Three thoughts on soil class maps: (1) Evaluating classification accuracy (2) Taxonomic vs. geographic soil classes (2) Soil geoforms & phenoforms

D G Rossiter
Adjunct Associate Professor

Section of Soil & Crop Sciences, SIPS, CALS, Cornell University

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Overview

- Three papers (two published, one in preparation) on various aspects of **soil survey practice**.
- These all deal with maps of **soil classes**, not soil properties.
- A chance to re-visit some concepts that have bothered me since my undergraduate days studying with Marlin Cline (1913–2009, Cornell PhD '42), during my soil survey work in North Carolina in the early 1970's, and during my PhD study with Armand van Wambeke (1989).

Fundamental papers by Cline

- Cline, M. G. (1944). *Principles of soil sampling*. Soil Science, 58(4), 275–288.
- Cline, M. G. (1949). *Basic principles of soil classification*. Soil Science, 67(2), 81–91.
- Cline, M. G. (1961). *The changing model of soil*. Soil Science Society of America Journal, 25(6), 442–446.
- Cline, M. G. (1963). *Logic of the new system of soil classification*. Soil Science, 96, 17–22.
- Cline, M. G. (1980). *Experience with Soil Taxonomy of the United States*. Advances in Agronomy, 33, 193–226.

Cornell agronomy monographs

Agronomy at Cornell

Soils, Field Crops
and Atmospheric Science
1868-1980

Professor of Soil Science, Emeritus
Marlin G. Cline

R P Murphy

Agronomy mimeo no. 82-16

Soil Survey of Cornell University Property and Adjacent Areas

by Marlin G. Cline and Arthur L. Bloom

Outline

1. Soil classes
2. Accounting for taxonomic distance in accuracy assessment
3. The soil series concept: taxonomic vs. geographic
4. A new look at the soil genoform vs. phenoform concept

Outline

1 Soil classes

2 Accounting for taxonomic distance in accuracy assessment

3 The soil series concept: taxonomic vs. geographic

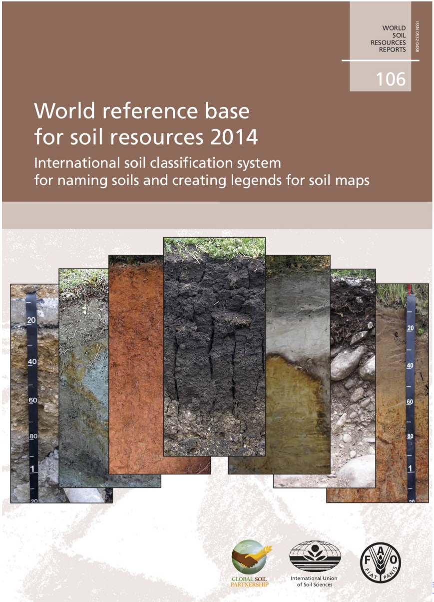
4 A new look at the soil genoform vs. phenoform concept

Soil classes

- Information carriers that present a **holistic** view of groups of soil individuals with a defined "personality".
- useful as the units of interpretation (**land suitability evaluation**)
- useful to explain **soil geography**
- many **users** of soil information are familiar with class maps and their interpretations

Monothetic hierarchical soil classification systems

- soil "individuals" (e.g., so-called "pedons") are allocated to **single classes** according to **sharp thresholds**
- **Monothetic**: **all** members of any class share a defined set of features; this combination *not* present in any members of other classes
- **Hierarchical**: lower levels must satisfy the criteria of all higher levels
- Examples:
  - World Reference Base for Soil Classification (WRB)
  - US Soil Taxonomy (ST)
  - Chinese Soil Taxonomy (CST)

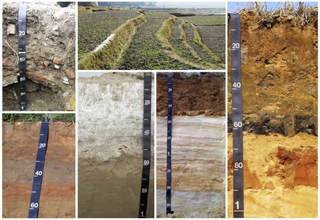

WORLD
SOIL
RESOURCES
REPORTS
106
World reference base
for soil resources 2014
International soil classification system
for naming soils and creating legends for soil maps
GLOBAL SOIL PARTNERSHIP
International Union of Soil Sciences
FIAT PANIS

USDA United States Department of Agriculture

NRCS Natural Resources Conservation Service

Keys to Soil Taxonomy

Twelfth Edition, 2014



Udalfs

Key to Great Groups

JEA. Udalfs that have a natric horizon.

Natrudalfs, p. 64

JEB. Other Udalfs that have *both*:

1. A glossic horizon; *and*

2. In the argillic or kandic horizon, discrete nodules, 2.5 to 30 cm in diameter, that:

   a. Are enriched with iron and extremely weakly cemented to indurated; *and*

   b. Have exteriors with either a redder hue or a higher chroma than the interiors.

Ferrudalfs, p. 57

JEC. Other Udalfs that have *both*:

1. A glossic horizon; *and*

2. A fragipan within 100 cm of the mineral soil surface.

Fraglossudalfs, p. 57

JED. Other Udalfs that have a fragipan within 100 cm of the mineral soil surface.

Fragiudalfs, p. 57

JEE. Other Udalfs that meet *all* of the following:

1. Do not have a densic, lithic, paralithic, or petroferric contact within 150 cm of the mineral soil surface; *and*

2. Have a kandic horizon; *and*

3. Within 150 cm of the mineral soil surface, *either*:

   a. Do not have a clay decrease with increasing depth of 20 percent or more (relative) from the maximum clay content [Clay is measured noncarbonate clay or is based on the following formula: Clay % = 2.5(% water retained at 1500 kPa tension - % organic carbon), whichever value is greater, but no more than 100]; *or*

   b. Have 5 percent or more (by volume) skeletans on faces of peds in the layer that has a 20 percent lower clay content *and*, below that layer, a clay increase of 3 percent or more (absolute) in the fine-earth fraction.

Kandiudalfs, p. 63

JEF. Other Udalfs that have a kandic horizon.

Kanhapludalfs, p. 64

JEG. Other Udalfs that:

1. Do not have a densic, lithic, or paralithic contact within 150 cm of the mineral soil surface; *and*

2. Within 150 cm of the mineral soil surface, *either*:

   a. Do not have a clay decrease with increasing depth of 20 percent or more (relative) from the maximum clay content [Clay is measured noncarbonate clay or is based on the following formula: Clay % = 2.5(% water retained at 1500 kPa tension - % organic carbon), whichever value is greater, but no more than 100]; *or*

   b. Have 5 percent or more (by volume) skeletans on faces of peds in the layer that has a 20 percent lower clay content *and*, below that layer, a clay increase of 3 percent or more (absolute) in the fine-earth fraction; *and*

3. Have an argillic horizon with *one or more* of the following:

   a. In 50 percent or more of the matrix of one or more subhorizons in its lower one-half, hue of 7.5YR or redder and chroma of 5 or more; *or*

   b. In 50 percent or more of the matrix of horizons that total more than one-half the total thickness, hue of 2.5YR or redder, value, moist, of 3 or less, and value, dry, of 4 or less; *or*

   c. Many coarse redox concentrations with hue of 5YR or redder or chroma of 6 or more, or both, in one or more subhorizons; *or*

4. Have a frigid soil temperature regime and *all* of the following:

   a. An argillic horizon that has its upper boundary 60 cm or more below *both*:

      (1) The mineral soil surface; *and*

      (2) The lower boundary of any surface mantle containing 30 percent or more vitric volcanic ash, cinders, or other vitric pyroclastic materials; *and*

   b. A texture class finer than loamy fine sand in one or more horizons above the argillic horizon; *and*

   c. Either a glossic horizon or interfingering of albic materials into the argillic horizon.

Paleudalfs, p. 65

JEH. Other Udalfs that have, in *all* subhorizons in the upper 100 cm of the argillic horizon or throughout the entire argillic horizon if less than 100 cm thick, more than 50 percent colors that have *all* of the following:

1. Hue of 2.5YR or redder; *and*

2. Value, moist, of 3 or less; *and*

3. Dry value no more than 1 unit higher than the moist value.

Rhodudalfs, p. 67

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2 Accounting for taxonomic distance in accuracy assessment

3 The soil series concept: taxonomic vs. geographic

4 A new look at the soil genoform vs. phenoform concept

Accounting for taxonomic distance in accuracy assessment

- Essential idea: **conventional accuracy assessment measures of soil class maps are unrealistically conservative**.
- Concepts are applicable to other class maps, but the method here is specific to soil classes.

Source: Rossiter, D. G., Zeng, R., & Zhang, G.-L. (2017). *Accounting for taxonomic distance in accuracy assessment of soil class predictions*. **Geoderma**, 292, 118–127. `https://doi.org/10.1016/j.geoderma.2017.01.012`

Accuracy assessment

Allocation is rarely perfect:

- Compare **predicted** class to **reference** ("true") class – as **observed in the field**
- Errors of **omission**: fail to predict an observation in a reference class
- Errors of **commission**: predict a reference class when in fact in another class
- Display these in the **confusion matrix** also called **cross-correlation matrix**

Example cross-classification matrix

Suborder	OP	SA	UA	UC	AV	AC
OP	**2**	1	0	5	0	0
SA	1	**74**	2	1	3	6
UA	0	5	**8**	6	1	3
UC	6	1	3	**91**	0	0
AV	0	4	0	0	**0**	4
AC	0	6	2	2	4	**38**

Rows: as allocated by spectroscopy
Columns: reference (true) class in Chinese Soil Taxonomy

OP = Orthic Primosols; SA = Stagnic Argosols; UA = Udic Argosols; UC = Udic Cambosols; AV = Aquic Vertosols; AC = Aquic Cambosols

Conventional accuracy statistics

- observed class row i, reference ("true") class column j
- count x_{ij} predicted as i, actually is j
- marginal sums x_{i+}, x_{+j}
- number of classes r

Overall accuracy $= \sum_{i=1}^{r} x_{ii} / n$

Map unit purity = per-class "user's accuracy" $= x_{ii} / x_{i+}$

Class representation = per-class "producer's accuracy" $= x_{jj} / x_{+j}$

terminology from: Brus, D. J., Kempen, B., & Heuvelink, G. B. M. (2011). *Sampling for validation of digital soil maps*. **European Journal of Soil Science**, 62, 394–407. `https://doi.org/10.1111/j.1365-2389.2011.01364.x`

Conventional statistics for example cross-classification matrix

overall accuracy $A_o = 0.76$

	Map unit purity	Class representation
OP	0.25	0.22
SA	0.85	0.81
UA	0.35	0.53
UC	0.90	0.87
AV	0.00	0.00
AC	0.73	0.75

Idea: not all errors are equally serious

. . . in terms of:

- soil properties
- map use
- pedogenesis
- ease of mapping
  - if we are evaluating the mapper's skill

So they should not all count equally towards the accuracy statistics.

Example of minor error – WRB

- WRB *mollic* horizon: thickness $\geq$ 20 cm
- Natural soil bodies where the thickness of a horizon that would otherwise qualify as *mollic* ranges from 18 to 22 cm.
- Soil with *calcic* horizon and a *dark, organic-rich, high-base saturation epipedon*
  - If thick enough for *mollic*: *Calcic Kastanozem*:
  - If too thin for *mollic*: *Haplic Calcisol*
- **These are very similar soils**
- Also: allocation depends on **selection of reference profile**, it is one $\approx$ homogeneous **map unit**

Key to the Reference Soil Groups

Other soils having:

1. a *mollic* horizon; *and*
2. a *calcic* horizon or a layer with *protocalcic* properties starting ≤ 50 cm below the lower limit of the *mollic* horizon, and if present, above a cemented or indurated layer; *and*
3. a base saturation (by 1 M NH4OAc, pH 7) of ≥ 50% from the soil surface to the *calcic* horizon or the layer with *protocalcic* properties, throughout.

KASTANOZEMS

Key to the Reference Soil Groups

Other soils having:

1. a *petrocalcic* horizon starting ≤ 100 cm from the soil surface; *or*
2. both of the following:
   a. a *calcic* horizon starting ≤ 100 cm from the soil surface; *and*
   b. no *argic* horizon above the *calcic* horizon unless the *argic* horizon is permeated throughout with secondary carbonate.

CALCISOLS

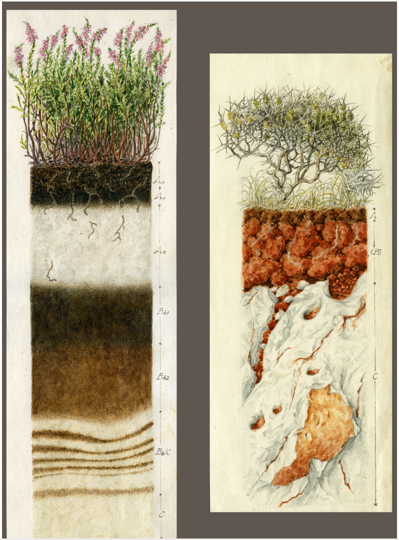
Calic Kastanozem (WRB); Calciudoll (ST)

if a thin mollic horizon:

Haplic Calcisol (WRB)
(Rendollic) Eutrudepts (ST)

Source: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/wv/soils/?cid=nrcs142p2_053603

Example of major error



left: humus Podzol on dune sands with *ortstein* (secondary iron pan)

right: Terra Rossa on limestone

Source: Kubiëna 1954 *Atlas of Soil Profiles*

Partial credit for errors

- Create a second matrix containing **weights**, same size as the cross-classification matrix
- Values from 0 (error is serious, no partial credit) to 1 (error makes no difference, full partial credit)
- All diagonals are 1
- Off-diagonals on the interval $[0 \ldots 1]$.
- These are **weights** that will be used in weighted accuracy assessment

Example weights matrix

Suborder	OP	SA	UA	UC	AV	AC
OP	**1**	0.05	0.05	0.15	0.05	0.15
SA	0.05	**1**	0.05	0.05	0.05	0.35
UA	0.05	0.05	**1**	0.20	0.15	0.15
UC	0.15	0.05	0.25	**1**	0.10	0.25
AV	0.05	0.10	0.15	0.10	**1**	0.15
AC	0.20	0.30	0.10	0.25	0.20	**1**

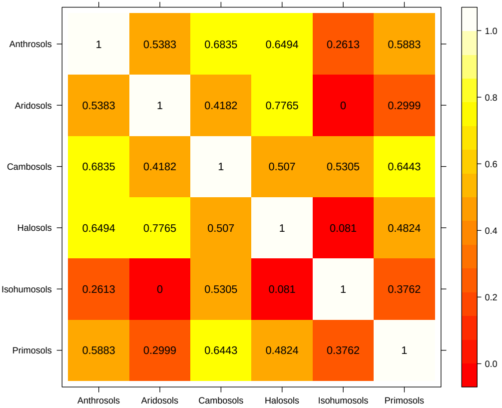
Partial credit for having **predicted, mapped . . .** the class given in the **row**, which is in fact (**map unit, field check**) the class given in the **column**

Here: mapping as `SA` (Stagnic Argosols) when in fact `AC` (Aquic Cambosols) received 0.35 partial credit – note not necessarily symmetrical

How to assign weights?

1. Expert opinion
   - Depends on point of view (user vs. producer)
     - user: how serious an error if used as mapped when in fact the reference class?
     - producer: how easy is it to make this error? (testing mapper's skill)
2. Numerical taxonomy
   - e.g., distance in **multivariate space** of soil spectra
3. Relative position in hierarchy
   - An artefact of the system structure
4. Error loss function
   - Loss to map user from incorrect information

Numerical taxonomy: Weights matrix based on spectral distance



scanned 830 genetic horizons from 189 profiles

stacked and sliced to standard depths

distance in 10-PC space

Example error loss function

Series	Soil Taxonomy family (partial)	Site index
Rains	Fine-loamy Typic Paleaquults	94
Lynchburg	Fine-loamy Aeric Paleaquults	86
Goldsboro	Fine-loamy Aquic Paleudults	88
Norfolk	Fine-loamy Typic Kandiudults	84
Wagram	Loamy Arenic Kandiudults	81
Tarboro	Mixed Typic Udipsamments	72

Some North Carolina soil series and their site indices for *Pinus taeda*

Site index a direct measure of tree productivity (greater index = more productivity)

Computing the partial credit due to loss

1. predicting Norfolk (84) when in fact Tarboro (72)
2. over-estimates productivity; loss is $(84 - 72)/84 = 0.143\%$.
3. similarity is $(1 - 0.143) = 0.857$
4. this is in the weights matrix at cell [Norfolk, Tarboro]

Conventional & weighted statistics for example cross-classification matrix

Unweighted accuracy A_o:	0.7634
Weighted accuracy A_{ow}:	0.8039

	Purity	Purity(W)	Class Rep.	Class Rep.(W)
OP	0.25	0.35	0.22	0.33
SA	0.85	0.88	0.81	0.84
UA	0.35	0.44	0.53	0.60
UC	0.90	0.92	0.87	0.89
AV	0.00	0.12	0.00	0.14
AC	0.73	0.79	0.75	0.81

The *tau* index τ

- Some of the “succcess” of the allocation can be due to **chance**; especially with **few** and **unbalanced** classes
- To judge the skill of the allocator, must adjust naïve statistics
- *kappa* was invented for this, but does not account for **prior probabilities** of allocation
- *tau* τ allows analyst to specify priors
  - **equal** priors: no prior knowledge of class distribution
  - **reference class** priors: allocation method uses these
- See paper for computations and discussion

Other approaches – 1

This method applies to **crisp, mutually-exclusive classes**
Another approach: **fuzzy** accuracy assessment: allocate to *all* classes with some *possibility*; compute various accuracy statistics

- Gopal, S., & Woodcock, C. (1994). *Theory and methods for accuracy assessment of thematic maps using fuzzy sets*. **Photogrammetric Engineering & Remote Sensing**, 60(2), 181–188.
- Laba, M., *et al.* (2002). *Conventional and fuzzy accuracy assessment of the New York Gap Analysis Project land cover map*. **Remote Sensing of Environment**, 443–455.

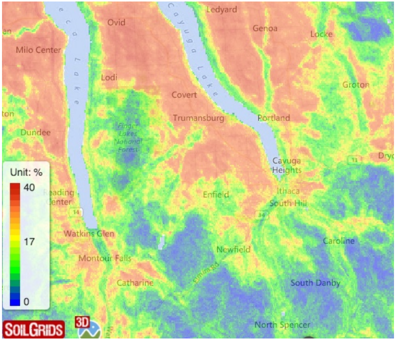
Other approaches – 2

Why allocate a profile or map unit to just one class?

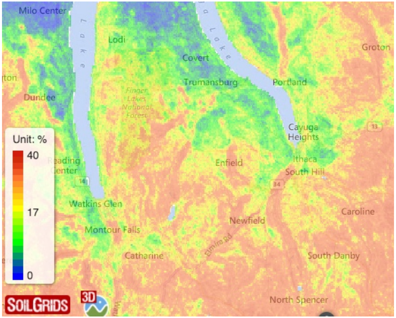
Multiple probabilistic allocation to classes

- e.g., multilogistic regression
- Ramcharan, A., *et al.* (2018).*Soil property and class maps of the conterminous United States at 100-meter spatial resolution*. **Soil Science Society of America Journal**, 82, 186–201. https://doi.org/10.2136/sssaj2017.04.0122
- Hengl, T., *et al.* (2017). *SoilGrids250m: Global gridded soil information based on machine learning*. **PLOS ONE**, 12, e0169748. https://doi.org/10.1371/journal.pone.0169748

Probabilistic allocation



Udalfs



Udepts

Source: `https://soilgrids.org`.

Allocation by random forests using a large set of predictors and training observations from NRCS.

Discussion – honesty in reporting

- Honesty in reporting:
  - Giving partial credit will usually **increase** the reported accuracy; never decreases it
  - Do not give partial credit to “cook” the results
  - It should be given to reflect the actual usefulness of the allocation/map to the user
  - Must be **transparent** on how weighting (partial credit) was done: **report** and **justify**

Discussion – soil classification

Are monothetic hierarchical systems the best way to organize our knowledge?

- Much of the "error" comes from the "taxonomic chop" of rigid limits
  - Butler, B. E. (1980). *Soil classification for soil survey*. Oxford: Clarendon Press.
  - Webster, R. (1968). *Fundamental objections to the 7th approximation*. **Journal of Soil Science**, 19, 354–366. https://doi.org/10.1111/j.1365-2389.1968.tb01546.x
- . . . compounded by field and lab. measurement uncertainty
- Also from selection of representative individuals within a natural map unit

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The soil series concept: taxonomic vs. geographic

- **Soil series**: the most detailed level of soil classification
- Used to name **map units** of **detailed soil maps**
- **These two purposes may not match**
- Already in 1980 Butler proposed a solution

Soil classification vs. soil mapping

Two procedures with different **objectives** . . .
. . . therefore different **concepts**

Classification a **taxonomic** concept

Mapping a **geographic** concept

Soil classification

Aim: **stratify** the universe of **soil individuals** into $\approx$ **homogeneous groups** $\rightarrow$ *taxonomic* concept

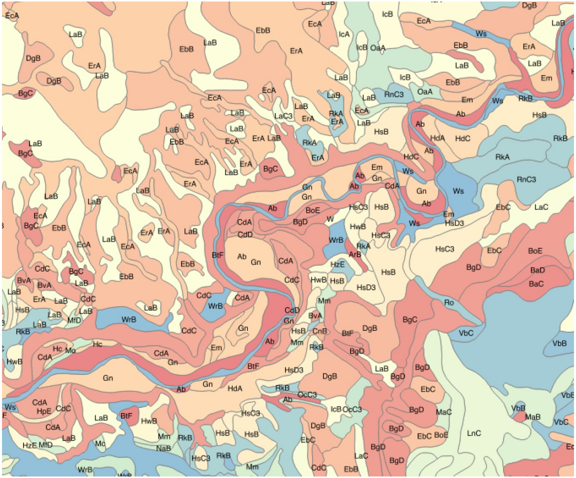
- "Homogeneous": according to some criteria decided by (human) taxonomist
    - numerical taxonomy also requires human judgement, e.g., selection of properties and methods
- Can be geography (e.g., climate zones), presumed pedogenesis, soil properties, use potential. . . depending on the objective of the taxonomist

Soil mapping

Aim: **stratify** the **soil landscape** into $\approx$ **homogeneous areas** $\rightarrow$ *geographic* concept

- The result is a **map** that shows the spatial distribution of soil types; maps can be used to:
    - make **management decisions**
    - **stratify** the landscape for **modelling**
    - understand **soil-landscape evolution**

Map units


EcA
LaB
DgB
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EcA
ErA
IcA
IcB
OaA
IcB
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HsB
HsD3
CdC
WrB
CdA
CoD
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BvA
BgC
Ro
VbC
VbB
WrB
CdC
Gn
Em
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HsB
CnB
BtF
DgB
RkB
BgD
Hc
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IcB
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BgD
MaC
VbB
MaB
VbC
HpE
CdC
LaB
BtF
HwB
HsC3
HsB
HsB
DgB
EbC
BgD
EbC
BoE
LnC
HzE
MfD
Mm
NaB
RkB
HsC3
RkB
Mm
CdC
EbB
LaC
BgD

Soil individuals

"The smallest natural body that can be defined as a thing complete in itself is an individual" – Cline (1949)

- Soil classification: **sampling units**
  - 2.5D profiles or 3D "pedons"
  - 1–10 m^2 surface area
- Soil mapping: **landscape segments**
  - 4 000–?? m^2 surface area
  - Separated by zones of **maximum inflection**: change in **properties** in response to change in **soil forming factors**
  - Boundaries may be sharp/diffuse (nature), clear/obscure (to mapper)
  - (Or, grid cells of fixed resolution, e.g., 100x100 m)

Taxonomic individual

Shandong province, Linyi prefecture 山东临沂郯城后赵村
"Shajiang"-Aquic Cambosols [沙姜 "ginger-shaped concretions"]

Landscape segment

Taxonomic vs. mapping soil series

Two distinct concepts:

Taxonomic the most detailed level in a **soil classification system** to group soil profiles / "pedons"

Mapping the most detailed level in a **map legend** to identify soil-landscape segments

- Most pedons in a delineation have the same landscape expression
- There may be contrasting series (inclusions) covering areas too small to map

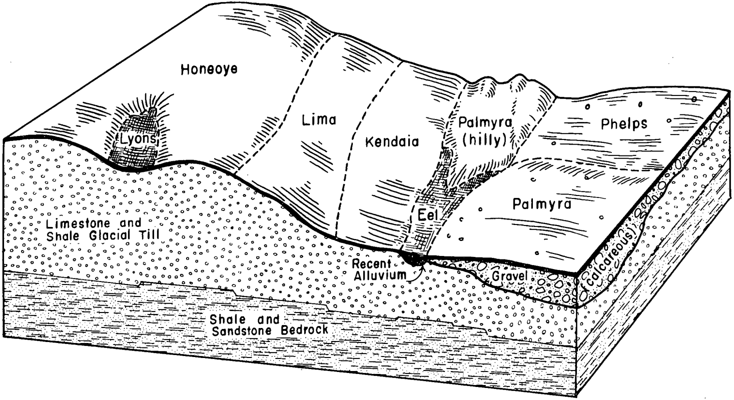
Can these concepts be reconciled?

Series as taxonomic classes – example from USA

Series	Soil Taxonomy family
Honeoye	Fine-loamy, mixed, semiactive, mesic Glossic Hapludalfs
Lima	Fine-loamy, mixed, semiactive, mesic Oxyaquic Hapludalfs
Kendaia	Fine-loamy, mixed, semiactive, mesic Aeric Endoaquepts
Palmyra	Fine-loamy over sandy, mixed, active, mesic Glossic Hapludalfs
Phelps	Fine-loamy over sandy, mixed, active, mesic Glossaquic Hapludalfs
Eel	Fine-loamy, mixed, superactive, mesic Fluvaquentic Eutrudepts
Lyons	Fine-loamy, mixed, active, mesic Mollic Endoaquepts
Alden	Fine-loamy, mixed, active, mesic Mollic Endoaquepts

According to Soil Taxonomy, all pedons classified into the series **must** satisfy **all** criteria of **all** higher levels in the hierarchy

Series as landscape segments – example from USA



parent material + landscape position → profile, properties

Can we expect all or even **most** pedons mapped in the series to strictly key out through **all** the higher levels of the Taxonomy?

Butler's concepts of mapping vs. taxonomic series

Butler[1] identified the **taxonomic hiatus** between:

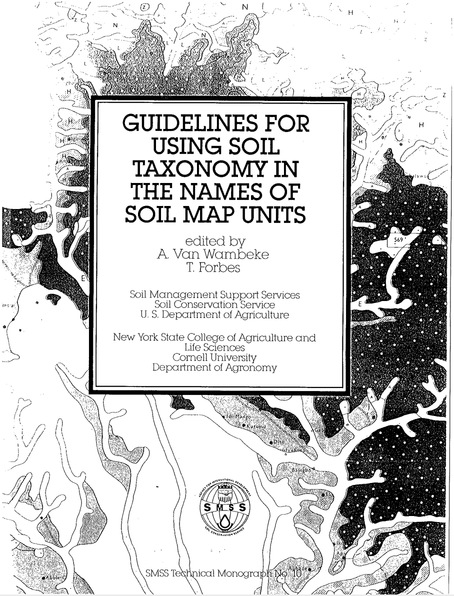
1. a **mappable** series which corresponds to **natural landscape variation**, and
2. a **taxonomic** series defined by **classifier-imposed property limits**
    - By definition, all individuals in the series must have all properties within the prescribed limits
    - If the classification system is hierarchical then within the limits for **all higher categories**
    - This is the case for WRB, ST, CST, ...

[1] Butler, B. E. (1980). *Soil classification for soil survey*. Oxford Science Publications

Soil taxonomy solution

- Rules for naming map units using (Chinese) Soil Taxonomy
  - Van Wambeke & Forbes (1986). *Guidelines for using "Soil Taxonomy" in the names of soil map units*.
  - 参看: 张甘霖 (编者). (2001). 土系研究与制图表达. 合肥: 中国 科学技术大学出版社.
- Cline 1980[2]
  - the taxonomic chop causes mapping problems as **artifacts** of Soil Taxonomy
  - the rules to handle such artificial geographic mixtures in legends are awkward

[2] Cline, M. G. (1980). Experience with Soil Taxonomy of the United States. Advances in Agronomy, 33, 193–226


GUIDELINES FOR USING SOIL TAXONOMY IN THE NAMES OF SOIL MAP UNITS
edited by
A. Van Wambeke
T. Forbes
Soil Management Support Services
Soil Conservation Service
U. S. Department of Agriculture
New York State College of Agriculture and Life Sciences
Cornell University
Department of Agronomy
S M S S
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Map unit composition

Edmonds, W. J., & Lentner, M. (1986). *Statistical evaluation of the taxonomic composition of three soil map units in Virginia*. **SSSAJ**, 50:997.
`https://doi.org/10.2136/sssaj1986.03615995005000040033x`

- Design scale 1:15 840 (Minimum Legible Area ≈ 1 ha); "consociations" map units
- "dominated by a single soil component; at least **one-half** of the pedons . . . are of the **same soil taxa** as the named soil. The remainder of the delineation mostly consists of soil so **similar to the named soil** that **major interpretations are not significantly affected**." (Soil Survey Manual 2017)
- Measured **taxonomic purity** 59, 78, **19**%; however map units were **interpetable** for land use

Butler's solution

- The **central concepts** of the *mappable* series can easily be grouped as necessary into any *taxonomic* system
  - This is in fact how existing mapped series in the USA were grouped to form the hierarchy of Soil Taxonomy
  - The central concept is determined from a **representative profile**
  - This is selected to be **the modal values** of the range of properties of the mappable series.
- There is no need to force all individuals of a *mappable* series into higher conceptual levels of a *taxonomic* system

How is the range of properties of series determined?

- All individuals in the mappable series must be similar enough in their **range of properties** for **interpetations**
- That is, their **use potential and limitations** must be similar enough for a single management
- If used for modelling, the range must be narrow enough so that the model results are not “too” different from that for the modal profile
- Does *not* consider limits at higher taxonomic levels!

How to set the range of properties for a soil series?

- Criterion 1: compact **geographic expression**
- Criterion 2: similar **pedogenesis**
- Criterion 3: similar **function** on landscape
- Criterion 4: similar **interpretations** for land use
- *Not* limits imposed by higher taxonomic levels

Outline

1 Soil classes

2 Accounting for taxonomic distance in accuracy assessment

3 The soil series concept: taxonomic vs. geographic

4 A new look at the soil genoform vs. phenoform concept

A new look at the soil genoform vs. phenoform concept

- Recent work with Johan Bouma
  - retired from Wageningen University; 2018 will receive IUSS Dokuchaev award
  - sabbatical @CU 1992 with Wagenet, van Wambeke, Hutson, Hoosbeek, Rossiter
- Resurrecting ideas from mid-1990's by Bouma, Droogers, van Lanen, Reinds, Boersma
- Due to the increasing appreciation of **humans as soil-forming factors**, increasing interest in so-called **soil health**, and new rapid mapping methods (**digital soil mapping**)
- We hope this will lead to more useful and timely soil class maps

Source: Rossiter, D. G., & Bouma, J. (2018). *A new look at soil phenoforms – Definition, identification, mapping*. **Geoderma**, 314, 113–121. https://doi.org/10.1016/j.geoderma.2017.11.002

Idea

1. Map units of soil class maps are named for relatively stable **soil classes** – Droogers & Bouma coined the term (soil) *genoform* (analogy with biological "genotype")
   - "soil" to avoid confusion – suggestion of Christine Stockwell
2. Humans alter soil properties by management
3. If these changes are **substantial** and **permanent** enough, the map unit name changes to another; this depends on the classification system
   - e.g., Plaggic Anthrosols (WRB), Stagnic Anthrosols (long-term paddy soils) (CST), Technosols (WRB)
4. But if the changes are not enough, still the **soil functions** can be strongly affected – we need some way to designate these
5. So Droogers & Bouma coined the term (soil) *phenoforms* (analogy with "phenotype")

Definitions

Soil genoform "soil classes as identified by the soil classification system used as the basis for detailed soil mapping in a given area"

Soil phenoform "persistent, non-cyclical variants of a soil genoform with sufficient physical or chemical differences to substantially affect soil functions, especially regulation and production functions."

- persistent
- non-cyclical
- physical or chemical differences
- substantially affect soil functions

Soil functions

1. **biomass production**, including agriculture and forestry;
2. **storing, filtering and transforming** nutrients, substances and water;
3. biodiversity pool, such as habitats, species and genes;
4. physical and cultural environment for humans and human activities;
5. source of raw materials;
6. acting as C pool;
7. archive of geological and archeological heritage.

European Commission. (2006). *Thematic strategy for soil protection*. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52006PC0232:EN:NOT

Example

318 SOIL SCI. SOC. AMER. PROC., VOL. 35, 1971

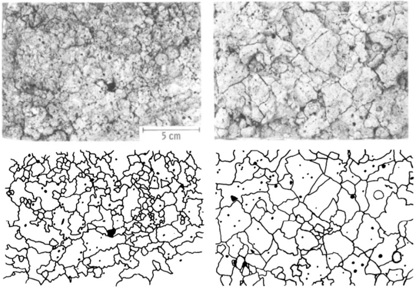
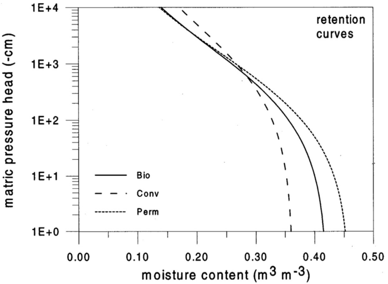


Fig. 1—Photographs and tracings of soil peels from horizontal sections at a depth of 80 cm through virgin (*left*) and cultivated (*right*) pedons of a Typic Argiudoll.

"[M]anagement-induced structural changes can strongly alter the hydraulic properties of a soil . . . may be of sufficient magnitude and continuity to consider recognition of **hydraulic soil phases of established soil series**. . ."

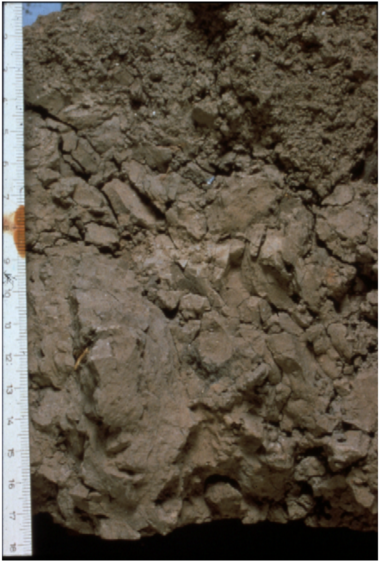
Bouma, J., & Hole, F. D. (1971). *Soil structure and hydraulic conductivity of adjacent virgin and cultivated pedons at two sites: a Typic Argiudoll (silt loam)*

Example



loamy, mixed, mesic Typic Fluvaquent, one map unit, different long-term management

Droogers, P., Bouma, J., & van der Meer, F. B. W. (1997). *Water accessibility to plant roots in different soil structures occurring in the same soil type*. **Plant and Soil**, 188, 83–91. https://doi.org/10.1023/A:1004256113198



Source: Henny van Lanen

Soil-forming factors

Conceptual equation describing the **inter-dependence** of the ecosystem, humans as **individuals** and humans in their **cultural context** on state factors:

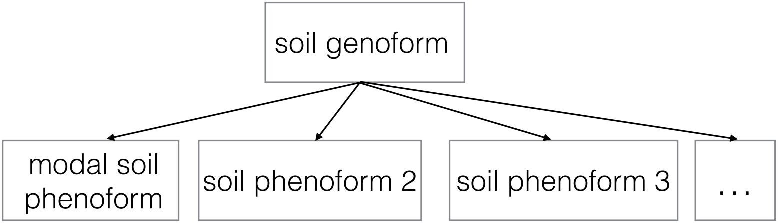
$$h, c, a, v, s = f(o_h, c_i, cl, o, r, p, t, \ldots)$$

(h)umans, (c)ulture, (a)nimals, (v)egetation, **(s)oil**
(o)rganisms, (cl)imate, (r)elief, (p)arent material, (t)time

Note that h is on both sides of the equation!

Amundson, R., & Jenny, H. (1991). *The place of humans in the state factor theory of ecosystems and their soils*. **Soil Science**, 151, 99‘‘106.

Relation between soil genoforms and phenoforms



How to select the soil genoform?

- *not* the "virgin", "original" . . . soil – that is often unknowable $\rightarrow$ not an operational definition
- instead, the **modal** soil within a genoform: the most common, the one for which most interpretations will be made

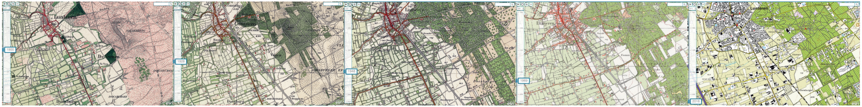
How to decide on soil phenoforms?

- Within the definition of the class *as defined in the system used for mapping* – e.g., the soil series
- Substantial difference in performance (evidence: yields, drought sensitivity, tillage difficulty & response . . .)
- Due to long-term management
  - evidence: historical land use maps, interviews . . .
- Reversible only in the medium to long term
  - Maybe new classes should be defined, if the change is quite difficult to reverse?
- Mappable (typically, per-field)

Challenges

- Methods must be developed to **rapidly map soil phenoforms** based on easily-available **covariates**
  - historical management, but how to get this information over wide areas?
  - remote sensing at critical times, e.g., drought; not attributable to soil genoform properties
- This would allow **repeat mapping** at short time intervals, to identify the results of changed management.

End



Land management changes. . . so do soil properties . . .

Lunteren, the Netherlands