Micromorphological Characteristic of Soils on the Nam Phong and Khon Buri Catenae, Northeast Thailand

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Abstract

On the basis of data from two soil catenae the relationships between the micromorphological characteristic of soils is discussed as well as the genesis of the soil minerals. Thin section analysis combined with analytical scanning electron microscopy was employed in this study. X-ray diffraction was used to identify mineral components. In the Nam Phong catena soils on the upper part are derived from colluvium of sandstone underlain by meta-sedimentary rock whereas the toeslope soil is derived from a fine grained sedimentary rock, possibly shale. For the Khon Buri catena all soils are formed on colluvium over residuum derived from weathered basalt.

For the Nam Phong catena, a bridged grain structure is the main microstructure of summit and shoulder soils, single grain structure is well expressed in midslope and footslope soils, and subangular blocky structure is predominant in the toeslope soil. The coarse material is mainly quartz grains, runi-quartz, polycrystalline quartz and chert, few sandstone rock fragments and chacedony, and rare anhedral zircon and tourmaline. A thick microlaminated ferri-argillan coating is evident in the 2C-horizon along with angular and large subangular quartz grains. This assemblage of materials indicates that there is a discontinuity of parent materials between the shoulder and midslope positions. For the Khon Buri catena, crumb and granular are the major microstructures of the crest soil. Subangular blocky structure is the main microstructure for backslope and footslope soils. The coarse materials of soils on this catena are mainly quartz grains, common runi-quartz and rare zircon and weathered pyroxene. In addition, highly weathered basalt rock fragments occur in the soils on the backslope and footslope positions, with amounts increasing with depth. Micromorphological features of soils in the lowest positions of catenae are thus different from those of upslope soils except for the minerals in coarse fraction.

For both catenae the clay fraction consists mainly of kaolin, hematite and goethite for upslope soils and 2:1 clay minerals for lowland soils. Kaolin-iron oxide clay coats pore walls and quartz grains in upslope soils indicating illuviation and eluviation. The matrix of upslope soils is characterized by a high degree of homogeneity, a red to reddish yellow color and undifferentiated b-fabric. The yellow groundmass of soils at the lowest positions contains much 2:1 clay mineral together with carbonate nodules reflecting the high pH of these soils.

Keywords: soil catena, b-fabric, quartz, lithorelict, pedogenesis

Introduction

The Northeast of Thailand is occupied by a plateau underlain by various sedimentary rocks along with some igneous rocks. The elevation of this region, excluding high hills and mountains ranges is between 150-250 m MSL. This region is under a tropical savanna climate with an average mean annual rainfall of 1,300 mm year^{-1} and the average temperature is 26^{o}C. Most of soils in this region are highly weathered exhibiting quite poor chemical status. For soils formed on young geomorphic surfaces, their properties are directly affected by the weathering rock which often contains high amounts of weatherable minerals. In contrast, soils on old geomorphic surfaces have properties that are independent of the parent rock which is a common situation for tropical regions. Micromorphological properties are widely applied in studies of soil formation (Eswaran, 1972; Eswaran et al., 1975; Kheoruenromne, 1978; Stoop, 1991; Stoop, 1994), to evaluate the intensity of weathering of soils (Bennema et al., 1970; Hussein and Adey, 1998), and are related to chemical properties (Schaefer, 2001; Schaefer et al., 2002). Soil micromorphological characteristics not only provide evidence of current pedogenesis but also indicate processes which the soil has undergone during its development (Eswaran, 1972).

The purpose of this paper is to characterize the micromorphological properties of soils in two catenae and to relate them to the development of the soils and physico-chemical properties of the soils.

Materials and Methods

Study Site

The Nam Phong and Khon Buri catenae are in Khon Kaen and Nakhon Ratchasima Provinces respectively in Northeast Thailand (Figure 1). The Nam Phong catena can be divided into 6 geomorphic positions: summit (SU: Typic Kandiustult), shoulder (SH: Kandic Paleustalf), upper midslope (UM: Typic Haplustalf), lower midslope (LM: Typic Haplustalf), footslope (FS: Oxic Dystrustept) and toeslope (TS: Aeric Endoaqualf). Altitudes are 209, 206, 202, 199, 191 and 180 m MSL respectively. Their coordinates range from 48 267414^{E} – 48 2678346^{E} and 18 55617^{N} – 18 55419^{N} from the highest position to the lowest position on the catena. The catena length is about 1 km. The Nam Phong catena has developed on sedimentary rocks of the upper Triassic to Cretaceous Khorat group and lower Tertiary to lower Pleistocene Krabi group. Soils from the summit to footslope positions are on the Khok Kruat formation of the Khorat group. The soil on the toeslope position is on Quaternary deposits of the Krabi group. The Khok Kruat formation consists of red to purplish gray bedded sandstone, siltstone and shale with interbedded calcareous conglomeratic sandstone, sandy limestone and calcareous siltstone which is mottled with purplish gray and greenish gray colors. The Quaternary Khok Kruat floodplain deposit comprises unconsolidated silt, clay, sand and gravel (Suwanasing, 1972). Soils on the summit to footslope positions are occupied by cultivated cassava fields but the main land use at the toeslope position of this catena is paddy rice field. For the Khon Buri catena, four soils were sampled on an undulating basaltic lava corrosion plain. This catena transect has a northeast-facing slope and soils are considered to have formed on residuum or/and colluvium derived principally from basalt. The elevations above sea level are 275, 271, 233 and 225 m for the four soils on this catena. The soils sampled were on crest (CT: Rhodic Kandiustox), backslope (BS: Typic Kandiustult), footslope (FS: Typic Plinthustult) and valley floor (VF: Typic Endoaquert) positions. Their coordinates range from 48 0205863^{E} - 48 0203086^{E} and 16 16056^{N} - 16 13349^{N} from the highest position to the lowest position on the catena. The catena length is about 5 km. The land uses are mainly cassava cultivation with some jackfruit, mango, sugarcane and rice.

Laboratory Analysis

Laboratory investigation included petrographic analysis of thin setions. Undisturbed soil samples of selected horizons were impregnated with a resin:monostryrene mixture using a benzoyl peroxide ($C_{14}H_{10}O_4$) catalyst. The resin mixture was poured onto samples at atmospheric pressure, followed by a period in a vacuum oven at 60 ^{o}C while the pressure was slowly increased from 10 to

65 cm Hg, and then the samples were left for 4 hours. Impregnated samples were cut into 0.5 cm thick slabs using a diamond saw and polished with corundum abrasives from 250 mesh down to 600 mesh. After ultrasonic cleaning, the polished samples were mounted onto glass slides followed by polishing and hand-finishing to produce thin sections of 0.03 mm thickness. The thin sections were analyzed under a polarizing microscope using standard micromorphological techniques as described by Bullock et al. (1985). Selected areas described under the polarizing microscope were examined by scanning electron microscopy with energy dispersive X-ray analysis (SEM/EDS) to determine the composition of the soil plasma matrix and nodules.

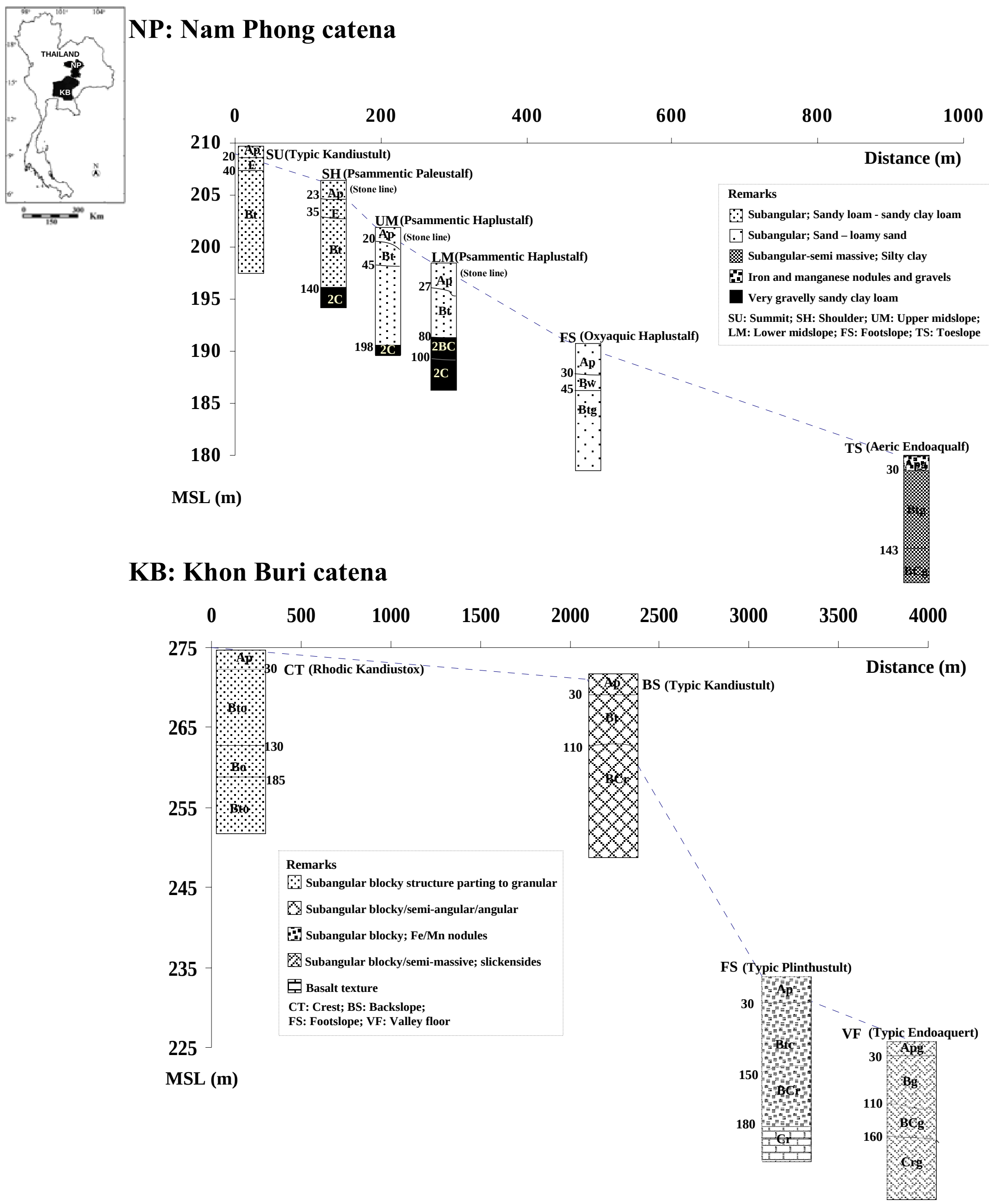

Figure 1 The catenary distribution of the soil profiles sampled on Nam Phong and Khon Buri catenae Northeast Thailand.

Semi-quantitative determination of minerals was by XRD of oriented clay samples on porous ceramic plates using CuKα radiation with a Philips diffractometer equipped with graphite monochromator and operating at 50 KV and 20 mA. The XRD scans extended from from 3 to 40° 2θ, using a step size of 0.02° 2θ and a scan speed of 0.02° 2θ sec^{-1}. Relative proportions of various minerals were calculated by comparing the XRD peak intensity with the intensities for standard minerals (Whittig, 1965; Klug and Alexander, 1974; Brindley and Brown, 1980).

Results and Discussion

Soil Morphology

Field morphology, particle size distribution, pH and soil features for the Nam Phong and Khon Buri catenae are given in Table 1. Changes of soil color within catenae are obvious in the field. The upslope soils on both catenae experience a continuous well drained condition, hence their red to dark red color with a lack of redoximorphic features. The lowest positions on catenae are poorly drained and have features characteristic of aquic conditions throughout the soil profiles. The upslope soils exhibit acidic conditions (pH 4.5-6.5) whereas the two lowest soil profiles are alkaline which is associated with the presence of $CaCO_3$. The accumulation of the clay in subsoil horizons of upslope soils is apparent in the field. Clay is coated onto pore walls and ped faces. For soils at the lowest positions, cracks and slickensides are well expressed in both surface and subsurface horizons.

Soils on the Nam Phong catena, have textures ranging from sandy-loamy sand to sandy-sandy clay loam for the top soil and the sub surface horizons respectively. Iron and manganese oxide nodules occur at 5-30 cm depth in the toeslope soil due to seasonal redox variations associated with the high water table. In addition, there is evidence of an abrupt change in materials from the Bt-horizon to the 2BC or 2C horizon at the shoulder and midslope positions because of a presence of various sized up to 3 cm rock fragment gravels in the 2BC or 2C horizon (i.e. a stone line). Hence, parent material unconformities are recognized in the field at shoulder and midslope positions.

All soils on Khon Buri catena have a clayey texture. Many iron and manganese nodules occur throughout the soil profile on the footslope position whereas only a few are present in the deep horizons of the soil on the backslope position. The presence of iron and manganese nodules in soils indicates the occurrence of wetting and drying periods inducing pedogenic redox processes (Acquaye et al., 1992). Small fragments of basalt are common in some horizons at all catena positions and weathered basalt bedrock is present in the deepest horizon of the soils on backslope and footslope positions.

Mineralogy

Semi-quantitative analyses of the minerals in the clay fraction are given in Table 2. Kaolin is the major clay mineral in upslope soils on both catenae. Soils on upper positions of catenae experience a leaching, base depleting environment due to the high rainfall resulting in the formation of kaolin and sesquioxides (Vijarnsorn and Fehrenbacher, 1973; Gallez et al., 1976; Boonsompoppunth, 1984; Suddhiprakarn et al., 1985). The 2:1 clay minerals dominate the clay fraction of soils on the lowest position on the landscape with their type presumably depending on the type of basic cations in soil solution. Relatively high K and Mg in soil solution induces the formation of illite rather than smectite. In the toeslope soil of Nam Phong catena, ions leached from upslope accumulate providing a higher pH and a favorable geochemical environment (high K) for formation of illite (Fanning et al., 1989). Soil on the valley floor of the Khon Buri catena is poorly drained and is saturated with water for at least some of the year. Reduced iron together with the accumulation of dissolved ions (Si, Al, Mg) from the leached profiles upslope have reacted to precipitate smectite (Harder, 1972) rather than illite. The relative abundance of illite and smectite in soil of the lowest positions on landscape represents contrasting situations of neogenesis of clay minerals. Quartz is present in the clay fraction of all soils on the Nam Phong catena, as generally occurs for soils in Northeast Thailand (Sindhusen, 1984; Suddhiprakran et al., 1985; Suddhiprakran and Kheoruenromne, 1992).

Table 1 Field morphology, particle size distribution, pH and soil features for the Nam Phong and Khon Buri catenae.

Depth (cm)	Horizon	Color (moist)		Field pH	Particle size distribution (g kg^{-1})			Structure[1/]	Other
		Matrix	Mottle		Sand	Silt	Clay		
Nam Phong catena									
Summit: Typic Kandiustult									
0-20	Ap	7.5YR5/4	-	6.3	851	104	46	12fmsbk	-
20-40	E	5YR6/8	-	6.4	830	114	56	12fmsbk	Few faint clay bridges among sand grains and few faint clay coats on ped faces and pore walls.
40-205+	Bt	2.5YR4/8	-	5.0	707	101	192	2fmsbk	Common few faint clay bridges among sand grains and few faint clay coats on ped faces and pore walls.
Shoulder: Psammentic Paleustalf									
0-23	Ap	10YR5/4	-	6.6	832	118	51	12fmsbk	-
23-35	E	7.5YR6/6	-	6.9	804	141	56	2fmsbk	-
35-140	Bt	7.5YR6/6	-	5.1	725	130	146	2fmsbk	Common distinct faint clay bridges among sand grains and common prominent clay coats on ped faces and pore walls.
140-190+	2C	2.5YR4/6	-	5.0	540	159	301	3fmsbk	Few distinct faint clay bridges among sand grains and few faint clay coats on ped faces and pore walls.
Upper midslope: Psammentic Haplustalf									
0-30	Ap	10YR4/3	-	6.0	909	61	30	1fmsbk	-
30-45	E	10YR5/4	-	6.3	888	87	25	1fmsbk	-
45-198	Bt	7.5YR6/6	-	5.9	855	96	49	1fm3fmsbk	Few distinct faint clay bridges among sand grains and clay coats on pore walls.
198-210+	2C	7.5YR7/6	-	5.3	678	101	221	2fmsbk	Few distinct faint clay bridges among sand grains and clay coats on pore walls.
Lower midslope: Psammentic Haplustalf									
0-35	Ap	10YR5/3	-	4.8	914	61	25	12fmsbk	-
35-80	Bt	10YR6/6	-	5.2	872	89	38	1fmsbk	Very few faint clay bridges among sand grains.
80-100	2BC	7.5YR6/6	-	5.0	870	75	55	1fmsbk	-
100-180+	2C	2.5YR4/8	-	4.9	680	78	243	m	Common faint clay coats on pore walls.
Footslope: Oxyaquic Haplustalf									
0-30	Ap	10YR4/2	-	5.3	895	93	13	12fmsbk	-
30-45	Bw	10YR7/3	-	5.4	894	101	5	1fmsbk	-
45-130+	Bt	7.5YR7/4	-	5.5	884	104	12	1fmsbk	Few faint clay bridges among sand grains and clay coats on pore walls.
Toeslope: Aeric Endoaqualf									
0-5	Apg	10YR5/3		6.0	723	191	86	3fmse-abk	-
5-30	Btcg	10YR6/4	2.5Y7/2 2.5YR4/6	7.0	401	245	354	3fmsbk	Few faint clay bridges among sand grains and few faint clay coats on ped faces and pore walls.
30-143	Btg	2.5Y6/6	2.5Y8/1 2.5Y7/2	8.9	228	372	401	1cabk; se-abk	Common distinct clay coats on pore walls and ped faces.
143-195+	BCg	5Y7/1	10YR5/8	9.1	68	472	460	1cabk; se-abk	Few faint clay coats on pore walls and ped faces.
Khon Buri catena									
Crest: Rhodic Kandiustox									
0-30	Ap	10R3/3	-	4.0	106	240	654	2fmsbk-3fg	Many roots, common clay balls, few rock fragments.
30-130	Bto	10R3/3	-	4.5	81	84	835	3mcabk	Many roots, few clay balls, few rock fragments.
130-185+	Bo	10R3/3	-	4.5	71	73	856	2fmsbk-cg	Few roots, common clay balls, very few rock fragments.

Table 1 Cont.

Depth (cm)	Horizon	Color (moist)		Field pH	Particle size distribution ($g\ kg^{-1}$)			Structure[1/]	Other
		Matrix	Mottle		Sand	Silt	Clay		
Backslope: Typic Kandiustult									
0–30	Ap	5YR3/3	-	6.5	243	221	536	2fmsbk-3fg	Common tubular roots, few clay balls, common rock fragments.
30-119	Bt	2.5YR4/6	-	5.5	138	115	747	3fmabk	Few roots, few clay balls, few crack, few rock fragments.
119-180+	BCr	2.5YR4/6	-	5.5	188	152	660	2fmse-abk	Very few roots, common clay balls, many rock fragments and gravel, traces of ant's nest.
Footslope: Typic Plinthustult									
0–30	Ap	5YR3/3	-	6.5	491	176	334	1mcsbk	Many roots, few clay balls, many gravels.
30-150	Btc	2.5YR3/6	-	4.5	207	112	681	2mcsbk	Common roots, few clay balls, many gravels.
150-180	BCrt	5YR3/4	-	4.0	199	177	624	1,2mcsbk	Few roots, common clay balls, many gravels.
180-197+	Cr	2.5Y6/1	-	6.5	-	-	-	-	Basalt texture.
Valley floor: Typic Endoaquert									
0-25	Apg	10YR3/2		7.5	143	265	592	2fmsbk	Many roots, few rock fragments, few pressure faces.
25-50	Bssg	2.5Y3/1		8.0	56	224	720	1cabk-se-m	Few roots, few clay balls, common pressure faces, common slickenside.
50-110	Bg	2.5Y4/1	10YR5/6, 5YR4/6, 2.5Y4/4, 2.5Y3/3, 5Y7/8	8.0	55	169	776	2fmsbk	Very few roots, common clay balls, common slickenside, few pressure faces, few rock fragments.
110-160	BCg	Mixed 10Y3/1, 5Y3/2		8.0	131	171	698	1cabk-r	Very few roots, few clay balls, few slickenside, few pressure faces, few rock fragments.
160-180+	Crg	Mixed 2.5Y3/1, 10GY3/2		8.0	188	296	516	1fmabk-r	No roots, few pressure faces, few variegated sand and rock fragments.

[1/] 1 = weak, 2= moderate and 3 = strong; f = fine, m = medium and c = coarse; abk = angular blocky structure, sbk =subangular blocky structure, se-abk= semi-angular blocky structure, m = massive and g = granular structure and R = rock structure.

Description of Main Micromorphological Features

A summary of micromorphological features of the soils on the Nam Phong and Khon Buri catenae are given in Table 3.

Microstructure

In the soils of the Nam Phong catena, pellicular grain structure and bridged grain structure are the main microstructures of the soils on the upslope positions indicating that these soils are highly developed. Single grain structure is well expressed in soils on the midslope and footslope positions. The toeslope soil is dominated by bridged grain structures and subangular blocky structure along with local intergrain microaggregates. For the Khon Buri catena, soil on the crest position has granular mixed with subangular blocky structures and locally a crumb structure, which is interpreted to result from long term biological activity (Nunes et al., 2000; Schaefer, 2001). Subangular blocky structure is mainly microstructure for the soils on the backslope and footslope positions. Granular structure is also present in the topsoil of soils on the footslope position. The subangular blocky structure and locally a crack structure are well expressed in the valley floor soil.

Table 2 Semi-quantitative mineralogy of the clay fraction of soils for Nam Phong and Khon Buri catenae.

Depth (cm)	Horizon	Mineral in clay fraction[1/]							
		Kao	Ill	Ver	Int	Sm	He	Goe	Q
Nam Phong catena									
Summit: Typic Kandiustult									
0-20	Ap	xxx	-	tr	-	-	tr	x	x
20-40	E	xxx	tr	tr	-	-	tr	x	x
59-73	Bt2	xxx	tr	tr	-	-	tr	x	x
142-172+	Bt5	xxx	tr	tr	-	-	tr	x	x
Shoulder: Psammentic Paleustalf									
0-23	Ap	xxxx	-	-	-	-	-	x	x
23-35	E	xxx	tr	-	-	-	-	x	x
58-82+	Bt2	xxx	tr	-	-	-	-	x	x
Upper midslope: Psammentic Haplustalf									
0-20/30	Ap	xxx	tr	-	-	-	-	tr	xx
30-45	E	xxx	tr	-	-	-	-	tr	xx
67-100	Bt2	xxx	x	-	-	-	-	tr	x
155-182+	Bt5	xxx	x	-	-	-	-	tr	x
Lower midslope: Psammentic Haplustalf									
0-27/35	Ap	xxx	x	-	-	-	-	tr	xx
46-63	Bt2	xxx	x	x	-	-	-	tr	x
80-100+	2BC	xxx	x	x	-	-	-	tr	x
Footslope: Oxyaquic Haplustalf									
0-10/20	Ap1	xxx	x	tr	-	-	-	tr	xx
30-45	Bw	xxx	xx	tr	-	-	-	tr	xx
45-80	Bt	xxx	xx	tr	-	-	-	tr	xx
110-130+	Btg2	xxx	xx	tr	-	-	-	tr	xx
Toeslope: Aeric Endoaqualf									
0-5	Apg	xx	xx	x	-	-	-	tr	-
5-23/30	Btcg	xx	xxx	x	-	-	-	tr	-
30-48	Btg1	xx	xxx	x	-	-	-	tr	-
80-113	Btg3	x	xxx	xx	-	-	-	-	-
162-195+	BCg2	x	xxx	xx	-	-	-	-	-
Khon Buri catena									
Crest: Rhodic Kandiustox									
0-15	Ap1	xxxx	-	-	-	-	xxx	-	x
30-51	Bto1	xxxx	-	-	-	-	xx	-	x
73-100	Bto3	xxxx	-	-	-	-	xx	-	x
130-160	Bo1	xxxx	-	-	-	-	xx	-	x
185-205+	Bto5	xxxx	-	-	-	-	xx	-	x
Backslope: Typic Kandiustult									
0-11	Ap1	xxxx	-	-	-	-	-	xx	x
30-59	Bt1	xxxx	-	-	-	-	-	xxx	x
88-119	Bt3	xxxx	-	-	tr	-	-	xx	x
119-151+	BCr1	xxxx	-	-	tr	-	-	xxx	x
Footslope: Typic Plinthustult									
12-30	Ap2	xxxx	-	-	-	-	x	xx	x
30-52	Btc1	xxxx	-	-	tr	-	tr	xx	x
72-103	Btc3	xxxx	-	-	-	-	x	xx	x
130-150	Btc5	xxxx	-	-	tr	-	tr	xx	x
150-180+	BCrt	xxxx	-	-	x	-	tr	xx	x
Valley floor: Typic Endoaquert									
0-15	Apg	xx	-	-	-	xxx	-	x	x
25-50	Bssg	xx	-	-	-	xxxx	-	x	x
76-100/110	Bg2	x	-	-	-	xxxx	-	-	x
133-160	BCg2	x	-	-	-	xxxx	-	-	x
160-180+	Crg	x	-	-	-	xxxx	-	-	x

[1/] Kao = kaolin, Int = Interstratified 10 Å and 14 Å minerals, Sm = smectite, Ill=Illite, Ver=Vermiculite, He = hematite, Goe = goethite, Q = quartz, Ana = anatase; tr = < 5%, x = 5-20%, xx = 20-35%, xxx = 35-50%, xxxx = > 50%.

Voids and porosity

The main voids are simple packing voids along with few vughs, chambers and vesicles present in the upslope soils on the Nam Phong catena. Planar voids are the major voids along with chambers, vughs and channel voids in soil on the lowest position of both catenae. For the Khon Buri catena, the compound packing void is the main void type inupslope soils. Both smooth and rough edge voids occur. Planar voids are usually intra-aggregate and consisting of straight and zig-zag types.

b-fabric and groundmass

For the soils on Nam Phong catena, the c/f related fabric is mainly chitonic in the topsoil for upslope soils. The presence of gefuric fabric is obvious in the deep horizons of soils on summit and shoulder positions and is rare in deep horizons of soils on midslope and footslope positions. The c/f related fabric is mainly gefuric in the toeslope soil while locally it is enaulic in topsoil; also the closed prophyric fabric is found in the subsurface horizons. The c/f related fabric of all soils on the Khon Buri catena is open porphyric due to the presence of a continuous fine matrix.

The undifferentiated b-fabric of upslope soils on both catenae is possibly due to the enrichment of Fe resulting in a brownish to dark red color which was intense enough to cause opacity. Grano- to porostriated b- fabrics are also clearly expressed in the deep horizon of upslope soils. Circular striae occur only in deep horizon of the soil on the crest on the Khon Buri catena. The humified organic fine materials scattered in groundmass are apparent in the topsoil and decreases down the soil profiles. The stipple speckling is mainly b-fabric along with few grano- to porostriated b- fabric of the soils on the lowest positions on catena. The speckled b-fabric is generally found in flooded soils with high clay content indicating weak plasma separation, a result of restricted swelling clay (Kalbande et al., 1992). Only crystallitic b-fabric is present in the deep horizon of the soil on the toeslope of the Nam Phong catena. The lack of grano- and porostriate b-fabric in the topsoil of the valley floor soil on the Khon Buri catena agrees with results of many researchers (Blokhuis et al., 1990; Hussein and Adey, 1998) who reported that surface-related plasma separations (porostriation and granostriation) are rare or lacking in surface horizon of Vertisols but generally increase with depth due to a greater stresses and shearing in subsurface soil.

Coarse material components in soils

Soils on all positions of the Nam Phong catena contain quartz grains, runi-quartz, polycrystalline quartz and chert, few sandstone rock fragments and chacedony, and rare anhedral zircon and tourmaline. Chert is common in sandstone derived soils in Northeast Thailand (Dabbakula Na Ayudhya, 1994). Soils at Khon Buri contain mainly quartz grains, common runi-quartz and rare zircon and weathered pyroxene. The presence of runi-quartz points to a material derived, at least partially, from the destruction of an older surface (Eswaran et al., 1975). The presence of resistance Ti minerals and magnetite in upslope soils on the Khon Buri catena indicates the influenced of the mafic parent material (Schaefer et al., 2002). Quartz is a ubiguitous constituent of these soils, due to quartz being a highly resistant mineral in soils (Sudom and Arnaud, 1971; Cornu et al., 1999; Stiles et al., 2003). Soils on the backslope and footslope positions of the Khon Buri catena contain weathered pyroxene and highly weathered basalt rock fragments (lithorelicts) that increase in abundance with depth indicating that the soil on the crest position is more highly weathered than soils on backslope and footslope positions.

Nature of the Soil Plasma of the Catenae

Clay illuviation

Figure 2 shows various coatings on pore wall, ped and quartz grains in the catenae. The presence of illuviation ferri-argillans is considered to be evidence for clay translocation within the soil profile. In the soils on the Nam Phong catena, the micro-laminanted clay coating is clearly observed in the deep horizons of soils on summit and shoulder positions. The thin to thick ferri-argillan coating along with gray silty clay cappings on grains occurs in soils on the midslope and footslope positions. It indicates that translocation and accumulation of fine material take place within the soil profiles. The soils on the backslope and footslope positions on the Khon Buri catena, have ferri-agrillan coating on pore walls and ped surfaces. However there is little of this coating in

Table 3 Soil micromorphological feature of soils on the Nam Phong and Khon Buri catenae.

Horizon	Microstructure	c:f at 10 μm	c/f related	b-fabric	Pedofeature
Nam Phong catena					
Summit: Typic Kandiustult					
Ap (0-20 cm)	Pellicular grain, bridged grain	95:5	Chitonic	Undifferentiated	Typic nodules, excrements of animal
E (20-40 cm)	Pellicular grain, bridged grain	90:10	Chitonic	Undifferentiated, grano-porostriated	Clay-iron oxide coating
Bt2 (59-73 cm)	Pellicular grain, bridged grain	85:15	Chitonic	Undifferentiated, grano-porostriated	Clay-iron oxide coating, microlaminated coating
Bt4 (105-142 cm)	Bridged grain, pellicular grain	80:20	Gefuric	Undifferentiated, grano-porostriated	Clay-iron oxide coating, microlaminated coating
Bt6 (172-205+ cm)	Bridged grain, pellicular grain	70:30	Gefuric	Undifferentiated, grano-porostriated	Clay-iron oxide coating, microlaminated coating
Shoulder: Psammentic Paleustalf					
Ap (0-23 cm)	Compact grain	90:10	Chitonic	Undifferentiated	Iron impregnative nodules
E (23-35 cm)	Compact grain	92:8	Chitonic	Undifferentiated	Iron impregnative nodules
Bt1 (35-58 cm)	Pellicular grain, bridged grain	85:15	Gefuric	Undifferentiated, grano-porostriated	Clay-iron oxide coating
Bt2 (58-82 cm)	Bridged grain	80:20	Gefuric	Undifferentiated, grano-porostriated	Clay-iron oxide coating, microlaminated coating
Bt3 (82-110 cm)	Bridged grain	80:20	Gefuric	Undifferentiated, grano-porostriated	Clay-iron oxide coating, microlaminated coating, iron impregnative nodules
2C (140-190+ cm)	Subangular blocky	85:15	Close prophyric	Undifferentiated, grano-porostriated	Clay-iron oxide coating, microlaminated coating
Upper midslope: Psammentic Haplustalf					
Ap (0-20/30 cm)	Single grain	98:2	Monic	Undifferentiated	-
E (30-45)	Single grain	98:2	Monic	Undifferentiated	-
Bt1 (45-67 cm)	Bridged grain, single grain	92:8	Gefuric, monic	Undifferentiated	Clay bridging
Bt3 (100-130 cm)	Bridged grain, single grain	90:10	Gefuric	Undifferentiated	Clay-iron oxide coating
Bt5 (155-182 cm)	Bridged grain	85:15	Gefuric	Undifferentiated	Clay-iron oxide coating, silty clay capping, psedomorphic nodules
Lower midslope: Psammentic Haplustalf					
Ap (0-27/35 cm)	Single grain, bridged grain	93:7	Monic, gefuric	Undifferentiated, stipple speckled	-
Bt2 (46-63 cm)	Bridged grain	90:10	Gefuric	Undifferentiated	Clay-iron oxide coating, iron oxide impregnative material
2BC (80-100 cm)	Bridged grain	90:10	Gefuric	Undifferentiated	Clay-iron oxide coating, iron oxide impregnative material, psedomorph after rock fragments
2C2 (130-180+ cm)	Bridged grain	90:10	Gefuric	Undifferentiated, poro-granostriated	Clay-iron oxide coating, microlaminated coating

Table 3 Cont.

Horizon	Microstructure	c:f at 10 µm	c/f related	b-fabric	Pedofeature
Footslope: Oxyaqic Haplustalf					
Ap1 (0-10/20 cm)	Single grain, bridged grain and intergrain microaggregate	95:5	Monic, gefuric, enaulic	Undifferentiated	-
Ap2 (20-30 cm)	Single grain, bridged grain and intergrain microaggregate	95:5	Monic, gefuric	Undifferentiated	-
Bw (30-45 cm)	Single grain, bridged grain and intergrain microaggregate	95:5	Monic, gefuric	Undifferentiated	-
Bt (45-80 cm)	Single grain, bridged grain and intergrain microaggregate	95:5	Monic, gefuric	Undifferentiated	-
Btg1 (80-110 cm)	Compact grain	95:5	Monic, gefuric	Undifferentiated	-
Toeslope: Aeric Endoaqualf					
Apg (0-5 cm)	Bridged grain, intergrain microaggregate	75:25	Gefuric, enaulic	Stipple speckled	Typic nodules, iron oxide impregnative nodules
Btcg (5-23/30 cm)	Subangular blocky	70:30	Close prophyric	Stipple speckled, poro-granostriated	Clay coating, iron oxide impregnative nodules, aggregate nodules
Btg1 (23-48 cm)	Subangular blocky	60:40	Close prophyric	Stipple speckled, poro-granostriated	Clay coating, iron oxide impregnative nodules, aggregate nodules, carbonate impregnative material
Btg2 (48-80 cm)	Subangular blocky	20:80	Close prophyric	Stipple speckled, poro-granostriated	Clay coating, iron oxide impregnative nodules, aggregate nodules, carbonate impregnative material
Btg4 (113-143 cm)	Subangular blocky	5:95	Close prophyric	Stipple speckled, poro-granostriated	Aggregate mottle, carbonate impregnative material, slickenside
BCg1 (143-162 cm)	Subangular blocky	5:95	Close prophyric	Stipple speckled, poro-granostriated	Aggregate mottle, carbonate impregnative material, clay coating, microlaminated coating
Khon Buri catena					
Crest: Rhodic Kandiustox					
Ap2 (15-30 cm)	Granular, subangular blocky, crumb	15:85	Open prophyric	Undifferentiated, poro-granostriated	Microlaminated coating, clay infilling
Bto1 (30-51 cm)	Granular, crumb, subangular blocky	8:92	Open prophyric	Undifferentiated, poro-granostriated	Typic nodules
Bto3 (70-100 cm)	Granular, crumb, subangular blocky	5:95	Open prophyric	Undifferentiated, Circular, poro-granostriated	Clay-iron coating, clay infilling, impregnative nodules
Bo1 (130-160 cm)	Crumb, granular, subangular blocky	2:98	Open prophyric	Undifferentiated, circular, poro-granostriated	Clay-iron coating, clay infilling, impregnative nodules
Backslope: Typic Kandiustult					
Ap2 (11-28/30 cm)	Subangular blocky, granular	15:85	Open prophyric	Undifferentiated, poro-granostriated	Clay fragment, typic nodules
Bt1 (30-54 cm)	Subangular blocky	12:88	Open prophyric	Undifferentiated, poro-granostriated	Clay fragment, typic nodules
Bt2 (59-88 cm)	Subangular blocky	8:92	Open prophyric	Undifferentiated, poro-granostriated	Clay fragment, typic nodules, psedomorphic nodules
BCr1 (119-151 cm)	Subangular blocky	10:90	Open prophyric	Undifferentiated, poro-granostriated	Clay fragment, typic nodules, psedomorphic nodules

Table 3 Cont.

Horizon	Microstructure	c:f at 10 µm	c/f related	b-fabric	Pedofeature
Footslope: Typic Plinthustult					
Ap2 (12-30 cm)	Granular	20:80	Open prophyric	Undifferentiated	Typic nodules, psedomorphic nodules
Btc2 (52-72 cm)	Subangular blocky, granular	25:75	Open prophyric	Undifferentiated	Typic nodules, psedomorphic nodules, clay fragment
Btc4 (103-130 cm)	Subangular blocky, Granular	25:75	Open prophyric	Undifferentiated	Typic nodules, psedomorphic nodules, clay fragment
BCrt (150-180 cm)	Granular, subangular blocky	25:75	Open prophyric	Undifferentiated	Typic nodules, psedomorphic nodules, clay fragment
Valley floor: Typic Endoaquert					
Apg (0-15 cm)	Subangular blocky, crack	10:90	Open prophyric	Stripple speckled, iron stain	Clay coating, aggregate iron mottle, typic nodule
Bssg (25-50 cm)	Crack, subangular blocky	10:90	Open prophyric	Stripple speckled, mosaic speckled, poro-granostriated	Clay fragment, aggregate iron mottle, typic nodule
Bg2 (76-100/110 cm)	Crack, subangular blocky	8:92	Open prophyric	Stripple speckled, mosaic speckled, poro-granostriated	Clay fragment, aggregate iron mottle, typic nodule
BC1 (110-133 cm)	Subangular blocky, crack	15:85	Open prophyric	Stripple speckled, mosaic speckled, poro-granostriated	Clay fragment, aggregate iron mottle, typic nodule, carbonate impregnative material
Crg (160-180+ cm)	Subangular blocky, crack	20:80	Open prophyric	Stripple speckled, mosaic speckled, poro-granostriated	Clay fragment, aggregate iron mottle, typic nodule, carbonate impregnative material

the crest soil. Clay fragments and clay infilling occur in soils on the backslope, footslope and valley floor positions possibly representing transported clay material from upslope. The argillans and ferri-argillans on skeleton grains and pore walls indicate prolonged leaching and the oxidizing state of the solum (Kheoruenromne, 1987) of the soil on the high position of the landscape.

Fabric characteristics and development

As all soil formation processes affect the plasma directly or indirectly a study of the plasma could indicate the development of the soil as a whole. Soil plasma of the upslope soils on both catenae have dark reddish brown, brown, reddish yellow reddish brown, dark red colors whereas yellowish brown and gray colors occur for the lowest soils on catenae. Generally, the difference in plasma color attributes a difference in the Fe content of soils (Bennema et al., 1970). The red shade of color of the fine material indicates that these soils are well-drained and that oxidizing conditions prevail. For the upslope soils on both catenae, soil plasma shows birefringence under polarized light which possibly be associated with oriented clay minerals. EDS analysis of soil plasma in thin sections (Table 4) of the soils from the lowest position in the catenae and exhibiting yellow and brown colors shows that the Fe_2O_3 concentrations are almost equal to those for upslope soils and that these soils contain microcrystalline iron oxides.

The element composition of the soil plasma was determined by EDS analysis at many points (up to 5-15 points per horizon) in thin sections (Table 4). All plasma of soils on both catenae contain mainly Al_2O_3, SiO_2 and Fe_2O_3 reflecting the presence of kaolin and iron oxides. A slightly higher Si concentration than ideal kaolin in the ternary diagram is possibly due to very fine quartz distributed in the soil plasma. The quite high content of K_2O of soils in low positions on the Nam Phong catena reflects the presence of illite which is abundant in the toeslope soils. For the valley floor on the Khon Buri catena, Mg has a relatively higher concentration than that for other basic cations which is associated with the presence of smectite.

Table 4 Average oxide element concentration in the soil plasma for Nam Phong and Khon Buri catenae[1/].

Depth (cm)	Horizon	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	K_2O	CaO	MgO	MnO
		(------------			%				------------)
Nam Phong catena									
Summit: Typic Kandiustult									
0-20	Ap	25.17	53.00	10.03	2.45	0.51	6.09	1.15	nd
20-40	E	35.67	50.99	10.87	0.96	0.81	0.32	0.37	nd
59-73	Bt2	35.19	51.38	10.94	1.20	0.62	0.20	0.37	nd
105-142	Bt4	26.53	64.10	6.54	1.10	1.11	0.12	0.46	nd
172-205	Bt6	34.52	50.25	12.34	1.37	0.89	0.11	0.51	nd
Shoulder: Psammentic Kandiustalf									
0-23	Ap	8.97	86.83	3.32	0.32	0.41	0.00	0.15	nd
23-35	E	32.05	56.49	8.41	1.14	1.25	0.20	0.46	nd
35-58	Bt1	25.44	60.28	8.85	3.68	1.43	0.02	0.26	nd
58-82	Bt2	32.82	56.93	8.08	0.59	0.96	0.35	0.27	nd
82-110	Bt3	36.02	49.82	11.52	1.02	0.96	0.23	0.44	nd
140-190+	2C	36.05	49.34	11.44	1.07	1.06	0.35	0.69	nd
Upper midslope: Psammentic Haplustalf									
45-67	Bt1	27.14	61.27	9.10	1.07	1.06	0.00	0.36	nd
100-130	Bt3	28.79	60.20	8.13	1.12	1.27	0.10	0.39	nd
155-182+	Bt5	34.96	51.29	10.55	0.97	1.46	0.18	0.55	nd
Lower midslope: Psammentic Haplustalf									
46-63	Bt2	27.23	63.22	6.67	1.13	1.14	0.12	0.46	nd
80-100	2BC	37.77	48.94	10.74	0.82	1.19	0.00	0.53	nd
130-180+	2C	35.13	50.61	11.97	0.60	1.28	0.00	0.40	nd
Footslope: Oxyaqic Haplustalf									
20-30	Ap2	18.64	74.21	3.35	0.42	2.32	0.23	0.83	nd
30-45	Bw	14.05	65.54	11.86	1.42	1.48	0.90	0.84	nd
Toeslope: Aeric Endoaqualf									
5-23/30	Btcg	27.19	52.53	13.47	0.78	3.57	0.69	1.72	nd
30-48	Btg1	25.13	50.16	17.18	0.70	4.01	0.73	1.95	nd
113-143	Btg4	21.88	63.79	6.16	0.50	4.15	0.78	2.25	nd
143-162	BCg1	25.03	57.13	9.07	0.31	4.61	0.70	3.06	nd
Khon Buri catena									
Crest: Rhodic Kandiustox									
15-30	Ap	34.67	40.10	20.30	4.39	0.38	0.02	0.11	0.04
30-51	Bto1	36.13	41.98	18.20	3.58	0.04	0.00	0.08	0.00
130-160	Bo1	36.38	42.90	17.57	3.07	0.05	0.01	0.01	0.01
Backslope: Typic Kandiustult									
11-28/30	Ap	34.61	46.72	14.25	3.74	0.16	0.27	0.20	0.00
30-54	Bt1	35.09	41.96	15.82	3.52	0.28	2.66	0.51	0.15
59-88	Bt2	36.69	46.28	13.71	3.17	0.08	0.07	0.00	0.00
Footslope: Typic Plinthustult									
12-30	Ap2	29.27	45.32	22.53	1.72	0.25	0.26	0.33	0.33
50-72	Btc2	33.48	42.05	22.14	1.75	0.18	0.00	0.29	0.10
103-130	Btc4	32.61	47.25	17.06	2.52	0.33	0.01	0.20	0.03
Valley floor: Typic Endoaquert									
0-15	Apg	26.94	51.49	17.05	2.15	0.39	0.61	1.38	0.00
76-100/110	Bg2	25.04	51.50	15.65	4.19	0.23	0.60	1.36	0.41
160-180	Crg	15.66	50.34	28.73	1.78	0.00	0.53	2.10	0.86

[1/] Up to 5-15 point in the soil plasma of thin section were analyzed by EDS analysis.

2C-horizon of soil on shoulder and midslope positions on the Nam Phong catena

The discontinuity of the C-horizon is recognized in soils on shoulder and midslope positions on the Nam Phong catena on the basis of both field and micromorphological features. The micromorphology is shown in Figure 3. The 2C-horizon contains quartz and common chert and sandstone rock fragments. Quartz grain size is larger than for other soils on the Nam Phong catena. Quartz grains are angular to subangular whereas quartz grains in other soils on the Nam Phong catena are subrounded to rounded. The quartz grains show a very strong red color due to ferri-agrillan coatings

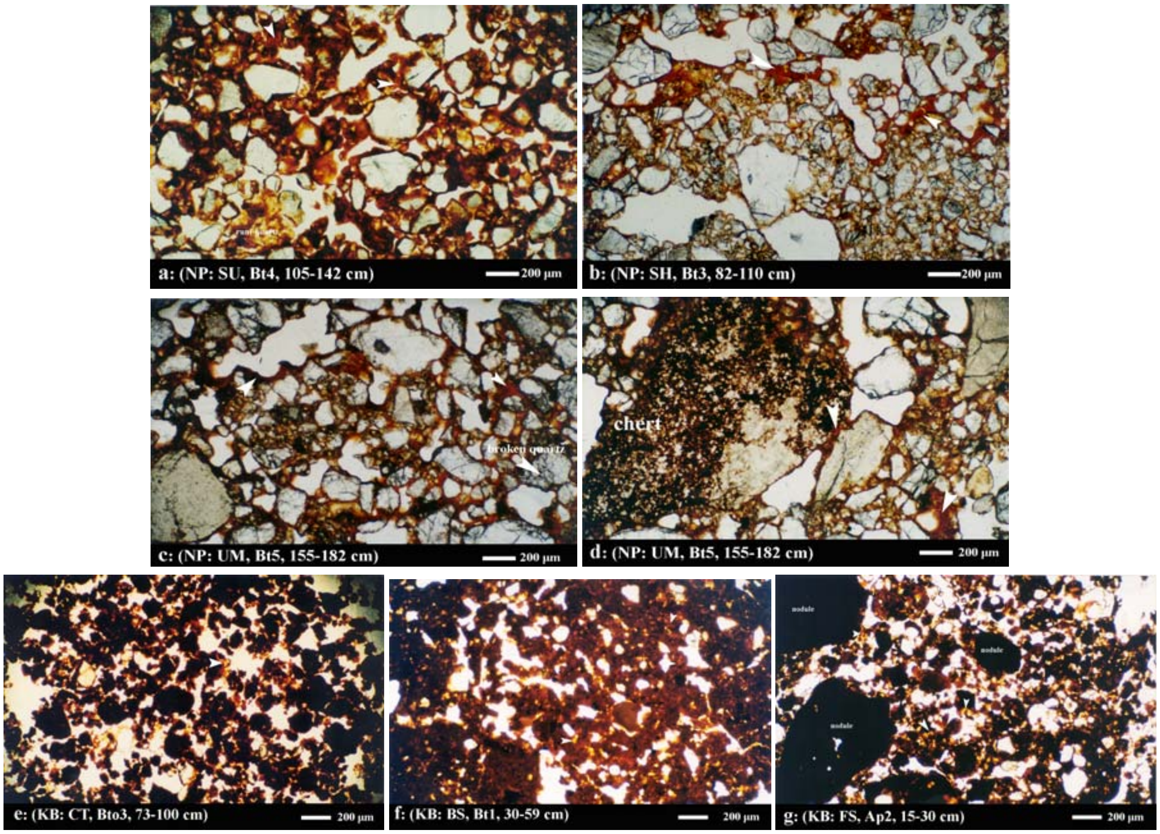

Figure 2 Thin section micrographs of soils under plane polarized light showing; red – orange laminated ferri-agrillan coating (a, b, c, d) and yellow clay infilling (e, f, g) occur on some peds or voids, humified organic fine materials scattering in groundmass, iron filling in the quartz vein (runi-quartz) and chert (weathered chert).

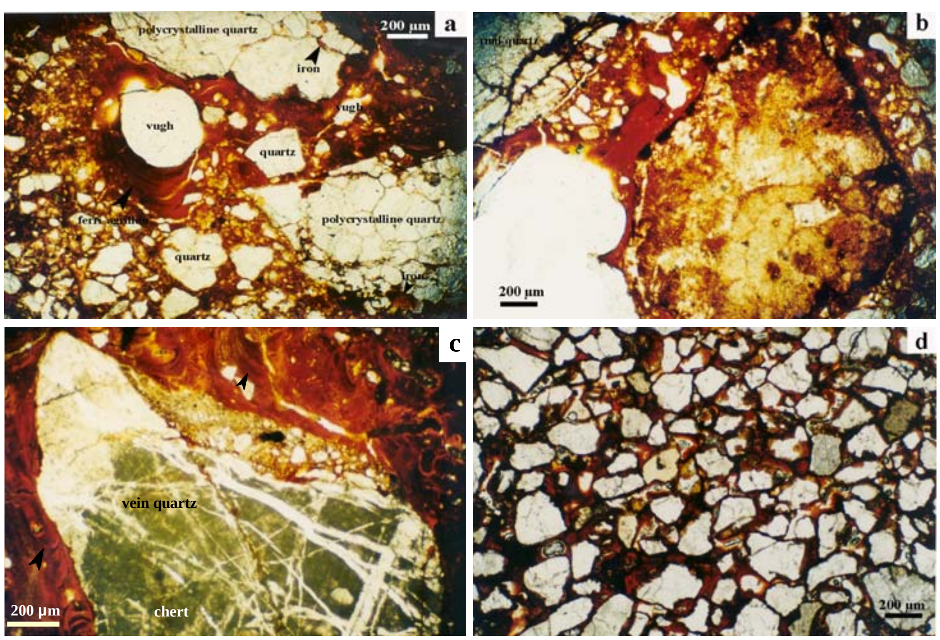

Figure 3 Transmitted light micrographs of a thin section of the 2C-horizon of Nam Phong catena showing thick laminated ferri-agrillan coated on quartz grains rock fragments and pore (a, b, c, d); iron filling in the polycrystalline quartz (a); weathered quartz (b); angular-subangular quartz poorly sorted (a) and well sorted (d).

(thickly laminated). In addition, these soils contain more fine material than do soils on shoulder and midslope positions. They are highly weathered as is indicated by the iron oxide infilling in the veins in the polycrystalline quartz.

Cr-horizon of soil on footslope position on Khon Buri catena

The microfabric of the Cr-horizon (weathered basalt rock) of the footslope soil is shown in Figure 4. Plagioclase, olivine and hornblende are common in the partly weathered basalt. Quartz is absent although quartz was reported in soils derived from basalt in Madagascar, Malaysia, Thailand and Ireland (Eswaran, 1972).

Origins of Mineral

Quartz

SEM backscatter micrographs of upslope soils on the Nam Phong catena (Figure 5) show pores and voids between sand grains. There is a loose arrangement of sand and silt particles with interparticle voids of various diameters for topsoils. The packing of the silt particles among sand particles increases in the subsurface horizons.

In this study, we will consider properties of quartz in the soils only for the Nam Phong catena because all soils in this catena contain much quartz (Figure 6). BSE images of the upslope soils show various sizes and shapes of quartz grains. There is a little evidence of rounded sand grains increasing in abundance downslope. Most of quartz grains are broken possibly reflecting their colluvial origin (Dabbakula Na Ayudhya, 1994). Several forms of quartz in the upslope soils of the Nam Phong catena are shown in Figure 6. In thin section, quartz grains include chalcedony, chert and quartz crystals. The quartz is present in polycrystalline, runi-polycry stalline, crystal growth and cutan forms. The presence of polycrystalline quartz confirms that the soil was derived from metamorphic rocks (Asumadu et al., 1979). Extensive dissolution of silica may occur along cracks and intercrystalline boundaries in strained and polycrystalline quartz grain (Little et al., 1978). Sometime cracks in quartz become filled with iron oxides.

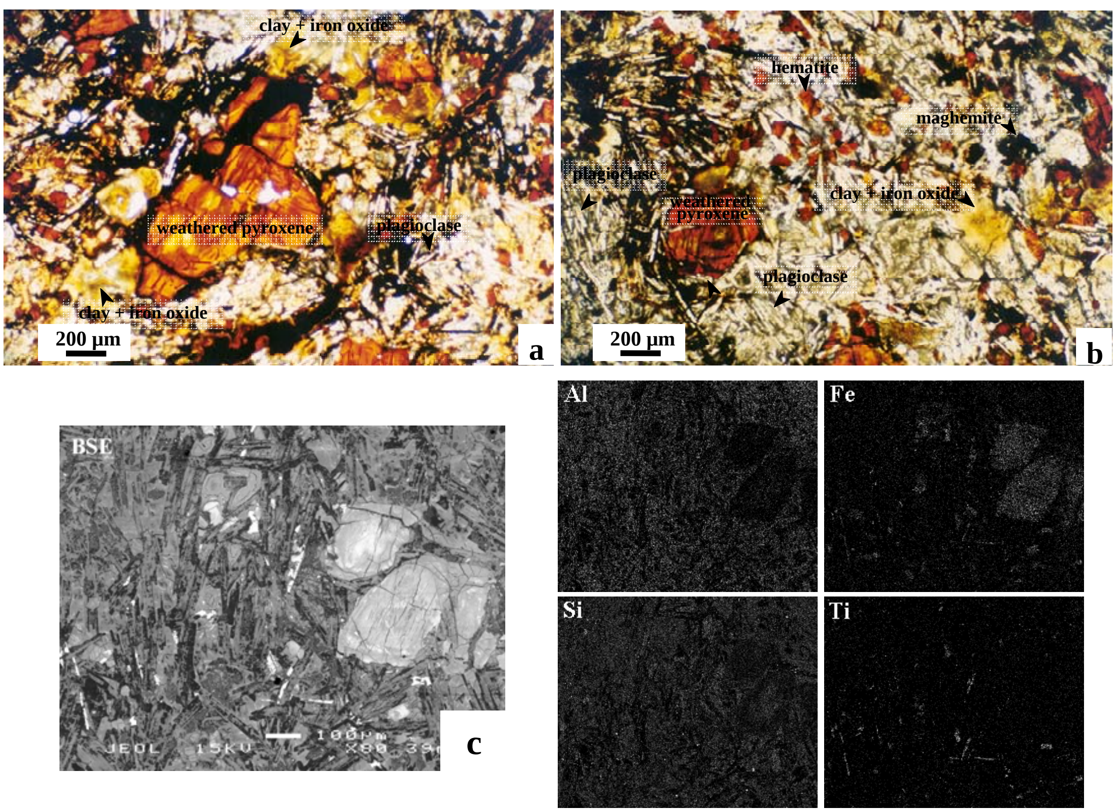

Figure 4 Thin section photograph (a, b) and element mapping (c)of the weathered basalt rock (Cr-Horizon) showing the weathered basalt rock consists of a groundmass of lath shape microcrystalline of calcic plagioclase feldspar with minor amount of pyroxene, olivine and maghemite; Al, Fe, Si and Ti mapping of the weathered basalt rock.

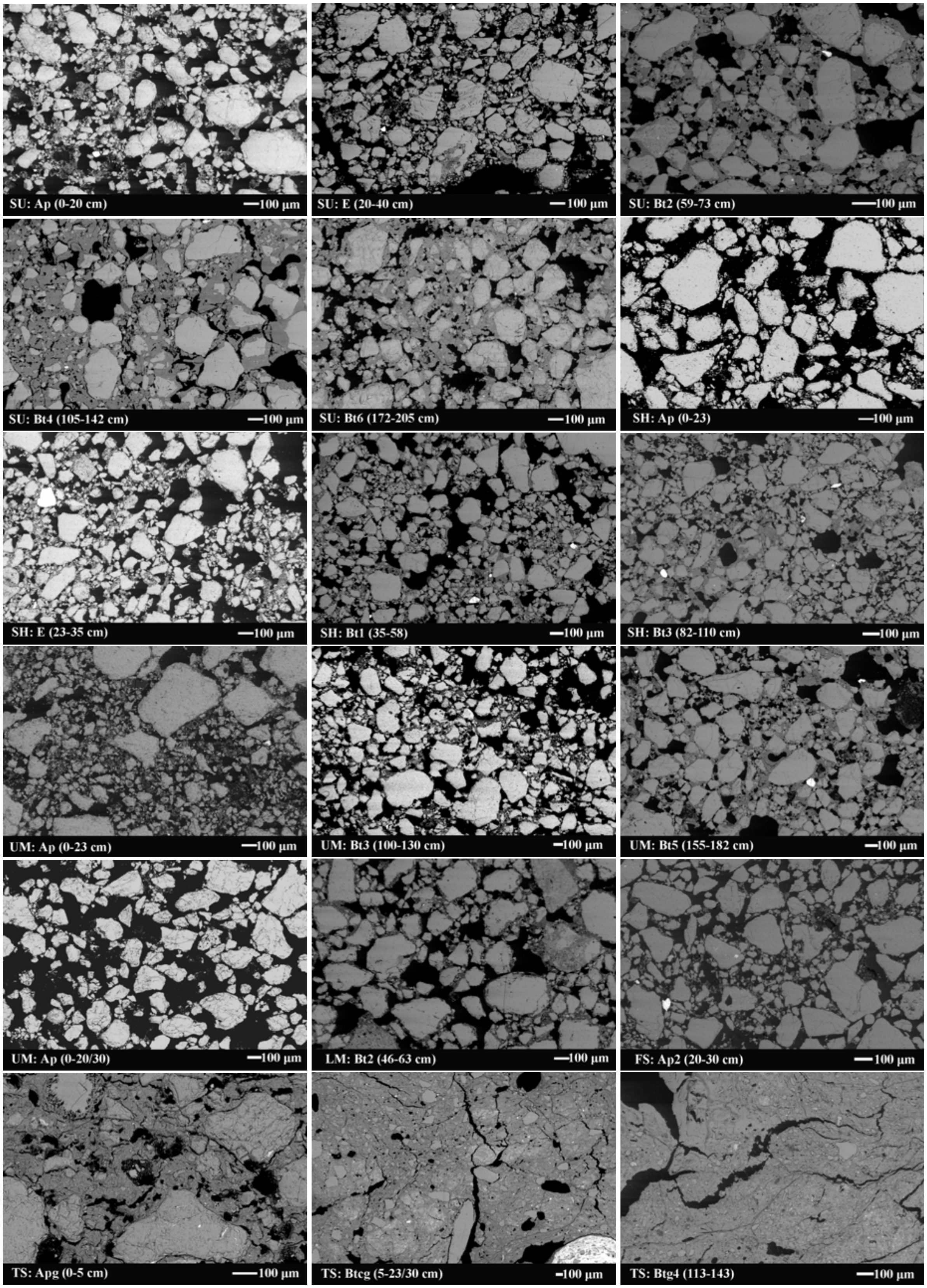

Figure 5 Backscatter electron micrographs of thin sections from the Nam Phong catena showing: voids which are black, homogeneous gray areas are quartz grains, very light colored particles are heavy minerals and the heterogeneous gray areas are packed fine silt and clay particles and associated porosity.

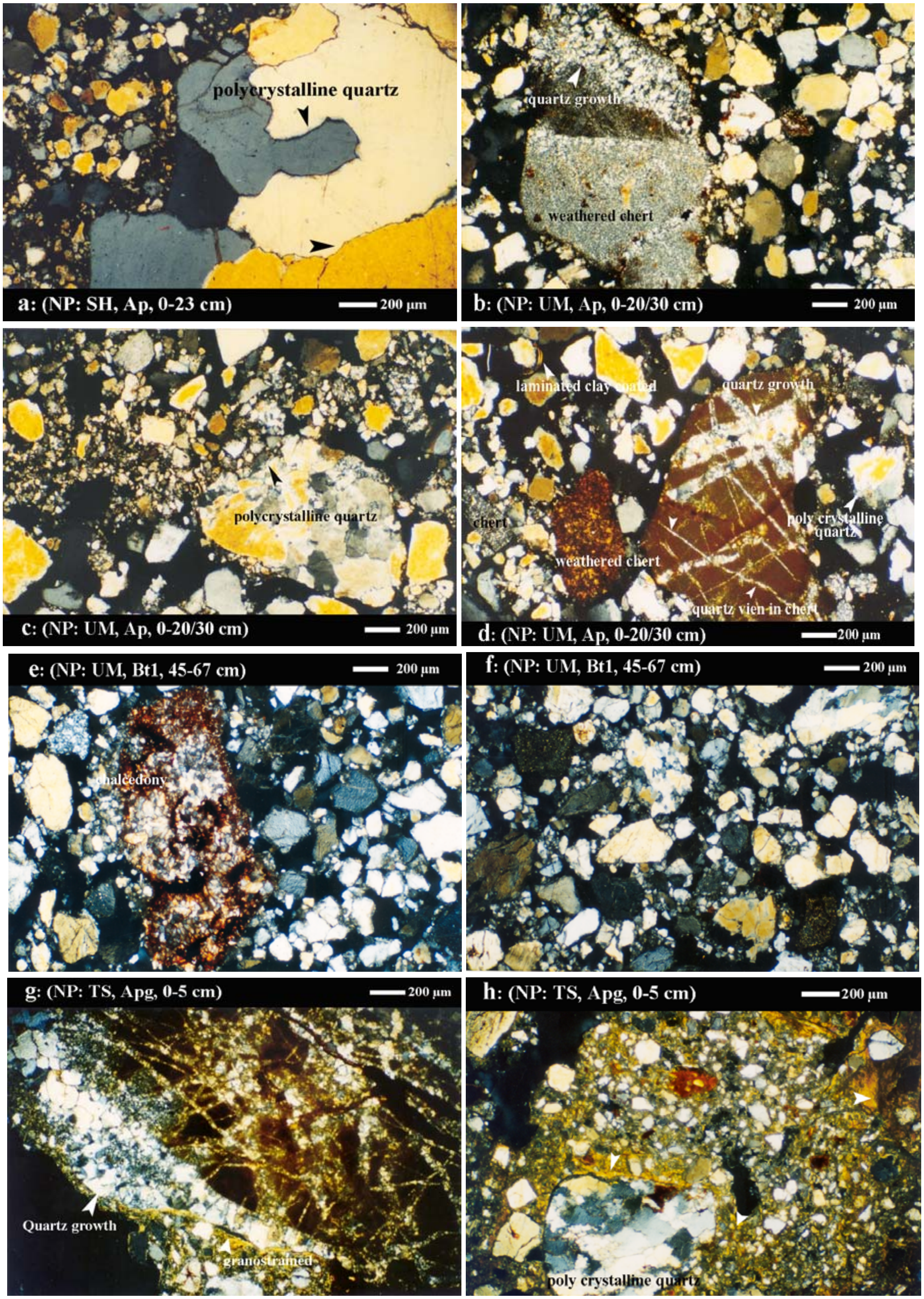

Figure 6 Micrographs of thin section of soils on Nam Phong catena under cross polarized light showing the various quartz forms: polycrystalline quartz (a, c, f, g), quartz from a chert vein (b, d, g), runi-polycrystalline quartz (e), secondary quartz in a cutan (h).

Lithorelicts

The lithorelicts are largely numerous in footslope soil decreasing in size and number toward the surface, but there are few in the soil on the backslope position. In these soils, the lithorelicts have been almost completely transformed but there are some partly weathered pyroxene and weathered plagioclase feldspar grains (Figure 7). In most cases, the lithorelicts are enriched in goethite, hematite and kaolin. Eswaran (1972) noted that weathering accompanied by leaching has resulted in the removal of dissolved elements so that only an ouline of the original mineral grain persists with in-situ crystallization of kaolin and a sesquioxidic rich material containing goethite and hematite.

Iron nodules

Typic nodules and psedomorphic nodules are present in all soil positions on both catenae. Also iron impregnative nodules commonly occur. Various nodule types occur in large amounts in soils on the Khon Buri catena possibly due to the iron rich mineralogy of the parent rock. Nodules in soils on the Khon Buri catena are shown in Figure 8. There is a sharp boundary between typic nodules and soil matrix. The iron impregnated nodules, mottles, and typic and aggregate nodules present in the soils are a result of oxidation-reduction (Buol et al., 2003).

Pedogenic carbonate

The carbonate impregnated nodules, recrystallized carbonate and carbonate impregnated s-matrix occur only in the soils on the lowest position of the catenae and they are present only in the deep horizon of soil on the valley floor position of the Khon Buri catena (Figure 9). The carbonate is contributed from the water table which introduces bicarbonate and calcium which in the dry season form carbonate nodules. These soils have high pH (more than 8).

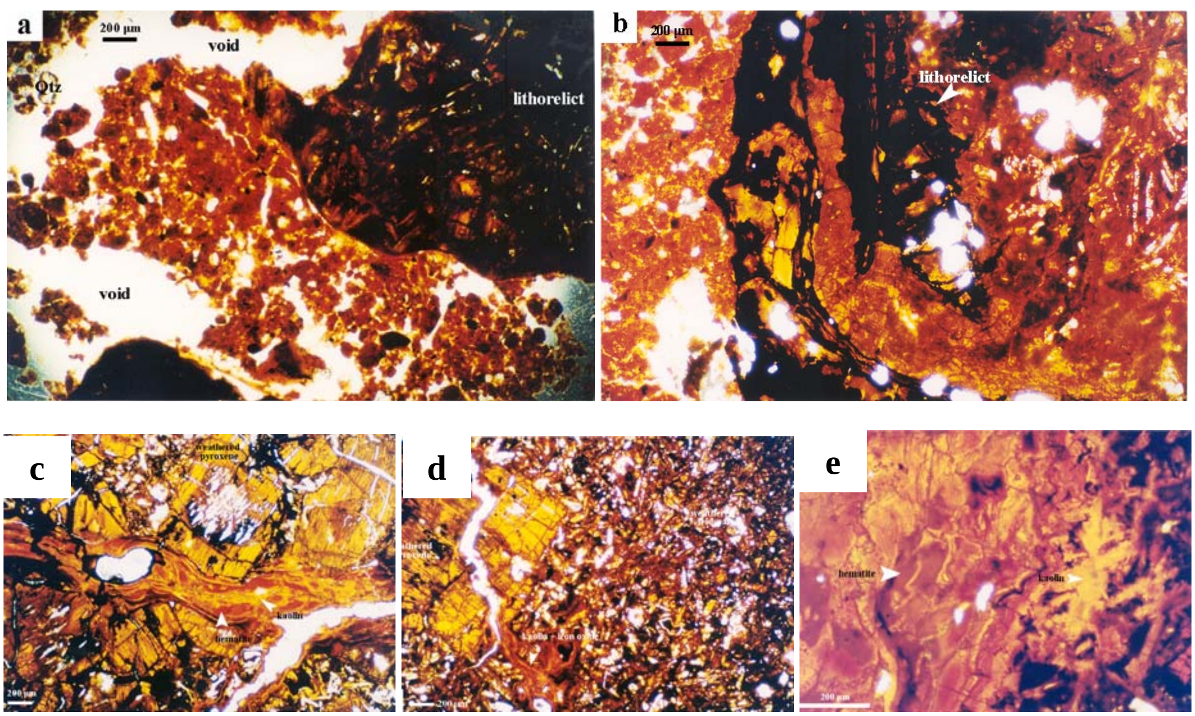

Figure 7 Transmitted light micrograph of thin section of the lithorelict (a, b) present in the footslope position on Khon Buri catena showing; the lithorelict almost completely transformed to goethite, hematite and kaolinite. Detail of the lithorelict (c, d, e).

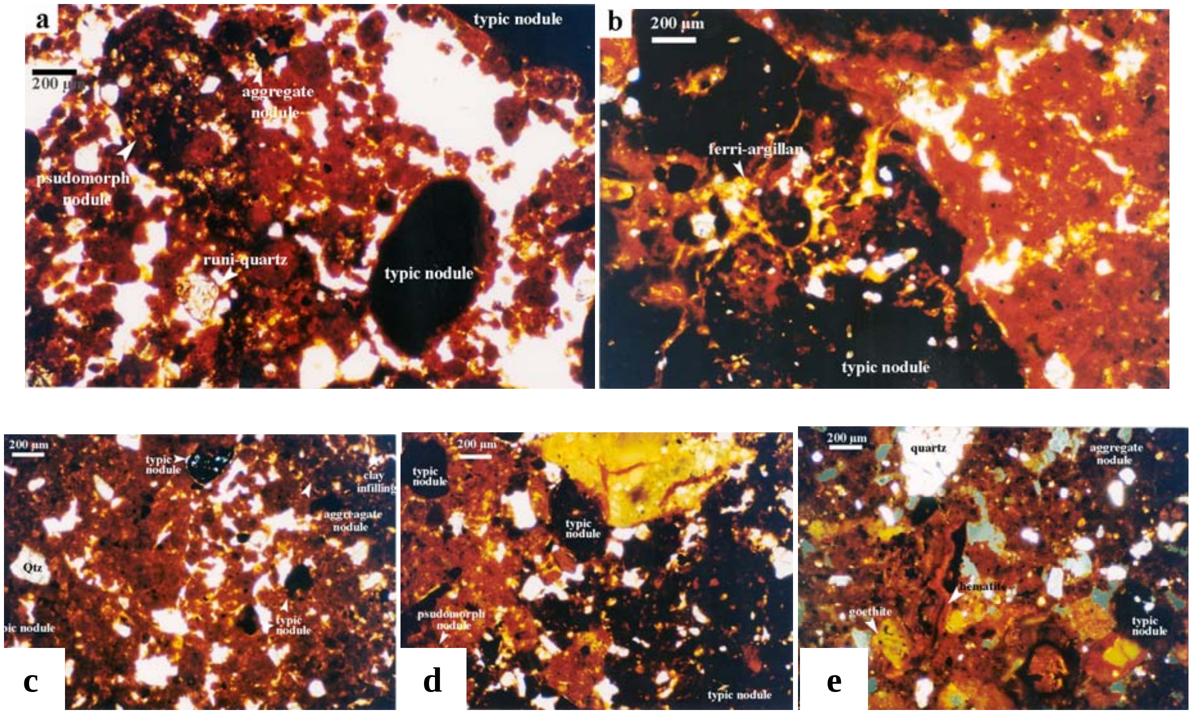

Figure 8 Transmitted light micrograph of thin section of the nodule present in soils on Khon Buri catena showing various nodule types; typic nodule (a, b, c, d, e), broken typic nodule (b, d), aggregate nodule (a, c, e), psudomorph nodule (d).

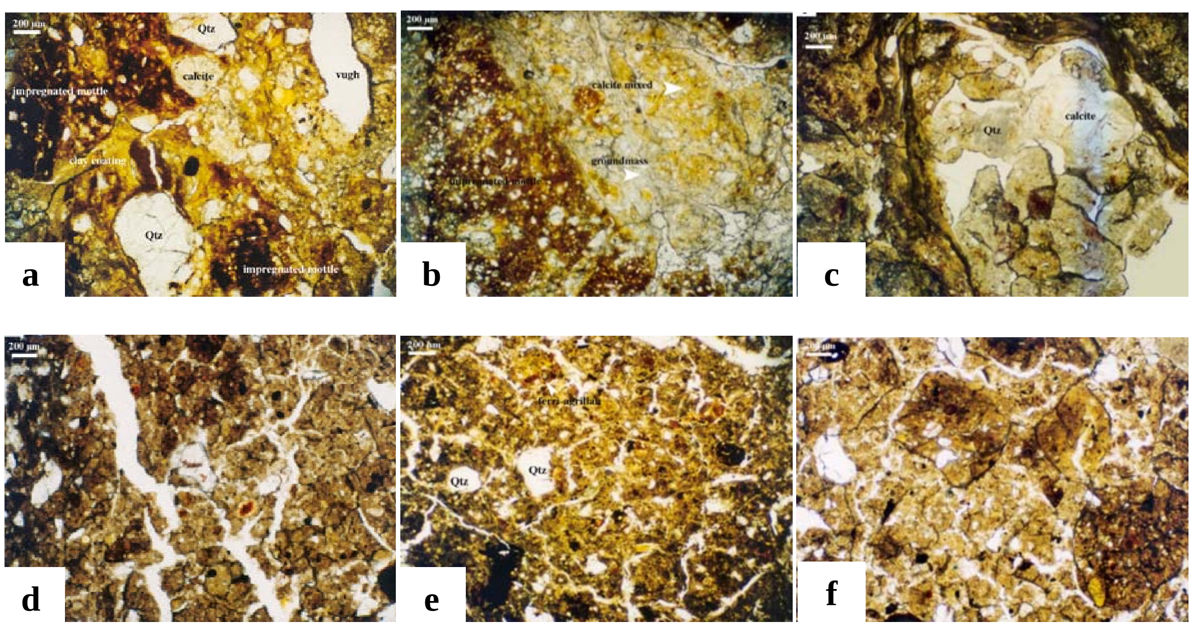

Figure 9 Transmitted light photograph of thin section of soils on the toeslope position on Nam Phong catena (a, b, c) and on valley floor position on Khon Buri catena (d, e, f) showing carbonate nodule and carbonate impregnated s-matrix.

Conclusions

The field morphology, mineral assemblages and micromorphological characteristics reflect differences in intensity of weathering at each position on the catenae. Upslope soils on both catenae are highly weathered and highly developed especially the soils on the highest position on catenae. Upslope soils showed bridge grain, subangular to granular microstructure along with undifferentiated b-fabric for Nam Phong and Khon Buri catenae. However, grano- and poro striated b-fabric can also be found. Soils on the lowest position of the landscape are dominated by subangular quartz and crack in some locally along with the speckle b-fabric which influenced by the water saturation. The fine material of the micromass consists mainly of kaolin mixed with iron oxide for the upslope soils, swelling clay occurs in soils on the lowest position on the landscape.

Quartz is the major constituent of the coarse material for soils on both catenae. Although quartz is not a primary mineral in basalt, Beckmann et al. (1974) proposed that it could be a product of weathering or geological alteration. Alternatively it could have been deposited onto the soils as aeolian sediment (Prone, 2003) and incorporated throughout the profiles by pedoturbation. Rounded grains increase downslope and the presence of broken quartz grains in all soils position indicates that colluviation has taken place. The lithorelicts in soils on the Khon Buri catena indicate that these soils are derived from basalt in situ. Nevertheless, various forms of quartz including chert, polycrystalline, runi-quartz and chalcedony are present in soils on the Nam Phong catena especially polycrystalline quartz reflecting colluvial addition from meta-sedimentary rock. Carbonate impregnated nodules and recrystallized carbonate occur only in soils on the lowest position on catenae possibly because the water table at this point introduces calcium and bicarbonate consequently which in the dry season form calcium carbonate nodules.

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