Carbonate-Rich Histosols
Proposed Changes to Soil Taxonomy

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Introduction

Various scientific disciplines (pedologists, ecologists, hydrologists) recognize wetland types, functions, and environmental values. Fens, by definition, are wetlands dependent on and dominated by ground water discharge. Fens exist where climate and/or hydrogeologic setting provide sustained water flow to or near the soil surface (rooting zone). Ground water discharge, especially mineral-rich water determines fen hydrology, drives wetland geochemistry, and greatly influences soil development.

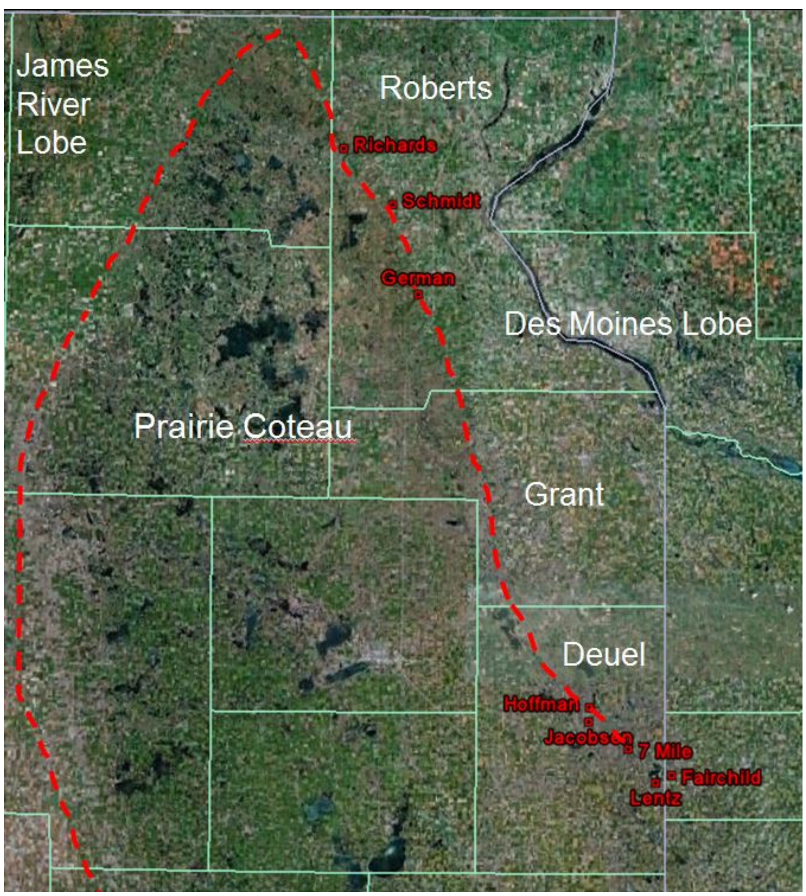

Figure 1. Fen names and locations in SD.

We described, sampled, and obtained detailed characterization data for nine organic soils (Histosols) in carbonate-rich fens in eastern SD (Figure 1). Similar carbonate dominated Histosols also occur in ND, MN, IA, and elsewhere in the US, where ground water is strongly influenced by limestone.

Our field observations, detailed soil descriptions, and characterization data identify three acute shortcomings for Histosol classification in the Keys to Soil Taxonomy 11 Edition (Soil Survey Staff, 2010). The three shortcomings are:

1. The criteria that defines "subaqueous" (i.e., Wassists and Wassents).
2. Histosol reaction classes (euic and dysic).
3. The criteria that segregate organic and mineral material (soils) as it pertains to carbonate-rich, organic soils.

We will explain and expand each concern below. We include proposed changes to resolve these limitations.

Subaqueous Criterion

Under the *Histosols Key to Suborders (*Soil Survey Staff, 2010), the second criteria (BB, page 155) states:

"Other Histosols that have a positive <u>water potential</u> at the soil surface for more than 21 hours of each day in all years."

The fen soils we studied form at <u>permanent </u>discharge sites. Water flow is upward and constant with the piezometric surface at or above the soil surface (Figures 2 and 3). This hydrology meets the stated subaqueous criteria, therefore, the fen Histosols classify as Wassists.

The intent of criteria BB is to define and key out "subaqueous" Histosols before other Suborders. The fen Histosols we studied would have classified as Hemists in previous Keys to Soil Taxonomy.

Figure 2. Water upwelling from auger hole during August sampling at Richards Fen.

Figure 2. Water discharge Richards Fen January.

The scientific goal for establishment of “subaqueous soils” is to define within the soil continuum those soils that have permanent water (e.g., tidal zones, lakes etc.) above the soil surface. Prior editions of Soil Taxonomy did recognize permanently inundated areas as soils. Traditional soil surveys depicted such areas as water.

Fen Histosols do not have water above the soil surface and occur in soil map units defined in traditional soil surveys. Moreover, fen Histosols, although wet, are managed and used similarly to other adjacent aquic but “terrestrial” soils.

The subaqueous criteria as currently defined include two hydrologic conditions. One is soils with permanent water above the soil surface. The second condition is soils at permanent discharge sites. We concur with the subaqueous classification for the first condition (water inundation). We, however, dispute the subaqueous classification for discharge soils and strongly advocate that they be retained as “terrestrial” soils.

Histosols or mineral soils that may be permanently saturated, but are recharge or flow through (downward or lateral flow) soils (wetlands) fail the subaqueous criterion (positive potential at the surface.). Thus, recharge and flow through soils in the same climatic and geomorphic setting would classify differently than discharge soils (terrestrial vs subaqueous). From a scientific basis, we reason that discharge, flow through, and recharge wetlands should all classify as terrestrial soils, as long as permanent water does occur above the soil surface.

Furthermore, water potential as a defining criterion adds unnecessary complexity. Water potential in itself is not an observable property. Water potential measurement requires a tensiometer or other technique. Field recognition of subaqueous soils relies on the observable water table position (i.e. above the soil surface); we do not observe or make water potential measurements to identify a subaqueous soil. The actual observable property should constitute the defining subaqueous criteria rather than an accessory property that is not directly observable and complex to measure.

Proposal 1 - Subaqueous Criteria

We propose that the “subaqueous” (Wassists and Wassents) criteria be amended to:

“Other Histosols (or Entisols) that have a field observable water table 2 cm or more above the soil surface for more than 21 hours of each day in all years”.

This change retains the same hydrologic requirement for subaqueous. Discharge soils, however, fail these criteria, as water does not permanently exist above the soil surface. This proposal does not change the key definition for subaqueous soils, all inundated soils will classify as subaqueous. We include 2 cm water depth as a suggested practical limit. We include this limit to avoid a pedantic argument that water does exist above the soil surface.

Histosol Reaction Classes

Groundwater controls the hydrology, geochemistry, and soil characteristics in Fens. Fen soils whether organic or mineral have a high base and metal content compared to nearby precipitation fed wetlands. Fens provide unique and spatially limited habitat for regionally rare plant and invertebrate species. Fens (especially calcium rich fens) are a natural heritage resource of local, state, and global significance.

The Keys to Soil Taxonomy (Soil Survey Staff 2010) presently recognizes two reaction classes for Histosols – Dysic and Euic. The euic criteria requires a pH value, *on an undried sample, of ≥ 4.5 (0.01m CaCl2) in one or more layers within the Histosol control section*.

An organic material pH of 4.5 corresponds to the "acid" pH 5.0 limit that is recognized for selected mineral soils.

The euic Histosol reaction class, as defined, includes both non-acid (pH 4.5 to ~ 6.8) and carbonate-dominated (pH > ~ 6.8) soils. Soil Taxonomy has no criteria for calcium carbonate dominated organic soils.

Proposal 2 - Kalkic reaction class

Soil Taxonomy needs an addition reaction class for carbonate-dominated Histosols. Figure 4 shows a pedon sampled at Richard Fen in Roberts County, SD. Table 1 contains pH, carbonate, and other data for Richards Fen. Table 2 contains and summary information for the same data from the nine SD fen pedons. For 54 O horizons, the median $CaCl_2$ pH is 7.2, the maximum is 7.6, and the minimum is 6.6. Based on these values and additional data from the SSL database, we propose:

A Histosol reaction class termed Kalkic with the following criteria.

Kalkic – a pH value, on an undried sample, of ≥ 6.8 ($CaCl_2$) and field reaction with dilute HCl in one or more layers of the surface or subsurface tier of the control section.

Carbonates and Histosol Classification

Soil Taxonomy (Soil Survey Staff, 2010) segregates mineral from organic soil materials based on the organic carbon content (weight). The organic carbon (OC) content requirement varies with clay content. Organic soil material must contain ≥ 12% organic carbon, if no clay occurs in the mineral fraction. The OC requirement is 18% when 60% clay is present. The mineral fraction of soil includes silicate minerals, calcium carbonate, and Fe oxides and oxyhydroxides, as well as other minerals. The mineral/organic criteria make no distinction concerning the type or origin of minerals within the mineral fraction.

Figure 4. Richards Fen pedon with horizons marked. Sampling depth exceed 4 meters. Note the material density and saturation.

In the Fen Histosols, calcium carbonate precipitates from discharge water due to CO_2 degassing and evaporative concentration. Precipitated carbonate, even if finely disseminated, may compose the major part of the mineral fraction. In many instances, the carbonate quantity is sufficient such that on a weight basis the OC is < 12%; by this definition, the soil material is mineral not organic.

The nine fen pedons include 61 O horizons (Table 2). During our field observations, we described observable, secondary carbonates and denoted such by a k subscript on the O or other genetic horizon (see Richard Fen description). A number of horizons contained no observable carbonate, but did react with HCl. Such horizons we designated as Oi, Oa, or Oe according to the field estimated rubbed fiber.

Lab data (Tables 1 and 2) show that with $CaCO_3$ included only 24 of 61 O horizons contained ≥12% OC, the remaining 37 have < 12%. Consequently, some of the nine pedons qualify as organic, some are mineral throughout, and some are organic in part and mineral in part (e.g., Richards Fen Table 1.). The mineral designation conflicts with the field observations and bulk density values. All soil scientists involved in sampling and description considered the material as organic.

Tables 1 and 2 present the OC content on a $CaCO_3$ free basis. On this basis, Fifty-one of the O horizons meet the 12% OC requirement and qualify as organic material. All nine pedons also classify as Histosols by this basis.

Table 1. Selected Data From Richards Fen Pedon ID: S11SD109002

Depth	Horizon	Total C	Est OC	Min Cont	$CaCO_3$	OC $CaCO_3$ Free	DCB Fe	pH $CaCl_2$	BD		VOL Δ	$CaCO_3$ Field Vol
									33 kPa	OD		
cm		%							g cm^{-3}		%	%
Richards Fen												
0-8	Oi1	14	6	85	73	21	4.9	7.6	0.21	0.38	45	3.10
8-25	Oi2	15	7	88	67	20	6.5	7.6	0.30	0.51	41	4.26
25-104	Oi3	20	15	70	47	28	0.2	7.4				
104-132	Oi4	24	20	60	38	32	0.9	7.1				
183-208	Oi5	27	23	54	37	36	0.6	6.9				
208-241	Oi6	22	16	65	45	30	0.5	7.1				
241-251	Oek	19	14	75	44	24	0.4	7.3				
251-267	Oa1	12	10	74	18	12	0.3	7.3				
267-279	Oa2	12	10	81	18	12	0.5	7.2				
279-292	Oek'	20	14	72	44	26	0.8					
292-305	Oa'	8	6	90	16	8	0.4	7.2				
305-340	Oe"	18	12	76	46	22	1.5	6.9				
340-368	Oak1"	15	7	84	63	20	1.1	7.0				
368-394	Oak2"	12	5	92	60	13	2.1	7.0				
394-419	Oak3"	14	8	88	52	17						

Table 2. Summary Statistics O Horizons Nine SD Fen Pedons.

	Total C	Est OC	Min Cont	$CaCO_3$	OC $CaCO_3$ Free	DCB Fe	pH $CaCl_2$	BD		VOL Δ	$CaCO_3$ Field Vol
								33 kPa	OD		
	%							g cm^{-3}		%	%
Mean	17	12	78	41	20	3.0	7.1	0.24	0.44	45	2.0
Median	15	10	82	46	21	1.7	7.2	0.24	0.43	44	1.9
Min	7	4	51	2	5	0.2	6.6	0.19	0.38	41	0.3
Max	29	28	95	75	40	22.2	7.6	0.30	0.51	53	4.3
Count	61	61	61	61	61	31	54	6	6	6	6

24 of 61 horizons with > 12% OC with $CaCO_3$ included

51 of 61 horizons with > 12 % OC on a $CaCO_3$ free basis

Figure 4 shows the Richards Fen pedon at sampling. Note the lack of visible CaCO3.Table 1 gives the BD data and $CaCO_3$ for Richards Fen. Two horizons (Oi1 and Oi2) with measured BD values (0.38 and 0.51 g cm^{-3}) contain 73 and 67% $CaCO_3$. The material has low bulk density (high saturated porosity).

Figure 4. Surface O horizons at Richards Fen. Note the root mat and lack of visible carbonate.

The bulk density (Table 2) for six near surface horizons in the sample pedons has a mean of 0.24 g c m^{-3} at 33 kPa water and a mean oven dry density of 0.43 g cm^{-3}. The mean volume change (porosity loss) between 33 kPa and OD was 44%.

The soils are permanently saturated under field conditions (always > 33 kPa water content). Based on the volume change from 33 kPa to oven dry, the saturated porosity is estimated at ~ 70%. From this field volume, we can calculate an estimated field volume for carbonate (particle density 2.71 g cm^{-3}); this volume is given in tables 1 and 2. On a field volume basis, the maximum estimated carbonate content is < 5% by volume.

The organic fraction controls soil volume and density and is the reactive fraction. The present mineral/organic criteria fail to consider organic volume and density as a control on soil properties. Calcium carbonate properties differ from those of the silicate minerals. Calcium carbonate control pH but has limited reactivity (water retention, CEC, etc.) compared to silicate minerals. Based on field morphology and density values, the fen pedons should all classify as organic.

Proposal 3 - OC on a $CaCO_3$ free basis

For soils (Histosols) in the ”Kalkic” reaction class, we propose that calcium carbonate be excluded from the mineral weight fraction. In other words, the OC should be calculated on a $CaCO_3$ free basis.

To prevent marls from meeting the organic criteria, we include these two sub criteria:

1. **An upper $CaCO_3$ limit of 80%. For soils with >80% $CaCO_3$, the OC would be determined on the existing criteria.**

2. **The oven dry bulk density for the material should be <0.75 g cm^{-3}. This restricts the CaCO3 free basis to low density materials (organic dominated).**

Richards Fen Pedon Description

Oi1--0 to 8 centimeters; 60 percent dark reddish brown (5YR 3/4) broken face and 40 percent black (N 2.5/0) broken face; many medium and coarse roots and many fine roots; 65 percent iron stains; violent effervescence; clear wavy boundary. Lab sample # 11N11533. 50 percent iron and carbonate concretions

Oi2--8 to 25 centimeters; 50 percent dark reddish brown (5YR 3/4) broken face and 40 percent brown (10YR 5/3) broken face and 10 percent black (N 2.5/0) broken face; many medium and coarse roots and many fine roots; 75 percent iron stains; violent effervescence; gradual wavy boundary. Lab sample # 11N11534. 15 percent iron and carbonate concretions

Oi3--25 to 104 centimeters; 60 percent dark grayish brown (2.5Y 4/2) broken face and 40 percent black (2.5Y 2.5/1) broken face; few medium and coarse roots and common fine roots; violent effervescence; gradual wavy boundary. Lab sample # 11N11535

Oi4--104 to 132 centimeters; black (2.5Y 2.5/1) broken face; violent effervescence; clear wavy boundary. 1 percent snail shells throughout

W --132 to 183 centimeters; supersaturated layer, abrupt wavy boundary.

Oi5--183 to 208 centimeters; 60 percent black (2.5Y 2.5/1) broken face and 40 percent very dark grayish brown (2.5Y 3/2) broken face; violent effervescence; gradual wavy boundary. Lab sample # 11N11537. 1 percent snail shells throughout

Oi6--208 to 241 centimeters; 60 percent dark gray (2.5Y 4/1) broken face and 40 percent dark grayish brown (2.5Y 4/2) broken face; violent effervescence; gradual wavy boundary. Lab sample # 11N11538. 1 percent snail shells throughout

Oek--241 to 251 centimeters; grayish brown (2.5Y 5/2) broken face; carbonate, finely disseminated and 21 percent fine carbonate masses; violent effervescence; clear wavy boundary. Lab sample # 11N11539. 1 percent snail shells throughout

Oa1--251 to 267 centimeters; black (2.5Y 2/1); violent effervescence; clear wavy boundary. Lab sample # 11N11540. 2.5 cm band of silty material in the middle of the horizon; 1 percent snail shells throughout.

Oa2--267 to 279 centimeters; 50 percent dark gray (2.5Y 4/1) broken face and 50 percent dark grayish brown (2.5Y 4/2); violent effervescence; clear wavy boundary. Lab sample # 11N11541. silt bands within the fiberous material; 1 percent snail shells throughout

O'ek--279 to 292 centimeters; 80 percent dark gray (2.5Y 4/1) broken face and 20 percent light brownish gray (2.5Y 6/2) broken face; carbonate, finely disseminated and 21 percent fine carbonate masses; violent effervescence; clear wavy boundary. 1 percent snail shells throughout

O'a--292 to 305 centimeters; dark gray (2.5Y 4/1) broken face; violent effervescence; clear wavy boundary. 1 percent snail shells throughout; silt bands within the fiberous material

O''e--305 to 340 centimeters; 60 percent very dark gray (2.5Y 3/1) broken face and 40 percent black (2.5Y 2/1) broken face; violent effervescence; gradual wavy boundary. 1 percent snail shells throughout; intact leaf material found at depths of 318 cm to 327 cm

O''ak1--340 to 368 centimeters; 50 percent dark gray (2.5Y 4/1) broken face and 50 percent dark grayish brown (2.5Y 4/2) broken face; carbonate, finely disseminated and 21 percent fine carbonate masses; violent effervescence; gradual wavy boundary. 1 percent snail shells throughout

O''ak2--368 to 394 centimeters; dark gray (2.5Y 4/1) broken face; carbonate, finely disseminated and 21 percent medium and coarse carbonate masses; violent effervescence; gradual wavy boundary. 1 percent snail shells throughout

O''ak3--394 to 419 centimeters; black (2.5Y 2.5/1) broken face; carbonate, finely disseminated and 21 percent medium and coarse carbonate masses; violent effervescence; gradual wavy boundary. 1 percent snail shells throughout; silt bands within the fiberous material

2Ck1--419 to 437 centimeters; dark gray (2.5Y 4/1); carbonate, finely disseminated and 21 percent medium and coarse carbonate masses; violent effervescence; gradual wavy boundary. Lab sample # 11N11548. fiberous material 1 percent rubbed within the horizon; 1 percent snail shells throughout

References

Soil Survey staff. 2010. Keys to Soil Taxonomy, 11th Edition. US Department of Agriculture Soil Conservation Service, Washington DC