Clays and Clay Minerals, Vol. 64, No. 5, 668–676, 2016.

TRAPROCK TRANSFORMATION INTO CLAYEY MATERIALS IN SOIL ENVIRONMENTS OF THE CENTRAL SIBERIAN PLATEAU, RUSSIA

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Abstract—The study of hard rock conversion into fine earths and clayey materials in the pedosphere is important in understanding the relative proportions of recent soil features to features that were inherited from ancient epochs. Cold environments are widely thought to be areas of physical weathering, but the coexistence of physical and chemical processes have also been shown. To further examine mafic rock (dolerite) weathering in soil environments and the conversion into clayey materials, Entic Podzols formed in the cold continental climate were studied. The key study was located in the central part of the flood basalt complex, or traps (traprocks), of the Central Siberian Plateau (Russia). The qualitative mineralogy was studied using X-ray diffraction and the quantitative mineral composition was determined using X-ray diffraction and subsequent Rietveld analysis. The micromorphological characteristics of the soils were studied in thin sections. Dolerite fragments and fine earths were sampled from soil profiles underlain by dolerite. XRD analyses indicated that pyroxene and especially plagioclase contents in the dolerite fragments and fine earths decreased from the bottom to the top soil horizons mostly in the mature soil profiles that were affected by chemical weathering of dolerite. The dioctahedral and trioctahedral smectites in the soils were inherited from a dolerite previously subjected to chemical weathering. The smectite was conserved in the inherited aggregates and protected against dissolution even in acidic soil horizons. Recent pedogenesis processes fractured individual fragments, converted it into soil micromass, and slightly decreased the total smectite content of the <1 μm soil fraction. However, in soil samples collected from the bottom to the top horizons of a mature soil profile, trioctahedral smectite contents decreased as dioctahedral smectite contents increased. This suggests that dioctahedral smectites formed by pedogenic alteration of inherited trioctahedral smectites.

Key Words—Dolerite Weathering, Entic Podzols, Petrography Study, Smectite, XRD-amorphous Phase.

INTRODUCTION

The processes that create fine earth materials from hard rocks are highly important for life on Earth. In the pedosphere, however, the ratio of recently formed fine earth materials to fine earths inherited from ancient epochs is still unknown. Studies of rock weathering in the soil environments of cold regions can act as a bridge to understand the processes that are active in the critical zone of high latitudes and polar zones. Cold environments are widely thought to be areas of physical weathering; nevertheless, both physical and chemical processes have been shown to occur and the progress of chemical weathering is limited by moisture availability (Hall *et al.*, 2002). The evidence of chemical weathering is illustrated by the weathering rims on cobbles from soil horizons (Thorn *et al.*, 2011) and clay mineral transformations in cold soil environments (Simas *et al.*, 2006; Borden *et al.*, 2010) that can even occur in an extreme continental climate (Alekseev *et al.*, 2003; Lessovaia *et al.*, 2013). The extent of chemical weathering depends on rock microstructural properties (Meunier *et al.*, 2007; Velde and Meunier, 2008). In the soils of cool climates, biochemical weathering is mostly controlled by the abundance of organic acids which lead to the prevalence of non-crystalline or poorly ordered materials and organo-mineral complexes in the weathering products (Wilson and Jones, 1983).

The flood basalt complex (traps or traprocks) of the Central Siberian Plateau (Russia) is one of the largest areas of platform volcanism in the world (Ross *et al.*, 2005). The landscapes in this region can provide information on pedogenesis and rock weathering in cold continental climates. For the first time, unique well-drained soils formed in autochthonous, fine earth accumulations that are underlain by traprocks were described and classified as "Ocherous Podburs (later

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DOI: 10.1346/CCMN.2016.064042

This paper is published as part of a special section on the subject of 'Clays in the Critical Zone,' arising out of presentations made during the 2015 Clay Minerals Society-Euroclay Conference held in Edinburgh, UK.

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press

Parapodzols)" (Sokolov and Gradusov, 1978) or Vitric Entic Podzols. Later, a study of pedogenesis processes specifically affected by traprock (*i.e.* dolerite) porosity and mineralogy illustrated the metastable nature of soil smectites inherited from altered dolerite (Lessovaia *et al.*, 2014). The aim of the present research was to further examine the conversion of traprocks into clayey materials and understand the role of clay minerals in future changes in the soils of the cold continental climate of Central Siberia (Russia).

STUDY AREA AND MATERIALS

The study area was located in the central part of the flood basalt complex on the Central Siberian Plateau (Russia) in the Nizhnyaya Tunguska River basin, close to the town of Tura. This area is characterized by a cold continental climate with a mean air temperature of −9ºC (annual), −36.0ºC (January), and +16.6ºC (July). The mean annual precipitation is ~370 mm. The vegetation is larch (coniferous) boreal forest and open woodlands close to forest tundra.

The studied soils were: (i) profile 1 (Pit E-2/8), a shallow Epileptic Entic Podzol (IUSS Working Group WRB, 2015) formed in local accumulations of fine earth segmented by traprock boulders of dolerite and (ii) profile 2 (Pit E-5/8), a mature Endoleptic Entic Podzol (Hypoturbic) developed in saprolite formed from traprocks. The horizon sequence of soil profile 1 was as follows: O horizon with slightly decomposed plant litter, a loamy Bhs horizon enriched with dolerite fragments, and an Rs horizon characterized by a significant proportion of dolerite fragments with sesquioxide films in Pit E-2/8. The horizon sequence of profile 2 was as follows: Oe horizon with moderately decomposed plant litter (2 cm), raw humus Oa and Ah horizons, a slightly cryoturbated, loamy Bhs horizon, a transitional BCs horizon, a BC horizon of saprolite with soft rock fragments, and a BR horizon with a mixture of pedogenic material and a high proportion of pedogenically altered, hard rock fragments in Pit E-5/8 (Lessovaia *et al.*, 2014). Profile 1 was located on the upper part of a stony slope and profile 2 was located on the summit area, which suggests that the fine earth in the soil profiles were autochthonous (*i.e.* formed in place).

METHODS

Mineral associations in powdered rock fragments and the <1 mm fine earth from soil horizons and in oriented <1 μm soil samples were studied using a Rigaku MiniFlex II (Rigaku Corporation, Tokyo, Japan) X-ray diffractometer (XRD) with CoKα radiation. The soil <1 mm fractions were obtained by gentle grinding with a mortar and pestle and by subsequent dry sieving. The <1 mm particle-size fraction of the soil samples was dispersed by adding 3–4 drops of ammonia as a peptizing agent, then the <1 μm fraction was separated by sedimentation and decantation according to the method of Gorbunov (1971). Pretreatment of the <1 μm fractions before XRD examination included Mg saturation and ethylene glycol solvation.

For several <1 μm samples, quantitative mineralogical compositions were determined on randomly oriented powder specimens using Bragg-Brentano geometry and a Bruker AXS D8 Advance X-ray diffractometer (Bruker Corporation, Karlsruhe, Germany) operating with CoKα radiation, followed by Rietveld quantitative analysis (Rietveld program AutoQuan, GE SEIFERT; Bergmann *et al.*, 1998; Bergmann and Kleeberg, 1998; Bish and Plötze, 2011). A <1 μm sample was packed in a front-loading XRD specimen holder and a blade was used to smooth the surface and minimize preferred orientation. The qualitative phase composition was determined using Bruker AXS DIFFRACplus software. On the basis of the peak position and the relative intensities, the mineral phases were identified by comparison to the PDF-2 database from the International Centre for Diffraction Data (ICDD).

For micromorphological studies, the horizon materials were collected into sampling boxes (5 cm × 3 cm) except for the Rs horizon of profile 1 (Pit E-2/8) and BR horizon of profile 2 (Pit E-5/8), which were enriched by rock fragments. Thin sections were made from air-dried samples using "Geoptic" (index of refraction – 1.534) epoxy resin. The thin sections were studied by optical microscopy using a Zeiss Axioplan 2 (Carl Zeiss, Oberkochen, Germany) and Polam P-312 microscopes (Lomo, Russia). Thin section descriptions were based on the optical methods described in Stoops (2003, 2007) and Stoops *et al.* (2010).

RESULTS

Soil characteristics

The morphological and physicochemical characteristics of the Entic Podzols were very similar to the "Ocherous Podburs" that developed from the fine earths of traprocks that are widespread on the Central Siberian Plateau (Sokolov and Gradusov, 1978). Summarizing the data (Lessovaia *et al.*, 2014), the soil profiles were characterized by (i) a high content of soil organic matter with a large C:N ratio (>20); (ii) pH values that ranged from slightly alkaline to acidic were observed even in a shallow profile 1 (Pit E-2/8) which formed in local accumulations of the fine earth that were not incorporated into continuous layers; (iii) increased extractable Fe, Al, and Si in the Bhs horizons (Table 1); and (iv) a high proportion of X-ray amorphous materials in the acidic horizons. Pure smectite was observed in the <1 μm fractions based on XRD data, but identification was not obvious because of the presence of kaolinite and amorphous silica that were identified using FTIR spectroscopy.

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press

Table 1. Some properties and micromorphological features of the studied soils.

Horizon, depth (cm)		Soil properties*					Micromorphological features			
		pH H_2O	%C	Fe_2O_3 oxalate extractable (%)	Al_2O_3 oxalate extractable (%)	SiO_2 oxalate extractable (%)	Micro-structure	Soil micromass	Coarse constituents	Features
Epileptic Entic Podzol (Profile 1, E-2/8)										
O	2–0	6.1	–	–	–	–	–	–	–	–
Bhs	0–15	5.7	2.56	2.1	0.56	0.32	mainly spongy, loose	*c.* in microzones	multiple *d.f.* up to 5 mm; coarse sand (1–1.5 mm) slightly *s.pl.*; *s.a.*	roots, *c* thin films
Rs	15–45	7.3	–	1.6	0.32	0.04	–	–	–	–
Endoleptic Entic Podzol (Hypoturbic) (Profile 2, E-5/8)										
Oe	2–0	5.1	–	–	–	–	–	–	–	–
Oa	0–4	4.8	–	–	–	–	loose	isotropic, *h.-i.*, *c.-i.*	well rounded, coarse sand - gravel *d.f.* with *s.pl.*	roots; cracks (0.014–0.030 mm) with clay and *Fe*; *c.-i.* films 0.019–0.12 mm
Ah	4–8	4.8	12.49	1.6	1.61	0.14	very loose	mainly isotropic *i.-h.*; *c.* in some segments	very crushed *d.f.*; silt to medium-sand *s.pl.*; fractured *s.a.*	roots; clay and *Fe* in cracks; *c.*, *h.-i.* films
Bhs	8–14	5.8	2.47	1.3	2.25	0.56	spongy	*c.-i.*	*d.f.* 0.6–1.5 mm; silt *s.pl.*; *s.a.*	clay and *Fe* in cracks; *i.-c.*, *c.-i.-s.* films (0.039–0.085 mm).
BCs	14–26	6.8	0.38	0.5	0.43	0.17	loose	*c.-i.* in microzones	silt *d.f.*, chipping from gravel; *s.a.*	clay and *Fe* in cracks; thin (0.3–0.7 mm) *i.-c.* films
BC	26–53	7.3	0.49	0.4	0.31	0.15	loose		gravel *d.f.*; *s.pl.*; *s.a.*	*s.-c.-i.* films
BR	53–100	7.7	0.28	0.5	0.33	0.10	–	–	–	–

Abbreviations and notes: C – total carbon; '–' – no data available; *d.f.* - dolerite fragments, *s.a.* - smectite aggregates; *s.pl.* - saussuritized plagioclase; *c.* – clayey; *c.-i.* - clayey-iron; *i.-c.* - iron-clayey; *s.-i.-c.* - silt–iron–clayey; *s.-c.-i.* - silt–clayey–iron; *h.i.* - humus-iron; *i.-h.* - iron-humus; *Fe* – iron (oxyhydr)oxides; * – data obtained from Lessovaia *et al.* (2014).

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press

Soil micromorphological characteristics

The Entic Podzols studied were characterized by (i) a loose microstructure, which was spongy only in the Bhs horizons; (ii) multiple dolerite fragments, which displayed signs of disintegration; (iii) cracks inside dolerite fragments that were filled with clay and iron (oxyhydr)-oxides; (iv) saussuritized (*i.e.* Ca-plagioclase alteration into a characteristic mineral assemblage) plagioclase; (v) coatings on rock fragments; (vi) smectite aggregates, which were previously described in dolerite thin sections (Lessovaia *et al.*, 2014); and (vii) a predominantly clayey and clayey–iron soil micromass (Table 1).

The specific micromorphological features are summarized below. In the Bhs horizon of profile 1 (Pit E-2/5), a spongy microstructure was predominant, but some loose material was also found. The areas were packed with multiple rock fragments that were disintegrated along the periphery and had accumulations of angular, silt particles that coated the surface of gravel particles as a result of rock disintegration. Singular plagioclase grains were saussuritized, smectite aggregates were rarely fractured, and the clayey soil micromass was only identified in several microzones.

The profile 2 (Pit E-5/8) Oa horizon contained mostly well-rounded dolerite fragments from coarse sand to gravel. Multiple cracks inside the gravels were partially filled with clay and iron (oxyhydr)oxides and, in some individual cases, the cracks were filled with clay. The dominant microaggregates were shaped by silt- and sand-sized grains coated with clayey–iron films. The gravel surfaces displayed discontinuous clayey–iron films with an admixture of fine and medium silt plagioclase grains. Fractured smectite aggregates were rare, but found.

In the profile 2 Ah horizon, the soil micromass was predominantly iron-humus, but clayey in some segments. The dolerite fragments were more fragmented than in the Oa horizon. The silt- to medium sand-sized grains had surface films that were enriched with clay, which sometimes were optically oriented. The sand and silt grains were often bound into aggregates by humus–iron coatings and smectite aggregates were fractured into individual fragments.

The profile 2 Bhs horizon was characterized by a clayey–iron soil micromass and was enriched with smectite aggregates in comparison to upper soil horizons. Rounded aggregates were dominant with a rock fragment coated with iron–clay and silt–iron–clay films (Figure 1a) and were bound together by 0.6–0.9 mm diameter microaggregates and clay and iron (oxyhydr)oxides filled the cracks inside gravel particles.

In the profile 2 BCs horizon, a large proportion of the gravel particle surfaces were coated. Several fragmentation stages were seen: (i) fractures in the gravel; (ii) detached silt particles; and (iii) gravel cracks were infilled with iron–clay material (Figure 1b). The gravel particles were bound into aggregates (diameter ~2–3 mm) by relatively thin iron–clay films. Smectite aggregates were also identified and were sometimes fractured (Figure 1c).

In the profile 2 BC horizon, only smectite aggregates were found. A large amount of dolerite fragments was found, along with saussuritized plagioclase. Thick silt–clay–iron films were on the surfaces of dolerite fragments (Figure 1d) and the clay component of the film was optically oriented.

Mineral associations based on XRD data

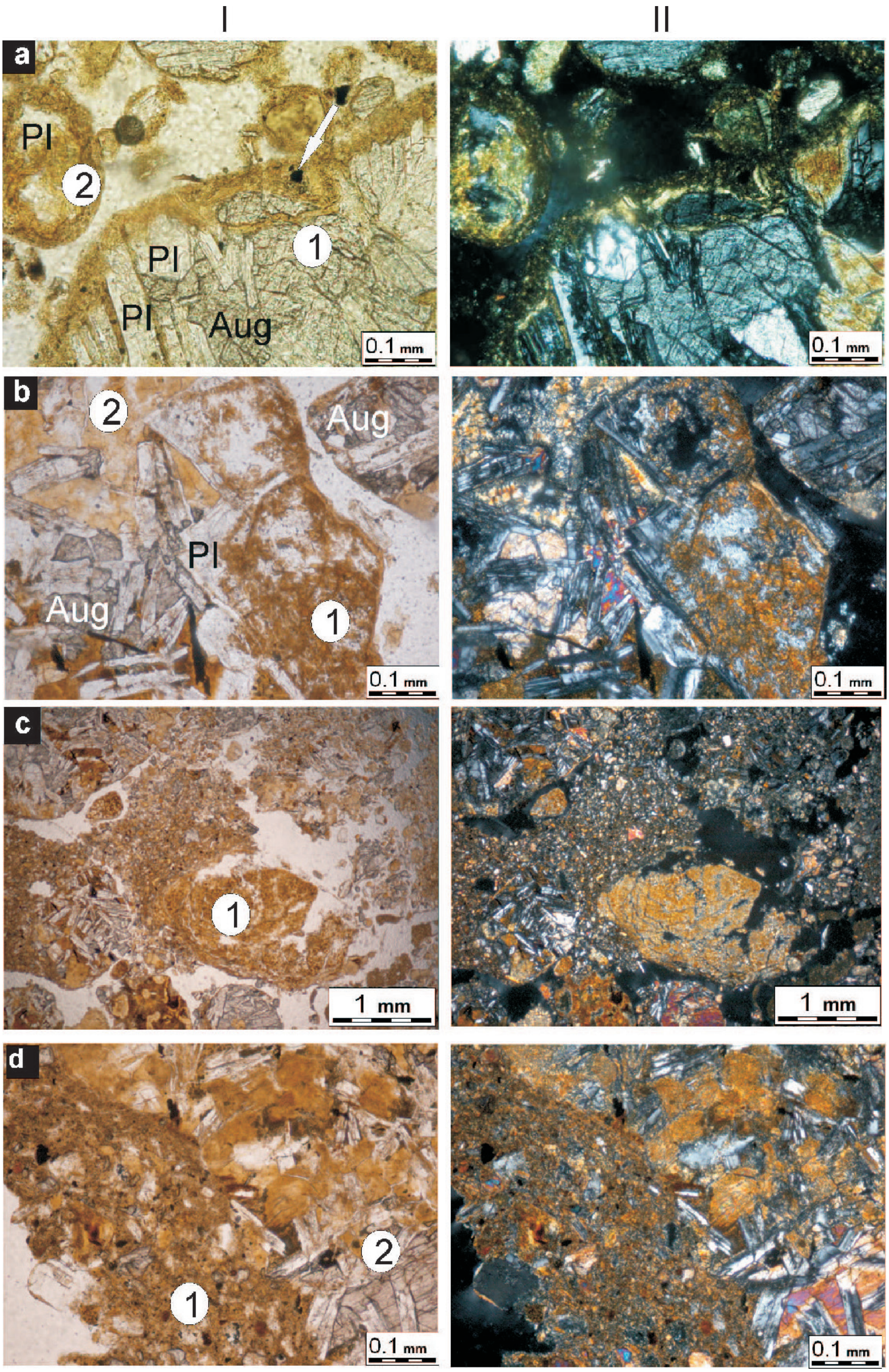
In the rock fragments and the <1 mm fine earth, plagioclase had *d* spacings of 0.407 nm, 0.376 nm, 0.362 nm, and two strong maxima at 0.321 nm and 0.319 nm; pyroxene peaks at 0.328 nm, 0.315 nm, 0.287 nm, 0.252 nm, and 0.211 nm were also identified (not shown). The presence of phyllosilicates was established based on peaks with *d* spacings of 1.46–1.5 nm, which was previously identified as smectite (di- and trioctahedral) in dolerite fragments using XRD and subsequent Rietveld analysis (Lessovaia *et al.*, 2014).

Based on the above criteria and relative peak intensities, the distribution of smectite was slightly smaller in the rock fragments from the Rs horizon of profile 1 (Pit E-2/8) and increased toward the Bhs horizon. In contrast, profile 2 (Pit E-5/8) smectite proportions strongly increased with soil depth. In the soil profiles, pyroxene and plagioclase contents decreased from the bottom towards the upper horizons, especially in profile 2. Concomitantly, the XRD background hump in the 20–30º 2θ range increased considerably, and thus indicated the presence of an X-ray amorphous phase. The same mineral distribution trends were observed in the <1 mm fine earth fractions of both soil profiles.

The XRD patterns of the <1 μm fractions of the oriented samples revealed smectite, which was identified by the shift of the Mg-saturated air-dry 1.43 nm peak to the d_{001} and d_{002} peaks at 1.7 and 0.849 nm (Moore and Reynolds, 1997). Smectite was predominant throughout the shallow profile 1 (Pit E-2/8) and only in the bottom horizons (BR and BC) of the mature profile 2 (Pit E-5/8), whereas smectite 00*l* peaks in the XRD patterns from other horizons of profile 2 were very low in intensity (Figure 2).

The XRD patterns from the randomly oriented powder specimens (<1 μm) and the subsequent Rietveld analysis indicated a significant proportion of dioctahedral and trioctahedral smectites. The second major component of the soil fractions was amorphous silica (Table 2). The general trends of dioctahedral smectite, trioctahedral smectite, and amorphous silica distributions are summarized as: (i) trioctahedral smectite proportion decreased from the bottom to the upper horizons as the dioctahedral smectite proportion

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press



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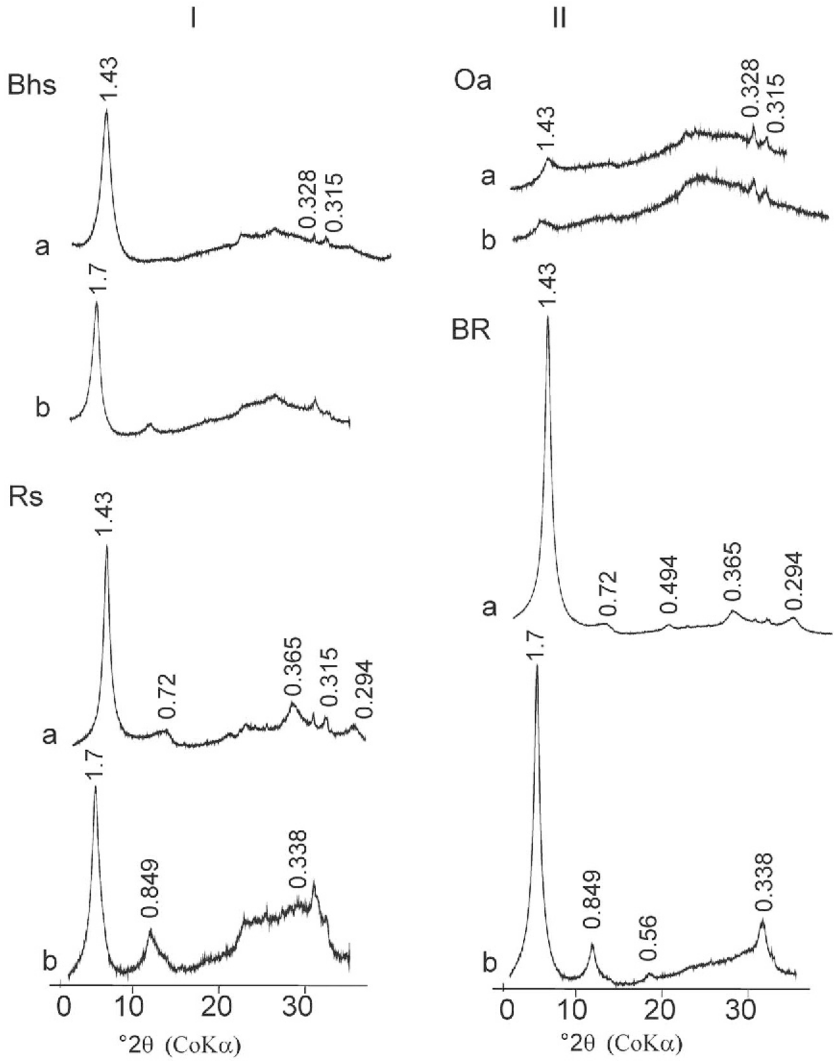

Figure 2. XRD patterns of the <1 μm fractions of oriented samples illustrating smectite presence in profile 1, (Pit E-2/8) (I) and the significant decrease of smectite content in the upper Oa horizon in profile 2, (Pit E-5/8) (II) based on 00*l* peak intensities; (a) Mg saturated air-dried samples and (b) Mg saturated ethylene glycol-solvated samples with *d* values in nm.

increased and (ii) the amorphous silica proportion insignificantly increased towards the top. These trends were more pronounced in profile 2 (Pit E-5/8). Total proportions of smectite decreased in the Ah and Bhs horizons of profile 2.

DISCUSSION

The presence of smectite in rock fragments in the <1 mm fine earth and the <1 μm fraction suggests that the clay was not pedogenic in the studied soils, but was inherited from chemically weathered dolerite. The most probable main process that resulted in the permanent release of smectite into the soil profiles with pronounced accumulations in the <1 μm fraction was physical disintegration of rock fragments due to extreme temperature amplitudes. The mechanical desegregation and grinding were thought to explain the accumulation of smectites inherited from chemically altered traprocks in soils and sediments under permafrost conditions

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Figure 1 (*facing page*). Micromorphological features of Entic Podzols studied in (I) – plain polarized light and (II) – crossed polarizers: (a) dolerite fragment (1) composed of plagioclase (Pl) and pyroxene (augite) (Aug) with silt–iron–clayey coating (arrow) and detached plagioclase grain (2), (b) saussuritized (1) plagioclase (Pl) in dolerite fragment and release of clayey material (2) from the rock, (c) destruction of smectitic aggregates (1) and conversion to soil micromass, (d) thick silt–clayey–iron coating (1) and altered plagioclase grain (2). Abbreviations are from Whitney and Evans (2010).

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press

(Pokrovsky *et al.*, 2005). Formation of the fine size fractions through physical disintegration has also been shown in soils on amphibolite (Lesovaya *et al.*, 2008, 2016), which is less sensitive to weathering than traprocks.

Development of chemical weathering in the soil environment was apparent by (i) a greater decrease in the proportion of primary minerals (plagioclase and pyroxene) both in the rock fragments and the <1 mm fine earth fraction in the upper horizons of the mature soil profile 2 (Pit E-5/8); (ii) a significant proportion of oxalate-extractable Fe, Al, and Si in the soil fine earth fraction; and (iii) a pronounced increase in amorphous silica content in the <1 μm fraction compared to the rock fragments. The decrease in plagioclase content in the upper soil horizons was more pronounced than for pyroxenes, which was also reported for basalts (Nesbitt and Wilson, 1992).

The fact that the 00*l* peaks in XRD patterns of oriented samples from horizons above the BC horizon of the mature Entic Podzol (profile 2, Pit E-5/8) had very low intensity might indicate smectite transformation into an amorphous phase due to the acidification. But according to the Rietveld analysis of the XRD patterns of randomly oriented powder specimens, the *hk* peaks of smectite were still present. The decrease in total smectite content and the increase in the amorphous phase content were rather insignificant. Identification of smectite based on the 00*l* peaks was most likely prevented by the presence of amorphous materials, such as extractable Fe, Al, and Si formed by the dissolution of dolerite primary minerals. The disintegration of rock fragments might also release the amorphous (poorly crystallized) iron (oxyhydr)oxides that were identified in cracks and clay material derived from saussuritized plagioclase, which can form in the weathering crust of basalts in a cold environment (Wilson and Jones, 1983).

Typical weathering profiles on basaltic rocks have been described by consistent stages of hard rock conversion: coherent altered rock → saprock (boulders) → clay-rich saprock → saprolite (Meunier, 2005). Taking into account that even the individual mineral grains in saprock are not extensively altered chemically (Wahrhaftig, 1965; Girty *et al.*, 2003), smectite in the aggregates can be protected against dissolution in the acidic Bhs horizon of a shallow Entic Podzol (profile 1, Pit E-2/8). In contrast, the dolerite fragments were more altered in the mature Entic Podzol (profile 2, Pit E-5/8) with saprolite. Smectite aggregates were in fact converted to soil micromass, especially in the Ah and Oa horizons. These observations are in good agreement with the idea that in saprolite zones unaltered remnants are fragmented and dispersed throughout a clay-rich matrix forming the secondary plasma (Meunier and Velde, 1979; Meunier *et al.*, 2007). Alternatively, the numerous coatings identified on the rock fragments can reduce the dissolution rate of the primary minerals (Schnoor, 1990; Hodson 2003; Ganor *et al.*, 2005).

Table 2. Quantitative mineralogical composition of the <1 μm of soil horizons determined using Rietveld analysis of XRD-data measured using corundum as internal standard and normalized to 100 wt% with 3σ absolute error.

Horizon	Components								
	Smectite		Amorphous silica	Ca-plagioclase	Pyroxene (augite)	Quartz	Olivine	Magnetite	Ilmenite
	dioctahedral	trioctahedral							
Epileptic Entic Podzol (Profile 1, E-2/8)									
Bhs	13.8±1.0	37.3±1.0	46.6±1.1	1.8±0.3	0.2±0.2	0.3±0.1	–	–	–
Rs	10.5±1.1	42.8±1.2	40.3±1.5	5.2±0.4	0.6±0.5	0.6±0.1	–	–	–
Rs*	2.5±1.7	10.0±1.2	12.9±2.1	41.7±1.2	26.5±0.9	0.5±0.2	2.0±0.3	2.6±0.3	1.3±0.2
Endoleptic Entic Podzol (Hypoturbic) (Profile 2, E-5/8)									
Ah	44.9±1.5	11.0±1.0	40.0±1.6	2.0±0.4	0.4±0.2	1.7±0.2	–	–	–
Bhs	48.1±1.7	10.1±1.1	39.0±1.7	1.0±0.3	0.4±0.2	1.4±0.2	–	–	–
BC	30.6±2.6	35.3±1.5	28.9±2.8	3.9±0.5	0.3±0.2	1.0±0.2	–	–	–
BR	28.1±1.3	33.5±1.1	34.7±1.5	2.7±0.3	0.6±0.2	0.4±0.1	–	–	–
BR*	6.3±1.8	15.0±1.2	8.4±2.2	43.8±1.3	24.4±0.9	0.4±0.2	nd	0.4±0.3	1.3±0.3

Abbreviations and notes: *Quantitative mineralogical composition of rock fragments from soil horizons, measured with zincite as an internal standard (Lessovaia *et al.*, 2014); '–' – no data available; nd – not detected.

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press

In Siberian traprocks, a trioctahedral oxy-smectite was described (Dainyak *et al*., 1981). Transformation of trioctahedral oxy-smectite into dioctahedral smectite on the weathering rings of traprocks of the basalt of the Putorana Plateau of Central Siberia was reported (Pokrovsky *et al*., 2005). Both dioctahedral and trioctahedral smectite were identified in the traprocks sampled from the bottom horizons of soils (Lessovaia *et al*., 2014). The proportion of trioctahedral smectite in a soil profile decreased from the bottom to the upper horizons as the dioctahedral smectite proportions increased, especially in the mature Entic Podzol (profile 2, Pit E-5/8). This can be explained as the transformation of less stable trioctahedral smectite into dioctahedral smectite. This process was less pronounced in the shallow Entic Podzol (profile 1, Pit E-2/8), which might be due to protection of the smectite in the aggregates against dissolution even in the acidic horizon.

CONCLUSIONS

The processes of weathering and pedogenesis led to a decrease in the proportions of pyroxene and especially plagioclase that were inherited from the dolerite in the <1 mm fine earth fractions of the upper soil horizons of Entic Podzols as acidification and extractable Fe, Al, and Si increased.

The appearance of dioctahedral and trioctahedral smectites in well-drained soils (Entic Podzols) formed from traprocks of the cold continental climate of Central Siberia was less affected by pedogenesis than by previous stages of dolerite weathering and alteration. The permanent and intensive physical disintegration of coarse fragments brought new portions of smectite into the soil profiles. The decrease of total smectite content in the <1 μm fraction of the soil, even in a mature Entic Podzol, was rather insignificant based on Rietveld analysis of the XRD patterns of randomly oriented powder specimens. This confirmed that the smectite *hk* peaks were still present, whereas 00*l* peaks in oriented-sample XRD patterns were very low in intensity.

The profile distribution of smectite in the mature Entic Podzol demonstrated a pronounced decrease in trioctahedral smectite content from the bottom to the upper soil horizons as dioctahedral smectite content increased. Smectite in the aggregates can be protected against dissolution even in acidic horizons. Recent pedogenesis converted "smectitic" aggregates into soil micromass.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research (14-04-00327), the Russian Science Foundation (14-27-00133) – morphological studies and soil classification, and St-Petersburg State University (18.38.418.2015). XRD study of soils was carried out in the X-ray Diffraction Centre of St. Petersburg State University. The authors are also grateful to reviewers for helpful suggestions and corrections to the article.

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(*Received 9 October 2015; revised 9 December 2016; Ms. 1047; AE: P. Schroeder*)

https://doi.org/10.1346/CCMN.2016.064042 Published online by Cambridge University Press