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DEPARTMENT OF SCIENCE

MINISTRY OF ECONOMIC AFFAIRS.

BANGKOK, THAILAND.

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PRACHUAP BUNNAG Ph. D., Director General

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CONTENTS

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NOTICE

We regret to make known to our readers that, owing to unsettled conditions prevailing in this part of the world at the present moment, we find that it is not possible to publish the Thai Science Bulletin quarterly as was previously announced. It will, however, be published as often as the opportunity permits beginning from 1942 till further notice.

Dr. Toa Labanukrom
(1898–1941)

OBITUARY.

Minister of State Dr. Toa Labanukrom, Director General of the Department of Science passed away on the 27th. August, thirty six hours after an operation for acute peritonitis. When he attended his last cabinet meeting on the 23rd. of August, he was still in good health, and on the 24th, he was cycling with a party of friends. His sudden illness, operation and death came as a shock to all his colleagues, friends and relatives, and is recognized as an irreparable loss to Thailand.

Born in 1898, he left Thailand at the age of twelve, after attending Debsirindra School and King's College, and accompanied H. R. H. Mahidol of Songkhla to Europe, to continue his education in Germany. His studied in the High School at Falkenberg (Mark) till 1917. When Thailand joined the Allies and declared war on Germany, he was interned in Celle Castle, with a number of his friends and compatriots, till the end of the war. After the Armistice, he went to Paris, where he joined the Thai Expeditionary Force as an interpreter, with the rank of sergeant-major. He was with the Army of Occupation in Rhineland till the year 1919 when he returned for a brief visit to Thailand and was awarded the Gold Medal of the Order of the White Elephant. He returned to Europe in same year and took up the study of Chemistry in the Universities of Berne and Geneva. He obtained his doctorate in Berne in the year 1928 with a brilliant thesis on "The Influence of Chemical Composition on the Structure of Crystals." Later he spent two years in Munich studying Pharmacy. Afterwards he studied Botany for another two years in Paris. Finally he visited most of the famous Scientific Institutes and Centres of Scientific Research in U. S. A. and Japan, and came home to join the Government Laboratory as an Assistant Chemist in the year 1931, after spending 21 years studying in the various universities in Europe.

He was a prominent member of the People's Party which brought about the Coup d'état in 1932. He was appointed a Minister of State in the first cabinet formed by Phya Mano, from which he resigned, when the Assembly was dissolved in 1933, but he has remained a second category member of the Assembly ever since. He was again appointed Minister of State in the Pibul Songgram Cabinet in 1938, and remained in the post until his death at the early age of forty three.

In spite of the active part he took in the Coup d'état and his appointment as a Minister of State on two occasions, his chief interest and major achievements did not lie in the field of politics.

He had a sound training in science and a brilliant University career. He was a voracious and versatile reader to the end of his days. His reading embraced several branches of science. For a scientist, his knowledge of literature, history, politics and economics was amazing. He was also a remarkable linguist. He spoke German, English and French fluently. He was frank, modest and retiring by nature. Endowed with a keen sense of humour, combined with a genial and attractive personality, he left a profound and pleasant impression upon all those who came in contact with him. Blessed with an ample private income, backed by long years of sound academic training and devoid of personal ambition, his outlook was independent, broad and firm throughout the ebb and flow of the political tides that swept over Thailand. He was an ardent patriot, and his patriotism was entirely free from chuavinism, which is rare in a generation in which all the world is acutely suffering from a malignant supranationalism.

As a scientist living in an age when the texture of the world is profoundly influenced and rapidly transformed by scientific discoveries and technical developments, he saw that the progress of a nation must go hand in hand with the development of science. Ever since his appointment as the Director General of the Department of Science in 1934, he devoted all his knowledge, energy and influence toward this end.

Under his conscientions leadership as the Director General, the Department of Science sprang into life after two decades of lethargic existence as the Government Laboratory of Thailand. The present technical staff of the department includes some of the ablest scientific workers of the generation and their work embraces practically every phase of national life.

The Department of Science as it is today, with its well equipped library, its School of Practical Chemistry, and its monthly lecture open to all, is wholly the outcome of his indefatigable labour. His wisdom in the choice of staff, which is drawn from men who have been trained in several different countries including England, France, Germany, Switzerland and the United States of America, besides our own, results in a cosmoplitan atmosphere in which all national prejudices were replaced by general cooperation and international outlook.

His arduous efforts to promote Industry, both private small scale and state controlled, have long endeared him to the hearts of the people and those who govern them.

His spirit of selfless sacrifice, as exemplified by his silent, tireless work, can never die. And his colleagues and immediate co-workers should take upon themselves as a sacred task the continuation of his life work.

At the time of his demise Dr. Toa Labanukrom held the following positions:

1. Director General of the Department of Science.
2. Minister of State.
3. Dean of the Faculty of Pharmacy of the Chulalongkorn University.
4. Chairman of the Board of State-owned Industries.
5. Chairman of the Alcohol Committee.
6. Adviser to the Department of Mines.

He also served as member and technical adviser to several other committees.

That his demise is an absolutely irreparable loss to the nation is evident from the fact that it would be quite a herculean, if not an impossible task, to find a number of men, let alone one single man, to fill all the vacancies left by him.

That one man could have accomplished so much single handed in so short a space of time is well nigh incredible, but it may be partly accounted for by the fact he remained a bachelor to the end of his days, this enabling him to devote all his time and energy to his work without being hampered by family ties and obligations. His life was short but his accomplishments during that little span far exceed combined work of many men.

Laterite, or Sila Laeng, a Peculiar Soil Formation[1]

BY

Robert L. Pendleton

Of the Department of Agriculture

Illustrated with photographs by the author

The fertile well-watered plains of Thailand, where grow large quantities of rice, are in many places bordered by great expanses of very gradually sloping land covered by slow-growing, open forest often known as *pa daeng*, *pa pae*, or *pa teng rang* (ป่าแพะ ป่าเต็งรัง), which are seldom cleared (Fig. 2), for their light sandy soils are not agriculturally productive (15).[2] Often in these soils, at a depth of a meter or less, there may be found a "layer" or "hardpan," of iron oxides and related compounds known locally as *sila laeng* (ศิลาแลง). Where exposed at the surface, usually as the result of erosion (Fig. 1), it is known as *hin dat* (หินดาษ). This material is laterite and has developed in the soil thru long ages. Unless rain and irrigation water can be held on these soils for 3 months or so, when padi can be grown, these lands can seldom produce enough crop to make clearing and planting worth while. Much of the northeastern or Korat region (ภาคอิสาณ), too, has laterite in a considerable proportion of its soils, (Figs. 3, 5, 6, 7).

Laterite has developed in these extensive portions of the Kingdom because the creeks and rivers have for so long a time been so near base level that erosion is near to a minimum—the land has reached the peneplain stage. Soils with a laterite horizon are usually very infertile because laterite develops so slowly that by the time this horizon is well developed most of the plant food has been leached away by the thousands of years of rainfall. Thus the presence of

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[1] Sila Laeng (ศิลาแลง) is the usual Thai name. "Luk rang" (ลูกรัง) refers to discrete more or less spherical iron concretions.

[2] References by numbers in parenthesis is to "Literature cited, page 69–70.

laterite in the soil warns that the soil is worn out and is not likely to be able to produce satisfactory crops. Unfortunately, there are no active volcanoes in Thailand to scatter ash over the country. Volcanic ashes would have rejuvenated the soils and would have helped prevent formation of laterite.

Another reason for our interest in laterite is that the ancient civilizations which have ebbed and flowed for more than 12 centuries in what is now Thailand often used laterite extensively in the construction of temples and other structures (16). (Figs. 19-24).

An Opportunity to Correct Erroneous Conceptions As to the Nature of Laterite and Its Mode of Formation.

But our most important reason for being interested in laterite is that by far the greatest proportion of the descriptions of "laterite" and "lateritic soils" found in the literature of soil science, and, as Pendleton has pointed out (14), the explanations as to how such formations had come into being are misleading, and in some cases quite incorrect.

That these largely erroneous conceptions as to the real nature of laterite and as to how it had been formed persist and are repeated over and over in the literature is because most of the world's capable students of soil fertility and most of the best soil morphologists and soil surveyors continue to live and work in regions where laterite and other equatorial soils are practically unknown. In endeavoring to explain the nature and mode of formation of the laterite which he observed and sampled in the course of his travels in Thailand, Credner (2, 4) insisted that the iron-rich, illuvial laterite horizons could not be laterite apparently because they could not have been formed in the manner postulated by the generally accepted hypothesis.

Since it has been my good fortune to have spent a number of years in studying the soils of Thailand, chiefly in the field, it has been possible to study various stages of laterite development as well as the manner of quarrying of laterite and how it has been used in building. It is hoped that the following notes and comments on the nature of laterite and laterite soils and some remarks regarding the points of view of certain earlier students of the subject will be helpful in spite of the already too voluminous literature and seemingly hopelessly confused conceptions of "laterite" and "laterite soils."

Extensive studies of the chemical characteristics of laterite and laterite soils, a joint work of the Department of Science, Ministry of Economic Affairs and of the Department of Agriculture, Ministry of Agriculture will be published elsewhere.

QUARRIED LATERITE USED AS A STRUCTURAL MATERIAL.

It was Francis Buchanan, travelling in South India in 1805, who first described in some detail (3) the quarrying of a partially hardened zone of certain soils and told how the blocks were trimmed into suitable shapes for construction of buildings and for other masonry structures. Even today along the Malabar coast of South India (6) and in Ceylon (7) laterite is regularly quarried and used in the construction of masonry buildings.

However, about 300 years before Buchanan's explorations, the Portuguese, in Goa, their colony on the Malabar coast of western India, had commenced to follow the Indian practice of quarrying and using blocks of laterite in the construction of many buildings, both sacred and secular. Some of the structures they built in that time, such as a Byzantine style church, are said to be of extraordinary size.[3] During that same period the Portuguese quarried and used laterite in their colony at Malacca, in Malaya, where numerous ancient buildings and quay walls of this material still stand.

In as much as the art of quarrying laterite (Figs. 15, 16) and using it structurally already was known in Thailand and had been carried on here for about 800 years before their arrival (Figs. 19-24), the Portuguese could not have introduced this art here. They did, however, by bringing the principles of arch construction to Thailand enrich the Thais' knowledge of building. It was in 1517 under Portuguese supervision in Ayutia that the arch was first used in Thailand.[3]

[3] Dr. Joaquim de Campos, Portuguese Consul, Bangkok, in a personal conversation.

The art of quarrying laterite and using it for building was probably introduced into Thailand about the 6th century by those early immigrants from South India whose art, culture and religion have so profoundly affected Thailand ever since. Ruined structures, in various modified Indian styles built of laterite about the 8th century A. D., or before, still exist. Temples and other structures, mainly of laterite, and believed to have been built between the 9th and 12th centuries are numerous in Thailand and in Cambodia (16). Among the connecting links between those civilizations and that of present day Bangkok are the ruins of the cities of Sawankalok (สวรรคโลก), Sukotai (สุโขทัย), Lopburi (ลพบุรี), Pimai (พิมาย) and Ayutia (อยุธยา), in all of which laterite was used as a structural material.

Since the texture of laterite is coarse and the material shatters easily, it cannot be carved into any elaborate or detailed design (Figs. 11, 17-19). Therefore at times, as in the Angkor (นครวัด) ruins, sandstone facing-slabs were used to receive the carving or bas-relief or as paving flagstones over the laterite. On the other hand, as illustrated by ruins at Pechaburi (Fig. 22) and Lopburi, more frequently in ancient structures now known in Thailand the laterite superstructure was covered by a lime mortar plaster which received the ornamentation. Elsewhere Pendleton (16) has described and figured the methods of quarrying laterite and how it had been used in structures in these and other localities in Farther Asia.

In Chantaburi Province (จังหวัดจันทบุรี) as far as is known are the only localities in Thailand where laterite is still quarried (Figs. 15, 16). In that province the material is still used, especially for well curbing. In Bangkok there are at least a few gardens which have terrace walls and path borders made of modern blocks of laterite, shipped in presumably by sea from Chantaburi.

Here in the Indo-Malayan region, where laterite continues to be used structurally, and is also used extensively for highway surfacing when more suitable rock is not conveniently available, the term "laterite" is generally understood in its orginal sense.[4] Also in Australia, and in Nigeria and at least some other parts of Africa, the term "laterite" carries the original, restricted meaning. In Ceylon, where quarried blocks of laterite still continue to be used structurally, the material is known as *cabook* (7).

How Variant Meanings of the Term "Laterite" came into Use.

It was especially during that period of world wide search for "bauxite" as a source of aluminum metal, that samples of "laterite" and other tropical soil formations which seemed strange to explorers from temperate zones were collected in considerable numbers and sent to the temperate Occident for analysis. Pendleton has pointed out (14) how notes and other data from equatorial regions collected by observers of widely varying qualifications were studied both in Europe and in the United States by chemists, geologists, and other scientists who had not themselves had field experience in the tropics. The result was that at least some of these more or less unsatisfactory hypotheses of temperate zone students' still today dominate the text book definitions and terminology, quite overshadowing the observations of the few competent field students who have themselves in the field carefully described and figured the nature and manner of formation of laterite (1, 12, 18). Thus it is, that especially in the temperate zones, various conceptions and definitions of laterite, mostly conflicting and incorrect, have come into use and have been applied to a wide range of "tropical" soils. As a consequence, in general works on soils and particularly in textbooks, confusions as to the nature and terminology of "tropical" soils in general and of laterite in particular are becoming more and more confounded.

When the earlier field observations were being made and the samples collected, the now generally accepted conceptions of soil

[4] Because of the use of laterite on Singapore island for the surfacing of secondary roads, which are not expected to carry heavy traffic, the expression used there "out onto the laterite" is used for places away from the main highways. E. H. G. Dobby in personal conversation.

profile development had not yet been evolved, nor was there an understanding of the actual conditions and limitations under which soil development can and does proceed. As is so often the case, the pen of the theorizer has been more convincing than the field notes of the competent observer. In Europe, Bauer and Harrassowitz led in the study of and speculation upon the significance of the analyses of samples and the field data which came to them. And much of these were chemical data that those scientific "arm-chair travellers" had to deal with. Even the chemical data were seldom adequate. That Bauer and Harrassowitz failed to interpret the data correctly is not to be wondered at, but the surprising and unfortunate fact is that Dr. C. F. Marbut, long the chief of the U. S. Survey and the world's leading soil morphologist of temperate zone soils, in the course of his study of all the available data concerning the soils of equatorial Africa (9), failed to grasp the importance of J. Morrow Campbell's basic studies (1) of the nature and manner of formation of the laterites of that same continent. And though he mentioned Campbell's work on laterite, Marbut persisted in basing his definition of laterite upon strictly chemical criteria obtainable only from thorogoing chemical analyses (9, 19). Unfortunately such chemical criteria are not only difficult to obtain, even in the laboratory, but they cannot be applied in the field, and a successful soil surveyor must have field-applicable criteria. In the study of U. S. soils Marbut was pre-eminent in the field.

MARBUT'S "GROUNDWATER LATERITE."

Later, after extended field observations in tropical South America, Marbut did observe and describe in 1926 and 1932 what he called "ground water laterite" (10, 11). In this case he came much closer to a satisfactory understanding of the nature of laterite as a whole and the conditions under which it may be formed than he had when writing about African soils without having been in the field in Africa (9). Nevertheless his earlier chemical definition and point of view as to the nature of "laterite" still confuse and dominate the scene (19, 20).

Paradoxically, it seems to have been because of his own earlier erroneous conceptions and chemical definition of laterite, that even today Marbut's discovery of the true character and mode of formation of "groundwater laterite," as he called it, and of the restricted conditions under which this material does develop in the soil, are not yet generally appreciated. Nor is it generally realized that Marbut's "groundwater laterite" is nothing other than the original and true laterite first discovered by Buchanan, and in which sense the word laterite is used consistently in this paper.

The Importance of J. Morrow Campbell's Basic Studies of Laterite.

While apparently interested primarily in bauxite as ores, Campbell, a British mining engineer, appears to have been the first student of laterite to painstakingly consider and correctly evaluate all of the conditions which affect the formation of laterite and bring about its transformations (1). His photomicrographs of thin sections of laterites in many different stages of formation, development, and transformation, which he published in his important paper on laterite, indicate that he thoroly understood the nature and manner of formation of this unique material. He pointed out that in the tropics there are two principal processes which are modifying the surficial rocks and developing the soil, namely: (1) alteration in the deeper zone where the rocks or other geologic sediments are permanently saturated. In this zone the materials with which water comes into contact are chemically altered; iron compounds in particular are dissolved and carried away in the ground water as ferrous carbonate. Then, above the zone of permanent saturation by water, in materials already changed by the alteration processes there is (2) a zone in which the upper limit of the vadose or ground water fluctuates with the annual or other variations in the rainfall. And Campbell points out that no matter how uniform the rainfall appears to be thruout the year, there is seldom a region in which there is not some seasonal fluctuation in rainfall and hence some oscillation in the position of the upper surface of the ground water level. When the zone of fluctuation of the vadose water lies close enough to the surface of the soil that sufficient oxygen from the atmosphere can penetrate into this zone and oxidize the ferrous compounds to ferric ones, precipitation of ferric oxides takes place in the moist pore spaces or other openings in the unconsolidated material just above this surface of the ground water. And provided the topography of the region continues to be that of a peneplain for a long enough period, so that the position of the zone of water fluctuation and the supply of ferrous compounds is maintained and the other conditions for continuation of laterite formation prevail during a long enough time, a laterite horizon will develop in the soil in this zone of vadose water fluctuation.

It is of course necessary that either in the zone of alteration, or elsewhere, there be a sufficient quantity of iron compounds which are carried in solution into the zone of fluctuating water levels and there precipitated to form the laterite. In parts of the Korat region (ภาคอีสาณ) and elsewhere in Thailand it appears that the rocks and alluvial sediments from which the soils have been derived are not sufficiently rich in iron to build up a really considerable and distinct laterite horizon. For example, where the parent rock is a quartzitic sandstone, containing relatively little iron, hardly more than a rather indistinct zone of more or less discrete iron concretions [*luk rang* (ลูกรัง)] seems to be able to develop (Fig. 14).

As Campbell states (1), the nature of the matrix in which the iron solutions are oxidized will determine the macroscopic character of the laterite. In a porous, sandy soil the air can permeate even the deeper portions relatively easily, and each sand grain may be a potential nucleus for an iron concretion (Fig. 18). On the other hand, if the zone in which the vadose water surface tends to rise and fall is occupied by a clay, there will be very little possibility of the iron-containing water itself moving thru the impervious mass, or of any considerable quantity of air penetrating dense clays into this zone to oxidize the ferrous compounds. Obviously, as a whole the oxidation will proceed very much more slowly in a clay matrix than in a porous, sandy one. In fact, in a clay practically no oxidation of ferrous compounds to ferric oxides can take place except on the walls of insect or worm burrows, or on the walls of the holes left by decaying roots of plants and trees (Figs. 11, 17). Samples of clays from 2 to 3 meters depth recently excavated at the Central Experiment Station, Bangkhen (สถานี ทดลองเกษตรกลาง บางเขน), show very clearly the importance of root holes in facilitating oxidation of ferrous compounds. Laterite formed in a clay matrix will ultimately have a mottled, flamed, or reticulate color pattern (Fig. 12) in which the interstices in the hard iron compounds will be occupied by a light bluish or whitish "clay." After exposure to the weather as by erosion or quarrying the white "clay" gradually washes out, leaving the often-described slag-like or tubulated mass in which holes or passages are often lined with limonite (13).

Since oxidation of the ferrous compounds in the vadose water to ferric ones is the determining factor in the formation of laterite, the laterite horizon cannot develop below the zone in which oxidizing conditions prevail, so that even though there is a *gradual* fall of the level of the zone of water fluctuation, laterite can practically never increase in thickness downward to more than about 10 meters. Actually it is seldom thicker than 3 or 4 meters. Where the level of the zone of fluctuation of the ground water has not changed, Campbell demonstrated that gradually the iron compounds in the deeper portions of the laterite may be replaced by aluminum compounds, so that bauxite may finally result. On the other hand, in case diastrophic movements of the earth's surface cause the submergence of the entire laterite horizon down into the zone of permanent saturation below the zone of fluctuation of the vadose water level, the reducing solutions which there prevail will dissolve the laterite, and carry away the iron as soluble ferrous compounds. This is why laterite does not long remain deeply buried below alluvial or volcanic deposits.

Dead or Fossil Laterite.

When thru a relatively rapid lowering of base level, a well developed laterite horizon is left some distance above the zone of fluctuation of the vadose water, the laterite does not undergo further change, especially if the overlying unconsolidated soil horizons are removed rather soon by erosion. Campbell calls such a laterite horizon "dead," which is perhaps a more logical expression than the more usual term "fossil laterite." In an equatorial region at low or moderate elevations, where the temperature never falls to 0°C a dead laterite horizon may remain exposed to the weather for geologic ages practically without alteration, even tho erosion carries away not only the overlying eluvial soil horizons but also most of the former peneplain, so that the dead laterite remaining caps hill tops or mesas of basalt. In Central India (13) and in Western Australia (18) laterite believed to have been formed in Tertiary times now caps hill tops. As a consequence of the alterations in the relative amounts of sea and land, in both these regions the present climate is very much drier; in the former cases arid, in the latter desert. Additional proof that the climate has actually changed is also given by the different soil profiles which have developed in these places subsequent to elevation and erosion. Exposed under the edges of the dead laterite capping bluffs of basalt in Central India under the present arid, sharply alternating wet and dry climate, a calcareous black earth with large $CaCO_3$ concretions is now developing from the rock.[5] In Tertiary time, on the contrary, under peneplain conditions and a heavier rainfall and more humid climate the basalt gave rise to the laterite profile! Now the same kind of basalt is the parent material of a pedocal! A similar condition reported from Africa puzzled Dr. Marbut (9).

At least partly because of their publication in a journal few soil scientists see, Campbell's fundamental studies (1) of laterites have not received the recognition they deserve by pedologists. Neither

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[5] In this case, with many tens of meters depth of basalt, and no other country rock, there could not have been any difference in parent material of this laterite and the calcareous Malwa clay loam (one of the soils often called "black cotton soil" or "regur").

have Professor Mohr's equally important and complementary studies (2) received the attention they should have, for his observations and conclusions appeared in the Dutch language in a publication of very limited distribution. After spending many years in the Netherlands East Indies studying the interrelations of soils, rocks, and climates, Mohr has explained and clearly figured his ideas as to the manner of formation of laterite, and how it is that as a result of erosion of the upper portion of the profile the hard, pavement-like laterite at times is found exposed the surface—a phenomenon which had been summarized in English elsewhere (14) and since they are along similar lines to those of Campbell, they need not be repeated here.[6]

In spite of these basic studies of the manner of formation of laterite, and the now well understood conditions which cause the alteration or modification of the laterite soil profile, the erroneous hypotheses of earlier, too often "armchair," students continue to persist, particularly in text books and general treatises on soil formation and soil weathering processes. Even though Mohr has shown (12) that little remains of Harrassowitz's hypothesis, yet writers in temperate regions (5, 8, 17), who have not been fortunate enough to study laterite and other equatorial soils in the field, continue to repeat Harrassowitz's supposition, on the nature of laterite and the process of laterization.

Soil Survey Methods Must Have Field Criteria.

Now what is the significance of all this discussion about the nature of laterite? about its manner of formation and as to how it should be defined? why raise the question of differences of definition and terminology when already here in the Indo-Malayan region the word "laterite" still retains much of its original connotation?

The soundest and most effective methods of scientificially classifying soils for most agricultural and other purposes, and for

[6] It is hoped that the recently completed English translation by Robert L. Pendleton of E. C. Jul. Mohr's most recent work on equatorial soils (10) will soon be published and its information be more generally accessible.

delineating such soils data on suitable base maps are those which have been evolved by the U. S. Soil Survey. And this has come about because forty years ago the United States Government was faced with the necessity of rapidly classifying and mapping the vast areas of agricultural soils of the country on a scale and with a degree of detail previously never attempted anywhere. To accomplish this work a soil survey organization and a system of soil identification and classification using field criteria had to be developed. In rapid work over vast areas the use of elaborate chemical and other laboratory methods could not be used, for they are entirely too cumbersome, too slow, and too expensive for routine soil survey and classification on any such scale. Laboratory methods can be used only occasionally to interpret certain soil profile conditions observed in the field but which cannot not otherwise be explained satisfactorily. For this soil survey an unusual corps of capable field men was built up—the art of soil survey gradually evolved and developed as it came to be applied to an ever increasing range of soils. Under the genius of Dr. Marbut, who was in turn stimulated by the Russian and other conceptions of the effects of climate on soils, the U. S. Soil Survey has developed the world's outstanding practicable methods of soil classification and mapping. The method is characterized by field applicable criteria and is based upon sound scientific concepts of the nature of most of the distinctly different types of soil profiles which developed under different sets of climatic and biological influences.[7] Proof of the soundness and effectiveness of the soil classification and survey methods for the purposes designed is that with but slight modifications these methods are being adopted by more and more governments thruout the world for the survey and classification of their agricultural soils. Among these countries are Great Britain, Canada, Mexico, China, Philippines, Australia, East Africa, and Thailand.

It should be added that earlier Hilgard had independently discovered the interrelationships between soils and climates. Follow-

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[7] To one concerned particularly with equatorial soils this statement must be qualified because there seem to be serious shortcomings in the concepts of "laterization," "podzolization," etc. as presented in "Soils and Men" (20).

ing Hilgard's lead, Mohr and his associates in the Netherlands East Indies evolved a similar theory as to the interrelations between climate, rocks and soils. As these principles have been worked out by Mohr under equatorial conditions his work is noteworthy. Unfortunately circumstances were such that neither Hilgard nor Mohr had any adequate opportunity to apply their discoveries in any large scale program of soil survey. If there had been such an opportunity for the development from Mohr's work of a thoroly practically and generally applicable technique of soil classification and mapping of equatorials soils, the present day knowledge and understanding of equatorial soils would have been much greater.

Persistence of the Chemical Definition of Laterite.

It must be remembered that the U. S. Soil Survey has been evolved and developed in a region of temperate and semitropical soils. Only occasionally have members of its staff done work in equatorial regions. Hence the concepts of equatorial soils which still prevail and dominate the U. S. Soil Survey classification are principally those which have been evolved by temperate zone soil scientists. A further factor restricting the comprehensiveness of the U. S. classification for equatorial soils is that Marbut's *chemical* definition of laterite is still the official one. Apparently it is for this reason that even in the latest publication of definitions by the U. S. Soil Survey (20) the definitions "laterite," "laterization," "lateritic" etc., seem entirely inadequate to cover equatorial soils as a whole.

True Laterite a Valuable Criterion of Soil Character.

Here in Thailand we have an unique opportunity for the independent study of equatorial soils and for describing anew the physical character of laterite and the manner in which it is developed and altered, as well as learning how laterite is quarried and has been used as a structural material. In our soil survey and land use and evaluation work here in Thailand, we consider the presence of laterite in the soil profile to be a danger signal, warning us that the soil is old, low in plant nutrients, and not likely to be very useful agriculturally (Figs. 2, 3, 5, 7). As a check upon our judgment the samples of laterite and laterite soils which we collect in the course of our field work are being analysed in the Department of Science by Nai Sangar Sharasuvana and his staff of Division of Agricultural Science. It is thus we have a real opportunity to contribute to the general understanding of equatorial soils.

Summary and Conclusions.

Laterite is a horizon ("layer") of iron-oxide cemented materials which has developed in equatorial soils which have long been exposed to weathering processes. Laterite only develops in such localities as have a peneplain topography so that over long periods of time the ground water level oscillates in an oxidizing zone not deep below the surface of the land. Even normal or geological erosion is relatively slight on such a land surface. Furthermore, a laterite horizon can develop only in such peneplains as do not receive any appreciable additions of such soil rejuvenating materials as wind borne dust, volcanic ash or water borne silt.

"Ground water laterite" is real laterite, in the strict sense of the term, for all laterite is formed thru the agency of ground water.

While here in southeastern Asia the term laterite continues to be used fairly consistently in the correct manner, in the temperate occident often very different and frequently confusing and conflicting definitions of the character of laterite have come to be more and more generally used. As criteria for judging a soil to be a "laterite" or "lateritic" chemical composition, ratios of silica to sesquioxides, color, or other physical characteristics have been proposed and are more or less widely used. These have confused rather than clarified the conceptions of the true nature of laterite. Therefore, in this paper the correctness and importance of the basic work by Campbell and Mohr on the physical and chemical characteristics and mode of formation and transformation of laterite have been emphasized.

Laterite occurs in two general physical types: vescicular and pisolitic. The former often has a slag-like appearance, and it is popularly though erroneously believed to be of volcanic origin. The pisolitic type more often develops in sandy soils.

Since laterite develops only after extensive leaching, a soil with a laterite horizon usually contains only extremely small amounts of plant nutrients or other available bases. Thus a laterite soil (the eluvial lixivium soil underlain by an illuvial laterite horizon) is usually highly acid. The presence of laterite is a field-distinguishable criterion of low to very low agricultural value of a soil; hence it is a warning signal extremely useful in soil survey and land utilization studies.

Dead or fossil laterite, believed to have been developed in Tertiary time in a former peneplain, now caps hill tops in arid India and Australia.

Laterite, though easily shattered, is usually quarryable into building blocks. In India and Farther Asia laterite has been quarried and used extensively in buildings. The art of using laterite appears to have been introduced into Thailand from India more than 1200 years ago. In Thailand as in India laterite has at times been used as an iron ore. Though soft and not durable as road metal, it is often so used because so much more accessible than suitable stone.

The use of the term " laterite " should be limited to the original iron-cemented, quarryable material, and the use of the term " laterite soil " should be limited to a soil with a distinctly developed laterite horizon. The term " lateritic " should be applied only to such lixivium soils as have an illuvial horizon which appears to be well along toward quarryable laterite. This is often best judged by the presence of the peculiar and characteristic flamed or variegated red and white color pattern of the illuvial horizon.

All too often any red equatorial soil has been called a laterite soil, when it should more correctly be called a " tropical loam " or " red loam." The color of the eluvial horizons of a true laterite soil is more often a very light yellowish brown, or a dirty white, tho it may even be quite red. So many different sets of conditions may produce any certain color that the color of the surface soil alone (eluvial horizon) is *not* a suitable criterion whether the material is a laterite or a lateritic soil or not.

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Fig. 1. Collecting a laterite sample (604-L) from the Spirits' market place (ตลาดพลี). This view is looking up the gentle slope of the exposed laterite near ancient Sawankalok (Si-sachanalai) (cf. Fig. 8 Geog. Rev. *31*, 183. It should be noted that in that paper, the legends for Figs. 6 and 8 were transposed). Sukotai Province (จ. ว. สุโขทัย), Northern Thailand. November 1937. RLP Foto 872—5.

Fig. 2. This whitish lixivium soil, with the laterite horizon generally close to the surface, is so infertile that it carries but a poor open forest. Krabinburi township (อ. กระบินทร์-บุรี), Prachinburi Province (จ. ว. ปราจิณบุรี), Eastern Thailand. December 1936. RLP Foto 767—5.

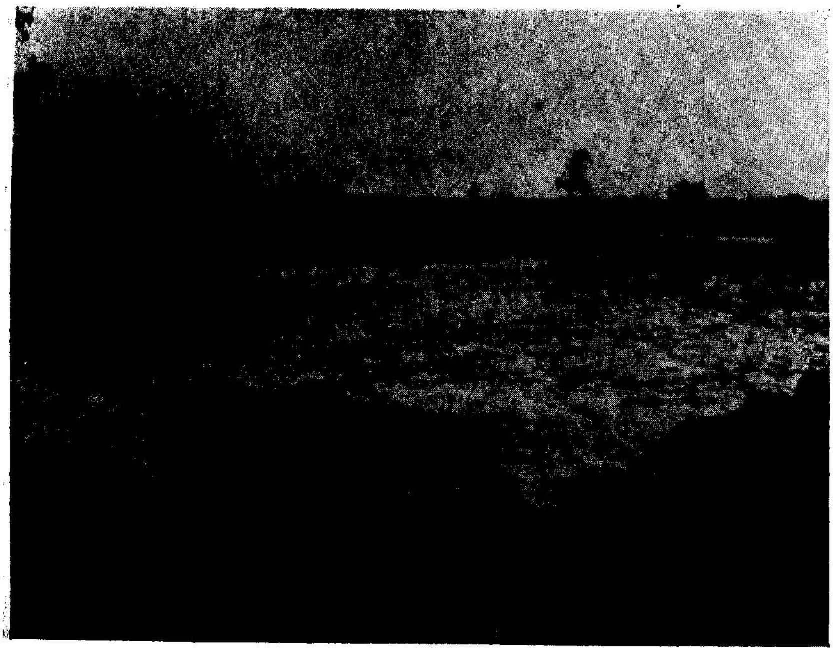


Fig. 3. Dirty white fine sandy loam lixivium soil. A laterite soil, for the laterite "heads" in the foreground were doubtless excavated from this diked padi field. This soil is very infertile, even of rice it produces but very little. (Samples 862—1, 2, L.) 28 kms SW of Roi Et (ร้อยเอ็ด), Northeastern Thailand. March 1940. RLP Foto 1228—1.

Fig. 4. Only in the distance, beyond the figure, where loose chunks of laterite have been used to help strengthen the field dikes has the thin layer of red tropical loam lixivium soil been held on the laterite, so that annual crops of padi can be grown. In the foreground erosion has exposed the hard laterite. Tamai township (อ. ท่าใหม่), Chantaburi Province (จ.ว. จันทบุรี). January 1937. RLP Foto 786—12.

Fig. 5. This poor laterite soil was sampled just beyond the large tree at the right. (Samples 871—1,2, 3). The trees are of slow-growing hardwood types the "brush" is mostly the wide-spread weed *Eupatorium odoratum*. Cf. the following Fig. 6 which shows erosion nearby and the underlying laterite.

0—25 cm light grayish brown fine sandy lixivium soil.

25—40 cm brownish yellow loam.

40—48 cm gravelly loam.

Wang township (อ. แวง), Roi Et Province (จ.ว. ร้อยเอ็ด) Northeastern Thailand. RLP Foto 1232—5.

Fig. 6. From the bridge in the foreground, looking up the slope of the road. Much of the fine sandy white lixivium soil has been eroded from this road, exposing as darker patches the iron concretions washed clean by the beating rains. The shallow gullies are eroded to the massive laterite, which was sampled (871-L) in the middle distance. (cf. preceding Fig. 5). Wang township (อ. แวง), Roi Et Province (จังหวัด ร้อยเอ็ด), Northeastern Thailand. March 1940. RLP Foto 1232—6.

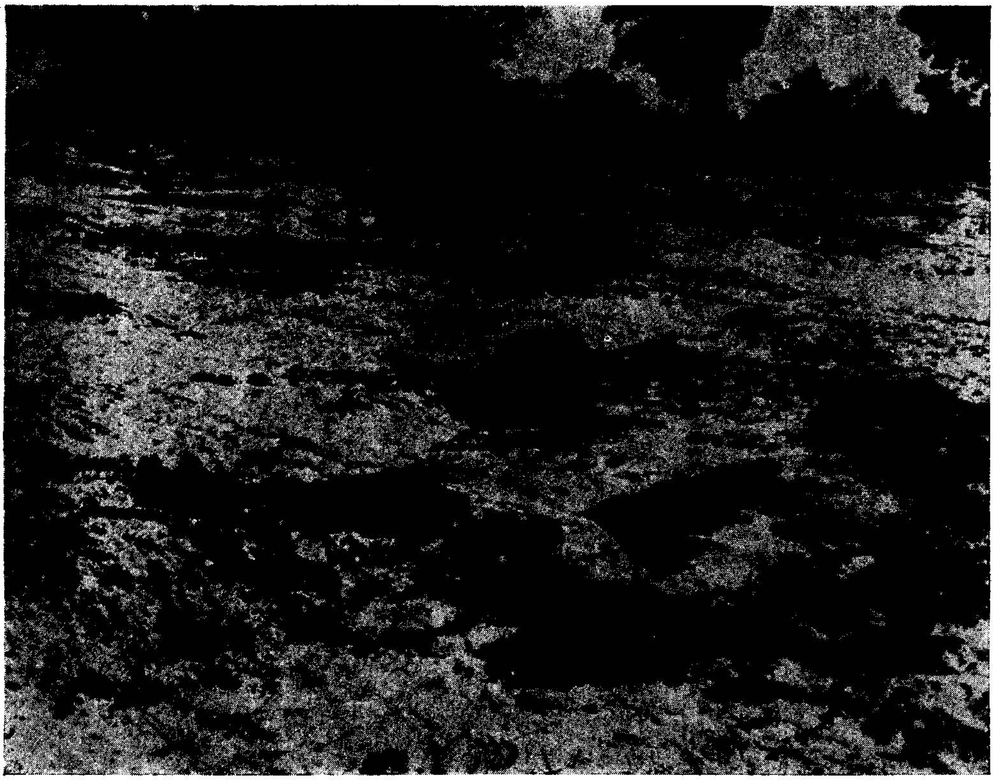


Fig. 7. The shallow light gray to light pinkish brown light fine sandy loam lixivium soil from this borrow pit had been used for the highway embankment at the left, this exposed numerous "heads" of pisolitic laterite. Doubtless but a little deeper the laterite forms a continuous horizon. In the right distance can be seen some padis, where, during favorable years, water can be held and at least a little padi raised. Amnat Charoen township (อำเภอ อำนาจเจริญ), Ubon Province (จังหวัด อุบล), Northeastern Thailand. March 1938. RLP Foto 1009—3.

Fig. 8. Chunks of laterite exposed on the forest floor. Since the laterite horizon is normally about ½ m. below the surface of the stony loam, it is supposed that these chunks were brought to the surface by tree roots when trees were overturned in storms. (See Samples 418—1, 2, 3 & L.)Kradat Island (เกาะกระดาด), Trat Province (จ. ว. ตราษ), Southeastern Thailand. November 1936. RLP Foto 742—8.

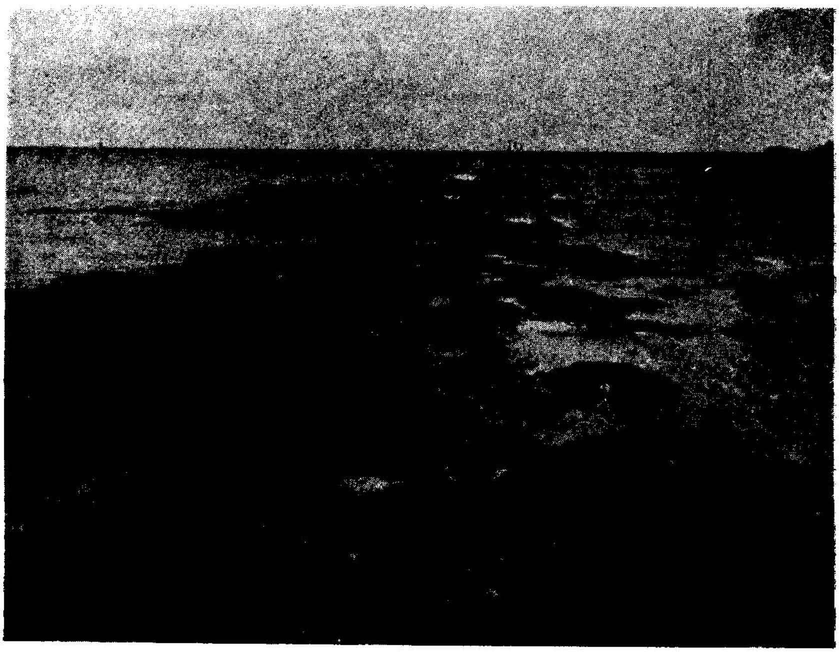


Fig. 9. Reef of laterite exposed at low tide. Southeastern tip of Kradat Island (เกาะกระดาษ), Trat Province (จ. ว. ตราด), Southeastern Thailand. (cf. Fig. 11) November 1936. RLP Foto 749—3.

Fig. 10. A view of the low water stage of the rapids in the Kuen Nieng river where it is cutting back into a laterite horizon. The upper portion of the opposite bank of the stream is the white lixivium eluvial horizon of the laterite soil, while exposed just above the water may be noted the laterite—a deep brownish red ground mass with light bluish white streaks of softer bluish white clay. During the swift, high water stages the harder laterite of the ledge in the right foreground has had the clay washed out of the tubules, leaving holes, giving a slag-like appearance to the surface (Samples 321-X, Y). Ratapum township (อำเภอรัตตภูมิ), Songkla Province (จังหวัดสงขลา), Southern Thailand. October 1936. RLP Foto 683—1.

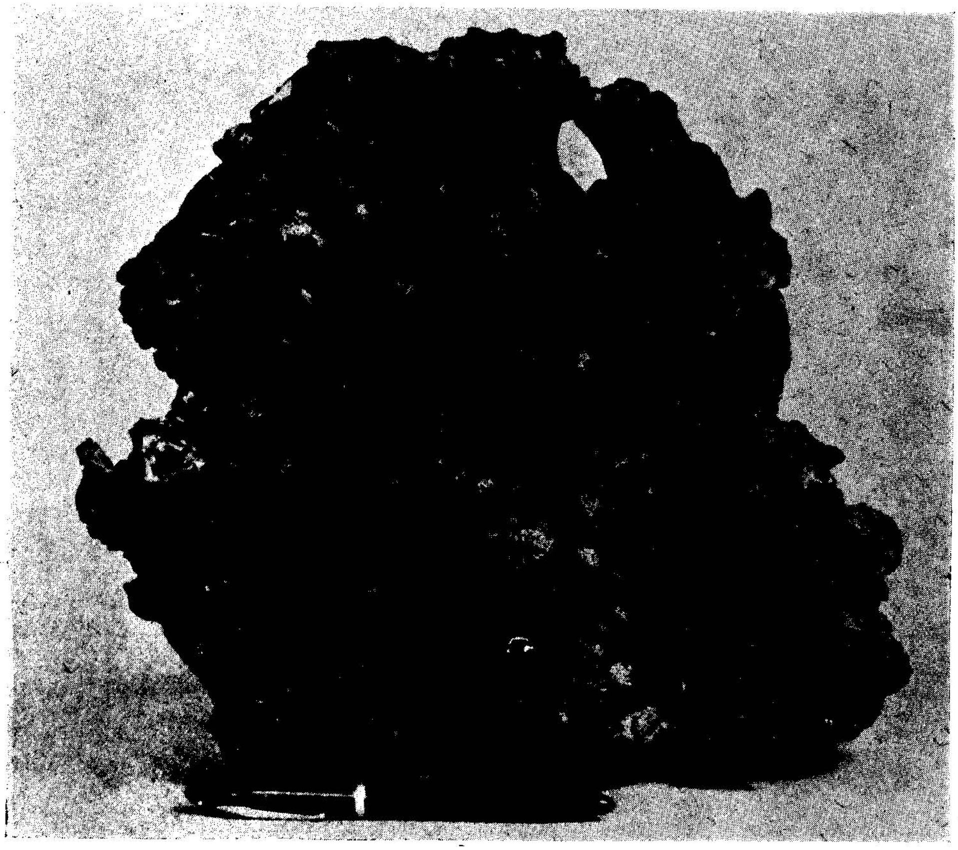


Fig. 11. Laterite from a reef exposed at low tide, northern tip of Kradat Island (เกาะกระดาษ), Trat Province (จังหวัด ตราด), Southeastern Thailand. (cf. Fig. 9) The surf has washed out all the light bluish clay from the tubules, leaving the dark red skeleton, considered to be a good iron ore. When this sample was collected, mollusks were growing in some of the cavities. Sample 426—L. November 1936. RLP Foto 1298—7.

Fig. 12. Characteristic lateritic "mottling", better termed "variegation" or "flaming", exposed on the bank of a freshly excavated irrigation canal. This horizon is about 2 meters below the ground surface. The texture of this material is a clay, structurally the light bluish portion is plastic and greasy, while the red portions feel rather "sandy". Parent material believed to be an alluvium. Mahasarakam Province (จังหวัดมหาสารคาม), Northeastern Thailand. March 1936. RLP Foto 597—5.

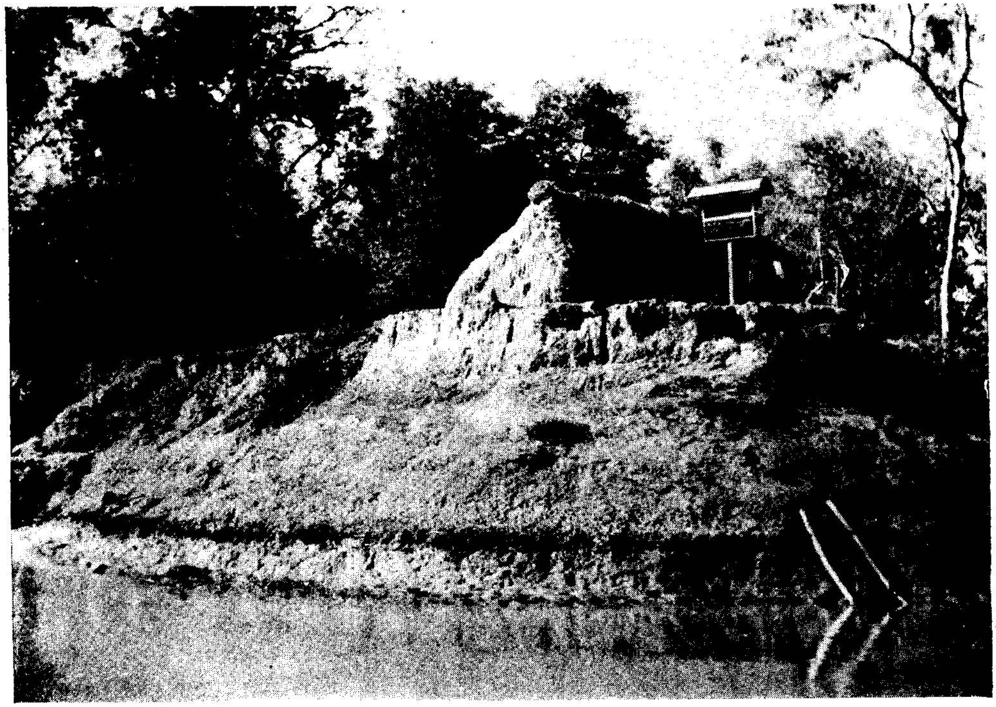


Fig. 13. An early stage of laterite profile development in alluvial materials is revealed in this eroded river bank. The surface horizon of 1 meter is dirty white, underlaid by 2½ meters of purplish gray material. The dark line marks the position of the ¼ meter thick harder horizon, with the lateritic bluish and red variegation or flaming, which grades downward, just above the water level, into ¼ meter with less red, and some yellowish streaks. It is likely that this lateritic soil is a fossil profile and that the uppermost 3 meters of the profile had been deposited by the river after the lateritic portion of the profile had developed to nearly its present stage. Panom Sarakam township (อำเภอพนมสารคาม), Chachoengsao Province (จ.ว.ฉะเชิงเทรา), Eastern Thailand. January 1938. RLP Foto 923—10.

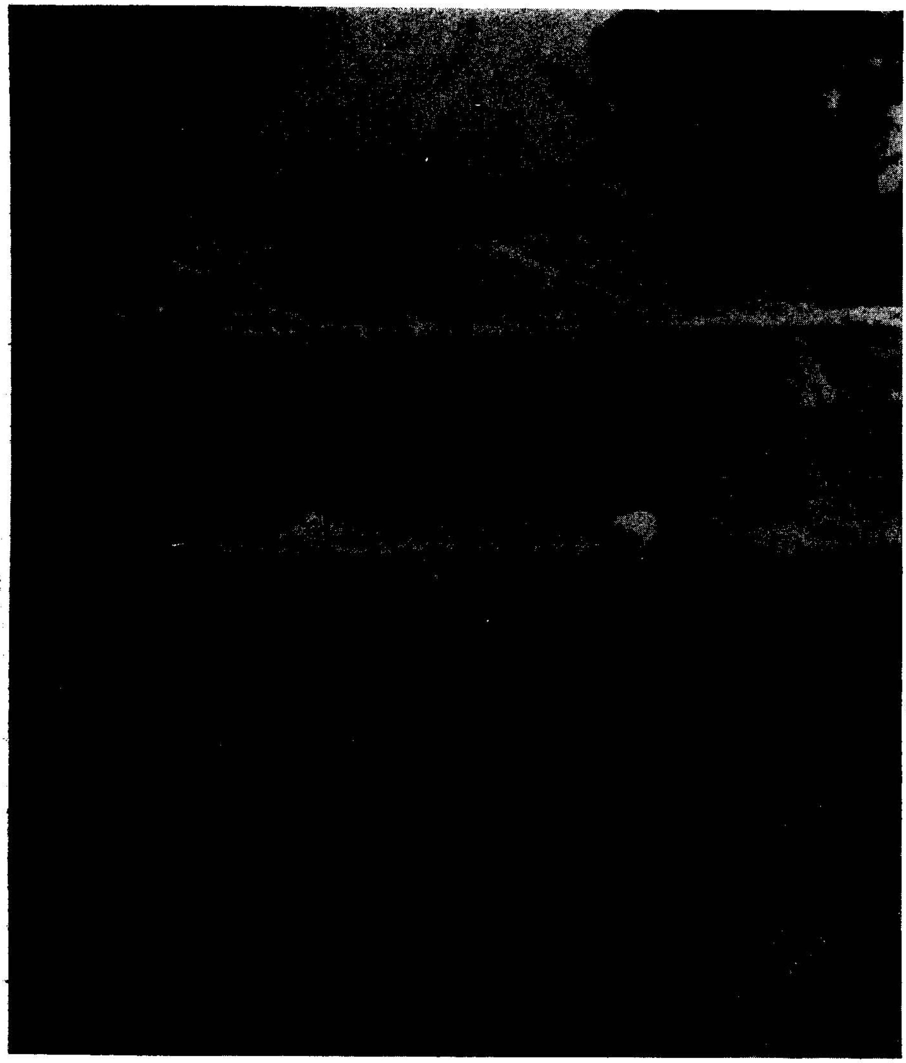


Fig. 14. A recent excavation exposes a lateritic soil profile: about a meter of very light brown very fine sandy loam (Sample 155-1). The figure is sampling the 2nd horizon, a clay loam (Sample 155-2); the depth of the third horizon (Sample 155-3), distinguishable by the dark color of the iron concretions, and mottling of the clay loam, is very variable. Underlying this profile, and exposed elsewhere in this pit, is a purplish sandstone (Sample 155-5) which first weathers to a light bluish gray (Sample 155-4). Ban Tam Yae (บ้านตำแย), Utumpawnpisai township (อ. อุทุมพรพิสัย), Srisaket Province (จ. ศรีษะเกษ), Northeastern Thailand. March 1936. RLP Foto 589—5.

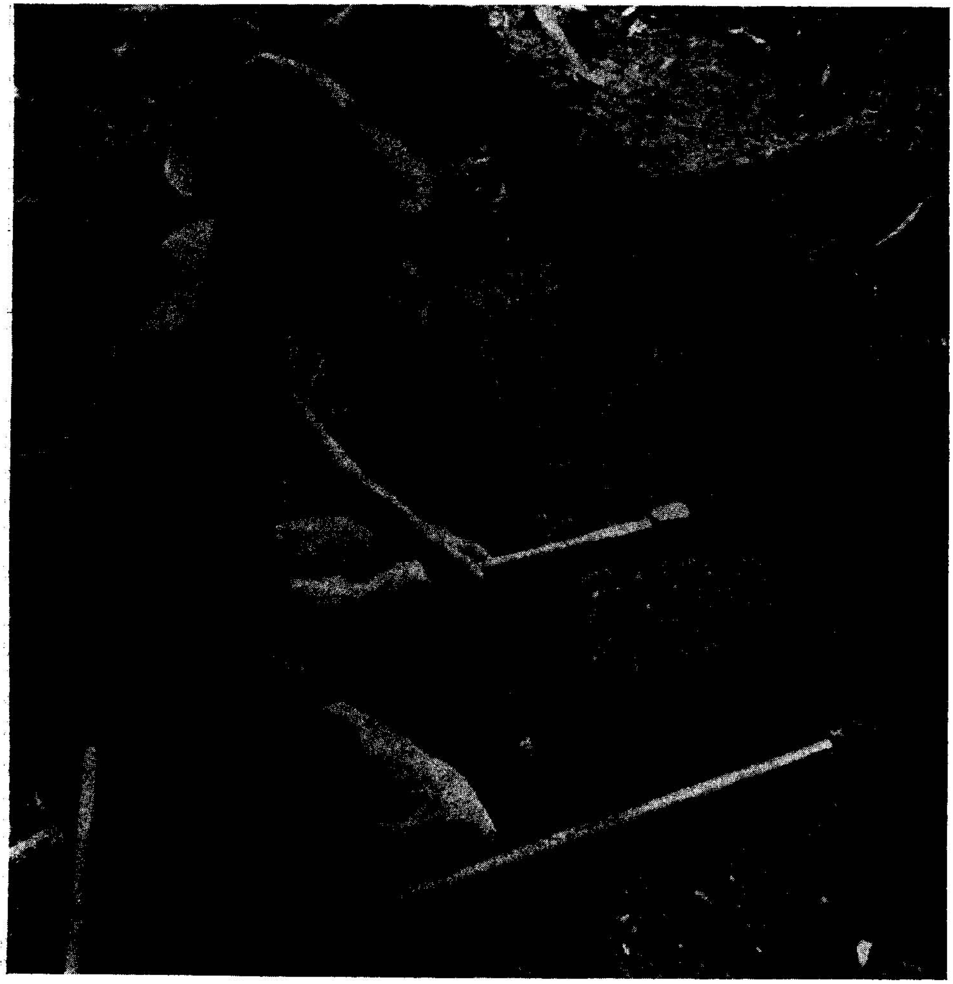


Fig. 15. The nearest block of laterite is being loosened from the quarry mass by striking a number of smart blows with the small axe directly into the *bottom* of the cut. It should be noted that it is imperative that the desired thickness of the blocks be determined by first trimming down the laterite on three sides to the required depth. In the right foreground is the hoe for "adzing" smooth the surface of the laterite blocks after loosening them from the mass (cf. Fig. 16). (Samples 485-L, M, T.) Hin Dat (หินดาย), Tamai township (อำเภอท่าใหม่), Chantaburi Province (จังหวัดจันทบุรี), Southeastern Thailand. January 1937. RLP Foto 783—11.

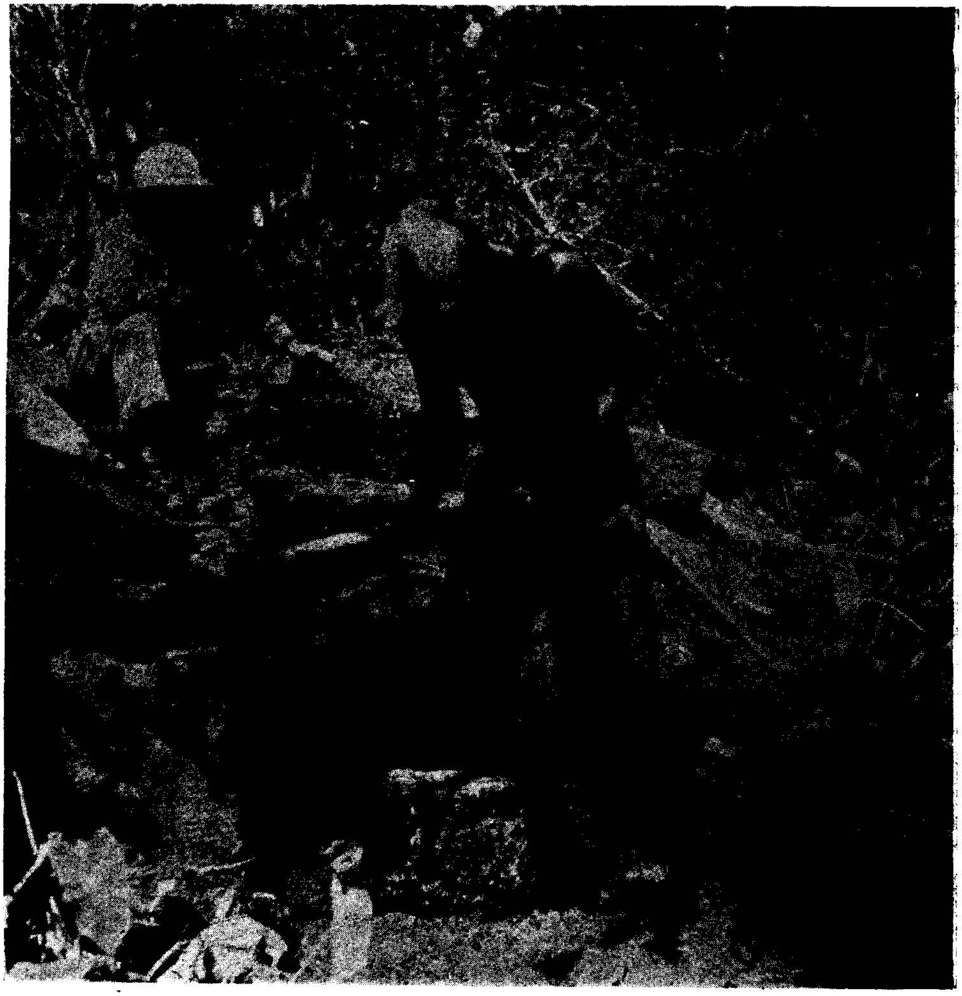


Fig. 16. Using a small hoe, adz fashion, the man is dressing the sides of a block of laterite just loosened from the mass. Beyond him may be noted several masses of laterite cut-around but not yet loosened. Dressed blocks of laterite are above, at the left. The plants of wet ground, just visible at the right call attention to the fact that this laterite exposure is not far above local ground water level, even in this dry season. January 1937. (Samples 485-L, M, T). Hin Dat (หินดาย), Tamai township (อำเภอท่าใหม่), Chantaburi Province (จังหวัดจันทบุรี), Southeastern Thailand. RLP Foto 782—5.

Fig. 17. Laterite block quarried from vescicular or slag-like laterite. Sample 576-L. Gaw: Kwang, Chantaburi township and Province (เกาะกวาง จังหวัดจันทบุรี), Southeastern Thailand. RLP Foto 1298—3.

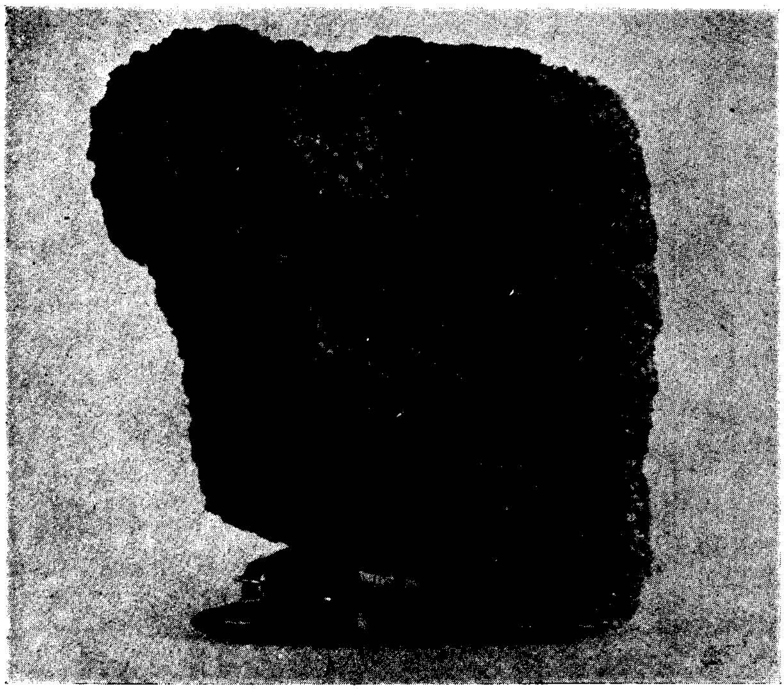


Fig. 18. Pisolitic type laterite (sample 891-L) from one of the central 10th century shrines, Pimai. Nakorn Rachasima Province (จังหวัดนครราชสีมา), Northeastern Thailand. March 1940. RLP Foto 1298—4.

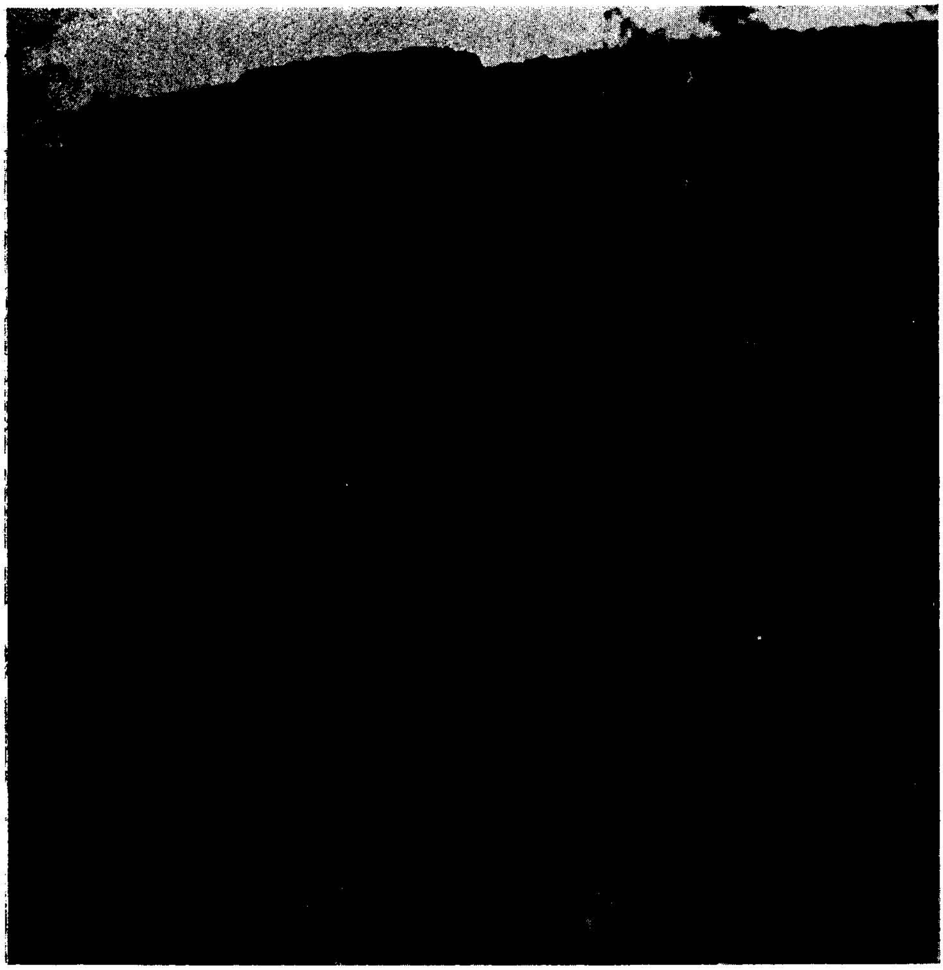


Fig. 19. This portion of the ancient town wall of Pimai is near the south gate. Note that these crudely shaped blocks of laterite are of laterite of an intermediate pisolitic/vescicular type: These blocks were doubtless quarried in the sandstone region to the south of the town. Nakorn Rachasima Province (จังหวัดนครราชสีมา) Northeastern Thailand (Sample 893-L). March 1940. (cf. Figs. 50 and 51 in the Geog. Rev. *31*, 195). RLP Foto 1241—4.

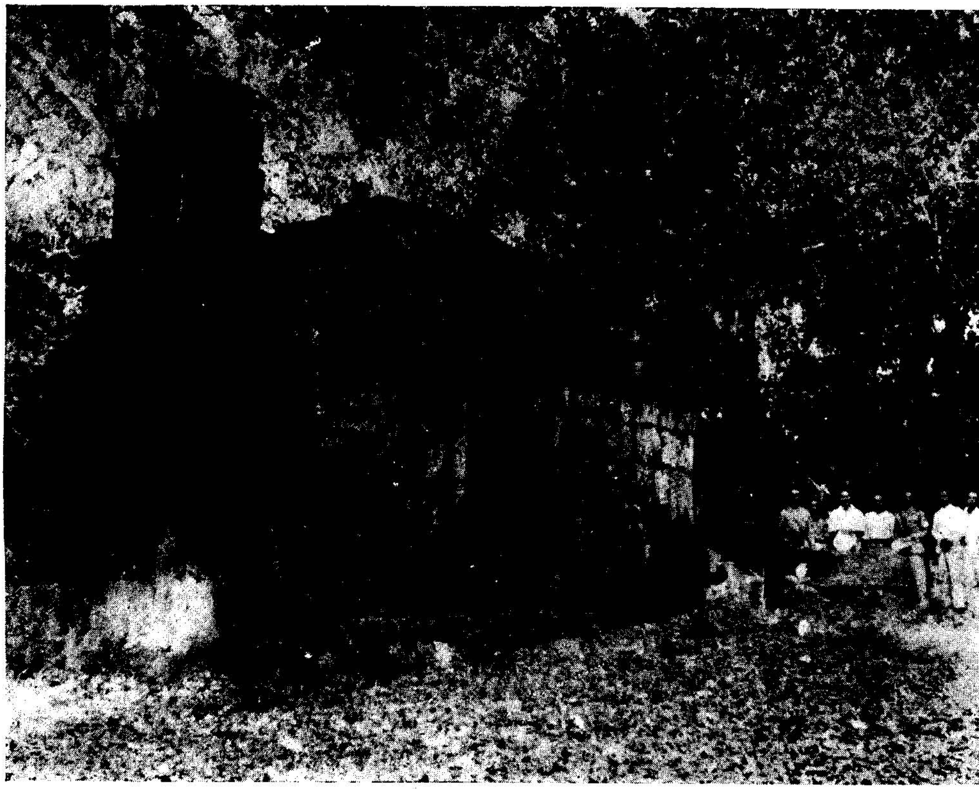


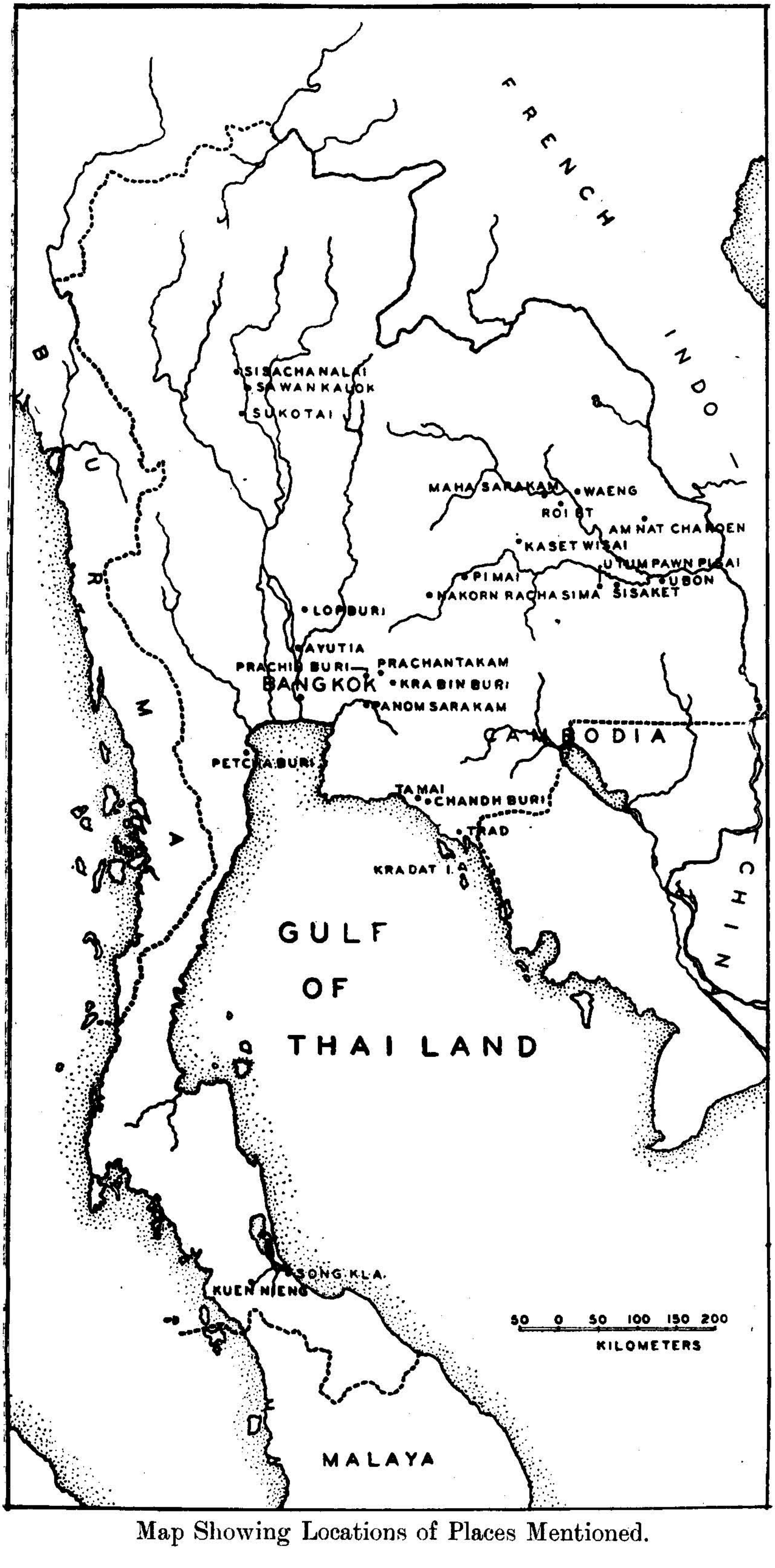
Fig. 20. Massive blocks of laterite compose the base of this ancient shrine "Wat Tat" a tenth century shrine near Kasetwisai, Roi Et Province (จังหวัด ร้อยเอ็ด). In front of the figures in the right distance is a large block of red sandstone, such as was used for posts and and lintels of this building. (Sample 860-L). Northeastern Thailand. March 1940. (cf. Fig. 45. Geog. Rev. *31*, 193 for another view of the same structure). RLP Foto 1227—3.

Fig. 21. The age of this prachedi of laterite is supposed to be less than of many because the roof of the vault at the left is of long slender, curved pieces of laterite leaning against each other. A few bits of the plaster finish still remain. This prachedi stands east of the Yom river (ม. ยม), Sisachanalai township (อ. ศรีสัชชนาลัย), north of Sawankalok (สวรรคโลก), Northern Thailand. (Fig. 58. Geog. Rev. *31*, 198, gives another view of the same structure which was sampled and analyzed under No. 593-L). November 1937. RLP Foto 867—11.

Fig. 22. Where the laterite was quarried, of which this Wat Kampang Lang (วัดกำแพงหลัง), at Petchaburi (เพ็ชรบุรี) was built about the 10th or 11th century is not known. (Sample 308-R). Note that the arch is not used, nor are the joints well broken. Lintels of wood or sandstone were used to span the doorways. At the left may be seen portions of the original plaster finish which carries the elaborate decoration. Western Thailand. October 1936. RLP Foto 720—8.

Fig. 23. Only the massive sandstone posts and lintels of this tenth century shrine of Ban Gu (บ้านกู่) are of sandstone, all the rest is laterite. As is often the case with structures of laterite, the joints were not well broken, so that portions of the tower have fallen away (Sample 874–L). 7 kms east of Roi Et (ร้อยเอ็ด), Northeastern Thailand. (cf. Figs. 42–44 Geog. Rev. *31*, 193 for other views of the same shrine). March 1940. Foto 1233—2.

Fig. 24. Ancient (probably 10th century) laterite ruins of Ban Kampeang (บ้านกำแพง) in Utumpawnpisai township (อำเภอ อุทุมพรพิไสย), Sri-saket Province (จังหวัดศรีษะเกษ), Northeastern Thailand. (samples 156-×, 157-×). (cf. Figs. 40, 41 Geog. Rev. *31*, 193 for other views of this same shrine) March 1936. RLP Foto 590—3.



Map Showing Locations of Places Mentioned.