THE FORMATION, DEVELOPMENT, AND UTILIZATION OF THE SOILS OF THE BANGKOK PLAIN

by

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The soils and agriculture of this plain are worthy of study for several reasons. This is one of the important padi[2] growing regions of southeast Asia. The fruit gardens around Bangkok, without an equal in quality and diversity of tropical fruits, are on radically modified portions of the low heavy clay soils. Other portions of the plain have been modified to produce important quantities of vegetables. A study of the soils themselves reveals relationships which aid in understanding soil developmental processes.

THE BANGKOK PLAIN : This roughly triangular plain of lower central Siam extends north about 250 kms from the Gulf of Siam to a little north of Chainat, where are the first of a number of hills scattered across the middle of the central valley of Siam. In the west the Bangkok plain extends to the Ganburi (Kanchanaburi) foothills of the western mountains. Between Ganburi and Prachinburi, in the eastern part of the plain, is its greatest width,

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2 *Padi is lowland or wet land rice; also the rough, unhulled grain. Padi fields or padis are the small diked fields in which lowland rice is grown.*

about 225 kms. To the east of Prachinburi, beyond the region covered by these notes, is an extension of the plain connecting it with the plains of Cambodia.

The Bangkok plain consists mainly of the delta of the Menam Chao Phya which, as it has grown southward, has coalesced with what were formerly separate deltas of the Maeklong river in the west and with the Pasak, the Nakorn Nayok, the Prachin and Klong Talat rivers in the east. The city of Bangkok is located in the southern portion of this plain, on the Menam Chao Phya River, about 30 kms from its mouth in the Gulf of Siam.

PRINCIPAL PHYSIOGRAPHIC AND SOIL REGIONS :

(1) The Bangkok plain proper, low and flat, occupied by dark gray clays which when flooded produce much padi. Close along the rivers and some distributaries are narrow threads of silt loams and very fine sandy loams, where fruits and vegetables are important crops.

(2) Along the western, northwestern, northern and northeastern parts of the plain are bodies of slightly higher, younger light grayish brown to light brown silt loams to light clay loams. These soils are less intensively cultivated, producing mostly upland crops, such as tobacco, cotton and sugarcane. When irrigated they are superior padi soils.

(3) Along the footslopes of the mountains, both to the west and to the east and southeast are vast expanses of fine to very fine sandy loams, often with laterite in the profile, and occupied mostly by poor open ***pa pae* (*pa daeng*)** forests. Here and there are hills, usually of quartzitic rocks.

THE MENAM CHAO PHYA RIVER : The vastly greater amounts of sediment brought down by the Menam Chao Phya have dominated the growth of the delta complex, and deflected the channels of the Maeklong, the Nakorn Nayok and the Prachin rivers toward the south. As the main delta grew southward the level of the river banks was also gradually tho not uniformly built up, maintaining the base level of the river slope. This means that in the high water seasons the river overflows its banks in numerous places along a considerable portion of its course thru the upper Bangkok plain. The Menam Chao Phya itself has a network of channels which divide and reunite in their southward course. The most important distributary is the Supan river (farther down known as the Nakorn Chaisi, then the Tachin). Other important distributaries are the Menam Noi and the Lopburi river. All three of these streams branch off near the head of the plain. All are silting up: their banks are not eroding even tho considerable portions of them are cleared of natural vegetation annually and planted to tobacco and vegetables. Farther down stream the banks of the Menam Chao Phya gradually become lower until at Ayutia, about the center of the plain, where the water levels commence to be affected by tides from the Gulf, the ecatural river banks are seldom more than a meter above average high water. In its lower course this river is usually several hundred meters wide and sometimes as much as 25 meters deep. By contrast, the bar in the Gulf, at the mouth of the river, has at times but 3 or 4 meters of water over it.

Fortunate it is for the agriculture of the Bangkok plain that above Chainat the valley is constricted. This helps to regulate the flow down into the plain, holding in the northern half or the Central Valley, above Paknampo, portions of the floods in any or all of the four rivers, the Ping, the Wang, Yom, and Nan which flow southward into the central valley from the mountains of northern Siam. Even so, the regulatory action is inadequate, for in perhaps one year in three the water does rise too rapidly in lower places in the Bangkok plain, especially between Singburi and Ayutia, drowning part of the young "deep water" rice because it cannot grow upwards fast enough to keep the terminal leaves above the water level.

Such unusual floods as of 1918 and 1942 in which most of Bangkok was flooded to a depth of a meter or more are of course in a different category. It is believed that these floods have been much more serious because of the construction of railway and other embankments, and a failure to keep in operating condition certain of the regulatory drainage works in the sea dike.

The Pasak, Prachin, Nakorn Nayok and Maeklong rivers have simple and relatively small catchment areas, and no natural weirs to moderate the floods. Hence their flow, where they come out into the Bangkok plain, is much more irregular, locally causing more serious flooding and damage in places along their courses.

PHYSIOGRAPHICAL AND AGRICULTURAL SUBDIVISIONS OF THE BANGKOK PLAIN : The following are subdivisions with more or less similar soils and water conditions, in which the agricultural conditions are relatively similar.

Upper and western banks of the Menam Chao Phya :

(1) Between the Menam Chao Phya at Intaburi and the Lopburi river is a low region. This depression extends down to Ayutia and west thru Sena township to the Supan river. Fig. 10. Most of the padi is of the deep water "floating" type.

(2) Between the Menam Chao Phya and Menam Noi is a strip of low land.

(3) Between the Menam Noi and the Supan river are higher, lighter colored, and lighter textured soils, for the most part not now cultivated because of inadequate irrigation.

(4) Below Sena and Rachakam townships and between the Menam Chao Phya and Supan rivers, extending to the Gulf is a strip of land on which flow irrigation and natural flooding are inadequate. Cross canals and the railway and highway embankments seriously interfere with normal flooding. This is a region of predominantly shallow water, transplanted padi.

The East Bank Plain: may be divided into

(5) the plain north of Lopburi, with deep water rice in the northwest, transplanted in the southeastern portion.

(6) Ayutia east bank plain, east and southeast of Ayutia, and between there and the Rangsit district, to the southwest and south of the higher lands along the Pasak. Well watered naturally and by irrigation works, this is a region of part transplanted and part broadcast deep water padi. No "salty" nor "sour" soil noted.

(7) The east bank strip, just east of the Menam Chao Phya, extending from Chienrak down thru Dawn Muang, Bangkhen, Prakanong to Paknam. A region of almost flat land with good padi soils, usually only shallowly flooded. A region of mostly transplanted padi.

(8) The Rangsit region, lying east of region 7, this district extends east to Ongkarak and the lower Nakorn Nayok river and to the northern part of Bang Nam Brio township. A flat plain marked by old shallow river channels and small circular ponds or depressions. The soils are of medium to low fertility, flooded mostly to only shallow depths with water diverted from the Pasak and Nakorn Nayok rivers Fig. 9. Considerable bodies of "sour" soils. Most of the padi is of the broadcast shallow water type---extensive farming on soils of low fertility.

(9) Klong San Saep region, lying south of the Rangsit region and between 7 on the west and Patrieu, on the Prachin river, on the east. This district includes especially Bang Kapi, Minburi, and Nawng Jawk townships. A well watered region of good padi soils. Shallow flooding types of padi are in some places broadcast, in others transplanted.

(10) Klong Samrong region, lying south of 9. It extends from region 7 on the west to Bang Pa Gong (Prachin) river on the east. It is a more diverse region with

(a) well watered, shallow flooded portions on the east, where transplanted padi is more important ;

(b) the central, lower portion, especially Bang baw township. Here on the good soils, because of excess water only transplanted padi can be grown.

(c) the Banghia - - Bang Ping uncultivated lands. Shut behind the sea dike, in a region where flooding and drainage are managed for the benefit of other subregions, this predominantly saline land produces some firewood but almost no agricultural crops.

Prachin river, left Bank : South of Prachinburi, outside of

(a) the minor natural levee, is

(b) a dark gray clay which extends southeast up the plain nearly to Simahapot township office, and southwest down the river to well beyond Bang Pa Gong township. These soils are usually planted to broadcast padi ; with favorable water conditions the yields are good.

Lower down the valley, as in Bang Kla township, Klong Talat has carried out different sediments which have given rise to lighter colored and textured less productive soils. The western edge of these soils is just east of Bang Kla market.

Farther down the Prachin river, as at Ban Po township,

(c) the soil is again a heavy dark gray clay, here underlain by a bluish gray and yellowish brown mottled clay subsoil.

(d) Below Patrieu most of the land near the river is low and heavy. Nipa palms and fruit gardens on *rong* are common. Fig. 15. The dense plantings of nipa about the gardens serve as an edge.

(e) Along the road to Ban Dong the topography is slightly undulating. The higher portions have shallow soils with thin horizons.

(f) The lower soils are darker and deeper.

(g) Farther south the soils are the outwash of fine, poor silicious silt and weathered out clay, carried out by the local streams from the poor lateritic slopes. The soils of the relatively unproductive padi lands just north of Bandong village are particularly light colored, a whitish gray, and very silty.

Nakorn Chaisi - - Maeklong region : The southwestern continuation of the Bangkok plain lies to the west of the lower Supan river and east of the lower Maeklong. Thus it is south of the railway line crossing this plain to the west. This region may be divided into the following districts.

(a) the northern and western portion with fertile soils and shallow to moderate depths of flooding. Transplanted padi predominates. Extending out into this district are

(b) some highter portions, natural levees of former channels of the Maeklong, and have more the characteristics of natural levees.

(c) The lower central Klong Chinda portion, which is usually deeply flooded and often rather suddenly, from the Maeklong river which overflows in many places in the vicinity of Potaram. A dike with sluiceways has been constructed in this vicinity and this has mitigated the damage. Fertile soils tho they are, they have not often produced their best because of the sudden rises in the water level, drowning the padi. Broadcast padi predominates.

(d) The Bang Chang or southwestern portion of the region, lying along Klong Pasi Charoen, is well watered but not deeply flooded. Transplanted padi had been important but is being displaced on the less deeply flooded portions by intensive vegetable gardening. Fig. 1.

DEPOSITION OF SEDIMENTS IN THE BANGKOK PLAIN : Inasmuch as there do not appear to have been any appreciable changes in the relative levels of the sea and the land for a very long time, tectonically this central portion of Siam must be unusually stable. The sediments which are brought down by the rivers continue to extend the land southward, so that the mouths of the rivers advance farther and farther southward. With the increase of the length of the channels the levels of the water in the channels rise proportionately higher and higher, so that most years during the annual high water season the rivers continue to more or less overflow their banks over long distances. This water floods all the back country, that is, the region between the several river channels. The coarsest sediments are deposited on the very banks of the rivers, building natural levees, and along a few stronger distributory streams which occasionally, here and there, break out thru the natural levees. The annually deposited silt maintains and gradually increases the height of these natural levees along the river banks. Because these levee soils are high and usually well drained, they are of great importance to the agriculture of the plain, for on them are the farmsteads, the fruit and vegetable gardens of the farmers, the numerous temples, Fig. 20 the villages, the rice mills and the markets. In fact, the river banks are almost continuous thinly strung out villages. Extra concentrations of people live closer about the markets, where there will often be a considerable number of floating houses and shops. Numbers of Chinese laborers and hog raisers usually live closer about the rice mills. These strips of higher, lighter textured natural levee soils are usually narrow, not over 100 meters wide. Fig 3. In fact, they are often much narrower than this. Behind them lie the lower, neavier and darker colored clay soils which gradually slope down away from the river banks.

In this region the water which overflows from the river channels forms vast shallow "lakes". More and more water flows over the river banks and through depressions in them, thence to increase the water in the "lakes" which stand where the land had been plowed after the early rains and the padi seed broadcast. The excess water gradually moves down thru these padi field lakes and on southward toward the Gulf. Sooner or later, usually many kilometers south in the plain, this water is intercepted by some cross channel, or still farther down, where the natural levees have hardly been developed, the water flows back into the same channel it originally left many kilometers upstream. Since this water moves only very slowly thru the fields of growing padi, even the finest of the sediment which it had carried out over the river banks gradually settles out. Hence when the excess water finally flows back into a stream again, it is no longer turbid. On the contrary, it is quite clear, tho because of dissolved organic matter it has taken up, it is brownish in color.

A modification of the normal, symetrical natural levee development occurs where this clear water flows into a more or less east or west-flowing portion of a channel carrying silt laden water from up the valley. In such a case, on the northerly or up-valley side of the channel there is practically no natural levee, for the clear water flowing out of the fields prevents the overflow of muddy water from the channel, and so prevents the deposit of silt. Fig. 10 On the southerly banks, on the other hand, where the silt-laden water of the river flows out unhindered, quite a pronounced natural levee has developed, with the result that along well developed east and west portions of channels, practically all the farmsteads are on the southern banks, because these are higher, broader and less deeply flooded. Fig. 11.

From time to time at some lower spot a distributary channel on a larger scale breaks through the natural levee and eventually a large and strong stream of silt-laden water flows out into the lower, back region between the well developed river channels. Such a stream flowing out across the low, heavy, dark clay soil deposits a long, more or less narrow strip of silts and very fine sands. Such strips of lighter soil may be planted in the winter season to melons.

If the force of the water enlarges the passage through the natural levee, the entire river may ultimately flow out thru this break, practically abandoning its former channel, which in time gradually fills with silt until it is navigable only during the very high water season. Many of the now important river channels reveal a dark clay horizon 2 to 3 meters or more below the top of the present banks (the natural levees). This dark layer is the original padi land clay which developed far back from the former channels of the river. Then the stream broke out, crossed the low lands, burying them under silts. Ultimately, as more and more water flowed through this new channel, it was eroded deeper and deeper, down through the dark clay soil. This was finally exposed to view during the low water stages in the new river bank. Fig. 4.

When the Bangkok plain is viewed from the air in the dry season all these stages in the evolution of a river channel and their relation to the soils and land use of the region are easily distinguished.

PARENT MATERIALS OF THE BANGKOK PLAIN SOILS : The alluvial sediments which are deposited in the Gulf of Siam are of two main size ranges,

(1) the extremely small particles of clay which are carried in suspension in the river water, and

(2) the relatively much coarser particles, principally very fine sands, which are rolled and pushed along the bottom of the river as bed load. Most of these fine sand particles are probably quartz, thus resistant and without assorptive capacity, they are unaltered by the sea water. The clay, however, may be greatly changed in its chemical composition, for it absorbs considerable quantities of such ions as calcium, magnesium and potassium from the sea water.

At the same time the minute clay particles clump together (flocculate) into much larger masses which rapidly settle and accumulate as mud on the bottom of the Gulf.

Another source of soil materials is the weathered laterite and related soils on the lower slopes of the foothills. Clays and fine silts from these sources are conspicuous in the Klong Talat region, east of the Prachin river.

ALTERATION OF THE RIVER SILTS: The river sediments, the "silts" while being carried by the river to the sea are a light brown color, for the river water contains much dissolved oxygen, so that the oxidized iron compounds which give the brown color remain in that state.

Almost as soon as the very minute particles of clay clump together in floccules, as a consequence of contact with the sea water, the sediments settle to the bottom. The color soon changes to a light bluish gray or a light bluish green, because of the effects of the decomposing organic matter which accumulates with the flocculated sediments. In decomposing, the organic matter takes up oxygen, a portion of which is obtained from the sediments, changing the brown ferric compounds to light bluish ferrous ones[1]. When the bluish muds are exposed to the air, as in dredging operations, in a few hours the oxygen from the air changes the surface color of the spoil to the oxidized grayish brown. The depth of penetration of the brown color into the moist masses of bluish mud indicates the depth of penetration of oxygen.

A similar effect can be observed in any padi soil which had been submerged. The surface of the root holes and cracks which admit oxygen into the moist soil is colored a light brown, contrasted with the light bluish gray ground color of the padi soil as a whole.

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[1] *With increased proportions of organic matter and less oxygen in the water, as is the case in stagnant canals and ponds, the color of the sediments becomes the familiar dark bluish gray.*

But if the soil dries out before the oxygen reaches the interior portions, the bluish ferrous color persists, for in the dry state the change from ferrous to ferric state does not take place.

Everywhere in the low alluvial plain the deeper, continuously saturated portions of the alluvium retain the light pluish or greenish gray colors. But as the diments from the serivers gradually fill up the Gulf, and the shore gradually moves south, in the course of tens of thousands of years, there are increasing opportunities for the surface soil in any particular locality to dry out somewhat during the long dry seasons. The rain which falls on the land, and the occasional floods of fresh water from the rivers gradually but steadily wash away more and more of the excess salts from the surface soil. Mangroves and other plants growing in saline soil along the shore are gradually replaced on the landward side by trees, shrubs and grasses which do not thrive on very saline soils. But the soil is still far from being suitable for agricultural crops. Hence it is that even though the sea water is excluded by dikes from the marine seacoast clays, such lands do not by themselves rapidly become suitable soil for agricultural purposes. If early utilization is desired, special methods have to be employed to remove the excess salt from the soil. As demonstrated in the reclamation of sea bottom soils in Halland, a suitable combination of leaching, drainage and growth of organic matter on the land being reclaimed will accomplish the result quickly.

During the dry seasons the movement of water in the surface few cms. of these clays is first upward, as the surface moisture is evaporated. The clay shrinks as it loses water, so cracks open up. Then additional moisture evaporates from the sides of the cracks, this leading to more shrinking and cracking. At shallower depths than a couple of meters, where seasonal variations occur in the water content of the sediments, because of drying in the dry season and rainfall and floods in the wet season, alterations in the clay and the very fine sand have taken place. The drying and cracking permit water to carry oxygen and carbon dioxide down rapidly, perhaps a half meter, into the profile, then to move very much slowly downward for perhaps another meter. Interaction is thus possible between the iron and other elements in the silt, the salts from the sea water, and the organic matter which accumulated with the sediments on the floor of the Gulf, as well as that produced in the soil by decaying roots. Some organic matter also falls into the cracks in the soil which open in the dry season.

Contrary to popular ideas that the dark flat clays, like those of the Bangkok plain, get their colour directly from formation on a lake or sea bottom, it is rather these alternating conditions of saturation and strong-drying, as a consequence of the long dry seasons, and of the plant growth on the soil which actually bring about the development of the dark color.

For the most part the deeper portions of the mud deposited in the Gulf have remained undisturbed since its deposition, even in places as far from the sea as Bangkhen, 40 kms from the present coast line, where the sediments are now accumulating. Here between 2 and 3 meters below the present soil surface, in a fresh excavation the deeper clay, with the small lenses of very fine sand, appeared to be perfectly fresh, just as they might have been shortly after they had settled on the floor of the Gulf. This is because under the conditions which prevail in this clay at this depth in this plain, such sediments never dry out. Moreover, since movement of water through such clays is believed not to exceed the order of about 2 to 3 millimeters per year, these sediments are practically impervious---they have been hermetically sealed for tens of thousands of years. However, within a zone a couple of millimeters around the occasional holes in this clay made by roots believed to be of a former swamp vegetation[1], iron has precipitated as limonitic clay.

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[1] *Thanks are due to M.R. Chakrtong Tongyai for identifying microscopically root fragments found in some of these holes. Nai Samak Buravas, of the Department of Mines, has suggested the term "limonitic clay". He also stated in conversation that these holes were always made by roots, for he, too, had microscopically checked the residues found in them.*

On soil heaps these latter are washed free by the rain and remain as rather firm tubules or hollow spheres. The spheres are sometimes as much as 5 cm in diameter.

In a recent and still deeper excavation[1], at between approvimetely 3 and 4 meters depth the color becomes a dark bluish gray to gray, while the texture becomes lighter, a silt loam or a fine sand. Quantities of unaltered mollusk shells, both spirals and bivalves, as well as some clumps of barnacles, were found in this horizon at about 3.5 meters depth. In some cases the shells were found scattered thru the deposits, in others as many as several score were found in masses. In this same horizon some chunks of wood 20 cm or more long and 10 cm across were found.

Another of the products of the interaction of the organic and inorganic components in the sediments is gypsum. This is usually found as conspicuous crystals in the third horizon, at between 1.5 and 2 meters depth. For the most part these sediments have remained saturated with water, and are so impervious that the gypsum crystals which have formed, remain undissolved in the deeper horizons. On freshly rainwashed spoil banks from excavations more than a meter deep, numerous gypsum crystals several millimeters across are often conspicuous. The water which collects in fresh excavations in the Bangkok plain contains an appreciable amount of dissolved salts. Some surface wells, even after years of pumping, do not always give potable water.

SOILS OF THE BANGKOK PLAIN: Because they have been developed from very fine grained alluvial materials, and because weathering has continued in the uppermost portions of these materials, the soils of this plain proper are almost entirely clays. The very narrow natural levees, along and close to the larger river channels, are of lighter textures — mostly silt loams and light silty clay loams. As the delta of the Menam Chao Phya gradually grows,

[1] *Thanks are due to Sarot Montra Kun (formerly Magdaleno M. Cero) who supervised this excavation reported these details in personal conversation.*

extending the muddy shore perhaps a meter farther each year, there is less and less chance for the land at any particular point inland to be reached by the sea water even at high tide. Thus more and more of the land is flooded only by rain water, from time to time supplemented by turbid water from the rivers. The river floods bring on some silt and clay from higher up stream. As before, part of this sediment carries plant nutrient materials, but another portion is already quite leached of nutrients and therefore inert. Nevertheless, all this suspended material brought onto the land does its bit to raise the elevation of the plain. That river silt does fertilize the land is well known to the farmers, who complain that where dikes, canals, roads and railway embankments or other constructions keep silty water from reaching their land, they cannot produce as good crops as they formerly could when the silt was annually washed out onto their padis. An example of this was noted along the northern part of Klong 13, in the Rangsit district. East of this large canal, where the land continued to be flooded annually by muddy water from the hills to the northeast, the padis were said to yield about 35 buckets per rai. But after the canal was built the muddy water could not cross it to the west side. Here the land was flooded mainly by rain water and relatively clear water from the main canal to the north. The padi yields were reported to have dropped to less than half as much, not even 15 buckets[1] per rai.

As has already been pointed out, the characteristics of the principal soils of this plain vary with the degree of wethering. The influence of the climate, particularly the amount and seasonal distribution of the rainfall, and the vegetation, which the climate influences to a marked degree, often have as much or more effect upon the ultimate nature of the soils of a region than the character of the parent materials from which the soils originally developed.

From the youngest to the most mature, or most weathered, the soils on this plain form a series. Beginning with the youngest, soils in the following localities may be taken as examples :

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[1] *a bucket is 20 liters.*

(1) The natural levee soils of the Menam Chao Phya ;

(2) Saline clays of the gulf coast ;

(3) low, darker bluish gray clays, with less salt, as near Bang Baw, Samut Pragan province ;

(4) dark Bang Chang clay, along Klong Damnoen Saduak ;

(5) Bangkok clay, the dark surface of which is underlain by light bluish gray clay ;

(6) Bangkhen clay, which differs in having red and yellow splotches, variegations, streaks and mottlings in the subsoil ;

(7) Rangsit clay, in which a greater degree of weathering is indicated by a more pronounced development of the subsoil horizons and a lower productivity ;

(8) Ongkarak clay, which shows the most marked development of the subsoil, thus the greatest alweration of the sediments of the present alluvial plain ; Fig. 5.

(9) Dawn Lakorn laterite soil, a relic of a former alluvial plain, and related to the laterite soils at Prachinburi and southeast of the Prachin river, is the most developed soil in the Bangkok Plain. It is a senile soil.

In a general way the degree of development of the soils increases toward the northeast, with the increasing rainfall. The younger soils are in the southwest. The amount and kinds of silt which have been added by the annual floods of the different rivers have undoubtedly been additional factors affecting the character and degree of soil profile development.[1]

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[1] *Periodical chemical analyses of the waters and silts of a number of rivers and canals in the Bangkok plain are being made by Roem Purnariksha, of the Division of Agricultural Chemistry, Royal Department of Agriculture. The results of this study should contribute materially to a clearer understanding of the relationships between river silts and soil characteristics in this plain.*

SALINE CLAYS OF THE COAST : Along the Gulf of Siam, particularly west of the mouth of the Menam Chao Phya, where the land is less effectively enclosed by protective dikes, there are great areas of low, wet clays. During spring tides these lands may be flooded. Important components of the vegetation are mangroves and nipa palms. A little farther from the shore expanses of tall grass are conspicuous from the air. This land, as it is not diked and there being no provision for irrigation or drainage, cannot be used for the production of food crops. Nevertheless, the demands of Bangkok for nipa thatch, mangrove firewood, charcoal and poles have led to the exploitation of these resources, even to the planting of considerable areas to nipa and mangrove seedlings.

These saline clays are so young that horizon differentiations have not yet become apparent. East of the Menam Chao Phya and inside of the sea dike, the excess salt in the soil is said to be decreasing gradually. One indication of this is the steady but slow extension southward of the land planted to padi, as in Ban Kao village. During the first few years that padi is grown on salty soils the growth of the straw is luxuriant, while the yield of grain is not only low but the quality is also poor. In Bang Pli and Samut pragan townships there is much land uncultivated because of the high percentage of salt in the soil. Here the main difficulty is that the control of irrigation and drainage waters have been inadequate. The soil itself is undoubtedly rich in plant nutrient substances, for where the water has been effectively controlled and held on the land, good yields are obtained. Proof of inherently good qualities of this soil is given by the intensive and successful padi farm just outside the dike, southeast of Paknam town.

West of the Menam Chao Phya and on toward the Tachin river, considerable areas of these poorly drained lands have been diked and used for evaporation of sea water to make salt. Suitable methods of maintenance for the earth floors of the crystallizing ponds during the rainy season will likely be one of the most difficult problems.

BANG CHANG CLAY: This is a dark gray clay, black when moist. The subsoil is a light gray clay, which grades into a bluish gray color with greater depth. No red color was noted in the subsoils in this region. (Utilization of this soil is described below.) Fig. 1.

BANGKHEN CLAY: The soils in the vicinity of Bangkhen are moderately developed. The dark clay soil cracks to a depth of half a meter or more in the dry season, while during the rainy padi growing season, when the land is long submerged, the color of the surface soil is a somewhat lighter gray. The surface soil gradually grades downward into the subsoil which is gray, with light brown root traces. In places there is a mottled light grayish brown horizon between 1 and 2 meters below the surface. Still deeper is a bluish gray horizon, splotched or marked with some red and some few light yellowish streaks along the cracks. In this horizon especially are soft, often hollow, rusty brown iron concretions, presumably formed inside insect burrows; other concretions of similar material are tubular, presumably having formed in root or other holes thru the clay. At times there are large numbers of gypsum crystals scattered through the clay.

At 2 meters depth or less the relatively unaltered light bluish gray silt and clay sediments are reached. These are probably still in very much the same condition as when they were originally deposited in the Gulf. These clays are interbedded with small lenses, at most a few millimeters thick and a centimeter or two long, of whitish very fine sand or silt. This must have reached the Gulf as bed load of the river. At this depth of 2 meters and down to about 3 meters apparently the only alteration of the sediments has taken place along the few small-diameter root holes which have penetrated to this depth.

In two profiles in this clay, which were sampled every 10 cms to a depth of a meter, the surface soil was found to be quite acid

(pH 4.9 to 5.). At about 70 cms the reaction was found to be neutral, while at 1 meter it was slighty basic. The large amount of exchangeable bases found in these samples show that this soil type is far from impoverished in plant nutrients. Instead, it contains abundant supplies of some of the important elements. Recent fertilizer experiments with rice indicate that phosphorus is a limiting factor, and that application of bone meal gives striking increases in yields.

RANGSIT CLAY: While the total area of this soil type is not as great as that of some of the other types in this plain, yet because of the problems which have arisen and continue to arise in the effective use and management of this soil as a consequence of irrigation on a large scale, this soil deserves special attention. On the Rangsit Rice Experiment Station, about 25 kms east of the Menam Chao Phya, a typical soil profile is as follows: (Colors are of the moist soil) :

0---15 cm Neary black clay. Where the fields have been plowed during the dry season and then moistened by showers, the surface is friable and granular. The lower portion of this horizon is very plastic as a consequence of the annual puddling of the soil for planting padi. A plow pan has developed.

15 to 25--35 to 50 cm A light purplish gray clay, with a rather pronounced blocky structure; the large blocks being faced by rather distinct joints (slickensides).

35 to 50--60 to 75 cm A light purplish gray clay with streaks and splotches of light yellow, and at times of light red. Frequently there are light yellowish brown non-plastic deposits, chiefly along the vertical cracks and joints. This horizon is the zone of oscillation of the upper surface of the water table.

60 to 75--100 cm and deeper. Light bluish gray plastic clay, with less light yellow and no red. If the moist chunks are broken apart carefully, structural surfaces are apparent, tho not pronounced. This horizon is one of permanent saturation by ground water.

The reaction of this soil is very acid, and the degree of acidity increases with depth. The surface samples have a pH of about 4, while the samples from about 1 meter have a pH of about 3.5. The usual yield of broadcast padi on this soil in a good year is between 15 and 20 buckets padi per rai.

More than half a century ago, prior to the excavation of the canals across this plain and the cultivation of rice here, the natural vegetation over vast expanses is said to have been grass so tall that it was difficult to see out any distance over the plain, even from the back of an elephant. Herds of wild elephants roamed here. It is believed that the numerous depressions, like oversize buffalo wallows which dot this plain are old elephant wallows. It seems unlikely that forest ever stood on this heavy dark soil. While planted trees do well on ridges (*rong*) made for the purpose, and on the slightly elevated spoil banks along the canals, where the soil is areated and drained and the roots can reach some water, yet on the flat undisturbed soil of the plain trees languish and die after only a few years. By contrast, along the Menam Chao Phya and other rivers, where the soils are younger, better drained, deeper and thus more fertile, manificient groves of *yang* (*Dipterocarpus sp.*) and other trees stand in the protected temple grounds. Fig. 6.

A rather common variant of the Rangsit clay was sampled in a slight depression, probably an old elephant wallow :

0---15 cm Practically black, apparently because the organic matter is not well decayed. Padi plants on this soil do not have a firm root hold, sometimes they float off. pH 3.9

15--40 cm	Transition to the second horizon
40---65 cm	Bluish gray clay splotched with red and yellow. pH 3.6
65---85 cm	Transition to the third horizon.
85--100 cm	and deeper. Light bluish gray plastic clay. pH 3.5

This phase of the type is a very acid soil, and in other ways is less desirable.

ONGKARAK CLAY: This soil type is common in the vicinity of the Sawapa canal locks and elsewhere in Ongkarak township.

0---15 cm	Dark to black clay loam to clay, with much organic matter.
15---50 cm	Dark clay, with red, bluish, bluish gray and yellow splotches.
50---70 cm	Bluish gray clay with yellow and red splotches.
70--100 cm	Bluish gray clay with yellow spots; almost no red.

Another boring, some kilometers distant, showed :

0--20 cm	Black clay.
20---30 cm	Bluish gray clay with red splotches.
30---50 cm	Bluish gray clay with red and yellow splotches.
50--100 cm	Bluish gray clay with some yellow and brown spots. Practically no yellow color at 100 cm.

The red color has not been observed deeper than about 60 or 80 cm below the surface. The yellow color extends deeper than the red. The more brown mottling there is in the color of the second and third horizons, the better the crops of padi that can be grown. Where the soil is low, but not highly acid, the principal colors are light bluish gray with brown mottlings. Where the surface soil is intensely black and seems to be rather looser, it is the most acid.

As a whole this type is extremely acid. The following are some values ;

Sample nos.	pH	
	Surface	Subsoil
477	3.9	3.6
478	4.2	4.6
479	4.2	3.8
480	3.9	3.5

Where this soil type is cultivated at all, it is planted to broadcast padi for 4 or 5 years, and then, depending something upon the rainfall for early plowing and the water supply for flushing and for irrigation, the land may be left fallow for several years. Fig. 5. With the gradually improving supply and better control of irrigation water, there is believed to be some improvement in the crops obtained. Water control is the most important problem. If flushing of the surface can be done in time and thoroly, and the proper depth of water maintained, particularly if the water is silty, at least modest crops of padi should be possible. It is likely that cheap rock phosphate will prove to be a profitable fertilizer for padi on this soil.

SOLUBLE SALTS IN RANGSIT AND ONGKARAK CLAYS: Apart from the excessive quantities of salt which still exist in soils near the Gulf, there are considerable quantities of soluble substances in the Rangsit and Ongkarak clays. Farmers in the region generally believe that if there is not enough flushing water in the canals early in the planting season, so that previous to planting the land can be flooded and then allowed to drain somewhat, then particularly if the rains do not come until late, when the rain does fall at the end of the dry season, the young padi plants will be killed. Some farmers classify these unfavorable soil conditions as ***k̦om*** (bitter), ***k̦em*** (salty), and ***prio*** (sour). Others refer to some of the soils as ***fart*** (astringent). To test if the water standing on the padi land is suitable for planting, the experienced farmer may taste it. Others use betel juice, spitting some of the red mixture into the water standing on the field. If the color remains red, the water is considered safe and broadcasting or transplanting can be done. But if the color turns black, the water is considered "sour" and planting should be delayed.

Water standing in deep excavations in these clays is very clear and of a deep blue color. It is said that when one of the important canals in the Rangsit region was dug, the water contained so much material in solution that for two years it could not be used to irrigate padi.[1] Professor Hardy[2] studied a few samples of soil from the Rangsit Rice Experiment Station, and reported the following data:

Sample No.	Depth	pH	Remarks
	Surface	efflorescence	Mainly aluminum sulfate, with some magnesium sulfate and calcium sulfate. Neither chloride nor phosphate.
8A	0---30 cm	4.2	
8	30---45 cm	4.0	
9	30--180 cm	3.7	
10	180--300 cm	3.1	

These data are of interest in showing the nature of the soluble material on the surface, and the extremely high acidity of the deeper portions of the profile.

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1. *Roem Purnariksha, chief of the agricultural chemistry division, continues study of the dissolved materials in Bangkok plain river & canal waters.*

2. *Of the Imperial College of Tropical Agriculture, Trinidad, British West Indies. The results were sent in a private communication to M.L. Yingsakdi Israsena, somtime a post graduate student at Trinidad, subsequently in charge of the Rangsit Rice Experiment Station, who had collected the samples and sent them to Professor Hardy.*

Since during the years 1942–1945 it was impossible to import alum for the clarification of river water at the Bangkok water works, local sources of supply were sought.[1] Near the Rangsit Radio Station, along the main north road a few kilometers beyond the Dawn Muang airdrome, in the subsoil was found a bluish gray clay with streaks of a light yellow, highly oxidized iron compound. This horizon contains about 0.5% alum and between 2% and 3% of calcium and magnesium sulfates. The alum is obtained by removing the overlying soil to expose the alum-containing clay to the atmosphere. The excavation was protected from rain by erecting a thatched roof over the large pit. Gradually the alum and other salts effloresced on the surface of the clay. The salts with as little as possible of the clay were then scraped off, mixed with water, and the clay allowed to settle. The liquid was then decanted and used for clarification of the Bangkok water supply.

It is believed that this clay subsoil originally accumulated in a swamp, and that the relatively large quantities of organic matter accumulating with mud was the reducing agent in chemical reactions between the iron compounds and the aluminum silicates of the clay. Alum was one of the final products of the complex series of chemical reactions taking place in that wet swamp soil over a long period of time.

South of these alum-containing clays the subsoil has been developed from fine silts rather than from a plastic swamp clay. These sediments contain considerable quantities of sea shells, hence it is concluded that this was a former beach line, behind which was the swamp, now the alum-rich clays. In lighter, beach-line materials, with the higher concentration of calcium carbonate from the shells, and the calcium of the sea water, calcium sulfate rather

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1. *Nai Samak Buravas of the Dept. of Mines and Geology supervised the work on alum. The facts stated in this section were related by him in a personal conversation.*

than alum was the dominant product of the chemical reactions, and this has crystallized as gypsum.

THE RED COLOR BELOW THE DARK GRAY SURFACE SOIL: As time goes on and weathering of the soil proceeds, red specks, spots, splotches, mottlings or variegations develope in the second horizon, which is the zone of intermittent saturation with ground water. That is, the red develops in that portion of the soil which is moist with ground water containing some oxygen. The oxygen gains access to this portion of the subsoil particularly during the dry season when the cracking of the surface soil allows air to enter to some depth. And rain water with its dissolved gasses readily enters the soil. Penetration of water and gases is also facilitated by the holes made by roots, insects, and other organisms. The oxidizing conditions which prevail in this zone gradually cause the precipitation as red or brown earthy or concretionary ferric compounds of the iron from the soluble bluish gray, ferrous forms.

Provided the soil material contains ordinary amounts of iron which can be oxidized and precipitated in this manner, the amount and intensity of the red color will roughly indicate the degree to which soil development has gone. The depth and thickness of the red-containing horizon indicates the position and annual range of fluctuations of the water table, provided this range lies entirely within the oxidizing zone. The nature and significance of the yellow streaks (believed to be ferric oxides) in the reddened and deeper horizons of the profile are not yet understood.

Provided there is some source of supply of sufficient soluble iron compounds, a continuation of this precipitation process in the zone of intermittant saturation results ultimately in the development of a laterite horizon. The root channels, insect burrows or other passages through the otherwise practically impervious clay have been important places for the precipitation of the ferric compounds and help give the vescicular, often tubulated pattern to the laterite. Frequently altered by re-solution and re-precipitation of the iron compounds, as a consequence of slight variations in the conditions prevailing in the mass, these channels are particularly important in the development of a laterite in a clay matrix. By contrast, laterite which develops in a sandy matrix usually has a pisolitic structure—coalesced masses of small, roundish concretions.

AGE OF THE ALLUVIUM AND DEGREE OF REDNESS: In general the red in the subsoil is more conspicuous, the farther it is from the Gulf and where less silt has come on from the rivers. Soils from near the coast, as in Samut Pragan or Samut Sakorn provinces, show no red in the profile. Even as far from the coast as Bangkok, some excavations noted have revealed no reddening. By contrast, 15 kms farther inland, at Bangkhen, the second horizon of the soil begins to show streaks and splotches of red. The material which now forms the soil in the vicinity of Bangkhen was probably deposited roughly 50,000 years ago. That is, it has been subject to soil developmental processes about twice as long as the soil at Bankok. Farther north from Bangkhen, at the Laksi crossing, and more especially still farther north, at Chiengrak, where the sediments away from the river are certainly still very much older, the development of the red horizon is still more pronounced. These differences in degree of development of this second horizon are all within a region with a similar rainfall regime. Another consideration is that none of these soils appears to have been modified by the rivers or have had any appreciable amount of silt deposited upon them after the developmental processes were well under way.

While the rainfall regime over the entire plain is similar, the total annual precipitation in the western portion is much lower than in the center. More easterly still, in the Ongkarak—Nakorn Nayok region, the rainfall is about double that on the western side of the plain, on the westhern, portion of the plain Bang Chang—Nakorn Patom practically no red has been observed in the subsoil. As one goes east, keeping roughly on alluvium of the same age, there is an increase in the amount of red, until near Ongkarak there is the most pronbunced development of the red color in the subsoil of those infertile soils. Fig 5.

VEGETABLE GROWING IN THE ENVIRONS OF BANGKOK: In the environs of Bangkok there are thousands of acres of land once used for padi growing, but which are now ridged up (*yok rong*), with deep ditches between, in order that the land can be planted to vegetables, sugar cane, bananas and fruit trees. Fig. 8.

The Chinese are physically able and willing to endure the hard and nearly continuous labor thruout the year necessary to successfully raise vegetables on this heavy, intractable clay soil. Except in the very dryest season there can be no relaxation in soil management, or else weeds become so well established in the ridged soil that it is easier to ridge up new land than to eradicate the weeds on the old. Moreover, in spite of the fact that the water table in this land is usually within three forth meter of the top of the curved bed, the capillary capacity of this heavy soil is so low that unless it rains, the young rapidly growing vegetables must be watered twice daily.

Fruit and vegetable gardens are as a whole not competetive for the same locations because the latter must have only fresh water in the ditches. Unlike the fruit gardens, Fig. 7 there is neither the need for the periodic rise and fall of the water in the ditches, nor can brackish water be permitted within the gardens. This would be detrimental to the vegetable crop.

The first step in preparing the land for a vegetable garden is to dig parallel north and south ditches, about 1.5 meter wide at the top and about 1 meter deep, leaving a space of from 4 to 5 meters between ditches. The truck gardeners lay out these beds north and south in order that all of each bed may receive equally the morning and afternoon sunshine. The spoil from the ditches is placed on the land between them, making raised beds. These beds are given a crown, that is, a rounded cross section, to insure through surface drainage, even during heavy rains. Between the elevated portion and the ditch is a narrow pathway, about 1/3 meter wide. Some of the surface soil of this path may be removed and added to the bed proper. The entire garden is diked high enough toprevent flooding during the usual floods of the rainy season. When necessary a wooden pump (*rahat*) is used to pump water out of or into the garden ditches, so that a convenient water level is maintained in them for the daily or more frequent waterings.

Once the ditching is done, the large blocks of earth and deeper clay cut out with the T-handled fish-tail clay chisel (Prua hang yiao) are allowed to weather for sometime before the crop is planted. To facilitate the reduction of these clods to suitable tilth, in the absence of showers, the beds are repeatedly watered and allowed to dry. This helps to break down the clods, which are then worked with a hoe or a forked, two-tined hoe. The gardener must be satisfied with a relatively course, cloddy surface, for to get a fine tilth on this soil is almost impossible, particulary since much subsoil clay from the ditches is in the beds. After hoeing is finished a light mulch of rice straw is spread over the beds, and daily watering continues. Soon thereafter the vegetable seeds are broadcast or the young plants set out. The principal crops raised are Chinese cabbage, turnips, cucumbers, squash, string beans, peas, and corn.

When watering the beds the gardener uses a dipper or scoop on the end of a long, light bamboo pole. The dipper is used for such crops as cucumbers, which need to have only the soil at the base of the plant watered, while the scoop is used where there are many smaller plants or germinating seeds, and it is necessary to lightly sprinkle the entire surface of the bed. As the gardener waters the bed he walks along the path on the opposite side of the ditch, lightly scooping up the water and with a deft turn neatly and uniformly sprinkles that portion of the opposite bed which faces him. The other side of the bed is watered from the path on the far side of the ditch on the other side of the bed. Watering is often done twice daily, the gardener being busy at this task much of every day.

Manure is essential for the successful production of vegetables in these gardens. While farmyard manure from local dairy cattle is available near at hand for the asking, the truck gardeners will not use it, prefering to pay high prices for duck manure. This duck manure is not only rich in plant nutrients because of the large quantities of marine mollusks fed the birds, but it also contains considerable lime in the form of shell fragments. At times also wood ashes are mixed with the manure. Freedom from weed seeds is another of the advantages of duck manure. For leafy vegetables ammonium sulfate is used when obtainable.

In June, or shortly before the beginning of the rains, a row of padi plants is transplanted out into the water along each side of each ditch in these gardens. The plants are placed in interrupted rows, with spaces about a meter apart, so that when the rains are inadequate, watering can be done with the scoop, without too much interference from the padi plants. The padi grows luxuriantly and usually matures its crop in September. This intercropping conserves the extra plant food which may have been washed from the beds into the ditches.

Immediately the vegetable crop is off the land the surface decimeter or so of the beds is dug up and the clods allowed to dry out. To expose the soil to sun and air between each crop is an important feature of the management of these soils. After a shower or several waterings, the earth is dug over. With much labor the chunks of clay are somewhat broken up, the light mulch of straw spread, the watering continued, and in a few days the bed is sufficiently prepared for the planting out of the next crop. Only in the very dry season may the soil be allowed to remain idle for more than a few days between crops.

RIVER MEANDERING AND SOIL ALTERATION: Apart from its effects upon the micro-topography of the alluvial plain, river meandering has effected the character of the soil and the utilization of the land. Inasmuch as the soil relationships which have developed along the rivers are closely related to the development of pomelo gardens and to other special land uses, the effects and probable reasons for the differences are briefly stated. These relationships were first observed along the Tachin portion of the Supan river.

Meandering of rivers is a general phenomenun: the stream curves from side to side, making larger and larger curves until, as loops, they finally cut themselves off. The width of the meander plain, the width of the channel itself, the speed of the current and other factors affect the magnitude of the meandering. Here no attempt is made to consider these complicated phenomena.

Along the Tachin river the soil on the outside bank of the curved river chamel, the bank of the river which is being cut into by the current, may be perhaps a meter above the average level[1] of the water in the river. Because of the swifter current along the outside, here and there, the bank has caved off, exposing fresh soil profiles. These exposures show that the usual very dark gray clay surface horizon is about 1/3 to 1/2 meter deep. Under this is a light bluish gray horizon, often flamed or mottled with red. Deeper, below the usual water level, the flamed horizon gradually grades into a uniformly colored light bluish gray clay. In other words, this is a well developed profile of the Bangkok plain clay. Weathering of this soil has left but little plant food in the upper horizons. Because this soil is a heavy clay there is almost no water movement by capillarity thru it. Though this soil is only about 1/2 meter above the average water level in the river, annual crops and weeds soon show the effects of rainless periods, and before the dry season is far advanced, most plants, even though only a few meters from the water's edge, are suffering from drought. This higher, outside curve of the river is locally known as *Kang ḳung* or *din daeng* ("red soil").

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1. *"Average level" is used because nearness to the sea and effects of the tides hold the fluctuations of the water level to a narrow range.*

The opposite bank of the river, the inside of the meander curve, is known as *kang len*. It is lower, for the river is slowly abandoning this portion of its channel as it cuts farther on the opposite, the *kang kung* side of the channel. Being on the inside bank of the river the current is not nearly as rapid as in the center of the channel, and very much less than that which strikes the outside (*kang kung*) bank. Consequently along the inside of the curve the river is depositing sediment which had been carried in suspension in the water, or as bed load, from up the channel. In part, perhaps, this material was from far up the stream, and part from bank cutting of the outside curves in many places, including no doubt some material which caved into the stream on the curves just above. In the relatively quiet water in the inside of the curve, where the sediment gradually accumulates, aquatic grasses and such trees as *ton lampoo* (*Sonneratia sp.*) grow luxuriantly ; nipa palms do particulary well. This vegetation slows down the speed of the water still more, and so aids sedimentation. At first these *Kang len* deposits are below the normal water level, but with the continued growth of herbaceous vegetation and trees, the level of the deposits gradually increases until ultimately these inside curve lands are hardly more than $\frac{1}{2}$ meter lower than the *kang kung* land which had been carried away from the same spot as the river enlarged its meander. A good idea of the rapidity with which these deposits accumulate is given by the now silted up channels in the Tachin (lower Supan) river. These channels were abandoned much less than a century ago when man cut short channels across very large meander loops.

With the gradual lengthening of the channels as meanders grow and so increase channel length, the base level slope of the river is flattened. Then the meanders finally cut themselves off, suddenly shortening the channel by many kilometers, thus again altering the relationships of the various portions of the channel. These changes in channel length markedly affect the amount of salt water which ascends the channel during high tide. Shortening the channel length to thesea may necessitate a complete change in the cultivated crops, from one such as sugar cane which is sensitive to brackish water, to padi which is relatively indifferent. Thus a large area of sugar cane had to be abandoned along the lower Tachin when the above-mentioned cutoff channels were opened across two long meanders.

As a whole the vegetation on the inside curves of the river is noticeably more luxuriant than on the outside. Close to the sea, however, these differences between the two sides are not marked, for all the deposits are younger and more fertile, and the broader channels tend to silt up on both sides. Whereever the differences are marked, it is always the more fertile inside curve soil which is selected for citrus gardens, areca palms, and for other intensive garden uses. Fig. 7. Such gardens are located along those portions of the river where tides prevail; yet the surface water in the river is not often salty, nor even brackish much of the year. The first step in developing a garden is to securely dike the land to keep out the flood waters, particularly the spring tides. Along the outside of the boundary dike mangrove seedlings are planted closely, or sometimes nipa palms which make an excellent hedge. After clearing the land of wild growth, the broad beds (*rong*) are made by digging the deep and wide ditches and throwing up the soil between them. Bananas and sugar cane are often planted the first two years, with maize a common alternative crop. At the end of two years the bananas along the centers of the beds are removed and the young citrus planted.

It is believed that the cutting away of the old weathered soil on the outside of the curves, the carrying away in suspension of the very finest portions of the clay which are presumably the most weathered and so the least fertile part of the soil, and the redeposition of the less fine and perhaps less completely weathered portions to build the inside-curve soil are at least some of the reasons for the greater fertility of these soils. Another factor is that during high tides the heavier salt water ascends up the bed of the river considerable distances, flowing under the lighter fresh surface water.

Salt from this sea water undoubtedly saturates the clay in suspension and accumulating on the river bed, forming aggregates of clay containing considerable quantities of such absorbed ions as calcium, potassium, magnesium and sodium. Such aggregate particles, being of larger size are, when carried by the currents, still more apt to settle out on the inside of the curve. Such altered soil may also be less impervious to water.

Probably another factor contributing to the fertility of these soils is that they are within the range of daily tidal fluctuations. While these gardens are diked and provided with automatic tide gates, there is considerable leakage thru them and thru the dikes, so that as the tide rises and falls in the river outside, the water in the ditches between the garden beds also rises and falls, though not with as great a range. Fig. 7. This variation in level is believed to beneficially aerate the heavy clay soil on the ditch banks, where are many of the fruit tree roots. The river water entering the garden also brings with it silt in suspension, and much of this settles out in the ditches. This sediment mixes with the soil washed off the high and steepsided beds on which the trees are growing, and with the decayed remains of tree leaves and other organic matter in the ditches. Once a year, in the dry season, the ditches are cleaned out; the rich mud scooped is spread uniformly on the beds.

There is a general belief that slightly brackish water is beneficial for pomelo (***som oh***) trees. In fact, once a year progressive horticulturists in this region scatter about 50 grams of sea salt about each tree. It is evident that there is some considerable beneficial effect from one or more of these factors, for where there is tidal change the fruit trees are in better condition and growing more vigorously: much better than where the fruit gardens are along canals inside locks which exclude tidal fluctuations and the water in the garden ditches is clear and stagnant, rather than brackish and muddy.[1]

1. *Otto Reinking and G. Weidman Groff have well described and figured the horticultural practices employed in these gardens, the types of pomelos, and the diseases and pests. Philippine Journal of Science 1920. Also: G. Weidman Groff in the Lingnan Science Journal. 1927.*

LATERAL DELTAS OF THE CENTRAL PLAIN: It is not usually realized that these soils are, in part, quite different from each other and from those of the Menam Chao Phya plain proper. The older, slightly higher deposits of the Chao Phya itself are between Chainat and Supanburi. Though distinctly better soils than the sandy pale lixivium soils all too common on the lower footslopes of the surrounding mountains, because they are above the usual flood levels of the rivers, they have not been used extensively for crop production.[1]

Chainat—Supan river region: Particularly along the left bank of the Menam Chao Phya below the Chainat market are considerable bodies of light brown to brown or grayish brown silt loam. These soils seem to remain hard and rather bare for years. When planted, they are used for upland crops, because seldom flooded, they are not suitable for padi. When they are flooded, violent changes in water level, from water coming in from the hills to the north, are destructive.

On the left bank of the Supan river, and between it and the Menam Noi is an extensive area of similar light grayish brown soils which extends south nearly to Supanburi. These soils are less jeopardized by sudden flooding, but for the most part have not been used for crop production because of the lack of any certain supply of irrigation water. The Chainat barrage scheme will make good this difficiency.

Pasak—Nonkae region: These soils begin above Saraburi and extend out southwesterly nearly to Ayutia, and southwards to beyond Nonkae township. The soils are light brown to light grayish brown light silty clay loams to light clay loam. The subsoils are

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1. *It is supposed that these older, higher soils were for the most part deposited as separate deltas when the sea level was perhaps 5 or 10 meters higher than at present.*

heavier and sometimes have numerous small iron concretions. The soil materials have not been in place long enough to have been excessively leached by the heavier rainfall in that part of the plain. Natural levees are not conspicous along the Pasak river. Where well drained these lands have great numbers of large termite mounds.[1] But the mounds on these soils are not as important for special crops as they are in regions of very poor sandy soils, such as the Korat region.

Nakorn Nayok River: The alluvial materials deposited by this river are wider in textural range, but of only minor importance in the soils of the Plain. Sands are abundant along some of the channels, but most of the sediment is fine and had not developed any great body of better soils—in fact, there has not been enough sediment to prevent the development of the very poor soils in the Ongkarak–Dhahup–Yotoka region. Fig. 5.

The immediate river banks have well developed natural levees with brownish silt loam to loams. These soils sustain good growths of fruit and shade trees, and are utilized in the customary ways for farmsteads and gardens.

Klong Talat: Klong Talat is a small river which rises in the hills and mountains to the southeast of the Prachin plain ; and pours its silt laiden water into the Prachin river during the rainy season. Since this Prachin plain as a whole is of heavy, dark clays, the Klong Talat river sediments contrast strongly---they are light gray light clay loams or silt loams. The subsoil is a light bluish gray light clay loam flamed with red. These lighter colored, less heavy, and less fertile soils are from sediments which Klong Talat had carried out from the sandy laterite and other senile soils which occupy the

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1. *Pendleton, Robert L. 1941. Some results of termite activity in Thailand soils. Thai Science Bulletin 3, 29–52. Figs. 12.*

thinly forested region between the Prachin plain and the higher peaks farther to the southeast.

The old deposits of the Klong Talat being low in plant nutrients, therefore less fertile, and topographically slightly higher and hence less well watered, have given rise to soils not suited to padi. Instead, they are largely planted to mangoes and other fruits, palmyra palms, and pineapples. Extensive plots have been ridged into high, flat topped beds on which pineapples are planted. Fig. 2. Farther up the river, at Panom Sarakam, where irrigation is possible, the padis are a dirty white to light bluish gray silty clay loam. The padi here is transplanted.

Farther down the left bank plain of the Prachin, beyond more of the heavy dark clays, the road to Ban Dong and Chonburi crosses slightly undulating land. The lowerportions of this land are occupied by padis, while on the higher portions, with inadequate water, ***sakae*** trees are common. On this higher land the soil is shallow, with thin horizons. Farther on these poor soil differences become more pronouced and it is clear that these light colored fine silicious silt and clay soils have developed on outwash materials from another portion of the light colored lixivia on the slopes to the southeast. The whitish gray very silty unproductive padi soils just north of Bandom village are an extreme sort.

Nakorn Patom—kampangsaen region: Between Wankanai on the west and the Supan river on the east, and extending north from Nakorn Patom for many kilometers is a region with slightly higher elevations of grayish brown to light brown medium textured soils, between which are meandering depressions which were originally river channels. The lower lands and old channels are mostly light bluish gray and light brown clay loam. This region is a former delta of the Maeklong river. Intensive cultivation of ***ya daeng***, a special type of smoking tobacco, is done by Chinese on the higher, browner soils.

Maeklong Delta: Along the Maeklong from Ban Nok Kwaek to the sea is a region of fertile alluvial soils which have been intensively developed for the production of coconut, coco sugar, areca nuts, mangoes and other fruits, and betel leaves. The channel of this part of the river has somewhat more grade and higher banks than any other river coming into this plain. Consequently this river meanders less, so that there is a relatively insignificant development of *ḳang len* and contrasting *ḳang ḳung* soils and land utilization.

East of Ban Nok Kwaek is the well known *Bang Chang* truck gardening district. It is estimated to comprise about 125,000 acres (300,000 rai). The development of this garden area commenced after the main canal connecting with Bangkok was completed. The canal and its locks kept salt water out and helped hold fresh water on the land.

The methods of market gardening used in this region are distinct from those used in the environs of Bangkok. Annually the entire Bang Chang countryside floods deeply, completely submerging even the high, flat-topped beds. Fig, 1. This flooding is considered important, for it insures extermination of small ants and other serious pests, No provision need be made for draining off excess rain water from the tops of the beds, because after beginning of planting there is little or no liklihood of rain. Hence the tops of the beds are quite flat, thus giving greater planting area. As soon as the tops of the beds are exposed by the receeding flood, the black clay soil is dug up. The clods are left lying loosely. Then as rapidly as possible the surface is worked up into a suitable tilth. Meanwhile in each of thousands of shallow trays made of bits of banana leaf, 3 watermelon seeds have been planted in a handful of a mixture of bat guano or duck manure and soil. By the time the melons are ready to set out in the beds, the land is ready for them. The planting distance is about a meter each way. Soon thereafter red pepper (capsicum) plants and onions are also planted out into the same beds. They are planted in such a chronological order and with such a spacing that while all three crops grow together, they mature and are harvested at different times. After the first two years that the beds are planted, these crops are fertilized with ammonium sulfate. Duck manure and bat guano are also used in quantity.

No portion of the raised beds is used for paths. Instead, the laborers who water the plants walk in the ditch. Later in the season 3 or 4 rows of hot season padi may be planted in the ditches.

In May or June, after the last of the peppers are off the land, the beds are dug deeply and allowed to lie exposed to the hot sunshine for a time. If there is still some time before the floods, a second crop of onions may be planted after the peppers. In any case, the land is left dug up in big, loose clods. This is said to insure a looser soil for the main crop following the floods.

LATERITE SOILS AND LATERITE: As has been implied, the beginnings of the development of a laterite horizon in the subsoil of the Ongkarak clay are clearly discernable. In this soil, with the extremely slow movement of water through the clay, and the limited total amounts of iron compounds which would likely accumulate to form a laterite hardpan, the process proceeds extremely slowly. By contrast, along the highway a few kilometers south of Saraburi, as near the airstrip, a very different and much less common type of laterite development may be noted. Here are some low hills of dark igneous rock which are weathering, liberating relatively large quantities of soluble iron compounds. During the rainy seasons, as the water seeps down through the weathering rocks the ferrous compounds are carried out laterally toward the surface, down the gentle slopes and into the soils of the plain surrounding these hills. Here with exposure to the oxygen in the soil air the ferrous compounds oxidize into ferric ones, which precipitate in the soil close to the surface. This process has resulted in a considerable formation of laterite in soils which themselves have not yet reached the senile or final stage in the weathering or soil developmental process. Normally in the development of a laterite soil (a soil with a laterite horizon) unless there have been modifying or ameliorating circumstances, or some rejuvenating process has come into play, a soil with a laterite hardpan in it is senile and quite infertile--practically useless for crop production. Since the nature and manner of formation of laterite soils has elsewhere[1] been described at some length, the subject will not be considered further here.

As has seen mentioned, outside of the Bangkok plain proper and the related river deposits from the lateral rivers are great expanses of poor sandy laterite soils on which a thin open dwarfish forest (*pa pae*) is conspicucus. This forest furnishes pasture and minor forest products for farmers of the Bangkok plain.

Southwest of Nakorn Nayok is Dong Lakorn, a low flat-topped hill covered with orchards and fruit gardens. On the plateau the soil is a light pinkish brown fine sandy loam about $\frac{1}{2}$ meter deep. The subsoil down to 1 meter is a light brown heavy sandy loam. The old moat nearby reveals that below this soil is a laterite horizon about 2 meters thick. This soil is similar to the extensive bodies of infertile laterite south and southeast of the Prachin river portion of the Bangkok plain. In this case the moderate fertility is probably the result of long habitation as a village site and the accumulation of manure from cattle coralled on this elevation at nights and

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1. *Pendleton, Robert L. 1936. On the use of the term laterite. American Soil Survey Association. Bulletin 17, 102–108.*
Pendleton, Robert L. 1941. Laterite and its uses as a structural material in Thailand and Cambodia. The Geographical Review 31, 177–202. Map. 62 illustrations.
Pendleton, Robert L. 1942. Laterite or sila laeng, a pecular soil formation. Thai Science Bulletin 3, 61–77. plates 24.
Pendleton, Robert L. and Sangar Sharasuvana, 1942. Analyses and profile notes of some laterite soils and soils with iron concretions of Thailand. Soil Science 54, 1–26. Fig. 8.
Pendleton, Robert L. and Sangar Sharasuvana. (in press). Analyses of some Siamese laterites.

especially during the rainy seasons. A few kilometers north of Prachinburi is Dong Praram, another flat-topped hill. The original surface soil has evidently been eroded off, leaving a reddish brown gravelly (concretionary) loam. The laterite horizon is visible on the slopes. It will be noted that these hills with laterite in the profile are both in that part of the Bangkok plain which has the heaviest rainfall, thus the most pronounced soil development. They appear to be relics of a former laterite plain which was at the level of the tops of these hills, and occupied the whole region, the rest of the formation having been carried away by stream erosion.

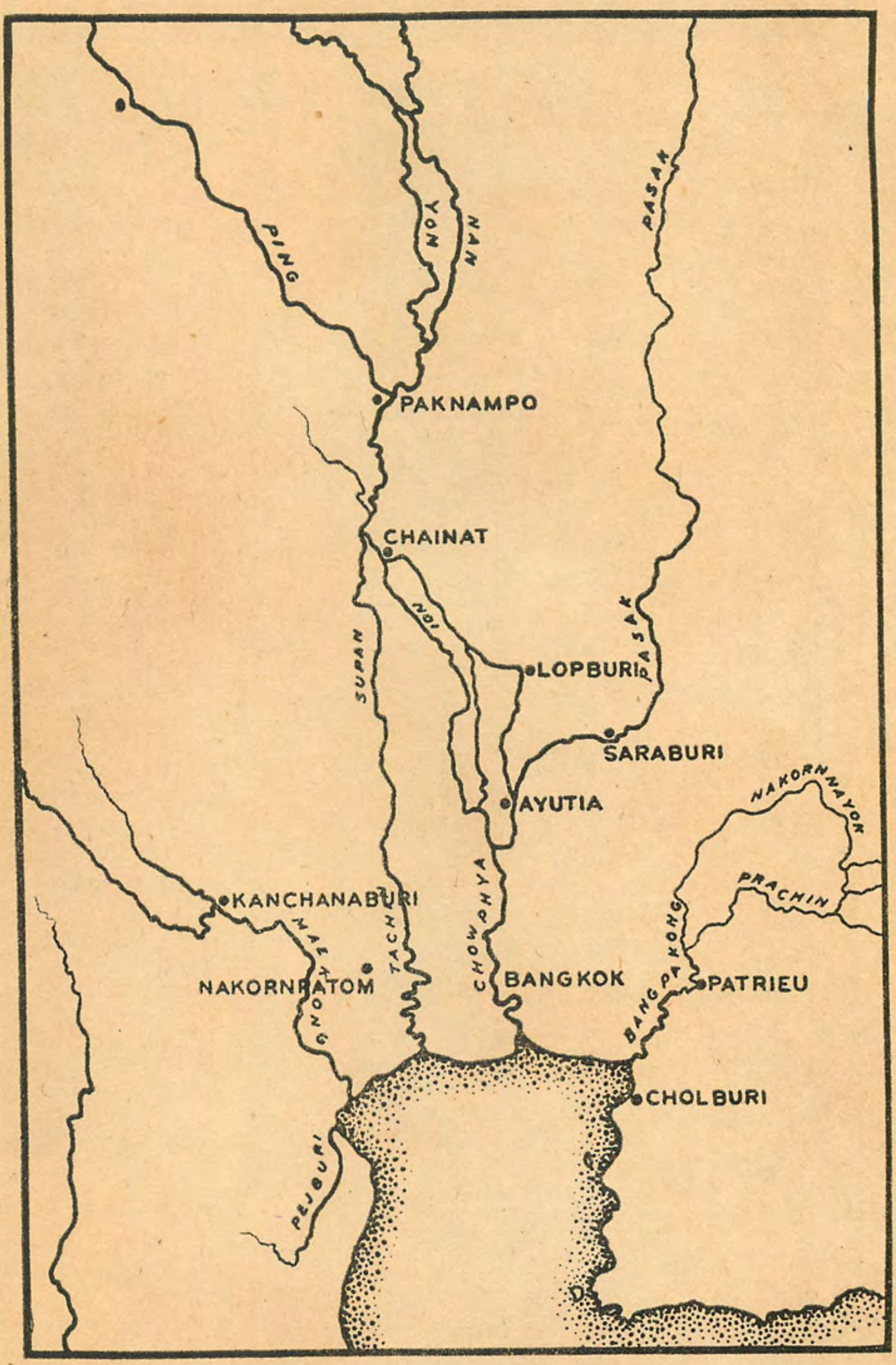
SUMMARY AND CONCLUSIONS: The soils of the Bangkok plain exemplify many stages in the development of laterite from riverborne alluvium. Some stages are : marine clays, young clays producing good padi, mature less fertile clays, senile unproductive soils, and laterite.

The rejuvenating effects of river action, of salt water, and of riverborne "silt" on mature and senile soils are evident.

Except on silts recently deposited from the rivers, padi (rice) is the only crop which can be grown on these soils.

Bangkok has long been a large consuming center and until recently, transportation from regions with soils naturally adapted to year round production of fruits and vegetables, was not practicable. Therefore Chinese methods of diking, draining, and ridging have been extensively used at Bangkok to adapt these heavy wet clays for the production of fruits and vegetables.

Robert L. Pendleton.
25. May 46.



The Bangkok Plain

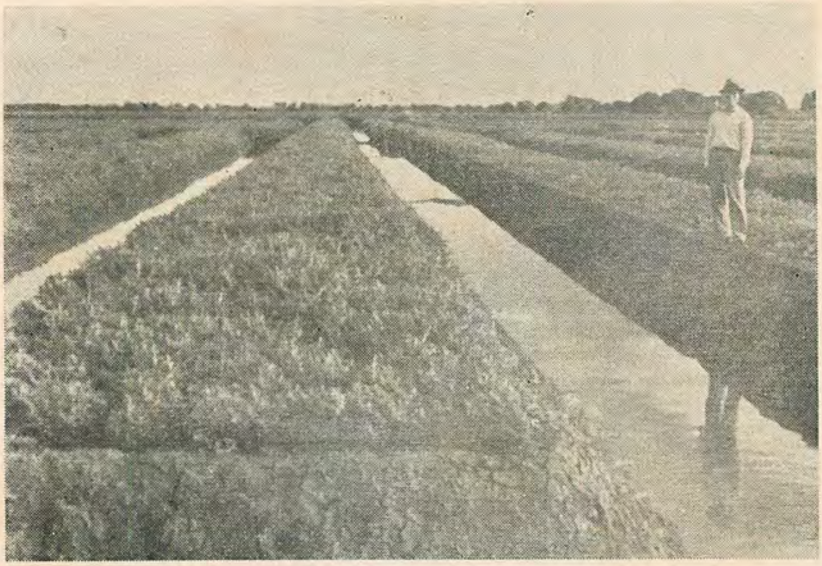


Fig. 1 Flat topped *rong* of Bang Chang clay planted to water melons. Later in the season onions and peppers will be interplanted, to mature after the melons have been harvested. Damnern Saduak township, Rajburi Province. Nov. 1940 - Foto 1289 - 8

Fig. 2 Pineapples growing on broad, flat topped *rong* in Bang Kla township, east of the Prachin River. Shajeungzao Province. Jan. 1938 - Foto 922 - 1

Fig. 3 Looking Southwest across the Menam Chao Phaya in Pratumtani. Padis. Inside Curve (*Kang len*) used for gardens. Note the natural levees along the banks of the river and distributory streams. May 1940 - Foto 1243 - 7

Fig. 4 Floods from the Maeklong River deposited a meter of light coloured silts burying the black clay on the plain, then some distance from the river channal. Later the river shifted its course, cutting deep thru the silt deposits and the buried clay soil beneath. The former surface soil is now clearly visible as a dark band in the bank of the river. Beyond the padi plain are bamboo clumps and palmyra palms about a village. Rajburi Province. Nov-

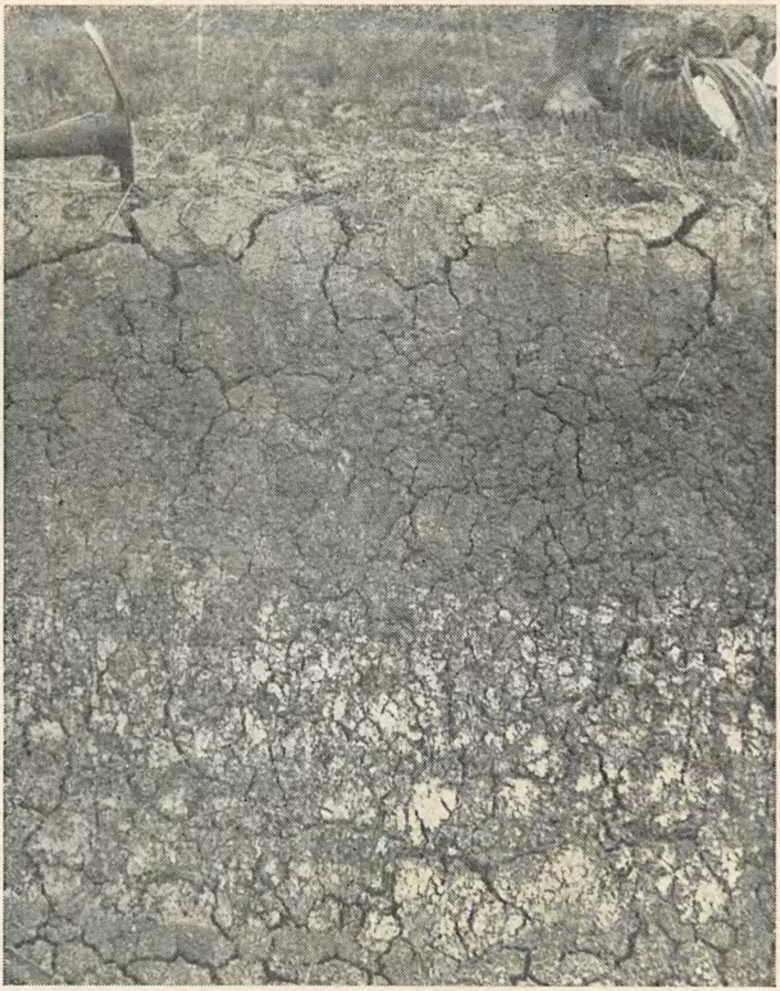


Fig. 5 A recently excavated canal thru Ongkarak clay shows the shallow gray surface soil, below which is dark gray clay ; with increasing depth there are red splotches, then whitish portions, and deepest some yellow streaks. Southwest of Dawn Lakorn, Nakorn Nayok Province. January. 1937 – Foto 775 – 11.

Fig. 6 On the temple grounds along the Chao Phya River are still preserved a few of the magnificent *yang* (*Dipterocarpus alatus*) trees which thrive on these natural levee soils. Pratumtani Province, above Bangkok, during high water season. Oct. 1937 - Foto 832 - 10.

Fig. 7 Pomelo (*som oh, khao puang*) orchard on *rong* formed from *kang len* soil. In the distance areca palms mark the back boundary of this garden. The tide in the river was low when this photo was taken. Sampran township, Nakorn

Fig. 8 Looking N.
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- Foto 1254 - 1

Fig. 9 Looking N. E. along Klong Tanon, an artificially excavated channel without pronounced soil alteration other than spoil banks. Transplanted padi fields & separate farmsteads surrounded by thorny bamboo. Dhanyaburi province. May 1940 –

Fig. 10 North bank of an east - west channel of the Menam Noi. No natural levee -- no trees. Rachakam township, Ayuthia. cf. Fig.- 11 November 1940 - Foto 1275 - 5

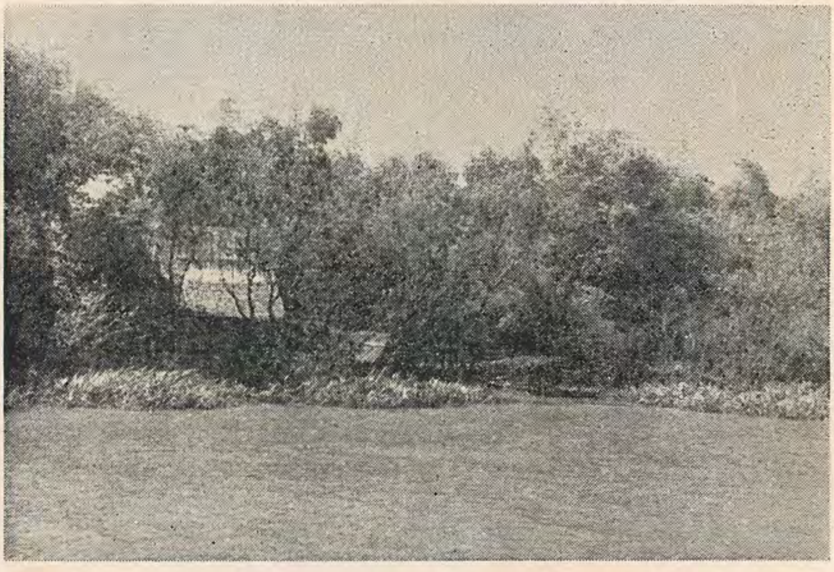

Fig. 11 South bank of an east - west channel of the Menam Noi, opposite from Fig. 10. Well developed natural levee carrying a good growth of trees. Nov. 1940 - Foto 1275 - 6