Chapter 1
Introduction and previous research

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Sumatra, with an area of 473 606 km^2 is the largest island in the Indonesian archipelago and the fifth largest island in the world. The island stretches across the equator for 1760 km from NW to SE, and is up to 400 km across (Fig. 1.1). Administratively, and for the purposes of this Memoir, Sumatra includes the Mentawai islands from Simeulue to Pagai, which with Enggano form a forearc chain to the SW, and the 'Tin Islands' of Bangka and Billiton and the Riau islands to the east. The backbone of the main island is formed of the Barisan Mountains, which extend the whole length of Sumatra in a narrow belt, parallel to, and generally only a few tens of kilometres, from the SW coast. The main peaks (which are mainly Quaternary or Recent volcanoes) commonly rise 2000 m above sea level, culminating in Mt Kerinci at 3805 m. Short, steep river courses drain the Barisans towards the SW, often cuttting deep gorges, while towards the east the rivers follow long meandering courses across broad coastal plains and swamps to the Malacca Straits, which separate Sumatra from the Malay Peninsula, or to the Java Sea. Eastwards, across the Java Sea, lies the almost equally large island of Borneo (Indonesian Kalimantan), and Java lies immediately to the SE across the narrow Sunda Strait.

The Malacca Strait and the Java Sea form the southern parts of the Sunda Shelf (Fig. 1.1). Across the shelf the seafloor is shallow with a depth of less than 200 m and remarkably flat. Virtually the whole of the shelf was exposed at the peak of the last glaciation. To the SW, Sumatra is separated from a linear ridge with emergent islands extending from Simeulue in the north to Enggano in the south, by marine basins more than 1000 m deep, which increase to a depth of more than 2000 m in the south. To the SW of the ridge the seafloor slopes steeply into the Sunda Trench, 5000 m deep in the NW, deepening to >6000 m towards Java in the SE. The floor of the Indian Ocean, with a depth of about 5000 m, lies to the SW beyond the trench, extending all the way to to India and the east coast of Africa. Immediately to the west of Sumatra the floor of the Indian Ocean is covered by the thick sediments of the Nicobar Fan, the currently inactive eastern lobe of the Bengal Fan, composed of debris eroded from the Himalayas. The fan is separated from the main part of the Bengal Fan to the west by seamounts of the north–south trending Ninety-East Ridge (Fig. 1.2).

In terms of present-day tectonics Sumatra forms the active southwestern margin of the Sunda Craton (Sundaland), the southeastern promontory of the Eurasian Plate (Fig. 1.2). The relative 7.7 cm a^{-1} NNE-directed motion of the Indian Ocean results in oblique (*c.* 45°) subduction at the Sunda Trench. Seismic profiles across the landward side of the Sunda Trench imaged the removal of packages of sediment from the downgoing plate to build a forearc ridge accretionary complex (Hamilton 1979; Karig *et al.* 1980) (Fig. 1.3). Oblique subduction results in the northwestward movement of a 'sliver' plate (Curray 1989), decoupled both from the downgoing Indian Ocean Plate and the Sundaland Plate, along the Wadati–Benioff seismic zone, which dips northeastwards at *c.* 30°, and along the vertical Sumatran Fault System. The Wadati–Benioff zone intersects the fault at a depth of some 200 km. The active Sumatran Fault System runs the whole length of the Sumatra, through the Barisan Mountains, from Banda Aceh to the Sunda Strait, and is paralleled by a line of Quaternary volcanoes, mainly quiescent, but some currently active (Fig. 1.4).

Geologically, Sumatra forms the southwestern margin of the Sunda Craton, which extends eastwards into Peninsular Malaysia and into the western part of Borneo (Fig. 1.2). A Pre-Tertiary basement is exposed extensively in the Barisan Mountains (Fig. 1.4) and in the Tin Islands of Bangka and Billiton. The oldest rocks which have been reliably dated are sediments of Carboniferous–Permian age, although Devonian rocks have been reported from a borehole in the Malacca Strait, and undated gneissic rocks in the Barisan Mountains may represent a Pre-Carboniferous continental crystalline basement. All the older rocks, which lie mainly to the NE of the Sumatran Fault System, show some degree of metamorphism, mainly to low-grade slates and phyllites, but younger Permo-Triassic sediments and volcanics are less metamorphosed. The area to the SW of the fault is composed largely of variably metamorphosed Jurassic–Cretaceous rocks. The Pre-Tertiary basement is cut by granite plutons that range in age from Permian to Late Cretaceous. Locally within the Barisans the basement is intruded by Tertiary igneous rocks and is overlain to the NE and SW by volcaniclastic and siliciclastic sediments in hydrocarbon- (oil and gas) and coal-bearing Tertiary sedimentary basins. These basins have backarc, forearc and interarc relationships to the Quaternary to Recent volcanic arc. Lavas and tuffs from these young volcanoes overlie the older rocks throughout the Barisans and, in particular cover an extensive area in North Sumatra around Lake Toba (Fig. 1.4). Recent alluvial sediments occupy small grabens within the Barisan Mountains, developed along the line of the Sumatran Fault and cover lower ground throughout Sumatra. These alluvial sediments are of fluvial origin immediately adjacent to the Barisans, but pass into swamp, lacustrine and coastal deposits towards the northeastern and southwestern margins of the island.

History of geological research in Sumatra before-WWII

During the late nineteenth and early twentieth centuries Sumatra was explored by geologists and engineers working for mining and petroleum companies under the auspices of the Bureau of Mines in the Dutch East Indies Colonial Administration. In 1925 a 'Palaeobotanic Expedition to Djambi (Jambi)' was undertaken to collect samples of the 'Djambi Flora'. This early work is summarized by Rutten (1927) in his 'Lectures on the Geology of the Netherlands East Indies'. Between 1927 and 1931 the Netherlands Indies Geological Survey conducted a mapping programme in South Sumatra with the production of a series of sixteen 1:200 000 Geological Map Sheets (e.g. Musper 1937), and carried out other geological studies in Central and Northern Sumatra (Musper 1929; Zwierzijcki 1922*a*, *b*, 1930*a*). Unfortunately, as a result of the global economic depression, this mapping programme was discontinued in 1933, before the mapping of the whole island was complete. However, the cessation of fieldwork provided an opportunity to publish the results of the 1925 Palaeobotanic expedition to Djambi (Zwierzijcki 1930*a*; Jongmans & Gothan 1935). Exploration by mining and petroleum companies continued throughout Sumatra, but for commercial reasons most of the reports remained confidential and unpublished. However, some of the results, notably for

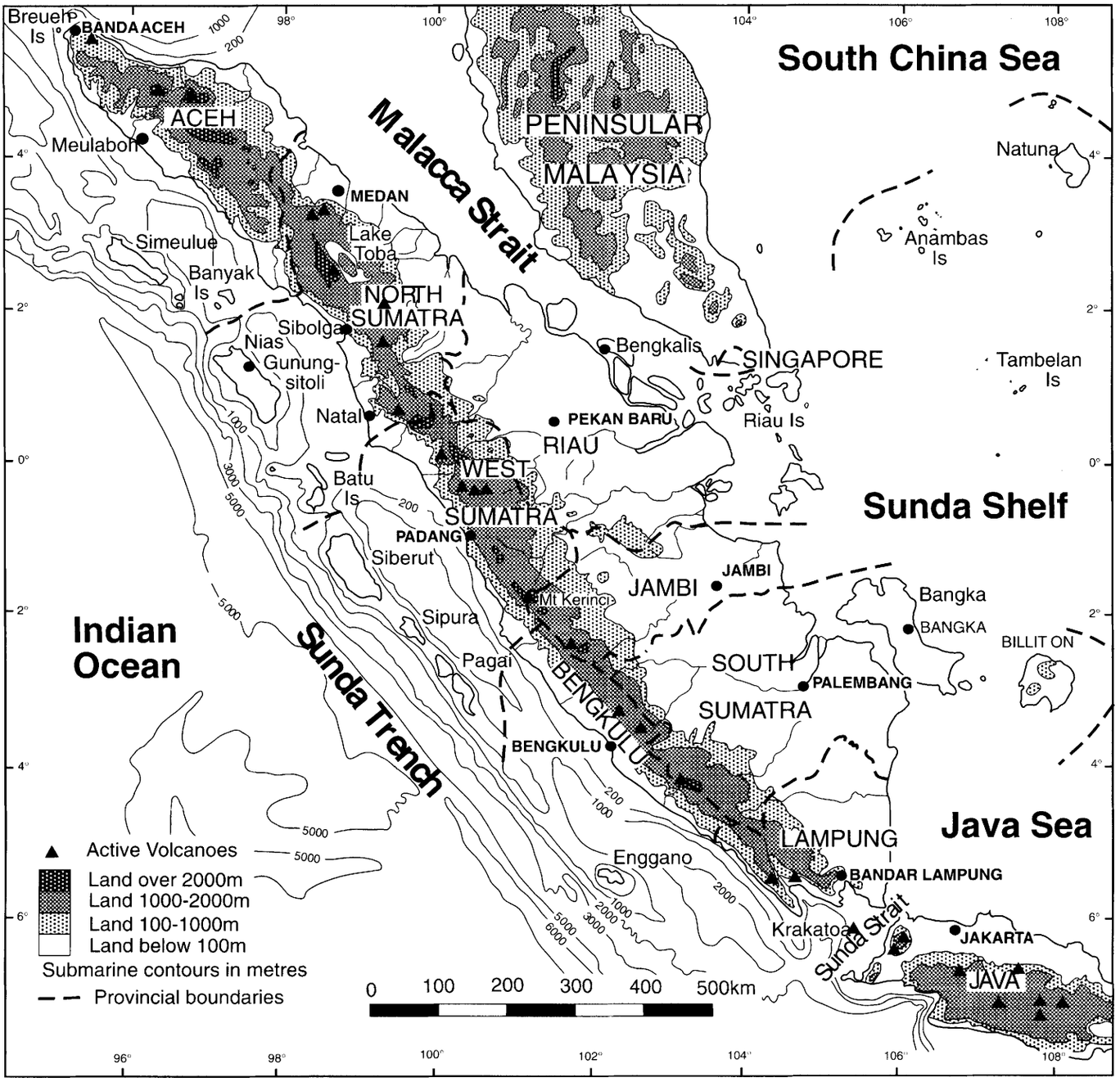

Fig. 1.1. Topography and bathymetry of Sumatra and surrounding areas with boundaries of administrative provinces and principal cities.

work carried out in Siberut, Nias and Simeulue and the other Outer Arc Islands on behalf of the Nederlands Pacific Petroleum Maatschappij and the Geological Service of the Baatafsche Petroleum Maatschappij before WWII (Elber 1939; Den Hartog 1940*a*, *b*; Hopper 1940), were made available to van Bemmelen (1949, 1970) during the preparation of his major synthesis of 'The Geology of Indonesia'.

Van Bemmelen began work on this comprehensive and masterly summary, immediately before WWII. The first manuscript version of this work was completed in Bandung between 1937 and 1941. When Java was invaded by the Japanese in 1942 van Bemmelen was taken into custody as a prisoner of war. There are reports that during the war he was permitted by the Japanese authorities to continue work on the volume. Van Bemmelen says that he entrusted his manuscript to an official of the Geological Survey, but after the war this official refused to return it (van Bemmelen 1949, 1970). On his release from captivity van Bemmelen returned to the Netherlands, where he was commissioned to rewrite the volume by the Director of the Netherlands East Indies Bureau of Mines. Work commenced in 1946 and the first edition was published by the Government Printing Office in the Hague in 1949. A second edition was published in 1970. The volume provides a complete summary of the state of knowledge of the stratigraphy, structure, igneous history and mineral deposits of the whole of Indonesia at that time. For Sumatra, van Bemmelen (1949, 1970) developed a tectonic synthesis in which deformation proceeded as a series of waves, across the island from NE to SW, with the earliest cycle having occurred in the Malay Peninsula during the Triassic, and the most recent continuing in the outer arc islands at the present day.

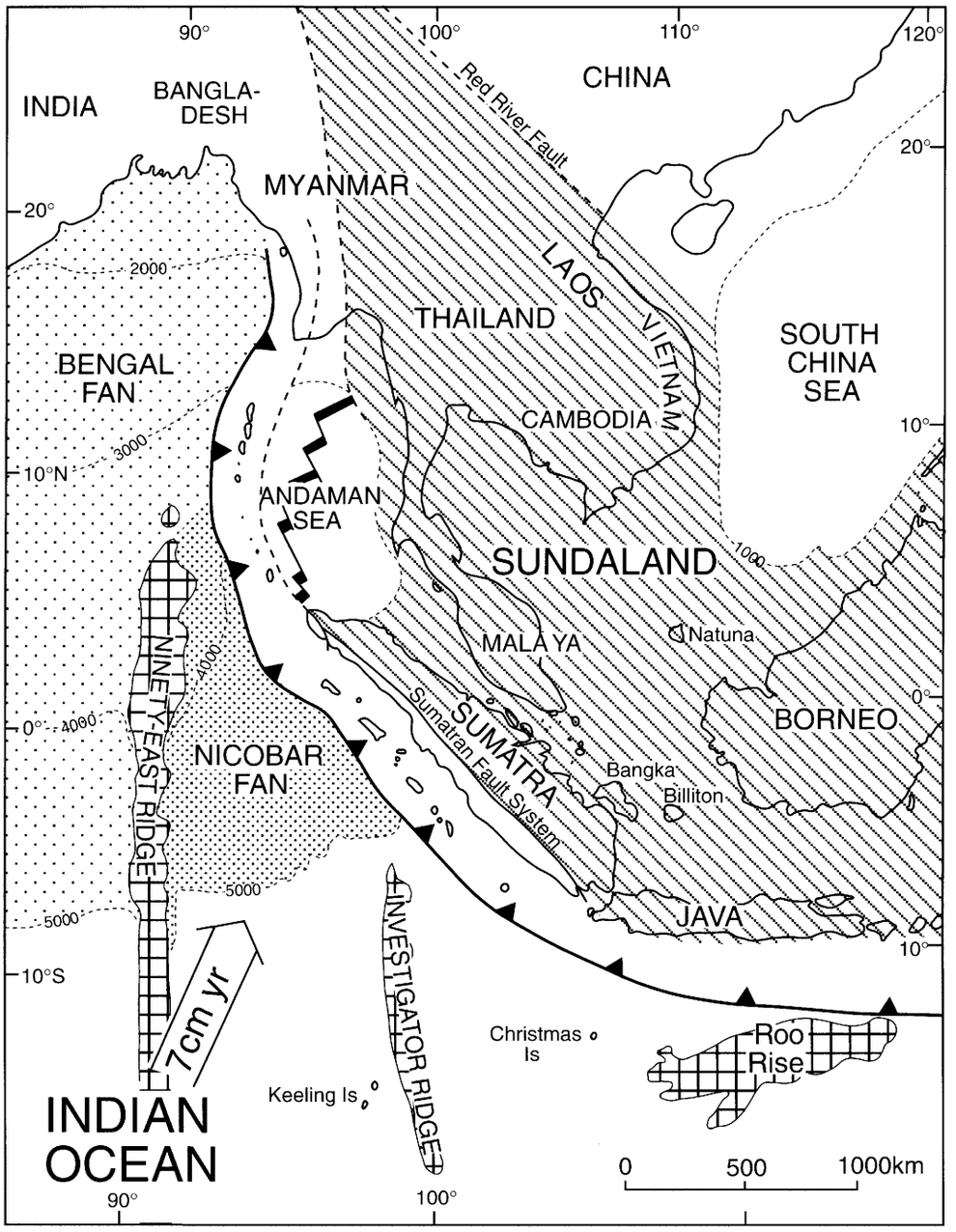

Fig. 1.2. The tectonic setting of Sumatra with the floor of the Indian Ocean subducting beneath the southwestern margin of the Sundaland Craton. The deformation front of the Sumatran subduction system is indicated by the toothed line; spreading centres and transform faults are shown in the Andaman Sea (after Curray *et al.* 1979).

Post-WWII research

Little geological work was possible during the years immediately after the end of WWII, but following Indonesian Independence in 1947 the Geological Survey of Indonesia (GSI) was established in the old Bureau of Mines building in Bandung. From 1969 to 1974 the Mapping Division of (GSI) commenced a systematic programme of mapping in the Padang area of West Sumatra, in collaboration with the United States Geological Survey (USGS), as part of the First Five Year Development Plan (PELITA I). Several 1:250 000 Geological Map Sheets were published as a result of this programme (Silitonga & Kastowo 1975; Rosidi *et al.* 1976; Kastowo & Leo 1973). As part of this collaboration a senior geologist of the USGS, Warren Hamilton, was commissioned to prepare a series of maps and a memoir reviewing the geology of the Indonesian region in plate-tectonic terms (Hamilton 1977, 1979). Hamilton's (1979) Tectonic Map, which includes Sumatra, shows clearly present views of the tectonic setting of Sumatra.

SEATAR Programme

In 1973 a meeting was convened by the United Nations Committee for the Coordination of Joint Prospecting for Mineral Resources in Asian Off-shore waters (CCOP) in Bangkok which established the Studies in East Asian Tectonics and Resources (SEATAR) Programme. At that time a review of the current understanding of the tectonics of eastern Asia was prepared by Deryck Laming on behalf of CCOP-IOC (1974). As a result of the meeting it was proposed to concentrate research along a series of transects across the island arc systems of East and SE Asia. Subsequently A. J. Barber (University of London) and Derk Jongsma (BMR) were engaged by CCOP as Technical Consultants to prepare a report on the current state of knowledge along the lines of these transects (CCOP-IOC 1980). One of the selected transects ran from the Malay Peninsula across northern Sumatra and the forearc island of Nias to the Sunda Trench. Although the final report for this transect was never published, a great deal of important research was carried out by American researchers

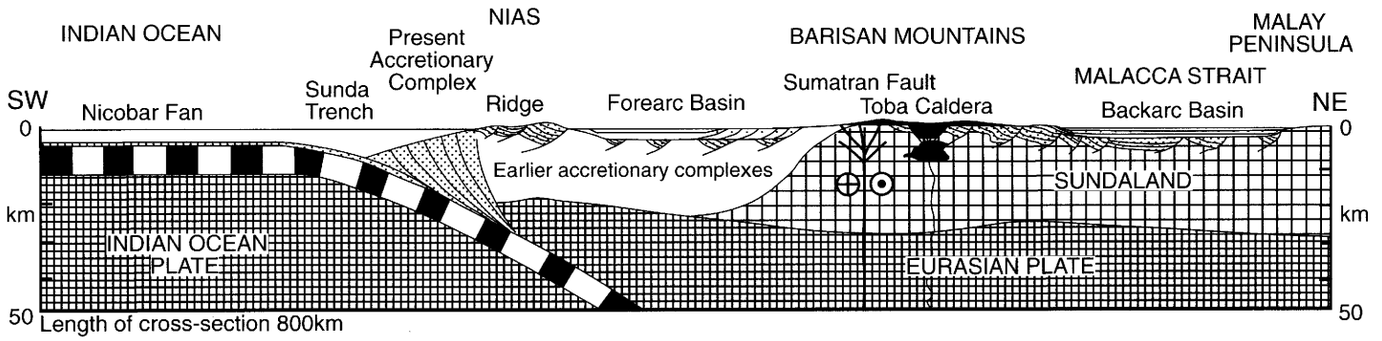

Fig. 1.3. Diagrammatic section across the Sumatran Subduction System from the floor of the Indian Ocean to the Malay Peninsula, drawn to scale.

under the auspices of the SEATAR Programme, particularly in Nias and the surrounding seas (Curray *et al.* 1982; Karig *et al.* 1980; Moore & Karig 1980). Also in conjunction with the SEATAR Programme, Cobbing *et al.* (1992) made a detailed study, including isotopic dating, of the granites on the Tin Islands of Bangka and Billiton, supported by the UK Overseas Development Administration as a contribution to the work of CCOP.

Since the effective termination of the SEATAR Programme, US research in Sumatra has been concentrated on neotectonics, an important part of which has been the monitoring of movement along the Sumatran Fault System, using GPS location systems (Prawirodirdjo *et al.* 1997).

Indonesian Petroleum Association

In 1971 the Indonesian Petroleum Association (IPA) was established by petroleum companies operating in Indonesia, in association with the Indonesian national oil company, Pertamina. Since its inception the IPA has held Annual Conventions which continue to the present day. At these conventions papers on the geology of Indonesia are presented and published as the Proceedings of the Indonesian Petroleum Association. The IPA Proceedings provide an invaluable source of information on the geology of Indonesia. Most of the papers deal with Tertiary deposits and details of the stratigraphy and structure of the oil and gas fields of Indonesia, including those of Sumatra, but more general papers on geology and tectonics have also been published. The publication of the IPA Proceedings has resolved van Bemmelen's (1949) complaint of the pre-WWII situation, in which large amounts of geological data, accumulated by the oil companies, remained unpublished for commercial reasons, and were not available for the compilation of regional geological syntheses.

British and Indonesian Geological Surveys

Major UK involvement in the geology of Sumatra began in 1975 when the Institute of Geological Sciences (IGS, now the British Geological Survey, BGS), in collaboration with the Geological Survey of Indonesia (GSI), commenced a five-year mapping and reconnaissance geochemical survey of northern Sumatra to the north of the equator (Northern Sumatra Project, NSP). In 1978 GSI was reorganized into a number of semi-autonomous directorates and the Directorate of Mineral Resources (DMR) became the designated Indonesian counterpart organisation in the NSP. The work of IGS in the Northern Sumatra Project, and subsequent projects by BGS in Sumatra, were funded from the Technical Assistance and Technical Cooperation budgets of the U.K. Overseas Development Administration (ODA).

The structural, stratigraphic, geochemical and tectonic results of the Northern Sumatra Project have been presented in a series of papers (Page *et al.* 1978, 1979; Cameron *et al.* 1980; Rock *et al.* 1982; Aldiss & Ghazali 1984) and unpublished reports. In a continuation of the NSP, geological maps and reports resulting from the project were edited by BGS personnel, and published by the Indonesian Geological Research and Development Centre (GRDC), one of the constituent directorates of GSI, as a series of 18 Geological Map Sheets at 1:250 000 scale, with accompanying Explanatory Notes. Follow-up studies of fossil localities, with the view of establishing the stratigraphical ages of the sedimentary units in Sumatra, were carried out by Metcalfe (1983, 1986, 1989*a*, *b*; Metcalfe *et al.* 1979) and by Fontaine and his collaborators, under the auspices of CCOP (Fontaine & Gafoer 1989). The results of the regional geochemical stream sediment sampling survey were published in a joint IGS/DMR Geochemical Atlas (Stephenson *et al.* 1982) and subsequently DMR published sets of single element proportional symbol distribution maps at 1:250 000, for many of the quadrangles to the north of the equator. Geochemical anomalies found during the NSP were followed up by BGS and DMR in the collaborative North Sumatra Geological and Mineral Exploration Project (NSGMEP, 1985–1988). The results of a separate programme of research into the mineralization in north Sumatra, also funded by UK ODA, have been published by Bowles *et al.* (1984, 1985) and Beddoe-Stephens *et al.* (1987).

University of London Southeast Asian Research Group, BGS and LEMIGAS

In 1978 members of the University of London Southeast Asian Research Group which had previously been active in Eastern Indonesia, commenced a programme of research projects in Sumatra, in collaboration with BGS, DMR and GRDC. In 1984 a joint University of London/BGS North Sumatra Basins Study Project, was set up with funding from the UK Overseas Development Administration, in collaboration with the Indonesian Research and Development Centre for Oil and Gas Technology (LEMIGAS) (Kirby *et al.* 1993). This project built on the major involvement by LEMIGAS in this productive basin, where one of the largest exploration blocks is operated directly by Pertamina. The overall programme was largely concerned with the stratigraphy, sedimentology and geophysics of the Tertiary basins in northern Sumatra, with the University contribution concentrating on field studies of the relationship of the Tertiary rocks to the underlying basement, with a view to understanding the tectonic evolution, of these basins (Turner 1983; Tiltman 1987, 1990; Kallagher 1990). More recently the University of London contribution, funded by the UK Natural Environment Research Council (NERC), ODA and a number of oil companies,

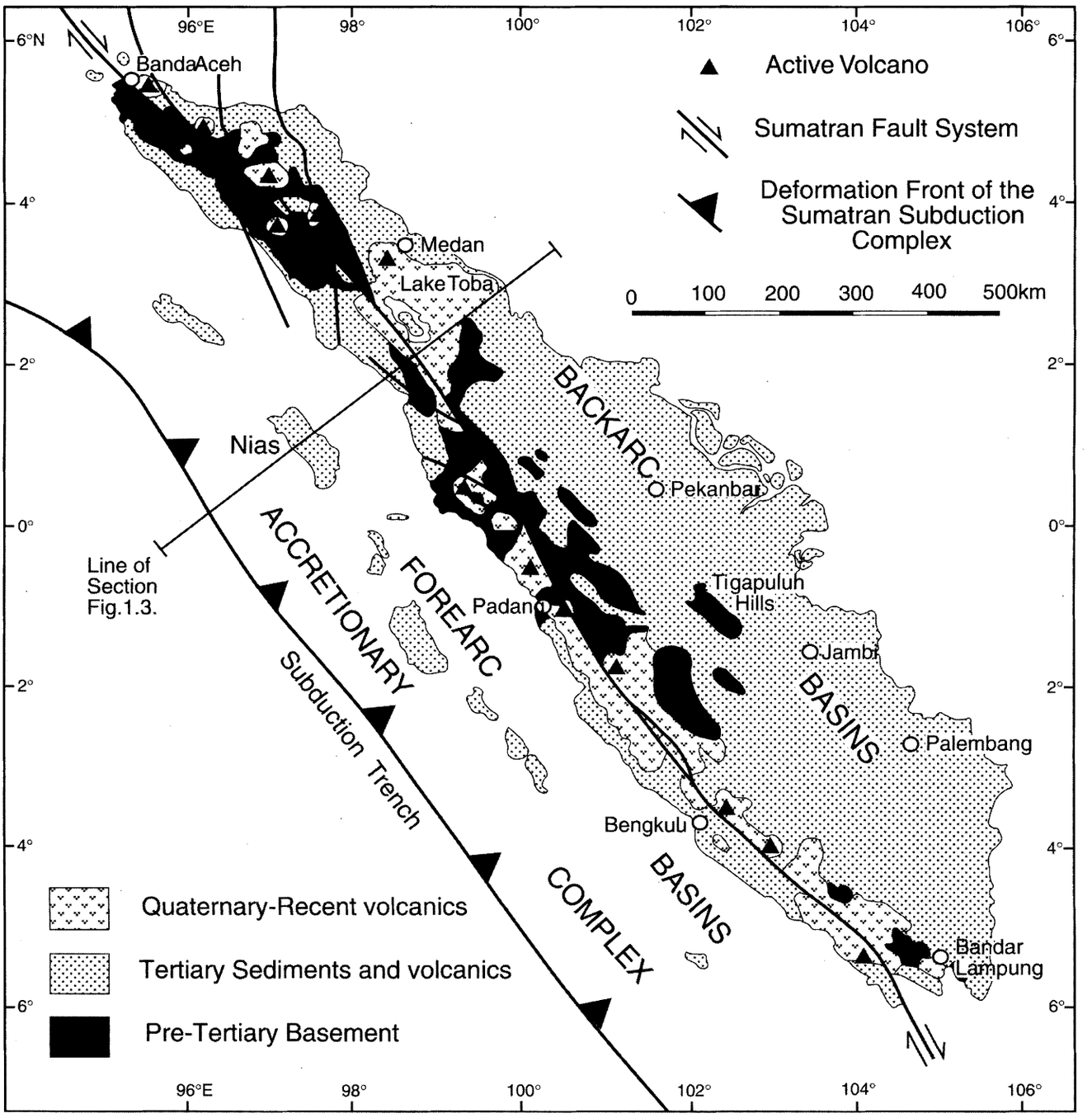

Fig. 1.4. Simplified geological map of Sumatra showing the distribution of the main stratigaphic units and the active volcanoes. Toothed line marks the deformation front of the Sumatran Subduction System. The line of section in Fig. 1.3 is also shown.

became increasingly concentrated in the forearc islands, where a series of geological mapping and gravity surveys were completed (Situmorang *et al.* 1987; Milsom *et al.* 1990; Harbury & Kallagher 1991; Samuel & Harbury 1996; Samuel *et al.* 1997). At the same time LEMIGAS collaborated with the French CNRS (Centre National pour Recherche Scientifique) in a number of studies in the forearc region using the Indonesian Marine Research Vessel Baruna Jaya III (Diament *et al.* 1992; Izart *et al.* 1994). Outside the bounds of the NSP, University of London Staff and research students with funding from NERC, ODA and a Consortium of petroleum companies collaborated with LEMIGAS on studies on the Ombilin interarc basin in central Sumatra (Lailey 1989; Bartram & Nugrahaningsih 1990; Howells 1997*b*), the Woyla Group in North Sumatra (Wajzer *et al.* 1991; Barber 2000; McCarthy *et al.* 2001) and a study of the Sumatran Fault System throughout the island (McCarthy & Elders 1997).

Southern Sumatra Project

Geological mapping, gravity surveys and geochemical programmes in Sumatra south of the equator were conducted by GRDC and DMR during PELITA II (1974–79) and in successive five year development programmes, continuing into the 1980s. In 1988 the Southern Sumatra Geological and Mineral Exploration Project (SSGMEP) was established, and BGS joined DMR and GRDC in the completion of these surveys and in research

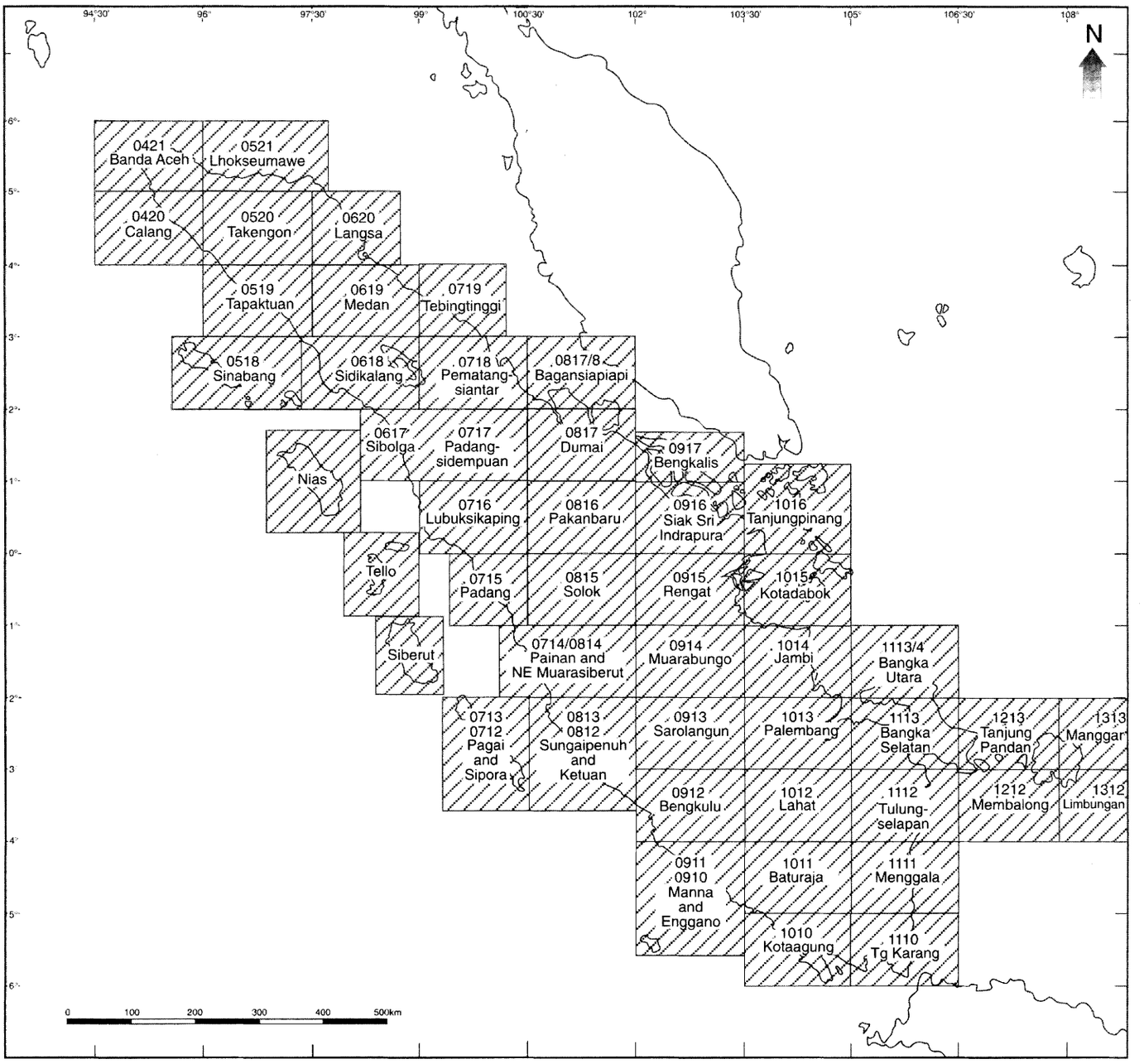

Fig. 1.5. Coverage, sheet numbers and names of the 1:250 000 Geological Maps published by the Indonesian Geological Survey, the Geological Research and Development Centre, Indonesian Ministry of Mines and Energy.

programmes with funding from UK ODA Technical Cooperation budget. This programme was completed in 1995 with the publication by GRDC of the last of the forty three Geological Map Sheets at 1:250 000 scale, covering the whole of Sumatra (Fig. 1.5) and 18 1:250 000 scale Bouguer gravity anomaly maps of southern Sumatra, including Bangka and Billiton islands, but excluding the coastal swamps and the Barisan Mountains. The collaborative geochemical survey was completed in 1994 with the publication by DMR of 14 quadrangle boxed sets of 1:250 000 single element proportional symbol geochemical maps (up to 15 elements) with accompanying reports on the geochemistry, geology and mineral occurrences. Subsequently the Sumatra geochemical data was made available on CD-ROM (Version 2 in 1999). In 1995 following a one-year 'Sustainability Phase' of the SSGMEP a Geochemical Atlas of Southern Sumatra was issued in digital form on CD-ROM (Machali *et al.* 1995). Publication in book form followed in 1997, with text in both Bahasa Indonesia and English (Machali *et al.* 1997). An evaluation of tectonic models for the Pre-Tertiary history of Sumatra based on BGS/DMR/GRDC and University of London research programmes has been published by Barber & Crow (2003).With the completion of this major phase of UK involvement in the study of the geology of the Sumatra, the time is ripe to review the vast increase in our knowledge of the geology of Sumatra since van Bemmelen's (1949, 1970) synthesis.