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THE ROLE OF THE SESQUIOXIDES Fe, Al AND Si FOR THE ORTSTEIN GENESIS IN THE BUNTSANDSTEIN-BLACK FOREST IN SOUTHWESTERN GERMANY

ROLA PÓŁTORATLENKÓW Fe, Al ORAZ Si W POWSTAWANIU ORSZTYNÓW W PIASKOWCACH CZARNEGO LASU W POŁUDNIOWO-ZACHODNICH NIEMCZECH

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Abstract: Ortstein genesis was investigated in the northern Black Forest, SW-Germany. Therefore, profiles with cemented and non-cemented Bh/Bs-horizons were selected. Their chemical composition and microstructure were compared with each other. Chemical extractions show always higher values of oxalate extractable aluminium and especially silica in the cemented horizons. The various iron fractions display no regular differences. The microstructure shows pronounced differences between cemented and non-cemented horizons. Non-cemented horizons have a granular structure, cemented ones have a distinct coat and bridge structure. Their coatings consist mainly of carbon, oxygen, aluminium and silica as shown by EDAX-analyses.

Key words: Podzol, Ortstein, micromorphology, EDAX,

Streszczenie: Badania genezy orsztynu prowadzone były w północnej części Czarnego Lasu (południowo-zachodnie Niemcy). Analizowano profile z poziomami Bh/Bs scementowanymi i niescementowanymi porównując ich skład chemiczny i mikrostrukturę. Poziomy scementowane zawierają większą ilość ekstrahowanego szczawianie glinu, a szczególnie krzemionki. Nie stwierdzono natomiast regularnego zróżnicowania w przypadku poszczególnych frakcji żelaza. Badania mikromorfologiczne wykazały wyraźne różnice między poziomami scementowanymi i niescementowanymi. Poziomy niescementowane mają strukturę gruzelko-
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In the Buntsandstein area of the northern Black Forest, SW-Germany, ortstein genesis was investigated. Ortstein is a hardened spodic illuviation horizon [Buol et al. 1989]. The degree of hardness depends on
(i) the spatial distribution (microstructure) and
(ii) on the amount of fine material in the pores.

It often is compared with the Raseneisenstein formation in gleyic profiles, though the genesis and the appearance is very different.

The cementation and formation of the ortstein horizons in Podzols might be explained by the following materials or a combination of them [according to Lee et al. 1988a and Nikitin & Fedorov 1977]: (i) organic matter, (ii) Al-oxides/-hydroxides, (iii) Fe-oxides/-hydroxides, (iv) Mn-oxides, (v) silica, and (vi) clay. Rabenhorst & Hill [1994] supposed a stronger influence of the microstructure on the genesis of ortstein horizons than their chemical composition. Nevertheless, it still is unknown why ortstein develops, a general theory is missing. The paper presents results on the factors and properties of ortstein based on a pairwise comparison of hardened and soft spodic horizons.

MATERIALS AND METHODS

The main investigation area is located in the 'Buntsandstein Black Forest' of southwest Germany (Figure 1). Podzols with Ortstein are only found in the middle Buntsandstein (mostly silica bound gravel carrying sandstones, usually hard). Nevertheless, the slopes are reworked by solifluction building mighty debris flow covers. These co-
vers are very blocky. Thus, parent material is a mixture of different sandstones and conglomerates. The mean annual temperature ranges between 7 to 8°C, the mean annual precipitation between 1200 to 1400 mm.

The main question in this study is: „Which physical, micromorphological and chemical properties are different between cemented and non-cemented Bh/Bs-horizons?” Therefore, profiles with and without ortstein are located very close to each other in order to assure similar soil forming factors (parent material, relief, climate, man).

The methods used are: field mapping, chemical extractions (dithionite-citrate extraction after Mehra and Jackson [1960]; ammonia-oxalate extraction after Schwertmann [1964]; pyrophosphate-extraction after Bascomb [1968]), micromorphology (description according to FitzPatrick [1993]) and EDAX investigations directly on the thin-sections.

RESULTS

Podzol-illuviation horizons can be divided into three classes:
(i) non-cemented horizons,
(ii) weakly cemented horizons – Orterde and
(iii) strongly cemented horizons – Ortstein.

Four types of Ortstein could be distinguished macromorphologically (depending on the appearance of the horizon):
1. Bh-Ortstein (very rare),
2. Bs-Ortstein (common),
3. Bsh-/Bhs-Ortstein (common, mixed forms),

FIGURE 2. Relief position of the sites with Ortstein + Orterde
TABLE 1. Comparison of the sesquioxides Fe, Al and Si within three pairs of Podzols (cemented / soft)

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Fe_d [g · kg^{-1}]</th>
<th>Fe_o [g · kg^{-1}]</th>
<th>Fe_p [g · kg^{-1}]</th>
<th>Al_o [g · kg^{-1}]</th>
<th>Al_p [g · kg^{-1}]</th>
<th>Si_o [g · kg^{-1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kc Bs</td>
<td>7.4</td>
<td>4.2</td>
<td>1.5</td>
<td>10</td>
<td>6.8</td>
<td>1.22</td>
</tr>
<tr>
<td>Ks Bs</td>
<td>7.9</td>
<td>4.2</td>
<td>1.5</td>
<td>6.6</td>
<td>5.4</td>
<td>0.62</td>
</tr>
<tr>
<td>P2 Bhs</td>
<td>10.6</td>
<td>9.2</td>
<td>1.8</td>
<td>42</td>
<td>16.7</td>
<td>11.61</td>
</tr>
<tr>
<td>P1 Bhs</td>
<td>22.2</td>
<td>10.8</td>
<td>4.6</td>
<td>38.5</td>
<td>22.7</td>
<td>5.29</td>
</tr>
<tr>
<td>P5 Bs</td>
<td>12.3</td>
<td>8.1</td>
<td>1.4</td>
<td>15.5</td>
<td>6.1</td>
<td>4.39</td>
</tr>
<tr>
<td>P7 Bsh</td>
<td>7.8</td>
<td>4.5</td>
<td>1.0</td>
<td>13.7</td>
<td>6.8</td>
<td>3.30</td>
</tr>
</tbody>
</table>

Relief and thus the geology plays an important role in ortstein formation. Field mapping showed, that ortstein most of all appears on the middle-slopes in the Buntsandstein area in the Black Forest (Figure 2). These slopes are normally built up by very hard silica-bound sandstones of the middle Buntsandstein covered with mighty debris flow.

On top or in the lowering with less strong bound sandstones, very few ortstein could be found.

The chemical extractions show some distinct differences between cemented and non-cemented horizons (Tables 1, 2). The oxalate extractable aluminium and especially the oxalate extractable silica always show higher values in the cemented horizons than in the non-cemented ones, whereas the various iron fractions display no regular differences.

FIGURE 3. EDAX-analysis of a coating in the cemented B[h]s-horizon
The role of the sesquioxides Fe, Al and Si for the ortstein genesis in Buntsandstein-Black Forest

TABLE 2. Comparison of different values among cemented and non-cemented pairs of profiles

<table>
<thead>
<tr>
<th>Pair</th>
<th>Fe_{d}</th>
<th>Fe_{p}</th>
<th>Al_{o}</th>
<th>Al_{p}</th>
<th>Si_{o}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kc Ks</td>
<td>=</td>
<td>=</td>
<td>(+)</td>
<td>(+)</td>
<td>+</td>
</tr>
<tr>
<td>P2/P1-</td>
<td>-</td>
<td>-</td>
<td>(+)</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>P5/P7+</td>
<td>+</td>
<td>=</td>
<td>(+)</td>
<td>=</td>
<td>+</td>
</tr>
</tbody>
</table>

The micromorphologic investigations show pronounced differences in the microstructure between soft and cemented horizons. The cemented ones always have a distinct coat and bridge structure. The coatings surround the sand grains and fill in the pores. They have a light to dark brown colour in plain light (Picture 1) and get isotropic (black) in cross polarised light. Thus, the coatings may consist of an organic or amorphous mineral material or a mixture of both. The non-cemented spodic B-horizons normally show a granular structure (Picture 2). Within these horizons, no coatings could be found.

The EDAX-analyses of the coatings are very similar. The main peaks are always the ones of carbon, oxygen, aluminium and silica (Figure 3). A little peak is shown by potassium. Sometimes a little peak of iron can be detected, sometimes not.

DISCUSSION

Within the last 100 years it often was discussed why there is a cementation in some spodic B-horizons. One of the first statements was made by Ramann [1886]. He supposed, that the cementation was due to humic substances. Schlichting [1963] agreed with this and said, that there is an illuviation of organic matter. McCracken & Weed [1963] thought of an accumulation of the solid phase. Wiechmann [1978] still pointed out an influence of the organic matter and supposed a physico-mechanical filtering of organic compounds. Nevertheless, new theories appeared. The research was directed more to the participation of iron. Moore [1976] stated, that a translocation of amorphous, inorganic Al-/Fe-compound might be responsible for the cementation. Others thought of iron-organic compounds [DeConinck 1980] or of ferrihydrite as a participant [Ross et al. 1989; Schwertmann & Taylor 1989]. More recent investigations estimate that aluminium (together with humic substances) is responsible for an illuviation of alumino-organic complexes as Al-fulvates [Miles et al. 1979; McKeague & Wang 1980; McHardy & Robertson 1983; Koopmann 1988; Lee et al. 1988b] or for the participation of amorphous alumino-silicates and (proto-)imogolite [McKeague & Kodama 1981; Farmer et al. 1984 and 1985; Ross et al. 1989]. The latest investigation of Thompson et al. [1996] differentiates by horizons. For Bh-horizons they suppose the influence of alumino-organic complexes, for Bs-horizons of proto-imogolite/allophane complexes.

In our investigations, the chemical analyses show differences only in the oxalate-extractable silica and to a lesser extent in the oxalate-extractable aluminium phases in all three pairs (Table 1 & 2). The cemented horizons have always higher amounts
PICTURE 1. Cemented B[h]s-horizon, plain light, width of picture – 1.6 mm (Q – quartz)

PICTURE 2. Non-cemented Bhs-horizon, plain light, width of picture – 1.6 mm

PICTURE 3. Cemented B[h]s-horizon, with spot of EDAX analysis, plain light, width of picture – 0.42 mm
(silica is twice as much) than the soft ones. Upon all other elements the extractions are very indifferent. Sometimes they are higher, sometimes equal or lower. This seems to be a clear hint for the participation of silica and aluminium in ortstein genesis.

As shown by the micromorphological investigations, the microstructure is very important for ortstein genesis. It is comparable to the microstructure of ortstein horizons investigated by McKeague & Wang [1980], Rabenhorst & Hill [1994] or Condron & Rabenhorst [1994]. Only the hardened horizons have a distinct coat and bridge structure. The appearance of the coatings support the results of the chemical extractions. They seem to consist of an amorphous material – mainly silica, aluminium – together with an organic compound. EDAX-analysis confirms this hypothesis. Iron could not be proved by EDAX within the coatings.

CONCLUSION

The obtained results suggest, that the cementation of spodic horizons is caused mainly by amorphous silica together with amorphous aluminium hydroxides and some kind of organic matter. Iron does not play any role upon ortstein genesis.

REFERENCES

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