Landform Development and Related Changes in the Chi River Basin, Northeast Thailand

著者	TAMURA Toshikazu
雑誌名	The science reports of the Tohoku University. 7th series, Geography
巻	42
号	2
ページ	107-127
発行年	1992-12
URL	http://hdl.handle.net/10097/45198

Landform Development and Related Environmental Changes in the Chi River Basin, Northeast Thailand

Toshikazu TAMURA

Abstract Based on field evidence, granulometry, and radiocarbon and fission track dates, this paper presents an idea of landform development of the gently-undulating area in central Northeast Thailand. Special attention has been paid to the fluvial, colluvial, and eolian deposits and laterites which form low hills, gentle slopes surrounding them, and floodplains. The results have been interpreted in terms of changing climatic and tectonic environment of a part of tropical inland Southeast Asia in Quaternary time. Suggested paleoenvironments are higher rainfall and/or more active tectonic movement in the early Pleistocene (and probably the late Tertiary also), increasing seasonal contrast in climate since the mid-Pleistocene, and alternating dry and wet climate in the late Pleistocene and the Holocene with humidification in the latter time.

Key words: Quaternary, environmental changes, landforms, terrestrial deposits, laterites, Thailand

1 Introduction

Northeast Thailand provides an area of contrasting dry and wet tropical climate which is expected to have changed in response to the vicissitude of the summer monsoon in Quaternary time. Situated in an inland part of the Indochina Peninsula which faces on shallow South China Sea, climatic change in the area seems to have been affected by extensive emergence and submergence of the continental margin due to the sea-level fluctuation. Although it is regarded as a relatively stable land mass, influence of tectonic activity in surrounding zones which connect the Himalayas and the Sunda Arc should not be ignored. Based on field observation and some laboratory analyses including radiocarbon and fission track dating, this paper discusses the morphogenetic history which is indicative of the changes in climatic and tectonic environment in the central part of Northeast Thailand in Quaternary time.

2 Regional setting and previous views of landform development

Northeast Thailand, which is sometimes called the Khorat Plateau, consists

THE SCIENCE REPORTS OF THE TOHOKU UNIVERSITY, 7TH SERIES (GEOGRAPHY)
Vol. 42 No. 2, December, 1992. 107-127.

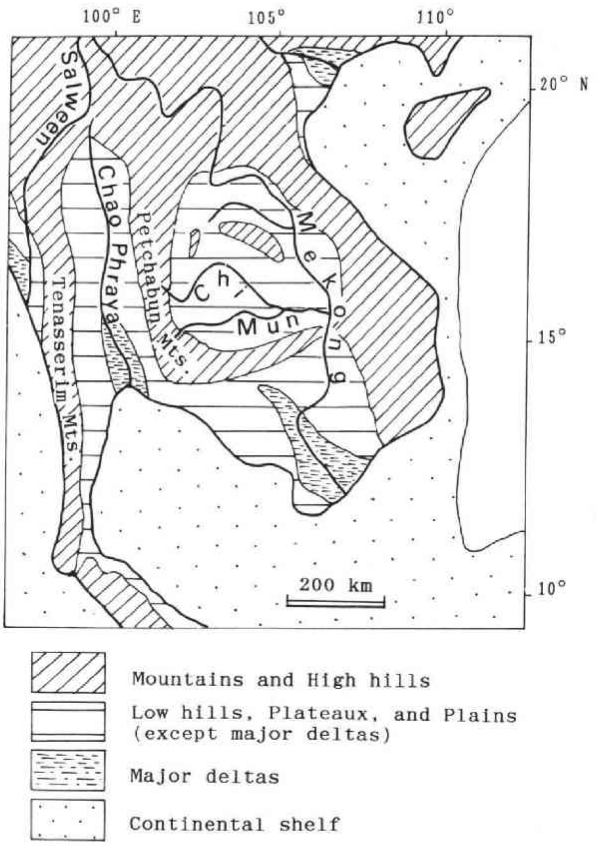


Fig. 1 A map of the investigation area (the Chi River basin in Northeast Thailand) and its surroundings.

predominantly of gently-sloping to undulating terrain ranging in altitude of 120 to 250 m, which is drained by three major and some small rivers to the Mekong. The terrain is underlain by sedimentary rocks of mostly Mesozoic age named the Khorat Group. The Khorat Group forms two structural basins, called the Sakon Nakhon Basin in the north and the Khorat Basin in the central and south, which were differentiated from a basin in late Cretaceous or probably early Paleogene Tertiary time (Piyasin 1985). The Sakon Nakhon basin extends structurally to the opposite side of the Mekong, the Laotian territory (Figs. 1 and 2). Mountain ranges which fringe and separate the basins are considered to have uplifted since at least late Mesozoic time. Influenced strongly by the condition of drying up of the lakes which were situated in the two basins in late Cretaceous or probably Paleogene Tertiary time, the Mahasarakham Formation, the uppermost member of the Khorat Group, contains rock salt strata and

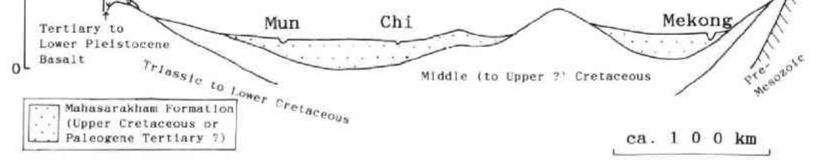


Fig. 2 A simplified geological cross-section of Northeast Thailand. (Surface deposits are omitted.)

salt-affected sediments (*e.g.*, Geological Survey Division 1983 ; Piyasin 1985).

The Chi River flows eastward through the northern part of the Khorat Basin and meets the Mun River which drains the southern part of the same structural basin. Although the Chi River basin receives annual rainfall ranging from 1,000 to 1,600 mm except its source area in the Petchabun Mountains which receives more, it is subjected to a long dry season amounting to seven months.

Several fundamental ideas of landform development of Northeast Thailand have been presented in connection with the interpretation of soil formation. For example, Pendleton and Montrakun. (1960) suggested that most soil series in low relief zones, except floodplains, of the area were of residual origin. It means that denudational landsurfaces are predominant. Contrary to this, Moormann *et al.* (1964) presented the "river terrace" model or the "old alluvium" model, in which they interpreted that almost the all soils of the area were developed from fluvial terrace deposits of various ages and that the differences in soil properties were due to the age of terrace as well as relief and parent material condition. Although it was a notable idea from the viewpoint of historical geomorphology, many discrepant facts from the Moormann's model were observed in various places. Based on cooperative works with the staff members of the Land Development Department in the undulating zone around Nakhon Ratchasima, western part of the Mun River basin, Michael (1981) considered that soil parent material was frequently provided by local alluvio-colluvial processes from adjacent bedrock outcrops. It means that he recognized neither overall residuum nor long-distance transported deposits as major parent material of the soils in the area. The above three ideas are diagrammatically illustrated in Fig. 3.

A kind of compromise between the "old alluvium" model and the "local alluvio-colluvium" model was presented by Ceruse (1983) in the explanation of the geomorphological map prepared by the use of Landsat imagery. He indicates extensive planation surfaces not only on the high hills surrounding the Khorat and the Sakon Nakhon Basins but also in the inner part of the Khorat Basin. Moreover the map shows the high and low terraces as well as the intermediate formations including the middle fluvial terraces and the thick sand formations. The high terraces in Ceruse (1983) seems roughly to correspond to some parts of the high terrace designated by Moormann *et al.* (1964). In the other geomorphological map prepared by the use of Landsat imagery, Pramojanee and Panichapong (1984) stressed the relation between relief features and rock types/geological structures.

Stratigraphic works made in 1970's and 80's on the Quaternary deposits in Northeast Thailand have been reviewed by Boonsener (1985), Wongsomsak (1987), Udomchoke (1989), Tamura (1992), *etc*. Among the deposits revealed in the works, the red and yellow fine-textured soil which covered laterized or unlaterized upland ground-surface was considered loess by Boonsener and Tessanasorn (1982), Udomchoke (1989), *etc*., contrary to the concept of local alluvio-colluvium proposed by Michael (1981). The former view supports the idea of aridity in the Last Glacial Maximum (*e.g.*, Sonsuk and Hastings, 1984; Nutalaya *et al*., 1987).

Löffler *et al.* (1984), observing boring core samples and interpreting electric prospecting records, recognized the organic sandy deposits which fill a valley more

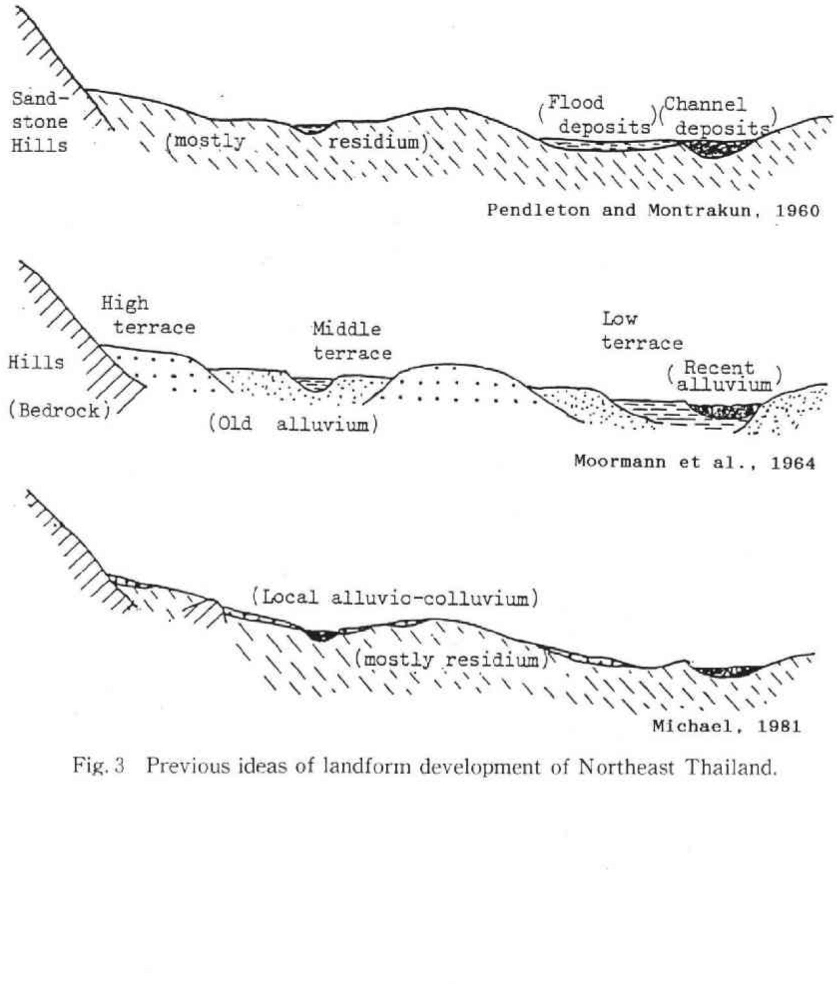


Fig. 3 Previous ideas of landform development of Northeast Thailand.

than 100 m deep below the present floodplain in Tung Kura Ronghai in the lower Mun River basin. The valley-fill deposits are overlain by non-organic eolian deposits. Referring to the radiocarbon dates of the deposits, Löffler *et al.* (1984) discussed that the humid environment which lasted up to some stage in late Pleistocene time were replaced by the arid one in the Last Glacial Maximum and also indicated the dry cool condition in latest Pleistocene time which enabled windblown redistribution of former river-bed sand around the lower Chi-Mun. Based on the interpretation of Landsat TM imagery, Hokjaroen and Parry (1989) considered that the sand was deposited along the former channels of the Mekong which ran across both the Sakon Nakhon and Khorat Basins and were later abandoned due to breaching out of salt domes midway. Corrosion and collapse of salt domes, which had been developed in the Mahasarakham Formation, attracted more attention by Furukawa and Wichaidit (1989) as a principal factor of landform development in Northeast Thailand.

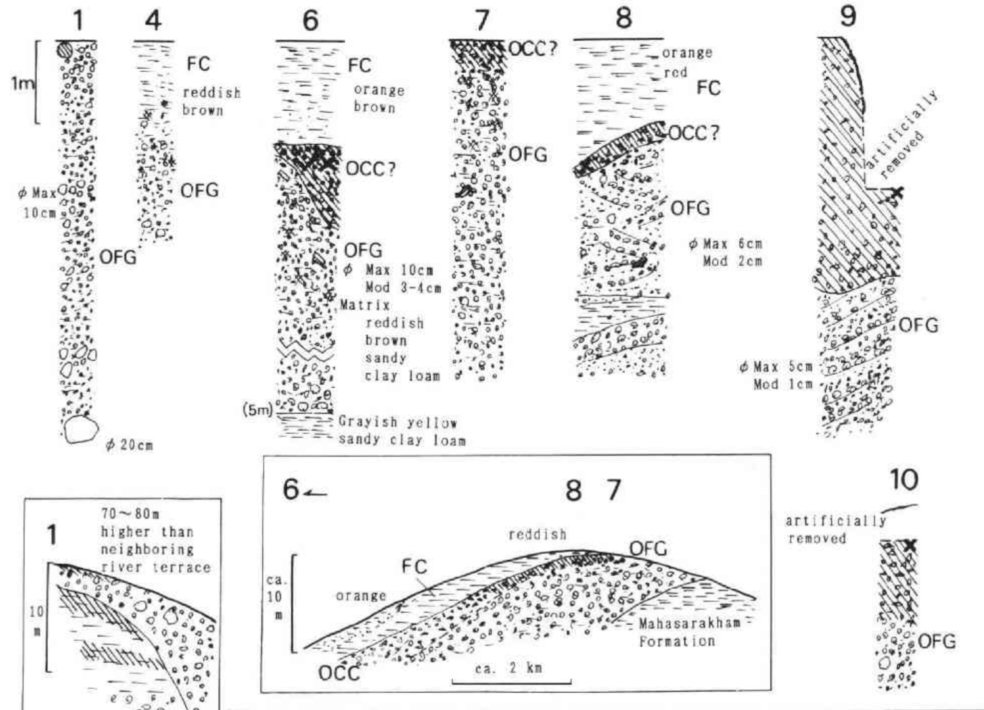
Although some eolian sand deposits which sometimes form rises on alluvial lowlands were reported by Boonsener and Tessanasorn (1982) *etc*., Pramojanee *et al.* (1985) demonstrated that the deposits are hardly discernible in their grain-size distribution characteristics from both river-bed deposits and weathering products of the Mahasarakham Formation. In addition, Furukawa and Wichaidit (1989) and Nutalaya *et al.* (1989) showed that some sand rises were made by man in the process of salt making from saline groundwater arisen from the Mahasarakham Formation. Udomchoke (1989) added some information of warm and humid climate in early and mid-Holocene time and somewhat drier condition since ca. 3,500 yr B.P.

3 Stratigraphic arrangement of surface deposits and weathering products

Although Northeast Thailand consists fundamentally of denudational terrain contrary to the view of Moormann *et al.* (1964), a considerable area in it is covered by several types of surface deposits and weathering products. Tamura (1986) recognized the followng five stratigraphic units, which include both sedimentary layers and weathering zones, in the Chi River basin: the Old Fluvial Gravels, the Gravelly Slope Deposits, the Laterites, the Fine Colluvium, and the Young Valley Fill. The subsequent observation leads to the subdivision of the Gravelly Slope Deposits to the Older Coarse Colluvium and the Younger Coarse Colluvium. Characteristics of the units and related landforms will be described below.

3.1. The Old Fluvial Gravels (OFG)

This unit is composed of well-rounded or subround weathered gravel underlain unconformably by the Mahasarakham Formation and older rocks (Fig. 4). Forming summit surfaces of low hill ranges several tens of meters to 100 m higher than the



Loc. 6 Ban Fang	Loc. 8 Khon Kaen Univ.	Loc. 9 Ban Non Chai
16° 27' 50" N	16° 28' 50" N	16° 22' 50" N
102° 37' 50" E	102° 49' 55" E	102° 51' 27" E
0.62± 0.17 Ma	**0.67± 0.10 Ma**	**0.70± 0.13 Ma**

Fig. 4 Selected geological profiles of the Old Fluvial Gravels, the Old Coarse Colluvium, and the Laterites with fission track dates of tektites contained. (continued) (The locations are shown in Fig. 5.)

present floodplain, it is intermittently distributed along the Chi River, particularly on its left bank, from the foot of the Petchabun Mountains to its confluence to the Mun and further lower (Figs. 5 and 6). Size of gravel decreases from 10-20 cm in Loc. 1, about 30 km west of Chaiyaphum along the upper reach, to 1 cm in Locs. 23 and 24, between Roi Et and Yasothon before the confluence with the Mun, and in Loc. 25 near the Mun-Mekong junction. The upper part of the gravels is frequently appeared to be laterized.

One of the typical profiles of the Old Fluvial Gravels is found around Moh Ding Daen in the north of Khon Kaen (Locs. 7 to 10). The occurrence of OFG in the area to the west of Moh Ding Daen indicates that their basal surface slopes down to south (Locs. 7 and 8). This unit is almost correlated to the high terrace deposits designated

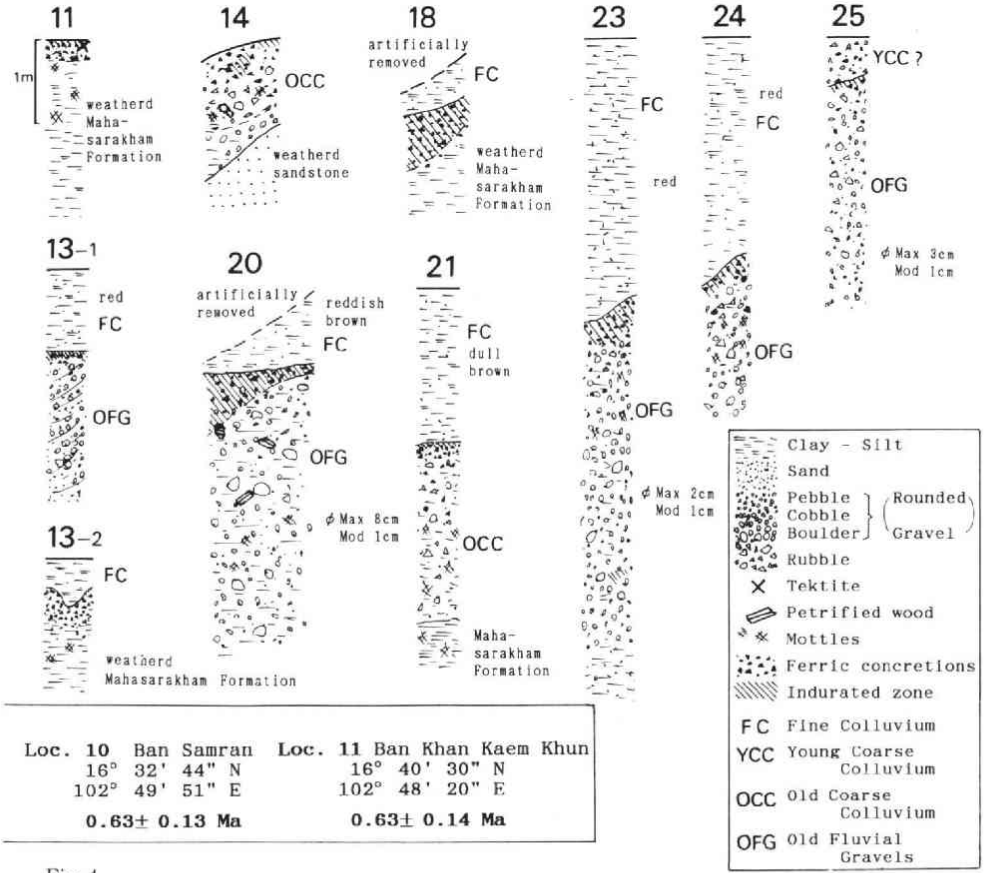


Fig. 4

by Moormann *et al.* (1964), the younger subunit of the gravel bed by Udomchoke (1989), and their corespondents. As suggested in Michael (1981), some staff members of the Land Development Department interpret that the gravelly deposits of resembling appearance to OFG were transported from adjacent exposures of conglomeratic rocks of the Khorat Group. Although the redeposited gravel is surely found, for example, in the south of Nakhon Ratchasima in the Mun River basin, most of the deposits recognized as OFG in this paper indicate somewhat long transportation by river. It should be remarked in this connection that the present Chi River and its tributaries hardly transport gravel except in their mountainous segments. Those facts suggest more powerful fluvial action of the days represented by the Old Fluvial Gravels than that of present.

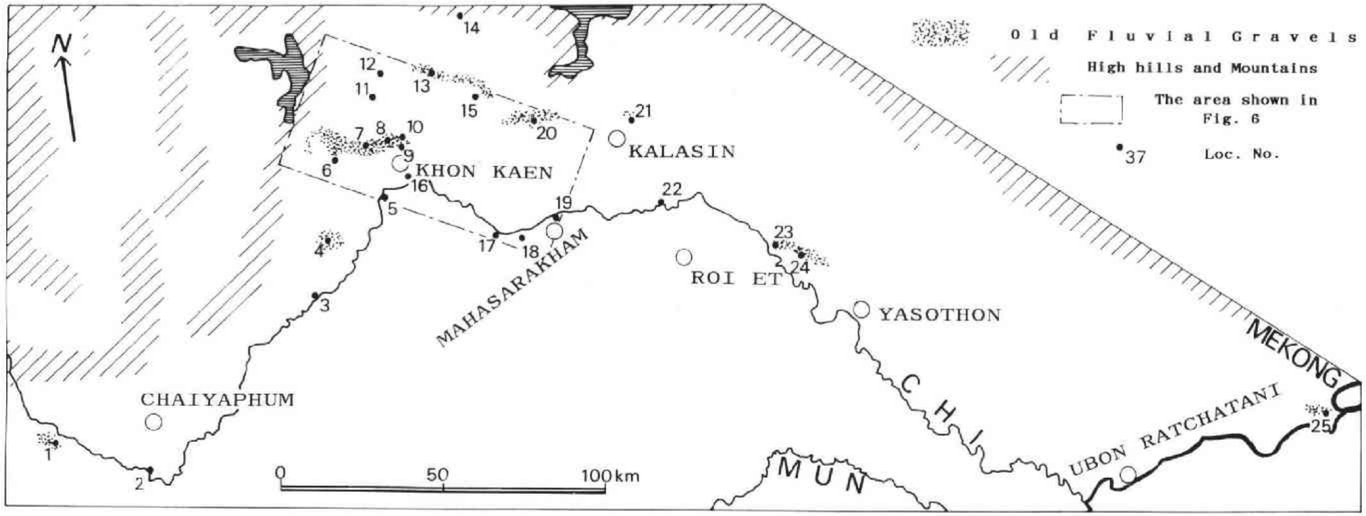


Fig. 5 Confirmed distribution of the Old Fluvial Gravels in and around the Chi River basin.

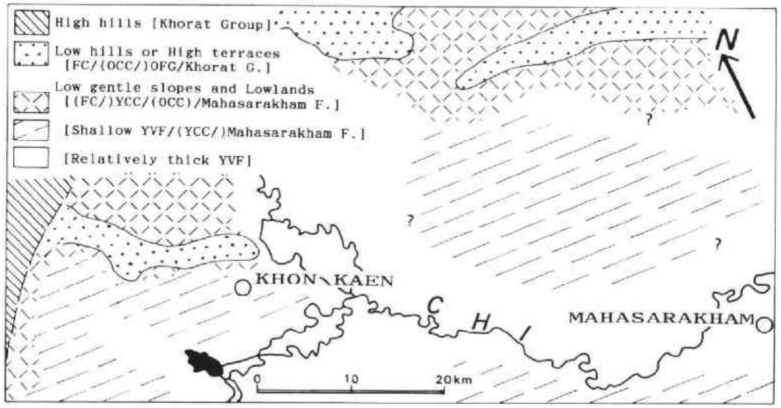


Fig. 6 A simplified geomorphological/Quaternary geological map around Khon Kaen. (OCC and/or OFG are frequently capped with the Laterites. See the text for the abbreviations of deposits.)

3.2. The Old Coarse Colluvium (OCC)

This unit provides a relatively thin layer of angular to subround gravel in various topographic locations. In some places on the upper part of the low hills composed of OFG, the Old Coarse Colluvium seems to have been derived from the Old Fluvial Gravel and slightly moved downslope. On some other hillslopes OCC directly covers the Mahasarakham Formation and older rocks unconformably. The OCC is more or less laterized frequently on its top (Fig. 4). Although no previous paper has explicitly mentioned the unit, some pseudofluvial gravel beds derived from conglomeratic bed rocks, to which were refered in the above section, may be correlated to it. The OCC indicates occurrence of some types of mass-movement after the deposition of OFG.

3.3. The Laterites

This unit is frequently developed on OFG or coexisting with OCC irrespective of its morphological differences, *e.g.*, pisolitic iron concretion, loose gravelly laterite, and hard sheet laterite. In the case that this unit is found in the uppermost part of clayey weathering zone of bedrock, however, it rarely takes the form of sheet laterite (Fig. 4). Plinthites which are frequently developed on bedrocks are expediently excluded from the Laterites in this paper. The Laterites contain tektites in their upper horizon in some places.

Although it has been widely accepted that the laterites were developed by the concentration of iron derived from the underlying mottled and pallid zones, Mitsuchi *et al.* (1989) have presented an alternative idea of laterite formation on the basis that content of free iron oxides in the mottled and pallid zones of some Northeast Thailand weathering profiles is as high as or even slightly higher than that in the underlying sapprolite zone and bedrock. In the idea, the laterites developed by the following two stages: (1) the in-situ segregation of iron which took place in the surface zone of groundwater fluctuation, underlain by permanently-saturated zone, (2) the mass-movement of the surface layer and/or selective removal of finer soil matrix, and resultant concentration of pisolitic iron concretion or loose gravelly laterite, which developed to sheet laterite in places.

The frequent occurrence of the Laterites in the upper part of OCC indicates that the second stage of laterite formation mentioned above took place almost in concurrence with the deposition of OCC. It seems to be the results of a kind of weak mass-movements or of removal of fine soil matrix only. The age of the phenomena's occurrence can be discussed on the basis of dating of tektites contained in the upper part of the Laterites in some places. The Laterites developed on the weathered bedrock are considered to have been formed simultaneously because they also contain tektites (*e.g.*, Loc. 11 in Fig. 4).

Fission track dates ranging from 0.62 to 0.70 Ma have been obtained from five

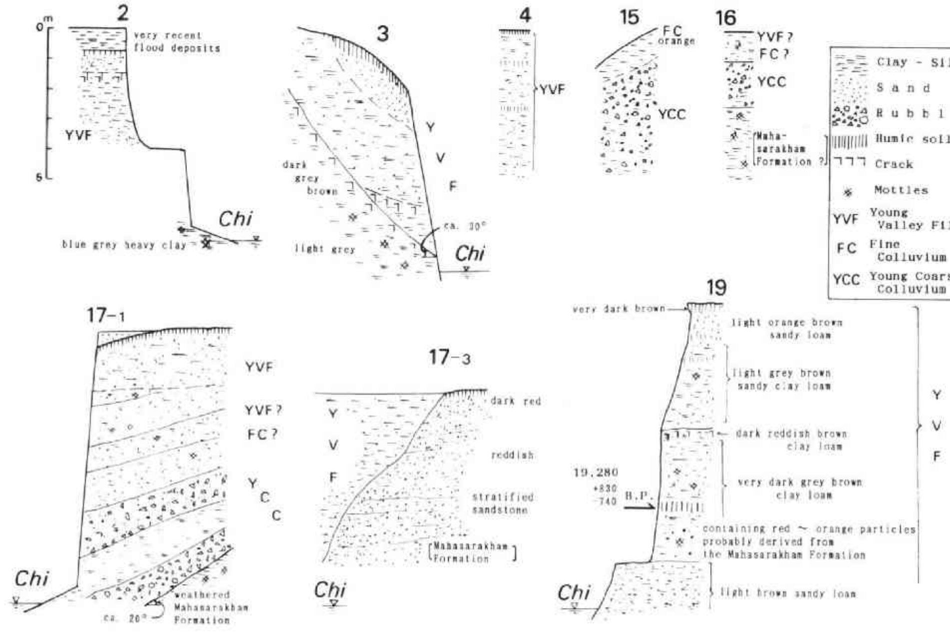


Fig. 7 Selected geological profiles of the Young Coarse Colluvium, the Fine Colluvium, and the Young Valley Fill with a radiocarbon date.
(See Figs. 4 and 8 also. The locations are shown in Fig. 5.)

tektite samples collected from the top or upper parts of the Laterites in several locations around Khon Kaen (Locs. 6 and 8 to 11 in Fig. 4)[1]. Although these are preliminary measured dates, they are not contradictory to the fission track ages and K-Ar ages of tektites reported previously in several locations in Southeast Asia (*e.g.*, Fleischer *et al.*, 1969 ; Gentner, *et al.*, 1969 ; Zahringer and Gentner 1963). The facts suggest that Laterite formation proceeded in time around or immediately after the Matsuyama-Brunhes boundary. The evidence that tektites had been present in the time of laterization was already reported from various places of Thailand (*e.g.*, Barnes and Pitakpaivan 1962 ; Wongsomsak 1987 ; Kiernan 1991).

3.4. The Young Coarse Colluvium (YCC)

This unit consists of thin layer of pebble- to cobble-sized angular gravel (Fig. 7). Although it resembles to OCC in its lithofacies, the Young Coarse Colluvium is not indurated and is distributed on lower position of hillslopes which is, in the case of low gradient, hardly discriminated from the apparent floodplain. In Loc. 17-1 along the midstream of the Chi, ca. 9 km west of Mahasarakham, a sloping angular gravel layer continues smoothly to the level lower than the present river-bed (Fig. 8). This unit

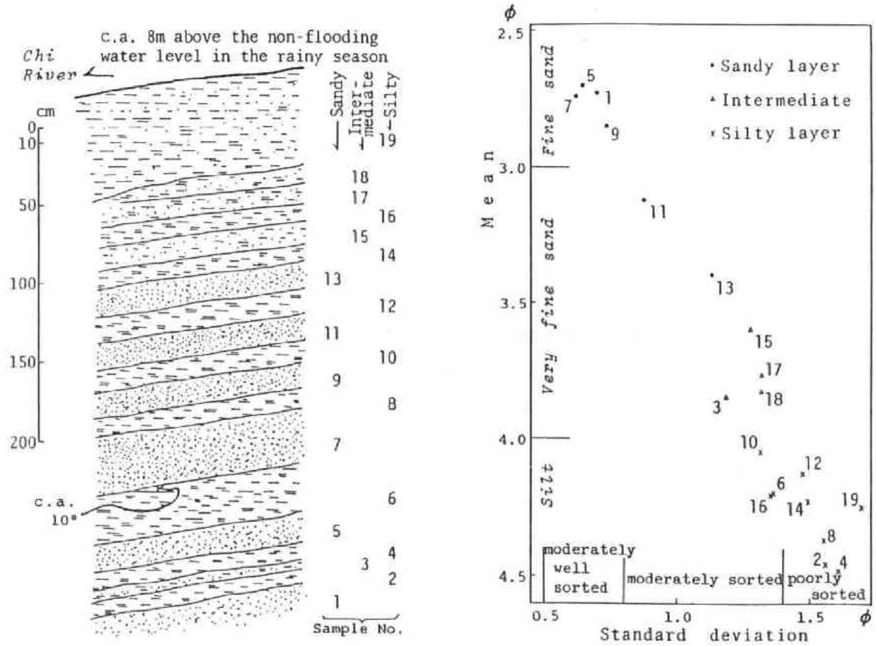


Fig. 8 A geological cross section and the results of particle size analysis of the alternation of the Fine Colluvium and the Young Valley Fill in Loc. 17-2, west of Mahasarakham.
(Sample numbers are common to the left and right diagrams. See Fig. 5 for the location.)

also indicates the occurrence of some kinds of mass-movements probably after the laterization. In some other locations, *e.g.*, Locs. 16 and 22, YCC contains fine gravel of laterites, some of which are considered to have been reworked from previously developed laterite profiles.

3.5. The Fine Colluvium (FC)

This unit takes the appearance of fine-sandy, loamy, and silty layers of various thickness and various colors ranging from red to dull brown, which cover all the deposits and weathering products described above as well as bedrock surface. Although it includes the loess or loessial soil reported by Boonsener and Tessanasorn (1982), Nutalaya *et al.* (1987), Udomchoke (1989) *etc.*, its facies and mode of occurrence indicate that the processes concerning its formation are various (Fig. 7) and unconcentrated surface wash, soil creep, wind action, and some biotic activity may be involved. The term "fine colluvium" in a usage of French-speaking geomorphologists particularly in the tropical world is convenient for expressing such heterogeneous subaerial deposits.

On the right bank of the Chi River ca. 9 km west of Mahasarakham (Loc. 17-2 in Fig. 5), occurs the alternation of thin fine-sandy layers and silty layers which form a landsurface several meters above the non-flooding river water level in the rainy season and sloping gently toward the river channel. Particle size distribution of each layer has been analyzed by the method of combining mechanical sieving and shading effects of falling particles at 0.5 ϕ interval. Some statistical treatment has been applied to each layer's particle size distribution in order to elucidate its sedimentary environment with reference to previously proposed criteria (*e.g.*, Friedman, 1961, 1967).

Some of the results are displayed in Fig. 8, which indicates that the lower sandy layers are of eolian origin and the character of eolian deposits becomes indistinct in the upper sandy layers while all the silty layers seem to be flood deposits. The top layer may have been disturbed by human action. The facts suggest the cyclic or occasional occurrence of wind action interrupted by flooding which has become more frequent probably due to the increase of wetter condition. Stratigraphically the alternation may demonstrate the interfinger of FC and the Young Valley Fill which will be described below.

Sonsuk and Hastings (1984) considered that the deposition of red loamy sand correlated to FC began around 20 ka on an upland site at Amphu Muang, west of Udon Thani in the western part of the Sakon Nakhon Basin, because charcoal found at 2.5 m depth in a 7.5 m thick red loamy sand showed the radiocarbon age of 6,620±160 yr B.P. Udomchoke (1989) reported that charcoal embedded at 2 m depth in yellow "loess" in the west of Khon Kaen was given the radiocarbon age of 8,190±120 yr B.P.

3.6. The Young Valley Fill (YVF)

This unit is composed of sand-loamy and clay-loamy layers distributed in relatively narrow zones along the present river courses. Containing several buried soil layers intercalated, the unit appears to be mostly flood deposits of relatively recent days. Some columnar sections in Fig. 7 show typical occurrences of the Young Valley Fill along the Chi River. Outside the narrow zones occupied by YVF, weathered Mahasarakham Formation is exposed or thinly covered by FC or YCC on the surface of the low plain which is almost the same elevation with the narrow zone (*e.g.*, Locs. 13-2 and 18 in Fig. 4 and Locs. 16 and 17-3 in Fig. 7).

The YVF exposed on the right bank of the Chi River at 4 km northwest of Mahasarakham town (Loc. 19 in Fig. 5) consists of the upper light gray to light brown sandy clay loam layers which intercalate a few buried A horizons and is considered recent flood deposits, the middle very dark gray brown clay loam layers which are topped with a dark reddish brown weathered zone and seem to be former back-swamp or oxbow-lake deposits, and the lower sandy loam layers (Fig. 7). Organic clay contained in the middle layers shows the radiocarbon age of 19,280 +820/−740 yr B.P. (TH-1287). Depth of the dated layer is 6.5 m below the surface of apparent floodplain which is about 10 m above the present non-flooding river water level in rainy season, and is the same landsurface with that composed of "the alternation" in Loc. 17-2 mentioned above. The facts indicate that both the active deposition of flood deposits in Loc. 19 and the increasing frequency of flood deposition in Loc. 17-2 took place at almost the same time in the latest Pleistocene.

Udomchoke (1989) reported organic-clayey swamp or oxbow-lake deposits which overlay the red and yellow "loess" around Khon Kaen. Radiocarbon ages of the organic clay range from ca. 7,600 to 3,500 yr B.P. He considered the deposits an indication of warm and humid climate in those days.

3.7. Unconfirmed old valley fill

In addition to the six time-stratigraphic units, sandy or clayey deposits which fill valleys excavated in the Mahasarakham Formation and are overlain unconformably by YVF are observed in several places along the Chi and its tributaries. It may take

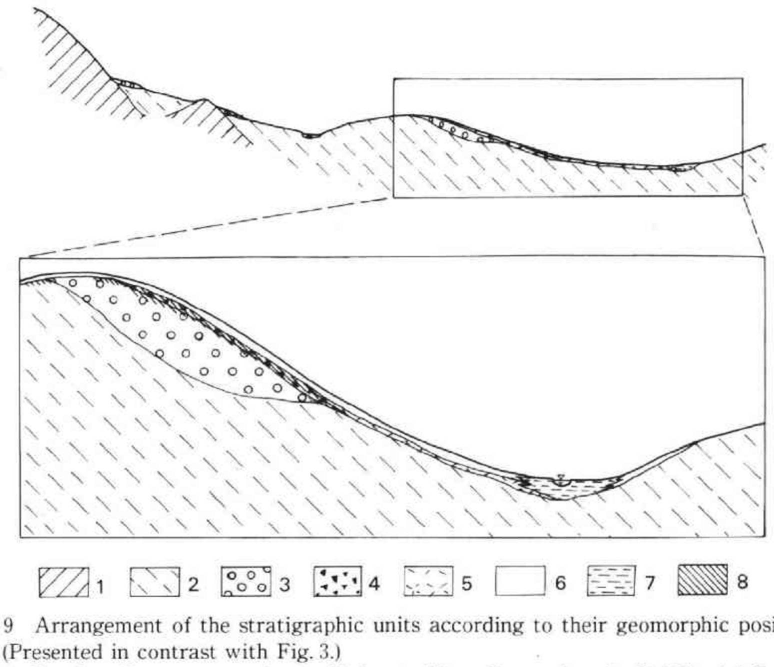


Fig. 9 Arrangement of the stratigraphic units according to their geomorphic positions. (Presented in contrast with Fig. 3.)
1 : Pre-late Cretaceous rocks, 2 : Mahasarakham Formation, 3 : Old Fluvial Gravels, 4 : Old Coarse Colluvium, 5 : Young Coarse Colluvium, 6 : Fine Colluvium, 7 : Young Valley Fill, 8 : Indurated zone.

somewhat resembling stratigraphic place to the Kham Sakae Saeng Formation or the Khu Muang Formation in the Buri Ram area (Wongsomsak, 1987) or the Organic sand deposits in Tung Kula Ronghai area (Löffler *et al*., 1984), both of which are situated in the Mun River basin, although each of them is estimated of quite different age from others. In any case further information is necessary for investigating the apparently older fine fluvial deposits occurred along the Chi River.

4 Landform development and environmental changes

The six units excluding the unconfirmed old valley fill described above are arranged as shown in Fig. 9 according to their geomorphic positions and stratigraphic relations. The arrangement leads to the following chronosequence of geomorphic processes.

1) The deposition of OFG occurred in the condition of greater tractive force of those days' river than the present one. It took place before the fall of tektites around 0.7 Ma.

2) Both the gravel bed and the bedrock suffered deep weathering in the period subsequent to the deposition of OFG. In-situ segregation of iron proceeded simultaneously in the surface layers.

3) Several types of mass-movement including reworking of the surface of OFG and selective removal of finer matrix took place on the bedrock and gravel-covered surfaces. They contributed to both the formation of OCC and the concentration of pisolitic iron concretion or loose gravelly laterite which developed to sheet laterite in places. Tektites dated about 0.7 Ma fell almost at the same time.

4) Colluviation occurred also after the tektite fall to have formed YCC on more or less sloping landsurface. The level of the river-bed in the midstream of the Chi of some days in YCC deposition was lower than the present one. In the time partially overlapping with YCC formation, relatively weak mass-movements including soil creep and unconcentrated surface wash and associated local wind action provided extensive occurrence of FC except on the floodplain. Some of such processes contributed to selective removal of fine material from OFG, OCC, and YCC. The FC was in places alternated with YVF. Deposition of FC continued to Holocene time.

5) The former river-bed was filled mostly by flood and swamp deposits, YVF, during the time extending over both before and after about 20,000 yr B.P. The alluviation has continued to the present and swamp and oxbow-lake deposits were also formed in the relatively narrow zone, about 7-8 km across at most, along the Chi River except both its uppermost course in the Petchabun Mountains and the lowermost course near the confluence to the Mun.

The chronosequence of geomorphic processes as above is indicative of environmental changes which will be discussed below.

1) *Higher rainfall and/or more active tectonic movement in the early Pleistocene or the late Neogene Tertiary*

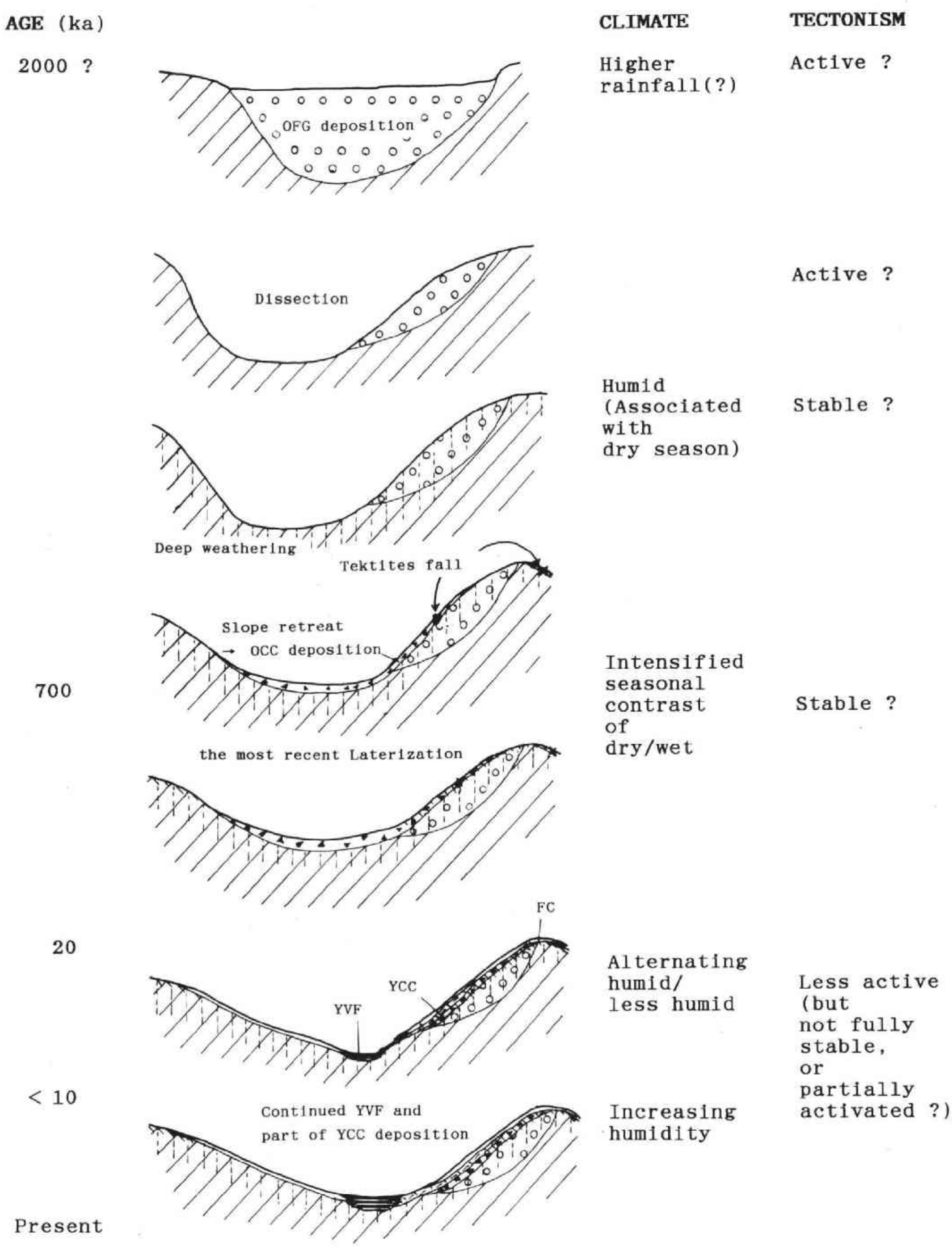
Similar situation to OFG in the Chi River basin, that is the higher terrace-forming fluvial deposits coarser than the present river-bed road, is observed not only in the Northeast but also in the North and the North Central regions of Thailand. Some examples have been reported by Kiernan (1991), Takaya (1968), *etc*. The greater tractive force of a river represented by OFG means more plenty river water discharge and/or steeper slope of a river-bed in early Pleistocene or late Neogene Tertiary time than at present. The more plenty discharge requires the higher rainfall or the incoming of a bigger river. The steeper river-bed slope is the result of more active vertical displacement of land-surface. The higher rainfall may have been conditioned by lower relief of the Tenasserim and the Petchabun Mountains, which is favorable to the deeper intrusion of the summer monsoon from the Indian Ocean in the time. The incoming of a bigger river, that is considered nothing else but the Mekong, also became possible via North Thailand in the condition of lower relief of the Petchabun Mountains. On the other hand the more active vertical displacement is a sign that the uplift of the mountains including the formation and differentiation of the Khorat and the Sakon Nakhon Basins had continued to the time.

2) *Humid climate with a marked dry season in the early Pleistocene*

Both the deep weathering of the bedrock and OFG and the in-situ segregation of iron are indicative of the climate which is essentially humid but has a marked dry season. Its age is subsequent to the deposition of OFG and preceding to the fall of tektites.

3) *Intensified seasonal contrast of climate around the mid-Pleistocene*

Mass-movements which provided the reworking of OFG and the deposition of OCC followed the deep weathering. They induced laterization on the top of the reworked OFG, in OCC, and in the weathered bedrock. Activation of mass-movements without correlated fluvial deposits indicate the occurrence of torrential rain less contributory to the maintenance of river flow. Such a condition is considered to have been provided by a climate with more rainfall than present as well as marked seasonal contrast. It is favorable for laterization also. Tektites dated ca. 0.7 Ma fell during or immediately preceding the laterization. Continuation of the seasonally contrastive climate with increasing aridity is inferable from YCC without laterite.


AGE (ka)
CLIMATE
TECTONISM
2000 ?
OFG deposition
Higher rainfall(?)
Active ?
Dissection
Active ?
Humid (Associated with dry season)
Stable ?
Deep weathering
Tektites fall
Slope retreat
OCC deposition
700
Intensified seasonal contrast of dry/wet
Stable ?
the most recent Laterization
FC
20
YCC
YVF
Alternating humid/ less humid
Less active (but not fully stable, or partially activated ?)
< 10
Continued YVF and part of YCC deposition
Increasing humidity
Present

4) *Alternating dry and wet climate in the late Pleistocene and the Holocene with increasing humidity in the latter time*

The topo-stratigraphic relations among YCC, FC, and YVF (Fig. 9) show that not-so-strong mass-movements, local eolian activity, and flooding took place almost concurrently on respective topographic locations. Both the diversity in the processes which provided the above deposits and the thinly alternating eolian and flood deposits illustrated in Fig. 8 indicate the alternation of dry and wet conditions during the formation of the deposits. The ^{14}C dates of ca. 20,000 yr B.P. for former swamp deposits under emerged floodplains, ca. 8,300 to 6,500 yr B.P. for intermediate horizons of FC on uplands, and ca. 7,600 to 3,500 yr B.P. for swamp or oxbow-lake deposits on lowlands demonstrate that such alternating climatic conditions continued, at least, from late Pleistocene to Holocene time. However, significant climatic changes should also have occurred within the age. The alternation in Loc. 17-2, west of Mahasarakham (Fig. 8), suggests the increasing frequency of flooding towards recent days. The preceding papers, *e.g.*, Löffler *et al.* (1984) and Udomchoke (1989), mentioned the dry environment in the latest Pleistocene and the humidification on the early to mid-Holocene. Detailed analysis of further stratigraphic facts is expected to provide important information on climatic changes at intervals of several thousands of years in late Pleistocene and Holocene time.

5) *Tectonic movement during the Quaternary*

As indicated by OFG, the area investigated was not free from the influence of the uplift of the mountains in and around Northeast Thailand at least in late Neogene Tertiary or early Pleistocene time. Climatic changes of subsequent ages as discussed above may have been also affected by tectonic movement. Many indications of recent tectonic activities are observed along the southwentern foot of the Petchabun Mountains.

If the interpretation of electric prospecting records by Löffler *et al.* (1984) that the bottom of the drowned valley lay deeper than 100 m below the present floodplain in Tung Kura Ronghal is correct, differential vertical displacement more than 100 m took place within the distance of about 200 km in the lower Mun River basin since late Pleistocene time, because the bedrock, that is the Khok Kruat and the Phu Phan Formations which underlie the Mahasarakham Formation, exposes on the river bed around the junction of the Mun and the Mekong. If such a movement is a matter of fact, it represents the continuation of the development of the Khorat Structural Basin, and the Chi River basin is also hardly escapable from the movement. The fact that

Fig. 10 A diagram illustrating the morphogenetic and environmental changes in the Chi River basin in Quaternary time.
(See the text for the abbreviation of deposits.)

YCC continues to the level lower than the present river-bed as illustrated in Fig. 7 may be also interpreted in the context of the same movement.

The morphogenetic and environmental changes as discussed above are summarized in Fig. 10.

5 Concluding remarks

Recognition of time-stratigraphic units which compose respective landforms in the Chi River basin and interpretation of their formation as well as radiocarbon and fission track dating have enabled the discussion on the changes of climatic and tectonic environments.

The early Pleistocene or the late Neogene Tertiary are characterized by higher rainfall and/or more active tectonic movement than present. Further stratigraphic and paleogeographic investigation of OFG not restricted in the Chi River basin will lead to revealing the history of uplifting of mountain ranges in and around Thailand, which controlled climatic change also, in the time. Although the relatively humid climate continued to the end of early Pleistocene time, seasonal aridity became emergent. The seasonal contrast of climate was intensified since around mid-Pleistocene time to induce the occurrence of mass-movement and laterization. In addition to the seasonal contrast, the alternation of dry and wet climate at intervals of probably several thousands of years became dominant in late Pleistocene and Holocene time. Although the latest Pleistocene corresponding to the Last Glacial Maximum was generally considered the age of climatic desiccation in the area, considerable swamp deposits were also formed at about 20,000 yr B.P. Humidity was increased probably in early to mid-Holocene time. More detailed studies of land-surface cover including eolian, slope and flood deposits will contribute to the elucidation of changing terrestrial environment particularly in the time ranging over the Last Glacial and Postglacial ages.

Considering the influence of uplift of the surrounding mountains, the climatic changes as above should be interpreted from the viewpoint of the vicissitude of the summer monsoon in the next step of the study.

Acknowledgment

The field observation of this study was made from July to September, 1986, when I was a short term expert of Japan International Cooperation Agency (JICA) assigned to the Agricultural Development Research Project in Northeast Thailand, and in December, 1988, when I received financial support of the Tokyo Geographical Society. Apart from the preliminary reports submitted to JICA (Tamura, 1986) and the Tokyo Geographical Society (Tamura, 1989), some results of the study were presented in collaboration with Pichai Wichaidit and Paiboon Pramojanee at 26 th International

Geographical Congress, August, 1988, in Sydney (Tamura *et al.*, 1988), and some additional matters were tentatively reported in Japanese (Tamura, 1987, 1992). This paper has been focused on the formation of areally differenciated land-surface characteristics in changing environment which is one of the matters of major concern in the research projects on the Past Global Changes (PAGES) in the International Geosphere-Biosphere Programme (IGBP) and the Commission on Global Continental Paleohydrology (GLOCOPH) in the International Union for Quaternary Research (INQUA). Evaluation of the land-surface characteristics from the viewpoint of regional environmental resources will be discussed in a separate paper.

I am deeply thankful to Dr. Masanori Mitsuchi (Agricultural Environment Research Institute, Tsukuba) and Dr. Pichai Wichaidit, Dr. Paiboon Pramojanee, and Mr. Montri Liengsakul (Land Development Department, Bangkok), for their helpful cooperation and valuable discussions. Thanks are extended to Mr. Poonya Paosritongkum and Mr. Saeree Jeungnijinirund (Land Development Department, Bangkok), Dr. Kenzo Miura (Universiy of the Philippines, Laguna), Dr. Yoji Amano (Agricultural Environment Research Institute, Tsukuba), and Prof. Toyohiko Miyagi (Tohoku Gakuin University, Sendai), for their cooperation in field research, Prof. Masao Suzuki (Rikkyo University, Tokyo) for fission track dating, Dr. Masayuki Toyoshima (Tohoku National Agricultural Experiment Station, Morioka), Dr. Win Maung (University of Mandalay), and Mr. Kiyoshi Saijo (Tohoku University, Sendai) for particle-size analysis and radiocarbon dating, Mr. Sompob Wongsomsak (Mineral Resources Department, Bangkok), Dr. Montree Boonsener (Khon Kaen University), Prof. Ernst Löffler (University of Saarlands, Saarbrücken), and Prof. Prinya Nutalaya (Asian Institute of Technology, Bangkok) for important suggestions, and Dr. Paitoon Ponsana and Dr. Sadao Hatta (Agricultural Development Research Center, Khon Kaen, in those days) for thoughtful consideration for the execution of field research work.

Notes

1) Tektites were sampled by the author in Locs. 6 and 8 and by Dr. Kenzo Miura, Agricultural Development Research Center in Khon Kaen in those days, in Locs. 9, 10, and 11. Fission track dating was made by Prof. Masao Suzuki, Rikkyo University.

References

Barnes, V.E. and K. Pitakpaivan (1962): Origin of Indochinite tektites. *Proceedings of the National Academy of Science, U.S.A.*, **48** 947-955.

Boonsener, M. (1985): Review on Quaternary geology in the North-Eastern, Thailand. *Proceedings of the Conference on Geology and Mineral Resources Development of the Northeast, Thailand*, 26-29.

——— **and A. Tessanasorn** (1982): The geomorphology of Quaternary deposits in Khon Kaen Province, Northeastern, Thailand. *Proceedings of the First Symposium on Geomorphology and Quaternary Geology of Thailand*, **2** 1-10.

Ceruse, J. (1983): Géomorphologie du Plateau de Korat (Thailande et RDP Lao): Basée sur l'interprétation des documents aérospatiaux. *Rapport d'étude pour le Secretariat du Comité du Mekong*, Ministère des Relations Extérieures, 19 p.

Fleischer, R.L., P.B. Price, J.R.M. Viertl and R.T. Woods (1969): Ages of Darwin glass, Macedon glass, and Far Eastern tektite. *Geochimica et Cosmochimica Acta*, **33** 1071-1074.

Friedman, G.M. (1961): Distribution between dune, beach and river sands from their textural characteristics. *Journal of Sedimentary Petrology*, **31** 514-529.

——— (1967): Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *ibid.* **37** 327-354.

Furukawa, H. and P. Wichaidit (1989): Salt and sinkhole — corrosion as a principal factor governing topography and mass movement in Northeast Thailand —. *Southeast Asian Studies*, **27** 3-34.

Gentner, W., D. Storzer and G.A. Wagner (1969): New fission track ages of tektites and related grasses. *Geochimica et Cosmochimica Acta*, **33** 204-210.

Geological Survey Division, Deaprtment of Mineral Resources (1983): *Gological Map of Thailand 1 : 500,000.*

Hokjaroen, S. and J.T. Parry (1989): Aeolian sand splays of northeastern Thailand: Analysis using Landsat TM imagery. *Remote Sensing, Soil and Water Management in Northeast Thailand, Technical Report Series*, McGill Univ./Khon Kaen Univ., 26 p.

Kiernan, K. (1991): Tropical mountain geomorphology and landscape evolution in north-west Thailand. *Zeitschrift für Geomorphologie, N.F.*, **35** 187-206.

Löffler, E., W.P. Thompson and M. Liengsakul (1984): Quaternary geomorphological development of the lower Mun River basin, Northeast Thailand. *Catena*, **11** 321-330.

Michael, P. (1981): Landforms, surface sediments and associated soil units in Nakhon Ratchasima Province, Thailand: A land-surface survey and an interpretation on the geologic genesis of the Khorat Plateau's upland soil. *Technical Bulletin, Soil Survey Division, Land Development Department, Thailand*, **No. 31** 106 p.

Mitsuchi, M., P. Wichaidit and S. Jeungnijinirund (1989): Soils of the Northeast Plateau, Thailand. *Technical Bulletin, Tropical Agricultural Research Center, Japan*, **No. 25** 55 p.

Moormann, F.R., S. Montrakun and S. Panichapong (1964): *Soils of Northeast Thailand. A key to their identification and survey.* Land Development Department, 32 p.

Nutalaya, P., P. Vella, S. Bunopas and S. Kaewyana (1987): Quaternary processes in Thailand. *Proceedings of the Workshop on Economic Geology, Tectonics, Sedimentary Processes, and Environment of the Quaternary in Southeast Asia*, 23-33.

———, **W. Sophonsakulrat, M. Sonsuk and M. Wattanachai**. (1989): Catastorophic flooding —An agent for landform development of the Khorat Plateau: A working hypothesis. *Proceedings of the Workshop on Correlation of Quaternary Successions in South, East and Southeast Asia*, 95-115.

Pendleton, R.L. and S. Montrakun (1960): The soils of Thailand. *Proceedings of 9th Pacific Science Congress*, **18** 12-32.

Piyasin, S. (1985): Problems of stratigraphic classification and environments of Khorat Group. *Proceedings of the Conference on Geology and Mineral Resources Development of the Northeast, Thailand*, 26-29.

Pramojanee, P. and S. Panichapong (1984): Geomorphological map of northeatsren part of Thailand. *Technical Bulletin, Soil Survey Division, Land Development Department, Thailand*, **No. 57**, 14 p. +map.

———, **M. Liengsakul and V. Enkagul** (1985): Grain size analysis of some sand rises and stream sediments in the Northeast of Thailand in order to indicate depositional environment. *Proceedings of the Conference on Geology and Minerål Resources Development of the Northeast, Thailand*, 235-253 (in Thai with English abstract).

Sonsuk, M. and P.J. Hastings (1984): An age from the Yasothon soil series in the Sakhon Nakhon Basin. *Journal of Geological Society of Thailand*, **7** 1-11.

Takaya, Y. (1968) : Quaternary outcrops in the Central Plain of Thailand. *Reports on Research in Southeast Asia, Natural Science Series,* **No. 3**, The Center for Southeast Asian Studies, Kyoto Univ., 7-68.

Tamura, T. (1986) : Geomorphological development of Northeast Thailand with reference to problem soil formation : A hypothesis based on preliminary observation. *Report of JICA Short Term Expert, Agricultural Development Research Center,* **No. 6** 11 p. (Unpublished).

——— (1987) : History of landform-soil formation in Northeast Thailand (Abstract). *Annals of the Tohoku Geographical Association,* **37** 211 (in Japanese).

——— (1989) : Environmental historical study of landform development and soil formation in Northeast Thailand. *Journal of Geography,* **98** 495-498 (in Japanese).

——— (1992) : A review of studies on Quaternary land-surface environmental change in Thailand. In : Fujiwara, K. (ed.) Preliminary Study on Paleoenvironment of Tropical Monsoon Asia. *Special Publication, Research Center for Regional Geography, Hiroshima Univ.,* **No. 22** 22-29 (in Japanese).

———, **P. Wichaidit, and P. Pramojanee** (1988) : Quaternary environmental changes and landform evolution in Northeast Thailand. *Abstracts of 26th International Geographical Congress, 1988, Sydney,* **2** 584.

Udomchoke, V. (1989) : Quaternary stratigraphy of the Khorat Plateau area, Northeastern Thailand. *Proceedings of the Workshop on Correlation of Quaternary Successions in South, East and Southeast Asia,* 69-94.

Wongsomsak, S. (1987) : Quaternary stratigraphy in Northeast Thailand : A stratigraphic research at Changwat Buri Ram. In : Progress in Quaternary Geology of East and Southeast Asia, *Proceedings of the CCOP Symposium on "Development in Quaternary Geological Research in East and Southeast Asia during the Last Decade", 1986,* 179-196.

Zahringer, J. and W. Gentner (1963) : Radiogenic and atmospheric argon content of tektites. *Nature,* **199** 583.