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Research paper

Mineralogy and pore space characteristics of traprocks from Central Siberia, Russia: Prerequisite of weathering trends and soil formation

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ABSTRACT

Pore space issues and mineral paragenesis of traprocks from the central part of the basaltic province (Central Siberia, Russia) were studied, as was the fine size fraction (<1 μm) of well-drained soils from two groups — “shallow with hard rock” and “deeper and mature with saprolite.” The explanation of coexisting of these two groups was given via rocks' characteristics.

The methods used included mercury intrusion porosimetry (MIP), impregnation of connective pores with a molten alloy (Wood's metal) combined with subsequent electron microscopy, optical microscopy, X-ray diffraction, and IR spectroscopy.

Rock from the lithic contact is represented by slightly weathered dolerite and shows a tendency to bimodal pore size distribution with a second maximum in pore size at 10 nm, which is due to the occurrence of phyllosilicates. Coarse pore systems are mainly due to cracks, which allow an easy exchange of water. Higher total porosity in the rock in one of two pits (~12 vol.% compared with 4 vol.%) appears to be a prerequisite for the formation of a deeper and more mature profile.

Secondary products of dolerite weathering are smectites determining the association of clay minerals in both soil profiles and Fe-oxides. Most likely, desegregation and weathering of the rock fragments from soil horizons are fast enough to keep sufficient amounts of smectite only in the fine size fraction of the shallow profile. In the mature profile, pedogenesis leads to acidification of upper soil horizons and to a pronounced decrease in the smectite proportion, not only in the soil but also in the rock fragments from soil horizons. Thus, smectite(s) that was stable in early stages of rock weathering and soil formation and became unstable due to soil acidification illustrates the metastable nature of clay mineralogy in the well-drained soils from basic rock.

1. Introduction

The Central Siberian Plateau with its flood basalt complex or traps (traprocks) together with the Deccan plateau in India are the largest areas of platform volcanism in the world where mafic rocks are the parent material for soil formation. The spatial distribution of traprocks on the Siberian Plateau (Russia) is estimated to be 1500×10^3 km^2, with a total volume 911×10^3 km^3 (Ross et al., 2005). Studies in Central Siberia provide information on the weathering and pedogenesis on mafic materials in cold continental climates.

Based on the approach of Velde and Meunier (2008), interactions between primary minerals and solutions often occur within confined or semi-confined microenvironments, such as pores, rather than in a bulk solution. In relatively dense volcanic mafic rocks, such as flood basalts, porosity is assumed to be a decisive factor for the progress of rock weathering, as mineral paragenesis consists of highly vulnerable minerals and the reaction rate depends on the accessibility of mineral surfaces for pore solutions. Furthermore, in the permafrost-affected zone, freezing and thawing cycles are an additional factor in physical weathering, which results in the formation of fresh mineral surfaces that are highly susceptible to chemical weathering (Allen, 2002; Arnaud and Whiteside, 1963).

The mineralogy of traprocks, including clay mineralogy, was studied in detail by Dainyak et al. (1981) who, in coarse-grained dolerite with poikilophitic texture from Tungusskaya syneclise, identified a specific mixed dioctahedral–trioctahedral Fe-rich smectite with a d_{060} spacing of 1.536 Å. Later, Pokrovsky et al. (2005) described dioctahedral smectite ($d_{060} = 1.52$ Å) and trioctahedral oxidized Fe-rich smectite from weathered traprocks of the Putorana Plateau of Central Siberia.

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Unique soils have been forming here in autochthonous accumulations of fine earth underlain by traprocks. The well-drained soils on traprocks of the Central Siberian plateau were classified as “Ocherous Podburs (later Parapodzols)” or Vitric Entic Podzols by I.A. Sokolov, who studied them and stressed the specificity of the soil landscapes of this territory (Sokolov and Gradusov, 1978; Sokolov et al., 2004).

Nevertheless, for the unique, vast region of traprocks in Central Siberia, many aspects of soil properties connected with phyllosilicate association, weathering of rocks in soil environments, and especially porosity, as well as element release and secondary mineral appearance and the overall progress in soil formation, are still poorly known. The aim of this study is to investigate the porosity and mineralogy of traprocks, the dependency of the progress of weathering on the porosity in the parent rock and details of their weathering in well-drained soils developed in the cold continental climate of Central Siberia.

2. Study location

The key plots for this study belong to the central part of the basaltic province and include the vicinities of the town of Tura on the bank of the Nizhnyaya Tunguska River (Fig. 1). Upper Permian–Lower Triassic lava flows, mafic volcaniclastic deposits, and intrusions are observed here (Czamanske et al., 1998; Lur'e and Masaitis, 1966). The age of the traprocks is 250 million years (Sharma, 1997). The depth of the flood basalt (tholeiitic basalt) is up to 300 m, and the depth of the underlain mafic volcaniclastic deposits is 700 m (Sharma, 1997; Zolotukhin and Al'mukhamedov, 1988).

The larch (*Larix gmelinii*), deciduous coniferous forest, which is typical for the watersheds of Central Siberia, has been documented in the study area. Apart from larch spruce (*Picea obovata*), birch (*Betula pendula*) are in the overstory; dwarf shrubs, mosses, and lichens cover the soil surface (Prokushkin et al., 2010). Based on records from Tura, the cold continental climate is characterized by a mean annual air temperature of −9.0 °C, a mean annual precipitation of 369.6 mm (mainly in summer and 40% of precipitation as snow) and a high contrast between summer and winter temperatures (+16.6 °C average for July and −36.0 °C average for January). The study site belongs to the continuous permafrost area with a thickness of >200 m (Prokushkin et al., 2010). The depth of the active (unfrozen) layer (June–August) ranges from 0.5 m on the northern slopes under peaty soils, to >1.5–2 m on well-drained stony soils, especially in the southern exposure. The average annual soil temperature (at the depth of 50 cm) does not exceed 0 °C.

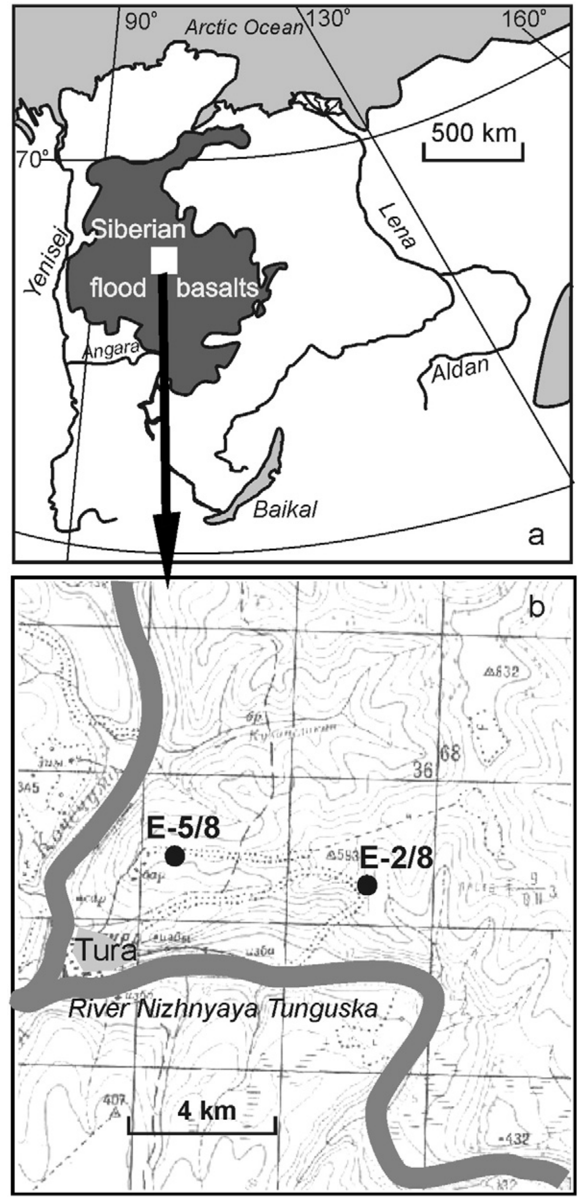

Fig. 1. Location of flood basalt complex in Central Siberia and the sampling sites (white) (a) for Epileptic Entic Podzol (E-2/8) and Endoleptic Entic Podzol (Hypoturbic) (E-5/8) (b).

3. Objects

Several dozens of soils were excavated and described in the region. The well-drained ones belong to two different groups — “shallow with hard rock” and “deeper with saprolite” with coherent altered rock from the lithic contact according to Meunier (2005). Several soil profiles from both groups were analyzed for morphology and general soil properties (pH, soil carbon content (C), N, particle size distribution). Based on these investigations and comparisons, the most representative soil profile from each of the two groups was sampled for the detailed study.

The first key plot was located on the upper part of the stony slope under the open larch-birch forest with dwarf–shrub–moss plant cover. The GPS coordinates are 64° 18′ 19.3″N and 100° 23′ 37.3″E at an altitude of 585 m. This shallow soil was classified as Epileptic Entic Podzol (Pit E-2/8) according to the World Reference Base for Soil Resources (2006). In accordance with the Guidelines for Soil Description (FAO, 2006), the soil consists of the O horizon with a slightly decomposed litter (2 cm); the Bhs horizon (0–15/20 cm) of 5YR 3/2 (Munsell color charts), which is loamy with many stones (rock fragments) and roots, strong blocky subangular structure, which have been developing only in the local accumulations of the fine earth and are segmented by boulders; and the Rs horizon (15–45 cm) of 5YR 2.5/2 which is stony with sesquioxides films on the stone and rock surfaces.

The second key plot was close to the first one (Fig. 1), located on the narrow (300 × 100 m) summit area under birch with rare larch open forest and bush–dwarf–shrub–moss plant cover. The coordinates are 64° 17′ 49.5″N and 100° 14′ 24.0″E at an altitude of 418 m. The slightly perceptible patterned ground is on the surface. The fine earth is incorporated in continuous layers, demonstrating a more pronounced step of rock disintegration than in the first key plot. This soil was classified as Endoleptic Entic Podzol (Hypoturbic). The soil profile consists of the Oe horizon of medium decomposed litter (2 cm), raw humus horizons with different organic/mineral material ratio; Oa (0–4 cm) and Ah (5YR 3/4) (4–8 cm); a spodic Bhs horizon (8–14 cm) of 2.5YR 3/6 that is loamy with a fine moderate subangular blocky structure, slightly cryoturbated; transitional BCs (5YR 4/3) (14–26 cm); a BC (5YR 4/3) (26–53 cm) horizon of saprolite with increasing soft stone content; and an underlying horizon (5YR 3/3) (53–100 cm) of saprock with a high content of pedogenically altered but hard stones. This horizon