

# Mapping and characterization of boreal acid sulfate soils

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## Abstract

Finland has the largest occurrence of acid sulfate soils (AS soils) in Europe. Due to their severe effects on coastal waters, there is a great demand for localizing hot spot areas, i.e. areas where preventive/mitigation measures are needed most. Thus, the Geological Survey of Finland has recently initiated a project on mapping AS soils in Finland. The work is demanding and therefore screening techniques are needed in order to narrow down areas of interest. In this work, we demonstrate the use of such techniques using Quaternary, geophysical and elevation maps prior to conventional soil mapping, and conclude that a broader concept of criteria than that of Soil Taxonomy and WRB is needed in order to enable appropriate characterization of Boreal AS soils.

## Key Words

Acidity, aeroelectromagnetic map, risk areas, mitigation, Finland.

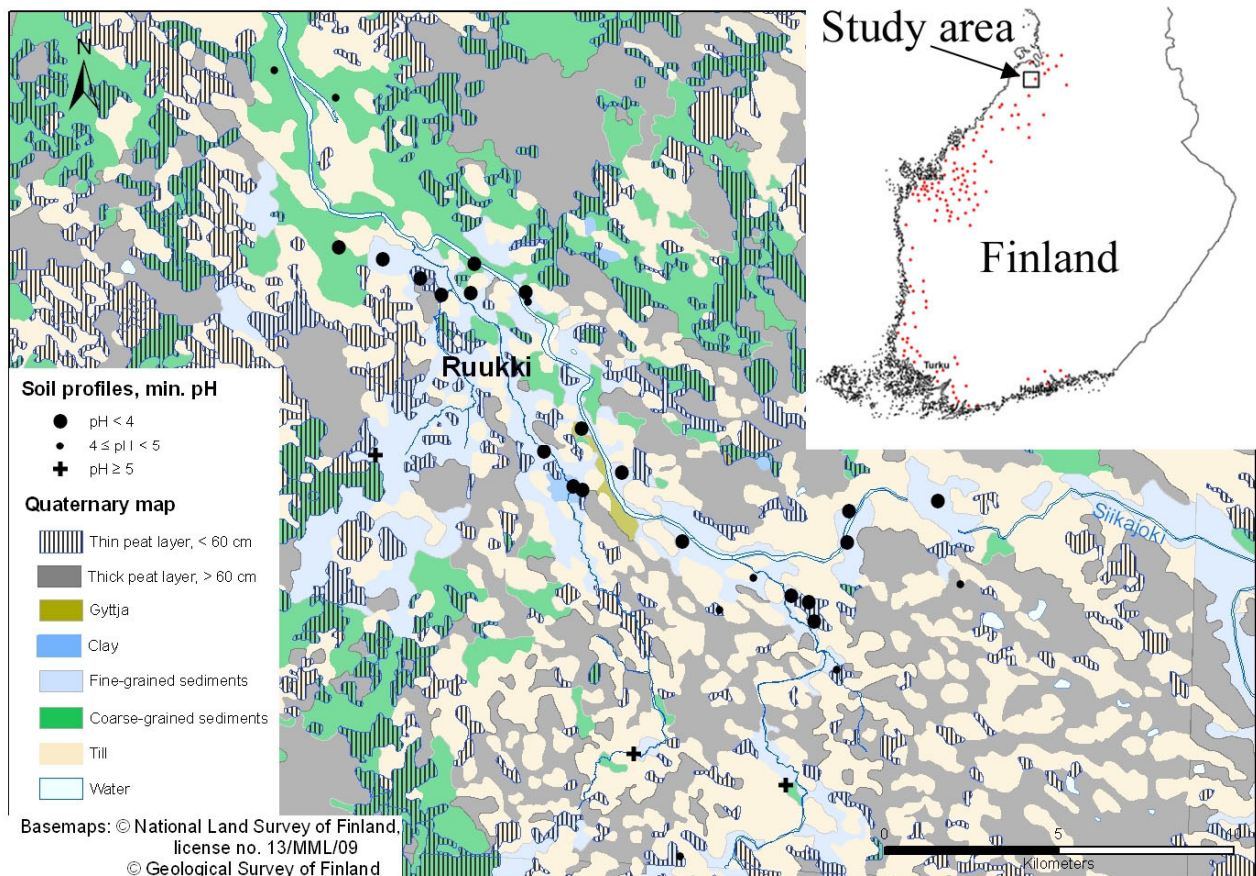
## Introduction

During the Holocene Epoch large areas of sulfide-bearing sediments have been deposited under reducing conditions on the bottom of the former and current Baltic Sea between Finland and Sweden. Because of the rapid postglacial rebound (today up to 8 mm/a) in the area, a large portion of these sediments have been raised up to 100 m above current sea level. Due to reclamation, the upper 1-2 meters have generally been oxidized into acid sulfate soils (minimum pH 3-4), giving Finland the largest known occurrence of acid sulfate soils in Europe, roughly 1000 km<sup>2</sup> using Soil Taxonomy criteria (Yli-Halla *et al.* 1999). It is well documented that these soils leach huge amounts of metals into watercourses (Österholm and Åström 2004), and for several heavy metals the amounts exceed the total metal discharge in effluents from the entire Finnish industry (Sundström *et al.* 2002) causing severe damage on the ecology.

Mapping of AS soils in Finland has been conducted by conventional soil sampling and subsequent soil-pH measurements (Palko 1994; Figure 1). However, the criteria for designating soils as AS soils has been rather inappropriate (commonly soil pH < 5 and > 100 mg SO<sub>4</sub>-S per dm<sup>3</sup>), not distinguishing hot spot areas and leading to a gross overestimation of the total area of AS soils in Finland (c. 3000 km<sup>2</sup>), as compared to if the criteria in Soil Taxonomy or the FAO/UNESCO systems had been used (Yli-Halla *et al.* 1999).

Nevertheless, due to previous work, we know in broad outline where AS soils are expected to be found; in general, they are found < 50 m above current sea level with local occurrences from the northernmost to the southernmost coastal areas, and largest occurrences are located in Midwestern Finland.

Due to large scale fish kills caused by AS soils along the coast in 2006 and because of the EU Water Frame Directive calling for good ecological and chemical status in surface waters by 2015, the demand for actions preventing environmental pollution by AS soils has accentuated recently. Preventive techniques that minimize oxidation of sulfidic horizons and reduce flow peaks are the most obvious measures required. Thus, there is currently also a great demand on a new relatively detailed risk map on AS soils, enabling measures to be tailored and taken for the strategically important hot spot AS soil areas. To meet these demands, a consortium led by the Geological Survey of Finland (GTK) has been formed in order to create a nationwide AS soil map. Similar to previous mapping programs, conventional soil sampling will be conducted. However, different screening techniques will be developed and used in order to narrow down areas of interest. Such techniques will involve processing of available landscape data in GIS (including available elevation, land form, Quaternary, bedrock and (aero)geophysical data) and the use of indicator variables in recipient waters (pH, electric conductivity, sulfate and metals). Below, we demonstrate the use of such techniques using Quaternary, geophysical and elevation maps prior to conventional soil mapping.



**Figure 1. Quaternary map (Geological Survey of Finland, in preparation) for the upper meter of soil and minimum pH for selected soil profiles in the Siikajoki River catchment. Location of the study area and occurrence of AS soils (dots) according to Palko (1994) are presented in the upper right.**

### Material and methods

The study area (c. 565 km<sup>2</sup>) is located in the Siikajoki River catchment in the northern part of the Finnish ASS province (Figure 1). The bedrock in the area is eroded to a peneplain dominated by mica gneiss with intrusions of porphyritic granite and, according to aeromagnetic maps, some layers of black schists occur in the area. The average thickness of Quaternary deposits overlying the crystalline bedrock is about 10 m and they consist of glacial till, reworked glaciofluvial sands, and postglacial alluvial, marine, and littoral sediments. Large areas are covered by mires that have developed on topographic lows after glacial isostasy induced marine regression. The map of Quaternary deposits (1:200 000) used in this study, describing the soil material distribution and textures for the topmost one meter, is still in process at GTK and will be published by the end of 2009. Till (35%) is the most dominant soil type in the study area followed by peat (31%), coarse-grained- (22%; D<sub>50</sub> > 0.06 mm) and fine-grained deposits (11 %; D<sub>50</sub> 0.002-0.06 mm). Clay (D<sub>30</sub> < 0,002 mm) and gyttja (clay with loss on ignition > 2%) comprise only 0.4 % of the area.

GTK measured aeroelectromagnetic data (AEM) at a height of 30-40 m, line spacing of 200 m and measurements for each 12.5 m at one frequency of 3.1 kHz in the Siikajoki area in 1983. The AEM data reflects the electric conductivity of soil material and bedrock down to several tens of meters. Fine-grained sediments, and, in particular, sulfide-bearing sediments having high contents of soluble salts, are expected to give strong AEM anomalies (Vanhala *et al.* 2004). On basis of the electric conductivity, an apparent resistivity map (the inverse of conductivity) with a resolution of 50 x 50 m was compiled. In order to identify areas where AS soils are likely to be found prior to soil sampling, we compared bedrock, Quaternary, aerogeophysical and elevation data and when possible pH and electric conductivity in recipient waters. Areas which had a low resistivity, fine grained sediments, large low-relief fields with low pH and high electric conductivity in recipient waters were prioritized (Table 1). Areas with till deposits were excluded as they are glacialic and lack underlying marine sediments.

Altogether, 48 soil profiles in the Siikajoki River catchment were sampled within the study area with a core sampler down to 3 meters and samples were taken for each 20 cm. Within 24 hours, soil pH was measured by inserting a pH-electrode directly into the soil material, after some deionized water had been added to allow proper contact between the electrode and soil material. Profiles with a minimum pH < 4 had underlying black parent sediment due to monosulfides (typical for Finnish AS soils; Boman *et al.* 2008) and were, thus, considered AS soils. For the purpose of this study, potential overrepresentation of certain high priority areas was reduced by inserting a grid of 1 km<sup>2</sup> squares over the study area. Only the profile closest to the middle of the square was chosen. However, profiles in the same square, that were located on different types of soil deposits (according to the Quaternary map) and had a resistivity difference inferior to 100 ohm-m, were included, giving a total number of 38 profiles in the study area (Figure 1).

**Table 1. Relative frequency of minimum pH, starting depth (SD) for horizons with a pH < 4 and resistivity in the selected sites (n = 38) in the study area.**

	Total	pH<4	pH 4-5	pH≥5	SD	Resistivity (ohm-m)		
	n	%	%	%	m	min	med	max
Fine-grained	16	69	19	13	1,1	40	186	844
Fine-grained + peat <60 cm	9	44	44	11	1.1	79	152	1950
Coarse-grained	7	29	71	0	1.3	142	829	2202
Thick peat layer (≥60cm)	4	50	50	0	0.6	120	548	878
Clay	1	100	0	0	0.9		219	
Gyttja	1	100	0	0	0.7		1913	
Total	38	55	37	8	1.0	40	383	2202

## Results and discussion

In the selected sites (n=38), AS soils were frequently found in all types of soil deposit areas indicated on the Quaternary map (Figure 1 and Table 1). They were particularly abundant on fine grained sediments (typically former marine sediments) and least abundant on coarse grained soil materials (Table 1). On the basis of pH measurements, only about 10% of the sites could be excluded as being “harmless” (pH ≥ 5) without further analysis (e.g. incubation). While the proportion of AS soils in the area is unknown, it is abundantly clear from the recipient river water quality (Beucher, unpublished results) that it is far lower (probably in the order of 5% or less similar to other rivers of this size) than that indicated by the selected soil profiles (55%; Figure 1). Consequently, while screening techniques are not yet fully developed, the results indicate that they can be used to narrow down areas of interest significantly. Nevertheless, it is notable that later preliminary results (not presented in this work) indicate that compared to other sections of the river catchment; the present study area seems to have a relatively high abundance of AS soils. Thus, care needs to be taken not to over-emphasize the seemingly remarkable results of this study (Figure 1).

The fine grained sediments on the Quaternary map exhibited a significantly lower resistivity than corresponding coarse grained soil materials (Mann-Whitney test of medians at p=0.1; Table 1). A correlation between minimum pH and resistivity was only found for areas indicated as coarse grained soil materials on the Quaternary map (Spearman correlation: 0.85 at p=0.05); in indicated coarse-grained areas. AS soils (2 profiles) were found in sites with resistivity values < 300 ohm-m. Confirmed by field observations, i.e. fine grained sediments below 1 m and the lower starting depth of the pH < 4 horizon (Table 1), this phenomena is explained by the occurrence of relatively deep fine grained sediments (causing low resistivity) overlaid by coarser sediments. Consequently, in the study area, the AEM map seems to be a useful complement to the Quaternary map in order to find such risk areas.

Owing to deep drainage and some soil characteristics, we cannot restrict us to the criteria of Sulfaquepts or sulfic subgroups, as defined in Soil Taxonomy (Soil Survey Staff 1999), or particularly those of the WRB system (FAO 2006), when mapping acid sulfate soils of Finland. These systems require that the typical characteristics occur within 1.5 m or 1.0 m of soil surface, respectively. As also noted in this study, sulfidic materials in our agricultural soils are often covered with soil materials that have not been sulfidic. The depth of the sulfides together with humid boreal climate, retards the oxidation, and these soils most often do not have sulfuric/thionic horizons (pH ≤ 3.5), the minimum pH being in the range of 3.5-4.0. However, owing to deep artificial drainage and intensive evapotranspiration, sulfidic materials down to at least 2.5 m are periodically oxidized (Österholm and Åström 2002; Joukainen and Yli-Halla 2003). Being formed in non-calcareous parent materials, the total S requirement of 0.75% for sulfidic materials in the WRB system is too high, 0.2% being more appropriate. Thus, the stringent Soil Taxonomy and WRB criteria for acid sulfate

soils can be embedded in the national mapping, but we need to use a broader concept for sulfidic materials and particularly for the depth of occurrence of the relevant characteristics in order to properly identify these soils.

## References

- Boman A, Åström M, Fröjdö S (2008) Sulfur dynamics in boreal acid sulfate soils rich in metastable iron sulfide – The role of artificial drainage. *Chemical Geology* **255**, 68-77.
- FAO (2006) World Reference Base for Soil Resources 2006. 'A framework for international classification, correlation and communication'. *World Soil Resources Reports* **103**. (FAO: Rome)
- Joukainen S, Yli-Halla M (2003) Environmental impacts and acid loads from deep sulfidic layers of two well-drained acid sulfate soils in western Finland. *Agriculture, Ecosystems and Environment* **95**, 297-309.
- Palko J (1994) Acid sulphate soils and their agricultural and environmental problems in Finland. Acta Univ. Oul. C 75. PhD thesis, University of Oulu.
- Österholm P, Åström M (2002) Spatial trends and losses of major and trace elements in agricultural acid sulphate soils distributed in the artificially drained Rintala area, W. Finland. *Applied Geochemistry* **17**, 1209-1218
- Österholm P, Åström M (2004) Quantification of current and future leaching of sulphur and metals from Boreal acid sulphate soils, Western Finland. *Australian Journal of Soil Research* **42**, 547-551.
- Soil Survey Staff (1999) 'Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys.' (2nd Ed. Agriculture Handbook 436, U.S. Government Printing Office: Washington, DC)
- Sundström R, Åström M, Österholm P (2002) Comparison of the metal content in acid sulfate soil runoff and industrial effluents in Finland. *Environmental Science and Technology* **36**, 4269-4272.
- Vanhala H, Suppala I, Lintinen P (2004) Integrated geophysical study of acid sulphate soil area near Seinäjoki, Southern Finland. In 'Sharing the Earth: EAGE 66<sup>th</sup> Conference & Exhibition, Paris, France, 7-10 June 2004: extended abstracts'. (Houten: EAGE).
- Yli-Halla M, Puustinen M, Koskiahho J (1999) Area of cultivated acid sulfate soils in Finland. *Soil Use and management* **15**, 62-67.