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INFLUENCE OF TOPOGRAPHY ON SOIL MORPHOLOGICAL AND PHYSICAL PROPERTIES ON THE NEWER BASALTS OF THE JOS PLATEAU, NIGERIA

***Samndi M. A.[1] and Adamu Jude [2]**
[1]Department of Soil Science, Faculty of Agriculture Bayero University Kano Nigeria.
[2]Federal College of Land resources Technology Kuru Jos Plateau State Nigeria.
*Correspondence author: samndiayuba@yahoo.com

ABSTRACT
This study evaluated changes in soil morphological and physical properties associated with slope positions along a toposequence on newer basalts of the Jos Plateau. Eight pedons were sunk along a toposequence on the crest, upper, middle and lower slope positions. The pedons were described according to their genetic properties; soil samples for laboratory analysis were taken from each pedogenic horizons. Results from the study showed that the pedons were well developed, with depths slightly exceeding 180cm at the crest and middle slope position. The thickness of the surface horizons varied with slope positions, with thicker horizons (25 -30cm) obtained at the middle and lower slope positions. The least developed pedons were those at the upper slope position. The soil texture varied from sandy clay loam (upper slope) to clay at the crest and lower slope position. Higher gravel content (57 – 70%) was obtained at the upper slope. Sand content followed similar pattern to that of the gravel. Clay content increased with profile depth, except at the upper slope where pedons were not well developed. Soils at the various slope positions were not highly weathered as shown by low silt to clay ratio values (0.36 – 0.96). Bulk density values were < 1 for surface horizons and slightly increased with profile depths. Generally bulk and particle density values did not differ with slope positions.
Keywords: Toposequence, Newer Basalts, soil morphological and physical properties.

INTRODUCTION

Jenny (1941) stated that topography is an independent soil-forming factor and its contribution to soil formation can be considered on its own. Incidentally most of the information on topography consider runoff and erosion in relation to slope, which deals with removal and destruction of soil. Topography as a soil forming factor influences radiation and the amount of water that enters the soil, thus leading to leaching and the redistribution of elements and soil materials (Hook and Burke, 2000). Temgoua *et al.* (2005) considered topography as both an internal and external factor in pedogenesis, thus influencing or a consequence of soil formation. Significant correlation between topographic indices and soil properties were reported by Seibert *et al.* (2007). Bockheim (2005), Cox et *al.* (2002) and Wilson *et al.* (2004) reported differences in soil properties as a result of local effects of topography, which accounted for between 26 and 64% total variation in soil properties and moisture. Durak and Surucu (2005) studied soil formation on different landscape positions and reported that the greatest degree of pedogenesis was observed on the summit followed by the back slope, with the least degree of soil development occurring at the toe slope. Hikmatullah and Prasetyo (2003) confirmed that elevation significantly affect soil properties and the degree of weathering.

Soil depth, clay content and structural development increased with decreasing altitude or down slope, soils on the crest and upper slope were weakly structured, while those at the lower slope were well developed according to Idoga *et al.* (2006). Subardja and Buurman (1980) confirmed that elevation influenced soil properties, development and degree of weathering. Soil colours are also influenced by topography, Curi and Franzmeier (1984) observed moist soil colour change from dark reddish brown (2.5YR3/4) in the upper slope position to dark yellowish brown (10YR4/4) in the lower slope position, this they attributed to decreased hematite and increased goethite content along the toposequence. Similarly Idoga *et al.* (2006) observed that the crest and upper slope soils had a dominant colour hue of 5YR, while middle and lower slopes had hue between 7.5 and 10YR.

Olatunji *et al.* (2007) worked on the influence of topography and parent materials and reported that gravel, coarse sand and clay contents were significantly influenced by topography. Similarly Brubaker *et al.* (1993), Salako *et al.* (2006) collaborated that particle size distribution varied along toposequences, with higher sand content at the lower position. On the contrary, higher clay content was observed at the lower slope by Shariatmadari *et al.* (2006). Essoka *et al.* (2006) reported increased bulk density (BD) values with soil depth which also fluctuated along a toposequence on gneiss and granodiorite, however increase in BD with decreasing slope position was observed by Hikmatullah and Prasetyo (2003).

Moorman (1981) reported a strong relationship between topographic positions and soil genesis on basement complex in Southern Nigeria, however this relationship on the basaltic parent materials of the Jos plateau have not been well documented.

The Newer basalts of the Jos plateau occupy nearly 241.35km^2 in the western and southern Plateau state of Nigeria and were erupted after the plateau had achieved almost its present day topography. The study therefore looked at the changes in soil morphological and physical properties associated with slope positions along a toposequence on the newer basalts of the Jos plateau.

MATERIALS AND METHODS

Environmental Settings

The study area is located in Vom Jos, Plateau State in the Southern Guinea Savanna zone of Nigeria. It lies between longitudes 08^o 45′ 01 to 8^o 47′ 56E and latitudes 9^o 43′ 17 to 9^o 45′ 15N, with an elevation of about 1270m above sea level. The soils of Vom were formed from the newer basalts, while the climate is considered as humid. The mean annual rainfall is about 1258mm with a peak period between July and August. The mean temperature is about 24 ^{o}C with April as the hottest, when temperature could be as high as 36 ^{o}C. The soil moisture regime is considered as Ustic and the temperature regime is Iso hyperthermic (Eswarm *et al.* 1997). Keay (1959) and Clayton (1957) described the vegetation of the area as being a transition between forest zone and the tree savanna.

Field Sampling

A stratified purposive sampling procedure was adapted, where four landscape positions were identified using Global Positioning System (GPS). The crest, upper, middle and lower slope positions were identified, each representing changes in topography. Two pedons were georeferenced at each topographic position, where they were sunk and described by genetic horizons for colour, texture, structure, consistence, clay firm, concretions, boundary, pores and roots according to Soil Survey Staff (1996). Each pedogenic horizon was sampled for laboratory analysis. Undisturbed samples were collected with cores for bulk density determination.

Laboratory Analysis

The bulk soil samples collected were air–dried, gently crushed with porcelain pestle and mortar and passed through a 2mm sieve to remove coarse fragments. The gravelly portion retained on the sieve (stones and gravels) was weighed and expressed as the percentage of the whole soil. Particle size distribution was determined by the Bouyocous hydrometer method as described by Gee and Bauder (1986). Core method as described by Blake and Hartge (1986) was used to determine the bulk density values. Particle density was determined after the expulsion of entrapped air in the soil using the pycnometer method as described by Blake and Hartge (1986). The total porosity (the sum of all pore volumes) was calculated mathematically from bulk density and particle density values as described by Anderson and Ingram (1998). Cross tabulation method was adopted in the interpretations of the results.

RESULTS AND DISCUSSION

Morphological properties

Results from the study (Table 1) showed that solum depths slightly varied with topographic positions. The solums are generally well developed particularly at the crest and middle slope position where depths slightly exceed 180cm. However, slightly shallow solums were obtained at the upper slope and profile 2 at the lower positions, where saprolites were encountered at the depths of 94 and 130cm thereby reducing solum depths. Similar observation was made by Buol and Weed (1990) where they reported that saprolite thickness is related to topographic position. This also suggests that factors influencing soil development might have acted independently in both vertical and lateral directions. The mean thickness of the surface horizons (Table 1), are in the order middle slope (30cm) > lower slope (25cm) > crest (15cm) > upper slope (12cm), there was no linear relationship between surface soil thickness and slope position, similar observation was also made by Owonubi *el al.* (2006) on a toposequence. The surface horizons were generally thicker at both middle and lower slope positions, which might be ascribed to the deposition of eroded materials from the crest and upper slope position as reported by Agbenin and Tiessen (1995).

Horizon colours were not well differentiated as the colour hue was 5YR (dark reddish brown) for surface horizons and 2.5YR (reddish brown) for the underlying horizons at the crest, upper and middle slope positions (Table 2). However profile 2 at the lower slope position had a slight change in colour hue 7.5YR (reddish brown to strong brown) and 5YR (reddish brown) for both surface and underlying horizons respectively. The redder colours obtained at the various topographic positions could be ascribed to the levels of soil development and the drainage conditions at those positions. This is corroborated by Nayak *et al.* (1991), that soil colour becomes redder with age. The higher hue values obtained at lower slope position suggests slight poor drainage conditions at the lower slopes as it receives runoff from the other slope positions. A similar colour differential between crest and lower slope position was also reported by Idoga *et al.* (2007) on a toposequence in Samaru Nigeria.

Soil textural distribution (Table 2) indicates that texture varied from sandy clay loam to clay. Solums on the crest and lower slopes contained clay throughout the entire solums, while the upper slope contained sandy clay loam. For the middle slope, the surface and underlying horizons had clay loam and clay accordingly. The higher clay distribution obtained on the crest and lower slope suggests that weathering is higher at these positions. This is substantiated by the development of Bt horizons at the crest and profile 1 at the lower slope position, which is in agreement with Durak and Surucu (2005) and Hikmatullah and Prasetyo (2003), that the degree of pedogenesis are greater at the summit and lower slopes. Surface soil structures at the crest, middle and lower slopes varied from weak to moderate sub angular blocky, while at the upper slope, the structure was weak. For the underlying horizons, structures were moderate to strong sub angular blocky.

The soil structures at the various topographic positions could be considered as being developed, which is characteristics of typical matured stable landscape according to Okunsami *et al.* (1997). The soils were slightly sticky to slightly plastic when wet, firm when moist and slightly hard to hard when dry, which is an indication of a developed soils.

Physical properties

Table 3, indicated that the particle size distribution slightly varied at the different slope positions. The gravel content were higher at the upper slope position, with values ranging between 57- 71% this is substantiated by weak solum differentiation (A, AC and Cr). At the crest, middle and lower slope positions, gravel content varied between 9 and 41%, except in solums where partially weathered basaltic materials were encountered, thus varying the gravel content between 51 and 61%. The distribution of sand content followed a similar trend as that of the gravel, where higher values were obtained in the upper slope position, while at the crest and lower slope values were slightly lower, which is in agreement with Hikmatullah and Prasetyo (2003) that, as elevation decreases sand content also decreased. There was a general decrease in sand content with profile depth, particularly in profile 1 at middle and lower slope positions. This implies that sand weathering is the major pedogenic processes occurring at these positions. Losses of sand decreases with depth according to Stolt *et* al. (1993), which implies the degree of weathering also increased with profile depth.

Stolt *et al.* (1993) stated that sand weathering results in several products including silt and clay. Table 3 indicate that at the crest and middle slope position, silt content varied between 17 and 31%, followed by the lower slope with 21 and 29% and slightly lower values at the upper slope position. The variations in silt contents at the various positions are very little substantiating similar results obtained by Owusu – Bennoah *et al* (2000) on a toposequence in Ghana.

Table 3, shows a general increase in clay content with increased profile depth for the various slope positions, except at the upper slope position where the solums were not well developed. The increase in clay with solum depth implies that illuviation and faunal pedotubetion are the major soil forming processes taking place at these positions.

Van Wambeke (1962), used silt and clay ratio to estimate the degree of weathering of soil pedon, and postulated that the lower the ratio the higher the degree of weathering. Results from the study (Table 3), indicated that silt to clay ratios at the various positions ranged between 0.36 and 0.96, except in Bt1 profile 2 at the crest were 1.23 was recorded. The ratios did not follow a particular trend with respect to slope position. However what seems to be obvious is the decrease in silt to clay ratios with increased with profile depth, which indicated that the silt fractions changed into clay fraction confirming increased clay content with profile depth.

Sampling for bulk density (BD) determination was not carried out in all the solums because rocky materials were encountered particularly in profile 2 on the crest and the upper slope position. This also affected the determinations of other parameters associated with bulk density. However some of the results obtained (Table 3) showed that surface bulk density values for two profiles at the crest and lower slope position were 0.964 and 0.986 gcm^{-3}, while for other slope positions values varied from 1.076 to 1.131gcm^{-3} and did not vary with slope position. For the underlying horizons, the BD values were slightly higher and ranged between 1.20 and 1.442gcm^{-3}. This is ascribed to clay illuviation as indicated by the development of Bt horizons. Idoga *et al* (2006) reported higher BD in subsurface horizons along a toposequence.

Particle density values generally increased with increased profile depths, except in profile 2 at the upper slope position where values decreased with depth. This might likely be attributed to the levels of profile development, as values were similar to those obtained in Cr horizons of some pedons. The particle density values were not influenced by slope positions. Total porosity values were higher for surface horizons and are as a result of higher organic matter content and root proliferation which encouraged granulation, thus resulting into higher total porosity. The total porosity values generally decreased with profile depth and did not differ much with slope position.

Conclusion

Soil morphological and physical properties were used to evaluate the effects of topography on basaltic parent material. The results showed that pedons at the crest and middle slope position were well developed with profile depths exceeding 180cm. Slightly shallow profiles were those at the upper slope position. Surface horizons were thicker at the middle and lower slope positions, with thickness varying between 25 – 30cm. Soil texture varied from sandy clay loam to clay, with the crest and lower slope positions having clay textures. Soil structures were well developed, except at the upper slope position where structures were weak. Gravel and sand contents were higher at the upper slope position, while clay content increased with increase in profile depth for the various slope positions except the upper slope where the pedons were not well developed. The surface soils the crest and lower slope position had a low BD values (0.964 and 0.986gcm^{-3}), while for the other slope positions values varied from 1.076 to 1.131gcm^{-3} and did not vary with slope position. Particle density values did not vary with slope position but increased with profile depth. The total porosity values were higher for surface horizons and decreased with soil depth.

Table 1: Pedon Depth and Surface Horizon Thickness of the Various Topographic Positions

Topographic position	Solum Depth Range (cm)	Mean (cm)	Surface Horizon Thickness (cm)	Mean (cm)
Crest	180	180	14 - 16	15
Upper slope	125 - 130	128	10 - 14	12
Middle slope	167 - 185	176	29 - 31	30
Lower slope	94 - 135	115	22 - 28	25

Table 2: Morphological Properties of Pedons at the Crest in the Study Area.

Horizon	Depth(cm)	Munsell Colour(dry)	Texture	Structure	Consistence Wet	Moist	Dry	Boundary	Other Features
				Profile 1					
A	0 - 14	5YR3/2	c	2msbk	ssps	fi	sh	cs	Few fine pores; many fine roots; few ant nests.
Bt1	14 - 39	10R2.5/1	c	2msbk	sp	fi	sh	ds	Few fine pores; common very fine to medium roots; few ant nests.
Bt2	39 - 73	2.5YR2.5/2	c	2msbk	sp	fi	sh	cs	Few fine pores; few fine roots; medium to coarse weathered basalt.
Bt3	73 - 120	2.5YR3/3	c	2msbk	ssps	fi	sh	gs	Few fine pores; few fine roots; few coarse weathered basalt.
Bt4	120 - 143	2.5YR4/3	c	2csbk	ssps	fi	sh	ds	Very few fine to medium pores; few fine roots; weathered basalt.
Bc	143 - 180	2.5YR2.5/2	c	2csbk	sp	fi	sh		Few fine pores; common fine roots; few weathered basalt.
				Profile 2					
A	0 - 16	5YR2.5/1	cl	1fmsbk	ssps	fi	sh	gs	Many fine pores; many fine to coarse roots; few fine to coarse weathered basalt.
AB	16 - 59	2.5YR2.5/1	cl	2msbk	ssps	fi	sh	cs	Common fine pores; many fine to coarse roots; few medium to coarse weathered basalt.
Bt1	59 - 94	2.5YR3/2	cl	2msbk	ssps	fi	sh	cs	Common fine pores; few medium to coarse roots; many medium to coarse weathered basalt
Bt2	94 - 137	2.5YR2.5/2	c	2msbk	ssps	fi	sh	gs	Few fine pores; few fine roots; many medium to coarse weathered basalt.
BC	137 - 180	5YR3/2	cl	2csbk	ssps	fi	sh		Few fine pores; few fine roots; many medium to coarse weathered basalt.

Table 2 (Contd): Morphological Properties of Pedons at the Upper Slope in the Study Area

	Depth(cm)	Munsell Colour(dry)	Texture	Structure	Consistence Wet	Moist	Dry	Boundary	Other Feature
				Profile 1					
A	0 - 10	5YR2.5/1	cl	1fsbk	ssps	fi	s	ds	Few fine pores; many fine to medium roots; few medium to coarse weathered basalt
AC	10 - 50	5YR2.5/1	cl	1fsbk	ssps	fi	s	cs	Few fine pores; many very fine to roots; common medium to coarse weathered basalts.
Cr	50 - 130	5YR2.5/2	c	2msbk	ssps	fi	sh		Few fine pores; few fine roots; many very coarse weathered basalt.
				Profile 2					
A	0 - 14	5YR2.5/1	cl	1fmsbk	ssps	fi	sh	gs	Many fine pores; many fine to coarse roots; few fine to coarse weathered basalt.
AC	14 - 39	2.5YR2.5/1	cl	2msbk	ssps	fi	sh	cs	Common fine pores; many fine to coarse roots; few medium to coarse weathered basalt.
Cr	39 - 125	2.5YR3/2	c	2msbk	ssps	fi	sh		Few medium to coarse pores; few medium to coarse weathered basalt.

Table 2: (contd). Morphological Properties of Pedons at the Middle Slope in the Study Area.

Horizon	Depth(cm)	Munsell Colour(dry)	Texture	Structure	Consistence Wet	Consistence Moist	Consistence Dry	Boundary	Other Features
				Profile 1					
A	0 - 29	5YR2.5/1	cl	2msbk	ssps	fi	s	cw	Common fine to medium pores; many fine to coarse roots; coarse colluvial basaltic boulders.
B	29 - 80	5YR3/2	c	2msbk	ssps	fi	s	gs	Common fine pores; common very fine to medium roots; coarse weathered basalt.
Bt1	80 - 122	2.5YR3/3	c	2msbk	ssps	fi	sh	ds	Common fine pores; few very fine to medium roots; few medium weathered basalt.
Bt2	122 - 147	5YR2.5/2	c	3msbk	sp	fi	sh	cs	Few fine pores; common fine to medium roots; many fine to medium Fe nodules; weathered basalt.
Cr	147 - 185	2.5YR2.5/2	c	3csbk	sp	fi	sh		Common fine to medium pores; many fine to medium Fe nodules; few weathered basalt.
				Profile 2					
A	0 - 31	5YR3/3	cl	1fmsbk	ssps	fi	s	cw	Few fine to medium pores; many fine to medium roots; many medium to coarse weathered basalt.
AC	31 - 62	5YR2/3	c	2msbk	ssps	fi	sh	dw	Many fine to medium pores; common fine to medium roots; few coarse weathered basalt.
Cr1	62 - 123	2.5YR3/3	c	2msbk	ssps	fi	sh	cs	Few fine pores; common fine roots; prominent weathered basalt; traces of pumice.
Cr2	123 - 167	2.5YR3/3	cl	1csbk	ssps	fi	h		Many fine to coarse pores; few fine roots; few pumice; partially weathered basalt.

Table 2 (contd): Morphological Properties of Pedons at the Lower Slope in the Study Area

Horizon	Depth(cm)	Munsell Colour(dry)	Texture	Structure	Consistence Wet	Consistence Moist	Consistence Dry	Boundary	Other Features
				Profile 1					
A	0 - 28	5YR2.5/2	c	2msbk	sp	fi	sh	cw	Many fine to medium pores; many fine to coarse roots; coarse to very coarse basaltic boulders.
Bt1	28 - 77	2.5YR3/4	sc	2msbk	sp	fi	sh	ds	Few fine pores; few fine roots;few medium basaltic boulders.
Bt1	77 - 135	2.5YR3/4	c	2msbk	sp	fi	sh	cw	Few fine pores; few very fine roots; few fine nodules.
Cr	135 +	10R3/4	c	3msbk	ssps	fi	sh		Many fine pores; coarse weathered basalt.
				Profile 2					
A	0 - 22	7.5YR2.5/1	c	1fmsbk	ssps	fi	sh	cs	Many fine to medium pores; many fine to medium roots; few coarse weathered basalt.
B	22 - 64	5YR3/2	c	2msbk	ssps	fi	sh	gw	Many fine pores; many fine to medium roots; few partialy weathered basalt.
BC	64 - 93	5YR2.5/2	c	2msbk	ssps	fi	sh	dw	Few fine pores; few very fine roots; partially weathered basalt;.
Cr	93 +	5YR2.5/2	c	2csbk	ssps	fi	h		Few fine pores; few fine roots; partially weathered basalt..

Table 3: Some Physical Properties of Pedons on the Crest and Upper slope in the Study Area.

Horizon	Depth cm	Gravel %	Sand %	Silt %	Clay %	Silt/Clay ratio	Texture	Bulk density gcm^{-3}	Particle density gcm^{-3}	Total porosity %
Crest Profile 1										
A	0 - 14	39.02	33.80	21.40	44.80	0.481	clay	0.964	2.03	52.51
Bt1	14 -39	42.00	11.80	31.40	56.80	0.553	clay	1.20	2.15	44.19
Bt2	39 - 73	31.67	15.80	31.40	52.80	0.595	clay	1.147	2.01	42.94
Bt3	73- 120	20.93	15.80	29.40	54.80	0.535	clay	ND	2.12	ND
BC	120- 143	32.50	25.80	31.40	42.80	0.743	clay loam	ND	2.16	ND
Crest Profile 2										
A	0 - 16	32.73	35.80	25.40	38.80	0.655	clay loam	1.131	2.04	44.56
AB	16 - 59	38.03	ND	ND	ND	ND	ND	1.192	ND	ND
Bt1	59 - 94	36.36	35.80	35.40	28.80	1.229	clay loam	ND	2.20	ND
Bt2	94 - 137	29.69	35.80	31.40	32.80	0.957	clay loam	ND	2.26	ND
BC	130 - 180	36.00	39.80	17.40	42.80	0.407	clay	ND	2.27	ND
Upper slope Profile 1										
A	0 -10	64.82	35.80	25.40	38.80	0.654	sandy clay loam	1.127	2.02	44.21
AC	10 -50	70.91	45.80	19.40	34.80	0.557	sandy clay loam	ND	2.11	ND
Cr	50 – 130	62.22	35.80	19.40	44.80	0.433	clay loam	ND	2.02	ND
Upper slope Profile 2										
A	0 - 14	57.17	45.80	21.40	32.80	0.652	Silty clay	ND	2.07	ND
AC	14 - 39	61.54	35.80	23.40	40.80	0.574	loam	ND	1.98	ND
Cr	39 – 125	60.71	33.80	25.40	40.80	0.623	clay	ND	1.96	ND

Table 3 (contd): Some Physical Properties of Pedons on the Middle and Lower slopes in the Study Area.

Horizon	Depth cm	Gravel %	Sand %	Silt %	Clay %	Silt/Clay ratio	Texture	Bulk density gcm^{-3}	Particle density gcm^{-3}	Total porosity %
Middle slope Profile 1										
A	0 - 29	41.67	29.80	31.40	38.80	0.809	clay loam	1.111	2.08	46.59
B	29 -80	39.66	15.80	31.40	52.80	0.595	clay loam	1.378	2.09	34.07
Bt1	80 - 122	26.03	11.80	23.40	64.80	0.361	clay	1.345	2.18	38.30
Bt2	122- 147	28.81	13.80	31.40	54.80	0.575	clay	1.442	2.55	43.45
Cr	147- 185	33.93	11.80	31.40	56.80	0.553	clay	ND	1.98	**ND**
Middle slope Profile 2										
A	0 - 31	39.95	43.80	17.40	38.80	0.4490	sandy clay	1.076	2.13	49.48
AC	31 - 62	51.79	25.80	25.40	48.80	0.521	clay	1.232	2.09	41.05
Cr1	62 -123	50.75	29.80	25.40	44.80	0.567	clay	ND	2.09	ND
Cr2	123 -167	59.09	45.80	19.40	34.80	0.558	silt clay loam	ND	2.18	ND
Lower slope Profile 1										
A	0 - 28	37.50	29.80	25.40	44.80	0.567	clay	0.986	2.10	53.05
Bt1	28 - 77	8.71	5.80	45.40	48.80	0.930	clay	1.318	2.27	41.94
Bt2	77 - 135	17.08	5.80	29.40	64.80	0.454	clay	1.375	2.02	31.93
Cr	135 +	16.14	25.80	23.40	50.80	0.469	clay	1.429	2.06	30.63
Lower slope Profile 2										
A	0 - 22	36.23	31.80	25.40	42.80	0.594	clay	1.112	2.07	45.49
B	22 - 64	43.33	19.80	25.40	54.80	0.464	clay	1.318	2.27	43.00
BC	64 - 93	35.39	15.80	29.40	54.80	0.537	clay	1.205	2.08	42.07
Cr	93 +	61.82	31.80	21.40	46.80	0.457	clay	ND	1.98	ND

ND = Not Determined

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