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Stoichiometry of cationic nutrients in Phaeozems derived from skarn and Acrisols from other parent materials in lowland forests of Thailand

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ABSTRACT

Some soils under tropical forests in western Thailand are derived from skarn complexes of hydrothermally metamorphosed granitic, calcareous and ultramafic rocks. We used data from six large, long-term forest ecological research plots to compare the soils derived from skarn with forest soils derived from granites and sedimentary parent materials elsewhere Thailand. The soils derived from skarn are Vermic Phaeozems and have deep, dark, worm-worked topsoils and bimodal particle size distributions of coarse sand and grit in clay or fine loam matrices. They are eutrophic with respect to both labile and non-labile forms of the mineral nutrients. The soils derived from other parent materials are mostly Acrisols. Analyses of variance for the cationic nutrients taken independently clearly distinguished the Phaeozems from the Acrisols. The two groups are also stoichiometrically distinct with respect to the main cationic nutrients, as depicted graphically by nutrient roses and as quantified as M^+:TEB ratios. The cationic stoichiometric proportions also differentiated between the Acrisols on different plots and parent materials; and between the Phaeozems in our study and eutrophic soils in lowland forests elsewhere in the lowland tropics, with the Phaeozems having lower exchangeable Ca and Mg contents but higher exchangeable K. Subsoil cationic stoichiometric profiles appear to derive from parent materials, but those of the topsoil may be modified by selective biotic recycling. Nonetheless, inherited lithogenic stoichiometric ratios are still apparent in our topsoils. The forests on skarn in West Thailand are varied and overlap with those on Acrisols and other soils. This confirms earlier findings that climate and disturbance history have more influence than soils on the regional distribution of forest types in Thailand, although soils can be important at more local scales.

1. Introduction

Skarns (calcsilicates) form when siliceous hydrothermal fluids suffuse carbonate or mafic country rocks in contact zones around granite intrusions. They are mineralogically heterogeneous, depending on the compositions of the suffusing fluids and the host rock. Many skarns have porphyritic structures, with coarse quartz or feldspar crystals embedded in fine-grained matrices of intermediate, mafic or ultramafic composition. Skarns are common in contact zones around large granite intrusions, but their outcrops are not extensive. Their location and mode of formation give considerable scope for mineralization, and skarn ore bodies have been prospected and mined for a wide range of resources, including arsenic, copper, gold, molybdenum, tin, tungsten, and rare earth elements. Many studies of soils derived from skarn focus on their potential as pedochemical indicators for mineral prospecting (Park, Jeon, Kim, & Chon, 2014), or on their contamination during mining (Pfeifer, Haussermann, Lavanchy, & Halter, 2007) and mineral extraction (Requelme, Ramirez, Angelica, & Brabo, 2003).

There are few studies of the pedological and edaphic aspects of soils derived from skarn. The combination of porphyritic quartz and base-rich matrices can give rise to eutrophic soils with high contents of siliceous coarse sand and fine gravel. This mixture gives soils derived from skarn unusual combinations of mineralogical, chemical and physical properties. Soils derived from skarn in Portugal have distinctive clay mineral composition, with substantial contents of pedogenic talc (Stahr, Zarei, Jahr, & Sauer, 2006). Soils derived from skarn in subtropical parts of Bhutan do not contain much coarse sand but are deep red fine loams and clays that are extremely susceptible to dispersion and erosion (Baillie et al., 2004).

Some of the lowland tropical forests of the Huai Kha Khaeng

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Wildlife Sanctuary in Western Thailand are located on a complex of skarn and less metamorphosed calcareous and igneous country rocks (DMR, 1983). However, most forests in Thailand are on deeply and intensely weathered soils derived from a range of igneous and sedimentary parent materials. These soils are brightly colored, intensely leached, acid, dystrophic, and have mainly kaolinitic clay minerals. Most are Acrisols, with some Ferralsols and Alisols (FAO, 2015). Agriculturally-oriented soil analyses emphasize immediately available nutrients, and tend to generalize Acrisols as acid and dystrophic. However, variations in the performance of perennial crops, and edaphically associated floristic and physiognomic patterns in tropical forests indicate that the long-term nutrient status of Acrisols is more variable than first apparent. Acrisols that are derived from different lithologies may be similarly dystrophic with respect to labile nutrients, but can differ substantially in their capacities to replenish the labile nutrient pools from slowly accessible reserves (Ashton & Hall, 1992; Bailey, 1964; Baillie et al., 1987).

The stoichiometric balance between nutrients can be as important as their individual contents. Most previous stoichiometric studies in tropical forest soils have focused on relationships between anionic macronutrients, i.e. C, N and P (Hall, Smith, Lyttle, & Liebold, 2005; McGroddy, Danfresne, & Hedin, 2004). Stoichiometry is also important for cations, as the cationic nutrients compete for sites on the non-specific part of the soil exchange complex and for non-specific uptake sites on root surfaces (Schofield & Taylor, 1955; Schuffeln, 1974). The suppression of Ca and K uptakes in many ultramafic soils is as much due to the domination of exchange complexes by Mg as to low absolute contents. Cationic stoichiometric influences have been noted in the floristics, structure and dynamics of dipterocarp forest on Acrisols in Sarawak (Russo, Davies, King, & Tan, 2005; Tan et al., 2009).

We here compare forest soils derived from skarn with those on other parent materials in Thailand. We test whether cation stoichiometry enhances the differentiation between the Phaeozems derived from skarn and the Acrisols; between Acrisols on different plots and parent materials; and between the Phaeozems derived from skarn in Thailand and eutrophic forest soils elsewhere in the tropics.

2. Methods

2.1. Study sites

We characterized the soils of six large long-term inviolate forest ecological research plots in Thailand, including three on the skarn complex in the Huai Kha Khaeng Wildlife Sanctuary in the west of the country. The plots span 12 degrees of latitude (Fig. 1), and a range of lowland tropical climates, with the climate of the most northerly and elevated plot, at Chiang Dao, marginal to lower montane (Table 1). Rainfall ranges from dry and seasonal at Huia Kha Khaeng (ca 1400 mm p.a. and 5–6 dry months dry) to almost perhumid at Khao Chong, with ca 2700 mm p.a. and only two dry months (Bunyavejchewin, Baker, & Ashton, 2002; Williams, Bunyavejchewin, & Baker, 2008). Annual rainfall and duration of the dry season are significant influences on the regional distribution of forest types and also soils in Thailand (Moormann & Rajanasoorthorn, 1972).

All six plots are located on the Sibumasu terrane of the Eurasian continental macro-plate (Puttapibhan, 2002), the basement of which is of Paleozoic age. However, most of the plots are on or near the granites (Hutchison, 1986) that were intruded during the Mesozoic. These granites form the mountainous spine of peninsular Southeast Asia (Fig. 1). The three plots at Huai Kha Khaeng Sanctuary in West Thailand are on a rolling pediplain that is underlain by a complex of skarn with granite, granodiorite, limestone and serpentinite. The Khao Chong plot is on the steep spur slopes of a Mesozoic porphyritic granite mountain and includes a concave colluvial toe-slope and a boulder-choked gully (Fig. 2). The Chiang Dao plot is on the steep mid-slope of a Mesozoic porphyritic granite mountain (DMR, 1983). The Mae Ping plot is on an undulating pediplain on Late Paleozoic - Early Mesozoic limestone (Kurihara et al., 2010). The plain is covered with a thick mantle of decalcified clay. The limestone outcrops as steeply dipping fins on a low rise in the south-western corner, and there is a low ridge of Paleozoic hard interbedded metargillite and quartzite across the southern end of the plot.

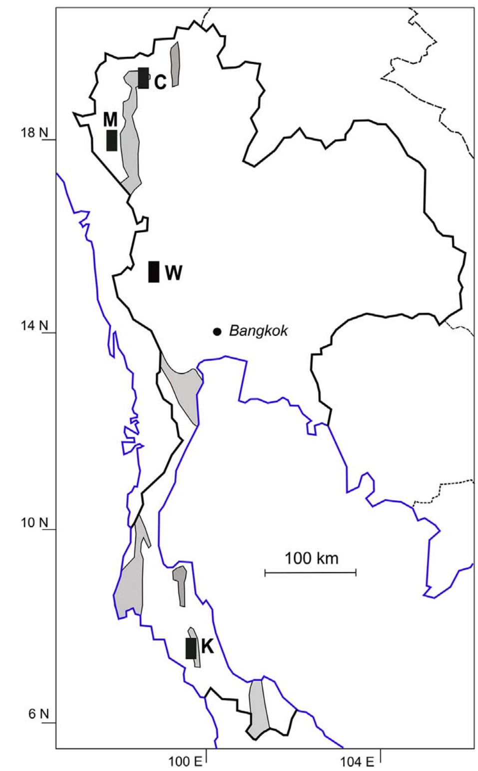

Fig. 1. Forest research plots in Thailand.
C Chiang Dao; K Khao Chong; M Mae Ping; W West Thailand plots (Huai Kha Khaeng, Huai Krading, Kapook Kapieng); Shaded Main granite outcrops.

2.2. Data collection

Baker (2001) sampled and analyzed soils derived from skarn as part of his ecological study of the forest on the Huai Kha Khaeng 50 ha plot in West Thailand. However, the data for this study come from systematic soil description and sampling in 2004–5 (Table 2). Soil morphology was described by auger at stratified random points along stratified random traverses at densities of 1.5–2 observations per ha. An example of the sampling layout, at the Khao Chong plot, is shown in Fig. 2. Those for the other plots are in Supplementary Figs. S1–S5. Surface litter, wormcasts, termitaria, and snails and their shell fragments were noted at each point, and the upper metre of the soil profile was described by natural horizons for matrix color, mottles, hand texture, consistence, and stones. In addition, soil structure, cutans, porosity, roots, concretions, and faunifacts were described in profile pits located outside the plots.

Auger samples were collected from the main horizons in the pit profiles, and at depths of 0–10 and 40–50 cm at a stratified randomized half of the auger sites (Fig. 2), although the proportion of sites sampled was higher on the 50-ha plot at Huai Kha Khaeng (Supplementary Fig. S1). The samples were analyzed at the Soils Laboratory, Faculty of Agriculture, Kasetsart University, Bangkok: pH electrometrically in 1:2.5 suspensions of fresh soil in water and 1 M KCl; organic C by Walkley-Black dichromate oxidation; total N by micro-Kjeldahl distillation; available P by Bray 2 extraction and colourimetric assay; exchangeable cations by leaching with 1 M neutral ammonium acetate and assay by atomic adsorption spectrometry (AAS); cation exchange