Kasetsart J. (Nat. Sci.) 31 : 237 - 253 (1997)

Properties and Landscape Relationship of Skeletal Soils in Upper Northeast, Thailand

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ABSTRACT

A study on properties and landscape relationship of skeletal soils in Upper Northeast, Thailand was conducted on six representative areas of a broad topographic sequence ranging between 250 to 160 meters above mean sea level (MSL). Field check and pedon analysis approach were used to identify soils and their landscape positions. Soil samples were collected from soil genetic horizons of each pedon. Laboratory analysis was carried out using standard techniques in soil analysis emphasizing physical, chemical and mineralogical properties of the soils.

Results of field and laboratory analyses revealed that these skeletal soils generally have poor physico-chemical properties. Their mineralogical composition does neither promote their exchange activity nor their fertility sufficiently, and coarse fragments in most of the soils are lateritic gravels. Generally, these soils have dense gravel zone in their profiles at a shallow depth and some of them also have plinthite or hardened plinthite layer(s) in their subsoil. Root restricting layers in these soils are both layers with abundant gravels and the semi-hardened or hardened plinthite layers. Their profile features vary with their topographic position and characteristics of terrain they occupy. The accumulation of gravels in the soils and the thickness of soils above the plinthite layers indicate seriousness of erosion of the landscape. Their position on landscape ranges from hillslope where skeletal materials are mostly ferruginous rock fragments down to depression in low erosional terrace region where lateritic gravels dominate the dense gravel zone. The presence of gravels and plinthite layers of various nature in their profiles and their generally poor chemical properties clearly restrict their effective uses for upland field crop cultivation. However, they can be used for tree crop and paddy rice cultivation successfully with proper current soil management practices.

Key words : skeletal soils, lateritic gravels, plinthite layer, erosional terrace, Northeast Thailand

INTRODUCTION

Skeletal soils generally have layers that consist of more than 35 percent (by volume) of materials coarser than 2 millimeters in diameter within the family control section (25-100 cm) in their profiles (Soil Survey Staff, 1992). The skeletal materials can be coarse fragments of various nature i.e. rock fragments, gravels, cobbles and lateritic concretions or nodules (Paramananthan, 1984; Racel, 1984; Vijarnsorn, 1984). These soils have been considered problem soils in Thailand along with few other groups of soils that posses adversary properties for plant growth (Panichapong, 1982). Though these soils can be found in all regions of Thailand, their extensive area has been reported for Upper Northeast, known as Sakon Nakhon Basin (Chintaskul, 1989; Dee-saeng, 1993; Pramojanee *et al.*, 1984). Their extensive distribution in this area covers a wide range of landscape portions and their properties appear to be diverse. Therefore, their properties and landscape relationship may have some important bearing on effective land utilization of the area. This paper includes details

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of the study on these skeletal soils emphasizing 1) their properties inclusive of profile features, physical, chemical and mineralogical properties and 2) their landscape relationship affecting their properties and their current uses.

MATERIALS AND METHOD

Materials used consisted of soil maps (scale 1:100,000), topographic maps (scale 1:50,000) soil survey field kit for field sampling and morphological analysis of soil pedons and laboratory analytical instruments inclusive of atomic absorption spectrophotometer, flame photometer, spectronic-20, x-ray diffractometer, mechanical analysis set, chemicals and glasswares necessary for sample preparation and analysis.

Field study included sampling of soils on broad toposequence to identify and select locations for pedon analysis. Pedon analysis for each soil was done in a selected soil pit of 1.5x2x2.5 (width x depth x length) meter. Soil samples (both disturbed and undisturbed) were collected from soil genetic horizons. Physical and chemical analyses of soils were carried out based on standard methods of soil analysis (Soil Survey Laboratory Staff, 1992). Mineralogical analysis of soil was done by x-ray diffraction analysis technique (Jackson, 1964; Whittig, 1965).

RESULTS AND DISCUSSION

Results of the study include 1) general characteristics, 2) morphology, 3) physical properties, 4) chemical properties, 5) mineralogical properties, and 6) landscape relationship of skeletal soils.

General characteristics of skeletal soils in Upper Northeast, Thailand

Distribution of sampling locations and skeletal soils in Upper Northeast, Thailand is shown in Figure 1 and their general characteristics are summarized in Table 1. The skeletal soils appear to occupy the landscape with the elevation ranging from 240 to 160 meters above mean sea level (MSL) and most of them have undulating surfaces. The geomorphic units that these soils are located range from lower hill side slope to erosional surface. Their parent materials are generally diverse. In the higher elevation ranges residuum and colluvium are more common and contrasting materials can be observed where the soil is formed on erosional terrace. In the lower part of the terrain, alluvium and wash deposits can be identified as their parent materials. All of these soils show good profile developement having clay accumulation in their subsoil along with coarse fragments. At three locations (P2, P5 and P6) plinthite layer can be clearly identified. Particularly for P5, plinthite layer is hardened. The overall general characteristics of these soils and the presence of coarse fragments in the profile at shallow depth suggest clearly the condition of landscape with noticeable degree of erosion and transportation on slope. Collectively, they can be considered well developed soils that had been affected somewhat seriously by erosion in recent past. Report on details of their genesis is being prepared separately for publication.

Morphology of skeletal soils in Upper Northeast, Thailand

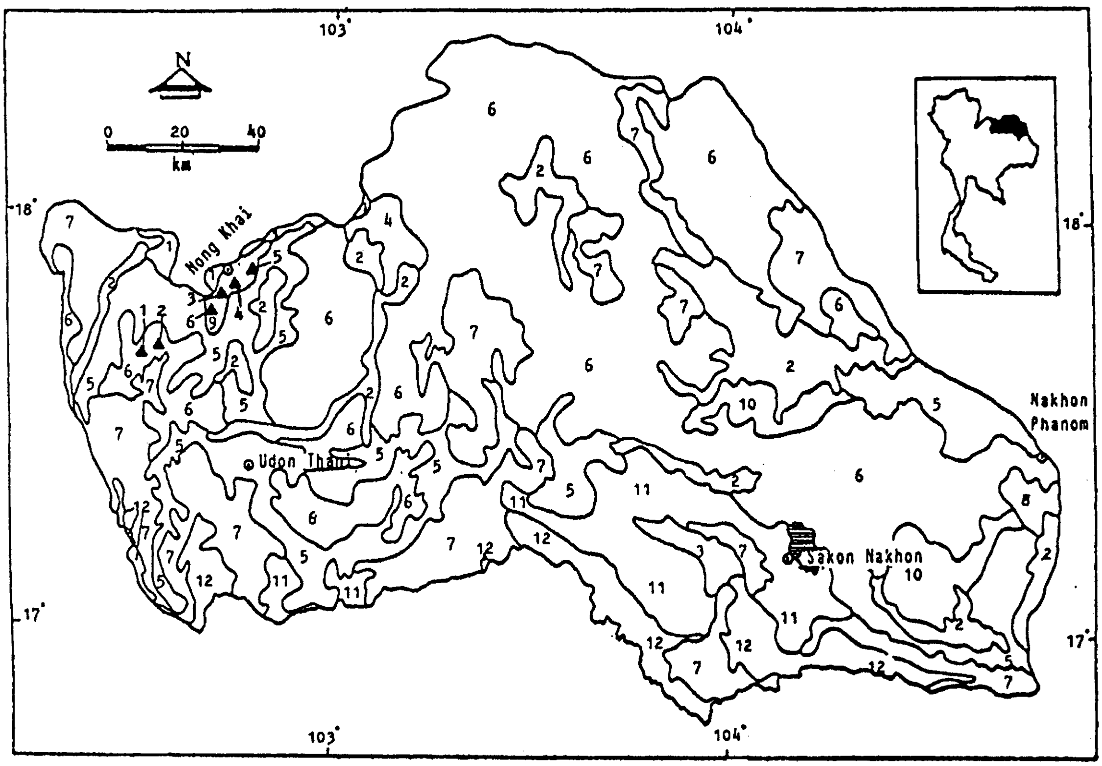
Table 2 summarized morphology of these skeletal soils. In general, these soils have reddish brown to yellowish red or reddish yellow color indicating oxidizing and well developed condition of their profiles. Their structure is commonly subangular blocky or angular blocky and their consistence when moist is friable to firm whereas their consistence at wet stage is slightly sticky and slightly plastic, also indicating the high stage of development (Buol *et al.*, 1989). The texture of these soils varies and this is due mainly to the different nature of the soil parent materials. Plinthite (Soil Survey Staff, 1975) layers are also present in some of the profiles as indicated earlier under the previous heading. The most common thing among these soils is the presence of layers with skeletal materials at a shallow depth. However, the degree of campaction of these layers and the nature of the skeletal materials vary. In the higher elevation area where residuum and colluvium are major component of soil parent materials, skeletal materials are generally rock fragments or ferruginous rock fragments, and the layers with these skeletal materials have low degree of

Table 1 General characteristics of skeletal soils in Upper Northeast, Thailand.

Pedon	Elevation (m) (MSL)	Profile Depth (cm)	Profile development	Slope (%)	Topography	Geomorphic unit	Parent materials
P1	240	178+	Ap-Btc1-Btc2-Btc3-Btc4-C1-C2	7	Rolling	Lower hillside slope of low hill	Residuum and colluvium derived from intermediate igneous and metamorphic rocks
P2	200	173+	A-Bw-2Btc1-2Btc2-3Btc3-3Bv1-3Bv2-3C	3	Undulating	Erosional terrace1/	Contrasting materials of local residuum derived from clastic sedimentary rocks
P3	180	192+	Ap-Btc1-Btc2-Btc3-Btc4-Bt1-Bt2	1	Undulating	Erosional surface2/	Alluvium on residuum derived from clastic sedimentary rocks
P4	170	200+	Ap1-Ap2-Btc1-Btc2-Btc3-Bt-BC-C	1	Gently undulating	Erosional surface	Wash deposits, local alluvium and residuum derived from clastic sedimentary rocks
P5	170	50+	Ap-Btc-Bv (hardened)	0	Flat	Erosional plain3/	Wash deposits and residuum derived from clastic sedimentary rocks
P6	160	190+	Ap-Bt1-Bt2-Btc-Bv-Bt3-Bt4	1	Gently undulating	Erosional surface	Alluvium on residuum derived from clastic sedimentary rocks

1/ showing step-like relief
2/ rise spottedly but no step-like relief
3/ broad flat land, thin soil over hardened plinthite surface

compaction. In the lower elevation area the skeletal materials are commonly iron-oxide or iron-manganese oxide nodules or concretions, or the combination of both iron-oxide and iron-oxide and iron-manganese oxide nodules and concretions. The layers with these nodules and concretions have a higher degree of compaction than that of the soils in the higher elevation ones. The different nature of skeletal materials indicates the more advanced development of soil in the lower elevation and the differential erosion or the deposition on the landscape subsequent to the formation of plinthite layer. In area where erosion was severe in the past the layer of the material above the plinthite layer is generally thin and the plinthite layer has become hardened or semi-hardened (as indicated for P5). Thickness of the layer with skeletal materials generally indicates the transportation and deposition on the landscape. In the lower elevation area, particularly in adjacent to river (P6) or depression pond (P4) the layers with skeletal materials are generally thicker than that of the higher elevation area, and the nodules and concretions are more rounded indicating a long distance transportation



Legend

- ▲ Sampling point
- 1 Loamy Ustifluvents
- 2 Clayey Tropaquepts
- 3 Loamy Halaquepts
- 4 Skeletal Plinthaquults
- 5 Loamy Paleaquults
- 6 Skeletal Plinthustults
- Soil boundary
- 7 Loamy Paleustults
- 8 Skeletal Paleustutls
- 9 Skeletal Paleustults/skeletal Haplustults
- 10 Skeletal Plinthustults/skeletal Plinthaquults
- 11 Loamy Paleustults/loamy Paleaquults
- 12 Slope Complex

Figure 1 Distribution and sampling locations of skeletal soils in Upper Northeast, Thailand.

Table 2 Morphology of skeletal soils in Upper Northeast, Thailand.

Pedon	Horizon	Depth (cm)	Color[1/]	Texture[2/]	Structure[3/]	Consistence[4/]	Field pH	Others[5/]
P1	Ap	0-10/18	5YR 3/4	GC	sbk	SH, Fri, SS/SP	8.0	Common ferruginous rock fragments
	Btc1	18-40/48	5YR 4/6	VGC	sbk	SH, SF, SS/SP	8.0	Many angular ferruginous rock fragments
	Btc2	48-75	5YR 5/8	VGC	abk	Fri, SS/SP	7.0	Many irregular ferruginous rock fragments
	Btc3	75-101	5YR 5/8	GC	abk	SF, S/SP	6.0	Common irregular ferruginous rock fragments
	Btc4	101-136	5YR 7/8, 10YR 8/8 10YR 8/2	GC	abk	SF, S/SP	5.5	Common weathered rock fragments
	C1	136-154	7.5YR 6/8, 10YR 8/3	GC	abk	SF, SS/SP	5.5	Common weathered rock fragments
	C2	154-178+	5YR 5/6, 10YR 8/4 10YR 8/6, 10R 4/6	C	abk	F, S/SP	5.5	Many weathered rock fragments
P2	A	0-5/9	7.5YR 4/6	LS	sbk	H, Fri, SS/NP	6.0	Few fine rock fragments
	Bw	9-33	7.5YR 6/3	LS	sbk	H, Fri, SS/NP	6.0	Krotovinas and charcoal fragments
	2Btc1	33-59	7.5YR 6/8	VGSC	abk	H, SF, SS/SP	5.0	Abundant subround and angular rock fragments
	2Btc2	59-75	5YR 5/8	VGSC	abk	H, SF, SS/SP	5.0	Abundant subround and angular rock fragments
	3Btc3	75-95/102	5YR 5/8, 10YR 4/6 10YR 8/6	GSC	sbk	H, SF, SS/SP	5.5	Common weathered rock fragments
	3Bv1	102-119/125	7.5YR 5/3, 10YR 4/6 10YR 7/6	GSC	abk	H, SF, SS/SP	5.5	Weathered rock fragments
	3Bv2	125-168	7.5YR 6/8, 10YR 4/8 10YR 7/6	SGSC	abk	H, SF, SS/SP	5.5	Weathered rock fragments
	3C	68-173+	10YR 7/6, 2.5YR 4/6 7.5YR 6/8	saprolite	-	-	5.0	-
P3	Ap	0-15/19	10YR 5/3, 7.5YR 5/8 5YR 5/6	Si	abk	H, Fri, NS/SP	6.0	Dead roots and charcoal fragments
	Btc1	19-27/31	10YR 6/6, 2.5YR 4/8	VGSCL	abk	VH,Fri,NS/SP	6.5	Dead roots and charcoal fragments
	Btc2	31-41/54	10YR 5/8, 7.5YR 6/8	VGSCL	sbk	SH, SF, NS/SP	6.5	Abundant coarse and very coarse irregular iron oxide nodules and concretions

Table 2 (cont.).

Pedon	Horizon	Depth (cm)	Color[1/]	Texture[2/]	Structure[3/]	Consistence[4/]	Field pH	Others[5/]
	Btc3	54-78	10YR 5/4, 10YR 6/8	VGSCL	sbk	SH, SF, SS/SP	6.5	Abundant coarse and very coarse irregular iron oxide nodules and concretions
	Btc4	78-95/113	10YR 6/6, 5YR 5/8	VGSCL	sbk	SH, SF, SS/SP	6.5	Abundant coarse iron oxide nodules
	Bt1	113-129	2.5YR 7/2, 10YR 7/8 2.5YR 4/8	SGC	abk	VH, VF, SS/SP	5.5	Common fine nodules
	Bt2	129-192+	2.5YR 7/2, 2.5Y 6/6, 5YR 6/8, 2.5YR 4/8	C	sbk+abk	VH, VF, S/P	5.5	Trace of dead roots
P4	Ap1	0-14	10YR 5/6, 5YR 5/6	VGCL	sbk	H, Fri, SS/SP	5.5	Abundant iron oxide and iron-manganese oxide nodules and concretions
	Ap2	14-22	10YR 5/4, 10YR 5/8, 2.5YR 4/6	VGl	abk	VH, Fri, SS/SP	5.5	Same as above
	Btc1	22-55	10YR 6/4, 10YR 5/4, 2.5YR 4/8	VGC	sbk	VH, Fri, S/SP	6.5	Abundant various sizes, rounded iron oxide nodules and concretions
	Btc2	55-85	10YR 6/4, 10YR 5/4, 2.5YR 4/	VGC	sbk	VH, Fri, S/P	7.0	Abundant various sizes, rounded dark gray iron oxide nodules and concretions
	Btc3	85-100	10YR 7/2, 10YR 4/8, 10YR 6/6	VGC	abk	VH, SF, S/P	6.0	Abundant larger rounded iron oxide and iron-manganese oxide nodules and concretions
	Bt	100-115	10YR 7/2, 10R 4/4, 10YR 6/8	SGC	abk	VH, F, S/P	5.5	Charcoal fragments
	BC	115-140/170	10YR 7/2, 10R 4/6, 10YR 6/8	C	abk	VH,F, S/P	5.5	Highly weathered rock fragments
	C	170-200+	10YR 5/6, 10YR 7/2, 10YR 6/8	SiC	abk	VH,H,S/P	6.0	Abundant highly weathered siltstone fragments
P5	Ap	0-10	10YR 5/3, 5YR 5/6	SGSL	sbk	SH, Fri, NS/NP	5.5	Charcoal fragments
	Btc	10-25/30	10YR 5/4, 2.5YR 4/6, 7.5YR 5/8	VGC	sbk	SH, F, SS/SP	6.0	Abundant iron oxide and iron-manganese oxide nodules and concretions

Table 2 (cont.).

Pedon	Horizon	Depth (cm)	Color1/	Texture2/	Structure3/	Consistence4/	Field pH	Others5/
	Bv (hardened)	30-50+	10YR 5/4, 7.5YR 5/6 2.5YR 4/8	VGC	-	VH, H, S/P	6.0	Mainly macropores in plinthite structure
P6	Ap	0-10	7.5YR 6/4, 7.5YR 5/2	SL	sbk	SH, Fri, NS/NP	5.5	-
	Bt1	10-24	7.5YR 6/4, 10YR 5/3, 7.5YR 5/8, 2.5YR 4/8	SL	sbk	SH, Fri, NS/NP	5.0	Few iron oxide nodules and concretions
	Bt2	24-50/64	7.5YR 5/4, 7.5YR 5/8	SL	abk	SH, Fri, NS/NP	5.5	Very few iron oxide concretions and nodules
	Btc	64-70/100	10YR 7/6, 10YR 5/6, 2.5YR 4/8	VGSL	sbk	H, F, S/P	5.5	Abundant iron oxide and iron-manganese oxide concretions and nodules
	Bv	100-115/140	10YR 7/2, 10YR 4/8 7.5YR 5/8	VGSC	sbk	H, F, S/P	5.5	Semi-hardened plinthite materials with abundant iron-manganese nodules and concretions
	Bt3	140-155/170	2.5YR 7/2, 7.5YR 6/8 10R 4/4	C	abk	VH, VF, S/P	5.0	Few fine iron oxide nodules and concretions
	Bt4	170-190+	2.5YR 7/2, 10R 3/8 10YR 5/6, 7.5YR 5/6	C	abk	VH, VF, S/P	5.0	Common trace of dead roots

1/ Munsell notation
2/ S = sand or sandy; Si = silty; L = loam or loamy; C = clay; G = gravelly; SG = slightly gravelly; VG = very gravelly
3/ abk = angular blocky; sbk = subangular blocky
4/ Fri = friable, SF = slightly firm; F = firm; VF = very firm; SH = slightly hard; H = hard; VH = very hard
NS = nonsticky; SS = slightly sticky; S = sticky; NP = nonplastic; SP = sligtly plastic; P = plastic
5/ Rock fragments in each pedon are those derived from parent materials indicated in Table 1.

by water.

Physical properties of skeletal soils in Upper Northeast, Thailand

Analytical results on physical properties of these skeletal soils are shown in Table 3. It can be observed that fine earth fraction in these soils varies considerably but the clay accumulation in their subsoil is always quite evident. The abundance of coarse fragments or skeletal materials also varies but at least one layer among others in each of the profile has more skeletal materials than 35 percent by volume. In general, these soils have relatively high bulk density values (>1.6 Mg m^{-3}) in their subsoils where skeletal materials are accumulated. This condition is also applied to surface soil with a high amount of skeletal materials such as in P4. Since most of these soils have layers with skeletal materials at a shallow depth the compaction of these layers as indicated partly by the high bulk density values becomes a factor to be considered carefully in cropping practices. The soil layers with dense skeletal materials can block downward penetration of plant roots substantially. It is a factor making them problem soils that need special attention for crop cultivation. Also, the amount of these skeletal materials reduces the fine earths of the whole soil markedly. It should be re-emphasized here also that the thickness of soil horizons without excessive amount of skeletal materials varies among these soils. This is also an important factor making their potential for cropping practices varied.

Chemical properties of skeletal soils in Upper Northeast, Thailand

Table 4 summarized chemical properties of these skeletal soils. Collectively, these soils show poor chemical properties. Except for the surface soil of P1 organic matter content of these soils can be considered low to very low (Land Classification Division and FAO Project Staff, 1973). Total nitrogen and available phosphorus values are also very low whereas values of available potassium vary. This condition mildly suggests the joint influence of differential leaching and accumulation of iron oxides in the soils. However, the condition in surface horizon of P1 and P4 related to available potassium and phosphorus is better than in the other three pedons. Therefore basic essential nutrients in these soils are generally low. These soils are generally acidic but the pH levels in their surface soils are acceptable for crop cultivation. Since ΔpH of these soils are negative the soil system still favors cation exchange (Sanchez, 1976). These soils have relatively poor exchange properties particularly in the surface layers. Their extractable base and cation exchange capacity (CEC) values are generally variable among pedons indicating the influence of leaching and nature of mineral complex in the soils. Nevertheless, their extractable aluminum and extractable acidity are not particularly high. This seems to suggest an inert system of these soils. Free iron oxide values of these soils are generally high especially in the horizons where skeletal materials are nodules or concretions of iron and iron-manganese oxides.

Mineralogical properties of skeletal soils in Upper Northeast, Thailand

Laboratory analytical results on mineral component of these soils are summarized in Tables 5 and 6. Kaolinite appears to be either dominant or it can be found in a large quantity in clay fraction of most soils. Other silicate clay minerals such as illite, chlorite and vermiculite however, can also be found in moderate amount in some of these profiles. Smectite can be detected in moderate to very small amount in some profiles only. Other minerals found in clay fraction of these soils include quartz, gibbsite, goethite, lepidocrocite and interstratified 1.0&1.4 nm clay. It can be noted that most of these soils except P1, P2 and P3 have mixed clay mineralogy. Soils in the lower elevation area generally have substantial amount of illite indicating influence of water transported materials (Fanning *et al.*, 1989). The presence of gibbsite, though in a very low amount, indicates a prolonging moist state during the year. This can be interpreted as the effect of the compact layers within the soils and lepidocrocite can also indicate the periodic water stagnancy in the profile (as in P3 and P4). Quartz dominates silt fraction of these soils as expected. Other minerals in silt fraction include goethite, hematite, gibbsite and 0.7 nm clay minerals. This group of minerals in silt fraction indicates a relatively inert condition since the soils appear to have lost most of their

Table 3 Physical properties of skeletal soils in Upper Northeast, Thailand.

Depth (cm)	Horizon	Particle size distribution: Coarse fragments (>2 mm) (% volume) 0-20 mm	>20 mm	Total	Fine earths (<2 mm) ($g\ kg^{-1}$) Sand	Silt	Clay	Textural[1/] class	Bulk density ($Mg\ m^{-3}$)	Elevation (m MSL)
Pedon 1										
0 - 10/18	Ap	26.09	0	26.09	257.0	163.0	579.4	GC	1.41	240
18 - 40/48	Btc1	67.00	0	67.00	292.5	101.1	606.4	VGC	2.00	
48 - 75	Btc2	48.64	0	48.64	270.8	118.8	610.3	VGC	1.68	
75 - 101	Btc3	37.35	0	32.35	160.4	72.8	766.7	GC	1.50	
101 - 136	Btc4	1.69	0	11.69	165.9	128.1	706.0	C	1.34	
136 - 154	C1	12.71	0	12.71	121.6	109.9	768.5	C	1.30	
154 - 178+	C2	13.70	0	13.70	155.9	180.1	663.9	C	1.34	
Pedon 2										
0 - 5/9	A	0.46	0	0.46	772.4	91.9	135.7	LS	1.34	200
9 - 33	Bw	0.35	0	0.35	763.1	98.9	138.0	LS	1.55	
33 - 59	2Btc1	41.50	0	41.50	481.5	35.1	483.4	VGSC	1.77	
59 - 75	2Btc2	21.79	0	21.79	433.7	20.6	545.7	GSC	1.52	
75 - 92/102	3Btc3	9.49	0	9.49	431.7	100.4	468.5	SC	1.52	
102 - 119/125	3Bv1	12.98	0	12.98	434.7	80.4	485.0	SC	1.57	
125 - 168	3Bv2	17.58	0	17.58	463.5	100.1	436.4	GSC	1.80	
168 - 173+	3C	4.97	23.48	28.45	575.2	120.3	304.5	GSCL	1.57	
Pedon 3										
0 - 15/19	Ap	5.75	0	5.75	139.6	827.0	33.3	Si	1.67	180
19 - 27/31	Btc1	38.33	8.33	46.66	592.0	186.6	221.4	VGSCL	2.10	
31 - 41/54	Btc2	22.58	55.25	81.83	534.3	176.3	288.9	VGSCL	2.47	
54 - 78	Btc3	28.73	35.55	64.28	526.8	246.0	227.2	VGSCL	2.25	
78 - 95/113	Btc4	13.66	67.93	81.59	465.0	192.7	342.3	VGSCL	2.46	
113 - 129	Bt1	11.59	0	11.59	257.9	159.3	528.3	C	1.66	
129 - 192+	Bt2	0.24	0	0.24	183.1	272.3	544.5	C	1.62	

Table 3 (cont.).

Depth	Horizon	Particle size distribution						Textural[1/] class	Bulk density	Elevation
		Coarse fragments (>2 mm) (% volume)			Fine earths (<2 mm) (g kg^{-1})					
(cm)		0-20 mm	>20 mm	Total	Sand	Silt	Clay		($Mg\ m^{-3}$)	(m MSL)
Pedon 4										
0 - 14	Ap1	42.22	0	42.22	308.2	381.2	310.5	VGCL	2.24	170
14 - 22	Ap2	41.55	0	41.55	329.4	405.4	265.2	VGL	1.93	
22 - 55	Btc1	1.25	24.07	55.32	295.1	203.8	501.2	VGC	2.01	
55 - 85	Btc2	37.26	0	37.26	280.7	287.1	432.1	VGC	2.04	
85 - 100	Btc3	31.68	4.89	36.57	211.4	256.4	532.3	VGC	1.85	
100 - 115	Bt	6.86	0	6.86	172.3	278.4	549.2	C	1.67	
115 - 140/170	BC	4.35	0	4.35	163.1	324.7	512.2	C	1.69	
170 - 200+	C	4.74	0	4.74	87.5	474.4	438.1	SiC	1.69	
Pedon 5										
0 - 10	Ap	18.08	0	18.08	566.6	279.0	154.4	SL	1.65	170
10 - 25/30	Btc	30.43	30.12	60.55	362.9	362.9	467.6	VGC	2.23	
30 - 50+	Bv	——Hardened Plinthite——			375.4	200.2	424.4	VGC	2.36	
Pedon 6										
0 - 10	Ap	3.17	0	3.17	591.0	239.6	169.4	SL	1.53	160
10 - 24	Bt1	3.03	0	3.03	630.2	185.3	184.5	SL	1.67	
24 - 50/64	Bt2	0.31	0	0.31	685.4	175.0	139.7	SL	1.55	
64 - 70/100	Btc	43.78	20.21	63.99	577.5	99.4	323.2	VGSCL	2.48	
100 - 105/140	Bv	53.21	0	53.21	473.3	49.3	477.4	VGSC	2.22	
140 - 155/170	Bt3	3.21	0	3.21	229.0	204.6	566.4	C	1.88	
170 - 190+	Bt4	3.25	0	3.25	294.2	203.6	502.3	C	1.77	

1/ C = clay
LS = loamy sand
SC = sandy clay
SL = sandy loam
SCL = sand clay loam
Si = silt
SiC = silty clay
G = gravelly
VG = very gravelly

Table 4 Chemical properties of skeletal soils in Upper Northeast, Thailand.

Depth (cm)	Horizon	pH (1:1) H_2O	pH (1:1) KCl	O.M.	Total N	Avail. P	Avail. K	Extractable bases Ca	Extractable bases Mg	Extractable bases Na	Extractable bases K	Sum bases	Extr. Al	Extr. acidity	CEC NH_4OAc	B.S by sum	Fe
				(--g kg^{-1}--)		(--mg kg^{-1}--)		(--------------------------cmol kg^{-1}							--------------------------)	%	(g kg^{-1})
Pedon 1																	
0 - 10/18	Ap	6.8	6.1	22.2	1.72	23.75	450.0	10.23	2.12	0.49	0.99	13.83	0.00	3.40	16.30	80.72	71.6
18 - 40/48	Btc1	7.0	6.0	8.4	0.55	2.69	195.0	4.53	1.94	0.21	0.47	7.24	0.00	3.00	9.89	70.70	76.6
48 - 75	Btc2	5.0	3.8	5.8	0.26	1.31	205.0	2.76	3.82	0.21	0.48	6.27	0.00	3.00	9.62	63.63	69.8
75 - 101	Btc3	4.8	3.7	6.7	0.13	1.64	185.0	1.74	0.93	0.09	0.29	4.05	2.22	6.00	11.63	40.30	82.5
101 - 136	Btc4	4.8	3.7	4.5	0.13	2.81	117.5	0.95	1.73	0.13	0.27	3.08	0.40	6.00	14.52	33.92	71.6
136 - 154	C1	4.8	3.7	4.3	0.14	0.70	71.0	0.79	1.68	0.08	0.20	2.75	4.20	6.00	10.25	31.43	84.2
154 - 178+	C2	4.8	3.8	2.7	0.10	1.21	44.0	1.79	2.21	0.08	0.12	4.20	1.77	3.90	10.44	51.85	74.5
Pedon 2																	
0 - 5/9	A	5.1	4.0	7.5	0.27	2.56	27.0	0.04	0.30	0.02	0.04	0.40	0.40	5.33	1.72	6.98	6.1
9 - 33	Bw	5.2	3.9	2.0	0.09	1.21	23.5	0.03	0.32	tr1/	0.04	0.39	0.45	5.13	1.44	6.27	7.0
33 - 59	2Btc1	4.9	3.6	3.7	0.26	1.01	140.0	0.99	1.62	0.09	0.28	2.98	4.90	6.69	8.80	30.82	41.9
59 - 75	2Btc2	4.8	3.6	3.0	0.22	0.80	119.0	0.37	1.12	0.07	0.27	1.83	5.90	13.27	9.89	12.12	73.4
75 - 92/102	3Btc3	4.7	3.6	3.4	0.20	1.31	99.0	0.96	0.56	0.09	0.24	1.85	6.56	7.79	9.89	19.19	59.0
102 - 119/125	3Bv3	4.6	3.7	1.8	0.21	0.70	63.0	0.66	0.34	0.06	0.17	1.23	6.37	6.79	9.62	15.34	55.5
125 - 168	3Bv2	4.8	3.6	2.0	0.14	0.80	34.0	0.19	0.26	0.01	0.09	0.55	6.61	3.50	9.07	13.58	45.8
168 - 173+	3C	4.8	3.7	1.4	0.12	0.90	31.1	0.65	0.18	0.01	0.06	0.81	5.25	5.92	6.35	12.04	30.3
Pedon 3																	
0 - 15/19	Ap	5.1	4.0	9.1	0.38	3.39	32.0	0.93	0.30	0.02	0.07	1.32	0.40	2.80	3.35	32.04	10.3
19 - 27/31	Btc1	5.1	4.4	5.0	0.24	2.75	24.5	0.91	0.48	tr1/	0.40	1.43	0.00	2.40	3.08	37.34	12.9
31 - 41/54	Btc2	5.8	4.6	4.5	0.26	2.26	55.0	1.69	1.05	0.00	0.13	4.27	0.00	2.00	4.44	62.15	20.3
54 - 78	Btc3	6.1	6.0	3.9	0.25	1.42	75.0	2.75	1.40	0.07	0.20	4.42	0.00	2.80	5.80	61.22	26.9
78 - 85/113	Btc4	5.9	4.7	3.2	0.26	1.00	73.5	3.27	1.66	0.14	0.20	6.27	0.00	2.70	7.44	66.12	33.6
113 - 129	Bt1	5.3	3.5	2.7	0.28	0.80	59.5	5.96	3.35	0.66	0.16	10.13	2.73	6.10	15.89	66.51	31.3
129 - 192+	Bt2	5.2	3.7	2.4	0.23	1.15	57.0	6.27	3.77	0.94	0.15	11.13	0.61	2.80	13.43	79.90	16.1

Table 4 (cont.).

Depth (cm)	Horizon	pH (1:1) H_2O	pH (1:1) KCl	O.M.	Total N	Avail. P	Avail. K	Extractable bases Ca	Mg	Na	K	Sum bases	Extr. Al	Extr. acidity	CEC NH_4OAc	B.S by sum	Fe
				(--g kg^{-1}--)		(--mg kg^{-1}--)		(---cmol kg^{-1}---							)	%	(g kg^{-1})
Pedon 4																	
0 - 14	Ap	5.4	4.3	10.3	1.19	3.32	215.0	1.31	0.97	0.27	0.44	2.99	0.35	5.00	7.71	37.42	56.4
14 - 22	Ap	6.0	5.0	9.8	0.56	1.00	156.5	2.80	1.42	0.24	0.43	4.89	0.00	3.40	6.35	58.99	62.7
22 - 55	Btc1	6.4	5.3	5.2	0.47	2.09	205.0	5.37	3.22	0.27	0.40	9.20	0.00	4.00	26.24	66.81	66.2
55 - 85	Btc2	6.5	5.5	3.4	0.40	1.42	160.0	6.36	4.23	0.25	0.32	11.16	0.00	4.60	16.70	70.81	102.2
85 - 100	Btc3	5.0	3.7	2.3	0.34	1.30	150.0	8.69	7.55	0.31	0.39	16.14	2.73	5.99	24.88	76.16	22.7
100 - 115	Bt	4.9	3.6	2.2	0.31	2.44	165.0	8.89	8.32	0.37	0.40	17.98	3.84	6.80	26.79	72.56	22.2
115 - 140/170	BC	5.0	3.7	3.4	0.27	1.11	157.5	9.87	10.12	0.36	0.38	20.72	2.78	5.90	27.88	77.84	35.6
170 - 200+	C	5.0	3.5	1.6	0.23	3.66	140.0	9.70	10.94	0.67	0.33	21.64	2.02	5.00	27.33	79.44	28.2
Pedon 5																	
0 - 10	Ap	5.0	4.1	8.2	0.48	8.64	35.0	0.86	0.27	0.02	0.08	1.23	0.50	3.00	2.50	29.00	86.7
10 - 25/30	Btc	5.7	4.5	8.6	0.50	4.15	65.0	3.00	1.34	0.09	0.15	5.18	0.43	3.10	8.53	62.56	33.4
30 - 50+	Bv	5.8	5.0	6.1	0.47	1.48	86.0	3.82	1.53	0.14	0.24	5.73	0.35	5.10	10.16	51.02	83.4
Podon 6																	
0 - 10	Ap	5.0	3.9	8.0	0.44	2.21	47.5	0.39	0.34	0.08	0.09	1.50	0.71	5.50	3.35	21.43	12.4
10 - 24	Bt1	5.1	3.9	3.0	0.19	1.26	16.0	0.02	0.10	0.04	0.03	0.86	0.71	2.40	2.53	26.38	11.2
24 - 50/64	Bt2	5.2	4.0	1.7	0.09	2.09	18.0	0.39	0.15	tr[1/]	0.03	0.57	0.72	1.40	1.44	28.93	4.2
64 - 70/100	Btc	5.8	4.5	2.8	0.23	1.75	7.0	2.70	1.43	0.09	0.14	3.46	1.17	3.00	6.35	53.56	16.5
100 - 115/140	Bv	5.2	3.9	3.4	0.27	0.80	63.0	3.68	4.63	0.18	0.18	5.67	3.49	6.80	14.52	45.47	70.2
140 - 155/170	Bt3	4.7	3.4	1.7	0.24	1.05	100.0	3.12	1.53	0.22	0.26	5.13	3.40	9.19	19.97	35.90	26.1
170 - 190+	Bt4	4.6	3.3	2.0	0.23	0.85	72.5	3.73	1.67	0.21	0.21	5.82	6.21	6.80	17.52	46.12	35.1

1/ tr = trace

Table 5 Minerals in clay fraction of skeletal soils in Upper Northeast, Thailand.

Depth (cm)	Horizon	Kao.	Smec.	Chl.	Ill.	Ver.	Qtz.	Goe.	Int.	Gib.	Lep.
				1.0+1.4 nm							
Pedon 1											
0 - 10/18	Ap	xxxx	-	-	tr	tr	tr	-	-	-	-
18 - 40/48	Btc1	xxxx	-	-	tr	tr	tr	tr	-	-	-
48 - 75	Btc2	xxxx	-	tr	-	tr	-	tr	-	-	-
75 - 101	Btc3	xxxx	-	-	-	tr	-	tr	-	-	-
101 - 136	Btc4	xxxx	-	tr	-	tr	-	tr	-	-	-
136 - 154	C1	xxxx	-	-	-	tr	-	tr	-	-	-
154 - 178+	C2	xxxx	-	-	-	tr	-	tr	-	-	-
Pedon 2											
0 - 5/9	A	xx	-	x	x	-	tr	-	tr	-	-
9 - 33	Bw	xx	-	x	x	-	tr	-	tr	tr	-
33 - 59	2Btc1	xxx	-	x	x	-	-	-	tr	tr	-
59 - 75	2Btc2	xxx	-	x	x	-	-	-	tr	tr	-
75 - 92/102	3Btc3	xxx	-	x	x	-	-	-	tr	tr	-
102 - 119/125	3Bv1	xxx	-	x	x	-	-	-	tr	tr	-
125 - 168	3Bv2	xxx	-	x	x	-	-	-	tr	tr	-
168 - 173+	3C	xxx	-	x	x	-	-	-	tr	tr	-
Pedon 3											
0 - 15/19	Ap	xxx	tr	tr	x	tr	tr	-	tr	tr	-
19 - 27/31	Btc1	xxx	-	-	x	x	tr	-	tr	tr	-
31 - 41/54	Btc2	xxx	-	-	x	x	tr	-	tr	tr	tr
54 - 78	Btc3	xxx	-	tr	x	tr	tr	-	tr	tr	tr
78 - 95/113	Btc4	xxx	-	tr	x	tr	tr	-	tr	tr	tr
113 - 129	Bt1	xxx	tr	tr	x	tr	-	-	tr	-	-
129 - 192+	Bt2	xxx	tr	-	x	tr	-	-	tr	-	-
Pedon 4											
0 - 14	Ap1	xx	tr	-	xx	tr	tr	tr	-	tr	-
14 - 22	Ap2	xx	tr	tr	xx	-	-	x	-	tr	tr
22 - 55	Btc1	x	tr	tr	xx	tr	-	tr	-	tr	tr
55 - 85	Btc2	xx	tr	-	xx	x	tr	tr	tr	tr	-
85 - 100	Btc3	x	x	-	xx	tr	-	-	-	-	-
100 - 115	Bt	x	x	-	xx	-	-	-	tr	-	-
115 - 140/170	BC	tr	xx	-	xx	-	-	-	-	-	-
170 - 200+	C	tr	xx	-	xx	tr	tr	-	-	-	-
Pedon 5											
0 - 10	Ap	xx	tr	-	x	xx	tr	-	-	tr	-
10 - 25/30	Btc	xx	-	-	x	xx	-	-	tr	tr	-
30 - 50+	Bv(hardened)	xx	-	-	x	xx	-	tr	tr	tr	-
Pedon 6											
0 - 10	Ap	xx	tr	tr	xx	-	tr	-	tr	tr	-
10 - 24	Bt1	xx	tr	tr	xx	-	tr	-	tr	tr	-
24 - 50/64	Bt2	xx	tr	tr	xx	-	tr	-	tr	tr	-
64 - 70/100	Btc	xx	tr	tr	xx	-	-	-	tr	tr	-
100 - 115/114	Bv	xx	tr	tr	xx	-	-	-	tr	tr	-
140 - 155/170	Bt3	xx	-	-	xx	tr	-	-	tr	tr	-
170 - 190+	Bt4	xx	-	-	xx	tr	-	-	tr	-	-

xxxx = Dominant (> 60 %) xxx = Large (40-60 %)
xx = Moderate (20-40 %) x = Small (5-20 %)
tr = Trace (< 5 %) - = Not detected in sample
Kao. = Kaolinite, Smec. = Smectite, Chl. = Chlorite, Ill. = Illite,
Qtz. = Quartz, Ver. = Vermiculite, Goe. = Goethite, Lep. = Lepidocrocite,
Gib. = Gibbsite, Int. 1.0+1.4 nm = Interstratified clay 1.0 and 1.4 nm

Table 6 Minerals in silt fraction of skeletal soils in Upper Northeast, Thailand.

Depth (cm)	Horizon	Qtz.	Mic.	Goe.	Hem.	Gib.	0.7 nm clay	1.4 nm clay
Pedon1								
0 - 10/18	Ap	xxxx	-	tr	-	-	x	-
18 - 40/48	Btcl	xxxx	-	tr	-	tr	x	-
48 - 75	Btc2	xxxx	-	tr	-	-	x	-
75 - 101	Btc3	xxx	-	tr	tr	tr	x	-
101 - 136	Btc4	xxx	-	tr	tr	-	x	-
136 - 154	C1	xxx	-	tr	tr	tr	x	-
154 - 178+	C2	xxx	-	tr	-	tr	x	-
Pedon2								
0 - 5/9	A	xxxx	-	-	-	-	tr	-
9 - 33	Bw	xxxx	-	-	-	-	tr	-
33 - 59	2Btc1	xxxx	-	tr	tr	-	tr	-
59 - 75	2Btc2	xxxx	-	-	tr	tr	tr	-
75 - 92/102	3Btc3	xxxx	-	-	tr	tr	tr	-
102 - 119/125	3Bv1	xxxx	-	-	tr	-	tr	-
125 - 168	3Bv2	xxxx	-	-	tr	-	tr	-
168 - 173+	3C	xxxx	-	-	tr	tr	tr	-
Pedon3								
0 - 15/19	Ap	xxxx	-	-	-	-	tr	-
19 - 27/31	Btc1	xxxx	-	-	-	-	tr	-
31 - 41/54	Btc2	xxxx	-	-	-	-	tr	-
54 - 78	Btc3	xxxx	-	-	-	-	tr	-
78 - 95/113	Btc4	xxxx	tr	-	tr	-	tr	-
113 - 129	Bt1	xxxx	tr	-	tr	-	tr	-
129 - 192+	Bt2	xxxx	-	-	-	-	-	-
Pedon4								
0 - 14	Ap1	xxxx	-	-	-	-	tr	-
14 - 22	Ap2	xxxx	-	-	-	-	tr	-
22 - 55	Btc1	xxxx	-	-	-	-	-	-
55 - 85	Btc2	xxxx	tr	tr	-	-	-	-
85 - 100	Btc3	xxxx	tr	-	-	-	-	-
100 - 115	Bt	xxxx	x	-	-	-	-	-
115 - 140/170	BC	xxxx	x	-	-	-	-	tr
170 - 200+	C	xxxx	x	-	-	-	-	tr
Pedon5								
0 - 10	Ap	xxxx	-	-	-	-	tr	-
10 - 25/30	Btc	xxxx	tr	-	-	-	x	-
30 - 50+	Bv (hardened)	xxxx	-	tr	tr	-	tr	-
Pedon6								
0 - 10	Ap	xxxx	-	-	-	-	tr	-
10 - 24	Bt1	xxxx	-	-	-	-	tr	-
24 - 50/64	Bt2	xxxx	-	-	-	-	tr	-
64 - 70/100	Btc	xxxx	-	-	-	-	tr	-
100 - 115/140	Bv	xxxx	-	-	tr	-	-	-
140 - 155/170	Bt3	xxxx	-	-	tr	tr	-	-
170 - 190	Bt4	xxxx	tr	-	tr	-	-	-

xxxx = Dominant (>60%) xxx = Large (40-60%)
xx = Moderate (20-40%) x = Small (5-20%)
tr = Trace (<5%) - = Not detected in sample
Qtz. = Quartz, Hem. = Hematite, Mic. = Mica,
Gib. = Gibbsite, Goe. = Goethite

weatherable minerals (Soil Survey Staff, 1992). Mineralogical data of these soils generally support their chemical data. They do not indicate any active condition within the soils.

Landscape relationship of skeletal soils in Upper Northeast, Thailand

Figure 2 illustrates profile morphology and relative positions of the skeletal soil areas in the study on landscape with respect to mountain and major river. It is clear that morphology of skeletal soils occupying the higher part of landscape indicates the control of weathering and erosion quite remarkably. P1 shows mainly influence of chemical weathering where oxidation and leaching are major processes. Skeletal materials in the soil are generally angular to subangular and the soil environment is characteristically upland. Morphology of P2 distinctly indicates mixed control of erosion and deposition where contrasting materials in the profile can be observed. Skeletal materials in the profile are mixture of both angular materials indicating short-distance transportation and also riverine gravels with more roundness. Weathered iron oxide enriched rock fragments layer was found in the lower part of the profile and the soil environmental condition is also upland. P3 and P4 show morphology of soils on transported slope favoring deposition condition on landscape at present. Skeletal materials are collectively lateritic gravels (nodules) with different degree of roundness and sorting. The relative positions on landscape of these two profiles seem to influence their morphology makedly. P4 shows a thick surface horizon and more well sorted and more rounded nature of the gravels than that of P3. P5 occupies landscape with the same elevation as of P4 but the profile is very shallow indicating severe erosion in the past. The skeletal materials in this soil are rounded lateritic nodules and concretions and the top part of plinthite layer is hardened. In the lower part of landscape adjacent to river channel deposition condition appears to be more pronounced with thick soil layer on top of the layer with skeletal materials and plinthite. However, the rounded lateritic gravels that include both nodules and concretions in the profile also suggest past erosion of the area.

Based on profile features and their relative positions on landscape it can be generalized that at present skeletal soils on higher part of the landscape is controlled mainly by weathering and erosion and the coarse fragments or the skeletal materials are generally angular. In the lower part of the landscape the general processes controlling their features are mainly deposition and transportation since the nodules and concretions are more rounded. Presence of rounded concretions generally explains the transportation and deposition. However, selective portion of the landscape of these skeletal soils might have had severe erosion in the recent past and the condition is indicated by the hardened plinthite at a shallow depth.

Based on their morphology, landscape relationship, physical, chemical and mineralogical properties these soils have poor agricultural potential. On the higher elevation area the presence of skeltal materials, their highly leached nature and poor fertility and their susceptibility to erosion making them poorly suited for upland annual field crop cultivation. In the lower elevation range these soil areas can be developed for rice cultivation successfully with less problem on their fertility and water retention capacity. These soils, nevertheless, can be used for tree crop production with spot management practice more effectively than for upland field crops or paddy.

According to soil taxonomy (Soil Survey Staff, 1992) P1 and P4 are Paleustalfs, P2 is a Plinthustult, P3 is a Kandiustalf, P5 and P6 are Plinthustalfs and all of them have skeletal particle size class but with different nature of the fine earths.

CONCLUSION

Results of the study have revealed that the skeletal soils in Upper Northeast, Thailand have relatively poor physical and chemical properties and their mineralogy is not sufficiently supportive to their exchange activities and fertility. Their profile morphology is controlled mainly by slope processes and their positions on landscape. Within the context of their development and properties it can be concluded that they are well developed soils with poor physical and chemical properties for

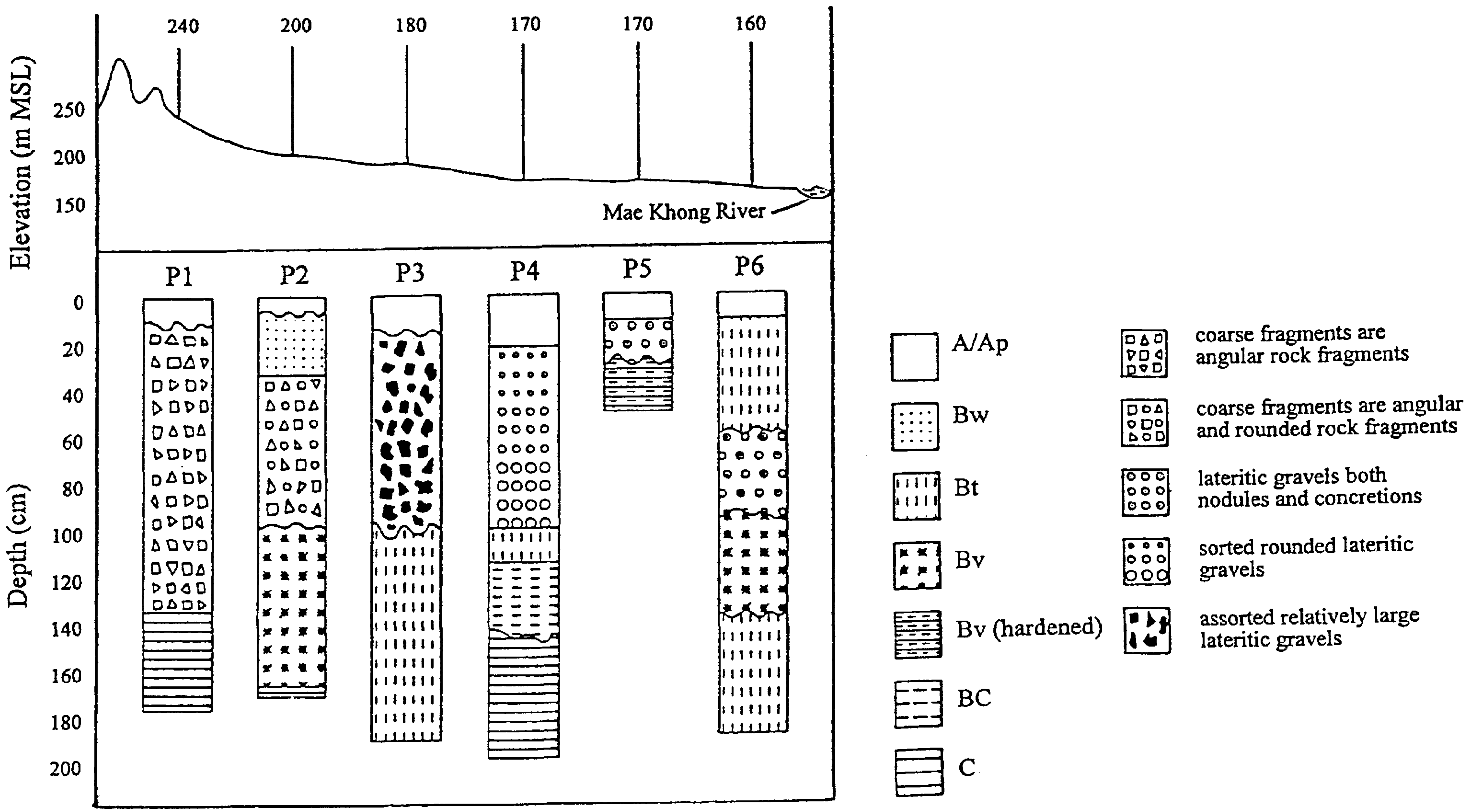


Figure 2 Profile models and landscape relationship of skeletal soils in Upper Northeast, Thailand.

crop cultivation. Their mineralogical properties in the fine earths vary but their affect is much hindered by the presence of skeletal materials. These soils cannot be used effectively for upland field crop production but in the lower elevation areas, with some land development measures they can be used for paddy rice practices successfully. It seems that the most proper use for these soils is for tree crop cultivation.

ACKNOWLEDGEMENT

This study was a part of the Project on Properties and Fertility of Skeletal Soils in Thailand supported by research fund granted through the Kasetsart University Research and Development Institute (KURDI), Kasetsart University, Bangkok.

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