Geologic Reconnaissance of the Mineral Deposits of Thailand

By GLEN F. BROWN, SAMAN BURAVAS, JUMCHET CHARALJAVANAPHET, NITIPAT JALICHANDRA, WILLIAM D. JOHNSTON, JR., VIJA SRESTHAPUTRA, *and* GEORGE C. TAYLOR, JR.

GEOLOGIC INVESTIGATIONS OF ASIA

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GEOLOGIC RECONNAISSANCE OF THE MINERAL DEPOSITS OF THAILAND

By Glen F. Brown, Saman Buravas, Jumchet Charaljavanaphet, Nitipat Jalichandra, William D. Johnston, Jr., Vija Sresthaputra, and George C. Taylor, Jr.

ABSTRACT

A reconnaissance geologic investigation of the mineral deposits of Thailand was made by three geologists of the United States Geological Survey and their colleagues of the Royal Thai Department of Mines under the auspices of the Technical Cooperation Administration of the Interdepartmental Committee on Scientific and Cultural Cooperation, United States Department of State. Many of the basic data in the report were obtained in field work from October 1949 through March 1950 during the stay of the American geologists in Thailand, but a large part of the report is based on earlier field work by Thai geologists and engineers.

Thailand's principal mineral commodities are tin, tungsten, lead, zinc, antimony, and gold which are produced mainly for export; and iron, manganese, building stone, road metal, cement materials, clay, gemstones, gypsum, quartz and feldspar, salt, soapstone, coal, and asphaltic sand which are produced mainly for domestic use. Other commodities exist in undeveloped prospects and may prove important under different economic conditions.

Factors which hinder mineral development are inadequate access roads or other transportation facilities; deep tropical soil cover, dense vegetation, and rugged terrain—all making prospecting difficult; and lack of efficient mining equipment and inexperience in effective mining methods.

Present mining activity in Thailand is concentrated mainly in a zone lying along the Burmese frontier and in the Peninsular region.

Thailand is divided into five geographic regions corresponding roughly to political divisions, and into five physiographic provinces which are the Northwest Highlands, Chao Phraya Plain, Korat Plateau, Chanthaburi, and Peninsular.

The Paleozoic rocks of the kingdom include schist, slate, argillite, and quartzite of the Cambrian (?) Phuket series; the Ordovician (?) Thung Song limestone; sandstone and shale or their metamorphic equivalents belonging to the Kanchanaburi series of Silurian, Devonian (?), and Lower Carboniferous (?) age; pre-Permian (?) gneiss and schist; and the Carboniferous (?) and Permian Rat Buri limestone. The aggregate thickness of Paleozoic sediments in Thailand is 9,000 meters or more.

Among the Mesozoic rocks are Triassic (?) granite in stocks and batholiths; Triassic (?) mafic and ultramafic intrusive rocks locally cropping out in northern Thailand; sandstone, shale, and some limestone of the Triassic and Jurassic Korat series; and Cretaceous (?) granite in extensive batholiths and stocks. Mesozoic sediments may attain a maximum thickness of 2,000 meters or more in Thailand.

Rocks of Tertiary age are basalt which occurs in many small scattered areas as dikes, plugs, and flows; andesite and rhyolite porphyry dikes and sills; diorite and quartz diorite in stocks and bosses; and marine, lacustrine and fluviatile limestone, marl, sandstone, conglomerate, shale, oil shale, and coal of the Mae Sot series and the Krabi series. In places the Tertiary sediments are 400 meters or more thick.

Quaternary deposits include unconsolidated silt, clay, sand, and gravel in the flood plains, in stream channels, or in terraces along stream channels; beach and estuarine clay, sand, and gravel, or raised coral reefs; and residual layers of laterite capping stabilized surfaces. The Quaternary deposits in most places are less than 50 meters thick but in the alluvial plain of Mae Nam Chao Phraya near Bangkok they are more than 300 meters thick.

Thailand includes three major structural provinces—the Korat Plateau, the Chao Phraya depression, and the northern and western folded mountain ranges which extend south through the Malaya Peninsula. Recorded in the rocks of Thailand are at least three orogenies—the oldest corresponding approximately to the late Paleozoic Appalachian orogeny of North America or to the Saalien orogeny of the Urals, a Mesozoic orogeny, and a late Tertiary (Wallachian) orogeny. In the earliest orogenic movements the Rat Buri limestone and older rocks were compressed in north-trending folds in the Peninsular, western, and northern regions of the Kingdom. The folding may have also affected the central and northeastern regions where Paleozoic rocks are buried beneath younger sediments. Possibly as a late phase of the Saalien orogeny was the intrusion of numerous stocks and elongated batholiths of hornblende-biotite granite which crops out extensively in central and northern Thailand. A late Mesozoic orogeny is suggested by folding in beds of the Korat series

along the west side of the Korat Plateau, in the Mae Sot region, and in other parts of the Kingdom. Evidence in Burma and Malaya indicates that the tin-and-tungsten-bearing granite in Peninsular and western Thailand was emplaced in late Cretaceous or early Tertiary time. The granite instrusions may thus have been related to the late Mesozoic orogeny. A late Tertiary (Wallachian) orogeny which affected central Burma was principally manifested in Thailand by the elevation and gentle down-warping of the Korat Plateau, by the depression of the Chao Phraya region, and by high-angle faulting and some thrusting in structural basins of northern Thailand.

Antimony deposits are mined in Changwats Lampang, Phrae, and Surat Thani. The total 1949 production of stibnite ore was 457 long tons of which 201 tons came from Lampang, 138 tons from Surat Thani, and 118 tons from Phrae. Production has steadily increased since 1943 and can be increased still more under favorable price and marketing conditions.

Copper prospects occur in numerous localities but none thus far explored has proved promising. However, in most places the mineralized outcrops are so weathered or mantled by soil that only by surface stripping and detailed geologic study may the true extent of veins or lodes be ascertained.

Gold deposits have been reported in 28 of the 70 changwats. Placers occur in many localities, and panning for gold is practiced by local natives as a means of supplementing income. Attempts at large-scale placer operations in the past have not been successful. The best known gold lodes are those of Krabin, Toh Moh, and Tha Tako. The Toh Moh deposit produced 62,739 fine ounces between 1936 and 1940.

Ilmenite is found in beach deposits in many places along the shore lines of southeastern and Peninsular Thailand. Many tailing dumps of tin washing sheds in the Peninsular region contain 60 to 90 percent ilmenite. Such dumps are potentially important sources of ilmenite ore, given economically feasible means of recovery and a favorable market. Just before World War II Japan bought 2,500 tons of ilmenite tailings from the washing shed of the Lam Phraya tin dredge.

Iron ore occurs in many widely distributed laterites and in several contact-metamorphic deposits which are relatively small but important or potentially important in the domestic economy. The largest known deposit in the Kingdom at Khao Thap Khwai contains an estimated reserve of about 720,000 metric tons of ore ranging between 48 and 66 percent iron. Mining of the deposit has been undertaken by the Thai Cement Co.

The mineralization of lead and zinc or lead alone has been observed in small veins in the Lampang region; in replacement deposits and

some veins in Changwat Kanchanaburi, and in a lead-zinc ore body associated with a tin-tungsten lode at Tham Thalu in Changwat Yala. The most important known deposit is in Kanchanaburi at the Nong Phai mine which is currently producing about 100 tons a month of ore ranging between 28 and 38 percent lead and 27 to 31 percent zinc. Three other lead-zinc bodies in the Nong Phai region offer considerable promise. The 1949 production of lead ore in Thailand was 351 tons, of which 345 tons came from Changwat Kanchanaburi and 6 tons from Changwat Lampang.

Manganese ore associated with sediments of the Korat series is found in several small deposits in Changwats Chon Buri, Kanchanaburi, Pattani, and Yala. None of these is sufficient in size for large-scale mining but may be important in supplying domestic manganese requirements. On the island of Ko Kram there are about 5,500 tons of ore containing roughly 25 percent manganese and 15 percent iron, and minable by hand breaking and sorting.

Molybdenum prospects thus far discovered in Thailand are not promising.

Monazite is found with ilmenite in the tailings dumps of tin washing sheds, but no method of recovery has yet seemed feasible.

Tin ore is the most important mineral of Thailand. In 1940, the year of greatest output, 17,116 long tons of metallic tin was produced. Production declined markedly during World War II but rose to 7,815 long tons in 1949. Placer deposits furnish about 92 percent of all the tin produced. Sixty-two percent of the tin produced is recovered by dredging, and 22 percent comes from gravel pump mines. Almost all the deposits are in Peninsular Thailand or in a narrow band along the Burmese frontier.

Tungsten ore ranks second in importance to tin among the mineral commodities of Thailand. The greatest production of wolframite concentrates was 1,579 long tons in 1943. The output decreased during the latter part of World War II but rose in 1949 to 674 tons. The most important tungsten deposits now known are in the Mae Sariang district; they produce about 300 metric tons of wolframite concentrates annually.

Asbestos prospects are known at five localities in Changwat Uttaradit but they offer little promise for large-scale development. About 60 metric tons of asbestos were mined from the Mon Kai Chae prospect for domestic consumption during World War II.

Barite has been found in narrow veins and small lenticular bodies. The only occurrence of possible commercial importance is about 55 kilometers west of Tak on the trail to Mae Sot.

Cement is manufactured in two plants operated by the Thai Cement Co., the only cement producer of the Kingdom. The present (1950) output is about 12,000 tons a month and it is all consumed in the domestic market.

Clay products, principally common brick and domestic utensils, are made in many small brick and pottery works but no production statistics are available. Domestic clays include residual, transported, and bedded deposits. No fire clay is known.

Diatomite crops out on the south bank of the Mae Chang about 18 kilometers south of Mae Tha station. The prospect is promising but the extent of the deposit is not known.

Fluorite in narrow veins has been reported from several localities but none of these deposits is apparently large enough to mine.

Gemstones, which include sapphire, ruby, and some topaz and zircon, are mined from several placer deposits in Changwats Kanchanaburi, Chanthaburi, and Trat. Mining is done by local natives using pitting and panning methods.

Gypsum deposits of small size have been worked since 1943. The 1949 output, all from one mine, was 151 long tons.

Salt is produced by the solar evaporation of sea water and of water from salt seeps on the Korat Plateau. Salt-water wells near Korat offer potential sources.

Soapstone (pagodite) is mined from a deposit in Changwat Nakhon Nayok and is used in the domestic market in limited quantities. The reserve in the deposit is estimated at 1,300,000 metric tons.

Coal deposits are known at 16 localities in 8 changwats. The moisture and ash content are generally rather high and the calorific value is low. Some of the seams contain an exceptionally high percent of sulfur. Attempts to mine the deposits in the past have been ineffective. The deposits will require careful exploration, sampling, and geologic study.

Oil shale deposits are present in substantial quantity in the Mae Sot basin and merit exploration by drilling, although inadequate transportation facilities may hinder development. The oil content ranges roughly between 30 and 330 liters per metric ton of shale.

Petroleum of naphthalene base has been found at tar seeps and in shallow wells in the Mae Fang basin. Asphaltic sand is quarried from the tar seeps for highway surfacing. Near the seeps a reserve of asphalt-impregnated sand and gravel is estimated at 3,800,000 cubic meters at depths ranging from 8 to 21 meters. About 300 barrels of heavy asphaltic crude has been pumped from a well 46 meters deep, and some exploration of the area by shallow drilling is currently (1950) being carried on by the Royal Department of Mines.

INTRODUCTION

By Vija Sresthaputra and William D. Johnston, Jr.

PREVIOUS GEOLOGICAL INVESTIGATIONS

Geological investigations in Thailand previous to the ones leading to this report were intermittent in nature and were carried out mostly by foreigners. Incidental accounts of mineral deposits are contained in many old travel books but the first important descriptive geology of the country was written by Halt Hallet (1890), a civil engineer. In search for a railway route from Moulmein to South China, he traveled through Mae Sariang to Chiang Mai, Maung Fang, and Chiang Rai. That he was a keen observer is borne out by his description of the rocks that lay along his route.

In 1891 the Royal Department of Mines and Geology was established, with a German mining engineer as its director, but despite the title little geological work was done. Its principal function was to grant mining concessions in the southern tin fields. The second director of the department, H. Warrington Smyth, made several trips through the country and published an account of his travels (1898), which contains some descriptions of mineral deposits.

The first critical geological investigation in Thailand was made by Prof. Bertil Hogbom of the University of Upsala (1914) in 1912.

Prince Kamphaengbej, as Commissioner of the Royal State Railways, seeking petroleum or coal for the railways' steam locomotives, engaged Wallace M. Lee, and American geologist, to investigate the mineral fuels then known in Thailand. Lee made three extensive investigations between December 1921 and January 1923. His first was in the north where he studied the petroleum and other mineral deposits (1923a); his second was in Peninsular Thailand (1923b). His third trip was to the Korat Plateau region, but an account of it has never been published. Lee deserves much credit for the extent and accuracy of his work which has been the basis for succeeding investigations.

Wilhelm Credner, privatdozent in geography at Kiel University, visited many regions in Thailand in 1927–29 that had not previously been described. During the years of his visit he gave several lectures on his observations before the Siam Society (1929) and subsequently published the most comprehensive description of the geology yet written (1935).

In 1934 the Ministry of Defense engaged two Swiss geologists, Hans Hirschi and Arnold Heim, to study the possibility of petroleum in the north, including the oil shales at Mae Sot and the long-known oil seeps at Maung Fang. Although the results of their petroleum studies were not made public, they did publish several papers (1938, 1939) on the petrography and structure of the rocks seen on their traverses.

In 1941 the Thai Cement Co. engaged the Aktiebolaget Elektrisk Malmletning to investigate the known iron deposits of the country. Their findings are summarized in a later section of this report.

Robert L. Pendleton's work on the soils of Thailand is varied and some of his studies have overlapped the field of geology (1940).

In 1941 a Geological Survey Division was established in the Royal Department of Mines, but it was not until after the end of the war in 1946 that the Division could be staffed and the beginning made on a long-term geological program. Some of the results of the investigations made under the new geological program are included in this report.

THE PRESENT INVESTIGATION

In 1948, upon their return from the International Geological Congress in London, the Director-General and the Chief Geologist of the Royal Department of Mines, stopped in Washington to discuss matters of common interest with officials of the United States Geological Survey and the United States Bureau of Mines. As a result of those conversations, the Government of Thailand, in 1949, invited the United States Government to send three geologists to Thailand to undertake, in cooperation with geologists and engineers of the Royal Department of Mines, a reconnaissance study of the known mineral deposits, including fuels, of the country.

Glen F. Brown and George C. Taylor, Jr., arrived in Bangkok on October 3, 1949, and W. D. Johnston, Jr., on January 6, 1950. Field work continued to the end of March 1950, and this report was prepared in rough draft in Bangkok during the first 3 weeks of April, before these American geologists left Thailand. The draft was subsequently revised in the period from August to October when Saman Buravas visited Washington for that purpose.

Vija Sresthaputra, Saman Buravas, Jumchet Charaljavanaphet, and Nitipat Jalichandra are the senior Thai geologists who took part in the reconnaissance and in the preparation of the report. They were assisted from time to time by other geologists and mining engineers of the Royal Department of Mines.

Throughout the field work and in the preparation of this report, the task has been cooperative in fact and in spirit. The parts of this report with unattributed authorship are the work of the group. Other parts are credited to the individuals who wrote them, including some authors not listed on the title page. Thus, it is possible to acknowledge specific participation and to recognize the different fields of labor and interest of the Thai participation. It serves also as acknowledgment, by the American geologists, of many prior investigations by their Thai colleagues.

It was impossible to make a reconnaissance of all the mining districts because of the strict limitation of time and the slowness of transportation away from railroads and highways. Travel frequently was by boat, or cart, elephant, or by foot, and often through heavy forests or over deeply weathered terrain. It is felt that the most promising areas in northern and central Thailand have been visited, but south Thailand was only sampled. This was a deliberate distribution of available time to give the most attention to the lesser-known restricted area of the north where mining is comparatively new and the deposits are not open to foreigners and to give less time to the better-known open area in the south where tin has been mined for many years by both Thai and foreign companies.

Because written English is not purely phonetic, many problems arise in the transliteration of Thai names into English. It has seemed wise to adopt, wherever possible, the English spellings of Thai geographic names that are used in the 1944 gazetteer (Army Map Service) compiled under the supervision of the United States Board on Geographic Names. This gazetteer was prepared by a group of Thais assembled by the Royal Thai Embassy in Washington.

Unfortunately it has been found necessary to use many place names in the text that do not appear on the accompanying small-scale maps. In the text such place names are referred to the proper Changwat, shown on plate 1, and can be located more closely by reference to standard atlases or to the Royal Survey Department maps and the aeronautical charts described on pages 11 and 13.

ACKNOWLEDGMENTS

The writers are indebted to several persons who gave material as well as intellectual assistance. His Excellency Nai Sukij Nimmanahaeminda, Minister of Industry, who is both hospitable and generous provided special funds for carrying out the reconnaissance. Nai Pathom Gajaseni, Director General of the Royal Department of Mines, provided facilities and assistance during the entire stay of the American mission, accompanying it on several trips. Without his enthusiastic cooperation the task could not have been completed in so short a time. The Thai Geological Survey gave access to its valuable file of reports and provided additional personnel whenever needed. The officials of the Royal Department of Mines, especially the supervisors

of several districts in the south, were helpful in supplying data and facilitating transportation to various mines. The Changwat Commissioners whom the writers met did much to make the field work more pleasant.

The writers appreciate the enthusiastic assistance of several government agencies. The Royal Air Force, under the command of Air Marshal Khun Ron Naphakaj, made a transport plane available for observation and aerial photography. Flying Officer Kam Singhachan and his crew were ever helpful. Dr. Chang Ratanarat, Director of the Department of Science, supplied reports of many chemical analyses. Capt. Charas Bunbongkarn, deputy director of the meteorological department of the Royal Thai Navy, provided climatic maps and data. Maj. Gen. Phya Salvidhan Nidhes, adviser to the Royal Survey Department of the Ministry of Defense, furnished information about maps available.

It is a great pleasure to acknowledge the generosity and hospitality of the mine operators who granted access to their properties and supplied information on production and grade of ore. Mr. W. J. Parsons, British vice consul in Phuket, himself an engineer supervising a group of Australian-operated mines on the west coast, made it possible to visit the properties under his jurisdiction. The warm welcome of Messrs. Isles, O'May, Jootee, Luang Anubas, Jankit, Suchit Geuawongse, Pradisht Burakarn, Tat Sirorasa, and many others was appreciated. W. T. Harry, general manager of the Thailand Tin Mines, Ltd., Yala, was especially helpful in furnishing maps of the Pinyok and adjoining mines, as well as information about the Cavaet process of tin recovery. R. A. Stratford of the Straits Consolidated Tin Co. guided the writers at the Laboo mine.

Thanks are due the Honorable Edwin F. Stanton, American Ambassador to Thailand, for assistance and encouragement. Mr. William O. Anderson of the American Embassy, besides being a dependable friend, was always ready and willing to help with arrangements for the mission.

While this report was being revised in Washington, reports of paleontologic examination of a group of fossils became available. These fossils had been collected by the Thai Geological Survey and sent for identification to the Smithsonian Institution, Washington. Identification of fossils gave new information about the relative ages of several stratigraphic units, and this information has been included in this report. Mr. G. A. Cooper of the United States National Museum examined the brachiopods; Mr. David H. Dunkle, also of the National Museum, studied the fishes; Mr. Lloyd G. Henbest of the United States Geological Survey identified the fusulinids; Mr. Ralph

W. Imlay of the Geological Survey identified the Mesozoic fossils; Mr. Teng-Chien Yen of the Smithsonian Institution examined the fresh-water mollusks; and Miss Helen Duncan of the Geological Survey identified the corals and bryozoans. The writers are grateful to all of these persons for their helpful work.

The writers will ever be grateful to the innately charming people of Thailand for their welcome and their hospitality.

GEOGRAPHY

By Vija Sresthaputra

POLITICAL DIVISIONS

The Kingdom of Thailand occupies a territory of about 518,000 square kilometers on the Indo-Chinese Peninsula of southeast Asia, extending from 6° to 20° north latitude (see pl. 1). The shape of the country is irregular, taking the form of an axe with the handle extending south along the Malay Peninsula. The length as measured from Chiang Saen in the north to Betong in the south is about 1,650 kilometers, and the greatest breadth from Three Pagodas Pass in the west to Chong Mek in the east is about 770 kilometers. The country is bounded on the north by the Lao States and the Shan States; on the west by lower Burma and the Andaman Sea; on the south by the Federation of Malaya and the Gulf of Thailand; and on the east by French Indochina. The coast line is long, measuring 1,930 kilometers on the Gulf of Thailand and 490 kilometers on the Andaman Sea.

Thailand has been a constitutional monarchy since 1932, but the divisions of administration have not been greatly changed from the old regime. The internal administration is centralized under the Minister of the Interior in Bangkok, the capital. For convenience in administration Thailand is divided into 70 changwats, or counties, each under the control of a commissioner (Kha Luang Pracham Changwat) who is directly responsible to the Minister of the Interior. Each changwat is again subdivided into amphurs, or districts, under the district officer (Nai Amphur) who is assisted by one or more assistant district officers (Palad Amphurs), according to the extent of the district. When an amphur is small it is called king amphur (subdistrict) or simply king with a Palad Amphur as head.

The amphur or king amphur is again subdivided into tambons, or villages, which are under an official called Kamnan and the tambon is made up of mu bans, or hamlets, each under an elder called a Phuyai Ban. The subdivision is based on population and convenience in communication.

A hamlet, or mu ban, is a collection of about 10 or more houses or 100 people who elect their own Phuyai Ban under the administration of the Nai Amphur. The duties of the Phuyai Ban are, in the main, to report any cases of crime to the Kamnan, the headman (mayor) of the tambon, to maintain a register of the people in his hamlet, and to assist in arresting criminals. A village, or tambon, consists of 10 hamlets. The Kamnan is elected by the council of Phuyai Ban and receives confirmation from the changwat commissioner. His duties are mainly to supervise the Phuyai Ban, to inform them of any new government regulation, and to provide transport and assistance for persons traveling on government business. Thus the Phuyai Ban and Kamnan are influential men from whom geologists may seek assistance while doing field work in the interior.

MAPS AVAILABLE

The Royal Survey Department of the Ministry of Defense has completed the detailed mapping of a part of the country. The maps, issued in the Thai language, are prepared on two scales, 1:50,000 and 1:200,000; the larger scale is more reliable as a base for geologic work. About 135,000 square kilometers in the central plain and a part of the Korat Plateau are shown by maps of the 1:50,000 scale. (See fig. 1.) These are published in three colors showing culture and contours. There are 405 10-minute quadrangle sheets, each of about 333 square kilometers. The coverage in maps of the 1:200,000 scale is complete for the whole country. These maps are highly generalized, show only a little culture, and are not satisfactory for detailed geological mapping. On this scale there are 74 sheets, each of which covers a 1-degree quadrangle, or about 12,100 square kilometers.

The aeronautical charts of the United States Air Force, on a scale of 1:1,000,000, serve perhaps as the most useful geographic map for those who do not read the Thai language. Thailand is covered by eight charts of this series that bear the following names and numbers: Irrawaddy River (556), Gulf of Tonkin (617), Gulf of Martaban (677), Chao Phra River (678), Tonle Sap (738), Gulf of Thailand (799), We Island (800), and Penang Island (859). These charts contain many place names that are mentioned in the text of this report but that do not appear in the maps accompanying it. It should be noted that the English spelling of both place names and geographic features on these maps does not always follow the recommendations of the Army Map Service gazetteer (1944).

The available maps can be used for broad-scale geologic reconnaissance, but for detailed mapping of mineral deposits the geologist

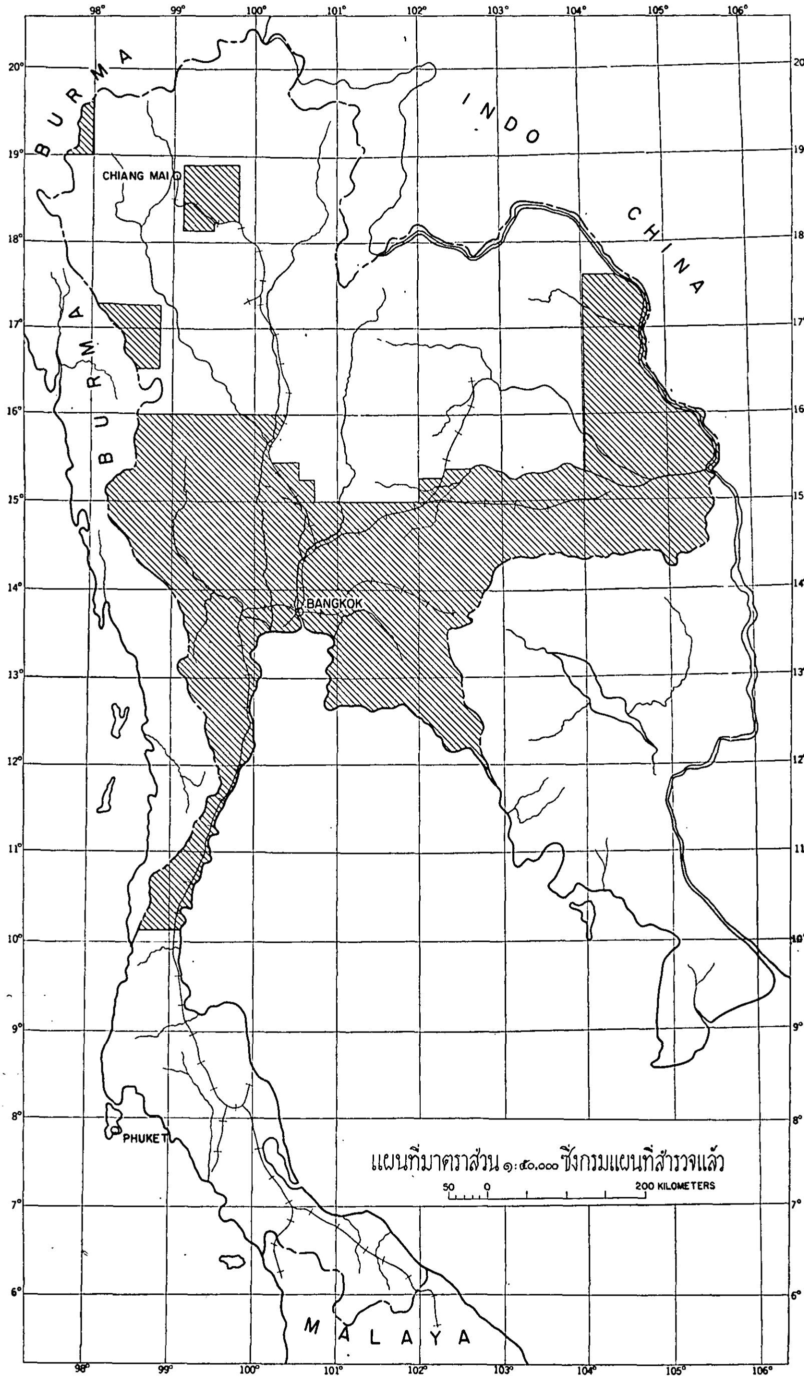

FIGURE 1.—Index map of Thailand showing the areas covered by maps of scale 1 : 50,000.

must prepare his own base map by plane-table or aerophotogrammetric methods. The Thai Government has recognized the need for good topographic maps of the whole country and contemplates making an aerial photographic survey at an early date.

CLIMATE

GENERAL FEATURES

The climate of Thailand (pls. 2 and 3) is controlled by the seasonal monsoons of southeastern Asia, modified by local topography. In the study of climate made by the Meterological Department of the Royal Thai Navy (Bunnag and Dhararaks, 1947), two types of climates are recognized: That of the tropical rain forest and that of the tropical savanna. Both are special types of the tropical rainy climate. The tropical rain forest climate is characterized by uniformly high temperature and heavy rainfall throughout the year; there is no distinctly dry season. The tropical savanna climate has less precipitation and has wet and dry seasons. Owing mainly to the modifying influences of topography, five climatic areas are recognized in Thailand: Northern Thailand, comprising the eight changwats from Uttaradit northward; northeast Thailand, comprising the whole of the Korat Plateau; the central plain, comprising the areas south of Uttaradit to the head of the Gulf of Thailand and including the area north of Prachuap; southern Thailand, or the peninsular area south of Prachuap; and the Gulf of Thailand east coast. Because these areas correspond roughly to the physiographic provinces, it is appropriate to discuss the climate of each and to note the effect of climate on rock weathering, vegetation, and seasonal accessibility to surveying and prospecting parties.

NORTHERN THAILAND

Because northern Thailand is generally mountainous, the tropical savanna climate is considerably modified by local elevation which imposes a so-called mountain climate in which there is an extreme range in temperature. The lowest temperature of record is 2.8° C. (37° F.) in January and the highest of record 39.5° C. (103° F.). Rainfall is generally moderate but of long duration, being more or less periodic in its distribution. The region is under the influence of the southwest monsoons, resulting in a wet season from the middle of May to October. The coolest and driest season lasts from October through February and the hot season extends from March to mid-May. Fog is most frequent in March and April when it sometimes lasts through the whole day. The period from October to February, before the peak of the hot season, is the best for making ground surveys and aerial photographs.

NORTHEASTERN THAILAND

The tropical savanna climate of this region is similar in temperature and rainfall to that of northern Thailand. Because most of the region is a plateau, topographic relief has less effect on climate than it has in northern Thailand. The rainy season coincides with the southwest monsoons which become more vigorous and bring torrential rainfall when typhoons of the South China Sea pass over the region, usually from June through September. The recorded monthly extremes of rainfall in the region range from 5.3 millimeters in January to 248.8 millimeters in May. The highest temperature of record is 43.0° C. (109° F.) in April and the lowest is 5.1° C. (41° F.) in January. The daily range of temperature may also be more extreme than elsewhere in the Kingdom. The distribution of seasons is about the same as in northern Thailand.

CENTRAL PLAIN

The central plain comprises the great plain of the Chao Phraya and other rivers and adjacent mountain borders on the west and east. The climate is the tropical lowland savanna type with an average annual rainfall of 1,344 millimeters. The maximum monthly rainfall is in September which has a recorded average of 284.7 millimeters; the minimum is in December which has 37 millimeters. Temperature variation is the same as in northern and northeastern Thailand but the extreme recorded diurnal range has reached 26.4° C. (79.5° F.). Fog is common between January and March but generally it occurs only during the early hours of daylight. The division of seasons is the same as in northern Thailand. Ground surveys can be carried out from the end of October to May and aerial photography is best done at the end of the rainy season in October and November.

SOUTHERN THAILAND

The climate of southern Thailand is the tropical rain forest type somewhat modified by the monsoons. It is characterized by uniformly high temperatures, two periods of greater rainfall, and rain at other times distributed throughout the year so that there is no well-marked dry season. However, many local modifications occur that depend on whether the winds blow from the water or from the land. The highest annual rainfall recorded in the region is 6,606 millimeters at Takua Pa, and the lowest of record is 1,300 millimeters. The temperature on both coasts is uniform. The yearly average temperature lies between 26.7° C. (80° F.) and 28.4° C. (83° F.). The highest temperature recorded is 39.3° C. (103° F.) and the lowest temperature is 17° C. (63° F.). The wet season which lasts from May to October has two peaks—one during the northeast monsoons and one during the southwest monsoons. The cold season, from November to mid-February, is characterized by a smaller range of temperature than that of other seasons. The hot season, during March and April, is milder than in central Thailand, because of the modifying influence of sea breezes. January to April is the best period for ground surveys.

GULF OF THAILAND EAST COAST

The climate of the Gulf of Thailand east coast is the tropical rain forest type, similar to that along the west coast of the Peninsula. The wettest period lasts for 6 months, extending from May to October. Precipitation at Chanthaburi is greatest in July and least in February, the annual average being 2,494 millimeters. Temperatures are generally high and uniform. The highest recorded temperature was 38.6° C. (101° F.) and the lowest 12.5° C. (54.5° F.). The seasons are similar to those in central Thailand, the only difference being that rainfall is more abundant and well distributed. The period between November and April is best for ground surveys.

PHYSIOGRAPHY

LAND FORMS

Because a typical monsoon climate prevails in most of Thailand, the weathering, erosional, and depositional processes are thus similar in most respects to those in other wet tropical regions of the world, and they are locally modified by vegetative cover and rock types and structure. The rocks of Thailand are widely diverse. They include shales, sandstones, and limestones which in places are regionally metamorphosed; granite batholiths and stocks intruded into sedimentary and metamorphic sequences; younger intermediate or felsic intrusive igneous rocks; and local plugs or flows of basalt. With the exception of the northeastern region most of the early Tertiary and older rocks of the Kingdom have been moderately to strongly folded and in places faulted. Thus, present land forms reflect physiographic processes operating on structurally deformed rocks of diverse physical and chemical character in a humid tropical environment.

Among the rock types the granites and limestones are generally more resistant to erosion than the shales and sandstones or their metamorphic equivalents. Resistant granite forms many prominent elongated ridges or isolated mountains whose prevailing slopes are smooth and rounded but steeper than those common in temperate humid climates. Notable examples of granite mountains include the range extending from the border of the Shan States near Muang Fang more than 500 kilometers south to about latitude 15°30′; the six granite ranges of Peninsular Thailand; the massif of Doi Pha Hom Pok northwest of Muang Fang in northern Thailand; and the mountain masses of Khao Klaet, Khao Sa Bap, and others in the Chanthaburi region. Characteristically, the granites weather deeply in the tropical environment, and the fresh rock is generally overlain by a mantle of soil and disintegrated and decomposed rock which in places is 15 meters or more thick. To a considerable degree this mantle tends to absorb rainfall and to retard erosion by slope wash. However, erosion by landsliding occurs when the rock mantle becomes oversaturated after heavy rains and toe slopes are undermined by stream action. Landslide scars are common features on slopes of granite mountains of the Kingdom. Economically important colluvial and eluvial tin and tungsten placers occur in the rock mantle where it overlies mineralized zones in or near the granites of western and Peninsular Thailand.

The land forms developed in limestone are perhaps the most spectacular features of the Thai landscape. The limestone generally resists stream erosion and mechanical weathering but is susceptible to solution by percolating subsoil water weakly charged with carbonic acid. Resisting active solution are the more massive and insoluble parts of the limestone that commonly form isolated pinnacled buttes or short serrated ridges similar in form and origin to the "mogotes" of Cuba or "pepinos" of Puerto Rico. These rise in places to heights of several scores of meters above surrounding lowlands and are bound by steep, vertical or even overhanging walls which are usually fluted and pitted by solution. Capping the pepino buttes and generally filling the areas between them are accumulations of residual red earth soils. Karst solution features are common land forms in all of the outcrop areas of limestone. Where the beds are steeply dipping, the pepino buttes are alined along the strike, but typical sinkhole topography and underground drainage are best developed where the limestones are flat or gently dipping. Alined belts of pepino buttes and ridges extend discontinuously from Phuket Bay at latitude 8° north along the eastern side of the Peninsula northward to about latitude 13°30′ near Rat Buri. Karst topography is extensively developed in the limestone regions to the southeast of the Mae Fang basin and to the northwest of Kanchanaburi. Pepino hills occur in several lineated belts on the west side of the Mae Wang valley near latitude 19°15′, to the northeast of Lampang, near Chiang Rai, between Chiang Mai and Muang Fang, and in other areas of central, northern, and eastern Thailand.

Sandstone, shale, and their metamorphic equivalents—quartzite, slate, phyllite, and schist—constitute the major part of the clastic rocks of Thailand. They are weakly to moderately resistant to erosion, depending on such factors as degree of induration, nature of cementation, and stratigraphic or structural position. Where strongly folded the quartzites and indurated sandstones commonly form prominent strike ridges such as characterize the highlands of western and northwestern Thailand. Where gently dipping, similar rocks cap flat-topped buttes or mesas such as those of the Nan-Chiang Rai region or underlie broad plateaus, such as that of Korat. The poorly indurated sandstones, shales, slates, phyllites, and schists are generally less resistant, and many of the lowlands of the Kingdom occur in them. Extensive erosion surfaces have been developed on areas of poorly indurated rocks by stream and by marine erosion along the coast. Among notable examples is the broad piedmont belt of smooth or gently undulating erosion surfaces which truncate deformed rocks around the interior margins of the Chao Phraya Plain. At Uttaradit and to the east and northeast, steeply dipping shales, slates, and schist have been planated over a wide area and mantled by a thin veneer of alluvium. Low hills of schist which in places rise 10 to 15 meters above the surrounding planated surface are common in the area. Similar erosion surfaces are cut in these rocks to the west of Rat Buri, near Tak, and in folded sandstones and shales in the Chanthaburi region. Along the west coast of Peninsular Thailand from Phuket north to Takua Pa inlet a narrow planated surface is developed on steeply dipping slates and schist. This surface was apparently formed largely by marine abrasion and is covered by beach, estuarine, and stream deposits which are locally tin bearing. On the east coast of the Peninsula discontinuous erosion surfaces have been cut in similar rocks, both by stream and marine planation. They extend from Surat Thani discontinuously north to the latitude of Phet Buri, and are interrupted from place to place by sandstone or quartzite monadnocks.

DRAINAGE PATTERNS

In its general outlines the present configuration of the drainage system of northern and western Thailand was probably inherited from late Tertiary time. High accordant summits preserved in ridge crests suggest that maturity in the erosion cycle may have been reached by many streams in the middle Tertiary and that a widespread peneplain truncating previously folded rocks may have existed.

Faulting and folding movements, which probably began in the middle or late Tertiary, led to the development of several structural basins transverse to the major streams. As a consequence streams were ponded in the depressed basins but in the intervening areas they have cut down in young narrow gorges. Evidently some structural movement took place concurrently with sedimentation in the basins because the older basin sediments show more evidence of warping than the younger. Evenutally, as sedimentation progressed, temporary lakes and ponds which had previously occupied the basins were filled with sediments and the present integrated streams established meandering courses across the basin floors.

Regional uplift toward the end of Tertiary time apparently rejuvenated the streams of northern Thailand and some downcutting occurred in the sediments of the basins. In areas between basins, major streams cut deeply below the old peneplaned surface truncating folded rocks. For the most part the streams adjusted their courses along bands of soft rocks to form strike lowlands, but in other places they cut down across bands of resistant rocks to form water gaps or narrow gorges. For example, below the Nan structural basin, the Mae Nam Nan is a mature stream with steep grades or rapids across bands of resistant rocks and graded reaches in soft rocks. Near Ban Hat La Tai to the northeast of Uttaradit, the river crosses a long strike ridge trending southwest in a deep water gap, but elsewhere along this course the stream generally follows wide planated lowlands cut on less resistant rocks. The Mae Aow, a large branch of the Mae Nam Nan, generally follows a subsequent lowland but minor tributaries of the Aow show trellised drainage etched in folded rocks in the area about 20 kilometers northeast of Amphur Tha Pla. Similarly, the Mae Yom after crossing the fault border at the south end of the Phrae basin follows a winding course through water gaps and gorges transecting strike ridges of resistant rock. Farther downstream to the south-southwest of Phrae the stream follows wide lowlands formed by planation of soft folded rocks.

Most of northeastern Thailand is occupied by the Korat Plateau which is drained by the river system of Nam Mun. Underlying the plateau are sediments of the Korat series which were downwarped in a large structural basin in late Tertiary time. The well-integrated dendritic pattern of the Nam Mun drainage system thus appears to be consequent to a gently downwarped surface with relatively uniform bedrock. However, in the southeast the Nam Mun crosses the structural lip of the basin in an antecedent course to enter the Mekong.

Late Tertiary structural movements in central Thailand resulted in the depression of the Chao Phraya region and began a cycle of alluviation which continued through most of Quaternary time to the present. At first the northern shore of the Gulf of Thailand may have lain as far north as Uttaradit, but the sediment loads of the Chao Phraya and other streams accumulating in the depressed region gradually moved the shore southward. Active alluviation continues at present by the Chao Phraya and other large rivers as they follow intricately interlaced courses and meander widely over the Chao Phraya Plain whose southern limit is gradually growing seaward.

In Peninsular Thailand the present drainage system is also largely inherited from late Tertiary time. Between latitudes 13° and 9°50′ streams draining east to the Gulf of Thailand generally follow steep grades through young canyons in headwater reaches, but in the coastal zone they flow in graded courses through open valleys or lowlands planated in folded rocks. Near Ban Don and in the coastal zone between Nakhon Si Thammarat and Narathiwat small discontinuous alluvial plains have been formed by short streams emerging from young canyons in the more rugged interior of the Peninsula.

The lower valleys of many streams on the western slope of the Peninsula have been drowned by recent submergence. Typical are the Kra River lying between lower Burma and Peninsular Thailand, the Takua Pa River, and the Phangnga River. In their middle and upper reaches these streams follow graded courses through mature valleys which in many places are transverse or oblique to structural trends. Structural movements in late Tertiary time also led to local development of several small basins in the region between latitude 9° and 7°. In some places the depressed areas were drowned by shallow embayments of the sea and in other places disrupted drainage resulted in ponding of streams. As the basin areas were filled with sediments, normal drainage was reestablished. Present streams crossing these areas generally follow sluggish meandering courses but elsewhere flow with steeper grades through young or mature valleys.

PHYSIOGRAPHIC PROVINCES

GENERAL FEATURES

Thailand contains a considerable variety of topography. In general there are three physiographic types—highlands, plains, and plateaus which grade into one another and support different types of vegetation. Highlands comprising several mountain ranges extend from north to south through the entire western length of the country. The central region is occupied by a great alluvial plain of deltaic form with the base at the Gulf of Thailand and the apex in the Uttaradit area. The northeastern part of the Kingdom includes an extensive plateau which is flanked by mountains along its western and southern borders.

For convenience of description Thailand may be divided into five physiographic provinces based largely on land forms which also coincide with a classification based on climate and ethnology. These provinces are the Northwest Highlands which is divided into two subprovinces, the Chao Phraya Plain, the Korat Plateau, the Chanthaburi, and the Peninsular. (See pl. 4.)

NORTHWEST HIGHLANDS

The Northwest Highlands province includes the mountainous country to the west, northwest, and north of Bangkok. It lies between the Burma frontier and the Chao Phraya Plain and to the south it merges with the Peninsular province. The chains of rugged mountains forming the province are the source of the streams that have bulit the great alluvial plain of the Chao Phraya River. Slight differences in physiography require the subdivision of the Northwest Highlands into two subprovinces.

PHI PAN NAM SUBPROVINCE

The Phi Pan Nam subprovince includes the northernmost region of the Northwest Highlands. It comprises the Changwats of Mae Hong Son, Chiang Mai, Chiang Rai, Lamphun, Lampang, Phrae, and Nan. The subprovince derives its name from the Phi Pan Nam range meaning the "spirits which divide the water," or in other words, the "watershed range." The central part of the subprovince is occupied by this range. Streams rising on the northern slopes of the range are tributary to the Mekhong, on the southern and eastern slopes they flow to the Chao Phraya, and on the western slopes they drain into the Salween.

Characteristic of the subprovince are parallel mountainous ridges which trend generally to the north-northeast. Between these ridges are the valleys of four large rivers, the Mae Nam Ping, Mae Nam Wang, Mae Nam Yom, and Mae Nam Nan which unite in the Chao Phraya River. In many respects the subprovince is comparable to the Valley and Ridge Province of eastern United States where the streams have cut down in folded rocks, carving valleys in the softer beds and leaving the harder beds as ridges. A notable feature of the subprovince is the occurrence along the larger streams of elongate level-floored basins separated by gorges. Typical basins of this kind are those at Chiang Dao and Chiang Mai on the Mae Nam Ping, at Phrae on the Mae Nam Yom, at Lampang on the Mae Nam Wang, and at Nan on the Mae Nam Nan. In intermontane basins of this type the soil is particularly suitable for the cultivation of rice and tobacco; consequently the density of population is fairly high. Within the basins the streams are generally sluggish and meander over narrow flood plains. Between the flood plains and the bordering ridges are belts of low undulating hills that are absent in some places but elsewhere may attain a width of 5 kilometers or more. In the gorges between the basins many of the streams follow winding courses which appear to be entrenched meanders, suggesting superimposed drainage on former peneplaned surfaces. To the north of the Phi Pam Nam range are a number of wide, level, and often swampy basins whose trunk streams drain into the Mae Nam Ing and Mae Kok, both of which are tributary to the Mekhong.

The average altitude of the peaks in the subprovince is about 1,600 meters. Doi Inthanon, the highest point in Thailand, rises to an altitude of 2,576 meters. The floor of the Chiang Mai basin is about 300 meters above sea level, and that of Chiang Rai farther to the north is about 378 meters.

TANAOSEE SUBPROVINCE

The Tanaosee subprovince forms a strip along the western frontier from about latitude 18° north to latitude 12° north and is limited on the east by the Chao Phraya Plain. Included within the subprovince are high rugged mountains through which streams have cut deep canyons and narrow valleys. In the north is the Thanon Thong Chai range which terminates near latitude 16°. In this area rise three large rivers of the subprovince. They are the Moei which flows northwest through the Mae Sot basin to join the Salween, the Sakae Krang which drains southeast to the Chao Phraya Plain, and the Khwae Yai, the larger tributary of the Mae Klong, which empties into the Gulf of Thailand.

South of latitude 16° the mountainous backbone of the subprovince breaks into three distinct subparallel ridges. At the north end of the western-most ridge is Three Pagodas Pass and the headwaters of the Khwae Noi, another tributary of the Mae Klong. The western ridge called the Tanaosee (known in English as Tenesserim) ranges in elevation from 700 to 1,500 meters and forms the western frontier of Thailand south to latitude 11° north. Between the Khwae Yai and the Khwae Noi is another ridge of bare limestone crags which reach elevations of 1,300 meters above sea level.

With the exception of the Mae Sot basin, the wide, level basins which characterize the stream valleys of the Phi Pan Nam subprovince are lacking in the Tanaosee subprovince. The rivers wind through steep rocky canyons or narrow valleys which rarely exceed a width of 2 kilometers. On emerging from the foothills they join other rivers of the Chao Phraya Plain.

CHAO PHRAYA PLAIN

The Chao Phraya Plain province occupies the central part of Thailand. The plain is bordered by a piedmont belt on the west, east, and north, and by the Gulf of Thailand on the south. The plain is more than 300 kilometers long from north to south and ranges from 50 to 150 kilometers wide from east to west. It is a mature deltaic plain which has been built up by the accumulation of alluvial materials eroded by streams from the Northwest Highlands. Dotting the surface of the plain are numerous isolated hills whose bases have been buried by alluvium and whose rocks are similer to those of the bordering mountains. The plain begins about latitude 18° north where the four rivers of the north emerge from their valleys and finally come together in the Chao Phraya River at Pak Nam Pho. About 50 kilometers farther to the south the river bifurcates at Chainat, the head of the delta, which stretches 90 kilometers south to the Gulf. Near Ayutthaya the Chao Phraya receives the waters of the Pa Sak River which rises near Phetchabun and drains the western slopes of the mountains bordering the Korat Plateau.

The plain also receives the drainage of two other rivers, the Mae Klong and the Ban Pakong. The latter river rises near the frontier of Cambodia and drains the region between the southern edge of the Korat Plateau and the Chanthaburi mountains. The river flows into the Gulf of Thailand at the southeast corner of the Chao Phraya Plain.

The southern part of the plain is flat, and the rivers are joined together by a network of canals which are used for irrigation, drainage, and transport. The plain is the rice bowl of Thailand. Because of its agricultural wealth the plain supports the greatest concentration of population with the highest standard of living of any region of the country.

Each year during the rainy season great quantities of silt are carried down by the streams of the Chao Phraya Plain and deposited in the flat rice-growing areas, thereby enriching the soil. Still more silt is carried to the sea where it is deposited at the mouths of the rivers. It is estimated that the land is growing seaward along the northern shore of the Gulf at the rate of about 4 to 5 meters a year.

KORAT PLATEAU

The Korat Plateau province is a young saucer-shaped plateau tilted to the southeast and having a narrow strip of swampy country to the north. It is limited on the north and east by the Mekhong River, on the west by the Phetchabun mountains and the massive flat-topped peaks of Dong Phraya Yen, and on the south by the San Kamphaeng range and the Dong Rek scarp. The plateau derives its name from the town of Korat (officially known as Nakhon Ratchsima), the largest settlement in the region.

A line of hills, with an altitude as great as 600 meters, lies between the plateau proper and the Mekhong on the north and east. The plateau itself is drained by the solitary river system of Nam Mun which escapes through the line of hills at the southeast and empties into the Mekhong.

The western and northern borders of the plateau range from 130 to 200 meters above sea level, and at the city of Ubon the altitude is reported to be about 50 meters. The mountains of Dong Phraya Yen include many flat-topped peaks which rise to altitudes of 800 to 1,300 meters. The altitude of the Dong Rek scarp is generally about 500 meters but in places it rises to 700 meters. From the scarp the land falls off sharply to the Cambodian Plain on the south, but the slope northward to the river Nam Mun is gradual.

Ranging in width from about 50 to 100 kilometers is a strip of land to the north of the plateau which drains into the Mekhong. Lying in this strip in Changwat Sakon Nakhon is Nong Lahan, the largest fresh-water lake in Thailand. The lake has an area of about 170 square kilometers and empties into the Mekhong by way of the Nam Kam. The strip is also drained by numerous other streams tributary to the Mekhong, but the only one of importance is Mae Nam Songkhram.

The surface of the interior of the plateau is gently undulating and dotted here and there by low hills and small shallow lakes. Large areas are flooded during the wet season, but in the dry season the region suffers for lack of water. The soils for the most part are thin and poor in plant foods.

CHANTHABURI

The Chanthaburi province is separated from the Korat Plateau on the north by the valley of the Ban Pakong River. It is limited on the west and south by the Chao Phraya Plain and the Gulf of Thailand and on the east by a line of flat-topped hills called the Khao Banthat, which lie along the Cambodian frontier. The region includes a well-dissected upland in the northern and central parts and a coastal plain in the south and west. It is drained by numerous streams all of which flow in southerly direction. The principal rivers are the Mae Nam Chanthaburi, Prasae, Wen, and Trat. The principal peaks are Khao Khieo, altitude about 800 meters, which is the only peak visible from Bangkok on a clear day; Khao Soi Dao, altitude 1,640 meters; and Khao Sa Bap, altitude 933 meters, near the city of Chanthaburi.

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The coast line of the region is much indented and fringed with rocky jungle-clad islands. The island of Ko Si Chang lying near the northeast corner of the gulf forms a natural sheltered anchorage for large steamers which cannot cross the bar at the mouth of the Chao Phraya. The largest island along this coast is Ko Chang with an area of 180 square kilometers and a peak which rises to 644 meters above sea level. In the vicinity of the muddy estuaries of Mae Nam Prasae and Mae Nam Wen mangrove swamps abound, but elsewhere along the coast are many white sandy beaches.

PENINSULAR

The physiographic features of the (Malay) Peninsular province include both plains and highlands. Plains fringe the coastal areas and highlands form the backbone of the peninsula. The total length of the region within this province is about 750 kilometers, and the width ranges from 15 to 200 kilometers. The mountainous backbone trends from north to south and is formed of short ridges arranged in echelon. Between these are small plains or valleys which are considerably dissected.

Along the western side of the peninsula the Tanaosee Range extends south from the Tanaosee subprovince but is split into two ranges by the trough of the Kra or Pak Chan River. The western range lies in Burma and the eastern in Thailand. The eastern range, also known as the Phuket Range, extends south from the Kra Isthmus skirting the Indian Ocean to the island of Phuket. The main range of the peninsula starts anew to the north of the city of Nakhon Si Thammarat and extends in a southerly direction to Changwat Satun. In the country lying between this main range and Phuket Range are isolated buttes and peaks which rise sheer from the surrounding lowlands. One such peak, Khao Phanom Bencha, attains an altitude of 1,404 meters, but for the most part the peaks are only a few hundred meters high.

South of Songkhla are three other ranges trending almost north-south. The highest peak is in the Malayan frontier range near Betong; its altitude is 1,530 meters.

Besides the principal ranges, there are many small subsidiary ridges trending parallel to them. The chief of these are the limestone ridges of Phangnga and Phatthalung.

The shore lines on the two sides of the peninsula are quite different from each other. The eastern shoreline is smooth and regular with long beaches like those of Nakhon, Si Thammarat, Songkhla, and Pattani. The only exception is in the delta lands at Surat Thania. Back of the shoreline is a coastal plain which ranges from 10 to 35 kilometers wide. At Nakhon, Si Thammarat and at Pattani two large sand spits are forming at the present time. In general the coast has the characteristics of a shoreline of emergence. Conversely, the western shoreline is very irregular and much indented with estuaries and fringed with islands such as those in Phuket Bay, Ko Yao, and Ko Lanta. The mountains extend down to the sea in many places. Beaches are rare and small but mangrove swamps are numerous. The lower course of the Pak Chan River has the appearance of a drowned valley, which gives evidence of a submerged shoreline (Rama Rau, 1929, p. 8). Remains of buried mangrove trees, exposed in hydraulic mining at levels several meters above present sea level, are found along the shorelines of Changwats Takua Pa and Phuket. At Satun there is a cave in a limestone monadnock 8 kilometers away from the sea with recent sea shells on the cave floor 15 meters higher than the surrounding plain. Thus the relation between the eastern and the western shorelines would suggest that the peninsula had been tilted slightly to the northwest because of unequal emergence.

On the east coast of the peninsula there are few bays, Ao Sawi, Ao Ban Don, and Ao Nakhon being the most important. Islands are also few in number. The largest are Ko Samui and Ko Phangan which are the northern continuation of the Nakhon range. On the west coast there are a number of large islands such as Ko Phuket, Ko Yao, Ko Lanta, Ko Phra Thong, Ko Libong, and Ko Tarutao. However, the largest and most important is Ko Phuket, the birthplace of the tin industry. Its area is about 600 square kilometers, and the population more than 20,000.

GEOLOGY

By Viji Sresthaputra, Saman Buravas, and Glen F. Brown

ROCK UNITS

SEQUENCE AND GENERAL FEATURES OF THE ROCKS

Within the boundaries of Thailand are widely diverse sedimentary, metamorphic, and igneous rocks ranging in age from doubtful Cambrian to Recent. Rocks of definite pre-Cambrian age have not been recognized in the Kingdom. Plate 5, a geologic map of Thailand, is a provisional attempt to assemble and interpret all the data now available about the areal geology. The authors are keenly aware of the inadequacy of these data.

The rocks of the Paleozoic age include clastic sediments of the Phuket series, metamorphosed to schist, slate, argillite, and quartzite; the Thung Song limestone; sandstone and shale of the Kanchanaburi series, in many places metamorphosed to slate, phyllite, and quartzite; gneiss and mica schist older than the Kanchanaburi series and younger

Summary of current (1950) knowledge of Thai stratigraphy

Age	Rock unit	Character	Thickness (meters)	Principal areas or changwats where rock unit occurs: Southern Thailand (between lat. 5°–12° N.)	Central Thailand (between lat. 12°–16° N.)	Northern Thailand (between lat. 16°–21° N.)	Economic value
Quaternary		Unconsolidated silt, clay, sand, and gravel of stream channels, flood plains, and terraces; beach and estuarine deposits; raised coral reefs and marine terrace deposits; residual lateritic deposits.	0–300+	Songkhla, Phuket, Phangnga, Surat Thani.	Central plain of Mae Nam Chao Phraya and tributary rivers.	In the basins of Mae Fang, Mae Rin, Lampang, Amphur Pai, Mae Sot and others.	Important alluvial and beach tin placers in southern Thailand; eluvial and colluvial tin and tungsten placers in southern and central Thailand; alluvial gold placers in many localities; gemstone placers in eastern Thailand; small lateritic iron deposits; good water-bearing beds in alluvial valleys and the flood plain of Mae Nam Chao Phraya.
Tertiary	Krabi series	Semiconsolidated fluviatile, estuarine, or marine deposits of clay, sand, gravel, marl, bituminous shale, lignite, gypsum, and marine limestone.	0–175+	In eight structural basins lying in southern Peninsular region.	Not recognized	Not recognized	Contains potentially important lignite beds in several places; gypsum and oil shale deposits of doubtful value.
	Mae Sot series	Semiconsolidated fluviatile and lacustrine deposits of clay, sand, gravel, marl, oil shale, lignite, gypsum, and fresh-water limestone.	0–430+	Not recognized	Mae Sot basin	In basins of Mae Fang, Mae Rin, Mae Moh, Lampang, Amphur Pai, and others.	Contains potentially important oil shale deposits in Mae Sot basin; a small oil-bearing bed in Mae Fang basin; lignite and gypsum deposits of minor value.

Tertiary (?)	Andesite and rhyolite porphyry.	Andesite porphyry in stocks and dikes but by younger rhyolite porphyry in dikes and flows; in places intrudes or overlies basalt or diorite.		Chumphon	Chanthaburi, Sara Buri.	Tak, Petchabun, Uttaradit, Chiang Rai.	In places used for road ballast.
	Basalt	Basalt in flows, dikes and plugs; nepheline and spinel in some localities; intrudes Korat series.		Not recognized	Kanchanaburi, Chanthaburi, Trat, Lop Buri, Buriram, Sisaket.	Tak, Lampang, Chiang Rai.	Yields sapphires, rubies, and topaz to eluvial and alluvial placers in Changwats Chanthaburi, Trang and Kanchanaburi.
	Diorite and quartz diorite.	Diorite and quartz diorite in dikes, bosses, stocks, and small batholiths; intrudes Korat series and other rocks.		Not recognized	Lop Buri	Phetchabun, Chiang Rai.	Associated with gold lodes and placers of Tha Tako, Krabin, and other localities; also the contact-metamorphic iron deposit of Khao Thap Khwai.
Late Cretaceous	Younger granite	Muscovite-biotite granite with hornblende generally present, and zircon, apatite, and tourmaline common accessories; in dikes, stocks, and elongate batholiths.		All of Peninsular region.	Western frontier area.	Mae Sariang area	Associated mineralized zones yield important deposits of tin and tungsten from lodes or eluvial and alluvial placers in western and Peninsular Thailand.
Jurassic and Triassic.	Korat series with Kamawkala limestone.	Sandstone, conglomerate, and shale, with some thin marly or concretionary limestone locally metamorphosed to quartzite, phyllite, and slate; massive gray impure Kamawkala limestone intercalated with Korat series in Mae Sot region.	366—2,000+	Southern Peninsular Thailand, Surat Thani, Chumphon.	Southeastern Thailand, Korat Plateau.	Northern and north central region, Mae Sot region, Korat Plateau.	Associated with most of Thailand's manganese deposits; also contains salt deposits in the Korat Plateau; hard sandstones used for building stone and abrasives.

Summary of current (1950) knowledge of Thai stratigraphy—Continued

Age	Rock unit	Character	Thickness (meters)	Principal areas or changwats where rock unit occurs			Economic value
				Southern Thailand (between lat. 5°–12° N.)	Central Thailand (between lat. 12°–16° N.)	Northern Thailand (between lat. 16°–21° N.)	
Triassic (?)	Older granite	Hornblende-biotite granite, with subordinate muscovite; in dikes, stocks, and elongate batholiths.		Narathiwat	Chanthaburi, Chon Buri, Nakhon Nayok, Korat region, western region.	Chiang Mai, Chiang Rai, western region.	Associated mineralized zones contain gold, copper, molybdenum, iron, antimony, lead, and zinc ores. Gold lodes are characteristic, and locally antimony, lead, and zinc deposits. Apparently tin mineralization rare or absent.
Triassic (?)	Mafic and ultramafic rocks.	Diorite, gabbro, pyroxenite, and minor perknites in dikes, small plugs, and stocks.		Not recognized	Not recognized	Chiang Rai, Uttaradit.	Serpentinized zones in Changwat Uttaradit contain small asbestos deposits.
Permian and Carboniferous ?	Rat Buri limestone.	Massive light gray limestone interbedded with sandstone and shale in Peninsular and northern Thailand; fossiliferous cherty beds and thin-bedded limestone occur locally.	752—2,350+	Scattered through Peninsular region.	Phet Buri, Rat Buri, Kanchanaburi, Nakhon Sawan, Prachin Buri.	Scattered through northern region.	Important as a source of lime, road and railroad ballast.
Pre-Permian (?)	Gneiss and schist	Biotite-muscovite para- and orthogneiss and associated mica schist in injected bodies in Kanchanaburi series.		Surat Thani	Prachuap Khiri Khan, Chon Buri.	Chiang Mai	Limited use for building stone and kitchenware.

Early Carboniferous (?), Devonian (?), and Silurian.	Kanchanaburi series.	Shale, sandstone, and sandy shale, in many places metamorphosed to phyllite, argillite, quartzite, and slate; thin beds of limestone locally present.	1,000—2,900+.	Southern Peninsular region.	Western and southwestern region.	Northern and northwestern region.	
Ordovician (?)	Thung Song limestone.	Dark gray limestone, with disseminated crystals of pyrite and thin stringers of brown calcareous material.	2,740±	Ron Phibun, Nakhon Si Thammarat, Satun.	Kanchanaburi, Chon Buri.	Not recognized	Limited use for road and railroad ballast; small scale use of dolomitic limestone of Koh Si Chang for refractory purposes.
Cambrian (?)	Phuket series	Dark colored pebbly shale, shale, and fine-grained sandstone, in many places metamorphosed to schist, slate, quartzite, and argillite; pebbles of quartz, quartzite, slate, and granite in pebbly shale may be pre-Cambrian.	1,220±	Central and western zones of Peninsular region.	Not recognized	Not recognized	

than the Rat Buri limestone; and the Rat Buri limestone. Paleozoic sedimentary and metamorphic rocks attain a total thickness of 9,000 meters or more in Thailand.

Among the Mesozoic rocks are granite that is doubtfully post-Rat Buri and probably pre-Korat, in stocks and batholiths; mafic and ultramafic intrusive rocks doubtfully post-Rat Buri and possibly of early Mesozoic age, locally cropping out in northern Thailand; sandstone, shale, and some limestone of the Korat series; and granite (post-Korat) in extensive batholiths and stocks. The maximum thickness of Mesozoic sediments may reach 2,000 meters or more in Thailand.

Rocks of Tertiary age include basalt which occurs in many small scattered areas as dikes, plugs, and flows; andesite and rhyolite porphyry dikes and sills (post-Korat); diorite and quartz diorite (post-Korat) in stocks and bosses; and marine, lacustrine, and fluviatile limestone, marl, sandstone, conglomerate, shale, oil shale, and lignite of the Mae Sot and Krabi series. The Tertiary sedimentary rocks are restricted mainly to six structural bodies in the north, and to eight small basins or local costal embayments in the Peninsular province. The maximum thickness of Tertiary sedimentary rocks may be greater than 400 meters in the Mae Sot basin and more than 200 meters in the Mae Fung basin and near Krabi.

Quaternary deposits include unconsolidated silt, clay, sand, and gravel in the flood plains, in stream channels, or in terraces along stream channels; beach and estuarine clay, sand, and gravel, or raised coral reefs; and residual layers of laterite capping stabilized surfaces. In most places the Quaternary deposits are less than 50 meters thick, but in the alluvial plain of the Chao Phraya near Bangkok they are more than 300 meters thick.

The sequence, physical character, and economic importance of these rock units are summarized in the preceding table and described in more detail on subsequent pages. Geologic names are introduced for seven sedimentary units which are areally extensive in Thailand; these are the Phuket series (p. 30), the Thung Song limestone (p. 31), the Kanchanaburi series (p. 32), the Rat Buri limestone (p. 33), the Korat series (p. 36), the Mae Sot series (p. 38), and the Krabi series (p. 40).

SEDIMENTARY AND METAMORPHIC ROCKS

PHUKET SERIES (CAMBRIAN)

Beds of metamorphosed sedimentary rocks occupy a large region along the central axis and west side of Peninsular Thailand and extend northward into lower Burma. In Thailand the metasedimentary rocks extend northward from Phuket to the latitude of Rat Buri (13°30′ N.) and in the vicinity of granitic instrusions in the Khao

Luang Mountain chain of eastern Peninsular Thailand. The beds stand on edge in most localities so that thickness and sequence cannot be determined. Lee (1923, p. 5) describes a section of 1,220 meters in the railroad cuts between Thung Song and Ron Phibun. The upper part contains many beds of fine sandstone mostly less than 3 centimeters thick interbedded in shale and gritty shale. Most exposures elsewhere are of dark well-bedded schists, slate, quartzite, and argillite.

An interesting rock composed of black slate or shale containing scattered pebbles is exposed on the east side of Phuket Island, on the west coast of Peninsular Thailand north of Phuket, northeast of Phangnga, and northwest of Chumphon. The pebbles are of quartz, quartzite, siliceous slate, and medium-grained biotite granite.

The only fossil locality now known is at the northeast promontory of Tongkhah Harbor on Phuket Island where "fucoidal" impressions were found in a dark gray shale or slate. These impressions were examined by Helen Duncan of the United States Geological Survey who reports as follows:

> The assignment of this problem fossil to *Eophyton* is probably as adequate an identification as can be made. Mansuy (1912, p. 19) referred markings of the same general type to *Planolites*?. Similar impressions are common in lower Paleozoic, especially Cambrian, rocks in many parts of the world. *Eophyton* has been interpreted as the trails of jelly fish tentacles or algae. In the absence of other fossils, a Cambrian age assignment cannot be contradicted. Mansuy's material came from the Cambrian of Yunnan (China).

The general relations indicate that the Phuket series may be the equivalent of the Mergui series, at least in part, of Burma. The Mergui series has been variously assigned ages from pre-Cambrian to Carboniferous (Chhibber, 1934, pp. 184–186).

THUNG SONG LIMESTONE (ORDOVICIAN?)

Dark to black limestone crops out along the northern flank of Khao Luang in Changwat Surat Thani, at Thung Song railway junction, at Ron Phibun, west of Phatthalung, in the vicinity of Satun, and north of Betong near the Malay border, all in the southern half of Peninsular Thailand. Farther north, bluish-gray crystalline dolomitic limestone found in outcrops on the island of Ko Si Chang in the Gulf of Thailand and in low hills just northwest of Kanchanaburi, is believed to be of the same age as the limestone of the Peninsula. Small disseminated crystals of pyrite are common in this limestone but in contrast very little or no pyrite is generally observed in the much younger limestone of Permian age. Among the Peninsular outcrops, thin stringers and blebs of a dark purplish-brown calcareous material occur at intervals in the black limestone along bedding planes.

Lee (1923, pp. 3–4) measured 2,740 meters of evenly bedded limestone at Thung Song. Clay and sand impurities mark the bedding planes, and thin discontinuous chert layers east of Thung Song contain markings resembling sponge spicules. West of Phatthalung Lee found the sandy dark limestone weathering to sand.

The Thung Song limestone lies above the Phuket series at a Buddhist monastery 1.5 kilometers northeast of Thung Song railway station. It underlies phyllite and quartzite believed to be of Silurian and Devonian age on the island of Ko Lanta Yai, southeast of Krabi. At Kanchanaburi it underlies quartzite or sandstone of Silurian age.

Bryozoans, crinoid stems, fragments of brachiopods, and cephalopods were found at Ron Phibun. A cephalopod specimen was identified as *Actinoceras* sp. by Josiah Bridge of the United States Geological Survey, suggesting an Ordovician or, at least, a lower Paleozoic age.

KANCHANABURI SERIES (SILURIAN, DEVONIAN?, AND EARLY CARBONIFEROUS?)

Clastic sediments, in many places metamorphosed to slate, phyllite, and quartzite, extend in Thailand from the Shan States border southward along the western side of Thailand to the Malay border. (See pl. 5.) Large areas in northern Thailand are underlain by these clastics which have been intensely folded and may include sediments of diverse Paleozoic age. Wherever limestone of Permian age is present the Kanchanaburi series disconformably underlies it, but relations with older beds are obscure. However, Lee found 2,900 meters of shale, sandstone, and sandy shale, here referred to the Kanchanaburi series, above the Thung Song limestone in Peninsular Thailand. These sediments underlie a thin-bedded limestone 60 meters thick which may be the lower part of the Permian sequence, although massive Permian limestone with fusulinids lies 2,350 meters higher in his section. A well-exposed section, at least 1,000 meters thick, of phyllite capped by quartzite was found on top of the Thung Song limestone in the island of Ko Lanta Yai, southeast of Krabi. This is believed to belong to the Kanchanaburi series. In northern Thailand the series appears to be as thick as in the south, but tight folding and faulting make accurate measurement impossible. The rocks of the Kanchanaburi series are generally deeply weathered, but along stream beds the slate or shale, phyllite or argillite, and quartzite or sandstone are uniformly dark gray-green.

Fossils from siliceous, fine-grained sedimentary rocks assigned to the Kanchanaburi series on the accompanying map (pl. 5) have been described by F. R. Cowper Reed (1920, pp. 113–120, 172–178) and assigned to the Early Carboniferous age. The fossil locality was described as a small quarry at Kuan Lin Soh or Kuan Sim Loh in Changwat Phatthalung, Peninsula Thailand. A place 16 kilometers west of the railroad station at Phatthalung has the name of Khuan Dinso (Slate Hill) and might be the same vicinity from which came the fossils described by Reed although a recent search for fossils there was in vain. Fossils from reddish-gray shale of the Kanchanaburi series have also been found recently near Na Suan, King Amphur Si Sawat in Changwat Kanchanaburi. Miss Duncan has noted that the "pteropods" that occur at this locality are similar to forms identified by Patte and Reed as *Tentaculites elegans* Barrande and by Mansuy, Patte, and Reed as *Styliolina clavula* (Barrande). Miss Duncan made the following comments regarding the probable age of these fossils:

> The tentaculite shales have been reported from a number of localities in southeast Asia. The reliability of the identifications of these "pteropods" with Barrande's species is perhaps to be questioned; but we have, and probably it is also true of the other reported occurrences, rather poorly preserved and inadequate materials to study. Owing to the fact that Barrande's species occurred in the Eifelien and Givetien of Europe, Mansuy and Patte referred the tentaculite shale of Indo-China to the Devonian. The *Tentaculites* beds of the Shan States are placed in the Zebingyi series. The lithologic character of the Siamese specimen appears to be identical with the "pinkish sandy shales" that carry the tentaculite fauna in the Shan States (Reed, 1915, pp. 95, 98; 1936, pp. 117–118) where Silurian graptolites have been found in association with *Tentaculites elegans* and *Styliolina clavula*. It therefor seems highly probable that the so-called *Tentaculites* shales are of Silurian age.

The meager paleontologic evidence now available indicates that the Kanchanaburi series contains rocks that range in age from probable Silurian to Early Carboniferous (?). Devonian beds may be included, but as yet no collections of Devonian fossils have been obtained from the Kanchanaburi series.

RAT BURI LIMESTONE (CARBONIFEROUS? AND PERMIAN)

A light gray crystalline limestone capping many hills and forming high cliffs is widely distributed through Thailand. Many of the limestone massifs are isolated buttes or hills resting on older rocks, but limestone terrain extends over large areas in west central Thailand along the west side of the Korat Plateau. In Peninsular Thailand and, to a lesser extent, in northern Thailand, the limestone regions are long, narrow, isolated belts following the lineation of the mountain chains. The limestone has seemingly been folded and somewhat recrystallized, but generally to a lesser extent than the underlying metamorphic and sedimentary rocks. Lee (1923, p. 3) measured a thickness of 915 meters in Peninsular Thailand; Credner (1935, p. 19) reported a maximum thickness of about 2,500 meters; and Högbom (1914, p. 106) estimated the thickness at Chiang Dao in northern Thailand at 2,000 meters. Heim and Hirschi (1939, p. 11) gave a thickness of 3,000 to 4,000 meters in the range east of Mae Sot, probably an excessive estimate based on the assumption that the limestone stands vertically. In the Khwae Yai watershed of western Thailand a minimum thickness is 752 meters.

The lower part of the limestone contains many thin layers and blebs of chert carrying fossils of Permian age. At the type locality, Rat Buri, such beds are found lying unconformably on top of the Kanchanaburi series, and in turn, the erosional surface of the limestone is capped by Triassic sandstone of the Korat Plateau type.

Recrystallization of the limestone is widespread, at places forming marble. Most of the limestone, which might be best described as marmarized, ranges in color from light gray to nearly white, with many pinkish stringers. Locally, and perhaps in extensive beds, it is dolomitic. However, the Permian sequence is not everywhere limestone or marble. In Peninsular Thailand fusulinids in a calcareous quartzite have been described by Newton (1926, pp. 49–64), and Lee (1923, p. 3–4), found a sandstone and shale sequence 2,350 meters thick between two light colored limestone beds which he believed to be of Permian age. The outcrops of Permian strata along the west side of the Korat Plateau, east of Sara Buri, contain many shale beds, according to Högbom.

Information now available on the fauna of the Rat Buri limestone and its probable age has been summarized by Miss Duncan:

> Studies of fossils collected from the Rat Buri limestone at a number of localities indicate that at least part of the formation is of Permian age. Most of the collections that have been examined contain genera of fusulinids or corals that in south China are considered to be diagnostic of the Yangsinian series, which is classified as Lower Permian and correlated with the Artinskian and Kungurian divisions of the standard Permian section. Assemblages of characteristic Permian brachiopods were obtained at two localities in Peninsular Thailand. A few collections from the extreme northern part of the country indicate that rocks of Late Carboniferous and Permian age (Uralian, as the term is commonly used in southeast Asia) are included in the Rat Buri limestone as now mapped. It is also possible that the formation contains equivalents of the Upper Permian Lopingian series of south China, but the faunal evidence is meager and the differences noted in a few assemblages might be due to varying sedimentary facies.
>
> At present it is not feasible to define the precise age limits of the Rat Buri limestone. Most of the collections submitted contain only a small variety of fossils—some, in fact, contain only one specimen. Because detailed stratigraphic data are not available, we have no information on the relative position of collections with reference to each other or to the formation as a whole.

Comprehensive studies of the formation at its various exposures and systematic collections of fossil faunas through a number of sections are needed before any attempt is made to distinguish faunal zones or to correlate the whole or parts of the Rat Buri limestone with the late Paleozoic rocks of neighboring regions.

To document the paleontologic evidence for the preceding remarks about the age of the Rat Buri limestone, faunal assemblages that have been identified from localities in three widely separated areas are cited in the following lists. Foraminifera were identified by L. G. Henbest of the United States Geological Survey; brachiopods, by G. A. Cooper of the United States National Museum; sponges, corals, and bryozoans, by Helen Duncan of the United States Geological Survey.

Southern Thailand

One collection from Changwat Krabi contains:

Sinophyllum multiseptatum Grabau.
Sinophyllum n. sp.
Ascopora? sp.
"*Streblotrypa*" n. sp.
Dictyoclostus gratiosus (Waagen).
Composita sp.
Chenetes aff. *C. molengraaffi* Broili.
Rhipidomella cora (D'Orbigny).
Productus opuntia Waagen.

A collection from another locality in Changwat Krabi contains:

Sinophyllum pendulum simplex Huang.
Allotropiophyllum? grabaui Chi.
"*Rhynchonella*" *wynnei* Waagen.
Leptodus tenuis (Waagen).
Dictyoclostus gratiosus (Waagen).
D. spiralis (Waagen).
Echinoconchus fasciatus (Kutorga).
Derbyia sp.
Hustedia sp.

A collection from a locality in Changwat Trang:

Dunbarinella sp.
Schwagerina or *Dunbarinella* sp.
Amplexocarina sp. cf. *A. abichi* (Waagen and Wentzel).
Fistulipora cf. *F. sinensis* Yoh.
Composita aff. *C. subquadrata* (Hall).

Central Thailand
(From an area between Lop Buri and Nakhon Sawan)

One collection from Amphur Koksamrong in Changwat Lop Buri contains a diversified fauna:

Ozawainella sp.
Parafusulina sp.
Schwagerina or *Parafusulina* sp.
Steinmannia sp.
"Lophophyllid" coral aff. "*Lophophyllum*" *amygdalophylloidea* Huang.
Wentzuella aff. *W. elegans* Huang.
Polythecalis cf. *P. multicystosis* Huang.
P. cf. *P. yangtzeensis polygonalis* Huang.
Yatsengia? n. sp.
Streptorhynchid brachiopod.
Composita sp.

Dielasma sp.
"*Spirifer*" aff. "*S.*" *increbescens* Hall.
Bellerophon sp.

A fauna composed mainly of fusulinids was obtained at Amphur Ta Kli in Changwat Nakhon Sawan:

Endothyra? sp.
Climacammina sp.
Parafusulina cf. *P. gigantia* (Deprat).
Parafusulina or *Schwagerina* sp.
Ozawainella sp.
Polydiexodina? sp.
Stylidophyllum cf. *S. gnomeiense* Huang.

A collection from another locality in this area consists of the following Foraminifera:

Climacammina sp.
Schwagerina or *Parafusulina* sp.
Parafusulina (possibly *Schwagerina*) sp.
Neoschwagerina or possibly *Colania* sp.
Verbeekina? sp.

Another collection from Amphur Ta Kli contains indeterminate fusulinids and the following coral:

Yatsengia cf. *Y. counilloni* (Mansuy)

Northern Thailand

A small lot of fusulinids obtained from a limestone near Ban Ai was described by Ryûzô Toriyama (pp. 243–248) in 1944:

Pseudoschwagerina turbida F. and G. Kahler.
P. taiensis Toriyama.
Pseudoschwagerina? sp.
Fusulinella cf. *F. chaoi* Lee.

Mr. Henbest also identified *Pseudoschwagerina* sp. in a sample from northern Thailand.

KORAT SERIES, INCLUDING THE KAMAWKALA LIMESTONE (TRIASSIC AND JURASSIC)

A thick deposit of continental sandstone and conglomerate covers most of eastern Thailand and forms the bedrock of the Korat Plateau. Similar beds occupy parts of intermontane valleys in northwestern Thailand and extend south along the west coast of the Gulf of Thailand. In the extreme southern part of Peninsular Thailand, quartzite, phyllite, and crumpled black shale form the northern extensions of beds recently mapped in Malaya by the Geological Survey Department of Federated Malaya (Ingham and others, 1948) as Triassic. Such an age assignment seems probable in part for the Korat series, which lies above and in contact with the Permian Rat Buri limestone at Mae Ping Gorge south of Muang Hot (Högbom, 1914, p. 99) in northern Thailand and east of Laem Kruat and on the island of Hang Naga in Peninsular Thailand. The top of the beds is marked by a widespread erosional surface on which Tertiary deposits (in the intermontane valleys) and Quaternary alluvial deposits lie. Lee (1927, p. 411) gives a thickness of 1,200 meters in the Korat Plateau and 366 meters for beds above the Rat Buri limestone in Peninsular Thailand. About 500 meters of the lower beds are exposed on the east flank of the Mae Fang basin (pl. 20) and more than 2,000 meters, including the Kamawkala limestone of the Korat series, have been measured at Mae Sot.

The Korat series, as shown in plate 5, includes beds of gray-green sandy shale, and marly, thin limestone beds, nodular and concretionary (except the massive Kamawkala limestone at Mae Sot), as well as red and violet sandstone, conglomerate, and shale, which form the bulk of the sedimentary rocks. The conglomerate locally contains limestone pebbles and cobbles derived from the Rat Buri limestone. Wells or springs of salty water in the Korat region suggest that salt deposits may be found at depth in the series. Högbom (1914) also found some tuffaceous beds east of Uttaradit, and gypsum lenses crop out in Amphur Nam Pat. Lignite fragments and carbonaceous shale are also found in the Korat region. Pebbles in the conglomeratic facies of the Korat series are composed of quartz, obsidian, and locally of feldspar fragments. The calcareous and argillaceous facies occur mostly in the lower part of the series. All of the known manganese deposits in Thailand are associated with the Korat series.

Fossils, other then petrified wood, found throughout the Korat Plateau are scarce and only two fossiliferous localities are known: A sandy layer at kilometer 60 on the Lampang-Chiang Rai highway in northern Thailand contains pelecypods identified as *Daonella* by Heim and Hirschi (1939, p. 6) or as *Halobia* by Ralph Imlay (personal communication) of the United States Geological Survey. A collection submitted to the United States Geological Survey in 1923 by Wallace Lee from the roadside 8 kilometers south of Chiang Rai near the northern border of Thailand was described by T. W. Stanton as follows:

Pelecypods:
- *Hoernesia*? sp. probably 2 or 3 species.
- *Macrodoni*? sp.
- *Myophoria radiata* v. Loczy.
- *Myophoria* sp. related to *M. laevigata* v. Albrecht.
- *Myophoria* sp. of same group as last but more elongate.
- *Trigonodus*? *sp.*

Gastropods:
- Two or three undetermined genera.

The fossils are not very well preserved, but enough of them are identifiable to make it certain that they are of Triassic age and probably Middle Triassic. The fauna is similar to that described from the Triassic of Tonkin.

The Kamawkala limestone, first described by Cotter (1923, pp. 275–286) in the Mae Sot basin, is shown as a formation in the Korat series in plate 5.

In the vicinity of Mae Sot the Kamawkala limestone or what is believed to be the Kamawkala limestone is composed of dense grey impure limestone, quartzitic red sandstone, and conglomerate, and contains fossils of early Middle Jurassic age, according to Imlay. A comprehensive study by several European geologists of corals, brachiopods, lamellibranchs, ammonites, sponges, calcareous algae, crinoid stems, echinoid spines, and a large gastropod led J. W. Gregory of the Geological Survey of India to assign an age of Late Triassic, "not more than the Carnian and the Norian," to the Kamawkala limestone (Gregory, 1930, pp. 155–167; Weir, 1930, pp. 168–173; Trauth, 1930, pp. 174–176; Pia, 1930, 177–181).

Limestone beds nearby, possibly belonging to the Korat series, contain fossils of Late Jurassic or Early Cretaceous age, according to W. Leupold (*in* Heim and Hirschi, 1939, p. 12). Imlay identified *Erycites* sp., *Tmetoceras* sp., and *Ludwigia* sp. from these beds at Ban Yang Puteh and those 5 kilometers east of Ban Mae Kon Den, about 23 kilometers southeast of the southernmost localities described by Cotter. Limestone beds interfringe brown and red quartzitic sandstones and conglomerates and apparently are conformable with the underlying and overlying continental beds. Heim and Hirschi (1939, p. 12) report a thickness of more than 1,000 meters for the limestone which is folded. It appears to be a marine tongue intercalated in the Korat series.

Widespread evidence suggests that the Korat series includes beds of Triassic and Jurassic age but also may include beds of Permain, as well as Cretaceous, age or younger. Quartzitic rocks mapped as part of the Kanchanaburi series in northern Thailand may prove to belong to the Korat series where the clastics have been metamorphosed by granitic intrusions. Apparently the lower part of the series has been folded—folded less intensely in western Thailand than the Kanchanaburi series, but as intensely as the Kanchanaburi in the region east of Uttaradit. The younger sandstones and conglomerates on the Korat Plateau are flat-lying or gently folded.

MAE SOT SERIES (TERTIARY)

Lacustrine or fluviatile sediments are known in six intermontane basins of northern Thailand and probably underlie a seventh. At Mae Moh and Mae Chang near Lampang, clay shale, sand, and marl beds of the Mae Sot series are reported to contain lignite-bearing sediments in a zone as much as 6 meters thick. Similar sediments are found north of Chiang Mai in the valley of Mae Rim and in the basin of Amphur Pai as well as in the Lampang basin. Exposures are meager, mostly along the banks of incised streams or in the low foothills of the surrounding mountains. In the Mae Fang basin in the extreme northern part of Thailand the tilted carbonaceous sediments are not exposed but they have been reported in drilling records. The best exposures are those of the Mae Sot basin which have been studied for possible commercial extraction of petroleum, and for which the series are named.

Where the relations can be observed the Mae Sot series rests disconformably on the Korat series and older rocks and disconformably underlies Quaternary alluvial and terrace deposits. Estimates of thickness are likely to be uncertain because the beds were deposited in active structural troughs or basins. About 200 meters of beds somewhat similar to the Mae Sot series were encountered in drilling operations in the Mae Fang basin and more than 430 meters of stratigraphic section have been measured at Mae Sot; both thicknesses should be considered as minimum.

The basal Tertiary beds at Mae Sot are composed of fossiliferous fresh-water limestone interbedded with sandstone and conglomerate. The upper portion is limestone, sandstone, oil shale, and at the top, limestone or calcareous sandstone (see p. 162). Bands and lenses of gypsum as much as 30 centimeters thick are found scattered throughout the sediments. In other northern basins the beds are semiconsolidated silt, clay, sand, marl, and gypsum. The series has been gentaly folded, but dips of as much as 40° occur in the Mae Sot basin and as much as 30° in the Lampang basin.

Fresh-water mollusks from the limestone of Mae Sot have been identified by Teng-Chien Yen of the United States National Museum as *Viviparus* sp., *Taia* cf. *T. naticoides* (Theobald), *Margarya* cf. *M. francheti* Mabille, *Oncomelania* cf. *O. fragilis* Annandale, *Hydrobia* sp., and *Stenothyra* sp. According to Yen, these indicate a Pliocene or Pleistocene age.

Fossils from the oil shale of the Mae Sot series include fish of the ostariophysian family Cyprinidae, according to D. H. Dunkle of the United States National Museum who comments on them as follows:

> The fossil remains of cyprinids are of common occurrence in the fresh-water sediments ranging in age from the Paleocene to the Present and are of cosmopolitan distribution. In southeastern Asia specifically, they have been reported from the Siwalik hills, India; from Laos, Indochina; and from various localities in the Dutch East Indies. All have in common, however, a late Tertiary assignment. It may, in consequence, prove permissible to assume a similar Tertiary age for the present specimens from Thailand.

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Insects, underminable dicotyledons, and a legume similar to *Mimosites* are found in limestone beds above the oil shales at Mae Sot. Vertebrate fragments and teeth, leaves, small plates resembling turtle plates, and fresh-water gastropods are reported from borings in the Mae Fang basin (Lee, 1923, p. 11).

Most of the fossil evidence suggests a late Tertiary age for the Mae Sot series, probably Pliocene, although some of the beds may prove to be Pleistocene.

KRABI SERIES (TERTIARY)

Beds comparable in age to the Mae Sot series but containing some marine fossils have been found in eight basins in Peninsular Thailand. The basins are at Kiansa, southwest of Surat Thani; at Hin Rao, east of Phangnga; at Hang Nak west of Krabi; at Krabi; at Sinpun, northeast of Krabi; at Kantang, southwest and west of Trang; at Bukit Arang, south of the railway junction at the Malay (Perlis)–Thai border; and at Betong on the Malay-Thai border. (See pl. 5.) The sediments, all of which include lignite beds, are best known near Krabi where they are being exploited for coal.

The Krabi series lies unconformably on the Korat series at Kiansa, Krabi, Sinpun, Kantang, Bukit Arang, and Betong. At Hin Rao and elsewhere the Krabi series lies on the Permian Rat Buri limestone or older rocks. Recent alluvium covers most of the series, restricting outcrops to stream beds and beaches. Thus, thicknesses cannot be measured except with the drill. However, Scrivenor (1931, p. 114–118) gives the greatest thickness of similar coal-bearing beds as more than 88 meters. At Krabi a minimum thickness of 175 meters is based on the assumption of uniform dip and no repetition by faulting or folding beneath the alluvial cover.

The lowermost beds exposed at Krabi comprise sandy shale, coal, and marl about 125 meters thick and underlie 30 to 50 meters of marl, bituminous shale, gypsum, and marine limestone. In other basins the sediments are composed of clay, sand, and gravel, locally coal bearing and locally containing thin beds of marl or limestone of marine origin. Because the Krabi series has accumulated in active structural troughs or grabens the beds are tilted and folded—as much as 35° in places now being explored for coal. Lee (1923, p. 8) reports dips as great as 80° at Hin Rao where the coal is found in down-faulted troughs resting on the Rat Buri limestone.

Marine gastropods of late Tertiary or possibly Pleistocene age are found in marl and limestone a few meters above the coal at Krabi. Similar fossils have been found at Surat Thani on the east coast.

TERRACE DEPOSITS AND ALLUVIUM (QUATERNARY)

Terrace deposits and alluvium are present in almost every stream valley of Thailand although in many places they are only a surficial veneer. The bulk of alluvial deposits underlies the great central valley of Thailand drained by the Mae Nam Chao Phraya. Isolated areas of alluvium many meters thick are also scattered over the Korat Plateau; in the larger stream valleys of northwestern Thailand; and at various places along the coastal plain around the Gulf of Thailand, especially along the east coast of Peninsular Thailand. (See pl. 5.) The alluvial deposits are of special interest in Peninsular and western Thailand because of the occurrence of tin and tungsten placers in them. Unlike the widespread residual deposits, including lateritic iron ores, many of these are of insufficient areal extent to show on plate 5.

Most of the terrace and alluvial deposits are less than 50 meters thick. Low dissected terraces along the west coast of Peninsular Thailand lie 3 to 12 meters above sea level and the associated clastics, which contain important tin deposits, reach a maximum reported thickness of about 16 meters. Along the east coast of Peninsular Thailand the alluvium is as much as 30 meters thick and in the great central valley of the Chao Phraya a depth of more than 300 meters has been drilled near Bangkok without reaching consolidated rocks. Quaternary deposits on the Korat Plateau have been drilled for water to depths of as much as 150 meters. Structural basins in northwestern Thailand may contain as much or more debris of Pleistocene and Recent age.

The Quaternary deposits are almost all of stream or beach origin. The seaward portion of the Mae Nam Chao Phraya Valley doubtless includes beds of deltaic character although little is known about their lithology. Wherever the Quaternary deposits are exposed they comprise sand, gravel, silt, and clay. The deposits support mostly soils of fine sandy loam, particularly on the Korat Plateau where the alluvium was originally derived from sandstone. In the lower Mae Nam Chao Phraya Valley dark heavy clay overlies marine or estuarine marly beds, sands, and gravel. The clayey terrain is flanked by sandy loams on each side of the valley as far north as Uttaradit. Locally the subsoil is a pistolitic laterite. Clay and silt, much of which stands in vertical banks resembling loess, are exposed along the banks of the Mae Nam Yom and the Mae Nam Nan north of Nakhon Sawan, along the Mae Nam Pa Sak, along the Mae Nam Mae Klong and its tributaries, the Mae Nam Khwae Noi and Mae Nam Khwae Yai. These soils are calcareous in the lower portions, in some places forming marl, in others containing small calcareous concretions similar to those found in loess.

Characteristically associated with many planated surfaces, marine and fluvial terraces, and elevated mesas or plateaus are residual capping layers of laterite which are generally mottled red and brown, are vesicular or pisolitic, and are composed principally of hydrated oxides of aluminum and iron. Laterite may be formed from rocks diverse in geologic age and in physical or chemical character. Conditions favorable for laterite development have been considered (Chhibber, 1934, pp. 280–281) to include: a tropical or subtropical climate subject to alternating wet and dry seasons; an elevated or gently sloping land surface not subject to appreciable erosion; a host rock that contains either or both and alumina iron oxide in appreciable quantities; a host rock possessing or developing a porous texture under weathering so as to allow rain water to move through it; infiltrating water that remains in the rock pores for an appreciable period but eventually drains out of them; infiltrating water containing acid or alkaline reagents which act on the rock and permit electro-kinetic reaction to take place; the continuation of these processes over a long period of geologic time. Furthermore, active laterization takes place within the zone of fluctuation of the water table so that when this is lowered by uplift or stream incision the process ceases. Thus in most places laterite layers are limited to thicknesses no greater than 3 to 5 meters.

During the course of laterization, silica is gradually leached out, but alumina and iron oxides are concentrated in the surficial layer. Depending on the chemical nature and activity of soil reagents and the original rock constituents, laterites tend on maturity to develop either an aluminous or a ferruginous character. High alumina laterites are apparently not common in the Kingdom, but in several places ferruginous laterites form small iron deposits. The stage of development of existing laterites in Thailand is apparently related directly to the physiographic age and position of the surface on which they form. Young laterites characterize young low level terraces or planated surfaces. At Uttaradit, for example, cuts in young laterite show parallel horizontal bands of pisolitic ferruginous nodules separated by thin layers of yellow and gray clay with pronounced vertical partings. In the same vicinity at Wat Ka Sem a more mature laterite caps a monadnock hill 10 to 15 meters above the surrounding plain. The capping layer has a well-developed vesicular structure, with septa of limonite and cavities partly filled with loose nodules of clay. Fossil or mature high-level laterites are found as capping layers on uplifted dissected terraces or other surfaces which have been preserved from erosion. Typical of these is the Boh Dam lateritic iron deposit (see p. 74) which caps a planated terrace remnant cut on folded shale and sandstone and lies about 50 meters above a younger erosion surface veneered by immature laterite. The Boh Dam laterite has a spongy or vesicular structure with septa of limonite and hematite and relatively little clay in the cavities.

The only age determination of Quaternary deposits in Thailand known to the writers is based on fossil mammals found in gravel excavated for bridge abutments at Nakhon Sawan on the banks of the Mae Nam Chao Phraya in the central plain. A hippopotamus skull and leg bones, a buffalo skull, and an elephant tooth were identified by the British Museum of Natural History as of the Pleistocene epoch. Although the terraces often show warping they are believed to be of late Pleistocene or Recent origin.

IGNEOUS ROCKS

GNEISS AND SCHIST (PRE-PERMIAN?)

Gneissic and schistose rocks occur in several areas of Thailand. Along the western side of the Kingdom such rocks crop out in an elongate band to the west of Chiang Mai, west of Tak, in a small are northwest of Kanchanaburi, in the Hua Hin area to the south of Phet Buri, and to the west of Surat Thani. (See pl. 5.) These areas are alined in a general north-northwest direction coinciding with the gneissic trend. There are also large outcrop areas in Changwats Chon Buri and Rayong and in the northwest corner of the Korat Plateau to the northeast of Loei.

MAFIC AND ULTRAMAFIC ROCKS (TRIASSIC?)

The mafic and ultramafic rock group consists of diorite, gabbro, and pyroxenite. Locally some of these rocks are serpentinized. Occurrences of the group are apparently limited to Changwats Uttaradit and Chiang Rai in northern Thailand. Along the lowland of Mae Nam Nan to the northeast of Uttaradit the rocks appear as diorite, gabbro, and pyroxenite dikes, small plugs and stocks intrusive into metasediments probably belonging to the Kanchanaburi series. Locally in the serpentine zones such as at Mon Kai Chae and Bo Sam Kha small asbestos deposits occur. In hills on the south margin of the Mae Chan flood plain near old Chiang Saen and along the upper reaches of the Mae Chan and the Mae Gok in Changwat Chiang Rai are outcrop areas of coarse textured gabbro associated with dioritic and granitic intrusives.

The age relations of these rocks are uncertain, but on the basis of available evidence they are tentatively assigned to the Triassic.

GRANITE (TRIASSIC? AND LATE CRETACEOUS?)

Granite is by far the most extensive igneous rock which crops out in Thailand. It occurs in stocks and batholiths intruding Paleozoic and Mesozoic sedimentary rocks and has been exposed at the surface by their erosion. It is believed that granite forms the core of most of the western mountain ranges, and where cupolas are developed concentrations of minerals of economic importance may be present.

In most places the rocks are biotite-muscovite gneiss with augen of feldspar. Associated with the gneiss is mica schist which is mostly biotic along the western side of the Kingdom and muscovitic in the east. To the west of Tak, Heim and Hirschi (1939, pp. 4–6) describe bands of augen paragneiss or gneissic granite interbedded with mica schist and phyllite, cut by small dikes and veins of pegmatite, tourmaline, and aplite, and striking to the northwest. Similar relations are observed in the outcrop area to the west of Chiang Mai. The paragneiss apparently originated through bed-by-bed injections of granitic melt into shale and sandstone probably belonging to the Kanchanaburi series. Orthogneiss occurs in other areas. Near Bang Saen in Changwat Chon Buri are extensive outcrops of banded micaceous granite gneiss with conspicuous augen or porphyroblasts of feldspar. Injected along the foliation are lenses and interrupted stringers of pegmatite containing pockets of muscovite and occasional small crystals of beryl. Thin but conspicuous veins of black tourmaline that transect the gneiss at angles oblique to the foliation are common, and in places the rock is cut by massive quartz dikes.

In a number of places the gneissic and schistose rocks are injected into sediments apparently belonging to the Kanchanaburi series, and near Kanchanaburi gneiss is unconformably overlain by Rat Buri limestone. The rocks are therefore tentatively classified as pre-Permian.

In the north and west there are several granite ranges trending in a general north-south direction. The great range west of Chiag Mai shows exposures of granite in several places extending from Pai far south to Amphur Mae Sot. Another granite range begins about latitude 15° N. and continues south through Changwats Kanchanaburi and Prachuap. A broad and continuous belt of granite starts at the Shan States frontier to the northeast of Muang Fang and follows a sinuous course south at least to the Khun Tan tunnel in the latitude of Lampang. However, it is very likely that this belt continues much farther south through Tak to the northern edge of Changwat Kanchanaburi.

In Peninsular Thailand there are six main granite ranges which lie in echelon. The most important of these extends, with minor breaks, from Ranong south to the island of Phuket. It is associated with the richest and most productive tin fields of the Kingdom. Second in importance is the range which begins on the islands of Phangan and Samui and continues on the mainland from Sichon to Satun in a southerly direction. Another belt of granite crops out east of Hat Yai and south of Songkhla and is believed to extend south into Malayan Kedah at Bukit Kachi. South of the railroad near Na Pradu, granite is exposed for about 15 kilometers and can be traced south by way of exposures in tin mines to Betong and into Malayan Perak. Another granite range begins in the Sai Buri district and extends south into Kelantan. The last of the six is the granite range of Toh Moh along the Talubain River. This range is actually an extension of the main range in Kelantan with which gold deposits are associated.

In southeastern Thailand, granite is exposed in several areas of which those in the Chon Buri and Chanthaburi regions are the most extensive. The granite in the Chon Buri region lies in the mountain range which is near the eastern coastline of the Gulf of Thailand and extends from Chon Buri in the north to Rayong in the south. East of this range is the granite of the Chanthaburi region which is exposed in Khao Glad and Khao Sa Bap near Chanthaburi and can be followed discontinuously to the north in Khao Soi Dao through Ban Nam Khun and probably as far as Changwat Prachin. Another granite area lies to the northwest of this, and yields some gold.

There is considerable evidence to indicate that the granitic intrusive rocks of Thailand are of two distinct geologic ages and slightly different from one another mineralogically. The older intrusions are commonly hornblende-biotite granite, with hornblende usually more abundant than biotite. To the northeast of Maung Fang in the canyon of the Mae Gok, Hirschi and Heim (1938, p. 484) described an older intrusion as coarse-textured porphyritic biotite granite with orthoclase phenocrysts as much as 4¼ centimeters long. The biotite is brown and shows well-defined pleochroic haloes. The border facies of the intrusive rock are fine-textured aplitic granite, with hornblende and tourmaline. Associated with the older granite intrusions are mineralized zones containing gold, copper, molybdenum, iron, antimony, lead, and zinc ores. Gold lodes are characteristic, and in places important deposits of antimony, lead, and zinc are genetically related to the granite. Apparently the mineralization of tin has been rare or absent.

The younger intrusions are generally binary granite, with muscovite usually as abundant or more abundant than biotite. Hornblende is generally present; zircon, apatite, and tourmaline are common accessory minerals. Almost all of the tin and tungsten deposits of Thailand are associated with the younger granite intrusions.

On the basis of available geologic evidence, nearly all of the granite bodies of central, eastern, and northern Thailand are considered to be older intrusions, commonly of hornblende-biotite granite. A notable exception is the younger granite stock with which are associated the important tungsten and tin deposits of Amphur Mae Sariang in Changwat Mae Hong Son. In Peninsular Thailand only two granite bodies considered to be older intrusions have been recognized—one to the north of Krabi and the other to the south of Narathiwat. Neither of these granites is apparently tin-bearing. Elsewhere in Peninsular and south central Thailand the granite intrusions are apparently younger.

The older granite has been assigned a tentative Triassic age because it intrudes Paleozoic rocks and is unconformably overlain by sandstone and shale of the Korat series in at least three widely spaced localities in Thailand. The younger tin-and-tungsten bearing granite has intruded and metamorphosed the Korat sedimentary rocks in the Peninsular region. Moreover, in Burma (Chhibber, 1934, p. 294) and Malaya (Scrivenor, 1931, pp. 19–23) there is considerable evidence that correlative granitic intrusions are of Late Cretaceous or Early Tertiary age. The younger granite in Thailand has therefore been assigned to the Late Cretaceous period.

DIORITE AND QUARTZ DIORITE (TERTIARY?)

Diorite and quartz diorite in bosses, stocks, and small batholiths intrude the Korat series and older rocks to the east of Prachin Buri, north of Lop Buri, northwest of Petchabun, and northeast of Chiang Rai. With the dioritic intrusive rocks to the northeast of Lop Buri and east of Prachin Buri are associated the gold lodes and placers of Tha Tako and Krabin (Buravas and Buravas, 1941, pp. 1–10). The contact-metamorphic iron deposit of Khao Thap Khwai, about 20 kilometers north of Lop Buri, is also related to a diorite stock. Elsewhere gold placers or lodes are characteristically associated with the dioritic intrusions. Because of their relations with the Korat series and other rocks the dioritic intrusive rocks are assigned to the Tertiary.

BASALT (TERTIARY?)

In Thailand basalt occurs in many widely scattered areas as local lava flows, dikes, and plugs. Perhaps the largest basalt flow in the Kingdom extends for about 20 kilometers along the Thai State Railway to the east of Lampang. The flow has been little touched by erosion and appears to be relatively young. At kilometer 610.3, about 500 meters west of Mae Mo station, is a railroad cut about 10 meters deep in the eastern margin of the flow. The upper 3 meters of the cut discloses platy vesicular basalt. Lying beneath this is a bed of basaltic glass shards, pellets, and granules and basalt ellipsoids. These ellipsoids are as much as 1 meter in diameter and are arranged in "foreset" bands which dip to the east. Individual ellipsoids generally show a core of dense fine-grained basalt having plagioclase laths as long as 2 millimeters and showing well-developed polygonal fractures. Surrounding the core is vesicular basalt and then a rind of ropy lava on the outside of the ellipsoid. A short distance farther west this same basalt bed passes into a massive flow of columnar basalt. Thus the relations suggest that the basalt flowed eastward into a small shallow body of water and consequently developed the ellipsoidal and foreset structures.

Elsewhere in Thailand basalt crops out southwest of Sukhothai, northwest of Lop Buri, to the south of Sisaket, and in an extensive sheet south of Burirum. The sapphire and ruby placers of the Chanthaburi region are associated with several scattered plugs and local flows of nepheline-olivine basalt, as are the sapphire placers to the north of Kanchanaburi.

The basalt flows and plugs of Thailand are definitely post-Korat in age and are probably related to Tertiary volcanic activity which occurred in Indochina and other neighboring countries. The comparative ages of the basalt and the dioritic intrusions are not known.

ANDESITE AND RHYOLITE PORPHYRIES (TERTIARY?)

Andesite porphyry in stocks, dikes, or flows cut by younger rhyolite porphyry in dikes and small flows, crops out near Sara Buri, northeast of Lop Buri, west of Petchabun, and east of Uttaradit. The andesite is generally green or purple and the rhyolite is buff or yellow. The andesite porphyry has intruded the Korat series and older rocks, and to the west of Petchabun and north of Lop Buri it apparently transects or overlies basalt and diorite. The andesite porphyry and rhyolite porphyry thus appear to be younger than the basaltic and dioritic rocks and also to be of Tertiary age or younger.

GEOLOGIC STRUCTURE AND HISTORY

Thailand may be divided into three structural provinces—the Korat Plateau, the Chao Phraya depression, and the northern and western folded ranges which extend south through the Malayan Peninsula. The Kingdom is flanked on the east by the Indochina massif and on the west by the Himalayan belt of compression which extends south through Burma and Malaya into Indonesia. Thus the structural elements in Thailand have originated within the Asiatic continental framework by adjustments to the massif on the east and the compressive forces on the west.

Current knowledge of the geology of Thailand permits only a very incomplete description of the history. The sedimentary record begins in early Paleozoic time if the assumption of a Cambrian age for the Phuket series is valid. This series includes black slate containing stretched granite pebbles and boulders derived from an earlier, possibly pre-Cambrian, granite (Credner, 1935, p. 15), as well as pebbles of quartz, quartzite, and siliceous slate. The country was the site of marine deposition throughout much of Paleozoic time. Most of the older Paleozoic sedimentary rocks are clastics, now forming a thick series of shale and sandstone or their metamorphic equivalents, paraschist, slate, quartzite, and argillite. The only important exception is the Thung Song limestone of Ordovician (?) age, although thin beds of limestone or marble occur elsewhere in the older rocks. Paleozoic sedimentation culminated in the widespread deposition of the Rat Buri limestone of Carboniferous (?) and Permian age. Following deposition of the Rat Buri limestone most of the country was elevated and the rocks were regionally metamorphosed by diastrophic movements approximately concurrent with the Saalien orogeny of the Ural Mountains and the Appalachian orogeny of North America (Umbgrove, 1947, 331–332). The Paleozoic beds may have undergone earlier orogenies but the degree of metamorphism of the Permian rocks superficially appears to be as great as that of the oldest beds of the Phuket series. The Saalien (=Appalachian) orogeny seemingly involved most of Thailand although the older beds are buried in the eastern part of the Korat Plateau and in the Chao Phraya depression. Wherever exposed, the Palezoic beds are moderately to intensely compressed into north-trending folds. In many places the beds appear isoclinally folded. The massive Rat Buri limestone in many places lies at flatter angles than the underlying beds, suggesting either that the limestone was deposited nonconformably on the intensely folded older Paleozoic sedimentary rocks or that the limestone was thrust up over them. Evidence is strong for overthrusting at the southwest corner of the Mae Fang basin in northern Thailand where some of the underlying beds may be of Triassic age or younger. However, if the first interpretation is correct, then a widespread orogeny antedates the deposition of the Permian Rat Buri limestone.

The extensive intrusion of granitic magma dates from early Mesozoic, perhaps from the late phases of the Saalien orogeny, for slightly disturbed and unmetamorphosed sandstone of the Korat series overlies granite stocks and batholiths intruded into the Paleozoic sedimentary rocks. This older hornblende-biotite granite, which must have been deeply eroded in post-Rat Buri time and before or in the period when the Korat series was being deposited, now crops out in the hills of central and northern Thailand. Accompanying this extensive intrusion were local intrusions of the mafic and ultramafic rocks.

A younger biotite-muscovite granite crops out widely in Peninsular Thailand and along the Burmese frontier. According to evidence in Burma (Chhibber, 1934, p. 294) and Malaya (Scrivenor, 1931, pp. 19–23), this important tin and tungsten-bearing granite magma was emplaced in Late Cretaceous or early Tertiary time. Certainly the folding of the lower part of Korat series along the western edge of the Korat Plateau, and the beds of possible Early Cretaceous age at Mae Sot (Heim and Hirschi, 1939, p. 12) suggest an orogeny rather late in the Mesozoic. Throughout most of the Mesozoic the country was elevated slightly above the sea, and widespread deposition of continental sandstone, shale, and conglomerate of the Korat series took place. A marine invasion in Jurassic time was apparently limited to the zone along the Burma frontier near the Mae Sot basin.

At the beginning of Tertiary time most of the country was above sea level and well-integrated drainage was established. The faulting and folding movements which led to the development of the structural basins characteristic of northern Thailand and common in the Peninsular region probably began in middle or late Tertiary time. In the basins of the north fluviatile and lacustrine sediments accumulated, and in the Peninsula terrestrial sediments were deposited in association with marine materials, especially in the coastal regions. The structural movements probably continued apace with the accumulation so that the basin sediments were gently to moderately warped and in places faulted.

Local volcanic and intrusive activity occurred in many scattered localities of the Kingdom—probably in late Tertiary time. This activity resulted in the basalt plugs, dikes, and flows of Changwats Chanthaburi, Trat, Kanchanaburi, and Lampang, and in isolated diorite stocks cut by later andesite and rhyolite porphyry intrusions in the central part of the Kingdom. Toward the end of Tertiary time regional uplift, accompanied by faulting and folding, of most of the country occurred. The Chao Phraya structural depression may have been formed at this time and the Gulf of Thailand may have extended as far north as Uttaradit.

Throughout Quaternary time to the present the Chao Phraya depression has accumulated the sediments supplied to it by tributary streams. During this period these streams have been grading their courses by erosion in the upper reaches and by alluviation in the lower reaches. The accumulation of Quaternary alluvial deposits in the stream valleys of the peninsula has produced most of the rich tin placers of Thailand.

In general the eastern limits of the belts of orogeny have moved west, insofar as the geologic history can be brought to light. The Saalien (=Appalachian) orogeny apparently affected most of Thailand, a Mesozoic orogeny of uncertain age affected most of the western half, and the late Tertiary (Wallachian) orogeny of the central belt of Burma moderately affected the Tertiary beds only along the western frontier. However, high-angle faulting and some renewal of thrusting, together with local eruptions of basaltic lava, perhaps as a manifestation of the late Tertiary orogeny, occurred throughout the Kingdom, elevating the Korat Plateau and depressing Tertiary and Quaternary deposits in the intermontane basins of northern and Peninsular Thailand. In comparatively recent times Peninsular Thailand has been tilted slightly to the northwest, for its east coast on the Gulf of Thailand has a smooth emergent shoreline backed by a broad coastal plain, whereas its shoreline on the Andaman Sea to the west is marked by drowned valleys and prominent headlands or offshore islands such as those of Phuket Bay.

METALLIC MINERAL DEPOSITS

The table on page 51 summarizes available statistics about mineral production in Thailand since 1932, when records were first kept by the Royal Department of Mines.

ANTIMONY

GENERAL FEATURES

The most notable occurrences of antimony ore in Thailand are in Changwats Lampang, Surat Thani, and Phrae. In all known localities the principal ore mineral is stibnite which is commonly associated with the hydrous oxide, stibiconite. The stibnite is usually found in quartz veins which occur in granite or in limestones or quartzites associated with intrusive rocks.

Antimony ore occurs in Changwat Lampang near Mae Ta Luang about 8 kilometers northeast of Amphur Chae Hom, and also at Huai Kathing, Ban Kaeŋ, and Doi Laem in Amphur Sop Prap. Some ore is mined from the Mae Ta Luang locality but in Amphur Sop Prap the deposits are reported to be relatively small. At Huai Kathing stibnite with chalcedony occurs in dark gray quartzite in a sequence of limestones, sandstones, and shales. The deposit may be associated with a porphyry intrusion nearby.

Metallic mineral production in Thailand

[Data from Royal Department of Mines]

Year	Metallic tin in concentrate averaging 72 percent Sn (long tons)	Wolframite ore (long tons)	Antimony ore (long tons)	Lead ore (long tons)	Iron ore (long tons)	Gold (fine ounces)
1932	9, 296	--------	--------	--------	--------	--------
1933	10, 185	--------	--------	--------	--------	--------
1934	10, 638	--------	--------	--------	--------	--------
1935	9, 876	70	--------	--------	--------	--------
1936	12, 734	77	--------	--------	--------	10, 337
1937	15, 909	90	--------	--------	--------	13, 768
1938	14, 820	229	--------	--------	--------	13, 620
1939	15, 637	342	--------	--------	--------	12, 711
1940	17, 116	377	--------	--------	--------	12, 303
1941	15, 827	873	--------	--------	--------	--------
1942	7, 833	1, 502	--------	--------	--------	--------
1943	5, 840	1, 579	40	--------	829	--------
1944	3, 296	1, 032	96	--------	6, 681	--------
1945	1, 775	419	73	--------	--------	--------
1946	1, 056	182	--------	--------	--------	--------
1947	1, 401	454	186	--------	--------	--------
1948	4, 240	449	211	20	--------	--------
1949	7, 815	674	457	351	200	--------
1950 (Jan.–June)	6, 462	405	113	522	(1)	--------

1 No report.

In Changwat Surat Thani antimony ore is mined from a deposit about 2 kilometers from Ban Song station on the Thai State Railway. The deposit consists of stibnite with quartz in red and gray quartzite. The mineralization of the antimony may be associated with a granite intrusion about 2 kilometers distant from the deposit.

Antimony from Changwat Phrae comes from the Pha Khan district which is described in detail later.

PRODUCTION

Annual production [1] of antimony ores in Thailand, 1943–49:

	Long tons		Long tons
1943	40	1947	186
1944	96	1948	211
1945	73	1949	457
1946	—		

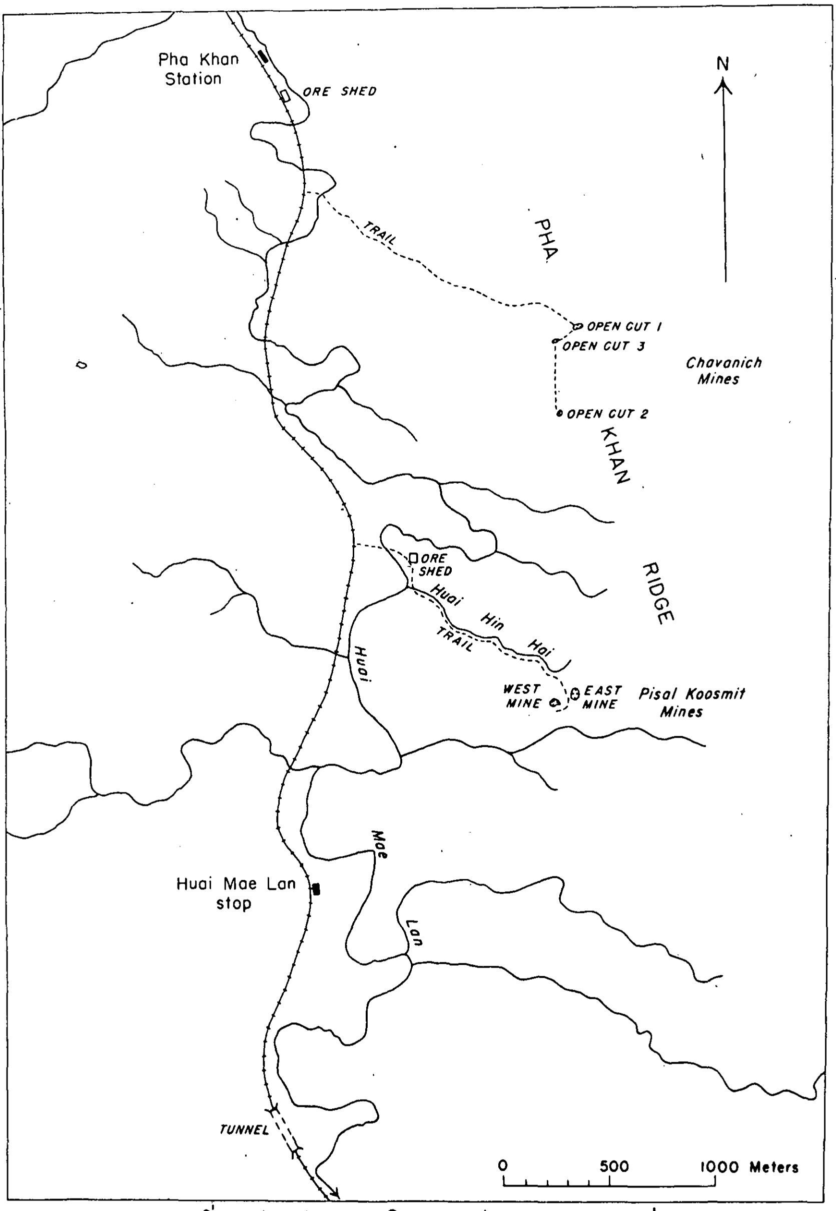
Of the 1949 production, 201 long tons came from Lampang, 138 tons from Surat Thani, and 118 tons from Phrae.

PHA KHAN DISTRICT

By George C. Taylor, Jr., and Saman Buravas

The Pha Khan antimony district lies in Changwat Phrae in north central Thailand (fig. 2). Pha Khan station, the shipping point for

1 From records of the Royal Thai Department of Mines.



แผนที่แหล่งแร่พลวงบริเวณผาคัน จังหวัดแพร่

FIGURE 2.—Map showing the location of the principal antimony mines in Pha Khan district, Changwat Phrae.

concentrates of the district, is 578 kilometers north of Bangkok by the Thai State Railway. There are two principal groups of mines in the district—those operated by the Chavanich Mining Co. and those of Pisal Koosmit. All of the mines are on Pha Khan ridge, 2 to 4 kilometers southeast of Pha Khan station.

GEOLOGY

The oldest rock group on Pha Khan ridge is a sequence of shale, limestone, and sandstone. Some beds of limestone contain fossils of doubtful Permian age, but the whole group is tentatively referred to the late Paleozoic which Lee (1923, pp. 3–4) has described in adjacent parts of northern Thailand. In the group there are three lithologic units which can be distinguished in the Pha Khan area. The youngest unit is a thick series of greenish gray and gray shales with some beds of sandstone. Underlying the shales are thin-bedded to massive gray limestones which form much of the crest of Pha Khan ridge and locally stand in jagged, honey-combed pinnacles. The limestone unit is in turn underlain by massive brown sandstones of fine to coarse texture. The general strike of the late Paleozoic rocks on Pha Khan ridge is north-northeast and the dip is to the northwest. These rocks lie on the northwest limb of a major anticline (Lee, 1923, geologic map) whose axis trends north-northeast.

Intrusive in the folded late Paleozoic rocks at the south end of Pha Khan ridge is a granite stock whose center lies about 7 kilometers south of Pha Khan station. The stock is roughly elliptical, extending about 10 kilometers in an east-west direction and 7 kilometers north-south.

MINERALIZATION OF ANTIMONY

The antimony deposits of Pha Khan ridge are of two distinct types. These are irregular or lenticular shoots lying in brecciated zones in late Paleozoic limestones, and narrow veins transecting the hood of the granite stock. In both types the only primary ore mineral is stibnite, which is accompanied by quartz gangue. At or near the surface the primary stibnite has been extensively oxidized to whitish yellow stibiconite. Other oxides of antimony may also be present but were not distinguished in the field.

Ore deposition in the limestones was localized in brecciated zones which afforded permeable channels to ascending hydrothermal solutions. In the granite the ore-bearing solution followed a pattern of fractures developed in the hood of the stock, possibly at the time of its emplacement. Field relations suggest that the mineralization of antimony occurred in the near-surface or epithermal zone at relatively low temperatures.

CHAVANICH MINING CO. PROPERTIES

GENERAL FEATURES

The Chavanich Mining Co. operates on Pha Khan ridge under a mining lease granted by the Royal Department of Mines. One relatively large pit designated open cut 1, a smaller pit called open cut 2, and 12 to 15 small pits and trenches are operated by the company. At all of these workings the ore occurs in shoots in brecciated zones in limestones.

OPEN CUT 1

The oldest and largest of the company mines is open cut 1 (fig. 3) located southeast of Pha Khan station on the crest of Pha Khan ridge at an altitude of 310 meters and 110 meters above the station. It is here that antimony ore was first discovered in Pha Khan district in 1939. Since that time mining has been done on an intermittent or seasonal basis by native farm laborers who work in the rice fields most of the year. In late 1949 the mine was inactive, in part because of recent declines in the price of antimony and in part because of the decline in the grade of the ore with depth.

Ore occurs in a porous siliceous breccia zone that lies approximately conformable between thin-bedded dark gray limestones which strike N. 58° E. and dip 39° NW. The thickness of the brecciated zone is irregular but averages about 3 meters. The ore is scattered through the breccia but is most abundant just below the hanging wall.

The ore consists of stibnite in a gangue of drusy quartz with some calcite. Except where enveloped by quartz, much of the stibnite is oxidized to stibiconite. The stibnite and stibiconite occur in roughly hemispherical masses with radiating acicular structure. Most of the masses range in diameter from 10 to 20 centimeters, but some are as large as 30 to 40 centimeters.

At the time of the writers' visit in November 1949 the brecciated zone had been mined for 21 meters along the strike and from the surface for 12 to 15 meters down dip. On the working face at the southwest end of the cut about 10 to 15 percent of the material in the brecciated zone is stibnite and stibiconite, thinning out at the northeast end of the cut to 5 to 10 percent. Through a width of about 1 meter just below the hanging wall at the bottom of the cut the ore may be as much as 20 percent of the brecciated material. Ore-bearing breccia thus continues in both directions along the strike from open cut 1 although the ore concentration appears to be somewhat stronger to the southwest.

OPEN CUT 2

About 400 meters S. 15° W. from open cut 1 is open cut 2. In this vicinity a zone of ore-bearing quartzitic breccia has a surface outcrop

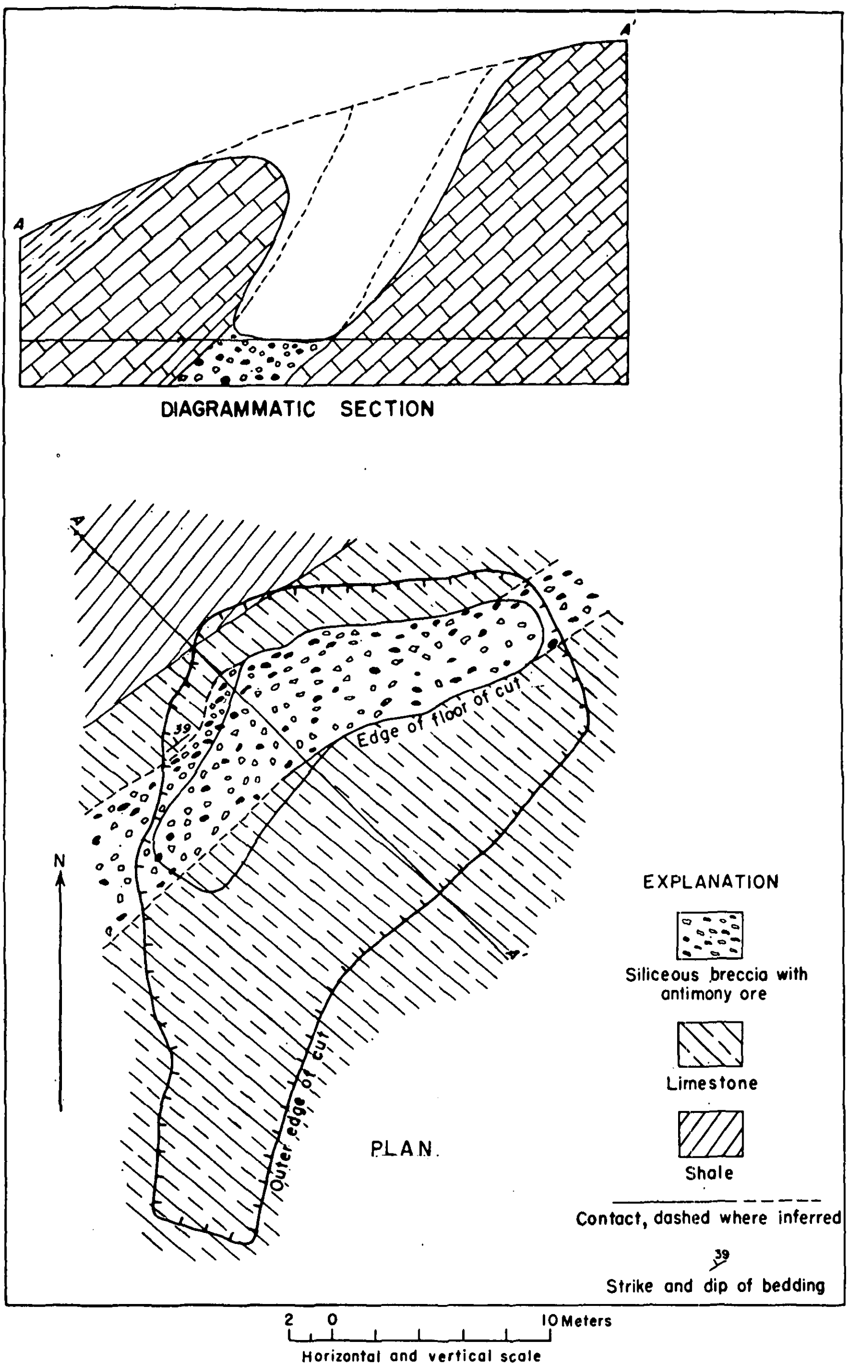


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FIGURE 3.—Plan and section of Chavanich open cut 1, Pha Khan antimony district.

about 12 meters wide. The brecciated zone strikes about N. 43° E. and lies between beds of massive gray limestone, which appear to dip to the northwest. Stibnite and stibiconite, in drusy quartz gangue, occur in irregular pockets 1 to 2 meters in diameter and in small hemispherical masses scattered through the brecciated zone. The ore has been mined from a shallow pit 7 meters long, 2 to 5 meters wide, and 1 to 2 meters deep. As based on visual estimate, the concentration of ore at the pit does not appear to exceed about 15 percent of the volume of brecciated material.

OTHER WORKINGS

About 100 meters southwest of open cut 1 and apparently in the same zone of ore-bearing breccia a short trench, here designated open cut 3, follows the brecciated zone for a length of 4 meters along the strike and to a depth of 1 to 2 meters below the outcrop. The brecciated zone is only 1 meter wide and lies conformably between beds of gray limestone. The strike of the limestone in the footwall is N. 35° E. and the dip is 44° NW. As at open cut 1, stibnite occurs with stibiconite in a gangue of drusy quartz with some calcite, but the ore is poor.

Between open cut 1 and open cut 2 and about 500 meters or more to the south-southeast are some 12 to 15 small shallow pits generally less than 2 meters deep. These are dug in brecciated zones lying between limestone and evidently were sunk on the richer pockets of antimony ore that crop out at the surface.

PISAL KOOSMIT PROPERTIES

GENERAL FEATURES

Two mines operated by Pisal Koosmit under lease granted by the Royal Department of Mines lie southwest of the Chavanich Mining Co. properties. Each mine consists of several trenches, pits, and short entries. All of the workings are on stibnite veins in granite.

EAST MINE

The East mine of Pisal Koosmit is approximately 1.8 kilometers south-southwest of the Chavanich open cut 1. It lies on the east slope of a sharp ridge and includes workings extending a horizontal distance of about 75 meters and through a vertical range of 30 meters. The altitude at the top of the working is about 274 meters. Some 10 trenches ranging in length from a few meters to about 12 meters have been cut into the slope of the ridge at 4 levels. In addition there are a number of shallow pits less than 2 meters deep.

The ore occurs in veins cutting medium-grained biotite granite. The primary ore mineral is stibnite in a gangue of drusy to massive quartz.

The stibnite generally appears in irregular masses or stringers in the quartz, but in places thin veins of almost pure stibnite are found. In the near-surface zone the stibnite is generally oxidized to stibiconite, and the granite wall rock adjacent to the veins is kaolinized.

Three intersecting ore-bearing veins were recognized in the workings. One of these strikes N. 85° W. and dips from vertical to 80° N., a second strikes N. 40° E. and dips 76° NW., and a third strikes N. 60° W. and dips 60° SW. The veins exposed in the trenches range from a few centimeters to about 50 centimeters in width, with an average width of about 30 centimeters. The richest ore concentrations occur in shoots at the intersections of the veins. In all of the veins now mined, the grade of ore is reported by the mine owner to decline with depth, although the extent to which this is true has not been verified by deep exploration.

WEST MINE

The West mine lies about 150 meters west of the East mine and on the opposite side of the ridge. Several shallow trenches ranging from a few meters to 10 meters long and from 1 to 3 meters deep have been cut in the slope of the ridge. The vein system developed by the trenches is evidently the same as that found in the East mine although the ore concentration appears to be somewhat lower.

MINING OPERATIONS

In all of the workings of Pha Khan ridge the ore is mined by primitive hand methods. A little blasting is done where hard ground is encountered. Bamboo stulls are used occasionally in trenches in soft or broken ground. The ore is carried in baskets from workings to dumps where it is hand broken, picked and sorted. The stibiconite is discarded with quartz gangue. The wastage of stibnite is also high because of careless picking and sorting.

At the Pisal Koosmit mines individual trenches are worked by family groups on a contract basis. The men do the heavy work of mining and blasting and the women and children hand pick and sort the ore. The owner furnishes blasting powder and pays the head of the family 50 satang ($0.025) per kilogram of stibnite concentrates delivered to an ore shed near kilometer 576 on the railway. The concentrates are carried on foot by basket and sling pole from the mines to the railway. Mining is carried on sporadically in the off-seasons between rice harvests.

PRODUCTION, GRADE, AND RESERVES

Reliable monthly or yearly production records are not available for the Pha Khan district. The stibnite concentrates are accumulated at the ore sheds of Pha Khan station and at kilometer 576 and are marketed in Bangkok when prices are favorable for antimony ore. According to the assistant mine manager of the Chavanich company at Pha Khan, delivery of 60.014 metric tons of stibnite concentrates was made to the company ore shed during the 10-month period ending Nov. 1, 1949.

An estimate of the average grade of antimony ore cannot be made for the Pha Khan district on the basis of available data. The ore concentration is spotty and varies widely in individual veins through the granite, as well as in ore shoots in brecciated zones. At the Chavanich company's open cut 1 stibnite and stibiconite were visually estimated to comprise 5 to 20 percent of material in the brecciated zone, and at open cut 2 less than 15 percent. Likewise available ore reserves cannot be estimated on the basis of present development work.

COPPER

By Jumchet Charaljavanaphet

GENERAL FEATURES

Copper minerals occur in many localities of Thialand, but no commercially valuable copper deposits have yet been found. Among the copper minerals which have been recognized are chalcopyrite, chalcocite, azurite, malachite, cuprite, and native copper. The principal copper prospects thus far reported in the country are at Khanong Phra, at Chan Thuk, at Boh Hin Riang, in two areas in Changwat Phetchabun, three places in Changwat Lampang, several places in Changwat Uttaradit, at the Tah Pha Mok prospect in Changwat Phrae, at Khok Kathiam in Changwat Lop Buri, and at Phanom Sara Kham. Their location is shown in figure 4.

KHANONG PHRA PROSPECT

The Khanong Phra prospect is in Changwat Nakhon Ratchasima about 15 kilometers south of Pak Chong station on the Bangkok-Korat railroad. The prospect lies in relatively level country covered by dense jungle. Definite outcrops of the lode are not discernible owing to deep weathering. The lode was first prospected about 40 to 50 years ago by a European company with a timbered shaft sunk to a depth of about 10 meters in the mineralized zone. Owing to difficulties with water, prospecting ceased at that depth. In 1943 the Thai Geological Survey further prospected the locality by test-pitting along the lode.

During this pitting, the copper minerals were found in a quartz vein whose average width is about 40 centimeters. The vein traverses gran-

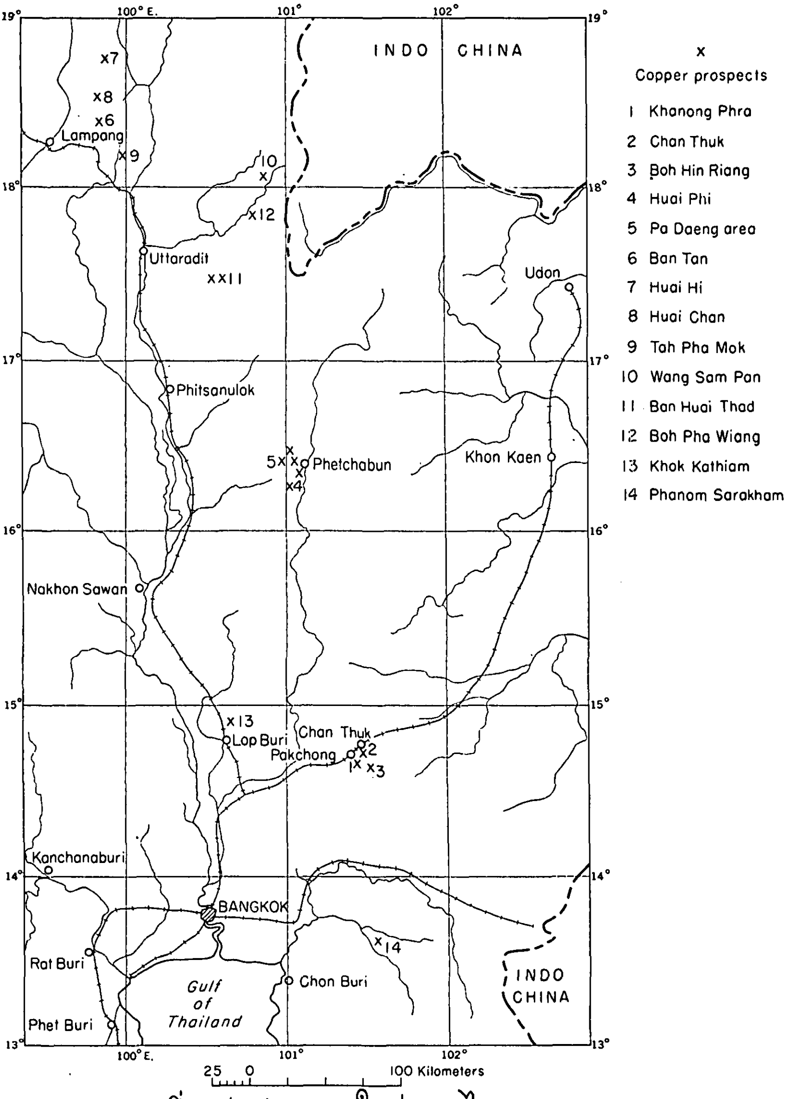

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FIGURE 4.—Map showing the principal copper prospects of Thailand.

ite country rock which is considerably weathered to a depth of at least 10 meters. The vein strikes about north, and to a depth of about 2 meters below the surface it dips about 60° E. From 2 to 8 meters below it dips vertically. The upper part of the vein exposed in an 8-meter pit is solid barren quartz, but the lower part is brecciated and contains malachite, azurite, and some chalcocite. The mineralization of the copper appears to have taken place in the brecciated part of the quartz vein. The solid quartz contains no copper. Samples taken from the brecciated vein contain as much as 4 percent copper.

The vein was traced for several meters but pinches out in both directions along the strike. Along the eastern border of the vein a band of altered contact rock contains amphibole and some chalcopyrite.

CHAN THUK PROSPECT

The Chan Thuk prospect is in Changwat Nakhon Ratchasima at Tambon Nong Chan about 6 kilometers south of Chan Thuk station on the Bangkok-Korat railroad. The copper minerals occur in quartz veins traversing syenite(?) country rock. Some prospecting in the locality was reported to have been done about 1915 by a Danish company. In recent visits geologists of the Thai Geological Survey have found three prospect pits. One of the pits is timbered 1½ meters square and 9 meters deep. No copper ore was seen on the dump. A second pit 8 meters to the south and 2 meters deep shows quartz fragments containing some malachite, azurite, and chalcopyrite. About 300 meters farther to the south a third pit 2.4 meters square and 9 meters deep shows evidence of recent prospecting activity. Exposed in the south face of the pit, between walls of mica schist, is a quartz vein about 50 centimeters wide containing malachite, azurite, and chalcopyrite. The copper content of the vein is about 3 percent.

BOH HIN RIANG PROSPECT

Copper minerals also occur at Boh Hin Riang about 17 kilometers south of Chan Thuk station. A quartz vein striking about north is exposed; mica schist crops out nearby. The quartz is stained with green copper minerals and also contains iron and manganese oxides. The quartz vein can be traced from Boh Hin Riang south for 200 meters to Boh Sub Kha, but no copper minerals were observed at the south end.

PETCHABUN PROSPECTS

Copper prospects in Changwat Petchabun occur along the Huai Phi, about 9 kilometers south of the city of Petchabun, and in the Pa Daeng area about 6 kilometers east of the city. At the Huai Phi prospect copper minerals occur in a thin lenticular quartz vein about 3 to 5 centimeters wide, lying along the contact between andesite porphyry and a sandstone-slate series. The vein strikes about north and can be traced for several meters. Chalcocite is the principal copper mineral but malachite, azurite, and cuprite are also present. A little prospecting was done at the locality in 1934 but the results were discouraging.

At Pa Daeng copper minerals occur in quartz lenses in andesite porphyry, and at Boh Khok Na Kea, in the same area, malachite and azurite fill crevices in quartzite. Copper minerals in narrow quartz veins at Boh Noen Thong have an occurrence similar to those at Huai Phi. At Boh Khao Thong, about 2 kilometers to the southwest, malachite and azurite appear in a gouge zone.

LAMPANG PROSPECTS

In Changwat Lampang copper deposits associated with sandstones and shales of the Korat series are found in three places, but none has been profitably mined. Malachite and azurite appear along crevices in sandstone at Ban Tan near the city of Lampang. The mineralized sandstone covers an area of about 10 square meters.

In Amphur Ngao, about 70 kilometers north of Lampang, is another prospect at Huai Hi near Ngiu Ngam hamlet of Tambon Wiang Teep. Here a copper-bearing sandstone occurs over an area of 10 by 100 meters on a hillside. The copper content of the sandstone is very low. No igneous rocks were found in association with the deposit.

At Huai Chan in Ban Luang Nua an outcrop of copper-bearing sandstone is 30 centimeters wide and 2 meters long.

UTTARADIT PROSPECTS

Small copper prospects associated with sandstones and shales of the Korat series have been recognized at several localities in Changwat Uttaradit. At Ban Wang Sam Pan in King Amphur Fak Tha cupriferous sandstone is found in an area of about 25 square meters; a similar deposit occurs at Ban Huai Thad in Tambon Nam Phi. In the same tambon at Ban Huai Niam malachite is found in a sandstone bed about 1 meter thick. The copper content in places runs as high as 10 percent. The locality has been prospected but no extension of the cupriferous bed has been found.

At Boh Pha Wiang in Tambon Ban Sieo a bed of cupriferous sandstone about 2 meters thick crops out in the ravine of Huai Sum. The bed appears on both sides of the ravine, which is about 10 meters wide, and about 30 meters above the stream channel.

PHRAE PROSPECT

About 15 kilometers to the northeast of Ban Pin station on the northern railroad is the Tah Pha Mok copper prospect. The ore occurs along a brecciated zone in a sedimentary series. The zone is limited by faults to an area of 20 square meters. In World War II about 10 tons of ore containing as high as 8 percent copper was mined.

KHOK KATHIAM DEPOSITS

The Khok Kathiam deposits are in Changwat Lop Buri about 160 kilometers north of Bangkok. The deposits lie on the slope of the small hill of Khao Phra Bat Noi at the edge of the Khok Kathiam military air field. They are readily accessible from Bangkok by train or automobile.

In the Khok Kathiam area granite intrudes the Rat Buri limestone, and slate, hornstone, and quartzite of the Kanchanaburi series. Copper minerals occur in two subparallel brecciated zones in the granite of Khao Phra Bat Noi which is capped by a limestone roof pendant. The lower zone, which is about 6 meters wide, strikes north and dips 45° W. The upper zone of similar thickness, strike, and dip, lies about 20 meters vertically above the lower zone. The ore minerals are malachite and azurite, but abundant hematite is also present. The tenor of the ore is low.

The upper zone was prospected about 1920 by a European company which sank a shallow vertical shaft.

PHANOM SARAKHAM DEPOSITS

The mode of occurrence of the Phanom Sarakham deposits is perhaps unique in Thailand. Native copper and other subordinate copper minerals are found in mica schist over an extensive area, and no igneous rocks appear to have been associated with the mineralization.

The deposits occur near Phanom Sarakham, an amphur seat in Changwat Chachoengsao. They are difficultly accessible from Bangkok by train, steam launch, and ox cart—the full journey requiring about 1½ days. The terrain at the deposits is gently undulating and is covered with jungle. Laterite beds 1 to 2 meters thick are common in the area.

The deposits occur in beds of cupriferous schist 10 to 30 centimeters thick, intercalated with barren schist. The schist, which is the country rock, strikes generally N. 30° W. and dips 30° E. The ore minerals include native copper in particles hardly visible to the unaided eye. Cuprite, malachite, and chalcopyrite appear in rounded grains through the schist. Limonite, ilmenite, and pyrite are also present. The best ore contains about 3 percent copper.

Considerable prospecting of the deposits was done by test-pitting and trenching during World War II. The typical section found in shallow pits from the surface downward is as follows:

Black soil and marcasite with 1 to 2 percent copper.
Pebbles of quartz with kaolin.
Crumpled disintegrated schist.
Leached schist with red spots.
Schist with pockets of native copper in limonite.
Schist with martite and cuprite.
Fresh cupriferous schist.

The deposit was worked by the Department of Mines from an open pit in 1945 for cupriferous schist. However, the ores do not continue at depth, and the average tenor of the ore mined was only about 1 percent copper.

GOLD

GENERAL FEATURES

Thailand has many gold deposits and this may have given rise to one of the Kingdom's early names, "Suwana Phum" meaning "The Golden Land."

Gold placers occur in many widely scattered localities through the country. Of 70 changwats gold has been reported in 28 (Buravas and Buravas, 1941, p. 1). Gold is still panned by local natives as a means of supplementing income. The most important placers in the Kingdom are probably those of Pa Ron. About 30 to 40 years ago these placers were well known for rich and extensive pay streaks. They have been worked by local natives for many years and by a French mining company for a few years. The yield of gold has gradually diminished through the years but some is still obtained by panning.

The known lode gold deposits of Thailand are relatively few in number. Among the best known lodes are those of Krabin, Toh Moh, and Tha Tako. The gold ores from these localities are described in detail by Buravas and Buravas (1941, pp. 1–11).

The Krabin and Toh Moh deposits have proved sufficiently rich to attract foreign investment. The latest gold mining operation was undertaken at Toh Moh by the French company, Société des Mines d'Or de Litcho. The company operated for 5 years from 1936 to 1940 with a total production of more than 60,000 fine ounces of gold. The mine was closed in 1940 when all of the high grade ore had been mined.

PRODUCTION

The only production statistics received by the Royal Department of Mines are for the years 1936–40 when the Société des Mines d'Or de Litcho was operating at Toh Moh.

Annual production of gold

	Kilograms	*Fine ounces*
1936	321.522	10,337
1937	428.246	13,768
1938	423.638	13,620
1939	395.369	12,711
1940	282.661	12,303

No gold mining leases have been granted by the Royal Department of Mines since 1941.

PA RON PLACERS, PRACHUAP KHIRI KHAN

By George C. Taylor, Jr., and Jumchet Charaljavanaphet

The Pa Ron gold placers occur about 750 to 2,000 meters north and north-northwest of the village of Pa Ron in Changwat Prachuap Khiri Khan (see fig. 5). Pa Ron is accessible by elephant and ox cart over a 16-kilometer trail from Amphur Bang Saphan, which is 373 kilometers south of Bangkok by the Thai State Railway. Ban Huai Chang Han near the center of the placer district is about 50 meters above sea level.

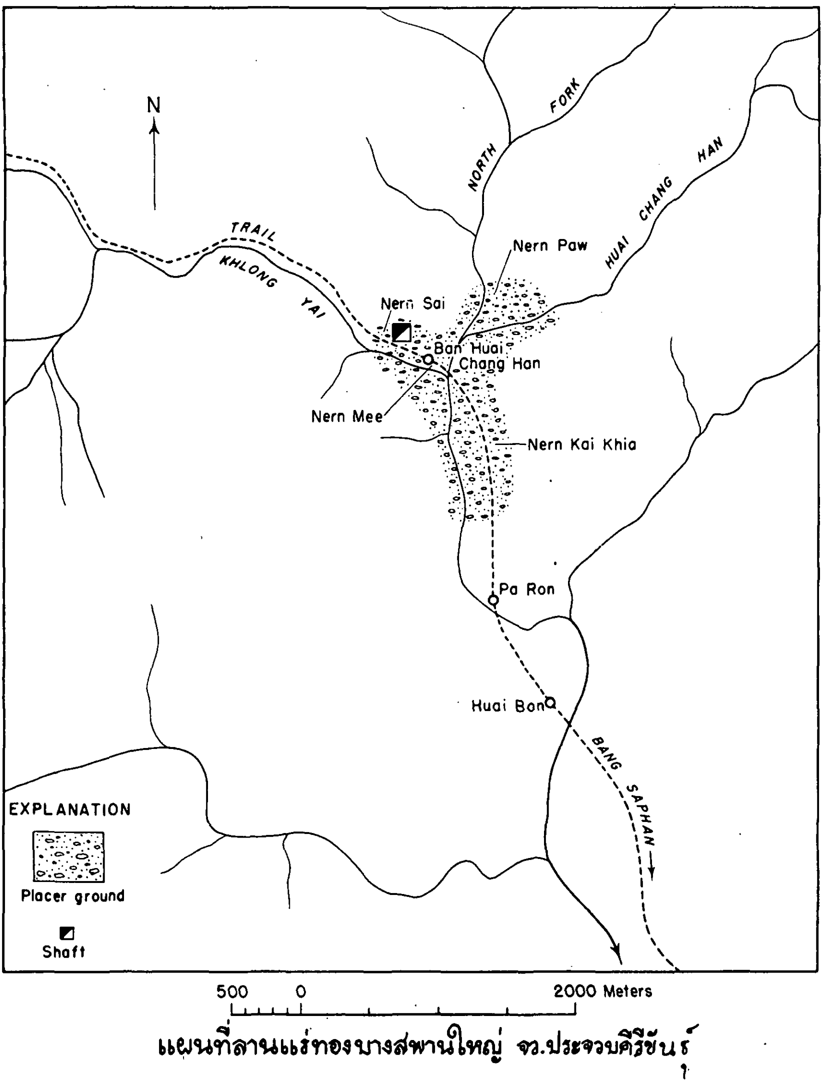

FIGURE 5.—Sketch map of Pa Ron gold placers, Changwat Pra Chuap Khiri Khan.

The principal streams of the district are the Khlong Yai and its tributary, the Huai Chang Han. During the dry season Huai Chang Han and its branches are without water, but Khlong Yai carries a small perennial flow of a few tens of liters per second. Active placer mining operations are thus limited to the 8-month wet season from May to December when water is plentiful in streams of the region.

GEOLOGY

The bedrock of the district is a sequence of gray, green, and blue-gray slates interbedded with gray and yellowish gray quartzitic sandstones. The age of these rocks is not definitely known, but judged by geologic relations in neighboring parts of Burma and Thailand they may belong to the Phuket series of Cambrian(?) age. Rocks of the sequence crop out along Khlong Yai and Huai Chang Han and lie within a few meters of the surface in most of the placer areas of the district. The Nern Mee, Nern Paw, and Nern Sai areas are underlain largely by slates, but in most of the Nern Kai Khia area the bedrock is quartzitic sandstone. The rocks strike from east to N. 55° E. and generally dip to the north and northwest at 15°–75°. In places narrow, discontinuous quartz veinlets and stringers traverse the rocks.

GOLD PLACERS

The gold-bearing placers occur in eluvium which forms a thin blanket over the bedrock. The eluvial blanket generally lies from 1 to 5 meters above adjacent stream channels on gently sloping benches. The eluvium consists of clay, silt, or sand with weathered fragments, and angular rock chips from the underlying bedrock.

In the Nern Kai Khia area the eluvial blanket is generally from 2 to 5 meters thick, and most of the gold is found immediately above bedrock in a layer about 50 centimeters thick. To recover the gold, pits are sunk to bedrock and short radiating drifts are dug in the gold-bearing ground. The material is raised to the surface in baskets and then is sifted, washed, and panned.

The thickness of the eluvium in the Nern Mee area is generally less than 2 meters. Coarse flake gold is reportedly obtained from a zone of weathered green slate about 25 to 35 centimeters thick, resting on unweathered slate bedrock.

The eluvium in the Nern Sai area is thin and discontinuous. Bedrock crops out in small knobs among which the eluvium is generally less than 1½ meters thick. Near the base of the eluvium is a layer of weathered slate, about 20 to 30 centimeters thick, which contains gold. West-northwest of Ban Huai Chang Han about 250 meters is a caved prospect shaft that reportedly was sunk to a depth of 8 meters by a

French mining company before World War I. According to local placer miners, the shaft passed through eluvium and green slate into blue-gray slate which was broken by blasting and found to be gold-bearing.

In the Nern Paw area the eluvium is generally about 1 to 3 meters thick. Weathered slate with some sandstone and vein quartz debris forms a gold-bearing layer, about 25 to 35 centimeters thick, lying on bedrock. About 600 meters northeast of Ban Huai Chang Han on the north side of Huai Chang Han is a narrow bank of gold-bearing alluvium which rests on slate bedrock. The bank is about 75 meters long, 3½ meters high, and 1 to 5 meters wide. The upper 1½ meters of the bank is reddish brown sandy silt and is reported to yield some flour gold. The lower 2 meters is coarse subangular quartz and slate gravel with some silt and sand. The local miners report that coarse flake gold occurs in the upper part of the gravel bed and still coarser gold is found near the base.

The gold recovered from the Pa Ron placers ranges from flour through coarse flake size to nuggets weighing as much as 50 grams. According to Nai Kob, a gold buyer of Bang Saphan, the gold runs as high as 990 fine. The local price for gold in 1949 was about 33 baht per gram, or $1.43.

MINING OPERATIONS

The occurrence of gold in the Pa Ron district has been known for 75 years or more, and placer mining by simple pitting and panning methods has been carried on intermittently by natives of the region for many years. Thus, much of the eluvium may have already been worked two or three times. At the time of the writers' visit in March 1950 there were many freshly dug pits. At Amphur Bang Saphan it was reported that some 100 permits for individual panning in the district had been issued during the past year.

During the dry season placer mining operations are limited to those areas where water is close at hand and the gold-bearing material can be readily carried to the streams for washing and panning. In most of the Nern Kai Khia, Nern Mee, and Nern Paw areas, mining operations practically cease in the dry season for lack of water. In the wet season water is diverted from the streams and ground sluicing is practiced in most of the district. Deeper gold-bearing material is raised from pits in baskets and is then washed in slucing channels. The gold-bearing alluvial bank on Huai Chang Han is also worked by ground sluicing during the wet season. When water is available some gold is also panned from small discontinuous pockets of gravel along the channels of Khlong Yai and Huai Chang Han.

HUAI LUANG PLACERS, CHIANG RAI

By Saman Buravas and George C. Taylor, Jr.

The Huai Luang gold placers occur about 9 kilometers airline southwest of Mae Chan (New Chiang Saen) in Changwat Chiang Rai (fig. 6). The junction of Huai Ngu with Huai Luang at the head of the principal gold-bearing ground is 2.1 kilometers by foot trail to the east-southeast of kilometer 256.4 on the Chiang Rai-Mae Chan highway.

The principal streams of the placer area are Huai Luang and its tributary Huai Ngu. Both are perennial streams carrying flows of a few tens of liters per second in the dry season. Small-scale placer mining operations are thus possible throughout the year.

GEOLOGY

Purplish gray or brown slates with some thin interbedded quartzites are the oldest rocks in the Huai Luang area. They strike northeast and dip northwest. These rocks probably belong to the Korat series although fossil evidence is lacking. Intruded into the series is medium-grained diorite which crops out in places near Huai Ngu. Quartz veins that traverse the slate-quartzite series on the north side of Huai Luang valley between bridges 2 and 3 may be genetically related to the diorite intrusion.

Cut in these rocks is a narrow alluvial valley followed by Huai Luang and Huai Ngu. The valley bottom lies about 25 to 35 meters

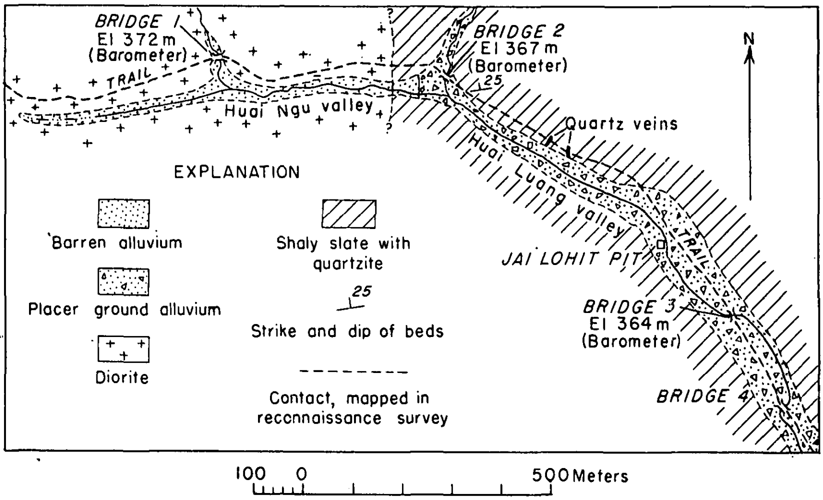

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FIGURE 6.—Sketch map of Huai Luang gold placers, Changwat Chiang Rai.

below adjacent uplands and ranges from about 20 to 60 meters wide in the area shown on the map. The downstream gradient averages about 4.1 meters per kilometer. The alluvium in the valley consists of subangular gravel of vein quartz, slate, quartzite, and some diorite, intermixed with poorly sorted clay and sand. The thickness of the alluvium above bedrock is 3 to 5 meters in the area mapped. Ground water saturates the alluvium to within 1 to 2 meters of the surface.

GOLD PLACERS

Gold occurs in the alluvium of Huai Luang Valley from a few hundred meters upstream from bridge 2 to about 1 kilometer downstream from bridge 4. According to local prospectors, the fill of Huai Ngu Valley yields no gold except in the vicinity of the junction with Huai Luang Valley.

The most productive ground was possibly that stretch of the Huai Luang Valley extending about 1 kilometer downstream from bridge 4. Gold in quantities of 10 grams or more a pit have been reported. This ground has been extensively worked for many years and much of the original gold may have already been recovered.

The local miners report that gold is very irregularly distributed through the alluvium in the stretch of valley between bridge 4 and headwaters of Huai Luang. In the vicinity of the junction of Huai Luang and Huai Ngu several pits about 1½ meters square have been dug to depths of 1 to 3 meters. It is said recovery of gold ranged from nothing to 5 grams a pit.

The only active mining at the time of the writers' visit was at the Chai Lohit pit on the south side of Huai Luang. Including the stream bank, there are about 3.5 meters of overburden underlain by a poor pay streak of gold-bearing clayey sand 0.3 meter thick. This streak rests on barren clay about 0.5 meter thick, underlain in turn by a second pay streak 0.2 meter thick. The second streak, considered the richer of the two, is composed of clayey sand with quartz gravel which rests on weathered bedrock of gray slate. About 2 grams of gold are reported to have been recovered from the pit.

Judged by reports of local miners the gold in the alluvium of Huai Luang Valley above bridge 4 does not appear to occur in well-defined pay streaks. Rather it is found in thin irregular lenses or pockets scattered through barren ground. Relatively little flour gold is found in panning. Most of the gold recovered occurs in flakes 1 to 2 millimeters in diameter. Flake gold from a pit near that of Chai Lohit is reported to have run about 950 fine.

MINING OPERATIONS

The gold placers of the Huai Luang Valley are well known to natives of the region and have been exploited intermittently by pitting and panning methods for 75 years or more. According to unverified local reports two or more unsuccessful attempts were made during the past 25 years by foreign or domestic companies to recover the gold on a commercial scale.

The local placer mining methods and costs are exemplified by the Jai Lohit pit. It is 1½ meters square and was sunk with split bamboo cribbing. A bamboo spring pole with rattan rope and woven basket was used for raising material to the surface for panning or disposal. For dewatering the pit during digging, a bamboo bailer with leather flap is fixed to the rattan rope and operated by a spring pole.

The pit was dug 4½ meters deep by three men working 7 days and at no cost in materials. Labor costs 3 baht per man-day, making the total cost of the pit 63 baht. The local price for gold at Mae Chan is reported to be 20 baht per gram. (At the present exchange of 21.60 baht per dollar, a gram of gold is equivalent to $0.92.) Since only 2 grams of gold were recovered from the pit, about 23 baht were lost on the operation. Judging from this experience, it would appear that the recovery of 3½ grams or more of gold per pit is necessary for profitable return by this type of placer mining. Fewer than half of the pits dug in the valley are reported to have yielded more than 3½ grams of gold.

KRABIN DEPOSIT, PRACHIN BURI

By Nitipat Jalichandra

The Krabin gold deposit is situated at Ban Bo Thong in Krabin district of Changwat Prachin Buri. It is about 160 kilometers east of Bangkok and is readily accessible by railway as well as highway. One can board the Eastern Route train at Bangkok in the morning and get off at Nong Sang station, which is also on the Bangkok-Prachin-Aranya highway, in the afternoon. A track leads from Nong Sang south 2.2 kilometers to the deposit.

The topography is gently undulating. The region is well covered with lateritic sandy soil and light vegetation. Very few exposures were observed in the mineralized area.

Although gold has been panned in the district for decades, the first organized attempt to mine it was made about 1880 by Phra Pricha, then the Commissioner of Changwat Prachin Buri, who employed about 300 men in the venture. The deposit turned out to be a bonanza with a weekly yield of gold of the "bulk of a coconut" reported.

Then in 1906, a second attempt to mine on a larger scale was made by a company of joint Siamese-European interests. Despite the mechanical methods employed, the yield of gold was not as rich as expected. After 10 years of operation the company disbanded in 1916, the probable reason being either the exhaustion of the richer ores or the difficulty in acquiring mining materials during World War I.

According to Phra Udom, the late Chief Geologist of the Royal Department of Mines, who visited the Krabin deposit in 1936, traces of mining were indicated by old water-filled shafts and shallow pits which are alined in a general east-west direction. This alinement may indicate the strike of the gold placer. Near the pit known as Boh Yai there is a dump pile which contains lumps of siliceous slate, quartzitic sandstone, limestone, diorite, and wollastonite with garnet.

In order to gain more definite knowledge of the deposit, Phra Udom had two test pits dug. The first pit, sunk to a depth of 3 meters, exposed a white sandstone bed dipping 50° E. The rock is badly crushed. A contact between crystalline limestone and the sandstone was also exposed. The second pit was 2.6 meters deep and exposed a bed of sandstone with an east-west strike.

Phra Udom concluded that the mineralized zone occurs in a crushed band through which an igneous mass forced its way upward. The presence of float of vein quartz containing specks of gold indicates the gold originated in quartz veins which were probably related to the intruding igneous mass.

According to Buravas and Buravas (1941, p. 10) the gold occurs with quartz, related to an intruded hornblende diorite porphyry. Green garnet and wollastonite were developed from the contact metamorphism of limestone wall rocks.

TOH MOH DEPOSIT, NARATHIWAT

By Nitipat Jalichandra

The important Toh Moh gold deposit lies near the southern border of Thailand in the Toh Moh district of Changwat Narathiwat which has a rugged terrain and thick tropical vegetation. The deposit can be reached only over rough elephant trails which are almost impassable during the rainy season.

This deposit has long been known, and sporadic mining by primitive methods has been carried on throughout the area by the Chinese and the natives for many years. Systematic mining was not undertaken until a French company was formed and a 25-year mining concession was obtained in 1932. After a period of prospecting and development work, the mine started operation in 1936, with a yearly production of more than 10,000 fine ounces of bullion. After 15 years of continuous operation, with an average annual output of 12,500 fine ounces of gold, the mine was shut down because the high grade ore was exhausted.

The country rock, which is composed of slate and schist of the Korat series, is intruded by a biotite granite stock trending generally north-south. Quartz veins are found in both granite and schist, but only a few of these are mineralized.

At the mine the main quartz lode has a north-south trend and dips 20° E. In the southern part of the lode, the strike changes to the northeast. A post-mineral fault which strikes N. 55° W. and dips 80° N. terminates the lode to the north. The width of the lode ranges from a few centimeters to about 2 meters. The average tenor of the ore mined was about 10 grams per metric ton.

THA TAKO DEPOSIT, LOP BURI

By Saman Buravas

The Tha Tako gold deposit is about 75 kilometers north by dirt road from Amphur Khok Samrong of Changwat Lop Buri at lat. 15°25′ N. and long. 100°40′ E. The deposit is named from the Amphur Tha Tako of Changwat Nakhon Sawan.

The deposit was discovered more than 60 years ago when early prospectors who panned the alluvium established a village called Ban Bo Thong (Gold pit village). About 40 years ago a European company prospected the rock outcrops but the project was abandoned after 2 years. In 1941 the Quartermaster General, Department of the Ministry of Defense, did further prospecting for about 12 months. Panning by local natives has continued since the discovery of the district.

The country rock is Rat Buri limestone intruded by quartz monzonite porphry and later by quartz diorite dikes. The gold occurs in quartz-calcite veins, some of which also contain a green calcium garnet. Both white and green veins contain some pyrite. In general, the veins are irregular in size and shape and erratic in content of gold which is reported to range between 2 and 90 grams a ton. The largest vein observed is 6 meters wide and was traced for 200 meters along the strike.

ILMENITE

By Saman Buravas

In Thailand ilmenite is always found associated with cassiterite and the Thai word for ilmenite is "khi rae" meaning mineral (tin)

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excrement. Originally it occurs in granites, pegmatites, and veins, where it may be associated with cassiterite, wolframite, monazite, tourmaline, zircon, and rutile. Sorted beach deposits, derived from the weathering of ilmenite-bearing rocks and containing 40 to 50 percent ilmenite, occur in various places on the shore line of the eastern Changwats and Peninsular Thailand. Two such deposits are at Phet Buri and Prachuap Khiri Khan.

The tailing dumps of the tin-washing sheds in southern Thailand contain much ilmenite. Dredge or sluicing concentrates, as received at the washing sheds, usually contain 20 to 40 percent cassiterite and 25 percent ilmenite, the remainder being quartz sand and the heavy minerals mentioned above. The first washing, in coffin-shaped troughs called lanchutes, at the tin sheds removes the quartz and other light minerals. The second washing, also in lanchutes, produces a concentrate containing 70 to 90 percent cassiterite. Ilmenite, along with other heavy minerals, is thrown on the tailings dump. These dumps contain 60 to 90 percent ilmenite and about 1 to 2 percent cassiterite. There are many thousands of tons of material in such dumps in southern Thailand. Shortly before the outbreak of World War II in the Pacific area, Japan imported about 2,500 tons of ilmenite tailings that had accumulated at the washing shed of the Lam Phraya dredge of the Pattani Tin Dredging Co. The reported price was 2 to 2.50 baht per ton. Should it become economically feasible to treat the tailing dumps by magnetic separator or other means to recover the ilmenite, the tin contained in the nonmagnetic fraction would be a valuable byproduct.

IRON

GENERAL FEATURES

The known iron deposits of Thailand are of two types: laterites that form a surficial blanket on many types of bedrock, and contact-metamorphic deposits where igneous rocks have intruded calcareous sediments.

The laterites are widely distributed. Limonite occurs as small rounded pellets, generally less than 1 centimeter in diameter in the residual soil. In places the pellets are cemented into lateritic masses that have long been used as building stone. In the past, such deposits have furnished iron ore for reduction in primitive furnaces to supply iron for fashioning simple tools. Characteristically, the iron content of lateritic ores depends upon the admixture of clayey or sandy material. Generally these ores contain 0.2 percent or more of phosphorus pentoxide. Some of the pellets are magnetic.

Contact-metamorphic deposits have a narrowly limited distribution but are known in both central and southern Thailand.

In 1941, the Thai Cement Co. employed the Swedish firm of Aktiebolaget Elektrisk Malmletning to prospect for iron deposits. The principal findings of this report, a copy of which was made available by the Royal Department of Mines, have been summarized in the following table.

Summary of the 1941 investigation of the iron deposits of Thailand by the Aktiebolaget Elektrisk Malmletning.

Name	Changwat	Amphur	Type	Iron minerals	Size
Uttaradit	Uttaradit	Muang	Lateritic	Limonite	?.
Hua Ngiu	Nakhon Sawan	Hua Ngiu	Contact metamorphic.	Hematite limonite.	Small.
Hua Wai	Nakhon Sawan	Hua Wai	do	Hematite	?.
Khao Dap Kwai	Lop Buri	Khok Kathiam.	do	do	700,000 metric tons.
Koh Samui	Surat Thani	Ko Samui	do	Specular hematite.	?.
Khao Phang	Nakhon Si Thammarat.	Sichol	Lateritic	Limonite	Small.
Khao Noi	do	do	Contact metamorphic.	Specular hematite.	?.
Khao Lek	do	Tha Sala	Veins (?)	do	Small.
Ban Wang	Phatthalung	Muang	Lateritic	Limonite	Do.
Nam Noi	Songkhla	Had Yai	do	do	Do.
Khao Thong	Krabi	Muang	Contact metamorphic.	Magnetite, chalcopyrite pyrrhotite.	Do.
Koh Cham	do	Koh Lanta	Lateritic Sea-water deposition.	Limonite	Do.
Koh Libong	Trang	Kantang	Lateritic	do	Do.

In the course of the present investigation, Taylor and Saman Buravas visited the Boh Dam laterite deposit in Changwat Phrae, and Samak Buravas, Saman Buravas, and Johnston visited the Khao Thap Khwai contact-metamorphic deposit in Changwat Lop Buri. Saman Buravas and Brown visited the contact-metamorphic deposit in Ko Samui and regard it as worthy of further prospecting.

PRODUCTION

Small amounts of iron ore were mined between 1943 and 1949 for the experimental blast furnace of the Thai Cement Co. The company expects to begin commercial production in 1950 and 1951. The following production figures are from the Royal Department of Mines:

Annual production of iron ore

	Long tons
1943	829
1944	6681
1945–48	----
1949	200

BO DAM LATERITIC IRON DEPOSIT, PHRAE

By George C. Taylor, Jr., and Saman Buravas

The Bo Dam (Black Pit) iron prospect (fig. 7) is in Changwat Phrae about 15 kilometers west-southwest of Ban Pin station by dirt road to Amphur Muang Long and thence by cart trails and footpaths passing through the villages of Ban Na Mauni, Ban Hua Thong, and Ban Na Tom. The occurrence is 3 kilometers S. 75° W. from Ban Na Tom.

The prospect is about 147 meters above sea level and lies at the southeast base of a range of hills which form the northwest border of the Mae Nam Yom lowland. The surface of the lowland is about 100 meters above sea level at the base of the hills near the prospect and about 80 meters near the junction of Huai Mae Long and Mae Nam Yom.

The Bo Dam area is underlain by yellowish green and gray shales and slaty shales. Intercalated with these beds are some yellowish

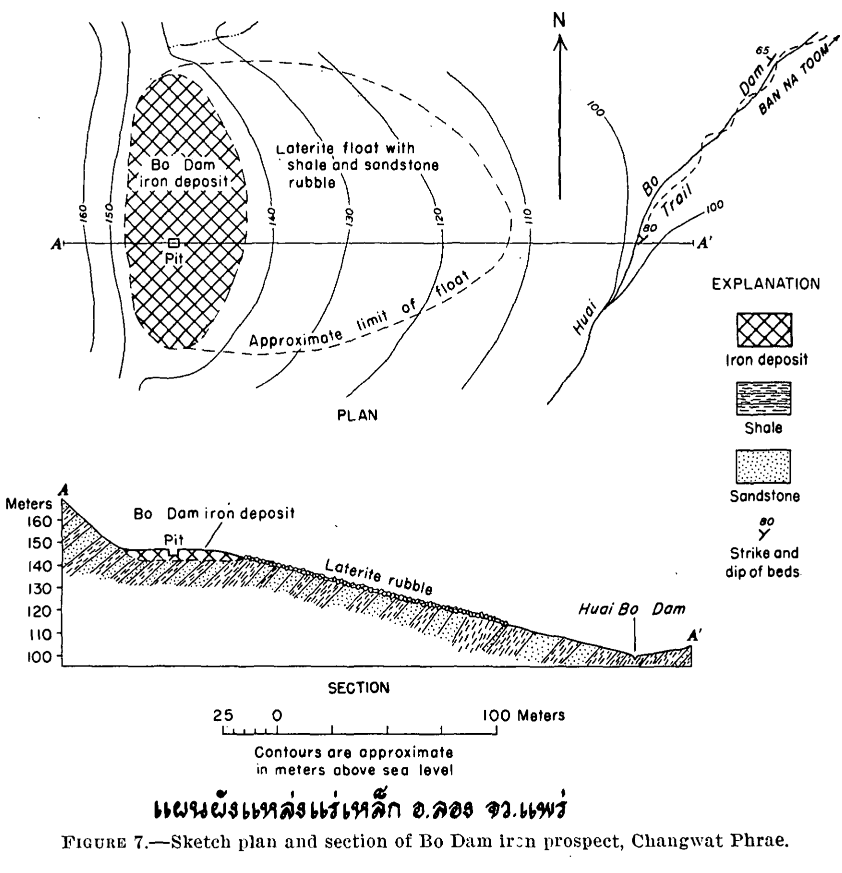

FIGURE 7.—Sketch plan and section of Bo Dam iron prospect, Changwat Phrae.

brown sandstones. These sediments are provisionally considered to belong to the Kanchanaburi series or to the Paleozoic sequence which Lee (1923, pp. 3–4) has described in northern Thailand.

The shale-sandstone series is strongly folded in the Bo Dam area. Between Ban Na Tom and the iron prospect, beds of the series strike N. 20°–50° E. and dip from vertical to 65° W. and NW. The structure suggests that the shale-sandstone series is involved in a sequence of small close folds whose limbs are almost parallel and locally overturned. Lee's map (1923a) indicates that the Bo Dam area lies on the northwest flank of a major anticline whose axis trends north-northeast. The close folding in the shale-sandstone series may therefore be a subsidiary feature on the flank of the larger structure.

The Bo Dam iron deposit caps an almost horizontal bench cut in steeply dipping beds of the shale-sandstone series. The bench extends about 125 meters in a north-south direction and 75 meters in an east-west direction. It is evidently the remnant of a once extensive terrace or erosional surface. Uplift of the region with downcutting by the Mae Nam Yom and its tributaries has left the bench 45 to 55 meters above the present lowland of Mae Nam Yom.

The iron deposit is a relict or high-level laterite formed from underlying slaty shales and ferruginous sandstones. The laterization probably occurred when the bench was part of a more extensive surface lying near the former base level of streams of the region. With uplift, erosion, and the consequent drop of the water table, laterization ceased. Erosion has since removed the cover of eluvial soil from the laterite and has destroyed most of the original extensive surface.

The iron deposit has the typical spongy texture characteristic of most laterites. The iron-bearing materials has a mottled yellowish brown to black color. Numerous interconnected vermicular or tubular openings traverse the material. In younger laterites such openings are commonly filled with residual clay, but in the Bo Dam laterite most of the clay has been removed. Evidently at Bo Dam laterization reached an advanced stage of development and the iron content of the material is high. The tubular openings of the laterite are lined with colloform bands of yellowish brown to dark brown goethite. The interior parts of the septa between passages contain thin bands of finely crystalline hematite apparently derived from the alteration of the goethite. Small pockets of yellowish brown earthy limonite occur in some of the cavities between septa.

Many years ago the deposit was mined for iron by natives who smelted the ore in primitive charcoal furnaces for the manufacture of jungle knives, swords, and farm tools. Most of the ore was dug from a shallow pit, now caved, near the center of the deposit. The total ore mined probably did not exceed a hundred tons.

Analyses of two grab samples of the ore were made in the chemical laboratory of the Royal Department of Mines in Bangkok and showed constituents as follows:

Constituents	Sample 1 (percent)	Sample 2 (percent)
Hygroscopic moisture	----------	1. 13
Loss on ignition	10. 36	9. 07
SiO_2	10. 35	13. 63
Al_2O_3	4. 50	4. 96
Fe_2O_3	71. 83	71. 23
MnO	2. 90	. 07
P_2O_5	. 28	. 20
	100. 22	100. 29

It is estimated that there are about 51,000 metric tons of "probable" iron ore in the Bo Dam deposit.

KHAO THAP KHWAI CONTACT-METAMORPHIC IRON DEPOSIT, LOP BURI

By Saman Buravas and William D. Johnston, Jr.

The largest known iron deposit in Thailand is in Changwat Lop Buri, about 20 kilometers north of the city of Lop Buri. It is on the

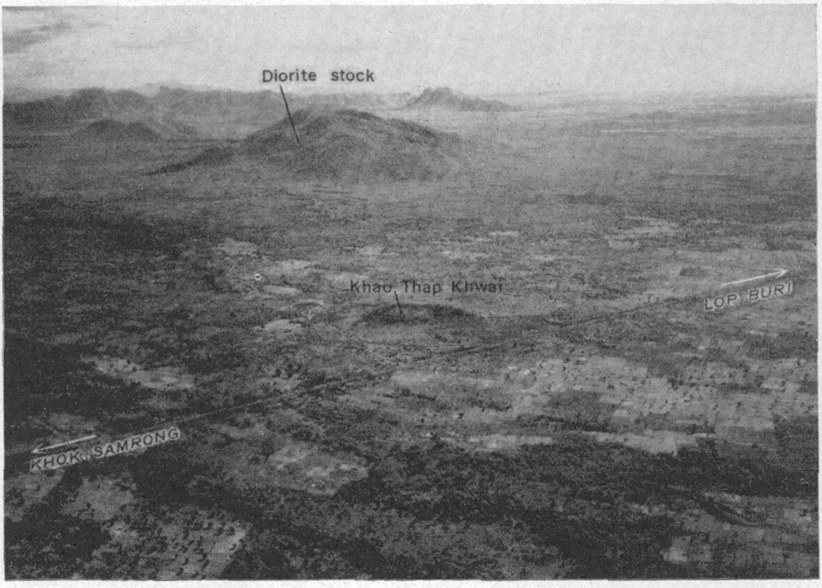

FIGURE 8.—Aerial photograph showing the Khao Thap Khwai contact-metamorphic iron deposit, Changwat Lop Buri.

highway connecting Lop Buri and Chai Badan near the 171.5-kilometer post. The deposit was found when the highway cut through a colluvial blanket of hematite rubble that forms an apron on the northwest slope of an isolated hill, known as Khao Thap Khwai, which rises about 50 meters above the surrounding plain (fig. 8).

The regional rocks are limestones, sandstones, and shales provisionally assigned to the Paleozoic, all of which have been intruded by a diorite stock which has recrystallized the limestone into marble and converted the clastic sediments into hornfels and quartzite. The intensity of the contact metamorphism can be well seen at Khok Kathiam, on the southern side of the diorite stock, where the limestone has been converted to a coarsely crystalline marble containing

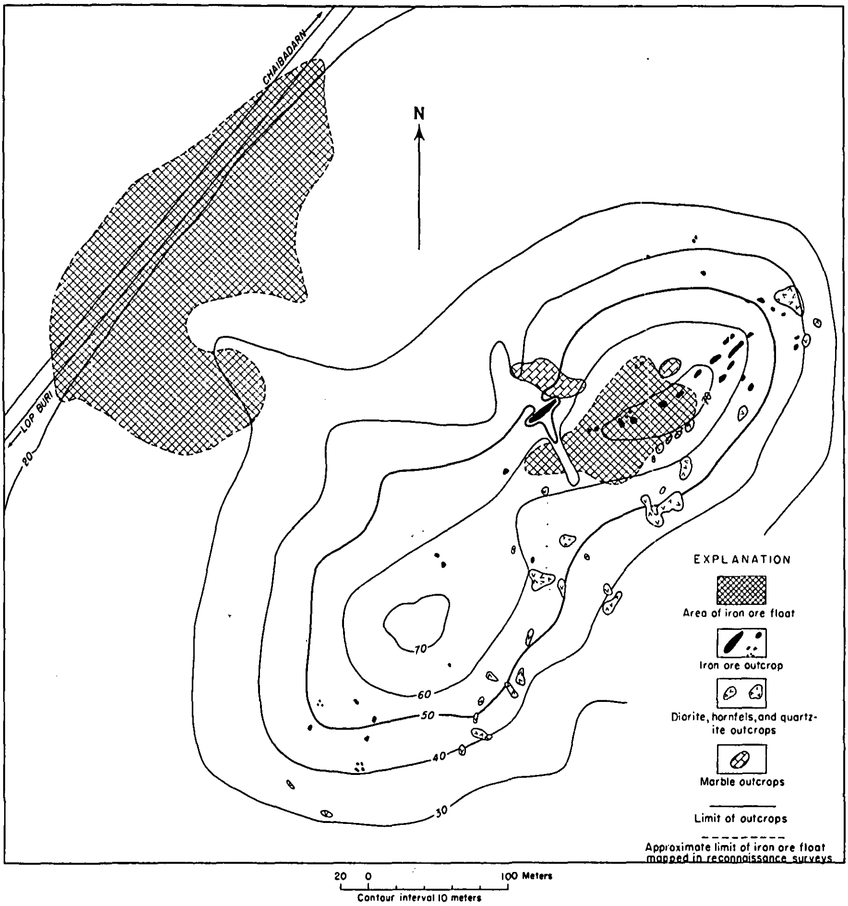

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FIGURE 9.—Outcrop map of the Khao Thap Khwai iron deposit, Changwat Lop Buri. Simplified from the 1941 map of the Aktiebolaget Elektrisk Malmletning.

green and reddish brown garnets, wollastonite, and green mica. Clear quartz crystals as large as 2 centimeters in diameter can be found in the slope wash near the great concrete Buddha above Wat Khok Kathiam.

The Khao Thap Khwai iron deposit was investigated in 1941 by the Aktiebolaget Elektrisk Malmletning, from whose report to Thai Cement Co. the accompanying geological map (fig. 9) was taken.

The primary ore body consists of a series of flatly dipping lenses of dense compact hematite, some of which is magnetic, which formed on the contact where the diorite intruded limestone. Only a small outcrop of coarsely crystalline marble is exposed, the remainder of the hanging wall having been removed by erosion. Scattered through the marble at this outcrop are small clusters of pyrite and chalcopyrite crystals. The footwall consists of diorite and garnetized hornfels.

There are two areas of residual hematite, one surrounding the outcrop of primary ore and one on the northwest slope of the hill. After some magnetic prospecting, a coordinate system of test pits on 50-meter centers was sunk by the Aktiebolaget Elektrisk Malmletning. These pits gave a reserve estimate of 720,000 metric tons of assured ore and 80,000 tons of probable ore in the residual blanket. The reserve of primary ore appears to be much smaller.

The following analyses, made in Bangkok, are given in the foregoing report for Khao Thap Khwai iron ore:

Analyses, in percent, of Khao Thap Khwai iron ore

Constituents	Primary ore (percent)	Residual ore (percent)
Fe	66. 4	48. 4
Mn	. 36	. 39
P	. 06	. 05
S	. 08	. 03
SiO_2	1. 8	15. 5
Al_2O_3	. 62	4. 7
CaO	. 13	3. 15
MgO	. 39	4. 7
Hygroscopic moisture	. 5	3. 2
Loss on ignition	1. 3	2. 3
	71. 64	82. 42

In September 1950 the Thai Cement Co. began operation of a charcoal blast furnace with a daily capacity of 10 tons of pig iron. The plant is located at Tha Luang near Sara Buri and is using iron ore from the Khao Thap Khwai deposit.

KO SAMUI CONTACT-METAMORPHIC IRON DEPOSIT, SURAT THANI

By Glen F. Brown and Saman Buravas

A contact-metamorphic iron deposit is exposed in a low hill near the beach village of Thong Tanode (shown erroneously on most maps as Ban Kau) in southwest Ko Samui, an island at 9°30′ north latitude in the Gulf of Thailand. The place may be reached by launch from either Ban Don or Nakhon Si Thammarat, ordinarily a day's journey. Specularite-magnetite ore, containing minor lime silicate minerals, occurs in siliceous rock at the southern edge of the intruded granite which forms the backbone of the island. The iron-bearing rocks are exposed for 71 meters along a north-south road which cuts across the contact 2.5 kilometers north of the beach at Thong Tanode. Apparently the deposit forms a hill extending 170 meters east of the road and paralleling the granite contact. West and south of the prospect bedded and metamorphosed limestone or marble stands on edge in the hills nearby. The size of the iron outcrop appears to warrant a detailed study of this deposit.

LEAD AND ZINC

Lead and zinc minerals together or lead minerals alone have been found in three general areas in Thailand. Small veins have been noted in the region of Lampang, northern Thailand; replacement deposits and possibly some veins have been found in the western mountains of Changwat Kanchanaburi; and a lead-zinc ore body occupies the center of a tungsten-tin lode at Tham Thalu in Peninsular Thailand near the Malayan border. The Huai Tham prospect in north Thailand, here described, is indicative of the type of mineralized zone thus far known in that part of the country. The most promising lead-zinc prospects are the replacement deposits in the limestone mountains of Changwat Kanchanaburi where at least three localities other than Nong Phai, which was examined by the writers, have been recently discovered or rediscovered. All are in geologic environments similar to that of Nong Phai. These localities are near Nong Lu on the river Khwae Noi and in the mountainous jungle east of King Si Sawat and Sum Sui on the river Khwae Yai. The ore specimens are fine-grained galena and sphalerite which contain a reported maximum of 1 percent silver. The prospects have not been explored sufficiently to be rejected as potential mines although their inaccessibility requires proof of large enough quantities of ore to justify the capital expenditure necessary for development.

The following production statistics are from the Royal Department of Mines:

Annual production of lead ore

	Long tons
1948	20
1949	351

Of the 1949 production, 345 tons came from Kanchanaburi and 6 tons from Lampang.

HUAI THAM PROSPECT, PHRAE

By George C. Taylor, Jr., and Saman Buravas

LOCATION AND TOPOGRAPHY

The Huai Tham (Tunnel Creek) zinc-lead prospect (fig. 10) is 1 kilometer east of the village of Ban Bo in Changwat Phrae. Ban Bo is about 1 kilometer northeast of Ban Pin station which is 564 kilometers north of Bangkok by the Thai State Railway. The prospect is reached by a footpath from Ban Pin station through Ban Bo to the junction of Huai Tham with Huai Mae Khok, and from this point the bed of Huai Tham is followed about 250 meters upstream.

The prospect lies in a narrow ravine on the northwest slope of a range of low hills. It is about 135 meters above sea level and about 25 meters above the valley of Mae Nam Lan at Ban Bo.

GEOLOGY

The oldest rocks in the Huai Tham area are dark gray and greenish gray shaly slates and slates with occasional beds of yellowish brown

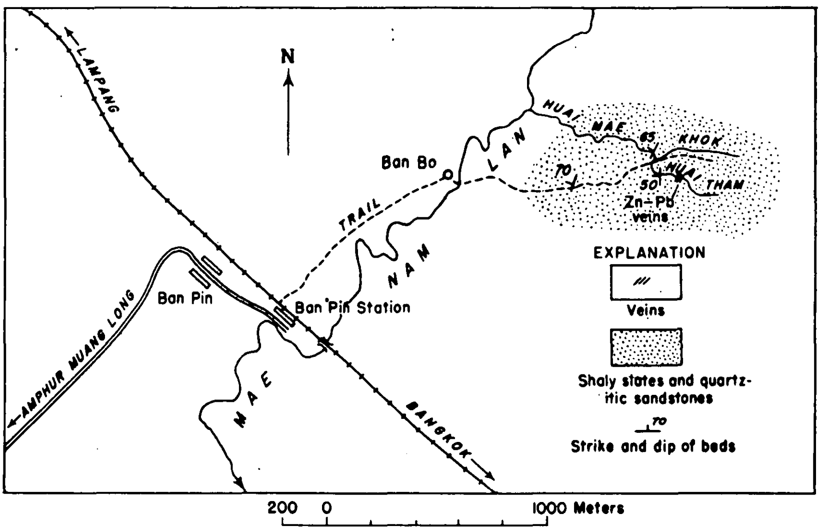

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FIGURE 10.—Sketch map showing location of Huai Tham zinc-lead prospect, Changwat Phrae.

quartzitic sandstone. No fossils were found in these rocks which, nevertheless, are tentatively referred to the Kanchanaburi series or the Paleozoic sequence which Lee (1923, pp. 3–4) has described in northern Thailand.

The slate series is strongly folded in the area. Along Huai Tham and Huai Mae Khok the beds strike from north to N. 30° E. and dip from 40°–75° W. NW. According to Lee's (1923) geologic map, the slate series of the Huai Tham area lies on the northwest flank of a major anticline whose axis trends north-northeast. Minor drag folding observed in a few incompetent beds appears to indicate that the slate series along Huai Tham is involved in a sequence of small close folds which are locally overturned. These folds may be secondary on the flank of the larger structure.

The rocks of the Kanchanaburi series to the north and northeast of Ban Pin and to the southeast of the Huai Tham prospect are intruded by granitic stocks. A narrow dike subparallel to the strike of enclosing slate is exposed in the creek about 25 meters west-northwest of the Huai Tham vein. Megascopically the rock appears to be a monzonite porphyry. This dike may be genetically related to the granitic stocks just described.

VEINS

At the Huai Tham prospect three or possibly four narrow zinc-lead and quartz veins are poorly exposed in the bottom of the ravine along the creek. The veins cannot be traced up the slopes of the ravine owing to the deep cover of tropical soil. Even at the creek, weathering is so deep that the original vein structures cannot be observed clearly.

The easternmost vein is only inferred from a strip of limonitic gossan containing relicts of reddish brown to brownish black sphalerite in a gangue of finely crystalline quartz. The gossan strip extends from the bed of Huai Tham up the north slope of the ravine for about 10 meters where it is lost beneath the soil cover. Neither the structure, the width, nor the textural character of the inferred vein could be observed. However, it appears to lie at least subparallel to the strike of enclosing beds of the slate series. The gossan has been worked by the local natives for sphalerite in two shallow pits less than 1 meter deep. Most of the sphalerite occurs in fragments of crystalline aggregates less than 5 centimeters in diameter in earthy gossan matrix.

About 5 meters downstream (west) is a second vein which has been prospected by a short adit driven into the south slope of the ravine 3 meters above the bed of Huai Tham. The adit bears S. 30° W. from the entry and is 10 meters long and about 1.5 meters in diameter.

Only the near-surface part of the vein is exposed because the adit bears 10° off the strike. Where exposed the vein averages about 30 centimeters in width, strikes N. 20° E., and dips 74° NW. Both the hanging and foot walls are greenish gray slate with drag folds in the vicinity of the vein. The strike and dip of the vein are conformable with that of the enclosing slates which appear to lie in the northeastern and overturned limb of a small anticline. The vein at the adit has been oxidized to gossan, although the adjacent wall rocks are comparatively fresh. The gossan contains relicts of reddish brown and brownish black sphalerite as much as 15 centimeters in diameter, with some quartz. The boxwork structure of the gossan suggests that the principal primary ore mineral of the vein is sphalerite.

About 5 and 8 meters downstream (west) from the second vein are two streaks of vein quartz float on the south slope of the ravine at the creek. Apparently the float comes from the weathered outcrops of two narrow veins. The quartz in the float fragments is milky and contains irregular masses of finely crystalline reddish brown sphalerite as large as 3 centimeters in diameter. Some galena and a little pyrite occur with the sphalerite. In places the milky quartz contains small vugs lined with crystals of later quartz.

The principal ore mineral in veins of the Huai Tham prospect is sphalerite, with some galena and a little pyrite. These minerals, together with the quartz gangue, were deposited from hydrothermal solutions which may have been related to the parent magma of the monzonite prophyry dike and the granitic stock southeast of the Haui Tham prospect.

NONG PHAI LEAD-ZINC MINE, KANCHANABURI

By Glen F. Brown, Kasetr Pitakspraivan, and Sangop Kaeo Phithum

LOCATION AND ACCESSIBILITY

The Nong Phai mine, in Amphur Si Sawat, Changwat Kanchanaburi, western Thailand, is located in a dense rain forest on the divide between the river Khwae Yai and river Khwae Noi which are tributaries of the Mae Nam Mae Klong at 14°45′ north latitude and 98°49′ east longitude (fig. 11).

The two streams furnish the only routes at present into the area, a limestone karst region covered with a thick bamboo jungle. Normally 3 days are required for a boat to reach the landings upstream from Kanchanaburi, the rail junction on the Mae Nam Mae Klong at the junction of the two tributaries, to either Si Sawat on the Khwae Yai or to Hin Laem on the Khwae Noi. About 2 days are normally required to make the trip downstream, but the time may be longer or shorter, depending on the stage of the rivers.

An unimproved timber access road with very steep grades extends west from Si Sawat to Nong Phai, a distance of 31 kilometers, and a road is being constructed from Hin Laem to the mine, a distance of about 24 kilometers. The current reconstruction of a part of the Burma-Thailand railway, built during Japanese occupation for military purposes along the Khwae Noi, should doubtless simplify shipment of equipment and ore.

Rainfall in the Nong Phai area is of the monsoon type, falling during the months from May to October when the roads are frequently impassable and the only transport to the stream is by elephant. The remainder of the year is dry; water is then hauled for camp use and the streams are low, exposing numerous rapids. During the time of low water in the streams, barge capacity is reduced to less than one-half of the normal load and the time required for each trip is considerably greater.

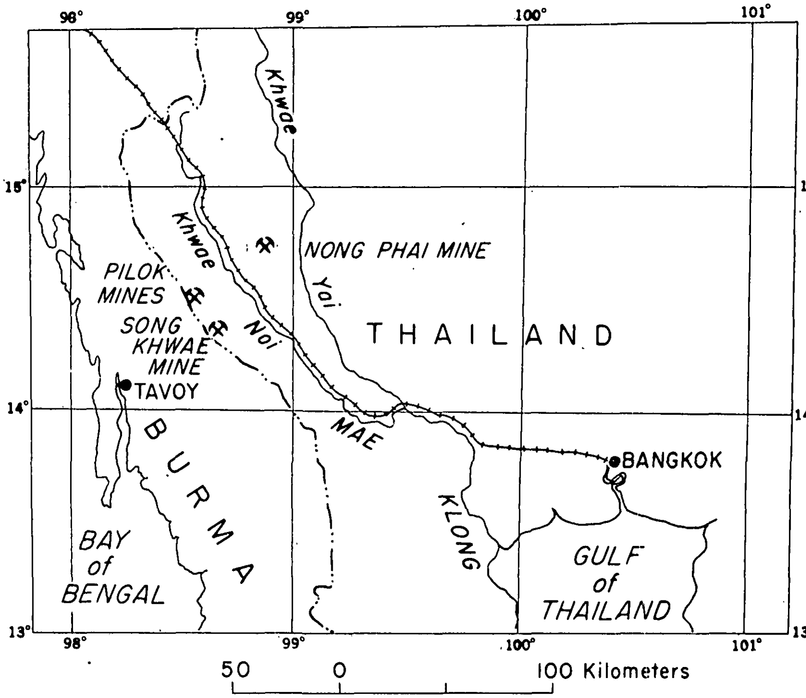

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FIGURE 11.—Index map showing location of Pilok, Nong Phai, and Song Khwae lead-zinc mines.

DEVELOPMENT

The ore body was discovered about 1912 by German prospectors whose work consisted of driving eight short adits (fig. 12) and a number of diamond drillings in and around the ore body. They also drove some short entries and trenched pockets of disseminated sulfides in the hills south of the ore body (pl. 6).

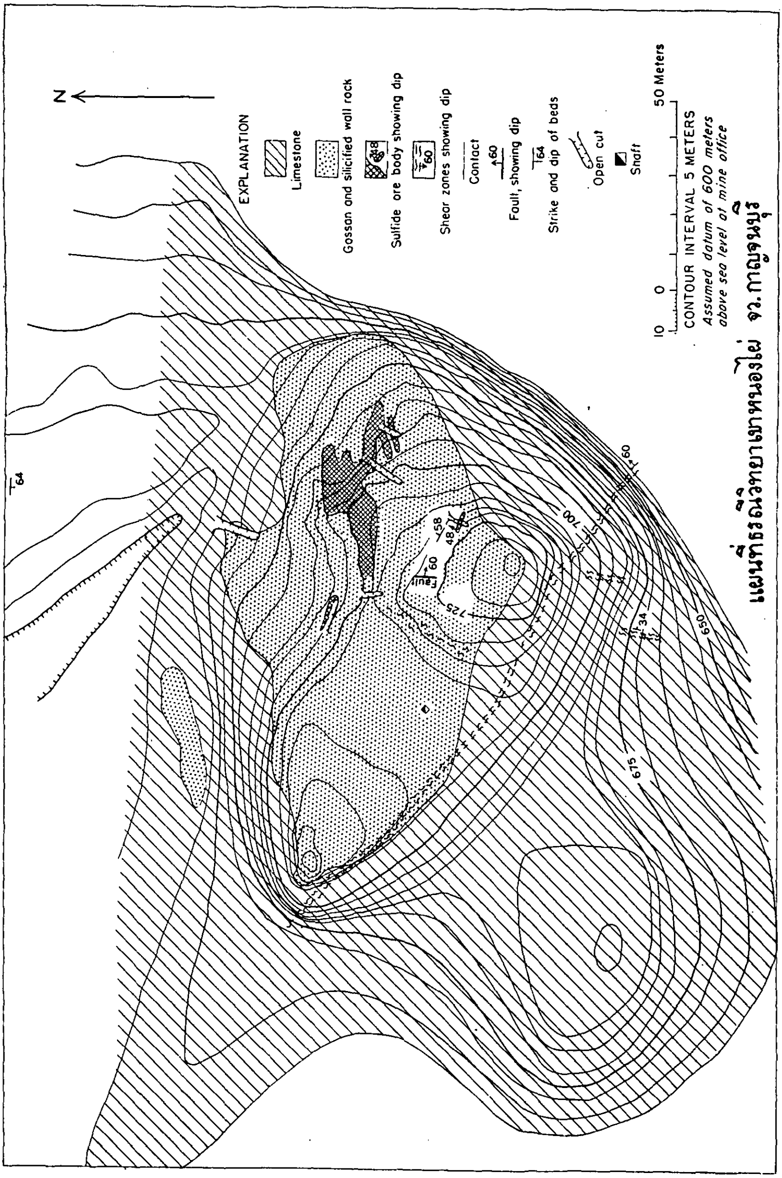


FIGURE 12.—Geologic sketch map of Nong Phai hill lead-zinc deposit, Changwat Kanchanaburi.

All work ceased during World War I and apparently interest waned because of the difficulties of reaching the outcrops. Then, during the local lead shortage of World War II the Thai Army Signal Corps mined and smelted some of the oxidized portion of the ore body in a locally built oven. Construction of the Burma-Thailand railroad during the Japanese occupation awakened Thai interest in the region and in 1948 Bangkok capital began mining and shipping from the sulfide portion of the ore body. The ore is hand sorted to bring it up to metallurgical grade for shipment to a lead-zinc smelter at Antwerp, Belgium. By December 1949 about 100 tons a month were shipped under optimum conditions.

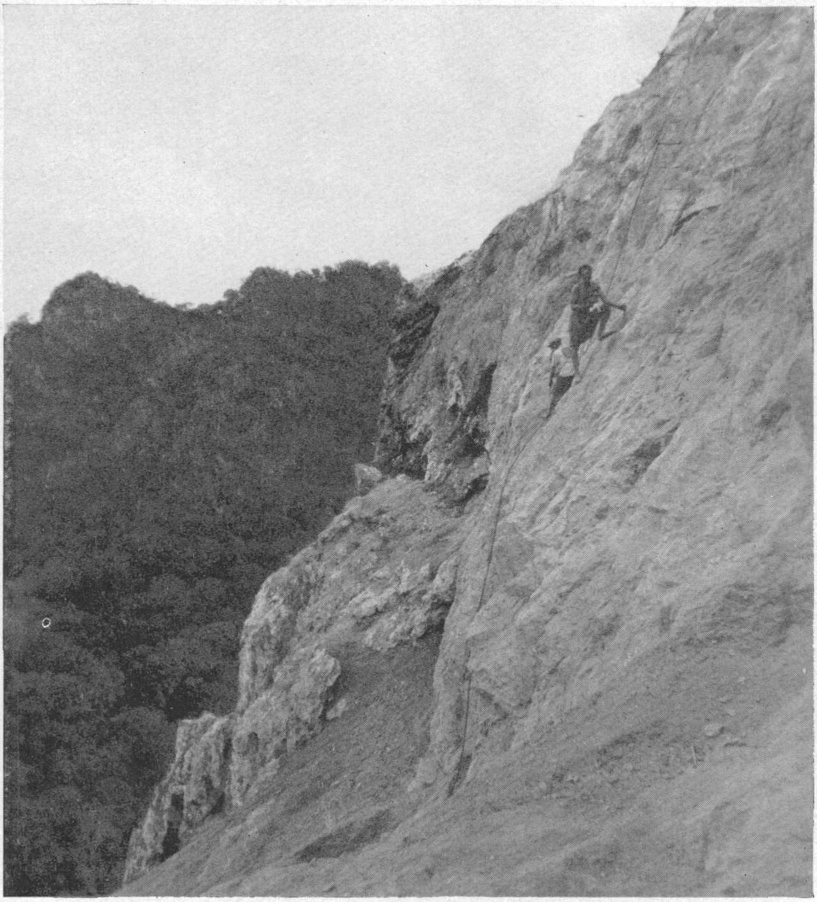


FIGURE 13.—View southeast across the ore face of the Nong Phai lead-zinc lode, Changwat Kanchanaburi. The massive sulfide ore is fringed beyond the figures by gossan and altered cavernous limestone.

GEOLOGIC SETTING

The lead-zinc ore body of Nong Phai is exposed on the northeast side of a steep hill of limstone at an elevation of about 100 meters above the surrounding karst terrain and at an altitude of about 700 meters (fig. 13). All of the surrounding region is underlain with thick marmarized limestone, supposedly belonging to the Rat Buri limestone and weathered by solution into sharp peaks, sinkholes, and caverns. Although the limestone is massive and recrystallized, bedding can be distinguished in a few places and older sandstone, quartzite, and phyllite crops out along the channels of both the Khwae Yai and Khwae Noi. Thus the regional structure is synclinal. At one place about halfway between Si Sawat and Nong Phai fossils, including what appears to be the glabella part of a trilobite cephalon, were found in calc-phyllite. If the metaclastic rocks are assumed to be older, the exposure may be on the upthrown side of a fault, as the outcrop is on the west-facing front of a limestone range—or, the regional synclinal folding may be here interrupted by an anticline. In either case the grain of the country rock extends north and slightly west of north in accordance with the regional strike of the mountain chain.

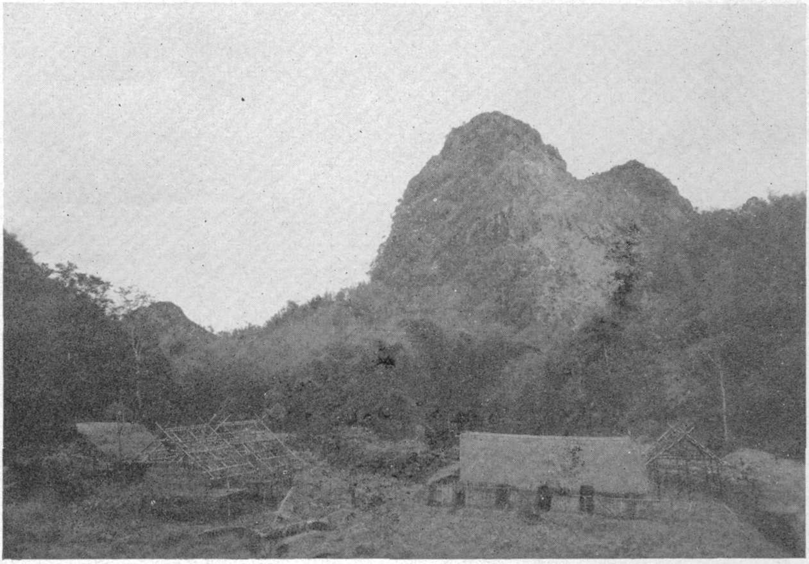


FIGURE 14.—View of Nong Phai hill looking toward the west and showing the light gray gossan and sulfide lead-zinc ore exposed high on the northeast flank. A smaller ore body crops out on the small bare hill on the skyline at left side of view above the unfinished house.

ORE DEPOSITS

The lead-zinc ore occurs as replacement bodies or fissure filling, associated with shear zones in limestone. Most of the shear zones follow three directions: N. 50° to 60° W., due north or nearly so, and about N. 40° E. (See fig. 12.) The principal lode is developed near a junction of shears trending N. 50° W. and due north, whereas the northeasterly fractures do not appear to be appreciably mineralized. The north-trending shear zones in the southern part of the area carry pockets and stringers of disseminated sulfides, partly in recemented breccia and partly in clayey seams parallel to the shear direction. At Nong Phai hill the replacement deposit lies mostly on the hanging wall of a north-trending shear, but considerable gossan covers the crest on the west side (fig. 14) of the north-trending shear and northwest of the northwestern shear trend. The pockets and lenses of disseminated sulfides are mostly less than a meter in length and a few centimeters wide. The Nong Phai replacement deposit is exposed over an irregular area of 320 square meters along a maximum length of 45 meters. The hypogene ore is fine-grained galena and sphalerite, containing a few scattered crystals of pyrite.

Post-ore faulting has formed mirrorlike surfaces of polished galena and locally has given the ore a foliated texture. The border of the sulfide mass is hard and flinty and contains considerable silica, and brecciation with many white calcite gash veins and veinlets may be seen in the tunnels and natural cavities under the sulfides.

Analyses of selected samples of ore from Nong Phai

[Analyses by the Royal Department of Mines]

Constituents	Samples	
	Lead ore	Mixed siliceous ore
Pb	70. 00	13. 95
Zn	7. 20	33. 20
Sb	. 20	
Cd	. 76	
As	. 06	
Se	. 05	
S	14. 20	
Ag	. 0302	. 0008
Fe_2O_3	. 54	2. 70
Al_2O_3		4. 75
MgO		. 55
SiO_2	4. 50	22. 80
CO_2		2. 95
H_2O		6. 60
	97. 54	87. 50

Analyses of channel-cut samples of ore from Nong Phai

[Analyses by Ledoux & Co., New York]

Samples	Constituents								
	Ounces per short ton	Percent							
	Ag	Pb	Zn	As	Sb	Fe	Cd	S	Insol.
1	2. 6	28. 2	31. 6	tr	0. 03	0. 47	0. 72	19. 11	3. 65
2	4. 0	21. 1	42. 0	0. 04	. 06	. 57	. 88	22. 1	1. 8
3	5. 2	38. 3	32. 7	. 10	. 09	. 37	. 62	20. 7	1. 2
4	3. 7	36. 8	32. 8	. 06	. 08	. 35	. 58	21. 8	. 7
5	4. 9	38. 4	27. 8	. 08	. 09	. 48	. 49	19. 5	2. 0

1. From exposure in small hill south of Nong Phai hill. Area of 0.5 by 3.6 meters of sphalerite and galena exposed.
2. From channel 5 centimeters wide and 2 centimeters deep extending 2.35 meters S. 32° W. across the west end of ore face of Nong Phai. South end of channel at slickenside in ore. North end stops 2 meters from north edge of ore body.
3. From channel cut for 3.5 meters across center of ore body at right angle to footwall.
4. From channel cut for 2 meters across ore on south side of limestone horse and including siliceous limestone fragments on south end. North end of sample against a clear surface striking N. 75° W. and dipping 72° NE.
5. From channel cut for 5.5 meters across east end of Nong Phai ore body on working face.

Considerable gossan covers the upper slopes of Nong Phai hill. The sphaleritic portion of the hypogene ore has leached out in the upper and outer faces, leaving cavities and fibrous boxworks of calcareous limonite. In the lower caverns, just above sulfide and below the ore body, considerable supergene calcite and hydrozincite form botryoidal masses, stalactites, and stalagmites. This material fluoresces blue white and cream under the ultraviolet lamp. Openings in the exposed edge of the sulfide ore are lined with crystals and coatings of pale green smithsonite and transparent anglesite.

The weathered outcrops are light gray, and the acid waters have inhibited plant growth so that the gossan stands out in the surrounding heavy tropical growth. Of the plants that seem to have some tolerance for the ore deposit waters, the most conspicuous are a dwarf date palm and a succulentlike shrub with leaf clumps called chan daeng (red spice).

MANGANESE

By George C. Taylor, Jr., and Saman Buravas

GENERAL FEATURES

Most of the manganese deposits of Thailand appear to be associated with rocks of the Korat series, chiefly with sandstones and conglomerates, and to lesser extent with shales and slates. Two general types of deposits are recognized: those of possible primary sedimentary origin, and those of secondary origin resulting from leaching of older manganiferous sediments with redeposition and concentration of manganese ore, especially in the littoral zone of the Gulf of Thailand.

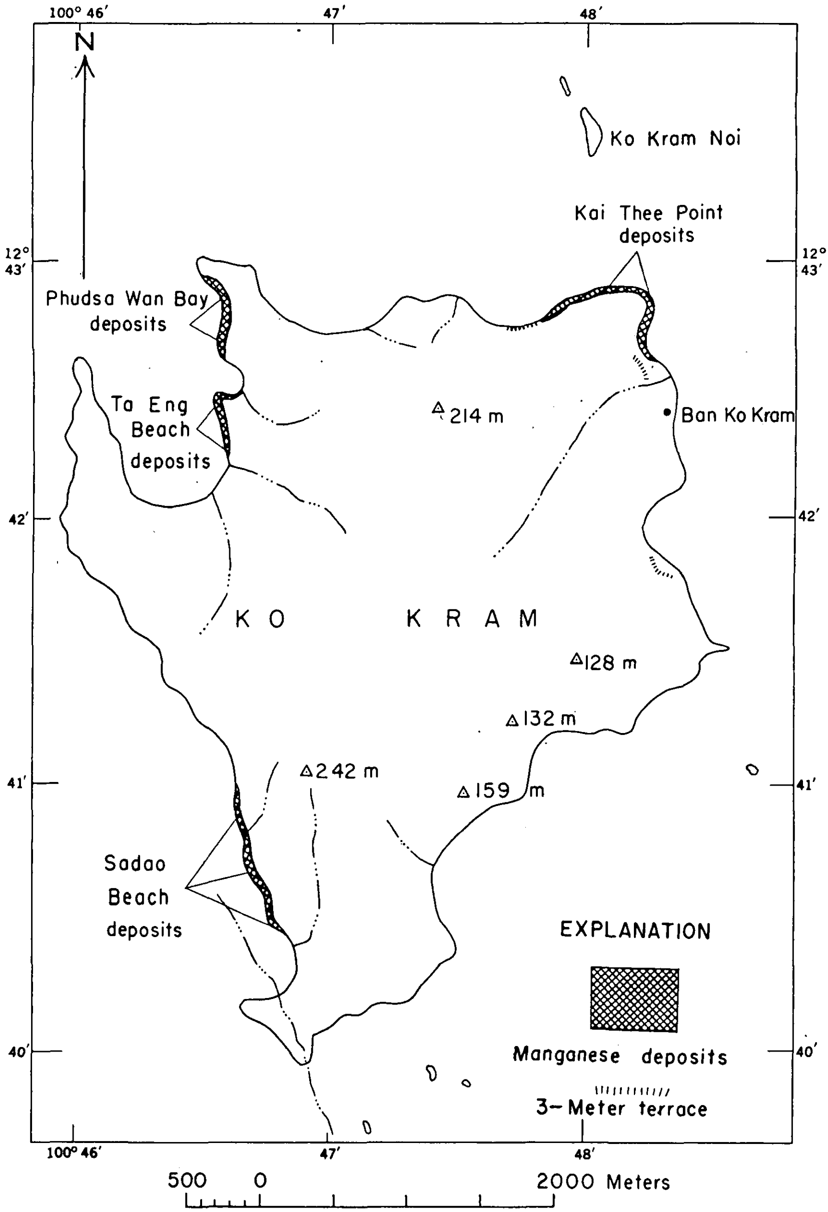
Manganese of possible sedimentary origin occurs in Changwat Kanchanaburi to the west of Bangkok and in the Changwats of Pattani and Yala in southernmost Peninsular Thailand. In Changwat Kanchanaburi a small manganese deposit is reported near Ung Lu, which lies on a tributary of the Khwae Yai about 25 kilometers north of Si Sawat. The ore of hard black manganese oxides occurs in sandstone which contains as much as 46 percent manganese. Near Luboh Jirai in Changwat Pattani manganese oxides occur as cementing material in conglomerate, and the ore is reported to contain about 19 percent manganese. Manganiferous sandstones of the Korat series are reported in Changwat Yala at four localities—Hua Toh Phran, Bralor, Samohsukeh, and Tibu. Some of the ore contains as high as 39 percent manganese.

Around the shores of the Gulf of Thailand stains, coatings, and surficial replacements of manganese oxides in the littoral zone are relatively common, but only in a few places do manganese deposits of appreciable size occur. Among the more important are deposits on the coast near Patiu (Bang Son) in Changwat Chumphon and on the islands of Ko Lan and Ko Kram in Changwat Chon Buri.

KO KRAM DEPOSITS, CHON BURI

Ko Kram (Indigo-blue Island) lies in the Gulf of Thailand about 4 kilometers west of the mainland. The Royal Thai Navy handles the administration of the island, but politically it belongs to Changwat Chon Buri. Ban Ko Kram on the southeast gulf coast is about 10 kilometers by power launch from the Sattahip Naval Base.

The island is underlain by a series of interbedded slates, sandstones and quartzitic sandstones probably belonging to the Korat series. These rocks are strongly folded and locally they are crumpled, overturned, or broken by small faults. Disseminated manganese oxides, small nodular concretions, and thin irregular stringers occur in some of the sandstone members in the interior of the island. The best manganese deposits now recognized are at Kai Thi Point, Sadao Beach, Ta Eng Beach, and Phudsa Wan Bay (fig. 15). At each of these localities manganese ore occurs in the littoral zone, chiefly in the range between high and low tides, but in places rising 1 to 10 meters above high tide. The average tidal fluctuation on Ko Kram is about 2 meters.



แหล่งแร่แมงกานีสเกาะคราม จว.ชลบุรี

FIGURE 15.—Map showing the location of the principal manganese deposits on Ko Kram, Changwat Chon Buri.

The ore consists of mixed oxides and hydrous oxides of manganese. Hard black manganese oxide is common, but soft black oxides of manganese, some of which are hydrous, are also present. The manganese ore occurs in irregular surficial replacements and in reticulated systems of narrow veinlets through sandstone and slate. In the tidal zone manganese ore commonly forms botryoidal, reniform, and stalactitic encrustations, or cappings, on the country rock.

KAI THI (THEE) POINT

Near Kai Thi Point interbedded dark gray and green shaly slates and hard brown sandstones form the country rock. Where exposed along the coast the sediments are strongly folded and in places are crumpled. Locally, narrow quartz veins traverse the sediments.

Manganese ore occurs in 10 small discontinuous cappings along a linear distance of about 1,000 meters around the northeast salient of the island (pl. 7). At high tide most of these deposits are submerged. The deposits consist chiefly of thin, spotty encrustations and irregular surficial replacements of manganese ore on the edges of steeply dipping beds of sandstone or slate. Botryoidal or reniform structure is common in most of the cappings which average only a few centimeters in thickness. Surficial replacement by manganese minerals occurs principally on ledges of sandstone and does not appear to penetrate to depths of more than 20 to 30 centimeters. Lying between manganese-capped ledges of hard rock are unconsolidated beach deposits which in places contain appreciable quantities of manganese in rolled pebbles, together with sand and gravel of quartz, coral, slate, and sandstone. A rough estimate indicates an aggregate of about 1,500 tons of manganese ore in the Kai Thi littoral zone minable by selective hand breaking and sorting.

About 30 tons of manganese ore was mined by sailors of the Thai Navy from the tidal zone about 250 meters south of Kai Thi Point. The material which included loose pebbles and hand-broken cappings was delivered to the Thai Cement Co. for experimental purposes. An analysis of the ore is reported to have indicated 26 percent manganese and 15 percent iron.

SADAO BEACH

The Sadao Beach manganese deposits lie in a strip from 5 to 15 meters wide and about 800 meters long on the southwest coast. In the southern 500 meters of the strip thin-bedded dark gray slates lie in the littoral zone, but to the north they are succeeded by red and gray sandstones which underlie the slates. Rocks of the slate-sandstone series strike N. 10°–40° E. and dip 5°–20° SE.

Manganese minerals in the southern 400 meters of the strip occur in narrow veinlets or seams which follows joints or bedding planes in gray slate. The veinlets are widely spaced and generally not more than 1 to 5 centimeters across. In places they extend 5 meters above high tide.

The northern 400 meters of the manganiferous strip is bordered by sea cliffs which rise 20 to 50 meters above high tide. In the tidal zone are numerous angular blocks of sandstone apparently fallen from the cliff faces. Manganese oxides occur through the blocks, generally as thin seams along bedding planes, joints, and minor partings. In places manganese oxides replace the sandstone almost completely to form small cellular masses of almost pure manganese minerals. Thin cappings of botryoidal manganese minerals are common on boulders near the low tide line.

Near the north end of the strip manganese minerals occur in reticulated joint systems (fig. 16) of narrow veinlets through red and gray sandstones for a distance of about 75 meters along the coast. The veinlets are exposed as high as 10 meters above sea level but are more numerous and thicker near the strand line. The recoverable manganese in the Sadao Beach deposits is probably less than 2,000 tons.

FIGURE 16.—Veinlets of manganese minerals in reticulated joint systems through sandstone, Sadao Beach, Ko Kram, Changwat Chon Buri.

TA ENG BEACH

The Ta Eng Beach manganese deposits lie on the east side of Phudsa Wan Bay and the northwest part of the island. They are in the littoral zone along a curved strip about 500 meters long, 5 to 15 meters wide, and extending from low tide to about 2 meters above high tide. Interbedded brown sandstones and gray slates, which strike north to N. 10° W. and dip 25°–45° W., form the bedrock.

The manganese (fig. 17) occurs as thin surficial coatings, as narrow fillings in openings afforded by joints, bedding planes, and other partings, and as small nodular replacements in sandstones and slates. The manganese ore, minable by selective hand breaking and sorting, is roughly estimated at about 1,200 tons.

PHUDSA WAN BAY

The Phudsa Wan Bay manganese deposits lie along the northeastern shore of Phudsa Wan Bay. The deposits occur discontinuously in a strip about 1,025 meters long. Because the coast line is steep the lateral

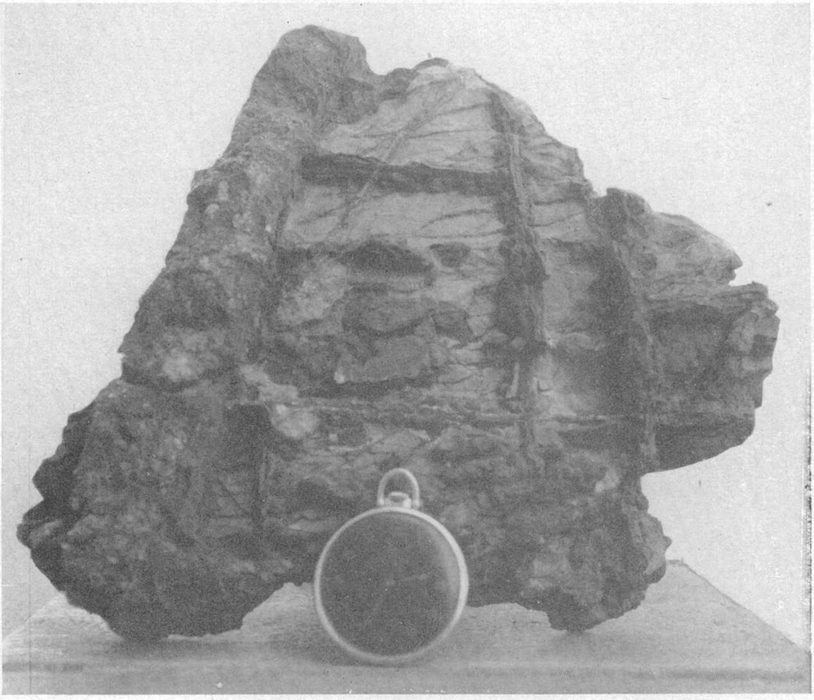


FIGURE 17.—Sample from Ta Eng Beach, Ko Kram, Changwat Chon Buri, showing tabular fillings and nodular replacements of manganese minerals in brown sandstone. Quartz vein on left is coated and partially replaced by manganese ore.

range between high and low tide lines is only a few meters. The rocks in the littoral zone are dark gray and brown slates resting on hard reddish-brown, cross-bedded sandstones. The slate-sandstone series strikes N. 10°–80° W. and dips 20°–45° N. and W.

Some manganese minerals occur as thin encrustations on rocks in the tidal range. However, the manganese is more commonly found as narrow veinlets in irregular reticulated systems through sandstones. The veinlets are seldom more than 1 to 2 centimeters wide. The aggregate minable ore in the manganiferous strip is probably less than 1,000 tons.

MOLYBDENUM

Powellite and molybdenite occurring as minor accessory minerals associated with tin-tungsten veins, intruded granites, pegmatite dikes, or other rocks, have been recognized at many localities. However, the Nam Khun prospect is the only known locality in Thailand where an attempt has been made to develop molybdenum on a commercial scale.

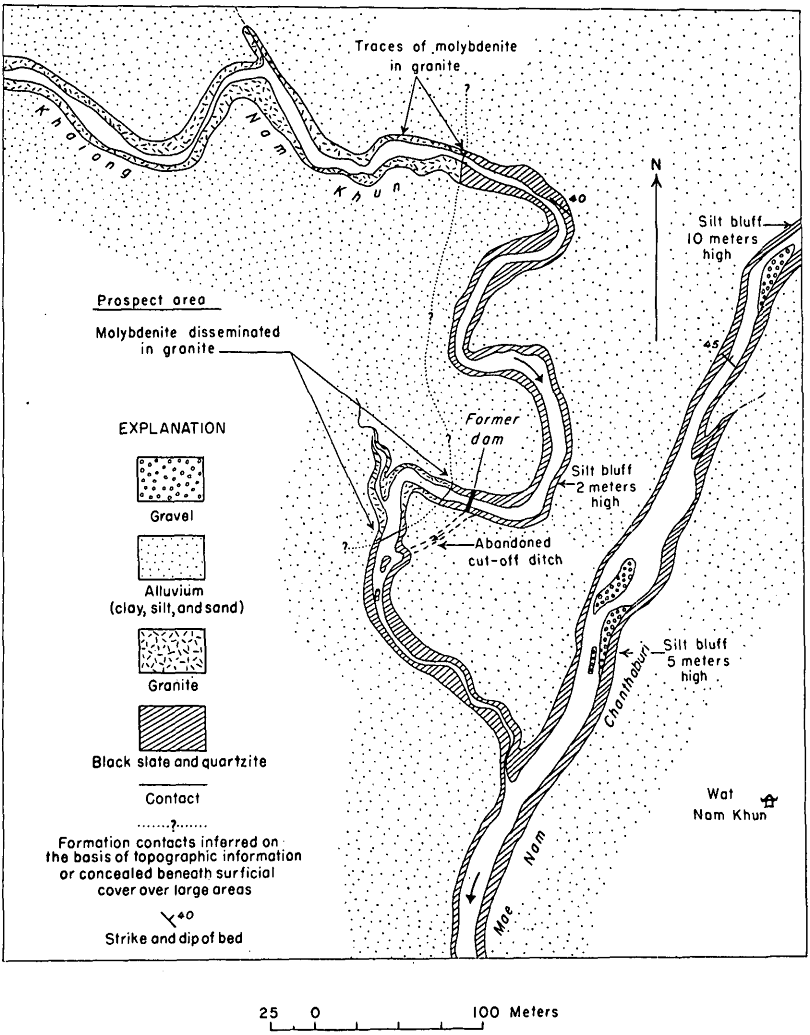
NAM KHUN PROSPECT, CHANTHABURI

By Saman Buravas, Jumchet Charaljavanaphet, and George C. Taylor, Jr.

The Nam Khun molybdenum prospect (fig. 18) is in Changwat Chanthaburi 35 kilometers airline to the north-northwest of the city and 250 meters east of Wat Nam Khun. To reach the prospect one follows a jeep track from Chanthaburi for 25 kilometers north to Ban Phluang and thence northwest on foot or by oxcart for 21 kilometers to Ban Nam Khun. The prospect lies in the channel of Khlong Nam Khun about 150 to 200 meters upstream from the junction with Maė Nam Chanthaburi. The prospect is about 35 meters above sea level.

The oldest rock in the area is a metamorphic series of interbedded dark gray slates and massive gray arkosic quartzites which strikes northwest and dip 30°–50° NE. The metamorphic series is intruded by biotite-muscovite granite. Both the granite and the metamorphic rocks are truncated by an erosion surface which is generally blanketed by sandy and silty alluvium to a depth of 5 to 15 meters. Recent downcutting by Khlong Nam Khun and Mae Nam Chanthaburi has reexposed the older rocks along the stream channels.

Molybdenite occurs in irregular scaly blebs ranging from a few millimeters to 20 millimeters in diameter. These are disseminated through the granite in the contact zone near rocks of the metamorphic series. Associated with the molybdenite is pyrite. The molybdenite-bearing granite crops out for a length of about 75 meters along the channel of Khlong Nam Khun. The average content of molybdenite



ธรณีวิทยาแหล่งแร่โมลิบเดนั่ม บ.น้ำขุ่น จว.จันทบุรี

FIGURE 18.—Geologic map of Nam Khun molybdenum prospect, Changwat Chanthaburi.

in this outcrop appears to be considerably less than 1 percent by weight of the total rock.

In 1942 the Thai Mineral & Rubber Co. built a small earth dam across Khlong Nam Khun at the head of the prospect area. The flow of the stream was then diverted through a short cut-off canal and delivered back into the natural channel below the prospect area. Several test pits 1 to 2 meters deep were then put down to prospect the outcrop, but this work ceased 5 months later when a monsoon flood destroyed the dam.

MONAZITE

By Saman Buravas

Monazite is one of the heavy minerals occuring with cassiterite in the tin dredging areas of southern Thailand. No monazite sands such as occur in Travancore, India, or in Brazil have been found.

In washing the concentrates from the dredges of the Kamunting Tin Dredging Co. on the Phangnga River, in Changwat Phangnga, monazite and ilmenite, together with a small percentage of cassiterite, are found in the tailings. When these tailings are run through a magnetic separator for further tin recovery, monazite is concentrated on one of the discs of the separator. The monazite was further concentrated and a sample containing 70 percent monazite was obtained. An analysis of this sample showed it to contain about 45 percent of cerium and other rare earths and 4 percent thorium oxide, together with 20 percent of tantalite.

Monazite has been reported from other dredge concentrates in southern Thailand but no method of commercial recovery has yet seemed feasible.

TIN AND TUNGSTEN

Because tin and tungsten are commonly found together, and in many places are recovered from the same deposit, they are here described together. It has seemed best to describe separately the tin-tungsten deposits of the northwest, where mining is relatively new, and the tin-tungsten deposits of the south, which have been mined for many years.

PRODUCTION

TIN

Tin production in Thailand reached a maximum of 17,116 long tons of contained metallic tin in 1940. As a consequence of the war years production dropped to 1,056 tons in 1946. It rose to 7,815 tons in 1949. Annual production statistics have been kept since 1932 by the Royal Department of Mines and the following tables are from that source:

Annual production of tin in Thailand, 1932–49

	Tin content of concentrates (long tons)		Tin content of concentrates (long tons)
1932	9, 296	1941	15, 827
1933	10, 185	1942	7, 833
1934	10, 638	1943	5, 840
1935	9, 876	1944	3, 296
1936	12, 734	1945	1, 775
1937	15, 909	1946	1, 056
1938	14, 820	1947	1, 401
1939	15,637	1948	4, 240
1940	17, 116	1949	7, 815

Annual production of tin in Thailand, by changwats, 1940–41 and 1946–49

[In long tons of metallic tin contained in the concentrates]

Changwat	1940	1941	1946	1947	1948	1949
Phuket	2, 633. 93	2, 380. 79	337. 59	319. 05	1, 264. 80	2, 111. 97
Ranong	2, 452. 67	2, 131. 39	151. 97	237. 72	710. 49	1, 299. 38
Phangnga	3, 236. 65	2, 745. 67	37. 77	146. 07	180. 17	1, 098. 73
Takuapa	2, 723. 97	2, 703. 58	280. 47	432. 61	1, 337. 53	1, 815. 91
Trang	332. 55	196. 46	7. 97	31. 72	34. 33	45. 99
Songkhla	1, 139. 34	1, 033. 12	11. 64	35. 38	138. 04	186. 73
Nakhom Si Thammarat	1, 197. 73	1, 164. 28	73. 61	73. 94	295. 94	445. 20
Surat Thani	613. 76	571. 73	32. 06	31. 00	76. 75	269. 35
Chumphon	479. 16	357. 86	38. 97	34. 10	40. 87	74. 74
Yala	2, 076. 37	2, 316. 36	67. 75	30. 87	124. 02	389. 97
Rat Buri	229. 60 (Rat Buri, Prachuap, Kanchanaburi combined)	28. 84	9. 35	--------	1. 88	15. 96
Prachuap		169. 94	5. 90	18. 38	19. 47	60. 76
Kanchanaburi		27. 14	. 96	. 34	15. 91	--------
	17, 115. 73	15, 827. 16	1, 056. 01	1, 401. 18	4, 240. 20	7, 814. 72

During World War II, tin was smelted in Thailand. Furnaces were small and inefficient and tin losses in the slag were high. No tin has been smelted since 1947 in Thailand.

Smelter production of tin ingot in Thailand, 1943–47

	Long tons
1943	2, 351. 8
1944	3, 534. 5
1945	1, 651. 6
1946	388. 6
1947	141. 3

The amount of tin produced by various types of mining, during 1949, is given in the following table:

Tin production in Thailand, by various types of mining, in 1949

Type	*Contained metallic tin (long tons)*	*Percent of total production*
Dredges	4, 868. 07	62. 29
Gravel pump mines	1, 727. 21	22. 13
Hydraulic mines	141. 04	1. 77
Other means (including underground mines)	653. 28	8. 36
Dulang washers	425. 12	5. 45
	7, 814. 72	100. 00

TUNGSTEN

The maximum annual production of wolframite in Thailand was 1,579 long tons in 1943. Production in 1949 was 674 tons, of which approximately a half came from south Thailand and the other half from the northwest along the Burma border. The average content of tungsten trioxide is about 65 percent. The Royal Department of Mines has kept production statistics since 1935 and the following is their record:

Annual production of wolframite concentrates (averaging 65 percent WO_3 in Thailand, 1935–49

	Long tons		Long tons
1935	70	1943	1,579
1936	77	1944	1,032
1937	90	1945	419
1938	229	1946	182
1939	342	1947	454
1940	377	1948	449
1941	873	1949	674
1942	1,502		

Origin, by changwats, of tungsten concentrates in 1949

Changwat:	Long tons	Changwat—Continued	Long tons
Phuket	6.6	Surat Thani	17.8
Ranong	26.4	Yala	1.8
Phangnga	1.5	Mae Hong Son	378.4
Takuapa	30.8		
Songkhla	80.1		674.1
Nakhon Si Thammarat	130.7		

Origin, by changwats, of mixed tin-tungsten concentrates in 1949

Changwat:	Long tons
Kanchanaburi	326.9

NORTHWESTERN AREA

Tin and tungsten deposits in western and northwestern Thailand are a northward continuation of the tin-tungsten metallogenetic province of Malaya and Peninsular Thailand. These metals were deposited in the fringes and tops of granitic stocks that form the core of the mountain chain along the Burma-Thailand frontier. The frontier mountain chain of Tavoy trends N. 40° W. from Peninsula Thailand, continuing northwest into Burma, south of the region of Three Pagodas Pass. The fissure veins, stockworks, and pegmatites carrying cassiterite and wolframite are all within 2 or 3 kilometers of the frontier and lie near the crest of the mountains at altitudes of 1,000 meters or slightly less. They are in granite, granitized schist, and metamorphosed slate, phyllite, and marble, all deeply weathered. Wolframite soon disappears in the tropical weathering process so that only cassiterite is found in the alluvium downstream. Mining, especially during the dry season, is difficult because there is a shortage of water in the altitudes of the lodes.

The districts of Pilok and Rat Buri, within the frontier range, are currently producing about 10 metric tons a month of cassiterite from small hydraulic mines and quartz lodes and about 25 metric tons of wolframite from veins. The other producing district is in Amphur

Mae Sariang, Changwat Mae Hong Son, near the Burma border southwest of Chiang Mai, in the Thanon Thong Chai Mountain range. About 35 metric tons a month of wolframite, with minor cassiterite, is being mined from veins in and near a circular granite stock. Some cassiterite-bearing alluvium derived from a large granite batholith extending south of the Mae Kok, near the Shan States border at Chiang Rai, has been worked by local people in the past, and now test boring is being undertaken.

MAE SARIANG TUNGSTEN DISTRICT, MAE HONG SON

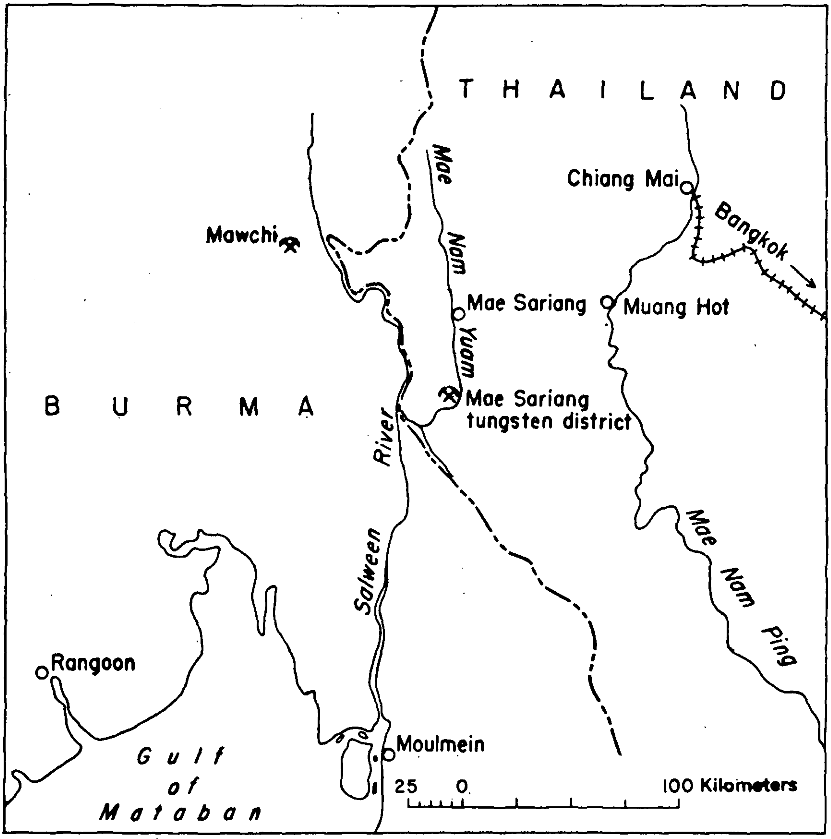
By Glen F. Brown and Nitipat Jalichandra

GENERAL FEATURES

The recently opened Mae Sariang tungsten district in northwestern Thailand is one of the country's principal producers despite its inaccessibility and poor communications. It is in rugged hills rising about 1,000 meters above the Mae Nam Yuam River, and mining operations are handicapped by insufficient water, especially during the dry winter months. Quartz veins containing scattered pockets of wolframite are found in a medium- to coarse-grained granite and in deeply weathered phyllite near the contact of the granite. The granite forms a stock that has intruded a metamorphic series of slate, phyllite, quartzite, and marble or marmorized limestone which strike northwest. High on the hills the metaclastic rocks are so deeply weathered that in the vicinity of the prospects the outcrops are sandy shale, and sandstone. Marble or marmorized limestone weathers much slower and stands out as cliffs and rough karst terrain. Vein widths range from a few centimeters to 2 meters. The principal lode, which is at the Mae Lama mine, is 460 meters long.

LOCATION AND ACCESSIBILITY

The Mae Sariang tungsten district lies in Amphur Mae Sariang, Changwat Mae Hong Son, 97°50′ east longitude, 17°52′ north latitude, in northwestern Thailand. It is 20 kilometers from the Burmese border and 140 kilometers from the famous Burmese tungsten district of Mawchi (fig. 19). The continuation of the Thanon Thong Chai range, through which the Mae Nam Yuam (fig. 20) has cut a canyon, affords the most accessible route to the veins. The nearest town in Thailand is Mae Sariang, the Amphur headquarters, 50 kilometers north in the valley of the Mae Nam Yuam. The valley is isolated by rugged mountains and can be reached by planes which must land at a small airfield 2 kilometers north of the town of Mae Sariang, or by following elephant trails for several days, either from Burma or



ที่ตั้งแหล่งแร่วุลแฟรมแม่สะเรียง จว.แม่ฮ่องสอน

FIGURE 19.—Index map showing location of the Mae Sariang tungsten district.

Muang Hot in the valley of the Mae Nam Ping. Mining equipment and ore are shipped through the northern railhead of Chiang Mai, 100 kilometers north of Muang Hot.

DEVELOPMENT

Wolframite was discovered more than 10 years ago by lumbermen working in the teak forests nearby. During the period of high tungsten prices of World War II considerable ore was mined from the outcrop of the principal lode, the Mae Lama, by local people and by Burmese, but organized development did not begin until the middle of 1948 when a group of Chiang Mai residents obtained a 3-year lease from the Thai Government. In the following 18 months about 450 metric tons of wolframite concentrates averaging 65 percent

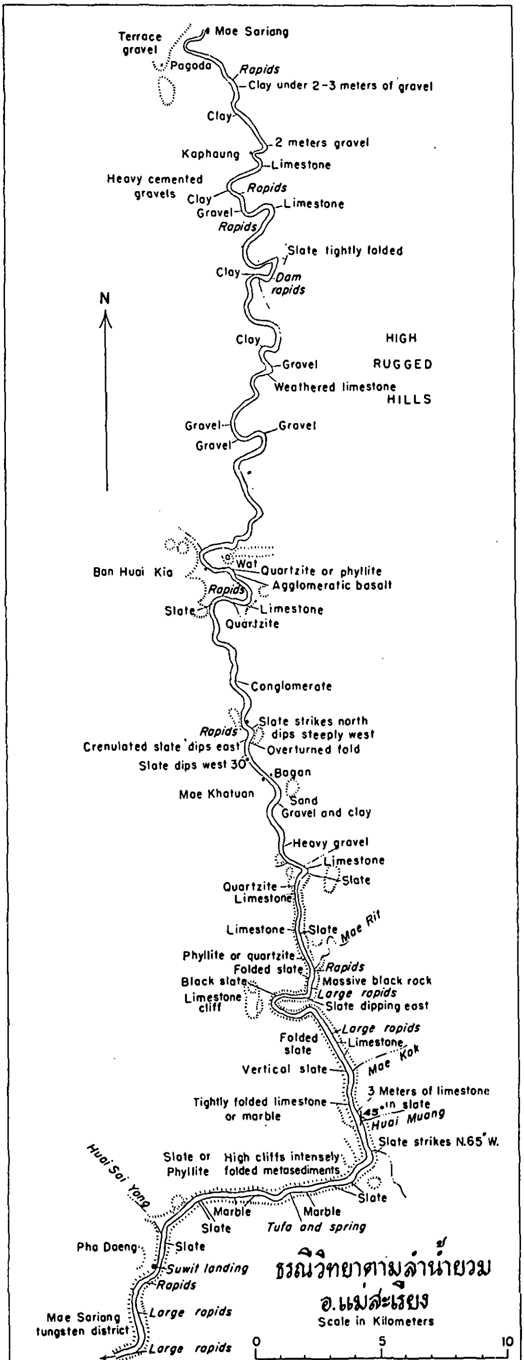


FIGURE 20.—Sketch of the Mae Nam Yuam showing geology along the banks from Mae Sariang to the Mae Sariang tungsten district.

tungsten trioxide was mined and shipped. Of the total production about 83 percent came from the Mae Lama lode, the discovery lease.

Common mining practice involves following the veins downward from the outcrops. The mine laborers are assigned working ground within the lease where they drill and crush the ore by hand methods, finally concentrating the wolframite by panning. The concentrates are then purchased by the lessee from the miners. Currently (1950) the mining cost is about two-fifths the market price of wolframite in Bangkok. Production has come from colluvium and surface mining of outcrops (fig. 21), mostly at depths of less than 5 meters. Recently crosscuts have been driven about 30 meters beneath vein exposures at the Mae Lama lode. High relief and the difficulty of disposing of water during the rainy season will lead to underground

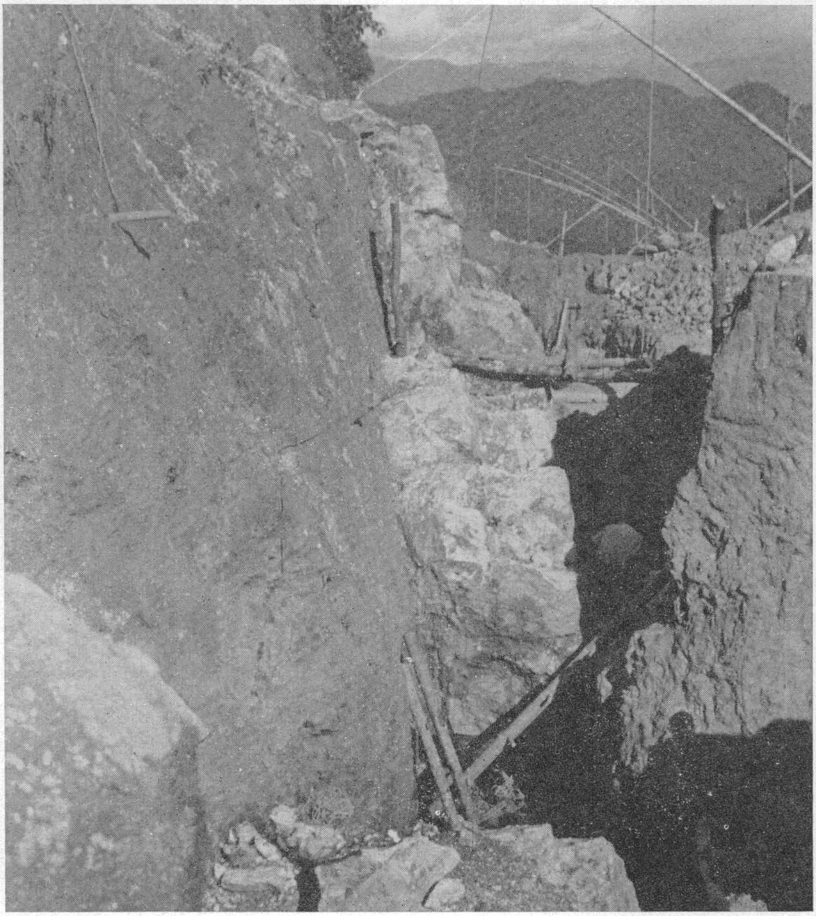


FIGURE 21.—Open cut in wolframite-bearing quartz of the Mae Lama vein, Mae Sariang district, Changwat Mae Hong Son. Ore hoisted by spring poles shown in background.

mining at the other veins too. Some sluicing was begun in the district late in 1949, but the shortage of water during the winter months sharply curtailed use of this method of concentration.

TRANSPORTATION OF ORE

Wolframite is shipped from the mines north to Mae Sariang by boat and by overland trail. Boats carrying 1,000 to 1,500 kilograms of ore are poled up the swift currents of the Mae Nan Yuam in 5 days. Eight days are required for horses, cattle, and sometimes elephants, carrying saddle packs of 40 to 60 kilograms, to make the trip overland. From Mae Sariang the ore is flown to Chiang Mai and thence shipped by train to the Bangkok market. One mine operator states that the cost of transport from the mines to Mae Sariang is 1.10 baht ($0.055) a kilogram; by plane from Mae Sariang to Chiang Mai, 2.25 baht ($0.11) a kilogram; and by train to Bangkok it is 0.50 baht ($0.025) a kilogram. Thus, transportation to the nearest market is roughly equal to one-third the value of the ore.

The only other feasible route from mine to market lies down the Mae Nam Yuam to the Salween River and by it to Moulmein, Burma. Such a route would require bypassing the Mae Nam Yuam rapids by constructing a trail or road round them, the return of peace to Burma, and low duty on the ore at the Burmese frontier. Transportation at the present time by this route is impossible.

GEOLOGIC SETTING

The tungsten veins crop out in an area of rugged hills whose concordant crests trend northwest along the regional strike of the metamorphic rocks which underlie most of the region (pl. 8). The trunk streams follow the regional strike except where entrenched meanders cut across the dip and where the Mae Nam Yuam flows west to join the Mae Nam Moei. There the river has cut a meandering gorge through the metamorphic rocks and across the southeast corner of a granite stock. At Pha Daeng, the landing used for transporting ore from the district, calcareous slate is interbedded with bands of marble 1 or 2 centimeters thick, which are intensely folded. The axes of drag folds trend slightly west of north. The higher hills east and north of the district are composed of marble or marmorized limestone, but near the veins granite, phyllite, and quartzite underlie the crests. The phyllite and quartzite are deeply weathered and altered by hypothermal solution so that the wall rocks in the vicinity of the veins appear to be sandy shale, clay shale, and sandstone. In comparison with the granite and the metaclastic rocks, the calcareous rocks tend to resist erosion so that they form cliffs and rugged, nearly impassable,

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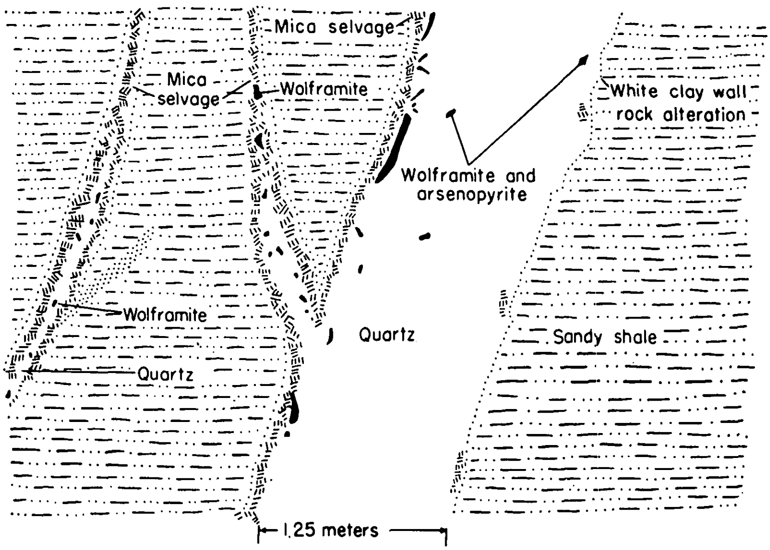
terrain. Granite, phyllite, and quartzite crests are rounded or, where dissected, form narrow ridges.

ORE DEPOSITS

The quartz veins containing tungsten occur in granite and sandy shale near the borders of the granite stock. They form two distinct vein systems, one striking to the east and the other to the north. The most eastward-striking veins are decidedly richer than the veins striking northward. The most productive veins, those of the Mae Lama mine and leases nearby, strike N. 65° E. and dip steeply south. They occur in sandy shale (pl. 9). Veins range in width from a few centimeters to 1.25 meters, the larger dimension being that of the Mae Lama lode which is exposed for 460 meters along the strike. The Mae Lama vein system consists of three closely spaced fissure veins arranged in echelon. Near the extremities of the veins the numerous off-shooting veinlets diminish to micaceous stringers. The rest of the veins in the district strike northerly, ranging in direction from N. 25° W. for those north of the Mae Lama mine to N. 25° E. for those situated near the eastern edge of the granite stock. All dip steeply. The veins are in granite except those at the Chanta and Kamfu leases in the northwest part of the district which are in sandy shale, and those on Mae Sariang Mining Co.'s lease at the northern edge of the district where the veins are in a decomposed sandy rock altered from quartzite or sandstone. At the Mae Sariang mine the veins follow the bedding along the crest of a small anticline which ends to the east against downfaulted shale or weathered slate. The veins appear to be tension fractures in the arenaceous rock and are best developed along the anticlinal axis. The anticline was possibly formed by drag of a fault produced prior to the deposition of the ore.

Almost all the tungsten ore is wolframite, but the ultraviolet lamp reveals scheelite as a substantial part of the ore at Mr. Pan's prospect in the eastern part of the district, as a minor part of the ore at two other prospects, and as a coating on some of the wolframite at the Mae Lama mine. The scheelite fluoresces blue, white, and pale yellow. The wolframite is found in grains, blades, and massive pockets scattered through white, subtranslucent quartz (fig. 22). Most of the larger crystals and crystal aggregates are concentrated along the walls of the massive quartz vein-filling and appear to have grown outward toward the middle of the vein from the mica selvage which envelops many of the quartz lenses. Scheelite occurs in two forms: as yellow-brown crystals replacing wolframite, and as a gray powder coating the periphery of wolframite crystals. The most common sulfide is



ภาพตัดแสดงสภาพสายแร่แม่ลามา

FIGURE 22.—Diagrammatic cross section of the Mae Lama tungsten veins, Mae Sariang district.

arsenopyrite which is associated with wolframite and scheelite in several quartz veins. One vein in granite on the east side of the district also contains pyrite; the outcrop of the Chanta vein contains chalcopyrite, molybdenite, and abundant arsenopyrite. Tin in the form of brown translucent cassiterite has been found in only one small vein at the Mae Sariang lease; coarse crystals constitute one-half of the ore concentrates.

THE PILOK TUNGSTEN-TIN DISTRICT, KANCHANABURI

By Glen F. Brown, Vija Sresthaputra, and William D. Johnston, Jr.

LOCATION AND ACCESSIBILITY

The mines of the Pilok district are within a belt 30 kilometers long and 2 kilometers wide along the Burma-Thailand border in Changwat Kanchanaburi, western Thailand (fig. 23). The veins crop out on the rugged eastern flank of the frontier range of Tavoy in an inaccessible and heavily forested hinterland. Before construction of a 60-kilometer road from Tha Khanon, a village on the Burma-Thailand railroad, to the river Khwae Noi, the ore was shipped from the district by elephants, which are still used for transport at Song Khwae in the southeast end of the district. Current (1950) transport is by truck, down the narrow and winding road descending 850 meters to

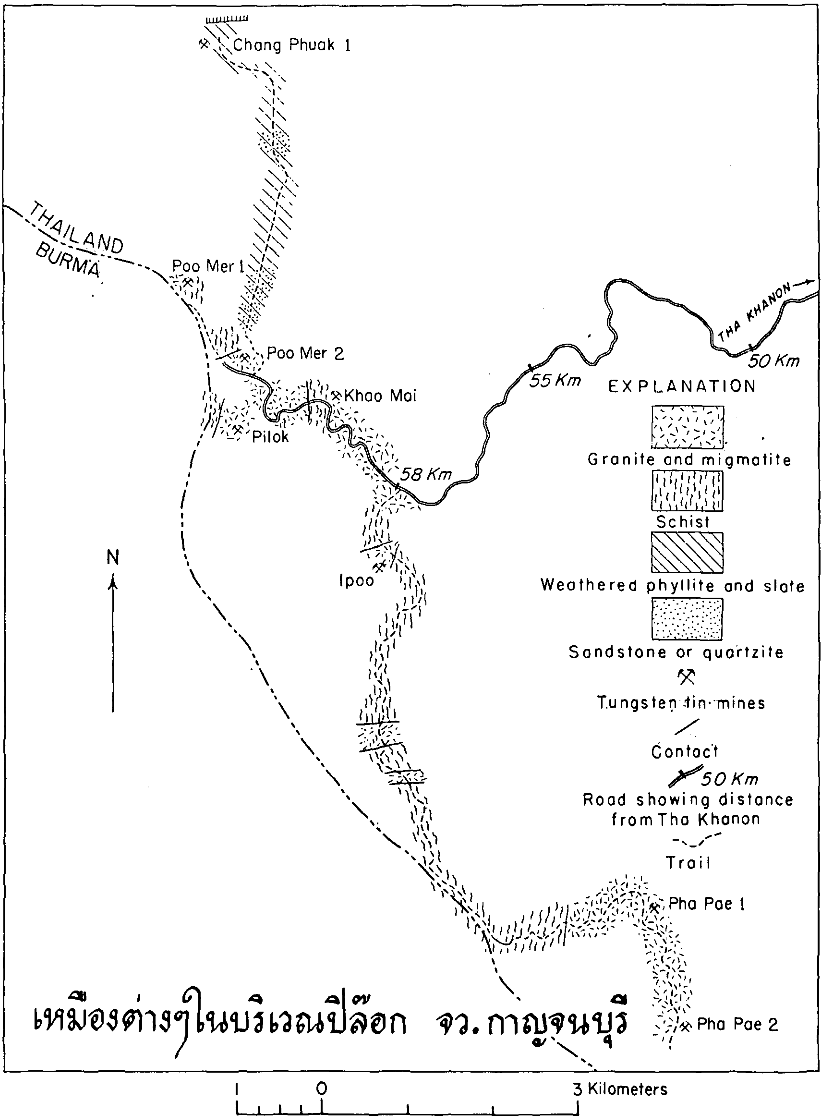


FIGURE 23.—Sketch showing location of mines in the Pilok tungsten-tin district, Changwat Kanchanaburi.

Tha Khanon where the ore is transhipped to Kanchanaburi by boat. Normally 5 days are required to reach Tha Khanon by boat on the river Khwae Noi from Kanchanaburi, and 2 or 3 days for the return trip downstream, but the time varies with the season and the stage of the river. Kanchanaburi is connected by rail and improved truck road with Bangkok.

DEVELOPMENT AND PRODUCTION

Tungsten and tin mining in the Pilok district has been important only in the past 10 years. Nothing is known of the discovery of the ore and early work, but the proximity of the district to the Zimba mines of Burma suggests that it might have first been worked by the Burmese. Production could not have been substantial because of transportation difficulties. Thai interests began operation in 1939, and in 1942 when the high price of wolframite stimulated production, they extended a timber access road from the river Khwae Noi, a distance of 60 kilometers. During the dry months when transportation is easiest, mining operations are difficult because of water shortage; the current production of 300 to 400 metric tons a year is mined mostly during the wet months from May to October. Of the concentrates shipped down the Khwae Noi, about three-fourths are wolframite and one-fourth cassiterite.

The oldest mines, Pilok and I Pu, have extended underground workings down to depth of 30 meters beneath the outcrops of the veins, but the other mines, many of which have been opened within the last 2 years, are mostly surface workings. The quartz veins throughout the district possibly average 1 percent wolframite. However, many veins are barren and a few contain pockets of ore weighing several hundred kilograms, a characteristic of tin-tungsten veins which makes it difficult to estimate reserves of ore. The streams carrying cassiterite-bearing gravel away from the lodes are mined locally by ground sluicing. The few hydraulic giants in the district are used mostly to wash weathered parts of the lodes.

GEOLOGIC SETTING

The tungsten-tin veins of Pilok are associated with granite which has intruded a series of metasedimentary rocks, and with schist of unknown origin. In the northwestern part of the district the quartz veins lie in shale, sandy shale, and sandstone which are the weathered upper edges of slate, phyllite, and quartzite. Farther south where mineralization was more intensive, the veins are in weathered granite although the contact of the granite with quartz-muscovite schist or chlorite schist is never far away. Along the road cuts to the mines, schist and phyllite, or their weathered equivalents, alternate with bands of granite or granitized schist. The older rocks strike northwest and dip steeply in folds parallel to the schistosity and also apparently parallel to the long axes of the granitic intrusions. Similar metasedimentary rocks in the adjacent district of Tavoy, Burma, have been assigned to the Mergui series of doubtful pre-Cambrian age

(Brown and Heron, 1923, pp. 178–184). However, these metasedimentary rocks grade eastward in Thailand to sandstone and phyllite which underlie Rat Buri limestone, and they are similar lithologically to beds in the region containing fossils of Silurian age that have been assigned to the Kanchanaburi series.

The granite rocks contain both biotite and muscovite and are of medium- to coarse-grained texture, with minor aplitic and pegmatitic facies. In the vicinity of the mines they have been altered to greisen by the introduction of coarse mica, tourmaline, and possibly hydrothermal clay minerals. The age of the intruded rock or rocks is unknown; elsewhere similar tin-tungsten bearing granites of the Sino-Malaysian metallogenetic province are considered to be post-Triassic and pre-Tertiary, possibly of Cretaceous age (Credner, 1935, pp. 13–15; Scrivenor, 1931, pp. 19–23).

ORE DEPOSITS

The tungsten and tin ores of Pilok occur in steep quartz fissure veins and vein networks containing coarse mica and tourmaline. A few localities contain feldspar which suggests that the "veins" might better be classified as pegmatite. Veins range from a few centimeters to 5 meters in width and are exposed for lengths of 100 meters although most exposures are less than 30 meters in length. Pyrite, chalcopyrite, molybdenite, scheelite, and beryl are minor constituents. The scheelite appears as two varieties under the ultraviolet lamp, and both are unimportant as ores.

The potential importance of the district warrants some description of the localities now being mined and prospected.

CHANG PHUAK 1 MINE

The Chang Phuak 1 or northernmost mine in the district is on four veins—three closely spaced in a distance of 30 meters, and a fourth about 500 meters farther west. All strike nearly north and stand vertical or dip steeply west in quartzitic sandstone, sandy shale, and clay shale (fig. 24). The easternmost vein is somewhat pegmatitic, containing a white feldspar which is probably orthoclase, as well as molybdenite, chalcopyrite, and white mica. The sulfides and mica are intimately associated with crystals of wolframite. The other veins which have been partially mined are composed of white and massive quartz, containing vugs and scattered books of golden brown mica. The veins are narrow and contain less than 1 percent of wolframite. The wall rocks are decomposed phyllite, which strike N. 20° W. and dip 58° W. The westernmost vein dips 60° W. in weathered phyllite and is being mined for cassiterite which occurs sparingly in the muscovite selvage.

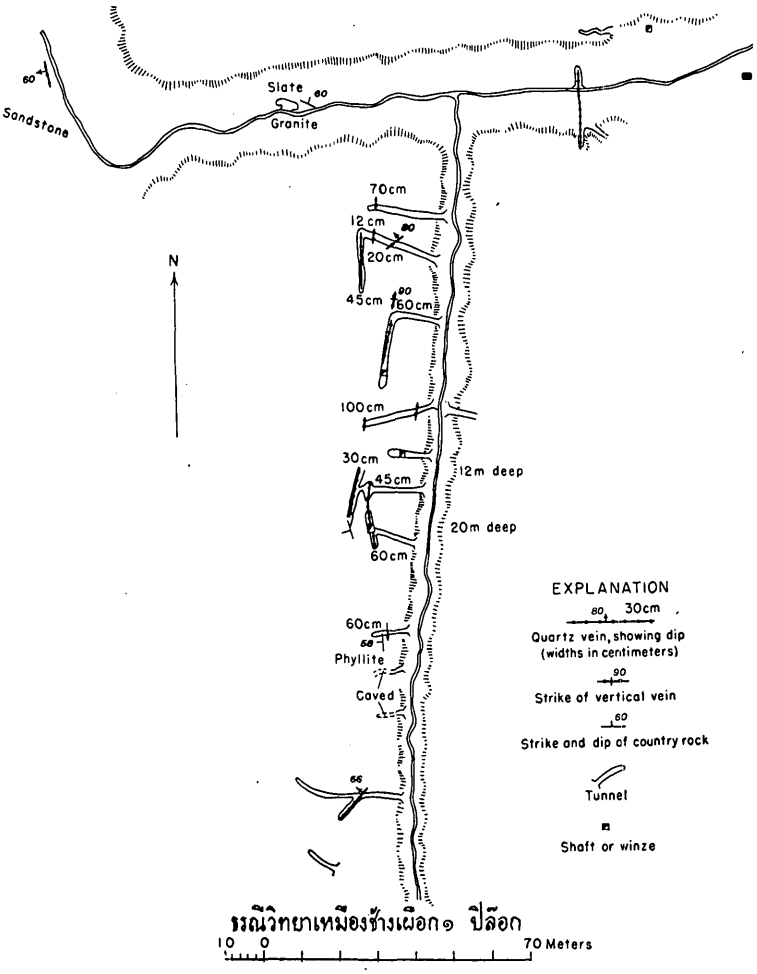


FIGURE 24.—Sketch map of Chang Phuak 1 tungsten-tin mine, Pilok district.

POO MER MINES

At the Poo Mer 1 mine of the Prachon Trading Co., southwest of Chang Phuak and near the Burma border, hydraulic removal of the colluvium has exposed several quartz veins and veinlets containing black tourmaline along the surrounding granite walls (fig. 25). The veins strike N. 35° E. and dip steeply northwest; they are cut by a few younger veins striking N. 40° W. and standing nearly vertical.

Small adits and open cuts near the granite-schist contact at the southeast corner and at the northern edge of the property are currently yieldingly about 2 metric tons of wolframite concentrates a month.

The newer Poo Mer 2 mine of the same company is about 1 kilometer northeast of the Pilok mine in a small valley cut in granite. Vertical

FIGURE 25.—A quartz vein in granite at the Poo Mer 1 mine, Pilok district, Changwat Kanchanaburi, showing tourmaline along the vein walls. Wolframite occurs in small crystals dispersed in gray and white quartz.

quartz veins striking N. 80° E. are exposed across the working floor of the quarry. On the north wall a flat-lying vein 1.5 meters wide caps the vertical veins. The hanging wall of the flat vein is a fine-grained tourmaline schist. Most of the wolframite, which is now being produced at the rate of 2 tons a month, comes from the lower part of the flat vein which parallels in place the contact of the schist and granite, and from the upper micaceous parts of the nearly vertical veins below.

PILOK MINE

The Pilok mine is on a faulted vein network wherein the vein segments strike within the arc N. 20° W. to N. 30° E. and dip at various angles into granite. The quartz veins crop out along the crest of a north-trending ridge about 1 kilometer east of the Burma border and below an eastern spur of the quartzite and schist crest of the border divide. Mining has followed veins for 300 meters along the strike and through widths of a few centimeters to 3 meters (pl. 10). The vein network follows a pattern of joints in the granite which is intensely altered. Much tourmaline and coarse muscovite occur along walls of the vein, both within the wolframite-bearing part of the quartz vein and in stringers in the granite away from the quartz veins (pl. 11). Later faulting has cut across granite and quartz, leaving white clay gouge in nearly vertical fissures. The veins at the southern and upper limit of the mine contain feldspar and beryl, along with some wolframite.

KHAO MAI MINE

The small Khao Mai mine at kilometer 60 on the Tha Khanun road east of the Pilok mine somewhat resembles the Pilok in that the quartz-wolframite veins follow a pattern of joints in the granite. However, east-trending veins are cut by north-trending veins, indicating two periods of vein formation and mineralization (pl. 12). Wolframite is erratically distributed throughout the veins. Some exposures are barren, others contain scattered wolframite crystals with occasional pyrite and chalcopyrite, and in one exposure the wolframite crystals were so closely grouped that 2 cubic meters of vein material yielded 700 kilograms of wolframite. Cassiterite, which comprises 30 to 35 percent of the concentrates, accompanies wolframite and is also erratically distributed.

I PU MINE

The I Pu mine is about 1.5 kilometers south of the Chang Phuak mine on a branch of the truck road to Tha Khanon.

A hill of weathered granite, 50 meters high, is cut by many quartz veins (pl. 13). Originally the Burmese washed the colluvial placer ground on the hillside and in the ravines that drain from it. Present workings are both underground and open cuts.

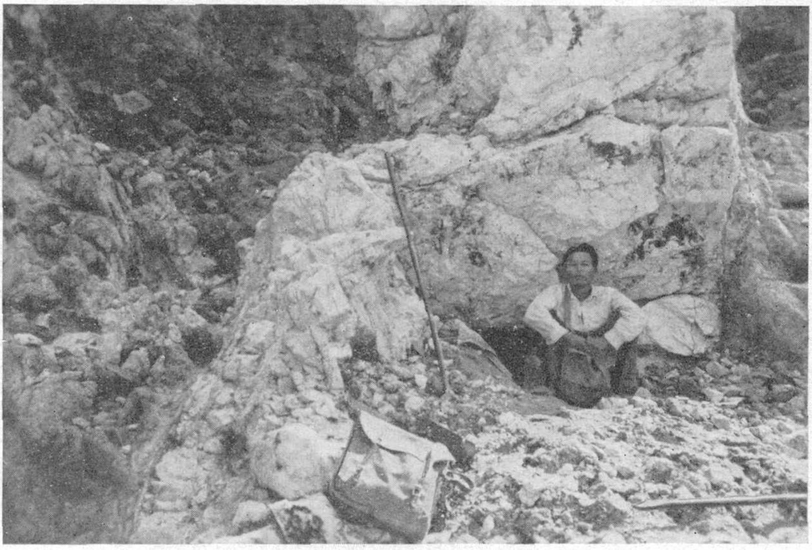


FIGURE 26.—A tungsten-bearing vein at the I Pu mine, Pilok district, Changwat Kanchanaburi, where wolframite and muscovite form pockets within the quartz, mostly near the vein walls (dark areas).

The quartz veins range in width from a few centimeters to 3.5 meters. The predominant strike is northward, but many veins depart from it. Dips range widely. The quartz is milky to glassy. In places it has been fractured by postvein movements that are recorded in gouge seams and in planes of granulated quartz. Many veins have a marginal selvage of black tourmaline and white mica. Mica also occurs as scattered rosettes throughout the vein. The wolframite occurs in individual crystals and in randomly distributed pockets, both on the margins of the veins and within the vein (fig. 26). Some of the wolframite is partially replaced by scheelite but the total amount of scheelite is not large. One of the upper adits showed a quartz face 1.5 by 2.5 meters in area. The quartz was estimated to contain between 2 and 5 percent wolframite. The largest wolframite crystals were 1 by 3 centimeters and showed conspicuous twinning on the cleavage surfaces. Such rich pockets occur occasionally.

Production is reported to average 4 tons per month in the dry season and 10 tons per month during the rainy season, when the open cuts in weathered granite can be worked by hydraulic methods. The proportion of wolframite to cassiterite is 4 to 1.

PHA PAE MINES

The Pha Pae hydraulic mines of the Thong Pha Phum Co. are about 8 kilometers by elephant trail southeast of I Pu.

At Pha Pae 1 mine hydraulic workings on a low hillside spur have exposed deeply weathered muscovite-biotite granite cut by many small quartz veins. The veins range in width from that of a knife edge to 50 centimeters, with an occasional wider lens. Most veins are bordered by black tourmaline which, in places, makes up one-half of the width of the vein. Secondary fine-grained white mica is common in the vein walls. Cassiterite and wolframite are sparsely distributed in the quartz veins. Several gouge zones mark small faults in the granite. A narrow horse of mica schist between two such faults indicates that the contact of the quartz and schist is not far distant.

Three to four meters of colluvial material overlying the bedrock has been removed by ground sluicing and hydraulic jet. Tin-bearing ground extends up the spur above the level to which water has yet been brought. It is said the mine yields monthly about 4 tons of concentrates, mainly cassiterite but also some wolframite, during the rainy season.

About 1 kilometer southeast of the hydraulic workings, a flat-lying quartz vein at least 2 meters thick had recently been exposed. Two short adits had been driven along wolframite pockets. The country rock is mica schist.

Pha Pae 2 mine, about 3 kilometers southest of mine 1, has been worked by ground sluicing and hydraulic jet for several years. It yields about 4½ tons of concentrates a month during the rainy season when water is abundant. The hydraulic concentrates are mainly cassiterite and a little wolframite.

The country rock, exposed in the hydraulic cuts, is deeply weathered muscovite-biotite granite. It is cut by steeply dipping quartz veins striking north. These veins contain less tourmaline and their walls contain less secondary mica than do the veins at mine 1.

During the dry season when water is scarce, the quartz veins are worked through short adits and yield a concentrate containing 20 to 30 percent cassiterite and 80 to 70 percent wolframite.

SONG KHWAE MINES

The Song Khwae area is about 20 kilometers airline southeast of Pilok on the Burma frontier. It is named from Khao Song Khwae, a prominent peak 1,328 meters high, which caps the divide forming the Thailand-Burma boundary. The area is about 42 kilometers by elephant trail northwest of Kui Yae on the Kwae Noi River, the usual route of access.

The trail from Kui Yae crosses the limestone ridge west of the river and descends to an alluvial flat at the headwaters of the Huai Kayaeng. It continues westward up the Huai Kayaeng over quartzitic sandstones and phyllites, with increasing quantities of granite gravel and boulders in the stream channel.

The Song Khwae mine consists of two hydraulic workings about 3 kilometers apart. The upper mine was first opened in the rainy season of 1949 when it produced 5 tons of cassiterite in 5 months. The lower mine is now being prospected. No wolframite has been recovered.

The bedrock exposed in the hydraulic workings consists of weathered muscovite schist containing quartzitic beds. The strike is N. 80° E., and dips are steep. The schist is cut by narrow quartz veins and small irregular pegmatites some of which contain cassiterite. Biotite-muscovite granite is exposed 300 meters up the hill from the workings and a mantle of granite slope wash covers the schist bedrock.

The material mined is the colluvial subsoil resting on the schist. The cassiterite generally is fine grained. The largest fragment so far found here had a volume of about 4 cubic centimeters. Sampling has shown as much as 2 kilograms of cassiterite per cubic meter. Because the water supply is seasonal, the mine can be worked only from May to November.

THE RAT BURI TIN DISTRICT, KANCHANABURI

By Glen F. Brown and Vija Sresthaputra

Several small tin placers along a 16-kilometer strip adjacent to the Burma border due west of Rat Buri are worked during the rainy season. They may be reached along two routes in Thailand (Fig. 27). The northern placers are most accessible from Kanchanaburi and the river Khwae Noi. A passable motor trail has been extended 48 kilometers west from the Ban Chorakhe Phuak landing on the river Khwae Noi into the foothills of the frontier range to a point where the alluvial

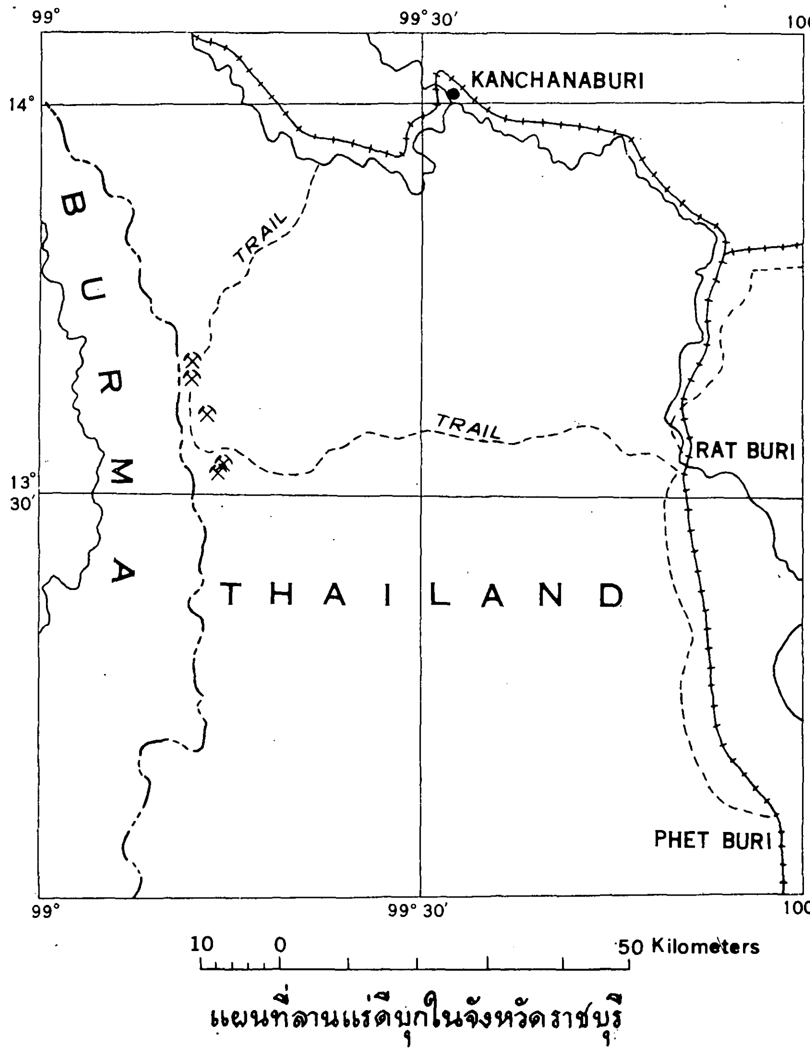


FIGURE 27.—Index map showing location of Rat Buri tin placers, Thailand.

deposits can be reached over a 3.5-kilometer trail ascending 300 meters toward the border divide. In the northernmost placer, Huai Nam Sai, cassiterite is recovered from a gravel bed 3 meters thick containing large boulders of vein quartz and granite. The bedrock is a grey micaceous granite, deeply weathered and intensely sheared. Southwest 1.5 kilometers another locality known as Tako Pit Thong yields black cassiterite from colluvium and alluvium at the base of a bare granite slope. The thickest part of the alluvium has been mined in former times by pitting. The pits, some as deep as 7 meters, cover an area of about 20,000 square meters. The alluvial cassiterite appears to have originated from greisenized granite, thin quartz veins, and pegmatites that lace the granite and contact-metamorphosed marble, slate, and phyllite nearby. Production from both localities has been only a few tons of cassiterite, mostly because operations are handicapped by insufficient water.

The southern part of the district is best reached by road from Rat Buri, a distance of 83 kilometers to the mining camp of Huai Pok Khang Khao. Here the black cassiterite is found in small alluvial placers containing large boulders of granite, pegmatite, and vein quartz. One working face contains weathered phyllite at the base; at another locality 700 meters southwest of the first locality the heavy gravel yields cassiterite and magnetite from above a porphyritic granite injected with pegmatite in the form of lenses. Total production from Huai Pok Khang Khao in 6 months of operation is said to be 6 metric tons of cassiterite containing some magnetite. The size of the mines is determined by the limited water supply.

SOUTHERN AREA

GENERAL FEATURES

Tin and tungsten deposits are widely distributed in Peninsular Thailand, extending from Changwat Chumphon, opposite the southern tip of Burma, to the Malayan border. Most of the tin and about one-half of the tungsten produced in Thailand in 1949 came from this area. It is the so-called open area in which mining concessions may be granted to either Thai subjects or to foreigners, in contrast to the closed area, comprising all of Thailand north of Changwat Chumphon, where all mining rights are reserved to the the Royal Department of Mines and only under unusual circumstances are subleases of limited duration granted to Thai companies.

The southern region is served by the Thai State Railway which extends the length of the Peninsula and connects with the rallway to Butterworth, opposite Penang Island, on the west coast of Malaya. The Malayan railway on the east coast, which formerly connected with the Thai State Railway at Rantu Panjang, was dismantled by the Japanese during World War II and the track has not been relaid. There is coastwise shipping in the Gulf of Thailand between Bangkok and the southern ports, and in the Andaman Sea from Phuket to Penang in Malaya. Most of the tin concentrates are shipped by sea from Phuket. There is frequent air service between Bangkok, Phuket, Songkhla, Penang, and Singapore.

GEOLOGIC SETTING

A series of granite batholiths, arranged in echelon, extend the length of the peninsula. In Burma on the northern continuation of the granite chain, and in Malaya to the south, the tin-bearing granite is considered to be of Cretaceous age. There appears to be no reason to question this assignment of age in Thailand. The granites are intruded into shales, sandstones, and limestones of Paleozoic and Mesozoic age. Near the granite contacts these rocks have been altered to phyllites, quartzites, and marble.

Granites form the backbone of the mountain ranges which rise to a maximum height of 1,500 meters at the Malayan frontier. Other conspicuous topographic features are the vertical cliffs and rugged terrain developed on the Rat Buri limestone which extends the length of the peninsula.

The tin and tungsten deposits in or near the granite bodies (pl. 14) show the distribution of mining concessions in the peninsula and their relation to granite, so far as the granite contacts have been mapped.

Cassiterite occurs as a primary constituent of both pegmatites and quartz veins and in the wallrock bordering the veins. The pegmatites and quartz veins occur both in the granite and in the metasedimentary host rocks near the granite contacts. Erosion has concentrated the cassiterite into eluvial (residual), colluvial (hillside creep), and alluvial (stream transported) placers.

There is some evidence that cassiterite also occurs as a primary constituent of granite. Two analyses of granite from the Nam Noi quarry on the south side of the highway between Hat Yai and Songkhla, in Changwat Songkhla, showed an average of 0.6 percent tin. Both samples were selected for their homogeneous texture and their freedom from veins or pegmatitic segregations.

TIN MINING

HISTORY

The Chinese were probably the first tin miners in Thailand. Chinese traders traveling to India by junk broke their sea voyage by crossing the peninsula and resumed their voyage in the Andaman Sea. Being traders by heritage, they would have discovered, worked, and smelted the tin that lay along the routes across the peninsula. Many Chinese settled there.

The Portuguese negotiated the first trade treaties with Thailand in 1511–16 (Wood, 1933, p. 98) and soon thereafter established a trading post in Phuket. Linschotten (Gerini, 1905, p. 141), in his journey of 1583–92, visited Phuket (then called Junkceylon) and visited some of the tin mines then operating.

In 1906, Capt. E. T. Miles (Jones, 1925, p. 215) from Australia adapted the continuous bucket dredge, then used only for deepening channels in rivers and harbors, to the recovery of tin from the floor of the harbor at Thung Kha, Phuket. That and succeeding dredges of the Tongkah Harbour Tin Dredging Ltd. have been working there ever since.

DREDGING

Captain Miles' first dredge, launched in 1906 at Thung Kha Harbor, Phuket, was followed by many others. Most of the dredging companies were Australian and British, though a few dredges were built by other European nationals and by Chinese. In 1941, at the time of the Japanese invasion of Thailand, 39 dredges were operating; they produced 62.6 percent of the tin mined that year. During the war most of the dredges were stopped for lack of fuel or repair parts, and in 1946 the operating dredges produced only 6.0 percent of the tin mined. Since then many of the dredges have been repaired with funds provided by the Government of Thailand in payment for war damage and early in 1950, 32 dredges were in service. The table on page 118 lists the dredges operating in April 1950, and gives their production, in long tons of contained tin, in 1949.

Only one dredge, that of the Tongkah Harbour Tin Dredging Ltd. at Phuket, is working offshore deposits. The others are working well-defined stream channels and occasional adjoining eluvium. Much dredging ground had previously been worked by Chinese miners through closely spaced vertical shafts sunk to bedrock, and short lateral galleries.

The tin content of dredging ground varies widely. In the opinion of the dredge operators who were interviewed, dredging ground, to be profitably mined under economic conditions prevailing in early 1950, had to have a content of at least 0.25 pound, or 0.2 catty, of cassiterite per cubic yard.

GRAVEL PUMP MINES

Placer deposits too small or too inaccessible for dredging are worked by gravel pumping. In 1941 there were 61 gravel pump mines being worked in Southern Thailand, and in 1949 there were 44 which yielded

Tin dredges operating in Thailand in April 1950

Changwat	Company	Company dredge number	Bucket capacity (cubic feet)	Monthly capacity (cubic yards)	Production of tin metal 1949 (long tons)
Chumphon	Peninsula Tin N. L.		7	150,000	39.26
Ranong	Bangrin Tin Dredging Co. Ltd	1	7	150,000	
Do	do	2	7	100,000	430.43
Do	do	3	7	175,000	
Do	Ranong Consolidated Tin Dredging Ltd		10	300,000	253.84
Do	Siamese Tin Syndicate Ltd	1	7	100,000	
Do	do	2	7	150,000	332.84
Do	do	3	7	150,000	
Do	Tongkah Compound No. 3 N. L.		9	150,000	
Takua Pa	Chuti Bunsung		5½	100,000	147.14
Do	Phra Pitak Chinpracha		7	100,000	43.49
Do	Satupulo N. L.		9	150,000	113.23
Do	Takua Pa Valley Tin Dredging N. L.	1	8	200,000	232.37
Do	do	2	8	200,000	
Do	Siamese Tin Syndicate Ltd	1	8	150,000	388.81
Do	do	2	8	150,000	
Do	Tongkah Compound No. 4 N. L.		12	175,000	248.09
Phangnga	Kamunting Tin Dredging Ltd	1	8	180,000	297.94
Do	do	2	8	180,000	
Do	Krasom Tin Dredging Ltd		12	150,000	140.08
Do	Luang Anupas & Son Co. Ltd		7	150,000	94.03
Do	Pangah Tin Dredging Ltd		10-12½	300,000	266.78
Phuket	Katu Tin Dredging Ltd		10	150,000	218.87
Do	Kamra Tin Dredging Ltd		10	185,000	175.47
Do	Puket Tin Dredging Ltd		14	250,000	422.00
Do	Tin Lay Ltd		13	200,000	143.22
Do	Tonghah Harbour Tin Dredging Ltd		9	200,000	
Surat Thani	Siamese Tin Syndicate Ltd		12	200,000	194.62
Nakhon Si Thammarat.	Ronibon Tin N. L.		7	160,000	284.88
Songkhla	Tin Songkla N. L.		8	150,000	64.89
Yala	Kampong Toh Tin Ltd		8	150,000	31.10
Do	Pattani Tin Ltd		13	250,000	180.56
					4,868.07

22.13 percent of the tin mined that year. Most of these mines are operated by Thai of Chinese descent.

Many of the mines are working eluvial material which is generally broken by means of hydraulic giants, supplemented by ground sluicing during the rainy season, and washed to the gravel sump where it is elevated to palong washers, which employ an intermittent surging of water through the sluice to separate the tin. The washers are cleaned and the concentrates collected at intervals ranging from 7 to 30 days, depending on the estimated load limit of the palong supporting structure (fig. 28).

The relation of veins containing tin to the overlying eluvial material is best shown on the floor of the gravel pump mines. Rich streaks in

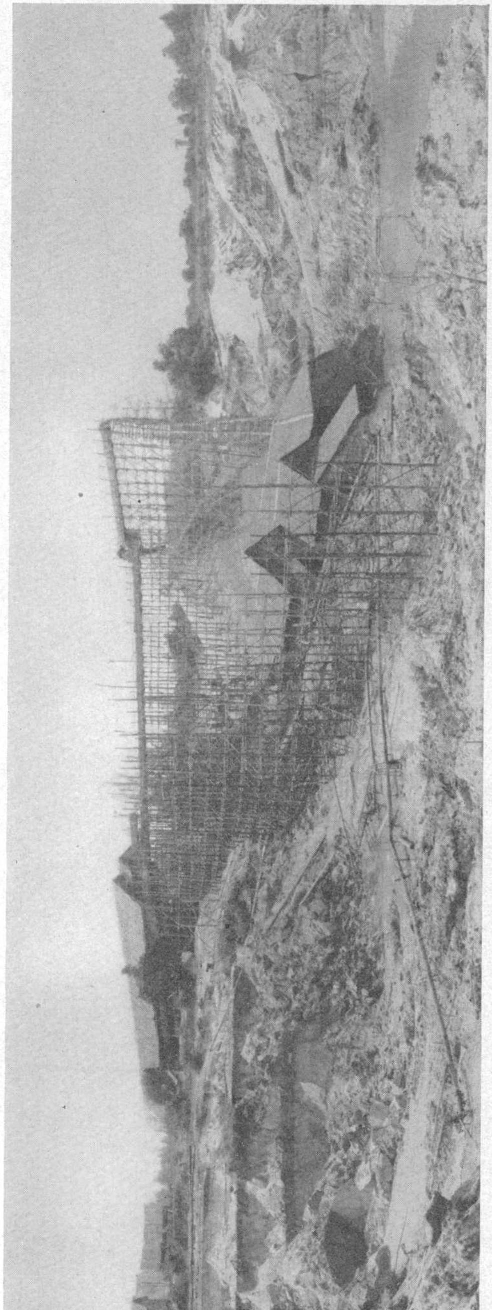


FIGURE 28.—Eu Kong, typical travel pump tin mine in Changwat Takua Pa. Panoramic view showing elevated sluice boxes, covered shed of palong washer, collecting sump at gravel pump shed and pipelines to hydraulic giants. Floor of pit in gray and brown slate directly overlain by cassiterite-bearing sand and gravel.

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the eluvium were found to overlie wide quartz veins containing cassiterite at two gravel mines on Phuket Island.

Unit mining costs are higher in gravel pump mining than in dredging. Several operators estimated that to mine profitably in early 1950 they would have to recover 0.5 to 0.62 pound, or 0.4 to 0.5 catty, of casserite per cubic yard of ground.

HYDRAULIC MINES

Hydraulic mining is possible where the working face is high enough on a hillside to permit proper slope in the sluices through which the material is removed, and adequate disposal of tailings. They entail simpler operations than the gravel pump mines and the main investment is in water pumps. Even that is sometimes avoided by employing ground sluicing during the rainy season. In 1949, hydraulic mines yielded 1.7 percent of the tin production of Thailand.

Most of the hydraulic mines in south Thailand are working hillside eluvium at or near a contact with granite. The writers were unable to obtain any figures on the grade of ground being worked. However, the profitability of mining depends in large measure on the relative quantity, dependability, and hydraulic head of the water supply.

LODE MINES

Lode mining produced less than 8 percent of the tin in Thailand in 1949. The larger lode mines in Changwat Yala that were closed during World War II have not yet reopened. In the smaller mines mining methods are primitive and many mines have no mechanical pumping or hoisting equipment.

TUNGSTEN MINING

The veins of wolframite and the pegmatites of southern Thailand are similar in most respects to those of the northwest described on pages 98–115. Eluvial placers yield some wolframite, but it is seldom found in transported placers. In Changwat Surat Thani, the Chenkit contact-metamorphic deposit in limestone yields both wolframite and scheelite. Elsewhere, scheelite does not appear to be an important ore mineral, although small amounts are commonly found with wolframite in the veins.

Because of the little time available for field work in the south, it was not possible to make either a systematic canvass of all producing districts or to make more than a rapid reconnaissance of those visited. Representative tin and tungsten districts that the writers were able to examine are described in the following pages.

CHON MINE, PHANGNGA

By Glen F. Brown and George C. Taylor, Jr.

The Chon tin mine is in rugged mountains in Changwat Phangnga Peninsular Thailand, at 9°19′ north latitude and 98°32.5′ east longitude. It lies north of the large tin-producing district of Phuket (pl. 14). The lode mine can be reached best from Phuket to Takua Pa by automobile, thence north by launch along the coast to Nang Yon. A second-class road extends northeast 8 kilometers from Nang Yon to Tha Kham, a small village at the base of the mountains, but the remaining distance of 15 kilometers to the mine is traversable only on foot or by elephant along a steep, winding trail through dense rain forest. The trail rises 1,200 meters to a mountain divide then descends 300 meters on the eastern side to the mine mill and headquarters. The mine, which is about 500 meters east of the mill, is on the steep north face of an eastern spur of the peak forming the junction of the boundaries between the Changwats of Ranong, Phangnga, and Surat Thani.

The tin ore comes from a pegmatite in schist (fig. 29) on the east flank of a large granite stock or batholith which forms the core of the range. The quartzitic and somewhat calcareous metaschist strikes N. 30° W. and dips 56° SW. at the mine. Along the borders of the pegmatite the schist is much altered by silicification and the addition of epidote, together with minor amounts of pyrite, chalcopyrite, fluorite, scheelite, powellite, and topaz. The pegmatite is an irregular sill-like intrusion consisting of fine-grained albite, potash feldspar, transparent and milky quartz, and cassiterite injected along the schistosity of the country rock. However, small stringers cut across the schistosity at high angles, passing into thin sheets of pegmatite (pl. 15). Thus, many veinlets of pegmatite, some of which contain scattered crystals of cassiterite, penetrate the schist in the hanging wall above the main pegmatite body which is exposed over an area of 167 square meters in the south face of the mine quarry. The cassiterite occurs in well-developed crystals as large as 5 centimeters in diameter, but mostly 5 millimeters or less. The crystals are generally grouped in irregular clumps or stringers that total perhaps 1 or 2 percent of the quartz-feldspar mass. Minor amounts of black tourmaline, pink garnet, apatite, and pyrite are associated with the cassiterite.

Mining of the pegmatite has been carried on sporadically for more than 40 years. A dam about 500 meters southwest of the mine headquarters diverts water from a stream into a canal leading to the mill. Part of the stream flow is dropped through a turbine to drive a 7-kilowatt generator which activates a mill having a capacity of about 4

FIGURE 29.—South and east face of Chon mine showing tin-bearing pegmatite (light colored) transecting schist (dark colored), Changwat Phangnga. Man in upper part of photograph shows scale.

tons an hour. The ore, crushed in jaw crushers and rolls, is concentrated in lanchutes.

CHENKIT MINES, SURAT THANI

By George C. Taylor, Jr., and Jumchet Charaljavanaphet

The Chenkit mines are in Changwat Suat Thani about 13 kilometers by truck trail east-southeast of Na San station on the Thai State Railway. The mining concession (pl. 16) of rectangular outline extends 920 meters east-west and 460 meters north-south. To the west-northwest of the concession is a tin-bearing alluvial valley. The concession itself includes jungle-covered hills which rise 10 to 50 meters above the valley.

Cassiterite in eluvium has been mined by hydraulic methods in 22 areas within the concession. In two of these areas scheelite is recovered with the tin concentrates, and wolframite is obtained with tin concentrates in a third area. Hematite occurs in the northwest corner of the concession.

Geology

Within the concession the rocks are everywhere so deeply weathered that it is difficult to observe geologic relations. Massive impure limestone, possibly belonging to the Thung Song limestone, forms the country rock. Biotite-muscovite granite has intruded the limestone. Near the contact the limestone has been extensively altered to contact-metamorphic lime-silicate rocks, or tactite. Garnet and epidote are common. Scattered through the tactite are relict horses of unaltered limestone.

Mineralization

Among the ore minerals, cassiterite appears both in the tactites and in the granite. In the tactites it commonly occurs in quartz-feldspar dikes or veins associated with mica, fluorite, tourmaline, pyrite, and chalcopyrite. The rocks are too poorly exposed to show the structure and distribution of the veins. At area 8 (pl. 16) a quartz-feldspar dike about 1 meter wide apparently strikes west. A vein of similar rock observed near the test shaft in area 7 strikes N. 10° W. At area 6 a dike of weathered quartz-feldspar about 1 meter wide strikes N. 15° W. and dips vertically.

In areas 1–4, (pl. 16) close to the contact between tactite and granite, cassiterite is found in quartz-feldspar dikelike masses. In other places it is apparently disseminated in tactite near limestone horses and associated with abundant arsenopyrite, some pyrite, and chalcopyrite. Malachite and azurite occur as alteration products of chalcopyrite in areas 2 and 4. Along the north side of area 1 scheelite is present in the tactite zone and was recovered with cassiterite in washed concentrates from hydraulic operations. Some wolframite was also obtained with cassiterite concentrates in area 2.

Cassiterite is found in quartz-tourmaline veins throughout the granite and in greisen. Several subparallel quartz-tourmaline veins striking about N. 50° W. were observed at area 9. Southwest of area 2 the granite is cut by a narrow quartz vein containing wolframite and some cassiterite and striking N. 75° E.

A small body of hematite, apparently primary, occurs adjacent to a limestone horse in a tactite zone just north of area 9. Along the west side of area 9 a low bench capped by a layer of cellular hematite ore about 1 to 3 meters thick rests on tin-bearing granite. The layer has a lateritic aspect but may be residual, having formed from concentration of primary iron ore in the zone of contact. Disseminated hematite was observed in tactite near areas 6 and 8.

Operations and Production

Tin-bearing eluvial and residual ground in the concession has been mined by hydraulic methods for many years and much of the richer ground may have already been worked. Apparently, however, no serious attempt has been made to prospect underlying parent lodes.

Under the present system of mining, water is stored in a reservoir in the hills above the concession. The water is delivered by gravity pipe lines to hydraulic monitors at the working faces. The hydraulicked material is conducted into palongs, or long sluices, for washing. The washed concentrates are then carried to an ore shed at the mine headquarters for further concentration by washing in boxes called lanchutes and by panning. Lack of water confines mining operations to a 6-month period in the wet season.

Arsenopyrite was somewhat difficult to remove from the tin concentrates from areas 1–4. However, roasting and repanning the concentrates removed most of it. From area 1 the final concentrates were reported to average about 80 percent cassiterite and 20 percent scheelite. Elsewhere in the concession, medium- to high-grade tin concentrates have been obtained by simple water separation.

The annual production of cassiterite concentrates from the concession during the past few years has averaged 13 metric tons. The tungsten and iron ore have not been marketed thus far.

RONG LEK DISTRICT, NAKHON SI THAMMARAT

By Glen F. Brown, Saman Buravas, and Pisoot Sudasna

The Rong Lek district comprises five mines in the Khao Luang Mountain chain in the eastern part of Peninsular Thailand at 8°45′ north latitude and 99°45′ east longitude. The access road extends north 25 kilometers from Nakhon Si Thammarat, the Changwat capital and railhead, to Tha Sala on the Gulf of Thailand, a terminus of a secondary road and trail which leds inland 24 kilometers to the village of Rong Lek near the center of the mining district.

The district is a part of a larger mineralized region surrounding the many granite stocks that extend south from the islands of Phangan and Samui beyond Ron Phibun. The region has been prospected and mined for many years; it produced much wolframite during World War I.

The wolframite and cassiterite ore comes from numerous quartz fissure veins, characterized by abundant arsenopyrite and pyrite. The veins strike within the arc N. 40° W. to west and stand vertical or dip steeply southwest and south. Ranging in width from 60 centimeters or less to 1.5 meters, some quartz veins can be followed for a kilometer but lengths workable by underground mining generally range from 50 to 400 meters. In addition, many small veins and stringers of quartz in granite have furnished cassiterite and minor amounts of wolframite to eluvial and alluvial deposits that are worked by ground sluicing, the only mining operations during the rainy season. The lodes are in alkali granite, phyllite, and slate, all deeply weathered.

Lode mining is through numerous shafts closely spaced along the veins. All of the important veins have been mined in this manner to depths ranging from 18 to 67 meters. With increasing depth, drainage becomes a major problem and dewatering, following each rainy season, becomes increasingly difficult.

The largest mine, the Nai property of Yip In Tsoi Co., is reported to produce an average of about 2.6 metric tons each month of tin concentrates containing about 70 percent wolframite and 30 percent cassiterite. The adjacent Khao Klom mine is reported to produce about 1 metric ton each month throughout the year from ground sluicing and about 2 metric tons for each month of the 6-month dry season from the shafts. The concentrates are composed of 60 percent wolframite and 40 percent cassiterite.

SAMUI AND PHANGAN ISLANDS, SURAT THANI

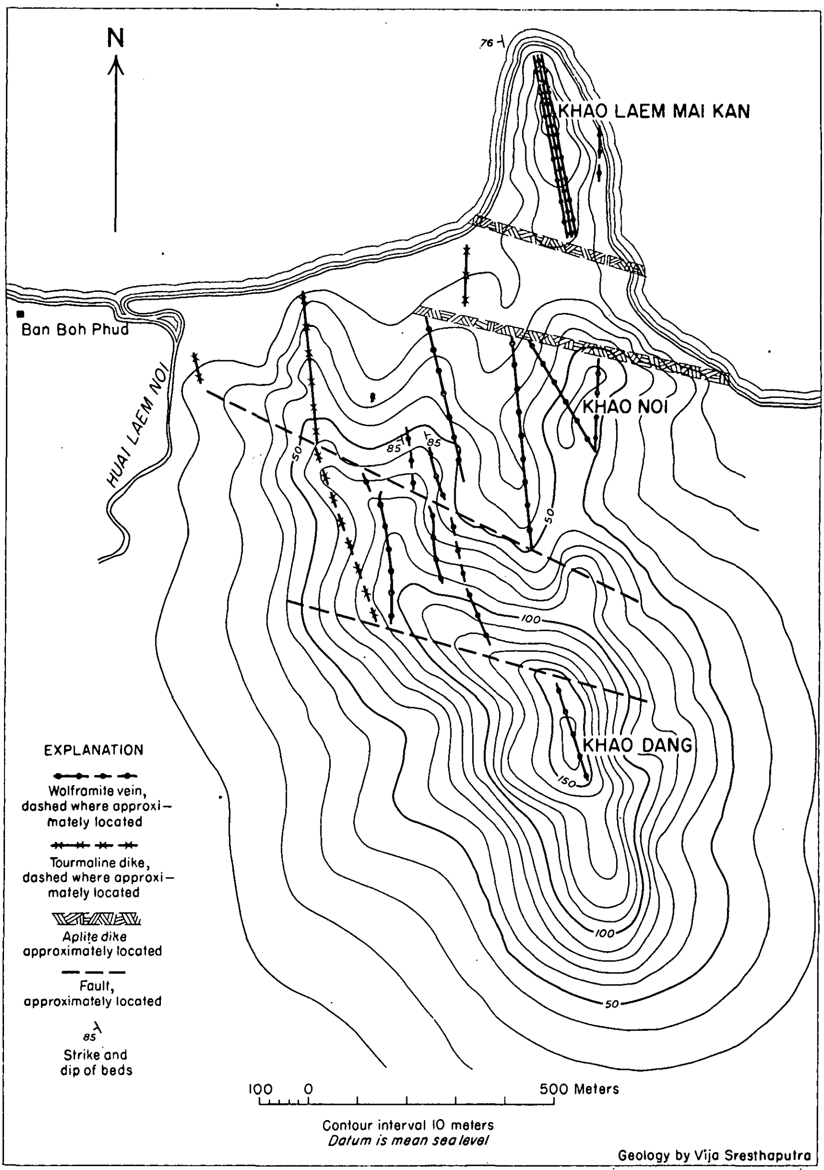
By Vija Sresthaputra and Glen F. Brown

Samui

Samui Island lies between Phangan Island and Peninsular Thailand at 9°30′ north latitude and 100° east longitude. The principal town and Amphur seat, Na Thon, is situated on the west coast of the island 80 kilometers by launch from Bandon (Surat Thani), the nearest rail station on the peninsula (fig. 1).

Structurally the island is similar to Phangan Island on the north and is in the Khao Luang chain. Granite forms the high central and eastern part of the island. The granite is irregularly fringed on the northwest and southwest by slate and sandstone of the Kanchanaburi series and beds of Rat Buri limestone. In the southwestern rim an iron deposit lies in the zone of contact between granite and limestone or marble (see p. 77), whereas in the northern part of the island the ore is mostly wolframite in quartz fissure veins.

The wolframite veins are mostly in the northeast, mineralization having centered at the hill Khao Dang where the lodes strike N. 15° W. on to the promontory of Laem Mai Kan (fig. 30). The veins range in width from a few centimeters to 0.6 meters. However, a major shear zone a meter wide and filled with quartz breccia cuts off the veins on the promontory of Laem Mai Kan. The mineralized veins are composed of tourmaline-arsenopyrite gangue in quartz, with wolframite crystals tending to cluster near and in the mica selvage of the walls as at Khao



ธรณีวิทยาแถบแหลมไม้แก่นและเขาด่าง เกาะสมุย

FIGURE 30.—Geologic sketch of Laem Mai Kan and Khao Dang tungsten area, Ko Samui.

Dang, or scattered throughout the quartz vein, with minor amounts of cassiterite and fluorite, as at Khao Ngiu, west of Khao Dang. Pyrite and chalcopyrite are also associated locally with wolframite.

The veins have been mined intermittently for many years, first by an English company during World War I, later by the Royal Department of Mines. Currently the mines are shut down.

Phangan

Phangan Island lies 100 kilometers northeast of Bandon (Surat Thani) off the east coast of Peninsular Thailand and in the Gulf of Thailand at 9°45′ north latitude and 100° east longitude. Ordinarily a launch trip of one day is required to reach the island which is sometimes isolated during periods of heavy monsoon winds.

The granite core of the island is the northernmost of a series of stocks or cupolas extending south on the peninsula in the Khao Luang chain. The intrusive granite forms hills in the northern and central parts of the island. Slate, probably belonging to the Kanchanaburi series, crops out in the northwestern headlands. Most of the island is less than 100 meters above sea level and is composed of an elevated coastal plain underlain with alluvium and coralline marl or limestone. The shore line has the general appearance of recent emergence.

Tin and tungsten veins in granite are worked intermittently by the natives of Laem Niat, at the northern headland of Si Nu Bay on the west coast, and at Tha Mai Liap, near the center of the island. At Laem Niat two wolframite veins, 3 meters wide and striking north-northwest, form cliffs in weathered granite. They dip 70° W. Besides quartz and wolframite, the veins contain galena and chalcopyrite. The ore is blasted, crushed by hammering, and concentrated by panning and sieving. Pegmatites at Tha Mai Liap contain both cassiterite and wolframite but the reported yield, composed of 70 percent wolframite and 30 percent cassiterite, is very small.

Placer cassiterite has been revealed by test boring in the alluvium of the western coastal plain adjacent to the granite hills, it is reported. The reports indicate that good ground without heavy boulders or abundant clay was found distributed above bedrock at depths of 6 to 15 meters. However, this ground is not being mined, and the current production comes principally from ground sluicing of areas nearby during the rainy season.

PHUKET ISLAND

By Saman Buravas

Phuket is the largest off-shore island in Thailand. It lies off the western coast of the Malay Peninsula at about latitude 8°0′ N. and longitude 98°20′ E. The island has a maximum length from north to south of about 45 kilometers and a maximum width from east to west of about 20 kilometers. Its area is approximately 600 square kilometers. At its northern tip the island is separated from the mainland of Changwat Pangnga by an 800-meter strait traversed by a ferry carrying passenger and vehicular traffic to and from the mainland. The principal center is the city of Phuket which is a port of call for shallow-draft vessels from Krabi, Kan Tang, and Penang, and larger ships from ports on the Indian Ocean.

More than half the island is mountainous, especially along the western side. However, the highest peak rises only 536 meters above sea level. Most of the streams are comparatively short and have small drainage basins. The stream discharges are therefore subject to considerable fluctuation, and a shortage of water is not uncommon during dry periods. Erosive forces have been active and have formed blankets of tin-bearing eluvium and alluvium, especially in the eastern and north-central parts of the island.

Granite underlies most of the mountainous area of Phuket. It forms the entire southern tip of the island and to the north it consists of two north-trending prongs. The western prong lies along the west coast and the eastern prong extends discontinuously along the central axis of the island. The granite intrudes a slate and sandstone sequence considered to belong to the Phuket series of probable Cambrian age and believed to be equivalent to the Mergui series of lower Burma. To the north of Phuket, rocks of this sequence crop out along the west coast of the peninsula in Changwats Ranong and Takua Pa. On Phuket these rocks lie along the eastern side of the island and in a wedge between the two granite prongs where they have been metamorphosed to phyllite, schist, and quartzite, as in the Kathu area (pl. 17). On a headland near the northeast point of Tongkah harbor fossils interpreted as *Eophyton* were found in slate. Because the age of these fossils is not definitely determined, judgment of the age of the sedimentary sequence on the island was based primarily on its physical similarity to the Mergui series of Burma.

Pegmatite dikes and quartz veins bearing cassiterite and wolframite, either together or separately, traverse both the granite and the adjacent country rocks in a number of places but especially in the Kathu area. Tungsten minerals appear to be largely limited to veins in an area just north of Phuket city, but tin-bearing dikes and veins occur in many places on the island. The width of the tin-quartz veins ranges from a few centimeters to 3 meters. The tin pegmatite dikes are generally somewhat wider. There appear to be two principal systems of dikes and veins—one striking about north and the other generally to the east. Associated with dikes and veins are the pneumatolytic minerals tourmaline, topaz, and the white micas. Zircon, ilmenite, monazite, and garnet are also present as accessory minerals. Tin-bearing eluvial and alluvial placers have originated on the island as a result of deep decay of the lodes and transportation and sorting of the weathered material by streams. Pegmatite veins and granite have been observed decomposed to depths of at least 6 meters but still preserving the original rock texture. Schist and phyllite weather to unctuous clay but still show original foliation. In the weathered eluvium lying over or near the lodes, as well as in the alluvium of the stream valleys, resistant cassiterite is concentrated in ground workable by placer mining methods.

Phuket has been called the birthplace of tin mining in Thailand, and it is certain that mining has been the basic enterprise of the island for many decades. Since the beginning of tin mining a wide variety of placer mining methods have been used on Phuket. Such methods include simple panning in creeks and river beds, ground sluicing, opencast mining, shafting and drifting in eluvium or alluvium, hydraulicking, gravel pumping (fig. 31), and dredging. At present the last two methods are most important in the tin mining industry of the island. In April 1950, 5 dredges and 17 gravel pump mines were in operation on Phuket.

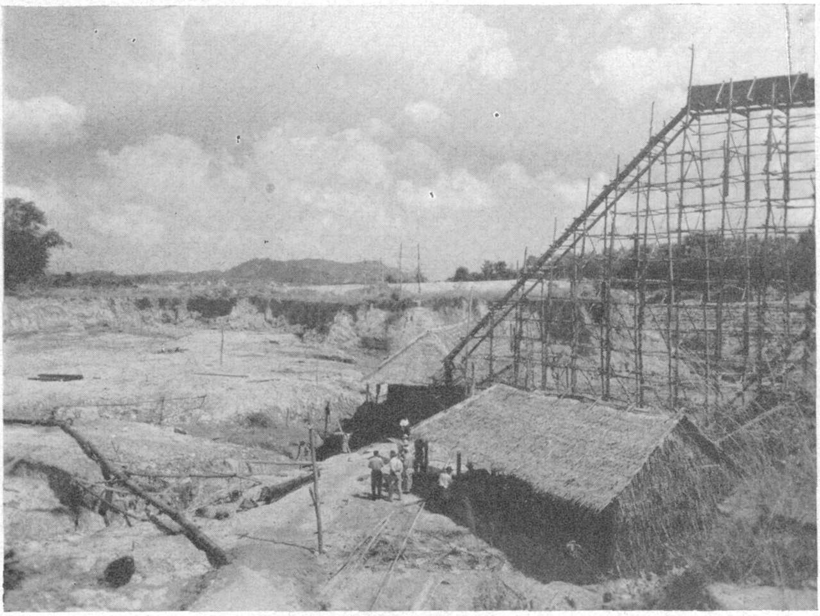


FIGURE 31.—Chao Fah 2, typical gravel pump tin mine, Phuket Island.

LODE MINES OF YALA

By Vija Sresthaputra and William D. Johnston, Jr.

General Features

The Pinyok-Labu area, in the southern part of the Changwat of Yala, contains most of the tin lode mines of southernmost Thailand. Plate 18 is a sketch map of that area compiled from maps of the various mining companies and of the district supervisor of the Royal Department of Mines. Most of the mines were active in the years preceding World War II, in the course of which they were taken over and worked by the Thai Minerals & Rubber Co., a governmental organization temporarily established to look after the alien properties. However, they were all closed before the end of the war because of a shortage of fuel and spare parts. Some have been reopened and others may be reopened.

During the 2 days the authors spent in the area they were able to visit only some of the mines; and no new geological mapping was possible. Consequently, they formulated more questions about the geology of the region than they answered.

The most prominent topographic feature of the area are the great cliffs of limestone that dominate the landscape. Many have vertical or overhanging faces and all of the limestone exposures are marked by vertical grooves and mullions due to solution. In the vicinity of the mines, the limestone is white and coarsely crystalline. No actual contacts with other rocks were observed.

Quartzite, phyllite, and shale, all presumably underlying the limestone, were in scattered discontinuous exposures.

Granite forms one wall of the ore body at Pinyok and New mines and is reported to have been revealed in a vertical drill hole at Labu.

If the age assignments of the rocks of Malaya (Scrivenor, 1928, p. 3) are applicable here, the clastic rocks are Paleozoic—probably of the Kanchanaburi series, the limestone is Rat Buri of Permian age, and the granite is Mesozoic (Cretaceous?).

The ore bodies consist of veins, stockworks, and, possibly, replacement deposits that appear to lie, not in limestone, but in quartzite, phyllite, and shale at or near a contact with granite. In the eastern part of the area, despite the fact that the mineral assembly suggests a contact-metamorphic deposit in limestone and that limestone is always nearby, the writers could not be sure that limestone served as the host for mineralization.

Pinyok

The Pinyok mine near the southern tip of Thailand in Changwat Yala is about 3 kilometers from the Malay frontier. It is on the highway from Yala to Betong, about 10 kilometers south of Yala. The mine is owned by the Thailand Tin Mines Ltd., a subsidiary of the Anglo-Oriental Tin Co.

Mr. W. T. Harry, general manager, has kindly furnished the following history of the mine: It was first worked by Chinese miners. In 1930, exploration was begun by the British American Tin Mines, which erected a 100-ton mill in 1935. The mine operated until the Japanese invasion of Thailand in December 1941, and was reopened late in the war under Thai management. It was closed at the end of World War II and has not since been operated. Mr. Harry estimates that 500,000 tons of ore averaging 3.6 percent tin were crushed during the life of the mill. Recoveries were very low, ranging from 18 to 36 percent of the contained tin. Low recovery is attributed to the fine grain size of the cassiterite contained in the ore. Thus, about 400,000 tons of mill tailings containing more than 1 percent of metallic tin are impounded on the property.

In 1939, in an attempt to increase the recovery of tin, the company began the construction of a chemical-treatment plant. The plant is the first to employ the Cavaet process, whose name is an acrostic for "Chloridization and volatilization and electrolysis (of) tin." In this process the tin ore is ground to 8 mesh and dried and roasted in a rotary kiln at 800° C. with charcoal and calcium chloride. Cassiterite is reduced by the carbon and combines with chlorine to form volatile stannous chloride which is easily dissolved in water at the lower end of the kiln. When the stannous chloride solution has built up to a suitable strength and other harmful chlorides such as antimony, arsenic, and copper have been precipitated, it is electrolized and the metallic tin is plated out of the solution. The tin is then stripped from the cathodes and cast into ingots. Operation of the Cavaet plant was begun during Japanese occupation, and continued for 2 or 3 weeks when trouble with the fire bricks in the rotary kiln caused the plant to close. It is stated that the stannous chloride solution was built up to 75 grams per liter of solution before being pumped to the electroplating plant. Reconstruction of the plant was begun in 1948, and it was expected to be ready for a trial operation in mid-1950. Should it prove successful in treating the mill tailings, it is probable that lode mining will be resumed.

The Pinyok mine lies in a small valley bordered by nearly vertical limestone cliffs. The ore body, now marked by a series of open cuts, lies on the south side of the valley. Phyllite and granite are exposed on the south side of the open cuts in such a way as to suggest that the granite forms the footwall. Much gossan remains in the open cuts but its distribution suggests a series of connected ore bodies rather than a single continuous one. No underground workings were accessible.

The following minerals were seen, either in place, in the gossan, or in hand specimens in Mr. Harry's collection: cassiterite, chalcopyrite, pyrite, pyrrhotite, galena, sphalerite, anglesite, cerrussite, pyromorphite, quartz, calcite, andradite, and hedenbergite. It is reported that the galena and sphalerite came from a vein lying within the body of tin ore.

New

New mine, north of Pinyok, was opened on a vein that lies in the zone of contact between granite and a crumpled black shale containing many thin cherty layers. A vertical solution face of limestone lies about 50 meters to the east, but the relation of the limestone to the other rocks is not clear and there appears to be no trace of minerals in the limestone. The vein has been mined for a strike distance of 80 meters and to a depth of 15 meters, and only fragments of gossan remain on the granite wall. At the time of the writers' visit, the north end of the vein was being stripped by means of a hydraulic monitor, and the cassiterite contained in the overburden was caught in a sluice box.

Guatomo

The Guatomo mine was opened before World War II by the Yala Mines Ltd., and has since been acquired by the Anglo-Oriental Tin Co. Several ore bodies were worked by open cuts and through vertical shafts but no information about the grade or the form of the ore bodies, other than their outlines as shown on pl. 18, could be obtained. A small ore body on the north end of the property was being worked under lease. The ore is high in arsenopyrite and must be roasted to render the iron magnetic and permit separation from the cassiterite.

Labu

The Labu mine is connected with the Yala-Betong highway by a fair road with good grades. Originally worked by the Chinese in an open cut at the north end of the property, the mine was extensively prospected by the Straits Consolidated Tin Mines, Ltd. Several hundred meters of drifting was done and a number of diamond drill holes were bored. A pilot mill is being erected and will be operating in 1951. The future of the mine probably will be decided by the results obtained from that mill.

The country rock, best exposed in the mine workings, is fine-grained quartzite and phyllite. It is reported that a vertical diamond drill hole revealed granite at the depths of 1,000 feet.

The north or "Tributor's" vein strikes east and dips 70° N. It consists of an irregular quartz vein 10 to 50 centimeters wide, carrying arsenopyrite, pyrite, galena, sphalerite, and cassiterite. In 1940–41 two drifts, about 150 meters long were driven on the vein. According to Mr. R. A. Stratford, manager for the Consolidated Tin Mines, Ltd., the material mined, both quartz and cassiterite-impregnated wall rock, averages 1.2 percent tin.

A second vein, called the Main Reef lies about 1 kilometer to the south. It strikes N. 55° W. and dips 60° S. A quartz vein 15 centimeters wide carrying cassiterite, arsenopyrite, pyrite, galena, and sphalerite is exposed in the face of the open cut.

Other Mines

Other mines in the area, which time did not permit the writers to visit, are the Dida, Bajar, and Meh Bulan.

NONMETALLIC MINERALS

ASBESTOS

GENERAL FEATURES

The known asbestos deposits of Thailand are limited to Changwat Uttaradit in the region 20 to 30 kilometers east-northeast of the city of Uttaradit along the Mae Nam Nan. In this region (Jalichandra, 1948, pp. 33–39) the country rock is a sequence of strongly folded interbedded shale, sandstone, slate, quartzite, argillaceous schist and greywacke whose strike trends generally northeast. Intruded into these rocks are dikes, sills, or small plugs of diorite, gabbro, and pyroxenite with which the asbestos deposits are associated. To the north of the Mae Nam Nan small bodies of the mafic intrusives are reported (Jalichandra, 1948, p. 33) to occur discontinuously along a 13-kilometer strip from near Hat Ngiu through the Pha Luat area to Charim and to the south of the river along a 4-kilometer strip from Ban Saen To by Ban Nong Hia to Khao Cherng Phra. Asbestos deposits associated with the mafic intrusives are found at Khao Sam Soo on the south side of the river about 6 kilometers from Ban Nong Hia, at Dek Lek, in Tambon Pak Nai on the shoulder of a ridge about 200 meters above the river, at Mon Kai Chae near Hat Ngiu, and at Bo Sam Kha about 5 kilometers to the north-northwest of Pha Luat. Descriptions of the last two localities follow.

MON HAI CHAE PROSPECT, UTTARADIT

By Nitipat Jalichandra, Saman Buravas, Glen F. Brown, and George C. Taylor, Jr.

The Mon Kai Chae asbestos prospect is 1.4 kilometers by footpath north of the village of Hat Ngiu in Changwat Uttaradit. Hat Ngiu is situated on the north bank of the Mae Nam Nan 32 kilometers upstream from Uttaradit. It can be reached by shallow-draft power launch. The asbestos prospect lies in a gently undulating upland at an elevation of about 101 meters above sea level and 20 meters above the Mae Nam Nan at Hat Ngiu (fig. 32).

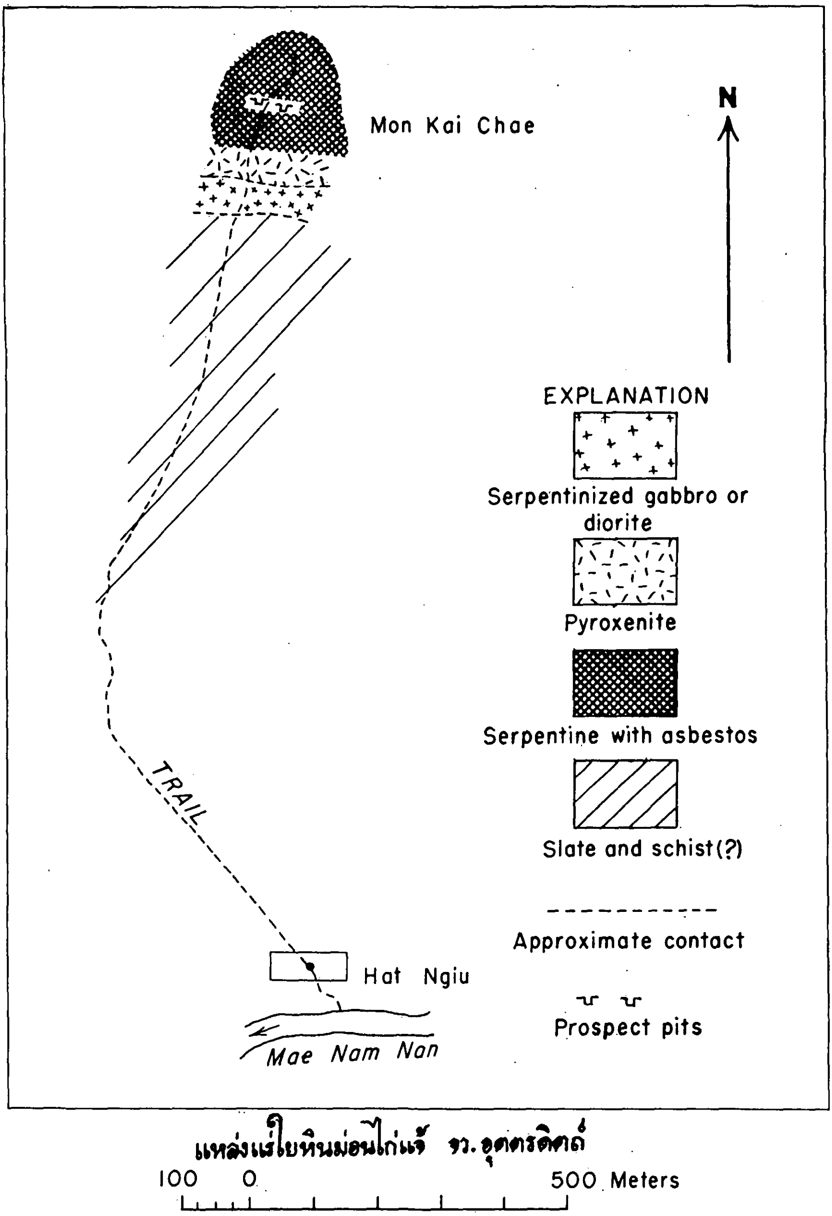


FIGURE 32.—Sketch map of the Mon Kai Chae asbestos prospect, Changwat Uttaradit.

The rocks in the Hat Ngiu area are poorly exposed and deeply weathered. Geologic relations are therefore obscured. The oldest rocks in the area appear to be steeply dipping slates or schists containing thin stringers and lenses of quartz. Intruded into this series are diorite or gabbro and pyroxenite in dikes, sills, or small plugs.

The asbestos occurs in irregular discontinuous veinlets and stringers, 1 to 12 centimeters wide, through serpentinized zones in pyroxenite. The material has a white or greenish white color and a silky luster. In most of the exposed veins the asbestos is slip fiber. However, cross-fiber veins also occur, and the length of the fibers is controlled by the width of the veins. Secondary partings within the veins are not common, and the fibers generally extend from wall to wall. The chemical analysis of a sample from the deposit made in the laboratory of the Royal Department of Mines, Bangkok, indicated the following:

Constituent:	*Percent*
SiO_2	57.0
$FE_2O_3+Al_2O_3$	8.5
MgO	20.1
CaO	14.0
Ignition loss	1.0
	100.6

The deposit has not yet been opened sufficiently to determine the distribution and continuity of the asbestos veins, but scattered fragments of asbestos float were observed on the surface over an area estimated at 5,000 square meters. It is reported that during World War II about 60 metric tons of asbestos was mined from a few shallow pits and trenches by local natives and sold to buyers from Bangkok. The principal use was for packing or insulation around steam pipes. Since 1944 there has been little or no mining activity, and when visited in November 1949, all of the workings were caved or filled.

BO SAM KHA PROSPECT, UTTARADIT

By Saman Buravas, Glen F. Brown, and George C. Taylor, Jr.

The Bo Sam Kha asbestos prospect is 5 kilometers airline to the north-northwest of the village of Pha Luat in Changwat Uttaradit. Pha Luat is on the northwest bank of the Mae Nam Nan 44 kilometers upstream from Uttaradit. The prospect can be reached by power launch from Uttaradit to Pha Luat and thence on foot, following Huai Thap and Huai Khlok Hin (fig. 33). The asbestos prospect lies near the crest of Doi Kang ridge at an altitude of 410 meters, and 325 meters above the Mae Nam Nan at Pha Luat.

The principal rocks of the Pha Luat area are slightly to moderately metamorphosed sedimentary rocks. These include interbedded shale,

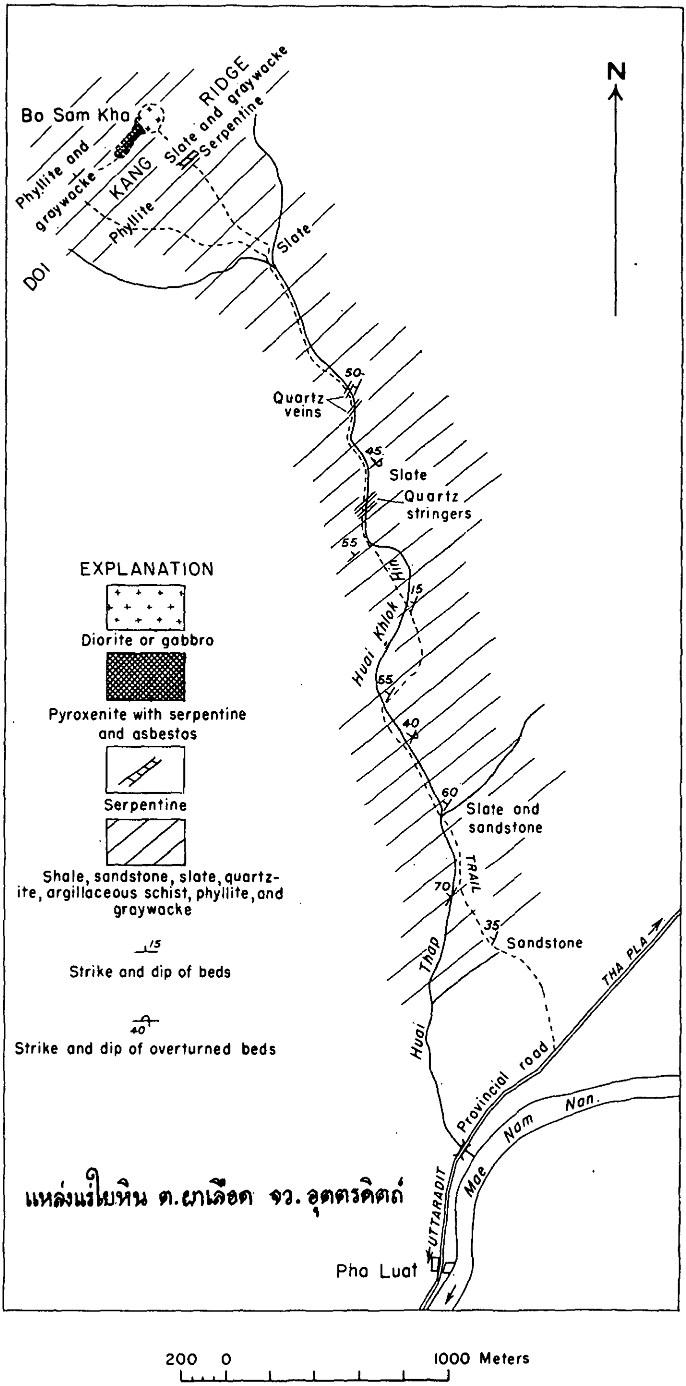


FIGURE 33.—Sketch map of the Bo Sam Kha asbestos prospect, Changwat Uttaradit.

sandstone, slate, quartzite, argillaceous schist, phyllite, and greywacke which locally contain thin lenses or stringers of quartz. Along Huai Thap and Huai Khlok Hin the metasedimentary rocks strike N. 20°–55° E. and dip 15°–85° NW. Evidences of shearing and overturning of the strata were observed at several points, suggesting isoclinal folding. On Doi Kang ridge the metasedimentary sequence is intruded by diorite or gabbro and pyroxenite—presumably in dikes, sills, or small plugs.

The asbestos of the Bo Sam Kha prospect occurs through a serpentine zone associated with pyroxenite and diorite or gabbro. Most of the asbestos is apparently cross fiber—being found in irregular discontinuous veins from a few millimeters to 25 centimeters wide, throughout antigorite serpentine. Secondary partings are not common in the veins and most of the fibers extend from wall to wall. Some slip fiber as long as 40 centimeters is found along minor shear partings in serpentine. The fiber is evidently too brittle for good spinning grade but would probably be suitable for packing. During World War II the Thai Cement Co. attempted to use the material in roofing shingles. The results were reported to be unsatisfactory.

The asbestos veins are evidently limited to a serpentine mass which crops out along the crest of Doi Kang ridge. The outcrop averages about 40 meters in width and trends east-northeast for a distance of about 100 meters. Some asbestos was mined from 6 to 8 shallow pits and trenches in World War II. The material was marketed in Bangkok for packing and other purposes. When the deposit was visited by the writers in November 1949, no mining activity was in progress and all of the workings were caved or filled.

BARITE

By Vija Sresthaputra

Barite is known in Thailand in veins associated with igneous rocks and as lenses or beds in sedimentary rocks.

It is the principal gangue mineral in the epithermal lead and copper veins of the north, especially those in the Ban Pin area, where the other gangue minerals are fluorite and quartz. The barite is milky white and massive, rarely showing crystal faces. The veins are 20 to 50 centimeters in width and can be followed for a short distance along the strike. These veins have never been worked, owing to the low tenor of the metallic ore present, but they are a potential source of barite.

Pure barite lenses occur in sandstones of the Korat series in Amphur Nam Pat, Changwat Uttaradit. The barite is white and massive but good transparent crystals are not uncommon. The lens crops out in a stream about 20 kilometers southeast of Amphur Nam Pat. It is about 1 meter wide and 3 meters long. The absence of igneous rocks and the form of the deposit suggest that it might be a chemical precipitate. Because of its remoteness to transportation, no attempt has been made to prospect for additional and larger bodies.

A bed of barite, 10 meters thick and dipping 50° W., and several narrower beds crop out at kilometer 55 near the crest of a hill on the trail from Tak to Mae Sot, Changwat Tak. They are interbedded in sandy shale believed to belong to the Kanchanaburi series. These beds can be followed laterally but appear to be faulted on the west. A partial analysis made in the chemical laboratory of the Royal Department of Mines shows:

Partial analysis of barite from an outcrop at kilometer 55 on the Tak-Mae Sot trail

$BaSO_4$	92.7
SiO_2	3.02
Fe	0
	92.72

This deposit is the only possible commercial source of barite so far known in Thailand and it is 174 kilometers from the nearest railroad.

BUILDING STONE AND ROAD METAL

By Saman Buravas

GENERAL FEATURES

Many of the old temples and palaces were built of local stone, but since the advent of concrete there has been little stone construction despite the abundance of suitable marble, limestone, sandstone, laterite, and granite. Limestone is preferred for railroad ballast and is generally available along the present railway lines. Limestone is also preferred for highway construction but quartzite, granite, porphyry, and even vein quartz is used locally, accessibility being the deciding factor in the selection of the rock.

No production statistics for either building stone or road metal are available.

BUILDING STONE

Sandstone of the Korat series which comprises most of the Korat Plateau and crops out in other areas of Thailand was used in the past for both building and ornamental stone. Many old temples built of laterite have facings and pillars of sandstone and it has been widely used for Buddhas and other religious images. The sandstone is fine grained and has a red ferruginous cement. It is generally very friable and, although easy to quarry and to carve, it is not resistant to wear. At the present time it is quarried only for grindstones and other abrasive stone.

Granites and granite gneisses, suitable for building, occur throughout Thailand, but few building-stone quarries have been opened in them. A grey granite gneiss at Laem Thaen near Bang Saen, a seaside holiday resort in Changwat Chon Buri, has long been worked for kitchen mortars and pestles. The gneiss contains so much mica that it is easy to quarry and to shape. The monument at Phya, Thai, commemorating the Thailand-Indochina conflict, was built of this material but it has not been quarried since for building purposes.

Despite the abundance of suitable limestone and marble in Thailand, these rocks have not been quarried for building stone.

Lateritic ironstone is widely distributed and has long been used in building temples and other structures (Blanck, Credner, and Olderhauser, 1935, pp. 419–452; Pendleton, 1941, pp. 177–202). It occurs as a layer within the zone of vertical fluctuation of the water table in equatorial soils that have long been exposed to weathering. Of the two types of laterite, pisolitic and spongy, the latter is used for building purposes. It has a slaglike appearance and clay-filled cavities. It generally grades downward into iron-stained clay. Laterite is easy to quarry and to shape into building blocks, which harden on long drying. Among the well-known ancient structures built of laterite are Ankor Wat in Cambodia, Indochina, Pimai Palace in Korat, and the old palaces at Lop Buri. With the availability of concrete and increasing accessibility of burned brick, the use of laterite for building purposes has practically ceased.

ROAD METAL

It is estimated that 80 percent of the road metal used in Thailand is limestone. With few exceptions, all railway ballast is quarried from the Rat Buri limestone. The quarries lie within 3 kilometers of the main lines and are connected by spur tracks. Drilling and breaking is usually done by hand, but mechanical crushers and sizers have been installed in a few of the railway quarries such as Ban Mae and Chong Khae. Limestone is also preferred for highway construction, and there are many small quarries along the highways of Thailand. The limestone generally used is the widely distributed Rat Buri limestone, but the quarry at Thung Song, in the south, is in the black Thung Song limestone of probable Ordovician age.

The tin-bearing granite at Nam Noi hill, near Songkhla in the south, is quarried for railway ballast and some is used in highway construction. A green porphyry is quarried for road metal at Chon Buri. Rhyolites and porphyries are used on the highways in the Nakhon Nayok area.

Other rocks used for road metal are vein quartz from Khao Sam Muk; hematite, contact-metamorphic rocks, and diorite from Khok Kathiam in Lop Buri; and slate and quartzite at Phet Buri, Fang, and Chiang Rai.

CEMENT MATERIALS

By Nitipat Jalichandra

Most of the cement used in Thailand is manufactured by the Thai Cement Co., the sole producer of cement in the country. During the 5-year period before World War II the average monthly output of cement was about 8,500 tons. In 1940 the company discontinued the manufacture of the standard portland cement and made a cement, containing about 30-percent sand, in order to increase production without increasing the plant installations. The company has begun an expansion program which it expects to complete within a year; then the monthly output will be about 15,000 tons. The present (April 1950) output is about 12,000 tons per month, which is slightly below the present demand. Some cement was exported by the company before World War II but none has been since then.

The company operates two plants, one at Bang Su railway station 11 kilometers from Bangkok, and the other at Tha Luang, about 150 kilometers north of Bangkok on the Pav Sak River. The Tha Luang plant is connected with the company marl quarry by a rail siding and similarly with the main northern railway at Ban Mo station in Changwat Sara Buri. The Bang Su plant has complete facilities for cement manufacture, but the Tha Luang plant produces only cement clinker. All grinding and packing of cement is done at the Bang Su plant.

The cement is manufactured by the wet process, using as raw materials clay, marl, and gypsum. The first two materials are available in abundant quantities of high purity at cheap cost. Although some gypsum is obtained from quarries in the Lampang region (see section on Gypsum) the company regularly imports gypsum to supplement the local supply.

The clay is obtained either from company-owned clay quarries very near the Bang Su plant or from excavations of canal and river beds. The marl is mined from a quarry near the Tha Luang plant in the Ban Mo district of Changwat Sara Buri. The marl is very soft and easily excavated at low cost. The marl deposits near the base of Phra Bat Mountain are very extensive and lie at shallow depth. They were probably formed by redeposition of dissolved calcium carbonate at the bottom of a former lake. The following analysis of the Ban Mo marl made in the company's laboratory was kindly furnished by M. L. Udom Sanidwongse, the assistant manager:

Constituents:	Percent	Constituents:	Percent
SiO_2	5.40	CaO	51.04
Fe_2O_3	1.35	Ignition loss	40.37
Al_2O_3	0.73		
MgO	0.40		99.29

CLAY

By Saman Buravas

The principal clay products in Thailand are common bricks and household utensils of fired red and brown clays. Because these products are so common to everyday life, it is not generally realized that domestic clay is one of the principal mineral commodities of the country and that the annual value of clay products is measured in millions of bahts. Because of the wide distribution and generally small size of individual brick and pottery works, no statistics have been kept on either the quantity of clay that is mined each year or the value of manufactured clay products. Although common bricks and pottery have been made since the beginning of historical times, the first white china made in Thailand was during World War II when imports from Japan and England were cut off.

Domestic industrial clay deposits may be classified into three categories: residual, transported, and bedded clays. No deposits of fire clay are known in Thailand.

TRANSPORTED CLAY

Blackish, plastic transported clay is found throughout the great central plain of the Chao Phraya River. Much clay is mined and processed in Changwat Nonthaburi and brought 10 kilometers downstream to Bangkok by boat. The layer of topsoil, generally about 1 meter thick, is stripped to expose the clay. The top of the clay bed is usually of a quality suited for common brick. Finer clays, which lie deeper below the topsoil, are used for crude products such as water jars, basins, stoves, and flower pots. The finest selected clay is used for thin vessels whose outer surface must be polished before firing, such as pots, bowls, kettles, and orchid pots. Fine sand is mixed with all of the clay used in pottery, and the pug is tramped by foot to homogeneity and left in a moist state for some time to improve the plasticity. As a red-burned finish is generally desired, iron oxide powder is commonly applied to the outer surface of the vessel before firing.

RESIDUAL CLAY

Search for a residual clay suitable for the manufacture of white china began during World War II. Suitable clays derived from the weathering of granites were known to occur in the tin mines in the south, but transportation to Bangkok is too costly. Some residual clay has been mined at Prachin Buri, northeast of Bangkok, where kaolin is formed by the decomposition of granite or granite aplite. Iron oxide, from the overlying lateritic soil, lowers the quality of the clay. The purer material is used in the manufacture of second-grade porcelain but most of it is used as a filler in paper.

BEDDED CLAY

The kaolin deposit at Sawankalok appears to be in a sedimentary bed but the quality of the fired product does not justify the cost of transporting the clay to Bangkok. Kaolin beds are reported from Chon Buri and Chanthaburi east of Bangkok, and a bed of white shale in the Korat series from which some shipments have been made is exposed at Thung Plang village on the shore of the main land opposite Ko Kram. Ware made from this shale burns to a light gray.

Analyses of specimens of clays of Thailand

[Analyses by the Royal Department of Mines except specimen 3 by the Department of Science]

Constituents	Specimens								
	1	2	3	4	5	6	7	8	9
H_2O	14. 0	15. 46	12. 65	12. 78	13. 40	14. 48	12. 40	12. 77	13. 12
SiO_2	46. 5	44. 15	47. 5	46. 33	47. 01	44. 80	47. 78	55. 08	49. 21
Al_2O_3	39. 5	34. 31	38. 6	39. 37	37. 63	37. 74	34. 63	21. 79	35. 07
Fe_2O_3	------	. 84	tr.	1. 04	1. 74	2. 45	2. 47	2. 70	1. 61
FeO	------	. 51	------	------	------	------	------	------	------
CaO	------	------	1. 1	. 32	. 22	. 50	. 29	7. 65	. 87
MgO	------	. 37	------	. 14	------	------	. 04	------	. 12
K_2O	------	. 28	------	------	------	------	------	------	------
Na_2O	------	3. 02	------	------	------	------	------	------	------
SO_4	------	. 82	------	------	------	------	------	------	------
Cl	------	. 09	------	------	------	------	------	------	------

1. Pure clay (theoretical value).
2. Residual clay from tin mine, Surat Thani.
3. Residual clay from tin mine, Phuket.
4. Residual clay, Prachin Buri.
5. Residual clay, Prachin Buri.
6. Residual clay, Prachin Buri.
7. Residual clay, Prachin Buri.
8. Bedded clay, Sawankalok.
9. Bed clay, Chanthaburi.

DIATOMITE

By Vija Sresthaputra

Diatomite in Thailand has been reported only from the basin of the Mae Nam Wang near Lampang. This basin occupies the Mae Nam Wang valley between Amphur Hang Chatr and Amphur Mae Tha.

About 18 kilometers south of Mae Tha railway station, a thick bed of diatomite crops out on the southern bank of the Mae Chang, a tributary of the Mae Wang. The exposure is reported to be 10 by 20 meters, and the bed dips westward toward the center of the basin. An analysis by the chemical laboratory of the Royal Department of Mines follows:

Analysis of diatomite from the Lampang basin

Constituents:	Percent	Constituents:	Percent
SiO_2	77.34	MgO	3.30
F_2C_3	2.85	Moisture	4.56
Al_2O_3	6.33		
CaO	5.14		99.52

A microscopic examination of the material by J. Charaljavanaphet showed several varieties of diatoms. Estimate of grain size is 5 percent 0.028–0.056 millimeter, 40 percent 0.003–0.028 millimeter, and 55 percent less than 0.003 millimeter. Because this deposit has never been mined its extent is unknown, but it is believed to underlie much of the Lampang Basin. The deposit is believed to be of fresh-water origin.

FLUORITE

By Vija Sresthaputra

In Thailand fluorite is sought for a gemstone rather than for an industrial mineral. It is known as soft gemstone by the natives. Several deposits are reported but all appear to be too small to warrant commercial exploration. The association of fluorite with epithermal barite-lead-copper veins of the Ban Pin area has been mentioned on page 137. It is a sparse gangue mineral in the tin-tungsten lodes of the south. Narrow fluorite veins, generally without other minerals, are found in the southern granite bodies.

A fluorite vein occurs in the main granite range about 15 kilometers airline west of Chaam station on the southern railway. It crops out on the low hill known as Khao Hua Waen (the gemstone hill) that flanks the western slope of the range. At one time it was worked for gemstones by natives who dug a pit 1 meter deep and 70 centimeters wide by 10 meters long. The fluorite ranges from colorless to green, blue, purple, and red. During World War II the Thai Rice Company used the material in making enamel, with satisfactory results.

Another Khao Hua Waen lies about 20 kilometers northwest of Huai Hin and the existence of several fluorite veins there has been reported.

In Amphur Pai, Changwat Mae Hong Son, veins of fluorite 30 centimeters wide are found in the porphyritic granite batholith that divides the Pai from the Chiang Mai basin. Here massive pieces of fluorite are sought to be carved into images of Buddha. It is reported that an image about 1 foot high was made from a piece of fluorite from this deposit.

GEMSTONES

GENERAL FEATURES

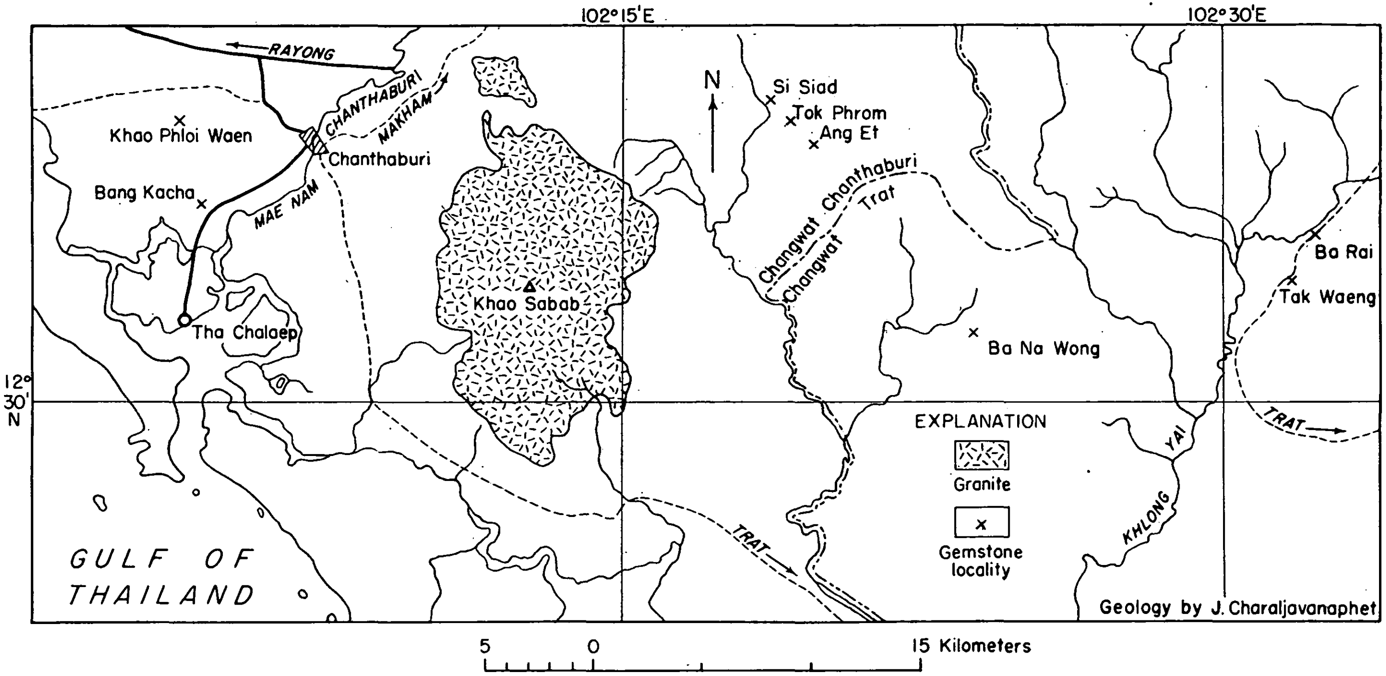
Thailand like neighboring Burma and India has been a producer of gemstones for many years. Most notable among the gemstones of the Kingdom are sapphire and ruby and some topaz and zircon. Good rubies, generally darker than the Burmese stones, are found in Changwat Trat. Because of their deep red color the Thai rubies command high prices. Fine blue sapphires also occur at several localities. The gemstones are generally found in eluvial or alluvial placers associated with Tertiary (?) basalt in lava flows or in plugs which intrude older sedimentary or metamorphic rocks. In some places gemstone occurences may be related to pegmatite or schist. The gem-bearing ground is generally mined from shallow pits and concentrated by screening and panning. From the washed concentrates the gemstones are selected by hand. The known gemstone localities, most of which are not being worked, lie in Changwats Chanthaburi and Trat in southeastern Thailand (fig. 34) and in Changwat Kanchanaburi to the west of Bangkok. The individual localities are described in some detail below.

KHAO PHLOI WAEN PLACERS, CHANTHABURI

By George C. Taylor, Jr., and Saman Buravas

The Khao Phloi Waen (Sapphire Mountain) gemstone placers (fig. 35) are in Changwat Chanthaburi about 6.5 kilometers west of the city of Chanthaburi. The placers are easily accessible by automobile from the city by a good dirt road. Khao Phloi Waen is an isolated butte which rises 89 meters above sea level and about 70 meters above the surrounding lowlands. It is approximately elliptical. At the base the butte measures about 400 meters in an east-west direction and about 200 meters from north to south. Near the southeast base is the Wat Khao Phloi Waen (Buddhist Temple).

The physiographic form of Khao Phloi Waen suggests that it is possibly a volcanic plug from which enclosing rocks have been stripped away by erosion. The butte appears to be formed entirely of massive dense dark gray basalt which yields a characteristic red soil on weathering. In outcrops on the upper slopes of the butte, the basalt is rich in black spinel, and near the wat the rock is reported to contain nepheline. Gemstones are found only rarely in fresh basalt outcrops and none was discovered by the writers during their visit in January 1950.



แหล่งพลอยในจังหวัดจันทบุรีและตราด

FIGURE 34.—Sketch map showing the principal gemstone localities of eastern Thailand.

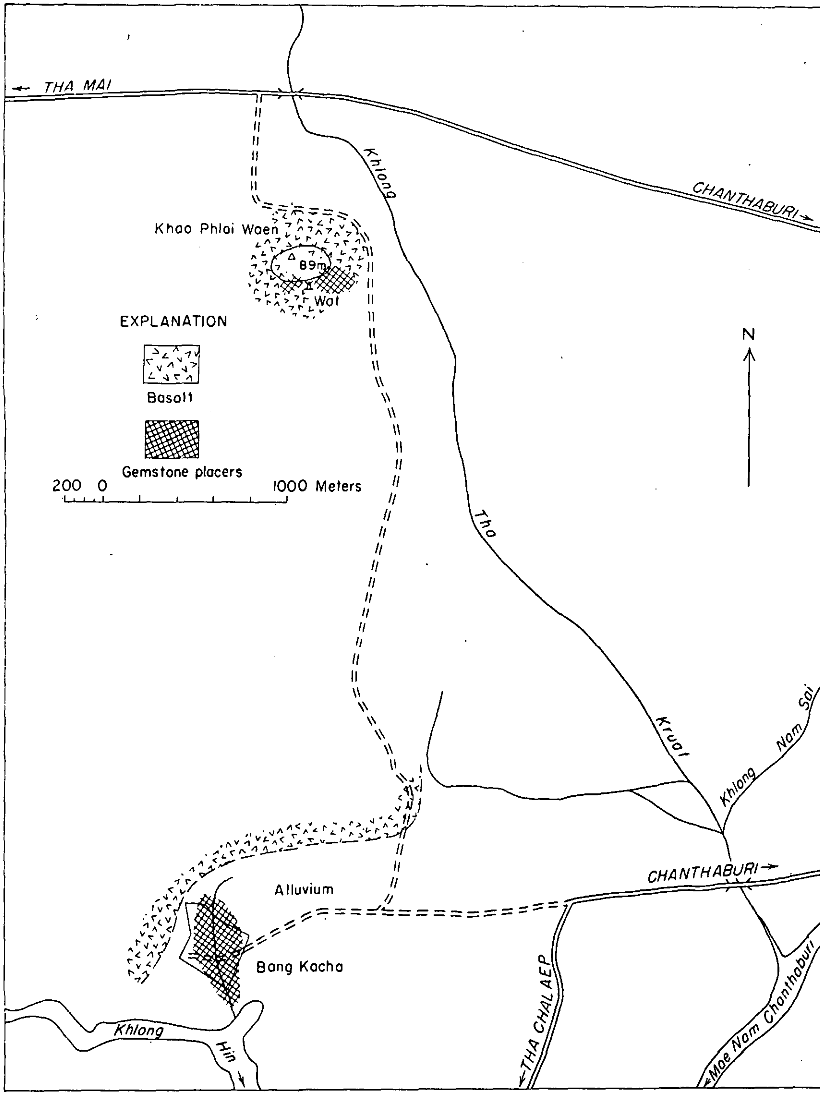


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FIGURE 35.—Sketch map of the Khao Phloi Waen and Bang Kacha gemstone placers, Changwat Chantha Buri.

The Khao Phloi Waen placers are essentially eluvial, lying on the basal slopes of the butte. The two principal areas of gem-bearing ground are 50 to 200 meters northeast of the wat, and west of the wat on the south slope of the butte. The placer ground consists of a mantle of red clayey soil, with weathered fragments and rock chips of basalt. In the two placer areas the mantle is from a few centimeters to about 3 meters thick and rests on basaltic bedrock. The gemstones are reported to be most abundant in the lower part of the mantle near bedrock.

According to monks at the wat, the placers have been known and worked intermittently for 100 years or more by local inhabitants. At the time of the writers' visit no mining activity was in progress and none has been reported since 1945. The placer ground has been worked generally through simple pits dug to bedrock. Where water is available the gem-bearing material may be concentrated by washing and panning, but in most cases the gemstones are selected entirely by hand picking.

Sapphire is the principal gemstone obtained from the placers although topaz and zircon are also found, and rarely ruby. Rough gemstones from Khao Phloi Waen were seen by the writers in Chanthaburi. The sapphires in the rough are rarely larger than 1 centimeter in diameter and average about 3 to 5 millimeters. Most of the stones are of the characteristic deep blue color, and occasionally stones of the star variety are found. Topaz from Khao Phloi Waen is considered by local gem dealers to be of exceptionally fine quality. Cut stones seen in Chanthaburi are rich honey yellow in color and contain few flaws. The rough gem zircon is usually found in small tetragonal crystals less than 5 millimeters in diameter. Most of the stones are transparent and colorless but some are brownish. A slight turbidity present in some of the natural stones generally disappears on heating.

BANG KACHA PLACERS, CHANTHABURI

By Saman Buravas and George C. Taylor, Jr.

The Bang Kacha gemstone placers (fig. 35) are in the Changwat of Chanthaburi about 7.5 kilometers southwest of the city. The placers can be easily reached by automobile from Chanthaburi by a good dirt road.

The placer ground occurs in and around the village of Bang Kacha which lies a few meters above sea level on a tributary of the Khlong Hin estuary. The village is situated on a lowland plain underlain by alluvium. Just west and north of the village is a low terrace about 5 meters high that apparently marks the edge of a basalt flow.

The gem-bearing placer ground occurs in the alluvium which averages about 3 meters thick above bedrock at Bang Kacha. The ground has been worked intermittently for gemstones by the villagers for many years, but little activity has been noted in recent years. The gemstones are recovered by pitting to bedrock and by panning and washing the excavated material. The gemstones are selected from the washed concentrate by hand picking.

The placers yield normal blue sapphire, topaz, a little gem zircon, and no ruby. In addition, green sapphire apparently peculiar to the locality is found. The gemstones are associated in the alluvium with common corundum, black spinel, and magnetite. The villagers report that occasionally pebbles of basalt containing sapphire crystals are found in the diggings. The angularity of rough gem material seen by the writers at Bang Kacha suggests only a short distance of stream transport from the parent rocks.

Rough blue and green sapphire stones of Bang Kacha seldom exceed 1 centimeter in diameter and average about 3 to 5 millimeters. The blue sapphire has good color and few flaws. Locally the green sapphire is much appreciated and commands a good price in Chanthaburi. The topaz of Bang Kacha has few flaws and a rich honey yellow color. Gem dealers of Chanthaburi consider it to be the finest in Thailand and comparable to the best grades of gem topaz found elsewhere in the world.

TOK PHROM DISTRICT, CHANTHABURI

By Jumchet Charaljavanaphet

The Tok Phrom gemstone district lies in Changwat Chanthaburi about 21 kilometers east of the city. Gemstones are mined in the district from three placer localities near Ban Tok Phrom, Ban Si Siad, and Ban Ang Et. Much of the district appears to be underlain by sheets of basalt which weathers to a characteristic red soil. The basalt in turn rests on country rock of sandstone or quartzite belonging to the Korat series. The gem-bearing ground occurs in eluvium on foot slopes of small rises or in alluvium along streams. Little mining activity has been noted in recent years, although local natives occasionally work the ground by pitting and panning methods. Sapphire is the principal gemstone obtained from the district, but some topaz and zircon and rarely ruby are found.

BO NA WONG PLACERS, TRAT

By Jumchet Charaljavanaphet

The Bo Na Wong gemstone placers lie about 13 kilometers southeast of the Tok Phrom district in Changwat Trat. They were mined most actively about 50 years ago by Burmese immigrants of the so-called Ku La tribes. During the past 20 to 30 years local Thai natives have intermittently worked the placers, but no activity has been reported since 1945. Low undulating terrain adjacent to the placers appears to be underlain largely by weathered basalt. The placers are confined in a rhombic area of about 1 square kilometer. The gemstones are reported to occur in gravelly ground and are recovered by pitting, panning, and hand picking. The most common gemstone obtained is ruby, but a little topaz and zircon and occasionally sapphire are also reported to be found.

BO RAI DISTRICT, TRAT

By Jumchet Charaljavanaphet

The gemstone district of Bo Rai is about 15 kilometers north-northeast of the Bo Na Wong placers in the northern part of Changwat Trat and near the southwestern base of the range forming the border between Thailand and Cambodia. Gem mining was at its peak about 40 years ago when a few thousand placer miners are reported to have worked in the district, but in recent years only small activity has been noted. Bo Rai and Tak Waeng are the principal placer localities of the district. The gem-bearing ground occurs in alluvium which averages about 8 meters in thickness at Bo Rai but much less at Tak Waeng. The gemstones are reported to be most abundant in gravelly material about 1 meter thick near the base of the alluvium. Simple pitting and panning is the general method of mining, but where the alluvium is thicker short drifts are dug from the pits to remove the gem-bearing ground. Ruby is the most common gemstone produced but a little gem zircon and topaz are also recovered. Sapphire is reported to be absent.

BOH PHLOI PLACERS, KANCHANABURI

By Jumchet Charaljavanaphet

In Changwat Kanchanaburi are the gem placers near King Amphur Boh Phloi about 25 kilometers by secondary road to the north of Kanchanaburi. Considerable mining both by local natives and foreign companies is reported through 1940, but in recent years activity has diminished with the increasing paucity of gem recovery. Lack of water in the dry season limits placer mining to the 8 months' wet period when stream flow is adequate. The placers are associated with nepheline-olivine basalt of Tertiary (?) age which has intruded slates and quartzites of the Kanchanaburi series. A small hill formed by the basalt shows columnar jointing near the top and sheetlike structure near the base. On the foot slopes of the hill, sapphire, together with black spinel, occurs in soft eluvial or residual ground lying in crevices through outcrops or boulders of weathered basalt. The gemstone material is scraped from the crevices and then is panned and hand sorted. Adjacent to the hill, gem-bearing material is found in alluvium at depths of 3 to 4 meters below the surface and is worked by pitting and panning. Sapphire is the most important gemstone obtained from the placers. The stones are generally lighter in color and of larger size than elsewhere in Thailand. One rough stone weighing 457 carats is reported to have been found. The placers also yield a little ruby of poor quality. Black spinel, which polishes well, is abundant and sustains much of the present mining by local natives.

GRAPHITE

Graphite in disseminated flakes or in small pockets through schist, gneiss, or granite has been recognized at several localities. However, the best known prospect of the Kingdom is that of Khao Phang.

KHAO PHANG PROSPECT, CHANTHABURI

By Jumchet Charaljavanaphet, Saman Buravas, and George C. Taylor, Jr.

The Khao Phang graphite prospect is in Changwat Chanthaburi about 14 kilometers airline northwest of the city (fig. 36). The prospect is 4.2 kilometers by footpath to the northeast of the Song Phi Nong school at kilometer 136.5 on the Rayong-Chanthaburi highway. By automobile the school is 20 kilometers to the west-northwest of Chanthaburi.

The prospect lies in a large open recess on the southwest slope of Khao Klaet ridge at an altitude of about 210 meters. The recess is marked by extensive landslide scars and large jumbled masses of talus blocks. The country rock is coarse-textured biotite-muscovite granite which forms most of the south end of Khao Klaet ridge. At the base of the ridge and the mouth of the recess the granite is overlain by flows of dark gray columnar basalt which forms an extensive bench to the east of Ban Sui. Between Ban Sui and Ban Song Phi Nong and to the northwest and southeast of these villages the surface is underlain by alluvium containing granitic and basaltic debris.

The graphite prospect is in a landslide area locally known as Khao Phang (Broken Mountain). The graphite occurs irregularly disseminated through granite in blebs ranging from several millimeters to 20 centimeters in diameter. The structure of the graphite is generally foliated or scaly, and in places hexagonal cross sections of small crystals are visible through a hand lens. The area of graphite-bearing granite is evidently of limited extent. In a zone about 10 meters in diameters at the center of the prospect the concentration of graphite may reach 1 percent of the total rock volume, but in the periphery around this zone the graphite content is much less.

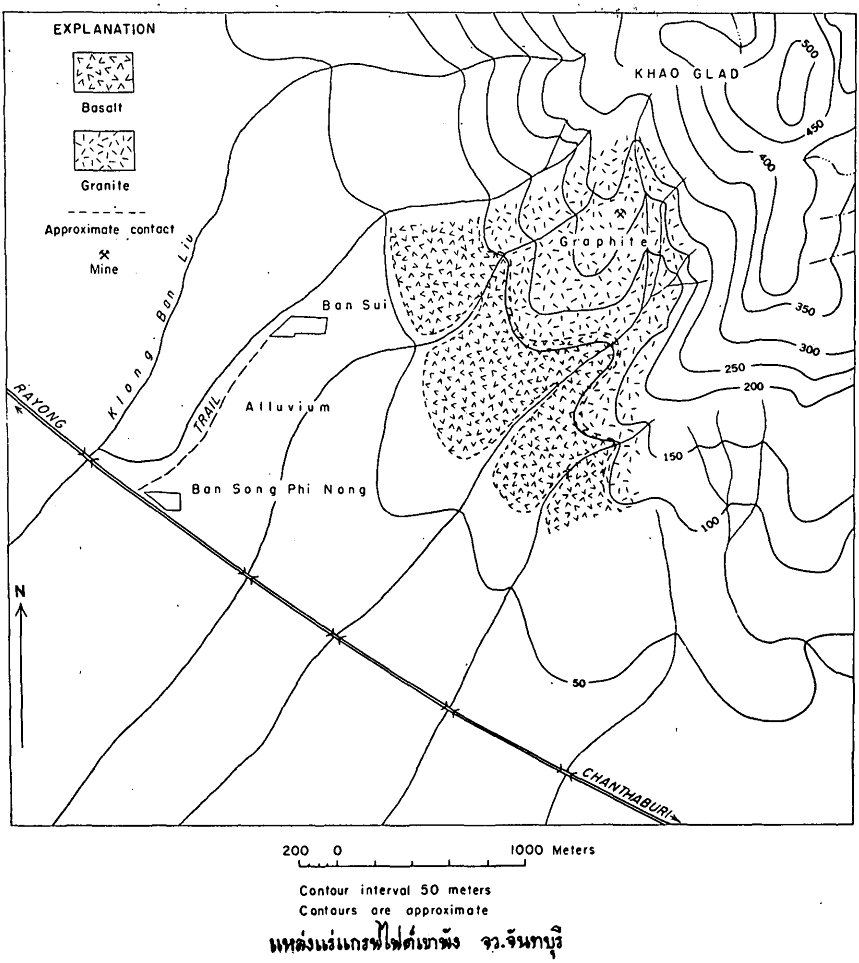

FIGURE 36.—Sketch map of the Khao Phang graphite prospect, Changwat Chanthaburi.

Local natives have mined some graphite by picking the material from pockets in outcrops and by sorting out loose fragments from arkosic wash near the prospect. It is reported that in 1940 some 500 kilograms of graphite concentrates from the prospect were marketed in Bangkok.

GYPSUM

By Nitipat Jalichandra

The consumption of gypsum in Thailand, principally by the cement industry, is not large. When imports were stopped during World War II, the Thai Cement Co. obtained its supplies from the vicinity of Lampang, in the north, where a number of small deposits had been found. Only one mine was in operation in 1949.

Annual production of gypsum, 1943–49, in Thailand

	Long tons		Long tons
1943	345	1947	69
1944	131	1948	197
1945	—	1949	151
1946	85		

At Ban Song Hong of Amphur Nampard, Changwat Uttaradit, gypsum rock was found interbedded in red bed sediments of the Korat series. The deposit is lenticular in form with a general N. 65° E. strike and 25° N. dip. One lens measures 80 centimeters at the thickest part and is 12 meters long. In order to determine the extent of the deposit the Thai Cement Company sank test pits in 1942, but the area was abandoned because of poor results and difficulty in transportation.

Another deposit of gypsum was located near Mae Mo, a district 50 kilometers east of Lampang along the railroad. At this locality selenite fills a dendritic system of cracks in a bed of white plastic clay 10 meters thick. The cracks are believed to have resulted from shrinkage of the clay bed upon drying. The width of the cracks ranges from a few millimeters to about 10 centimeters. The gypsum apparently originated from gypsiferous ground water which percolated through a porous bed of red soil underlying the white clay and moved upward by capillary action through the cracks in the clay. This origin is suggested by the red stains on walls of the cracks and inclusions of red soil material in the selenite.

Mining was accomplished by sinking a number of vertical but unsupported shafts to the top of the underlying red soil at depths ranging from a few meters to about 10 meters. The gypsum, usually contaminated with clay, was washed and then transported by ox carts to the nearest railroad at Mae Mo, a distance of 8 kilometers, to be shipped to Bangkok by rail. All the gypsum was sold to the Thai Cement Co., f. o. b. Mae, at 175 baht a ton. By 1947 the total production had been about 1,000 tons. At that time the deposit was exhausted and the mine was closed.

A deposit of satin spar gypsum occurs at Mae Kua about 45 kilometers south of Lampang along the Lampang-Thern highway. The occurrence of the gypsum is reported to be similar to that of Mae Mo, and mining is conducted in the same manner. This mine was idle for many years but was recently reopened and is producing about 70 tons a month. It is the only gypsum mine being worked in Thailand at present (1950).

Anhydrite deposits are reported at Mae Sot where they occur as thin beds in the oil shale, and at Krabi where anhydrite bands 6 to 10 centimeters thick are interbedded with the late Tertiary oil shale and marl exposed along the bank of the Krabi estuary.

QUARTZ AND FELDSPAR

By Saman Buravas

Small quantities of vein quartz, quartz sand, flint, and feldspar are used in the glass and ceramic industries in Thailand. Of some interest is the use of burned rice husks, containing 80 to 95 percent of silica, in the manufacture of ceramic glazes. The material is abundant and cheap and does not require grinding.

The following analyses of various types of quartz have been made by the Department of Science, Ministry of Industry:

Analyses of quartz materials of Thailand

Constituents	Specimens							
	1	2	3	4	5	6	7	8
SiO_2	90. 10	96. 25	93. 85	96. 03	96. 17	96. 40	95. 43	95. 02
Al_2O_3	4. 46	2. 90	2. 87	2. 26	2. 03	2. 36	2. 07	3. 53
Fe_2O_3	3. 51	. 78	. 84	. 52	. 90	. 61	. 78	. 62
CaO	. 48	------	. 22	. 53	. 21	. 22	1. 33	. 22
MgO	. 60	------	------	. 50	------	. 06	. 07	. 10
Ignition loss	. 69	. 69	. 21	. 21	. 68	. 32	. 28	. 48
	99. 84	98. 62	99. 99	99. 60	99. 99	99. 97	99. 96	99. 97

1. Flint, Kanchanaburi.
2. Vein quartz, Chon Buri.
3. Vein quartz, Ko Samui.
4. Vein quartz, Yala.
5. Vein quartz, Nakhon Si Thammarat.
6. Quartz sand, Chanthaburi.
7. Quartz sand, Chanthaburi.
8. Quartz sand, Chanthaburi.

Orthoclase feldspar was formerly obtained by hand sorting of porphyritic granite and pegmatites found at Khao Phra Bat in Changwat Chon Buri. Two new pegmatite localities have recently been found where the feldspar occurs in large crystals free from quartz inclusions. One is on the coast near Khao Phra Bat and the other at Tambon Tha Di in the Amphur and Changwat Nakhon Si Thammarat. The former is now worked on a small scale for making pottery glaze, but no production figures are available. The latter deposit, which has not been mined, also contains muscovite and beryl.

SALT

By Jumchet Charaljavanaphet

Salt is produced in the coastal towns along the Gulf of Thailand by solar evaporation of sea water. Salt water seeps from sandstones of the Korat series on the Korat Plateau to the north and northwest

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of the city of Korat, to the west of Khon Kaen, and between Roi Et and Ubon and near Buriram. The seeps form efflorescences of salt on the land surface. This material is leached in hollow logs and the liquor is evaporated to dryness in the sun. It has been supposed that salt beds in the sandstones of the Korat series lie fairly near the surface in the vicinity of these seeps. A hole drilled for fresh water near the city of Korat showed salt water and some solid bitumen at a depth of 80 to 100 meters and bottomed in salt water at 140 meters. Another salt well was drilled on the eastern edge of the Amphur Selaphum near Korat. Salt crusts on the surface have been reported from Amphur Sung Noen and on the bank of Nam Songkhram northwest of Nakhon Phanom.

SOAPSTONE (PAGODITE)

By Saman Buravas

Pagodite, one of the minerals to which the term "soapstone" is loosely applied, is found in Changwat Nakhon Nayok, at the crest of Khao Changok (lat. 14°17′ N., long. 101°09′ E.). The deposit is accessible by a good dirt road that branches north from the Hin Kong-Nakhon Nayok highway at kilometer 30 which is 8 kilometers away.

The deposit was formerly worked by the Government paper factory for a paper filler. Blocks and slabs were also fashioned into vases, trays, lampshades, and tile, similar to but not so finely made as articles of like material imported from China. An attempt was made to burn shaped bricks for refractory use but the material spalled and cracked in firing. When imported soapstone and talc became available after World War II, operations ceased. Recently the Thai Navy Signal Corps has mined the material for refractory and electrical use.

The purest pagodite is subtransparent to translucent, colorless or bluish white. Under the microscope its structure is cryptocrystalline. Its specific gravity is 2.7+, and its hardness is 2.5. Most of the material contains iron oxide and slate fragments, resulting in colors ranging from various shades of gray to honey yellow with blotches, bands, and streaks of either dark gray or red, similar to the colors of the pagodite from China. The table (next page) gives chemical analyses of Thai and Chinese pagodite.

The mineral occurs in a tabular body 40 meters wide, 200 meters long, and at least 80 meters deep. It is flanked on the northeast side by a band of chalcedonic quartz 25 meters wide, and on the southwest side by a rhyolite dike. Lenses of rhyolite and chalcedony, as well as xenoliths of pyritic slate, occur within the pagodite body. The slate xenoliths clearly show a gradation of chemical assimilation by

Analyses of pagodite

Constituents	Origin of specimen	
	China	Thailand
SiO_2	48. 72	50. 38
Al_2O_3	31. 56	33. 27
Fe_2O_3	2. 43	
H_2O	5. 75	12. 36
CaO	------------	3. 98
MgO	1. 81	------------
K_2O	9. 48	------------
Na_2O	. 31	------------
	100. 06	99. 99

the rhyolite resulting in the formation of pagodite. The body shows a gradual thinning toward the south end and is cut off by a later intrusive body of quartz monzonite porphyry on the north.

The pagodite appears to have resulted from chemical reactions, under conditions of moderate temperature and pressure, between silica, water, and alkalies, exuded from the rhyolite, with alumina and iron ozides from the slate country rock in which the rhyolite was emplaced. The resulting complex hydrous aluminum silicate so closely resembles the Chinese pagodite (or agalmatolite) that the same name has been applied.

Reserves are estimated as 480,000 cubic meters, or 1,300,000 metric tons.

FUELS

COAL

By Junchet Charaljavanaphet

GENERAL FEATURES

Coal, generally considered as lignite in rank, has long been known in fairly widely scattered localities in Thailand (table 1, p. 159). Several attempts have been made to develop coal deposits in the southern part but none of the operations has been successful because of lack of capital, inefficient mining methods or management, or lack of adequate transportation facilities. The need for coal to replace wood in running railroads or in the development of electric power is so great that the Thai Government has recently undertaken an exploration program of the coal resources.

Coal deposits are known at 16 localities in 8 Changwats of Thailand. These deposits occur in Tertiary sediments of continental or brackish-water marine origin, enclosed in intermontane basins or bordering the present coast lines.

The deposits of northern Thailand are characteristically lignite in shades of brown, with woody textures, low calorific values, and rapid weathering on exposure to air. The coals of southern Thailand have been called lignite also, but they are rather dense and black, and most of the analyses (see table 2, p. 160) show them (undried) to contain 4,700 to 6,200 calories per kilogram.

The calorific content can be converted to British thermal unit content by multiplying the number of calories by 1.8. Accordingly, coals having more than 4,611 calories per kilogram would be classified as subbituminous rather than lignite; coal having more than 6,111 calories per kilogram and lacking either the weathering or the non-agglomerating characteristics of subbituminous and lignite is classified as bituminous. By this classification, the analyses of at least two of the coals from southern Thailand are indicated as probable bituminous coals. More detailed analyses of fresh samples of coal will be needed before it can be definitely ascertained whether these coals are subbituminous or bituminous. Most of the remaining coals of southern Thailand are probably subbituminous rather than lignite.

The Tertiary coal beds are exposed at the surface at relatively few places because there are widespread unconsolidated deposits of clay and sandy clay that effectively conceal the bed rock. This mantle is generally less than 2 meters thick. The Tertiary coal-bearing beds had been folded, faulted, and eroded before the deposition of the surficial mantle. In most places the beds dip 10°–30°. Although several of the beds are in areas near sea level and the ground water table, some of them can be exploited by strip mining or shallow underground mining without interference by water.

KIANSA DEPOSITS

Coal deposits occur in Changwat Surat Thani near Kiansa which is about 65 kilometers upstream from Bandon on the Tapi River. During the wet season the locality can be reached by motorboat or steam launch from Brandon, 20 or more hours away.

Development of the deposits was begun in 1921 when the Siam Coal Mining Co., Ltd., was organized with Thai capital. At that time offices and dwellings were constructed, a wharf with coal loading chutes was built on the river, and a 20-kilometer railroad was laid between the wharf and the mine. Operations ceased in 1928 after several thousand tons of coal had been mined and futile efforts had been made to increase production. The venture apparently failed because of inadequate prospecting of the deposits and lack of technical supervision. At present the Anglo-Oriental (Malaya) Co. has a prospecting license for the Kiansa deposits.

The Kiansa deposits were visited in 1923 by E. G. Lee, then mine inspector of the Royal Department of Mines. In his report on the area Lee describes the coal seam then being worked by the Siam Coal Mining Co. as striking about north and dipping about 20° W. The seam ranges from 30 centimeters to 2 meters thick and is exposed along the strike for about 22 meters. It lies between stiff gray claybeds which require timbering. On its eastern margin it pinches out, but to the west it is cut off sharply as though by faulting. The coal is subbituminous or bituminous and of good quality but it does contain considerable pyrite. Four prospect shafts sunk near the workings and to the west of them indicated that good quality coal is present between beds of shale at shallow depth. Analyses of Kiansa coals are listed under samples 13 to 17 of table 2.

LAM PHURA PROSPECTS

Two coal-bearing localities have been recognized near Lam Phura which lies in Changwat Trang about halfway between Trang and Huai Yod on the Kantang-Thung Song railway. Coal float has been observed at the junction of Khlong Lam Phura and Huai Bang Thep to the east of Lam Phura village and also along Huai Sura near Ban Han Chin Khao. According to old natives, coal cropped out in a number of places along Khlong Lam Phura some 40 to 50 years ago but the outcrops have since been buried by sandy tailings from tin mining upstream. Loose fragments of coal may still be traced along the stream for 120 meters. White and yellow sandy clays underlain by brown shale, with fragments of fossil shells and leaves crop out on the stream banks in the same locality. The clays strike N. 20° E. and dip 15°–20° W. and the shales strike N. 20° W. and dip 15°–20° W.

Along Huai Sura no outcrops have been found but considerable float of good quality coal occurs. The analysis of sample 12 (table 2) from this locality indicates good quality subbituminous coal. The sulfur content is comparatively low and the moisture content of the sample may be somewhat high, owing to surficial hydration, but even so the calorific value is higher than average for Thai coals.

BAN PU DAM AREA

The Ban Pu Dam coal area is in Changwat Krabi about 25 kilometers southeast of Krabi. The coal deposits lie at or near the surface of a low coastal plain which fringes the Andaman Sea. The coal occurs in seams associated with late Tertiary sands, clays, and marls, some of which are of marine origin. The area is readily accessible from the sea by shallow-draft boat through the estuary of Khlong Praka Sai.

Exploration of a favorable seam is currently being conducted by the Thai Geological Survey from a camp near Ban Pu Dam. A block of about 320 hectares north of the camp has been selected for test drilling. Holes put down to date indicate that the coal seam lies at depths of about 2.5 to 7.0 meters beneath an overburden of sandy white clay. However, the thickness of the seam has not yet been determined because of limitations of drilling equipment. The same seam crops out for a considerable distance along Huai Pu Dam adjacent to the camp. Both the base and top are exposed so that by careful mapping of outcrops the thickness was estimated by the Thai Geological Survey to be about 28 meters. Just north of the camp the seam strikes N. 10° E. and dips 15°–25° E.

Coal, most of which is covered at high tide, crops out discontinuously through a distance of about 480 meters along Khlong Praka Sai estuary. The seam may attain a thickness of 11.5 meters. At Tha Rong Chak a seam about 11 to 15 meters thick is exposed. Downstream at Khlong Mak is an exposure which shows both the base and the top of a seam along a stretch of about 25 meters. The seam strikes north and dips about 35° E. Roughly calculated, the thickness is about 14.5 meters. The relation and structure of the Khlong Praka Sai outcrops suggest that they are part of a single thick coal seam. About 3,000 tons were reported to have been mined from the seam in 1914 under the direction of a Mr. Young, an Englishman. The coal was taken from a pit near the landing on Khlong Praka Sai, about 4 kilometers south of Ban Pu Dam. The pit is now abandoned and filled with water.

The analysis of a sample from outcrops on Huai Bang Pu Dam that was made in May 1948 (no. 10, table 2) indicates a subbituminous coal. The coal is about average in fixed carbon and comparatively low in sulfur. The specific gravity is somewhat lower than average for Thai coal. The coal is black, with a dark brown streak, and subconchoidal fracture. It contains pyrite which can be perceived by eye and which causes iron staining on decomposition. The coal tends to check into 5 to 10 centimeter fragments after exposure in the sun for 2 days or more.

KANTANG AREA

The Kantang coal area is in Amphur Kantang of Changwat Trang. Coal crops out in a small tidal estuary near Phra Muang to the west of the mouth of the Kantang river and also in Khlong Kasem about 500 meters north of Phra Muang. The deposits are easily accessible by launch from Kantang which lies 12 kilometers to the north.

The coal exposed near Phra Muang lies in a mangrove lowland. In outcrops which are covered at high tide, the coal strikes N. 20° E. and dips 20° W. The seam is overlain by soft clay and rests on light blue-green sand which crops out in several places. The locality was prospected by the Thai Geological Survey in 1948 when some 15 test pits were sunk to prove the thickness and extent of the seam. It was 1.25 meters thick and had partings of earthy carbonaceous material. The higher grade coal from the seam has a bright lustre and breaks into slabs 30 to 50 centimeters across. It shows only moderate checking after exposure for some time. The analysis of sample 11 (table 2) from Phra Muang indicates the coal is subbituminous in rank. With the exception of a somewhat higher sulfur content, the quality is similar to the coal of Ban Pu Dam.

MAE MO DEPOSIT

Lignite is found about 5 kilometers northeast of Mae Mo station on the northern railway in Amphur Mae Tha of Changwat Lampang. The deposit, continuous except for breaks of a few meters, lies in gently undulating terrain. According to informal reports by E. G. Lee and M. Boyer, the lignite occurs in a seam about 6 meters thick. The seam contains partings of barren clay or silt and beds of shells. The deposit is the only one in northern Thailand readily accessible to rail transport. Analyses of lignite samples from the Mae Mo deposit are given under nos. 2 to 7 of table 2 and show the range in quality.

OIL SHALE

By Saman Buravas

Oil shale deposits have been recognized in Thailand in two areas: in Mae Sot (lat. N. 16°40′, long. E. 98°35′) in Changwat Tak about 70 kilometers west of the city of Tak, and in Changwat Krabi in the

TABLE 1.—*Coal localities of Thailand*

Locality	*Tambon*	*Amphur*	*Changwat*
Klong Kasem	Na Klua	Kantang	Trang.
Lam Phura	Lam Phura	Huai Yod	Do.
Kra Soom	Kiansa	Na San	Surat Thani.
Kra Pan	do	do	Do.
Sin Pun	Tha Yang	Tha Yang	Nakhon Si Thammarat.
Laem Pho	Khao Thong	Muang	Krabi.
Ban Pu Dam	Khlong Khanan	do	Do.
Laem Chamuk Khwai.	Khao Thong	do	Do.
Huai Pong Nok	Mae Chaem	Mae Chaem	Chiang Mai.
	Mae Khuk	do	Do.
Khao Rua	Ban Wan	Hang Dong	Do.
Huai Kum	Uan	Pua	Nan.
Huai Pluak	Muang Teep	Ngao	Lampang.
	Nam Cho	Mae Tha	Do.
Mae Mo		do	Do.
	Yarom	Betong	Yala.

TABLE 2.—*Analyses of typical coals of Thailand*

[By Department of Science, Bangkok]

Sample	Locality	Calorific content (dried)	Calorific content (undried)	Percent									Specific gravity
				Ash (dried)	Ash (undried)	Volatile matter (dried)	Volatile matter (undried)	Fixed carbon (dried)	Fixed carbon (undried)	Sulfur (dried)	Sulfur (undried)	Moisture	
	CHANGWAT LAMPANG												
1	Mae Tha	5,500	----------	4.98	3.97	47.66	38.00	47.36	----------	----------	----------	----------	----------
2	Mae Mo 1	3,670	2,519	20.27	13.72	61.45	----------	----------	----------	----------	----------	31.36	----------
3	Mae Mo 2	4,874	3,483	21.06	14.59	55.75	----------	----------	----------	----------	----------	28.52	----------
4	Mae Mo 3	4,422	3,187	13.38	9.56	59.52	----------	----------	----------	----------	----------	27.93	----------
5	Mae Mo 4	5,047	3,707	23.72	17.30	50.30	----------	----------	----------	----------	----------	26.56	----------
6	Mae Mo 5	3,076	2,075	33.25	22.18	50.33	----------	----------	----------	----------	----------	32.52	----------
7	Mae Mo 6	5,332	3,855	20.51	14.75	50.25	----------	----------	----------	----------	----------	27.71	----------
	CHANGWAT KRABI												
8	Khlong Khanan	5,445	----------	11.80	9.20	42.60	55.20	45.60	----------	----------	----------	21.90	1.36
9	Krabi estuary	4,730	----------	16.70	12.50	42.80	57.20	40.50	----------	----------	----------	25.10	1.336
10	Ban Pu dam	5,902	[1] 4,734	8.63	----------	47.07	----------	41.20	----------	3.11	----------	19.79	1.292
	CHANGWAT TRANG												
11	Phra Muang	5,758	[1] 4,789	11.34	----------	42.52	----------	40.79	----------	5.35	----------	16.82	1.487
12	Lam Phura	6,000	[1] 4,853	10.14	----------	48.87	----------	38.83	----------	2.16	----------	19.12	1.314
	CHANGWAT SURAT THANI												
13	Thai State Ry	[3] 6,600	----------	8.10	6.80	----------	----------	----------	----------	----------	----------	15.90	1.310
14	Kiansa 1	[3] 5,830	----------	10.40	8.80	39.10	48.60	50.50	----------	----------	----------	15.60	1.375
15	Kiansa 2	[4] 7,672	----------	3.50	----------	33.22	----------	43.62	----------	5.56	----------	14.10	1.323
16	Kiansa 3	[3] 5,770	----------	12.00	----------	29.30	----------	43.70	----------	7.22	----------	15.00	1.380
17	Kiansa 4	7,094	[2] 6,168	3.50	3.00	39.50	34.30	49.90	40.80	4.00	3.40	13.10	1.290
	OTHER LOCALITIES												
18	Huai Kum, Nan	3,689	----------	----------	3.10	----------	----------	----------	----------	----------	----------	21.10	1.203
19	Kuchinari, Nakhon Phanom	[3] 6,710	----------	4.50	----------	37.10	----------	48.30	----------	----------	----------	8.20	----------
20	Sahas Kan, Kalasin	[4] 7,150	----------	5.50	----------	34.70	----------	49.80	----------	----------	----------	6.10	----------

[1] Subbituminous coal.
[2] Bituminous coal.
[3] Incomplete analysis indicates subbituminous coal.
[4] Incomplete analysis indicates bituminous coal.

southern peninsular region. The Mae Sot oil shales are associated with lacustrine or fluviatile basin sediments, but those of Krabi are apparently of brackish water or coastal swamp origin. The deposits in each of these areas are described in more detail below.

MAE SOT DEPOSITS

Oil shale crops out along small streams in many places through the Mae Sot basin. The nature of the oil shale was first discovered by local natives who attempted to use slabs of the material as supports for cooking pots and found that it burned when heated and gave off an oily odor. The deposits were studied in some detail by the Swiss geologists H. Hirschi and A. Heim in 1935 and later in the same year by the Japanese geologist Y. Naito. Additional studies were made by geologists of the Thai Geological Survey in 1947 and again by members of the present mission. A report describing oil shale deposits in that part of the Mae Sot basin lying in Burma was made by Cotter (1924, pp. 273–313).

The Mae Sot Basin (pl. 19) is one of the intermontane valleys typical of northern and western Thailand. The trunk stream is the Moei River which flows north to the Salween. The Moei forms the boundary between Burma and Thailand so that the western third of the basin lies in Burma. The central axis of the basin is occupied by the Moei flood plain which is bordered on either side by gently undulating and little dissected uplands. These in turn merge with higher mountain ranges flanking the basin.

The mountains are formed principally of Mesozoic and Paleozoic rocks. The eastern and southern flank of the basin is bordered by sandstones and impure Kamawkala limestone of the Korat series. Ammonite, coral, and brachiopod fossils occur in the limestone. Farther to the east and southwest is massive Rat Buri limestone. Quartzite and limestone of the Korat series also appear in an inlier 6 kilometers northwest of Mae Sot.

The basin contains a fill of fluviatile and lacustrine sediments that may attain a thickness of 500 meters or more. Most of these sediments are probably of late Tertiary age, but the Moei flood plain appears to be underlain by younger Quaternary stream deposits. In the bordering uplands, Tertiary sedimentary rocks crop out or are mantled by a thin veneer of younger deposits.

The Tertiary sedimentary rocks are gently warped, especially in the north end of the basin. To the south and east of Mae Sot the sedimentary rocks dip to the west, and in outcrops along the Moei river they dip to the east. This relation suggests that Mae Sot lies near the synclinal axis of the strata and therefore most of the oil shale section in that area has been preserved from erosion.

Generalized section of sediments in the Mae Sot basin

Top of section	*Meters*
Quaternary:	
1. Stream deposits	?
Unconformity.	
Tertiary:	
2. Limestone, sandy marl, and calcareous sandstone	20+
3. Oil shale, in tough massive chocolate brown beds, in finely laminated beds with fossil fish, and in somewhat calcareous beds poorer in oil	10+
4. Sandstone, micaceous and calcareous, with some lignitic wood	?
5. Limestons, white, well-bedded, and somewhat bituminous, with fossil leaves; intercalated with some bituminous, calcareous, or sandy shale	100+
6. Limestone, grayish white, bituminous, grading into sandstone and conglomerate to the west	300+
	430+

In March 1950 two samples of oil shale were collected from an outcrop 2 meters thick and 4 meters long, which lies about 9 kilometers south of Mae Sot. Sample 1 was a thin-banded gray and brown finely laminated oil shale with irregular fracture and fair to good cleavage along the bedding laminae. The lamination was not so fine as in the high-grade sample. The oil shale of sample 2 was dark chocolate brown and very finely laminated, with irregular hackly fracture and poor cleavage along the bedding laminae. The sample contained minute grains of bitumen. Analyses of the two samples given below were made in the Petroleum and Oil Shale Experiment Station of the United States Bureau of Mines at Laramie, Wyo.

Average yield of oil shale from the Mae Sot basin

	Sample 1 (low grade)	*Sample 2 (high grade)*
Weight (percent):		
Oil	2.4	26.1
Water	3.1	3.8
Spent shale	93.8	66.3
Gas and losses	.7	3.8
Liters per metric ton:		
Oil	29.8	332.0
Water	34.4	42.3
Specific gravity of oil at 15.5° C	.922	.876

Properties of the spent shale

Percent of original shale:		
Ignition loss	24.0	10.4
Ash	69.8	55.9
Tendency to coke	none	slight

In other parts of the Mae Sot basin some of the high-grade material may contain 35 percent or more of hydrocarbons, and the inferior grade 20 percent. According to Cotter (1924, p. 291), high-grade oil shale in the Burmese part of the basin yields as much as 200 liters of crude oil per metric ton of shale. The reserve of oil shale as estimated by geologists of the Thai Geological Survey may reach 2,500 million tons. The exploration and exploitation of the deposit has been hindered by the inaccessibility of the region.

Analysis (mass spectrometer) of retort gas from sample 2

Methane	19.3	Propylene	3.0
Ethane	8.2	Butene-1, butene-2, and isobutene	1.2
Propane	4.8	Cyclopentane	1.9
n-Butane and isobutane	1.5	Cyclohexane	.9
n-Pentane and isopentane	.8	Heptenes	.3
Hexanes	.4	Cyclopentene	.3
Carbon dioxide	12.7	Cyclohexene	.3
Carbon monoxide	7.3	Carbonyl sulfide	.3
Nitrogen	2.1		
Hydrogen	28.2		
Hydrogen sulfide	4.9		100.0
Ethylene	1.6		

Gas, dry, air-free, at 15.5° C. and 760 mm. of mercury; liters per metric ton 262

KRABI DEPOSITS

Near Krabi landing on the western coast of Peninsular Thailand oil shale crops out along a tidal estuary for a stretch of about 300 meters. The oil shale occurs in layers as much as 30 centimeters thick, intercalated with limestone, marl, hornstone, and anhydrite. The oil shale sequence lies in the upper part of the lignite-bearing formation of the Krabi series. The age as determined from marine gastropod fossils, is late Tertiary. Because of limited exposure the total thickness of the oil shale sequence is not known.

PETROLEUM

By Glen F. Brown, Nitipat Jalichandra, and George C. Taylor, Jr.

MAE FANG BASIN

The only occurrence of natural asphalt and oil known in Thailand is in the Mae Fang basin in Changwat Chiang Mai. Amphur Fang, the largest town in the basin, is 152 kilometers by highway to the north-northeast of Chiang Mai.

The basin is about 50 kilometers long and 8 to 16 kilometers wide. Its central lowland has an average altitude of about 485 meters. The trunk stream is the Mae Fang which drains north-northeast to the Mae Kok, a tributary of the Mae Klong. Along the lowlands axis of the basin the Mae Fang follows a meandering course through an alluvial flood plain which averages about 5 kilometers in width. Low sandy hills border the flood plain on either side and rise 30 to 80 meters above the river. Along the west side of the basin the hilly belt ends abruptly against a high rugged range whose summits rise about 1,400 meters above the valley floor. A range of somewhat lower elevation borders the basin on the east. The two ranges merge on the south where the Mae Fang has cut a canyon that is followed by the Chiang Mai-Fang highway.

HISTORY OF DEVELOPMENT AND GEOLOGIC WORK

The asphalt seeps in the Mae Fang basin have long been known and, according to local reports, asphaltic sand has been dug intermittently for more than 100 years. In 1921 Wallace Lee, an American geologist, was engaged by the Royal State Railways Department to make a geological survey of Thailand, with special reference to petroleum. His studies (1923) included the Mae Fang basin. The same year a well was drilled to a depth of 216 meters by the Railways Department at an asphalt seep about 7 kilometers southeast of Muang Fang.

In 1935 the Fuels Department of the Ministry of Defense employed the Swiss geologists, H. Hirschi and A. Heim, to study the petroleum possibilities of the basin and other areas in Thailand. On the basis of their work test pits were sunk in the vicinity of the Bo Ton Kham asphalt seeps about 9 kilometers south-southeast of Muang Fang. Under the Highways Department of the Ministry of Communications the test drilling program was expanded about 1938. About 100 shallow holes were drilled by hand auger on a grid oriented northeast and with coordinates spaced at 200-meter intervals. The holes were put down to depths ranging from 15 to 25 meters. About the same time a small experimental cracking plant was built near the present project headquarters. In 1942 the Highways Department drilled two shallow wells about 200 meters apart near the Bo Ton Kham seeps and oil-saturated sand. Fresh water was found in both wells.

The project was discontinued in 1944 but was resumed in 1948 by the Royal Department of Mines. The geology of the basin is currently being studied in some detail by geologists of the Geological Survey Division of the Royal Department of Mines. A preliminary geologic map was prepared by Nitipat Jalichandra and others in 1948–49. The accompanying map (pl. 20) includes data from the earlier map, as well as additional information from ground reconnaissance by the present mission, to correlate the topographic expression of the several rock units with aerial photographs. The dashed geologic contacts and drainage lines shown on plate 20 were taken from aerial photographs with stereoscope and sketchmaster, and the dotted boundaries are more approximate from rough pace and compass traverses. The ground control for the map was a transit-stadia traverse of the highway by Bhong Bhan Na Chiang Mai of the Geological Survey Division.

STRATIGRAPHY

Rocks ranging in age from Paleozoic to Recent underlie the Mae Fang basin and the bordering mountain ranges. The principal rock units from oldest to youngest are: (1) a thick sequence of metamorphosed marine and continental sedimentary rocks of the Kanchanaburi series; (2) massive limestones belonging to the Rat Buri limestone; (3) granite in an elongate batholith intrusive in the Kanchanaburi series; (4) continental sedimentary rocks provisionally considered to belong to the Korat series; (5) local granitic stocks or dikes which appear to be intrusive in rocks of the Korat series but which may be contemporary with the granite (3); (6) fluviatile and lacustrine sediments deposited in the Mae Fang basin in late Tertiary or Quatenary time; (7) young stream deposits in the lowlands of the basin.

The sedimentary rocks of the Kanchanaburi series in the bordering highlands of the Mae Fang basin are slightly to intensely metamorphosed; the degree of change appears to depend on the extent of their structural deformation. Included in the series are intercalated beds of sericite slate, phyllite, talcose schist, quartzite, sandstone, shale, and crystalline limestone. Insofar as could be determined from the present reconnaissance, no significant source beds of petroleum are contained in the series. The Kanchanaburi strata underlie the mountain range to the west of the basin. They also appear at the south end and to the north of Muang Fang. Hirshi and Heim (1938, pp. 480–490) describe similar metamorphic rocks along the Mae Kok to the northeast of Muang Fang that may also belong to the Kanchanaburi series.

The southwestern margin of the basin is formed by cliffs of massive gray limestone which Lee (1923, pp. 9–10) referred to the Paleozoic and which recently has been shown by fossils to belong to the Rat Buri limestone. An isolated area with jumbled masses of similar limestone occurs at the southern extreme of the basin.

The range to the east of the basin is formed of granite, which is part of an elongate batholith extending from the Shan States border on the north to beyond the latitude of Lampang on the south. The batholith is thus at least 200 kilometers long and averages about 16 kilometers wide. Along the Mae Kok to the northeast of Muang Fang the batholith is split into two prongs according to Hirschi and Heim (1938, p. 489). The western prong, which is about 12 kilometers wide, is composed of coarse-textured porphyritic, biotite-muscovite granite megascopically identical with the granite to the east of Muang Fang. Hornblende-biotite granite, with rose-colored quartz, forms the eastern prong which is about 10 kilometers wide. At the south end of the Mae Fang basin the batholith is intrusive in rocks of the Kanchanaburi series. Comparable relations are described by Hirschi and Heim (1938, pp. 485–487) along the Mae Kok.

Resting with sedimentary contact on the granite along the eastern margin of the basin are strata referred to the Korat series and described by Lee (1923, p. 5) as the "Red" formation. The basal units are gray arkosic sandstones and conglomeratic grits which grade upward into well-bedded, medium-grained red sandstones intercalated with red and gray shales containing thin beds of marl and concretionary limestone nodules. The formation has a thickness of 500 meters or more to the east of the Department of Mines field headquarters. Sedimentary rocks of similar lithology, except perhaps somewhat more indurated, flank the basin on the west in the foothill belt where they appear to have a more gentle dip than the metasedimentary rocks of the Kanchanaburi series farther to the west. From fragmentary fossil evidence and geologic relations in adjoining regions of northern Thailand, Lee (1923, p. 5) concluded that at least the lower part of the "Red" formation (Korat series) in the Mae Fang basin was of doubtful Triassic age. Post-Paleozoic age for the Korat series is also implied by sedimentary contact with the granite which intrudes rocks of the Kanchanaburi series. The lithologic character of the rocks of the Korat series is similar to sedimentary rocks of the same age in other regions of southeast Asia. Such sediments are generally considered to have been deposited under arid terrestrial conditions.

Small dikes or stocks of granite rocks which occur along the western margin of the basin have intruded sediments which appear to belong to the Korat series. The sediments may be locally metamorphosed by the intrusions. About 6.5 kilometers west of the highway at Ban Mae Soon is a small mass of granite gneiss intruded into sandstone. A short distance farther west is a dikelike body of biotite-rich granitic rock exposed in the Mae Soon, a tributary of the Mae Fang. The intrusion lies between slate and quartzitic sandstone. Farther north at the Fang hot springs, boiling water and steam issue from gneissic rock of quartz, biotite, and feldspar that has intruded sandstone.

Lying between bordering mountain ranges and the Mae Fang flood plain are belts of low hills which are underlain by semiconsolidated fluviatile and lacustrine deposits of probable late Tertiary or Quaternary age. The log of the 216-meter well drilled in 1921 by the Railways Department indicates that the deposits include interbedded soft conglomerate or gravel, sand, clay, and seams of lignite. According to Lee (1923, p. 11), fossil fragments of vertebrates from the well-cuttings show that the deposits are of continental origin, presumably having been derived by erosion from the surrounding highlands and accumulated in the lower part of the Mae Fang basin.

The alluvial flood plain of the Mae Fang is underlain by unconsolidated stream deposits which are somewhat younger than the dissected deposits of the bordering hills. Low terraces which are present in places along the western margin of the flood plain merge farther to the west with broad coalescing alluvial fans of streams tributary to the Mae Fang. These fans are graded to the flood plain and near the base of the mountains rise 60 meters or more above it. The streams tributary to the Mae Fang from the east flow through narrow alluvial valleys on somewhat lower gradients; thus near the Bo Ton Kham seeps the land is only about 30 meters above the flood plain.

STRUCTURE

The Mae Fang basin is a syncline in strata of the Korat series. On the eastern flank of the basin the strata strike from N. 5° W. to N. 40° E. and dip from 25° to 45° W. On the opposite flank they dip to the east and in the center of the basin are covered by younger sediments.

Geologic relations in the southern end of the basin are obscure. Highly contorted beds of Kanchanaburi series show drag folds, with axes trending about N. 10° W. These beds lie beneath massive Rat Buri limestone whose attitude appears to be horizontal or gently inclined. Thrust faulting probably occurred although the evidence is not conclusive. The massive limestone extends along the western margin of the basin northward to the latitude of Ban Huai Phai where Kanchanaburi rocks emerge from beneath it as the surface formation.

In the mountains to the west of Ban Mae Soon traverses by Lee and members of the present mission have shown that the metasedimentary rocks of the Kanchanaburi series dip generally to the east at steep angles. North of Muang Fang the massif of Doi Pha Hom Pok appears to be largely of granite, but Kanchanaburi rocks are present in its eastern foothills and dip to the east. A linear break along the front probably representing a cuesta in beds of the Korat series but possibly may be a fault scarp whose northern end is near Huai Bon cave.

In his report Lee (1923, pp. 12–13) suggests that the asphalt seeps may lie along a fault which cuts through the younger sediments in the east-central part of the basin. However, if such a fault is present, there is no topographic evidence of it, and an aerial view of the region does not show the seeps to be in line. Because of their position the seeps appear simply to be the result of natural drainage in the valleys of small streams tributary to the Mae Fang.

ASPHALT AND OIL

OCCURRENCE

Asphalt seeps occur at Bo Ton Kham 9 kilometers south-southeast of Muang Fang and also near the site of the 216-meter well about 3 kilometers north of Muang Fang. At Bo Ton Kham asphalt-impregnated sand and gravel is mined by the Department of Highways for use in patching road surfaces. The material is dug from 3 pits, each about 25 meters square, near the bank of a small stream. When fresh, the material is viscous or sticky but hardens on exposure. According to local reports, the asphalt accumulates principally during the wet season, apparently floating upward on the rising water table. The asphaltic sand and gravel are mined in the dry season when the water table declines.

In 1938 and the following years test drilling by the Department of Highways near the Bo Ton Kham seeps disclosed asphalt-impregnated sand and gravel in two linear zones trending about N. 30° E. and approximately parallel to the strike of older beds farther to the east. In the western zone asphaltic sand was found at depths ranging between 8 and 21 meters on either side of the Bo Ton Kham seeps along a stretch of about 800 meters. In the second zone about 800 meters east of the first zone, discontinuous beds of asphaltic sand were encountered at comparable depths through a distance of about 1 kilometer. Computations based on records of the Department of Highways indicate that about 3,800,000 cubic meters of asphalt-impregnated sand and gravel are present in the two zones.

The two wells drilled by the Department of Highways in 1942 are located about 200 meters apart and 400 meters west of the Bo Ton Kham seeps. The north well was reported to have reached a depth of 79 meters, and the last 9 meters showed oil-saturated sand. The south well was reportedly drilled to 46 meters and found oil-saturated sand in the last 5 meters. This well was developed and subsequently has produced a total of 300 barrels of heavy naphthene base oil. The maximum yield reported in pumping was 5 barrels a day; about one-third of the fluid pumped was fresh water. An analysis of an oil sample taken from the old stock collected from this well was made in the laboratory of the United States Geological Survey in Casper, Wyo. The results follow:

Examination of dehydrated sample of oil collected Nov. 5, 1949

[After U. S. Geological Survey examination]

A. P. I. gravity	14.4	Specific gravity	0.97
Base	naphthene	Sulfur percent	.22
Color	brownish black	Carbon residue percent	11.7

Fractionation by distillation (dehydrated sample)

Light gasoline	0
Total gasoline and naphtha	0
Kerosene distillate	0
Gas oil	10.3
Nonviscous lubricating distillate	4.1
Medium lubricating distillate	1.9
Viscous lubricating distillate	10.7
Residuum	73.0
Distillation loss	0
	100.0

In the 216-meter well three beds of asphaltic sand were penetrated within 20 meters of the surface but no petroleum was found. When visited by the writers in October 1949, the well was flowing fresh cool water with a little inflammable gas.

ORIGIN AND MOVEMENT OF THE OIL

Heavy naphthene base oil moves up dip through young sediments under fresh-water pressure and emerges at the surface in asphalt seeps on the east side of the Mae Fang basin. The features bearing on the origin of this oil are discussed in the following paragraphs:

Among the Kanchanaburi strata are carbonaceous beds of limited thickness and distribution that are possible source beds of petroleum. However, the Kanchanaburi strata adjacent to the basin have been metamorphosed and deformed to such a degree that they seem precluded as the source of the Mae Fang oil. Moreover, if the oil were to come from such a source it would likely be of paraffin base and light gravity. Significant petroleum source beds apparently do not occur in the Rat Buri limestone.

The alternative origin of the oil is from sediments of the basin, either the Korat series or the younger Tertiary and Quaternary deposits. Insofar as known, the Korat series in the basin contains no beds likely to yield petroleum; so, the conclusion of Lee (1923, p. 13) that the Mae Fang oil is derived from the distillation of lignitic or sapropelitic material in the Tertiary and Quaternary deposits seems most adequate. The steam and boiling water, with hydrogen sulfide, which issue from igneous rocks at Fang hot springs, suggest the presence of warm near-surface intrusions and a possible heat source for distillation.

Conditions which may relate to the movement of the oil are: The Tertiary and Quaternary deposits crop out on the west flank of the basin at elevations 30 to 40 meters higher than the asphalt seeps and contain permeable beds saturated with fresh water. Sufficient hydraulic head is thus available to flush and drive oil from the west toward the asphalt seeps. The reported seasonal rise of new sticky

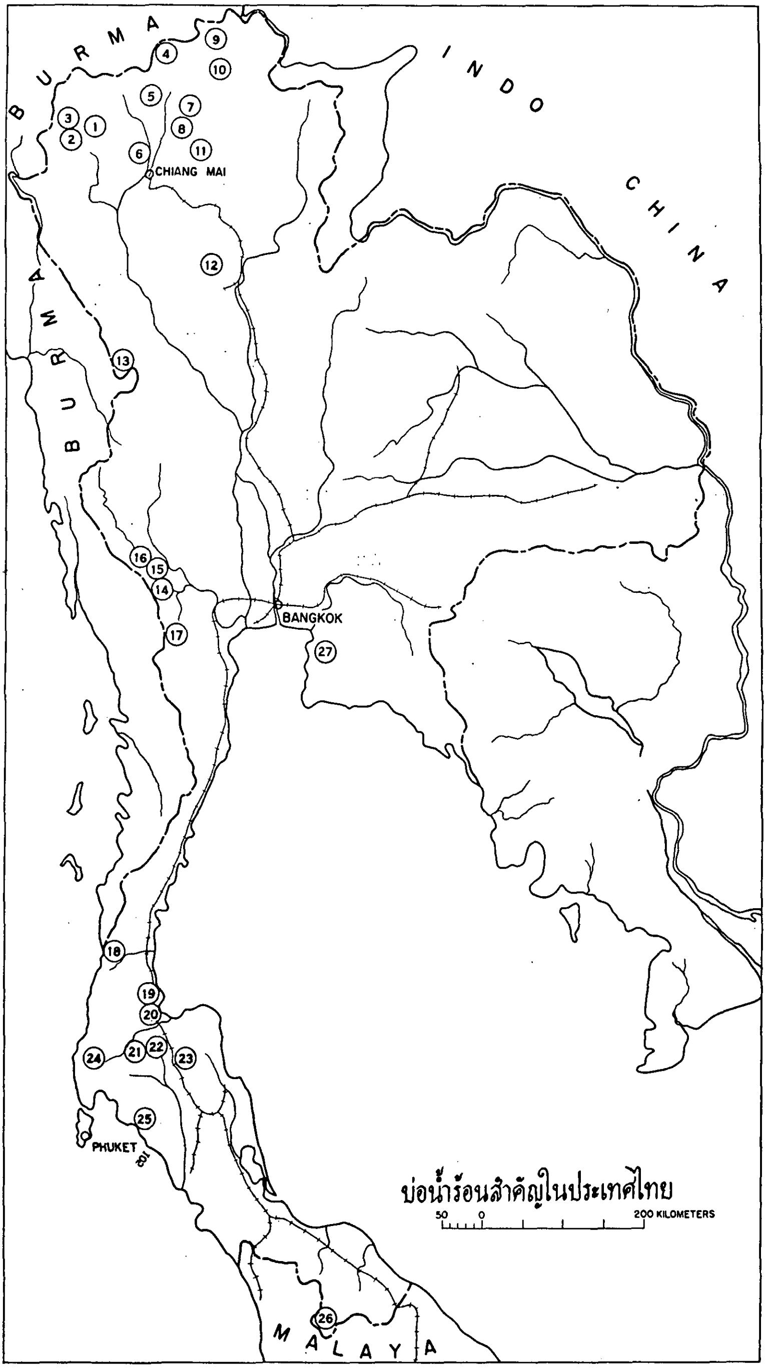

FIGURE 37.—Map showing principal hot springs of Thailand.

oil at the seeps during and shortly following the rainy season suggests a relation to artesian circulation in permeable members of the Tertiary and Quaternary deposits.

HOT SPRINGS

By Vija Sresthaputra

Hot springs are relatively numerous but unevenly distributed in Thailand, being most abundant in the north near the Burma frontier and in the southern part of the Peninsular region. Available data on hot springs of the country are given in table 3 and the approximate locations are shown in figure 37. It can be seen that almost all the hot springs are restricted in area between long. 98° and 100° E. In the northern region at least 11 hot spring localities have been reported, and 5 occurrences are found in the piedmont zone along the western margin of the central plain. On the eastern side of the Gulf of Thailand warm springs occur near Si Racha in Changwat Chon Buri. No hot springs have been reported from the plateau region in the northeastern part of the country. In the southern part of Peninsular Thailand nine hot spring localities are distributed through five Changwats, Changwat Surat Thani having the most.

Many of the hot springs occur in structural valleys or basins partly filled with Tertiary or Quaternary sediments. Faults are present or

FIGURE 38.—A vent of boiling water at Fang hot springs, Changwat Chiang Mai.

TABLE 3.—*Principal hot springs of Thailand*

Springs	Changwat	Amphur	Tambon	Temperature (° C.)	Number of orifices	Type of rock	Remarks
NORTHERN REGION							
1	Mae Hong Son	Pai	Muang Paeng		1	Granite wash	About 100 m. from the Mae Paeng River.
2	do	Muang	Huay Pong		2	Quartzite	At foothill 36 km. south of Mae Hong Son.
3	do	do	Pa Bong		1	Limestone	At foothill 12 km. south. of Mae Hong Son.
4	Chiang Mai	Fang	Mon Pin	91–100	50+	Granite gneiss	Water issues from joints. Northwest of Amphur Fang about 9 km.
5	do	Chiang Dao	Ping Khong	51	1		In bed of Mae Ping River 82 km. north of Chiang Mai on Fang highway.
6	do	Samerng					Similar to spring 4.
7	Chiang Rai	Wiang Pa Pao	Ban Pong		1	Granite	At foothill 5 km. southwest of Wiang Pa Pao.
8	do	do	Pong Chedi		1		On West bank Mae Lao River about 25 km. south of Wiang Pa Pao.
9	do	Mae Chan	Pong Nam Ron	60–100	15–20	Porphyritic granite	Water issues from intersecting joints at edge of Mae Chan valley.
10	do	Phan	Ban Pong	55	1	Sandstone	At km. 198 on Lampang-Chiang Rai highway.
11	Lampang	Chae Hom	Chae Son		1	Granite	At foothill 25 km. northwest of Chae Hom.
CENTRAL REGION							
12	Sukhothai	Si Satchanalai	Mae Sin		1		In small stream near Mae Yom River.
13	Tak	Mae Sot	Phoe Pha		1	Granite	In small streamlet near path.
14	Kanchanaburi	Sai Yok	Sai Yok		1	Limestone	Water issues from fissure on west bank of Khwae Noi near Phu Thong Chang.
15	do	do	Kui Yae	58	1		On east bank of Khwae Noi north of Kui Yae.
16	Kanchanaburi	Sai Yok	Hin Dat		1		In the plain of Ban Hin Dat.
17	Rat buri	Chom Bung	Suan Phung		1	Granite	At foothill near Ban Suan Phung.

SOUTHERN PENINSULAR REGION

18	Ranong	Muang	Khao Nivet	68	3		On coastal plain, 1 km. from Ranong.
19	Sarat Thani	Chai Ya	Phumriang	70	1		On coastal plain, 1 km. from Chai Ya.
20	do	do	Ta Chang	70	(1)		On coastal plain near the southern railroad at km. 603.
21	do	Na San	Kian Sa		1	Quartzite	At foothill 20 km. west of Ta Pi River.
22	do	do	do		2		Near east bank of Ta Pi River 2 km. south of Ban Kian Sa.
23	do	do	Kop Kaep		1	Granite	Near foothill 6 km. east of Na San station.
24	Pang-nga	Kapong	Ta Na	62			Reported 10 km. north of Kapong.
25	Krabi	Muang	Nua Khlong	48.5	2	Clay	On east side Krabi-Trang highway 96 km. from Huay Yot.
26	Yala	Betong	Tanoh Merah		(1)		West of Yala-Betong highway 6 km. from Betong.

SOUTHEASTERN REGION

27	Chon Buri	Si Racha	Bang Phra	29–40	3	Quartzite	In small valley bordered by quartzite hills. About 8 km. north of Si Racha.

[1] Several.

indicated in most of the basins, and the fractured zones resulting from faulting may afford channels for deep circulation and heating of meteoric water or for rising water from warm near-surface intrusive masses. Hydrogen sulfide and carbon dioxide are carried by many of the hot spring waters and may escape with some bubbling at spring orifices. Perhaps the most spectacular hot springs in the Kingdom are those (No. 4) near Amphur Fang in Changwat Chiang Mai. The springs rise from granite gneiss in an area about 150 meters in diameter. Water issues at boiling or near boiling temperature from more than 50 vents (Fig. 38) along joints or partings in the rock. A number of the vents yield only steam vapor. The water is sulfurous and thin encrustations of sulfur have been deposited around many of the vents. A partial analysis of the water from one of the vents is given in table 4 below.

The most frequently visited warm springs (No. 27) in Thailand are those 8 kilometers by road northeast of Si Racha. The springs rise in a small valley bordered by hills of quartzite possibly belonging to the Korat series. The water issues from three principal spring heads at temperatures of 39°–40° C. and the total discharge is estimated at 2 to 5 liters per second. The spring heads have been curbed and covered with an open shelter. Concrete bathing stalls have also been erected. The chemical quality of the water is indicated in table 4 which follows.

The hot springs in Amphur Muang (No. 25) of Changwat Krabi are distinctive because of their high salinity. They are at Ban Nua Khlong, 96 kilometers from Huai Yod on the Krabi-Trang highway.

TABLE 4.—*Partial chemical analyses of waters from hot springs of Thailand*

[In parts per million]

Constituents	Spring 4,[1] Amphur Fang, Chiang Mai	Spring 25, Amphur Muang, Krabi	Spring 27,[2] Amphur Si Racha, Chon Buri
Total dissolved solids	347	16, 800	374
Total hardness	------------	------------	280
Chloride (Cl)	tr	9, 910	28
Sulfate (SO_4)	19	946	------------
Bicarbonate (HCO_3)	tr	tr	------------
Calcium (Ca)	25	1, 020	22
Magnesium (Mg)	3	234	53
Sodium (Na)	tr	------------	19
Potassium (K)	------------	------------	7
Aluminum (Al)	4	0	------------
Iron (Fe)	tr	0	------------
Silica (SiO_2)	------------	------------	20
Free CO_2	------------	------------	34

[1] Analyses by the Department of Mines, Bangkok.
[2] Analyses by Department of Science, Bangkok.

The water at a temperature of 48.5° C. issues from two seeps and discharges at a rate of about 3 to 4 liters per second. The region around the springs is a low coastal plain underlain by Tertiary clays and marls. The springs rise near the bank of a small creek which is tidal a short distance downstream, but the open sea is only 9 kilometers to the west. The hot saline water may therefore be derived from sea water which has percolated to considerable depth and has returned to the surface along faults or other permeable channels. Warm, near-surface intrusive masses if present might also account for the heat of the water.

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