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Short Communication

Soil taxonomy proposals for acid sulfate soils and subaqueous soils raised by the 8th International Acid Sulfate Soils Conference§

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The 8th International Acid Sulfate Soils Conference presented examples and discussions for classification of 'acid sulfate soils' and related issues for 'subaqueous soils'. When these soils are disturbed or exposed, the sulfides (predominantly pyrite) react with oxygen to produce sulfuric acid; soil materials that do this to a great extent are recognised as 'sulfidic materials' in *Soil Taxonomy. Soil Taxonomy* describes physical and chemical properties and thresholds for incubation of sulfidic materials for acidification, and has developed definitions for features and materials commonly seen in these soils. However, based on discussions and examples from field tours the conference has several proposals to modify and add to existing definitions, such as adding new subgroups, defining sulfuric materials and editing the definition of the sulfuric horizon. These changes are centred on improving the interpretative value of taxa in *Soil Taxonomy* as well as use and management recommendations and their value in soil survey products.

Keywords: acid sulfate soils, coastal systems, soil classification, soil taxonomy, subaqueous soils

Acid sulfate (AS) soils include "all soils in which sulfuric acid may be produced, is being produced, or has been produced in amounts that have a lasting effect on main soil characteristics" (Pons 1973). 'Potential' and 'active' AS soils contain sulfide minerals (e.g. pyrite) that can oxidise and produce sulfuric acid if these soils are disturbed or exposed, ruining ecosystems and infrastructure (Fanning et al. 2010, 2017). Subaqueous soils (SAS) are soils that are permanently or nearly-permanently submerged (Soil Survey Staff 2014). Many marine SAS are also AS soils due to the sulfate source in seawater (Fanning and Burch 2000). The description and classification of AS soils and SAS is a developing topic within soil science, spearheaded by eight international meetings over the past several decades (Fanning et al. 2017). The first of these led to the creation of the Acid Sulfate Soils Working Group of the International Union of Soil Sciences. This paper is a summary report of the findings and discussions at the most recent meeting of the Working Group, the 8th International Acid Sulfate Soils Conference (8th IASSC), held in College Park, Maryland, USA, from 17–22 July 2016. These findings were shared with the international soil classification community at the 5th International Soil Classification Congress, held in Bloemfontein, South Africa from 5–7 December 2016. Proposed criteria for *Soil Taxonomy* (ST) (Soil Survey Staff 2014) and discrepancies with the *World Reference Base for Soil Resources* (WRB) (FAO 2015) and the *Australian Soil Classification* (ASC) (Isbell et al. 2016) are offered, with suggestions for further research.

Soil Taxonomy recognises 'sulfidic materials' as sulfide-containing soil materials that can produce net acidity if disturbed and allowed to oxidise. These are evaluated by monitoring pH change during moist aerobic incubation (MAI) over a 16-week period (Soil Survey Staff 2014). Sulfidic materials have a pH greater than 3.5 and undergo a pH decrease of 0.5 or more pH units to a final pH of less than 4.0 during MAI. The WRB and ASC (using similar pH thresholds) recognise these as 'hypersulfidic materials', also recognizing 'hyposulfidic materials' as those that acidify to a final pH above 4.0. The ASC further recognises soil materials that contain metastable Fe sulfides, which change colour from black to grey after several minutes of oxidation, as 'monosulfidic materials'. *Soil Taxonomy* should recognise these three types of materials. Recent

§ This article is based on a paper presented at the 5th International Soil Classification Congress, 5–7 December 2016, Bloemfontein, South Africa papers provide in-depth discussion of these proposals (Payne and Stolt 2017; Wessel and Rabenhorst 2017).

Soil horizons that have acidified as a result of sulfide oxidation are recognised in ST as 'sulfuric horizons'. Sulfuric horizons have a pH of 3.5 or less (4.0 or less if unoxidised sulfide minerals are present). They show evidence that the pH is caused by production of sulfuric acid – by containing jarosite or similar minerals, 0.05% or more water-soluble sulfate, or underlying sulfidic materials. Sulfuric horizons must be at least 15 cm thick, a common thickness for major diagnostic horizons (Fanning and Witty 1993). Thinner horizons that contain sulfuric materials are not identified in a way that reflects their extreme acidity and impact to plant growth and soil chemistry. Sulfuric materials are described in the definition of the sulfuric horizon, but should be defined separately (as sulfidic materials are). *Soil Taxonomy* should define sulfuric materials with no thickness requirement and edit the definition for the sulfuric horizon to be a horizon that consists of at least 15 cm of sulfuric materials. This would allow the recognition of sulfuric materials (thinner than 15 cm) at the subgroup level.

Subaqueous soils presently fall into two ST suborders: Wassists and Wassents. Surveys of SAS have discovered soils that do not fit within these suborders (Bakken 2012). The ST definition of 'buried soils' requires at least 50 cm of overlying mantle of new material, so submerged subaerial features can cause soils to key out in orders before the Entisols if the mantle is absent or thinner than 50 cm (Soil Survey Staff 2014). Examples in the USA include submerged argillic (Erich and Drohan 2012) and spodic (Ellis 2006) horizons. In Australia, some SAS contain sulfuric horizons formed during exposure by extreme drought. These soils key out as Inceptisols in ST, and a Wassept suborder has been proposed (Creeper et al. 2015). However, recent changes to ST exclude SAS from Inceptisols using several lines of reasoning. First, the critical characteristic of this type of soil is that it is permanently underwater. By classifying these soils as Inceptisols, emphasis would be placed on the diagnostic horizons. In many cases the diagnostic horizon that supports Inceptisol instead of Entisol classification did not form in the current soil environment, nor does it affect major interpretations. Another reason to exclude SAS from orders other than Histosols and Entisols is the movement to simplify ST by making fundamental changes (Stolt and Needelman 2015). Allowing SAS with shallow to buried diagnostic horizons to classify as Wassepts (or Wassults, Wassods, etc.) would increase the complexity of ST. New suborders would need additional great groups and subgroups, expanding the number of taxa. One solution would be to add Sulfuric subgroups to the great groups of Wassents (i.e. Sulfuric Haplowassents). Another would be to create a new wet soil order that includes all wet mineral soils including SAS.

One Typic Sulfudept showcased at the 8th IASSC contained a sulfuric horizon, hypersulfidic materials, and a duripan-like layer. This layer did not meet the definition of a duripan because the silica-cementation was so extensive that fragments would not slake. The ST slaking requirement for duripans may be too restrictive; if it were removed a new subgroup would be required for Duric Sulfudepts. Given that it occurs at the soil surface in places, and duripans are subsurface horizons, we recommend that ST recognise 'duricrusts' as the surface expression of these features, as the ASC does. A recent paper describes this soil in detail (Wessel et al. 2017).

During discussions about testing dredged materials for contaminants (Koropchak et al. 2016), it became clear that mapping contamination in SAS could be useful to dredgers. Aside from the description of contaminants as 'particulate artifacts' in soils, ST lacks definitions and language to describe contaminated soils (though Human-Altered and Human-Transported family classes have been established to otherwise describe soils that may pose potential health hazards to humans) (Soil Survey Staff 2014). The WRB describes these soils using the 'toxic' supplementary qualifier (Rossiter 2007). The recognition of contaminated soils should be considered by the National Cooperative Soil Survey (NCSS). Challenges include developing a better understanding of the toxins found in contaminated soils and the dangers they pose, determining with what certainty they can be mapped, and dealing with legal and economic issues associated with identifying land as being 'toxic'. In the short term, Superfund sites and other documented contaminated sites could be marked by a map unit boundary or spot symbol and identified as 'potentially hazardous areas'.

In summary, improvements to ST can be proposed that align it with WRB and ASC definitions and criteria regarding AS soils and diagnostic characteristics. New taxa and definitions are needed in ST for silica-cementation and SAS containing sulfidic and sulfuric materials. Finally, recognition of potential hazards from dredging contaminated material could be incorporated into the NCSS system for mapping purposes.

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