and joined the geology department as a tutor. He did his postgraduate studies in the Virje Universiteit Brussels (1979), Belgium, (MSc in Quaternary Geology – Geophysics), Imperial College, University of London (1980), (MSc in Geophysics), and University of Durham (1986), United Kingdom, (PhD in Geophysics). He was appointed a Lecturer in 1981 and has since served the University of Malaya as a Geophysicist. His research interest is application of the geophysical methods for geological and engineering applications.

John Kuna Raj

graduated from the University of Malaya in August 1972 with a B.Sc. (Hons) degree in Geology. He received the Diploma in Photo-Interpretation for Geomorphology in July 1973 and the M.Sc. degree in January 1975 at the International Institute for Aerial Survey and Earth Sciences at Enschede, Netherlands. He joined the University of Malaya as a lecturer in March 1975, where he received his Ph.D. in July 1983. He was promoted to Associate Professor in January 1985 and appointed Professor of Engineering Geology in August 1994. He retired in October 2004, but continues as a professor on contract.

Dr. Raj was Deputy Dean of the Science Faculty from October 1991 to March 1992 and was the Head of the Department of the Geology Department from April 1994 to March 1998. He was Vice-President in 1984 and President of the Geological Society of Malaysia in 1985–1986. He was honorary secretary of the Institute of Geology of Malaysia from 1986 to 1990. He has also been active as a consultant on geology and has been involved in several engineering projects in Malaysia. Dr. Raj's main research interests and publications are on landslides and the geotechnical properties of weathered materials.

Wan Hasiah Abdullah

began her academic career in 1984 upon undertaking a tutorship/postgraduate programme in the U.K. and started teaching in the Department of Geology, University of Malaya, in 1990. She was appointed Associate Professor in 1999 and Professor in 2005. She specializes in organic petrology and petroleum geochemistry. Her research interest is in assessing the oil-generating potential of coals and determining depositional environments of oil-prone source rocks. For her MSc, she worked on the Brent Formation coals of the North Sea and for her PhD she worked on a succession of sedimentary rocks from Spitsbergen (Norway). She has also taken up consultancy work with Sarawak Shell Bhd., Sabah Shell Petroleum Company, and PETRONAS Research and Scientific Services Sdn. Bhd. She was Head of the Department of Geology from 2004 to 2007 when she oversaw the introduction of an M.Sc. degree programme in Petroleum Geology by coursework, the first of its kind in Malaysia.

Robert B. Tate

was a graduate of Imperial College, University of London. He commenced his career in the Geological Surveys of Nigeria and Ghana, mapping basement rocks and conducting mineral exploration. He was then appointed State Geologist, Negara Brunei Darussalam, in 1966 and studied palaeo-environments of the Miocene-Pliocene sequences that are exposed spectacularly along the coast. He worked subsequently in Afghanistan, Ethiopia, Somalia, Sudan, and China. He graduated with an M.Sc. from the University of Malaya and in 2001, he compiled a CD Rom on the "Geology of Borneo" as well as the first complete regional geological map of Borneo. He compiled Bulletin 50 of the Geological Society of Malaysia and has compiled a 1:1 million geological map of the Malay Peninsula to parallel the new edition of this volume as was done in the original 1973 publication. Sadly, Robert died in Warrington on the 22nd August 2008 before he could see the map and book published.

Nuraiteng Tee Abdullah

is a Senior Lecturer in the Geology Department, University of Malaya. She is a former graduate of the department and joined the department upon obtaining her doctorate from the University of London. Her current research interest is on the biostratigraphy and sedimentology of the Permian and Tertiary carbonates of Malaysia.

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graduated from the University of Malaya in August 1992 with a B.Sc. (Hons) degree in Geology. He completed his Ph.D. at Liverpool University on the geochemistry of Donegal Granites, Ireland, in 1997, and joined the University of Malaya as a lecturer in the same year. He was appointed Associate Professor in 2001 and Professor in 2006. He has been visiting professor at the National Taiwan University. He is presently Head of the Geology Department of the University of Malaya. Dr. Azman's main research interests are on geochemistry and petrology of igneous rocks. He has published papers on geochemistry and mineralogy of igneous rocks from Peninsular Malaysia and granite of Donegal, Ireland. He was appointed Head of the Geology Department in September 2007.

Ng Tham Fatt

graduated from the University of Malaya in August 1987with a B.Sc. (Hons) degree in Applied Geology. He obtained an M.Phil. degree in 1993 and a Ph.D. in 2002 from the same university. He worked as an independant consultant before joining the University of Malaya in April 2007 as an Associate Professor. He has compiled Bulletin 34 of the Geological Society of Malaysia. His current research interest is microstructures of fault rocks and application of GIS to geology.

2

Geomorphology

J. K. Raj

2.1 INTRODUCTION

Peninsular Malaysia, with a total land area of 130,268 km^2, forms part of Sundaland, which includes Borneo, Java and Sumatra, as well as the intervening shallow seas from which emerge a number of smaller islands (van Bemmelen, 1949). Sundaland is the partly submerged southeastern extension of the Asian continent to which the Peninsula is connected by the Isthmus of Kra, which at its narrowest is only 64 km wide. The Peninsula is elongated in a general NNW–SSE direction with a maximum length of 750 km and breadth of 330 km. To the south, it is separated from Singapore Island by the narrow Johor Strait whilst, to the west, it is separated from Sumatra Island by the Straits of Malacca. To the southeast and east the South China Sea separates the Peninsula from Borneo Island.

The Peninsula has been largely or entirely emergent throughout the Cenozoic and is considered to have been relatively stable tectonically; activity being confined to epeirogenic uplift and tilting, some fault movement, and local gentle downwarps (Stauffer, 1973a; Gobbett & Tjia, 1973). More recent work in Sumatra, however, suggests otherwise and it is pertinent to briefly describe here its Cenozoic geologic history that started with shallow-water continental margin sediments deposited directly on the eroded surface of the pre-Tertiary Sundaland basement; erosion extending from the latest Cretaceous into the early Tertiary (de Smet & Barber, 2005). In the Late Eocene, continental margin sedimentation was brought to an end by the development of horst and graben structures throughout Sundaland from Late Eocene to Late Oligocene. This process had a dramatic impact on landscapes and sedimentation patterns; the former Sundaland peneplain being transformed into a mountainous landscape with isolated deep, lake-filled, basins where terrestrial, fluvial and lacustrine sediments were deposited (Barber *et al*, 2005a).

In the Late Oligocene, there was a change in the regional tectonic regime, with an area of predominant uplift in Sumatra, marked by the Barisan Mountains, becoming contrasted with areas of continued sedimentation in fore-arc and back-arc basins, west and east of the Barisan Mountains, respectively. There was then regional subsidence in a sag phase from the Late Oligocene to Middle Miocene, the effects of which extended well to the east of Sumatra into Malaysia. At the same time, the arc system of Sumatra started developing and the Barisan Mountains became an important source of sediments for the fore-arc and back-arc basins. For the first time in the Tertiary, rivers formed regional inter-connected systems that transported their sediment load to a few broad basins; deltas extending westwards from Malaysia and from the present Gulf of Thailand, controlling sedimentation in Central Sumatra (de Smet & Barber, 2005).

Continued regional subsidence led to marine transgression from Early to Middle Miocene and, at the time of maximum transgression in the Mid-Miocene, the sea gained access to almost the whole of Sumatra with source areas in the Malayan Shield, much reduced in size and relief, and the Barisan Mountains almost drowned. The climax of uplift and erosion of the Barisan Mountains occurred in the Late Pliocene and was accompanied by intense volcanism; this event coinciding with inversion tectonics in the back-arc basins. Quaternary deposits in Sumatra mostly consist of conglomerates derived from the Barisan Mountains with a high proportion of volcanic debris in the neighbourhood of Recent volcanoes, passing into fluvial deposits away from the mountains, and swamp deposits to the east along the shores of the Straits of Malacca and the Java Sea (de Smet & Barber, 2005).

The geomorphological development of

3

Regional geological setting

C. S. Hutchison

3.0 INTRODUCTION

Peninsular Malaysia is an integral part of the Eurasian Plate, the South-East Asian part of which is known as Sundaland (Hutchison, 1989, 1996). The Sunda Shelf, with less than 200 metre water depth, is a continuation eastwards and southwards and Sumatra, Natuna and western Borneo are integral parts of the same plate and the Sunda Shelf is common to all (Fig. 3.1). The edge of the Sunda Shelf extends N-S a short distance east of Vietnam and then curves eastwards as far as the West Baram Line (Hutchison, 2004, 2005). East of the Shelf edge is the continental slope-rise, formed of continental crust that is increasingly attenuated eastwards. On navigation charts it is shown as 'Dangerous Grounds', characterized by deep water containing a large number of reefs.

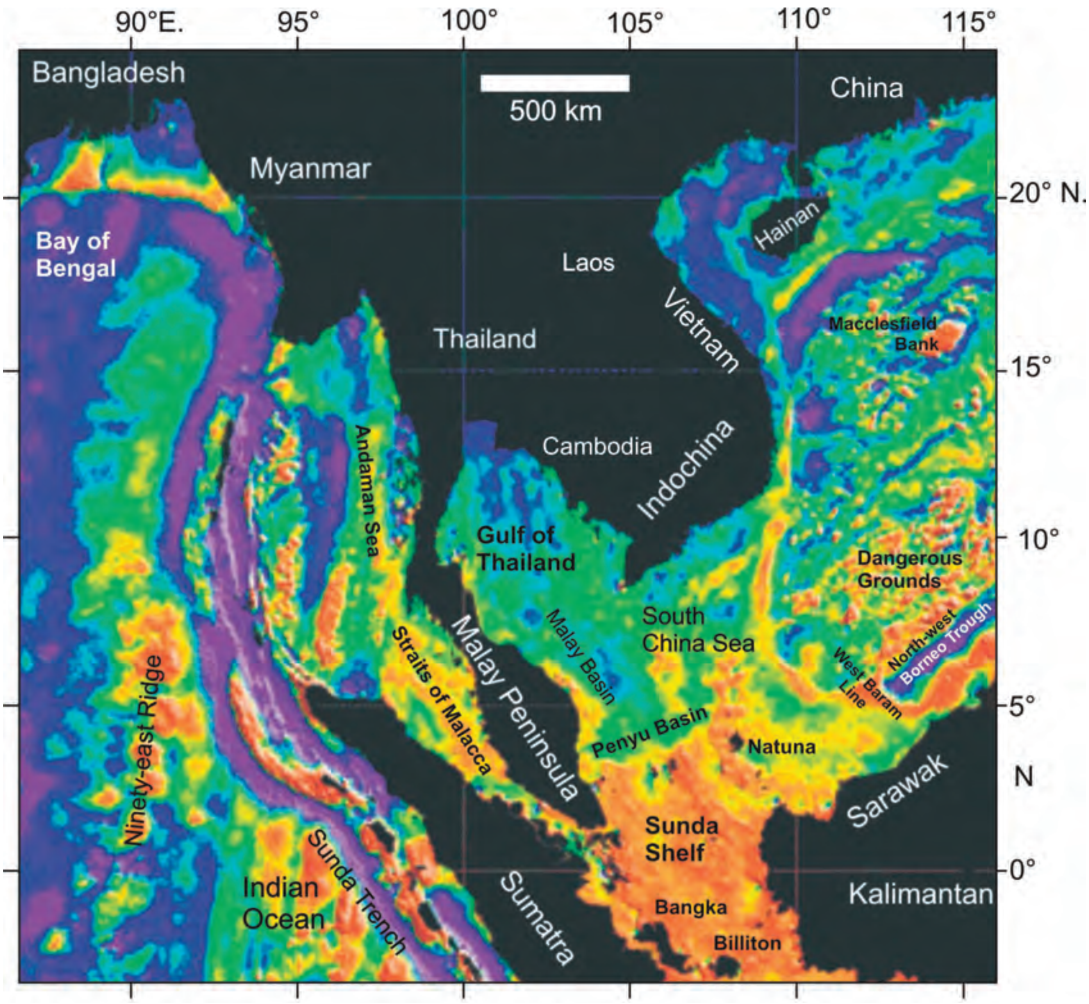

Fig. 3.1: Global marine gravity anomalies from SEASAT, GEOSAT, ERS-1 and TOPEX/POSEIDON altimeter data of South-East Asia by Oxford University Department of Earth Sciences (*www.earth.ox.ac.uk*).

4

Bentong—Raub Suture

C.S. Hutchison

4.0 INTRODUCTION

Because the eastern 'Foothills' of the Main Range are constructed of metasediments, associated with radiolarian chert and contain serpentinite and metabasite, Jones (1968, 1973) interpreted them as marking a 'eugeosyncline' separating western from eastern Peninsular Malaysia (Malaya). Haile and Stauffer (1972) pointed out rather amusingly that the "Bentong Group" of Alexander (1968) should be abandoned because it contained both radiolarian chert and continental redbeds, but they were sceptical that the Foothills Range represented a subduction zone. Haile (1973) and Hutchison (1973d) then interpreted the Foothills as a former subduction zone. The 'Foothills' zone thus became recognised as the central Malaya suture and Hutchison (1975) named it the "Bentong-Raub ophiolite line", that subsequently became widely known as the "Bentong-Raub Line". The main occurrences of the suture zone rocks are shown in Fig. 4.1, after Metcalfe (2000b). The Bentong-Raub Suture represents the Palaeo-Tethys in Peninsular Malaysia. It is a southwards extension of the Nan-Uttaradit and Sra Kaeo sutures of Thailand. The suture zone contains oceanic ribbon chert that has been dated by radiolaria ranging in age from Upper Devonian to Upper Permian (Metcalfe, 1999). Graptolites in the associated slates of the Tuan Estate south of Karak are dated Lower Devonian (Jones, 1970). Limestone clasts in mélange are of Lower and Upper Permian age. The Palaeo-Tethys therefore opened in the Lower Devonian, caused by separation of Sibumasu from Gondwanaland, and closed in the Triassic, caused by the Indosinian orogenic collision with the Indochina Block that was earlier sutured to Eurasia.

4.1 CENTRAL AREA

The most accessible and therefore the best known part of the suture extends southwards from Cheroh (Fig. 4.2), through the Raub and Bentong areas and southwards towards the Kuala

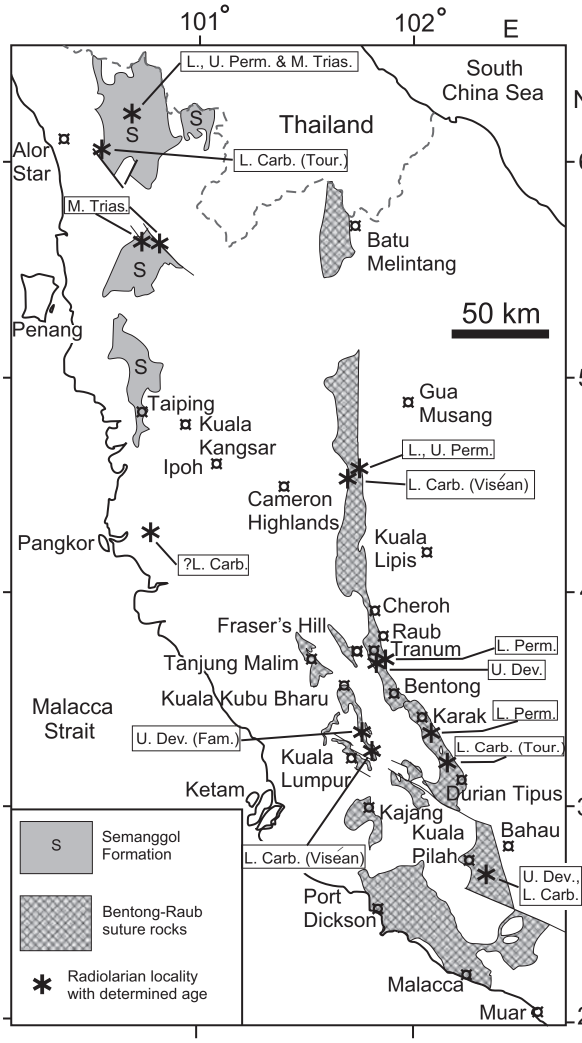

Fig. 4.1: Bentong-Raub suture zone. Distribution of suture zone rocks in Peninsular Malaysia and ages determined from radiolarian chert localities. The Semanggol Formation is interpreted to be related to the suture and may represent a foredeep basin. Redrawn and modified after Metcalfe (2000b).

5

Palaeozoic Stratigraphy

Lee Chai Peng

5.0 INTRODUCTION

Palaeozoic rocks outcrop over about 25% of the Peninsula. Forty-two formations were included in the Stratigraphic Lexicon of Malaysia (Lee *et al.*, 2004), but several new formations have been added since, particularly in refining the stratigraphy of the transitional units between the Setul Group and the Singa Formation in the northwest (Meor & Lee, 2002a, 2002b, 2004, 2005, Cocks *et al.*, 2005).

Another advancement, after Jones (1973a), is the replacement of the geosynclinal concept by the plate tectonic paradigm. This necessitated updating the familiar subdivisions of the Palaeozoic rocks in different parts of the geosyncline, such as miogeosyncline, geanticline and eugeosyncline, into their modern equivalents. The miogeosyncline, of shallow marine shelf sediments, is now recognised as part of the margin of Gondwanaland, to which Langkawi was attached on its west in the Early Palaeozoic. The geanticline represents the accretionary prism with volcanic input from the forearc, and the mud-rich deepwater eugeosynclinal sediments are oceanic.

The Peninsula may be subdivided into three belts characterised by different stratigraphy (Fig. 5.1). The western belt contains a northwestern domain that is also shown in this figure. A summary of the stratigraphy is given in Fig. 5.2.

5.0.1 Western Belt

Lower Palaeozoic rocks are confined to the western part of the peninsula, and Upper Palaeozoic rocks are found in all three belts in the tripartite peninsular divisions (Figs. 5.1, 5.2). The most complete sequence of Palaeozoic sedimentary rocks, ranging in age from Upper Cambrian to Upper Permian, is exposed in the Northwestern Domain of the Western Belt, in Langkawi, Kedah and Perlis. These are mainly shallow-marine shelf sediments of the Machinchang and Jerai Formations, Setul Group, Timah Tasoh and Chepor Formations, Singa and Kubang Pasu Formations and Chuping Limestone that deepen eastwards to the Mahang and Sungai Patani Formations.

Palaeozoic rocks of the rest of the Western Belt are distributed in the foothills along both flanks of the Main Range granite batholith stretching from the Malaysian–Thai border southwards to Malacca. On the western side of the Main Range is the Baling Group sediments consisting of the Papulut Quartzite, Grik Siltstone, Lawin Tuff and Bendang Riang Formation in north Perak of probable Cambrian to Permian age. Other important Palaeozoic

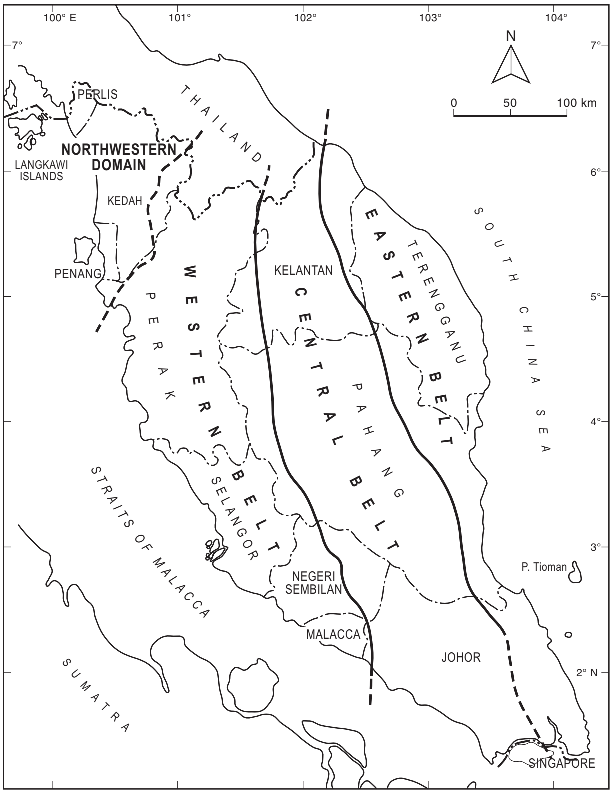

Figure 5.1: Map of Peninsular Malaysia showing the three belts and the northwestern domain within the Western Belt.

6

Mesozoic Stratigraphy

Nuraiteng Tee Abdullah

6.0 INTRODUCTION

At the beginning of the Mesozoic Era, a large part of the newly-formed landmass of the Peninsula was uplifted and remained subaerially exposed. Marine sedimentation was centred in two areas: the northwestern Kodiang–Semanggol depocentre and the Gua Musang–Semantan depocentre in the Central Belt (Fig. 6.1). The former was developed on the Upper Palaeozoic Sibumasu landmass, and was the only remnant of what was once an extensive area of marine deposition in Late Palaeozoic time. The Gua Musang–Semantan depocentre was areally more extensive and was developed on the Upper Palaeozoic shelf of East Malaya. The extensive occurrences of tuff and associated lava, tuffaceous siliciclastics and conglomerate, in the Gua Musang–Semantan depocentre during Triassic times, indicate that volcanic activities and basinal instability were active during the life span of the basin. In the deeper parts of the Gua Musang–Semantan depocentre, thick accumulations of turbidites have prompted geologists to refer to these rocks as flysch.

As the Triassic period ended, a new regional pattern of sedimentation was established in the aftermath of tectonic disturbances and widespread plutonism that formed the Main Range, Central Belt and the Eastern Belt plutons. Voluminous sediments, eroding from newly elevated sources, were transported and infilled existing basins. Significant faulting, especially strike-slip, dissected the landmass, created new basins and caused partial inversion of earlier ones. These new basins were infilled rapidly by red, ferric-rich, siliciclastics that were deposited in diverse terrestrial settings, ranging from alluvial fans, braided rivers, flood plains, lakes and deltas. These redbeds, aptly named in reference to their colour, were likened to molasse deposits and marked the end of marine sedimentation throughout the Peninsula during Jurassic to Cretaceous times.

Burton (1973a) remarked that the Peninsula was given its present form during the Mesozoic Era. His statement remains undisputed and his work on the Mesozoic of Peninsular Malaysia continues to be the standard reference. Much

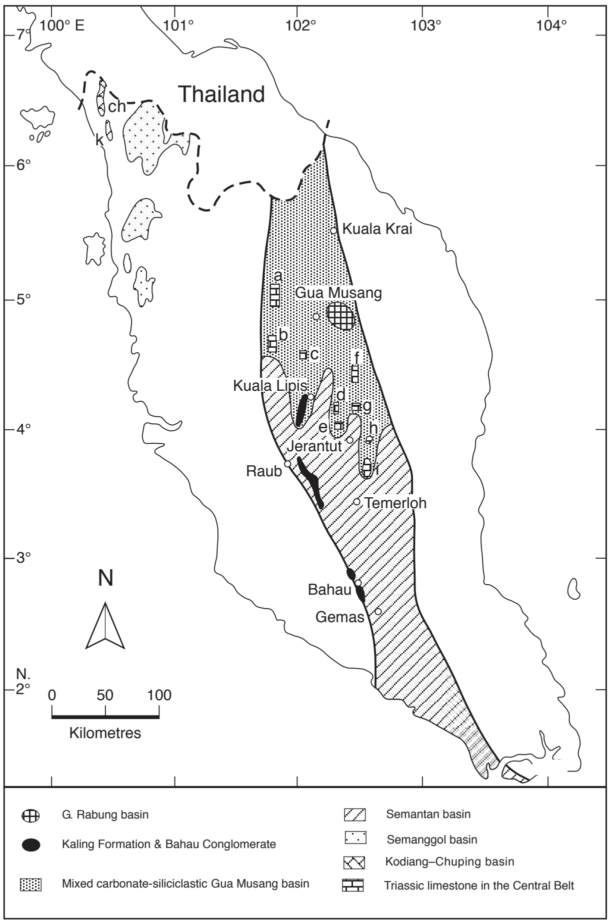

Figure 6.1 Triassic depocentres of Peninsular Malaysia (modified after Khoo, 1983; Kamal, 1990; Fontaine & Ibrahim Amnan, 1994). Localities of Triassic limestone in the Central Belt: (a) Kg. Lambok – Gua Cha; (b) South of Pos Blau (G. Belong); (c) Gua Panjang; (d) Sg. Kenong Area; (e) South of Kerambit; (f) Gua Telinga – Gua Luas; (g) Bt. Darang Harimau; (h) Kota Gelanggi; (i) G. Sinyum – G. Jebak Puyuh. Localities of Kodiang Limestone: (ch) Chuping, (k) Kodiang.

7

Cenozoic Stratigraphy

J.K. Raj, D.N.K. Tan and
Wan Hasiah Abdullah

7.0 INTRODUCTION

Cenozoic sedimentary rocks occur both onshore, mainly along the West Coast, and offshore in the Straits of Malacca and the South China Sea. The Peninsula onshore has been almost entirely emergent throughout the Cenozoic, with inland Tertiary sedimentary rocks reported from ten localities. Most recent work, however, indicates that only seven have proven, or very likely to have, sedimentary rocks of Tertiary age. These occur at isolated and widely separated sites on the West Coast, indicating that the sediments were probably deposited in individual discrete basins. These are pull-apart basins that developed during the Eocene to Oligocene and occur at Bukit Arang in north Perlis and Kedah, Lawin in north Perak, Enggor in central Perak, Batu Arang in Selangor and Kampong Durian Chondong, Kluang–Niyor and Layang-Layang in central Johor. Other localities that were previously suspected to have Tertiary sedimentary rocks are at Nenering in north Kedah (now known to be of Cretaceous age) and at Tanjong Rambutan in north Perak and Merapoh in north Pahang (now believed to be Quaternary). The onshore basins can be separated into four broad groups: a northwestern occurrence at Bukit Arang, a north-central group comprising Lawin and Enggor, a central occurrence at Batu Arang, and a southern group comprising Kampong Durian Chondong, Kluang–Niyor and Layang-Layang.

Most of the Tertiary sedimentary rocks occur offshore in the Straits of Malacca and South China Sea. In the Straits of Malacca, they were deposited in 15 grabens and half-grabens, which can be grouped into four N–S-trending belts. The northern belt consists of the Northern, MSS-XA, Thai Border West and Thai Border East grabens. The Central belt comprises the Southern, Central, Eastern, and the West, East and North Penang grabens. The Port Klang belt is made up of the Port Klang, Angsa and Sabak grabens, and the Johor belt consists of the Johor and Kukup grabens. These offshore grabens are probably related to the North and Central Sumatra basins in Indonesia. The relationship, if any, between these offshore grabens and the onshore Tertiary basins is uncertain. However, it would not be unreasonable to surmise that the onshore Batu Arang basin may be related to the Port Klang belt, and the Kampong Durian Chondong, Kluang–Niyor, and Layang-Layang basins to the Johor belt. It is interesting that the onshore basins are much smaller in size than the offshore grabens. The relationship between the onshore basins in the north to the offshore basins is less clear.

The two major Tertiary basins are the Malay and Penyu basins, which occur in the South China Sea, offshore East Coast (see Chapter 8). These two basins are distinctly different from the onshore basins and the Straits of Malacca grabens, and are filled with more than 14 km of Tertiary sediments.

The Quaternary Period is represented by extensive deposits of unconsolidated to semi-consolidated boulders, gravel, sand, silt and clay that underlie the coastal and inland plains as well as infilled valleys. Such sediments also form river terraces and beach ridges, locally known as '*permatang*'. All these sediments have traditionally been known as 'alluvium', though some are definitely of a colluvial, littoral or marine origin. Ongoing research indicates that some of them may be much older, possibly Middle to Late Tertiary.

The coastal lowland regions contain a discontinuous fringe of peat swamp and mangrove forests that form a transition buffer between the land and sea. The peculiar conditions responsible for the formation of peat swamp forest resulted in the establishment of a unique ecosystem that

8

Malay and Penyu Basins

D. N. K. Tan

8.0 INTRODUCTION

The Malay and Penyu Basins, offshore the East Coast of Peninsular Malaysia, are part of a series of Cenozoic sedimentary basins in the South China Sea and Gulf of Thailand, extending from the Pattani Basin (or Pattani Trough) in Thailand, in the north, to the West Natuna Basin in Indonesia in the southeast (Fig. 8.1).

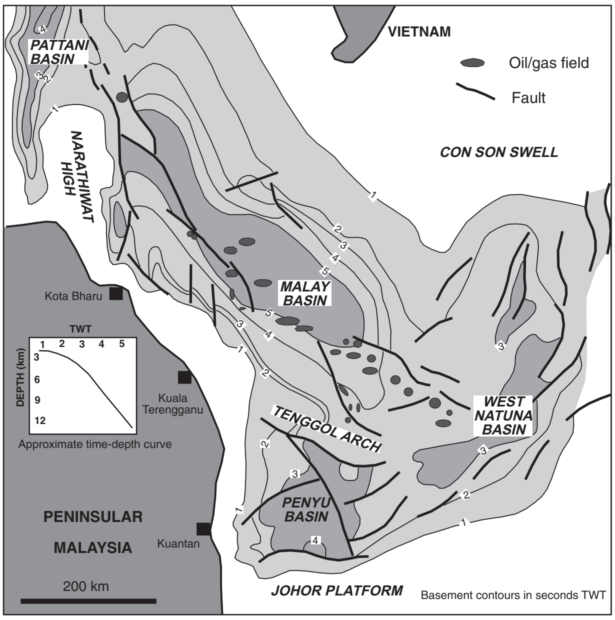

Fig. 8.1: Outline of the Malay and Penyu basins (modified from Khalid *et al*., 1996; Tjia, 1998b)

The Malay Basin, separated from the Pattani Basin in the north by the Narathiwat High, and from the Penyu Basin in the south by the Tenggol Arch, is about 500 km long and 200 km wide, with a total area of about 83,000 km² (Tjia, 1999b; Bishop, 2002). To the northeast, the basin rises to shallow depths over the vast Con Son Swell. The Western Hinge-line Fault Zone forms the southwest margin of the basin. The basin is elongated NW–SE to NNW–SSE, generally parallel to Peninsular Malaysia. It comprises 2 parts: a southern part which trends NW–SE, and a northern part that trends NNW–SSE. These two are separated by a broad transition zone, the so-called Kapal–Bergading Tectonic Line, aligned along the 103° 30′ E longitude (Tjia & Liew, 1996). The basin is filled with more than 14 km of Cenozoic sediments. The Malay Basin is an important hydrocarbon province in Malaysia, with production of more than 1.9 billion bbls (barrels) of oil and 2.8 TCF (trillion cubic feet) of gas by end of 1997 (Wong, 1999).

The Penyu Basin is separated by the Tenggol Arch from the Malay Basin to the north and the West Natuna Basin to the east. It is bounded to the south by the Johor Platform and the northwest by the Pahang Platform. The basin probably extends onshore under the Sungai Pahang delta (Tjia, 1998b). The basin is elongated roughly E–W, approximately 160 km by 100 km, and is filled with up to 8 km of Cenozoic sediments (Mazlan & Azlina, 1999). It is separated by the NW–SE-trending Rumbia fault into 2 parts (Khalid *et al*., 1996). The western part is dominated by two E–W-trending half-grabens, whereas the eastern part is characterised by NW–SE- to WNW–ESE-trending structures (Tjia, 1998b).

The Malay and Penyu basins are filled with Cenozoic siliciclastic sediments, ranging in age from Oligocene to Recent. The stratigraphy of the Malay Basin is different from that in the Penyu Basin. Different stratigraphic schemes have been used in the Malay Basin by different companies and workers, and these are summarised in Figure 8.2, which also shows the stratigraphy of the Penyu and West Natuna basins.

The fault patterns in onshore Peninsular Malaysia and in the offshore Malay and Penyu basins are shown in Figure 8.3. The onshore faults are described in Chapter 12. The offshore faults were inferred from structural styles in the overlying sediments and magnetic/gravity

9

Volcanism

Azman A. Ghani

9.0 INTRODUCTION

Contemporaneous lavas and pyroclastic rocks occur interstratified within Lower and Upper Palaeozoic and Mesozoic strata. There are also post-orogenic flows of Cenozoic age. Most are dated by their stratigrapic position. Early studies by Willbourn (1917) grouped them under the name Pahang Volcanic Series, because most are best developed in Pahang (Fig. 9.1). However, later field investigations showed that contemporaneous volcanic and pyroclastic rocks are much more extensive and include occurrences within Lower Palaeozoic strata in the Western Belt and Upper Palaeozoic and Mesozoic strata in the Central and Eastern Belts. The latter are mainly rhyolitic to dacitic and are both pyroclastics and lavas. The other significant volcanic occurrence is the Cenozoic post-orogenic flows of alkaline basaltic lavas in the Segamat and Kuantan areas. This chapter also includes the dykes of intermediate to basic composition that intrude mainly the rocks of the Eastern Belt.

The overall occurrences of volcanic rocks have been reviewed by Hutchison (1973a) and this chapter does not repeat the details of the field relationships and their petrography. This chapter will focus more on the available geochemical data. These volcanic rocks have generally only been studied at reconnaissance level, mainly to correlate them with the closure of the Tethys Ocean during Permo–Triassic time. A complete modern geochemical and radiometric-based study that comprises data for all the volcanic rocks from the Peninsula does not yet exist. Not many have been dated and analysed for major,

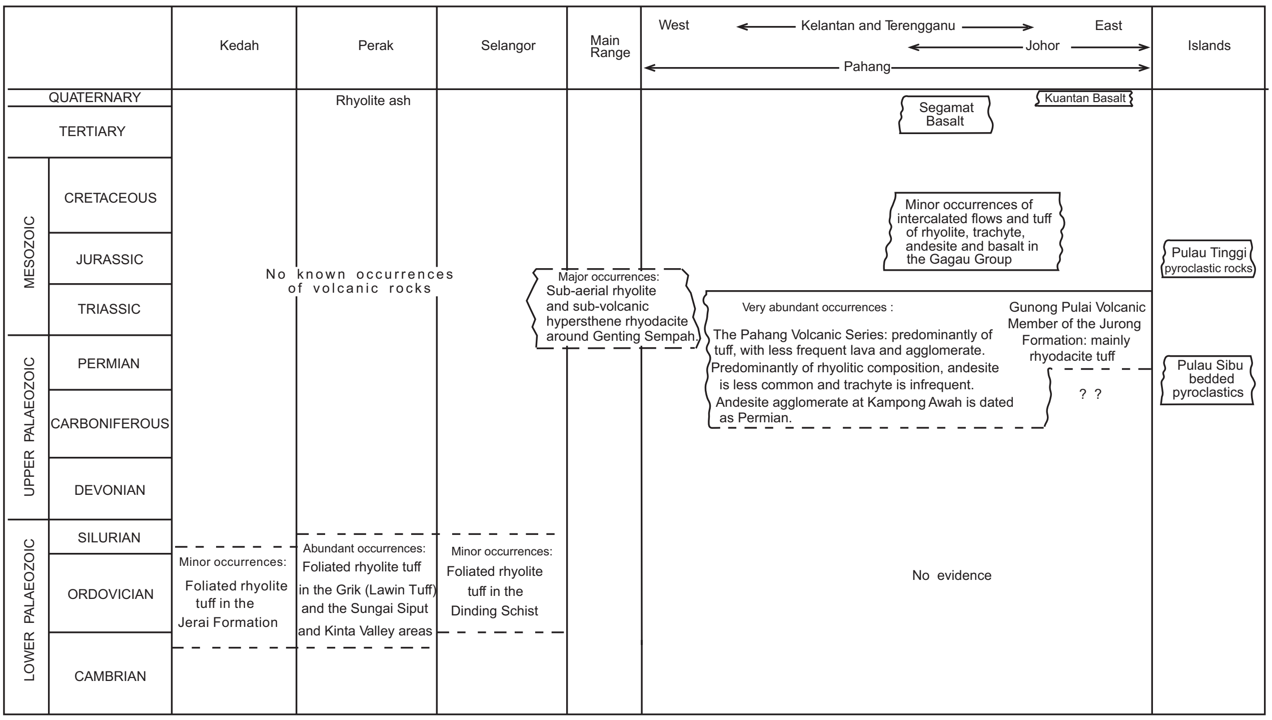

Fig. 9.1: Summary of ages of volcanic rocks across the peninsula (modified after Hutchison, 1973a).

10

Plutonism

Azman A Ghani

10.1 INTRODUCTION

The plutonic rocks are part of the Southeast Asian tin belt (Schwartz *et al.*, 1995). More than 90% are granitic. The granitoids of Malaysia, Thailand and Myanmar have petrological and geochronological characters that permit them to be put into belts (Cobbing *et al.*, 1992). They have been divided into three: Western province, Eastern province and Main Range province (Hutchison & Taylor, 1978; Beckinsale, 1979; Cobbing *et al*. 1986) (Fig 10.1).

The Main Range granites are concentrated mainly in Peninsular Malaysia but extend through Peninsular Thailand as far as the latitude of Bangkok. The Main Range and Eastern Belt granites of Peninsular Malaysia demonstrate distinctly different petrological and geochemical varieties. These provinces are separated by the Bentong-Raub suture (Hutchison, 1975). The Main Range granites have a more restricted composition (SiO_2 >65%) whereas the Eastern Belt granitoids are compositionally expanded, SiO_2 ranging from 50 to 78%. The granites that have been responsible for the tin mineralization are exclusively of S-type, formed by collision of continental lithosphere. The Eastern and Central belts consist of both I and S type granitoids. In contrast to the Western Belt, some of the complexes and plutons of the Eastern Belt contain mafic to intermediate plutonic rocks that are closely spacially related to the granitic plutons. The mafic rocks constitute less than 5% of the total exposed plutonic areas. They are marginal to the granitic plutons, as well as synplutonic dykes and as late intrusive dykes mainly of dolerite composition. In this chapter the plutonic rocks will be divided into three: (1) The Main Range, (2) the Eastern Belt, and (3) Cretaceous plutonic rocks. The distribution of the Peninsular Malaysian granitic plutons and associated rocks is shown in Fig.10.2.

10.2 GEOCHRONOLOGY

Geochronological studies of the granitoid batholiths were initiated by the Institute of Geological Sciences (IGS) of London in 1974 and the results of the Rb–Sr and K–Ar work were published by Bignell and Snelling (1977). Bignell (1972) carried out the field work and subsequent laboratory analyses for his D.Phil. thesis. The striking feature of all west Coast Province granites is the large discrepancies between K-Ar mica age, Rb-Sr whole rock isochrons and the U-Pb zircon ages. The K-Ar data give a wide range between 40 to 210 Ma in contrast to the Rb-Sr and U-Pb data, which give Late Triassic ages (200 to 230 Ma) (Bignell & Snelling 1977, Liew 1983, Darbyshire 1988). The absence of K–Ar ages older than 210 Ma was interpreted to be the result of Ar loss caused by Late Triassic intrusions and young fault-related disturbance (Bignell & Snelling 1977). A summary of the geochronology of the Peninsula is shown in Table 10.1.

10.2.1 Main Range Granite

The ages of 207–230 Ma are in agreement with the results of Bignell & Snelling (1977), Liew (1983) and Darbyshire (1988). The high initial $^{87}Sr/^{86}Sr$ ratios are in agreement with the S–type characteristics. The initial ratios range from 0.71 to 0.73 as shown in Fig. 10.3, from Hutchison (2007), using the data of Cobbing *et al.*(1992).

However there are also some younger granitic rocks in the western part of the Main Range, for instance the Gunung Jerai Granite of Kedah Peak. Analyses of different rock types in this pluton gave an age no more than 135 ± 6 Ma. Biotite and muscovite from the Jerai Granite have been dated using the K–Ar method to give an age of 47 ± 3 Ma and 59 ± 3 respectively (Bignell & Snelling 1977). The oldest component of this

11

Metamorphism

C.S. Hutchison

11.0 INTRODUCTION

High-grade metamorphic complexes are confined to the northern part of the Peninsula, giving rise to the general belief that the Peninsula has been uplifted and more deeply eroded in the north and tilted down towards the south.

11.1 STONG MIGMATITE COMPLEX

This migmatite complex forms mountainous country lying about 8 km west of the railway towns of Kemubu and Dabong. It is readily identified from the railway line by the reclining spine-like protrusion at the summit of Gunung Stong. Excellent outcrops occur in rapids along the Sungai Kenerong and Sungai Semuliang, both accessible from Kemubu (Fig. 11.1). The road links Dabong with Jeli, and some 17 km north of Kuala Balah, it transects the Sungai Renyok. Ibrahim Abdullah and Jatmika Setiawan (2003) described the Late Cretaceous Kenerong Leucogranite and its enclaves, exposed at waterfalls near the electricity power station.

11.1.1 Granitoids

There are three plutonic components (Singh *et al*., 1984). The earliest two phases (Berangkat Tonalite and Kenerong Leucogranite) are in part highly deformed in a manner similar to that of the marginal country rocks (Fig. 11.1). The third phase, the distinctive pink Noring Granite, is undeformed.

The Berangkat Tonalite, at the southern end, is a coarse grey K-feldspar megacrystic biotite-hornblende tonalite that locally is highly deformed. It may be of Permo-Triassic age (Cobbing *et al*., 1992), but no dating has been carried out and the similar abundance of enclaves to the Kenerong Leucogranite suggests that a Cretaceous age may be more appropriate. The tonalite is cut by the Kenerong leuco-microgranite. It forms a complex network of small intrusives and vein systems emplaced into the predominantly pelitic amphibolite-facies metasedimentary envelope. Three samples define an Upper Cretaceous Rb:Sr age of 79 ± 3 Ma, with an initial ratio of 0.70801 (Cobbing *et al*., 1992). The pink Noring Granite is an undeformed megacrystic biotite-hornblende granite. It is a larger pluton extending northwards to intersect the East-West Highway west of Jeli. The Rb: Sr data define an isochron of 90 ± 30 Ma with an initial ratio of 0.70865. The Noring Granite intrudes the earlier Kenerong Leucogranite. Bignell and Snelling (1977) have reported the following K:Ar ages: 65±2 for muscovite and 70±2 Ma for biotite in the Noring Granite at Batu Melintang, and 69±2 Ma for the Kenerong Leucogranite of the Stong Complex. These dates reinforce the interpretation of a Cretaceous age.

11.1.2 Granitoid-metamorphic rock relationships

The appropriate description is that the Stong is an injection migmatite of great complexity. The three main types of migmatite are well represented, with transitions between them (Fig. 11.2):

- Agmatite, in which angular enclaves of darker gneiss and schist are surrounded by more homogeneous granitic material. It appears to have formed by magmatic injection. Some contacts are concordant while others are discordant. Good examples occur along the Sungai Kenorong and Sungai Seladang.
- Venite, in which discrete layers and patches of granitic material occur in schist. The individual layers are narrower than in agmatite. Good examples occur along the Sungai Semuliang (Fig. 11.2)
- Nebulite, in which there is a more complete mixing of granitic material and schist. They are more homogeneous but contain schlieren generally enriched in biotite and hornblende,

12

Major Faults

Mustaffa Kamal Shuib

12.0 INTRODUCTION

The Peninsula has a NNW–SSE elongated shape with a slight dog-leg bend in the south near Klang and Mersing. The shape is controlled by the regional structures. The NNW–SSE general structural trend is also influenced by the distribution of the Main Range Granite, the backbone of the Peninsula. Extending from the Malaysia–Thailand border to the southern state of Negeri Sembilan, this central spine effectively separates the eastern and western parts of the Peninsula (Fig. 12.1).

As reflected by the strike ridges illustrated in the lineament map (Fig. 12.1) and the geological map (back pocket), the main structural trend of the Peninsula is NNW–SSE, defined by the strike of bedding and lithological boundaries, axial traces of folds and the strike of axial planes.

This NNW–SSE general structural trend is superimposed by later N–S, NW–SE, NNE–SSW, and E–W major faults (Fig. 12.2). These later structures, combined with the bedrock lithologies, controlled the irregularity of the surface topography and the coastlines. The dog-leg bend, which starts at the western coastline near Klang and ends at the eastern shoreline near Mersing, is because of NW–SE-trending strike-slip faults and, to a lesser extent, NNE–SSE-trending faults. In the East Coast, especially in southeast Johor, the strike ridges and faults control the coastline.

The NNW–SSE structural trend is reflected by the elongation of the Peninsula, Straits of Malacca and Sumatra. There are important differences as well as similarities between the Peninsula and Sumatra, because of a regional orocline, shown in Figure 3.4(C). The NW–SE faults of the Peninsula are parallel to the structural grain of most of Sumatra (Fig. 12.1). By contrast, the N–S structural grain of the Peninsula is parallel to faults in central Sumatra (Hutchison, 1994). The spectacular Bengkalis Graben, aligned at 102.3°E, extends southwards from the Straits of Malacca over a distance of 265 km.

The N–S to NNW–SSE structural grain has been used to divide the Peninsula into 3 major belts (Fig. 5.1) with a less obvious fourth domain in the NW (Tjia & Zaiton, 1985). The boundaries between the NW Domain and Western Belt are less well defined than the boundaries between the Western, Central and Eastern Belts. The NW Domain has a N–S grain, compared to the NNW–SSE structural grain of the rest of the Peninsula. A distinct N–S lineament along the eastern foothills of the Main range, called the Bentong–Raub Line (Hutchison, 1973d), separates the Western Belt from the Central Belt. The boundary between the Central and Eastern Belts is marked by the Lebir Fault Zone. Most workers correctly showed that the longitudinal belts of the Peninsula curved towards the southeast (Fig. 3.4) to include the "tin islands" of Bangka and Billiton (Hutchison, 1994). However, Tjia and Zaiton (1985) and Tjia (1989a) proposed that the Bentong and Lebir lineaments, which bound the Central Belt, may be extended across the Straits of Malacca in a southerly direction along the N–S-trending Lalang and Berangkat Lineaments of Central and South Sumatra. However, this proposal was not supported by Barber *et al*. (2005a), as shown in Figure 3.4.

These structures are the expression of several brittle-ductile deformations ranging from the pre-late Lower Permian to the Tertiary. The general NNW–SSE structural trend is believed to be the result of three main deformation phases: an Upper Triassic–Lower Jurassic transpression and Upper Cretaceous and Tertiary strike-slip deformations. The Upper Triassic–Lower Jurassic orogenic event is popularly believed to be due to the collision between Sibumasu and East Malaya. The Upper Cretaceous event not only deformed

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Structures and Deformation

Mustaffa Kamal Shuib

13.0 INTRODUCTION

The structures of the Peninsula reflect a long and complex tectonic evolution, starting possibly from as early as Cambrian right up to the Cenozoic. It is thought that the western Gondwana part of the Malay Peninsula (Sibumasu) collided with the Indochina continental block (East Malaya) during the Upper Triassic Indosinian Orogeny. The Bentong–Raub Line is taken as the collision suture zone (Hutchison, 1975). Although the long suture zone, extending from Thailand to Peninsular Malaysia, has been widely accepted in almost all palaeo-tectonic reconstructions of Southeast Asia, it is also believed that the Bentong–Raub Line could represent a major normal fault (Tan, 1976; Harbury *et al.*, 1999) that formed the western boundary of a Mesozoic graben and that the geology reveals a major orogeny in the Permian and a less severe deformation in the Cretaceous (Harbury *et al.*, 1990). These contrasting views on the palaeo-tectonics have wide implication for the tectonic development of Southeast Asia as well as the evolution of Gondwanaland and the Tethys.

Several authors have reviewed the structural geology. They include Khoo and Tan (1983), Tan (1976, 1981b, 1982, 1996), Tjia (1972, 1978, 1986a, 1996), Tjia and Zaiton (1985), Harbury *et al.*, (1990), Mustaffa and Abdul Hadi (1999), Metcalfe (2000b) and Mustaffa (2000a). This chapter summarises the current state of knowledge.

The Peninsula can be divided into three major belts with a less clearly defined fourth domain in the NW (Fig. 5.1). It is popularly believed that the three-belt configuration and structural trends are the result of tectonic developments in the Mesozoic. The widely-accepted subduction-collision models assume that the Mesozoic Central basin is either a back-arc basin (Hutchison, 1973d; Ridd, 1980), a fore-arc basin (Mitchell, 1977; Şengör 1984b, 1986; Hutchison, 1989a), a fore-arc/intra-arc basin (Hutchison, 1989a) or a post-suturing extensional basin (Tjia & Syed Sheikh, 1996). Extensional models assume that the Central Basin is a graben (Tan 1981; Khoo & Tan, 1983) or a Triassic back-arc basin (Harbury *et al.*, 1990). Since its nature is disputed, the structural styles within and along its margins are very significant for elucidating its configuration, leading to a more accurate interpretation.

The boundaries between the NW Domain and Western Belt are less well defined than the others. A distinct N–S lineament along the eastern foothills of the Main Range, called the Bentong–Raub Line (Hutchison, 1975), separates the Western from the Central Belt. Isolated serpentinite outcrops associated with radiolarian chert, schist, chaotic deposits and conglomeratic diamictites occur along the lineaments. These associations have been popularly used to indicate that the Bentong–Raub Line is a tectonic suture zone. The chaotic deposits have been referred to as mélange, olistostrome or slump deposits. Their clasts have been stretched, boudinaged and sheared. Mud injection structures along the extended clasts indicate soft-sediment deformation. However, convincing tectonic mélange with scaly matrix has yet to be reported. Bedding-parallel shear zones, wrapped around the clasts, suggest that soft-sediment deformation is consistent with tectonic faulting or they may have been superimposed later.

The boundary between the Central and Eastern Belts is marked by the Lebir Fault Zone. It is marked by NNW–SSE-trending curvilinear lineaments along Sungai Lebir near Manek Urai in Kelantan (see Chapter 12). It is believed that uplift and subsidence along the fault zone give rise to deposition of the Jurassic–Cretaceous Gagau and Koh Formations. Tjia and Zaiton

14

Tectonic Evolution

C.S. Hutchison

14.0 INTRODUCTION

It has been shown in Chapters 3 and 4 that the Bentong–Raub Suture is an important line separating terranes of contrasting geology and that the suture can be traced northwards into Thailand. To the west of the suture lies the *Sibumasu* tectonic block, an acronym coined by Metcalfe (1984a), constructed from *Si* (Sino = China), *bu* (Burma), *ma* (Malay Peninsula = Shan-Thai of western Thailand and western Peninsular Malaysia) and *su* (Sumatra). The name has become more universally used than *Sinoburmalaya* (Gatinsky *et al*., 1984). The equivalent term *Shan-Thai* terrain of Bunopas and Vella (1983) remains only of local use in Thailand. Sibumasu extends from Sumatra and Peninsular Malaysia as far north as Yunnan in southwest China. To the east of the suture lies the East Malaya terrane that continues beneath the Gulf of Thailand to reappear as the Indochina terrane. Sibumasu and East Malaya (Indochina Block) have contrastingly different geology until they amalgamated at the Triassic Indosinian Orogeny. The sutures and terranes are shown in Figure 14.1, after Wakita and Metcalfe (2005).

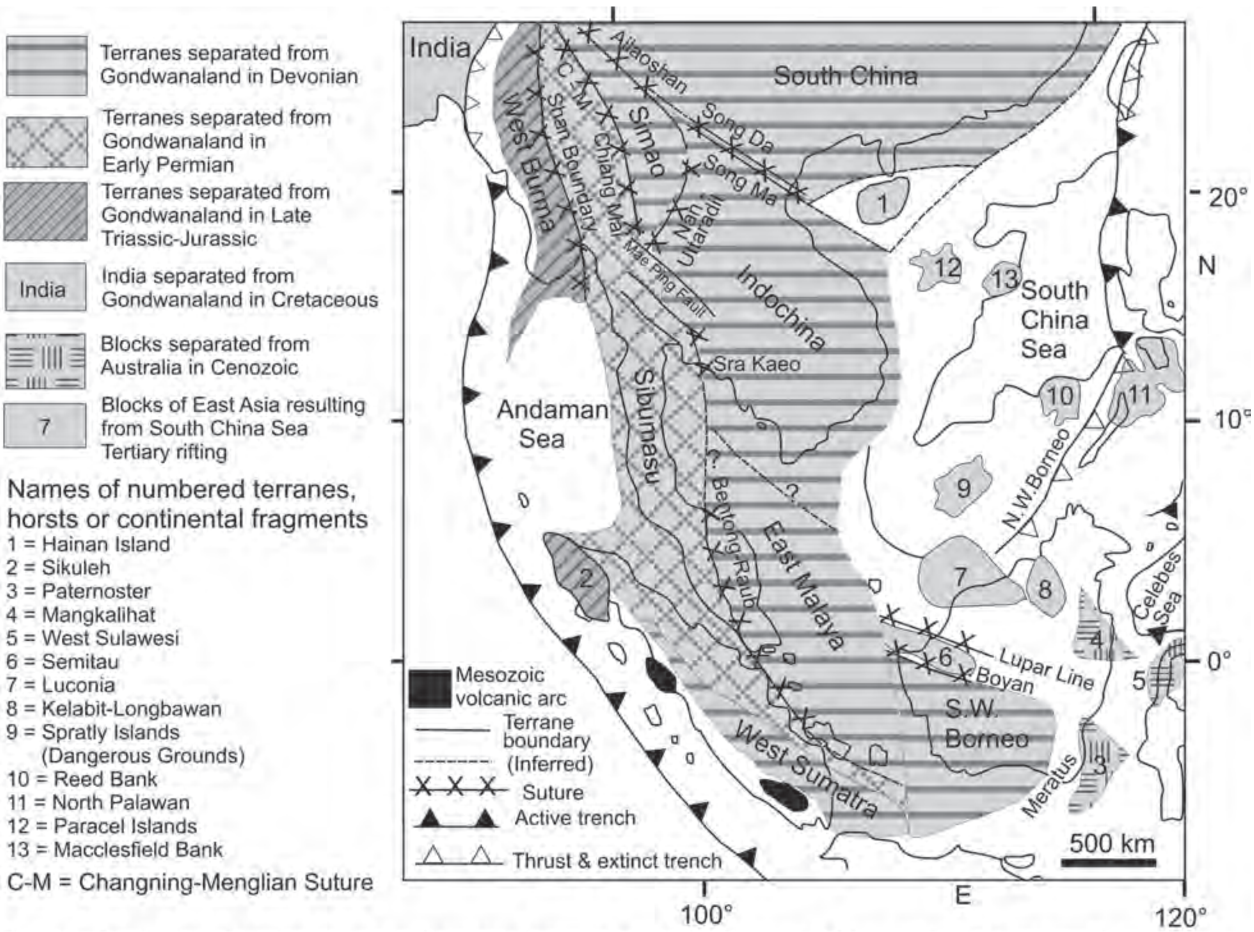

Fig. 14.1: Distribution of continental blocks, fragments, terranes and principal sutures of Southeast Asia, redrawn from Wakita and Metcalfe (2005).

15

Mineral Deposits

C.S. Hutchison

15.0 INTRODUCTION

Peninsular Malaysia was the pre-eminent tin mining region of the world until the industry crisis following the collapse of tin price in 1985. At the peak of the mining, the ore was smelted in Penang, the daily tin price set there, and posted above the long bar at the Royal Ipoh Club in the heart of the great Kinta Valley. Rapid decline in price and demand, as plastic replaced tin plate, caused near extinction of the industry and the great placer tinfields and their tailings were built upon by housing estates. Many of the tailings had already been reworked as separation techniques became more efficient. Increase in price to RM 32.77 per kilogram in December 2004 has only slightly revived the industry, but Malaysia may well take a lead from the ongoing revival in Cornwall.

Tungsten was never as important as tin, and mining came to an end much earlier. Iron was extracted at two large and remote mines and elsewhere iron is presently produced on a limited scale. Bauxite was mined at Pengerang on the southern tip of the Peninsula but is now in severe decline.

Gold continues to be mined. Placer workings were numerous. Lode mining continues to be important immediately to the east of the Bentong–Raub Suture Zone.

15.1 RECENT MINING DEVELOPMENTS

The 2004 mining developments were reviewed by Azemi and Salmiah (2007), and are summarised below:

Perak: There were ten mines (gravel pump and opencast) that produced a total of 2,153 t of tin in 2004. Twenty amang treatment plants recovered ilmenite, monazite, zircon, stuverite and rutile. Fourteen mines in the district of Batang Padang produced a total of 220,737 t kaolin. Two mines near Bidor produced 136,000 t of mica.

Selangor: Five opencast mines produced a total 392 t of tin in 2004. There were five amang treatment plants.

Johor: Bauxite continued to be mined in two localities at Telok Ramunia, Pengerang, but total output has dramatically declined to only 1,680 t in 2003. Two mines produced a total of 33 t of tin in 2004. Three mines produced a total of 44,225 t of kaolin in 2004.

Pahang: Five gold mines produced a total of 4.181 t of gold in 2004. Four iron mines produced a total of 313,822 t iron ore. Two mines produced a total of 146 t of tin in 2004. One mine produced 36,000 t of kaolin.

Terengganu: Two iron mines produced 196,910 t of iron ore in 2004. The single gold mine at Sungai Kerak produced 1.122 t of gold but closed in late 2004.

Kelantan: In 2004 there were four gold mines, but only one remained operating at the end of the year. Total production in 2004 was 38.182 t gold

15.2 REGIONAL DISTRIBUTION OF TIN

The cratonic core of peninsular Sundaland was the source of more than 70% of the tin mined last century in the whole world. The major producing centres lay in a broad arc 3400 km long and up to 800 km wide. The distribution of tin is strongly heterogeneous, with six major centres accounting for over 75% of the mined output. The balance comes from a further fourteen minor fields (Fig. 15.1).

The tinfields fall into two distinct types, those where virtually all the production was derived from mining placers, and those with a significant deep mined production. The former are by far the larger and the first four fields (Fig. 15.1) fall into this group. They were the unique feature of the region and the reason for its former dominance in world production. The larger and

16

Oil and Gas

D.N.K. Tan

16.0 INTRODUCTION

The oil and gas fields are located offshore in the Malay Basin. Exploration for oil and gas in the offshore Tertiary basins of Peninsular Malaysia commenced in 1968, with the award of concession blocks to Esso Exploration and Conoco. Esso's acreage covered the offshore Malay Basin, north of the 5° N latitude, whereas the acreage south of the 5° N latitude, covering the southern Malay Basin and Penyu Basin, was granted to Conoco (Fig. 16.1). Off the west coast, Mobil was awarded a concession in the northern part of the Straits of Malacca (Fig. 16.1). The first exploration well was drilled in 1969 in the Malay Basin, resulting in the Tapis discovery. Exploration efforts have continued in the Peninsula since 1969. By the end of 1997, more than 194,000 line-km of 2D seismic and 247,000 line-km of 3D seismic have been acquired, and a total of 158 wildcat and 184 appraisal wells have been drilled (Wong, 1999). These exploration activities resulted in significant successes in the Malay Basin. Unfortunately, results in the Penyu basin and the Straits of Malacca have been disappointing.

The exploration efforts up to end of 1997 resulted in the discovery of 53 oil and 28 gas fields, with oil-initially-in-place (OIIP) of 12.5 billion bbls (barrels) and gas-initially-in-place (GIIP) of 57.1 TCF (trillion cubic feet). The estimated recoverable reserves are 4.3 billion bbls oil and 39.4 TCF gas, excluding small oil discoveries with <8 million bbls (MMB) recoverable reserves and gas discoveries with <50 billion cubic feet (BCF) recoverable reserves.

The first oil production from the Malay Basin came from the Tapis field in March 1978, and the first gas production was from the Duyong field in 1984 (Mazlan *et al.*, 1999a). By the end of 1997, 15 oil and 4 gas fields were in production, with cumulative production of some 1.9 billion bbls oil and 2.8 TCF gas (Wong, 1999).

16.1 ACREAGE SITUATION

In 1971, the acreage situation of exploration blocks, awarded under the concession system, in offshore Peninsular Malaysia consisted of 3 blocks, namely, Mobil's block in the northern part of Straits of Malacca, Esso's block in the northern half of the Malay Basin north of the 5° N latitude, and Conoco's block south of the same latitude (Fig. 16.1).

In 1974, Malaysia introduced the Petroleum Development Act (PDA), under which the entire ownership of the petroleum resources of the country was entrusted to the newly-established government-owned company, called Petroliam Nasional Berhad (PETRONAS). This company was incorporated on 17 August 1974. PETRONAS introduced Production Sharing Contracts (PSCs) to replace the concessions previously

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ACRONYMS and TERMS used in this chapter: **Acreage** = an area of land or sea; **API gravity** = American Petroleum Institute specific gravity; **AU** =Assessment Units; **Bbl** = barrel = 36 imperial gallons or 42 U.S. gallons (roughly 192 litres); **bbls/d** = barrels per day; **BCF** = billions of cubic feet; **Boe** = bbls of oil equivalent; **CPOC** = Carigali-PTTEP Operating Company; **CTOC** =Carigali-Triton Operating Company; **E & P** = exploration and production; **EPMI** = Esso Production Malaysia Inc.; **EUR** = estimated ultimately recoverable; **FAMM** = Fluorescence Alteration of Multiple Macerals; **GHA** = Gas Holding Area; **GIIP** = gas-initially-in-place; **GOC** = Gas-oil contact ; **GWC** = gas-water contact; **HC/g** = hydrocarbon content per gram; **HI** = hydrogen index in pyrolysis; **HPHT** = High-pressure high-temperature; **IPC** = International Petroleum Corp.; **JAPEX** = Japan Petroleum Exploration; **JDA** = Joint Development Area; **mD** = millidarcies (measure of permeability); **MMB** = million barrels [Scientists use M for million, oil companies use MM]; **MMscf/d** = million standard cubic feet per day; **MTJA** = Malaysia-Thailand Joint Authority; **OIIP** = oil initially in place; **OWC** = Oil-water contact; **PCSB** = PETRONAS Carigali Sdn. Berhad; **PETRONAS** = Petroliam Nasional Berhad; **PIDC** = Petroleum Investment and Development Company; **PSC** = Production Sharing Contract; **PTT** = Petroleum Authority of Thailand; **PTTEP** = PTT Exploration and Production; **R/C** = Revenue-Over-Cost; **scf** = standard cubic feet; **STOIIP** = Stock Tank Oil Initially In Place; **TCF** = trillion cubic feet; **TOC** = total organic carbon; **TPS** = total petroleum systems; **VRe** = equivalent vitrinite reflectance.

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