QUANTITATIVE RELATIONSHIPS BETWEEN NET VOLUME CHANGE AND FABRIC PROPERTIES DURING S011. EVOLUTION.

O.A. CHADWICK* and W.D. NETTLETON**
* JPL, California Institute of Technology, Pasadena, CA
** USDA-SCS National Soil Survey laboratory, Lincoln, NE

ABSTRACT

The state of soil evolution can be charted by net long-term volume and elemental mass changes for individual horizons compared with parent material. Volume collapse or dilation depends on relative elemental mass fluxes associated with losses from or additions to soil horizons. Volume collapse occurs when minerals are weathered followed by leaching of elements, volume dilation occurs when carbon or other elements ate introduced into a horizon in greater abundance than loss through weathering and leaching. For selected soil parent materials, the related-distribution-pattern of plasma and skeleton grains provide a parallel description of these pedological changes that can be quantified through image analysis. Here, we investigate relationships between chenlica]/mineralogical and micromorphological measures of volume change during pedogenesis. For coarse-textured, arkosic, fluvially laid parent materials, fabrics progress from monic to porphyric related-distribution-patterns as new elements are introduced into a horizon or as secondary products form due to primary mineral weathering. Porphyric related-distribution-patterns evolve from single-space to open with increasing dilation or collapse, because in either case plasma is augmented relative to skeleton grains. Since coarse-textured soils evolve to the same fabrics under differing intensities of additions from external sources and accumulation of weathering products, a true understanding of the state of soil evolution implied by observation and classification of fabric properties requires quantification of both net volume change and net mass change during soil development.

INTRODUCTION

In microscopic studies of soil, the relationship between fine and coarse constituents (ie. plasma and skeleton grains) is termed 'related-distribution-pattern' (hearafter shortened to RDP) and is accorded special importance (Kubiena, 1938; Brewer, 1964; Brewer and Pawluk, 1975; Stoops and Jongerius, 1975); Bullock et al., 1985). In essence, micromorphologic classification schemes recognize that plasma may fill voids between skeleton grains, coat grains, or compose the matrix within which skeleton grains are distributed. RDPs are useful for studying soil evolution where parent material composition, grain size, and mode of deposition are kept constant, In this case, it is desirable to relate changes in RDPs to quantitative measures of soil development.

Evolution of RDPs from parent material to soil horizon implies changes in soil volume caused by the combined effects of pedogenesis (Brewer, 1964; Stoops and

Jongerius, 1975; Bullock et al., 1985). Thus, a quantitative measure of volume change between parent material and the horizon being described microscopical] y has special interest (Haseman and Marshall, 1945; Brewer, 1964; Brimhall and Dietrich, 1987; Chadwick et al., 1990; Brimhall et al., 1992). In an ideal situation, wc should be able to ascribe a volume-change value to the RDP described for each horizon. If this is possible, soil fabric observation would provide a visualization of a quantified value and would be a more robust tool in studying soil genesis. Here, we invest i gate the possibility y of developing quantitative relationships among RDPs, plasma content, and volume change in coarse-textured, arkosic, fluvially laid parent material that has evolved to form soil horizons.

METHODS

We selected examples from soil profiles whose characterization database resides in previously published papers or in the USDA National Soil Survey Laboratory (referenced by laboratory number in Table 1). Samples were selected to represent a range of horizon types, but are not inclusive; results are presented as an example of our approach that is constrained by a specified set of initial conditions. Standard procedures were used for chemical and physical characterization and preparation of thin sections (USDA, 1991). RDP descriptions follow the classification of Stoops and Jongerius (1975) and Bullock and others (1985). Areas of skeleton grains (> 50 µm in diameter), plasma and void space (> 50 µm in diameter) were measured for five fields in thin sections using an Olympus C-2 image Analyser[1] and are reported as a mean. The coefficient of variation ranges from 10-40% for skeleton grains.

We quantify volume change (strain) in soil ($\varepsilon_{i,w}$) by identifying bulk density (ρ_w) (g cm^{-3}) and the mass of an immobile component ($C_{i,w}$) (wt. % or ppm) in a soil horizon

[1] Given for the convenience of the reader and does not imply endorsement by JPL or USDA-SCS.

and compare it with bulk density (ρ_p) and the mass of an immobile component ($C_{i,p}$) in the soil parent material as follows (Brimhall and Dietrich, 1987; Brimhall et al., 1992):

$$\varepsilon_{i,w} = \frac{\rho_p C_{i,p}}{\rho_w C_{i,w}} - 1$$

Positive volume changes represent dilations; negative volume changes represent collapse. Collapse occurs when the increase in concentration of an immobile element ($C_{i,w}$) caused by loss of mobile constituents is not exactly compensated by an inversely proportional decrease in bulk density (ρ_w) due to increasing porosity. This formulation is derived under the constraints of mass conservation in deformable media and is functionally similar to one derived by Brewer (1964, p. 81).

In these calculations, we use either the mass of Zr as an immobile element, or for selected soils from the NSSI, database, the mass of the medium sand size-fraction. We evaluated the validity of immobility assumptions on a case-by-case basis.

RESULTS

We classified RDPs, measured areas of fabric components in thin sections, and calculated volume change ($\varepsilon_{i,w}$) for 26 horizons (Table 1), and plotted each RDP into a graphical field defined by the numerical volume change and % plasma (Fig. 1). The graph is separated into four regions (dashed lines) defined by collapse or dilation along the x-asis which is controlled by the net mass loss or gain within each horizon and the change from skeleton supported matrix to plasma supported matrix along the y-axis which is interpreted from the RDPs. By our selection criteria, all soil parent material has monic RDP and zero volume change; they evolve in the direction of increasing plasma with either positive or negative volume change.

The RDPs plot into four overlapping fields shown as shaded areas in Fig. 1. Enaulic (EU), chitonic (CT), and gefuric (GF) RDPs (stippled field) range from O to 50%

weathering and leaching are less important than external inputs such as silicate and carbonate dust or calcium in rainwater (path IV, Fig. 1), soil horizons may more than double in volume as plasma from external sources is incorporated by deformation] mass transport (Brimhall et al, 1992). The double-space and open porphyric RDPs result from floating of skeleton grains in the increased plasma (a generalization of the K-fabric concept (Gile et al., 1965)). Commonly, where external inputs arc balanced partly by leaching losses (path 111, Fig. 1), soil horizons are slightly dilated even though much plasma has accumulated, Along path 111, the single- space, double-space, and open porph yric RDPs rc.suit from both accumulation of externally derived plasma and weathering derived plasma,

DISCI-JSS1ON AND CONCI ,USIONS

'I'he relationship between RDPs and volume change is summarized by the diagrams in Fig. 2. Two diagrams are shown, one for cases where cohesive forces dominate and the other case where adhesive forces dominate. Cohesive forces occur in humid environments when covalently bonded silica, iron, aluminum, and organic matter form the non-silicate clay portion of the plasma and adhesive forces dominate in arid environments when ionically bonded salts form the non-silicate clay portion of the plasma (Chadwick and Nettleton, 1990). The diagrams show the progression of fabrics from monic (the orthogranic of Brewer and Pawluck (1975)) to open porphyric. In the cohesive case, the progression is through gefuric and chitonic to close porphyric, whereas, in the adhesive case the progression is through enaulic and gefuric-chitonic to close porphyric. The enaulic to close porphyric pathway occurs in the adhesive case because irregularly shaped aggregates first accumulate in the spaces between grains. In this case, continual plasma addition fills the spaces that develop between grains such that former groin-to-grain contacts are forced apart to produce a close porphyric RDP. None of the categories defined by Bullock et al., (1985) describe this intermediate class very well. It best fits the plectic class of Brewer and Pawluck (1975), Progressive filling of inter-skeleton grain voids by plasma drives an inward movement along the discs in Fig. 2 and produces small dilations. Once soil evolution produces a plasma supported matrix, the same sequence of fabrics can develop from either dilation or collapse as shown by progression from single-space to open porphyric along both ends of the orthogonal line through the discs. Thus, while it is possible to relate RDPs to quantitative volume change and plasma content, it is not possible to develop a cause and effect relationship between these measures of soil evolution. To relate RDPs, volume change, and soil plasma uniquely, it is also necessary to calculate net mass-balance change during soil evolution (see Chadwick et al., 1990).

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FIGURE CAPTIONS

Fig. 1. Relationship among volume change ($\varepsilon_{i,w}$), soil plasma, and related-distribution-patterns (RDPs) for soil horizons listed in Table 1. RDP abbreviations are: MN=monic, EU=enaulic, CT=chitonic, GF=gefuric, PS=single-space porphyric, PD=double-space porphyric, PO=open porphyric. Shaded areas and arrows are explained in the text,

Fig. 2. Relationship of soil fabrics to soil volume changes where either cohesive or adhesive forces dominate.

TABLE 1. Related Distribution Patterns, Strain, and Areal Measurements for Soil Horizons Plotted in Figure 1.

RELATED DISTRIBUTION PATTERNS[1]	$\varepsilon_{i,w}$ [2]	AREA[3]			HORIZON	REFERENCE
		Skeleton Grains (%)	Plasma (%)	Void Space (%)		
MN	0	42	—	58	[parent mat.]	Chadwick et al., 1990
GF	0.2	16	73	11	2Bs1	Pedon 1 - Merritts et al., 1991
EU	0.2	20	68	12	2Bs1	Pedon 1 - Merritts et al., 1991
CT	0.4	43	48	9	ABs	Pedon 1 - Merritts et al., 1991
EU-CT	0.5	37	53	10	2Bs1	Pedon 1 - Merritts et al., 1991
PS	0.2	32	68	—	A1	Pedon4b - Merritts et al., 1991
PD	0.1	17	83	—	A2	Pedon4b - Merritts eta!., 1991
PD	0	12	88	—	AB	Pedon4b - Merritts et al., 1991
Po	-0.2	7	93	—	Bwl	Pedon4b - Merritts et al., 1991
Ps	0.3	30	70	—	Bw3	Pedon4b - *Merritts et* al., 1991
Po	0.1	6	94	—	AB1	Chadwick eta!., *1990*
PD	-0.3	12	88	—	Bw	Chadwick et al., 1990
PD	-0.3	13	87	—	Bt	Chadwick et al., 1990
Ps	-0.3	18	82	—	Bt	Chadwick et al., 1990
Po	-0.2	8	92	—	B02	Chadwick eta!., 1990
Ps	0.1	14	86	—	A	? 18 ka Soil, Figure1 - Brimhall et al., 1992
Ps	-0.1	18	82	—	Bw	118ka Soil, Figure1 - Brimhall et al., 1992
Ps	-0.3	19	81	—	BC	1 18 ka Soil, Figure1 - Brimhall eta!., 1992
GF	0	43	46	11	c	118ka Soil, Figure1 - Brimhall et al., 1 992
PD	1.1	14	86	—	K22m	Soil Number 3 - Gile et al., 1965
PS	0.3	29	71	—	Bt2	Lab Number 81 P4572
Po	1.2	10	90	—	Bt1	Lab Number 64658
Po	2.0	3	97	—	Bt2	Lab Number 64651
Po	0.7	15	85	—	Bt2	Lab Number 66727
PD	2.2	13	87	—	Bt2	Lab Number 66649
PS	0.4	30	70	—	Bt2	Lab Number 40A1 794

[1] MN= Monic; GF = Gefuric; EU = Enaulic; CT= Chitonic; PS = Single-Space Porphyric; PD = Double-Space Porphyric; and PO = Open Porphyric

[2] $$\varepsilon_{i,w} = \frac{\rho_p C_{i,p}}{\rho_w C_{i,w}} - ,$$

[3] Cross-Sectional *area* of thin section.

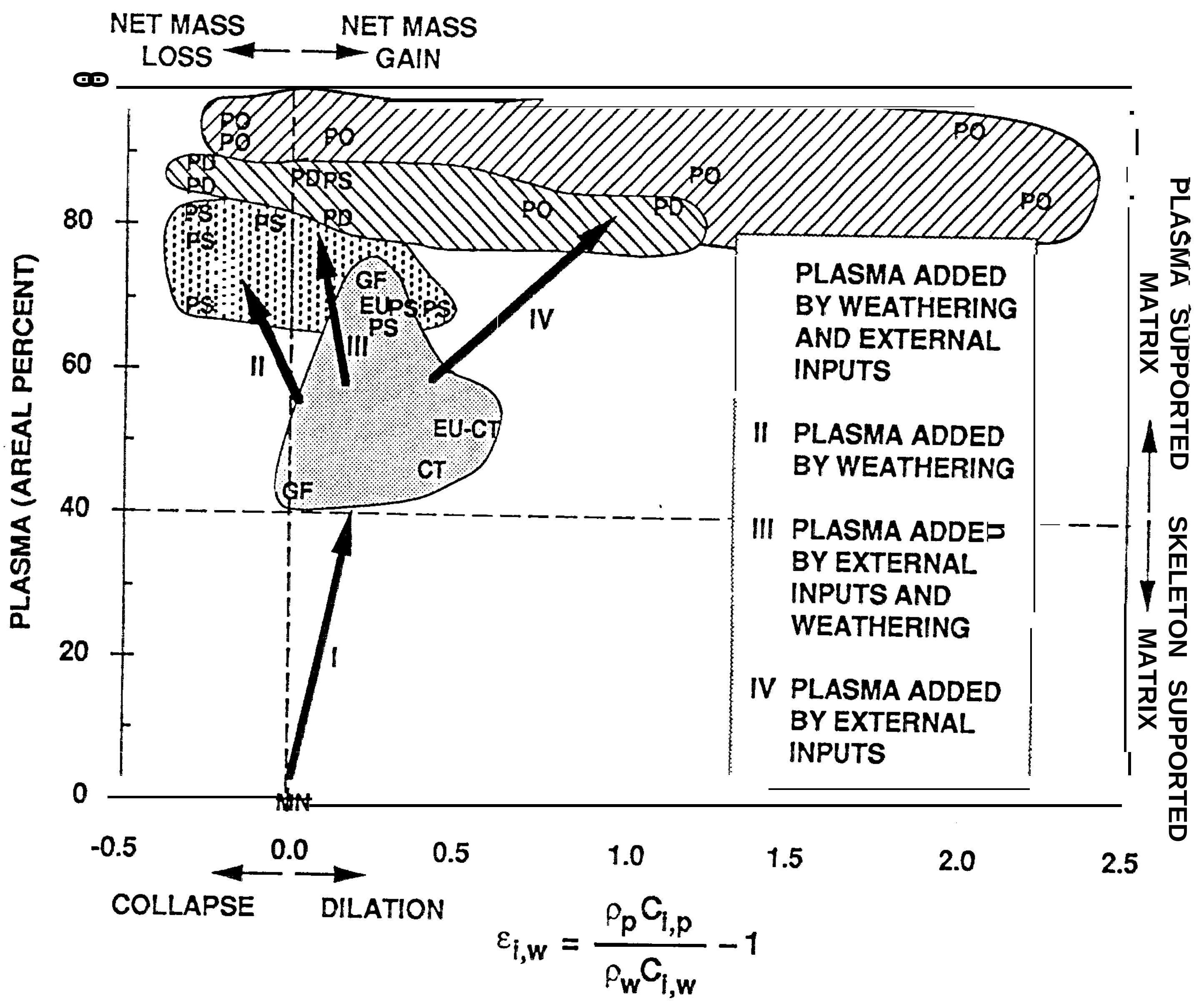
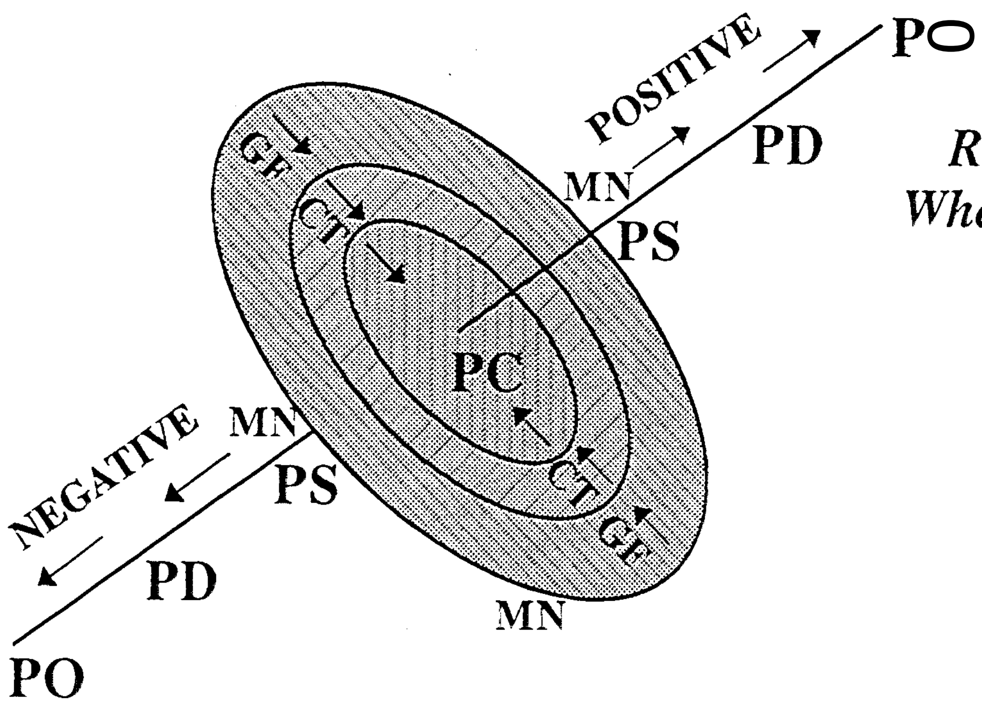

NET MASS LOSS
NET MASS GAIN
PLASMA (AREAL PERCENT)
80
60
40
20
0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
COLLAPSE
DILATION
ε_{i,w} = ρ_p C_{i,p} / ρ_w C_{i,w} − 1
PLASMA SUPPORTED MATRIX
SKELETON SUPPORTED MATRIX
PO
PD
PS
GF
EU
CT
EU-CT
NN
I
II
III
IV
I PLASMA ADDED BY WEATHERING AND EXTERNAL INPUTS
II PLASMA ADDED BY WEATHERING
III PLASMA ADDED BY EXTERNAL INPUTS AND WEATHERING
IV PLASMA ADDED BY EXTERNAL INPUTS

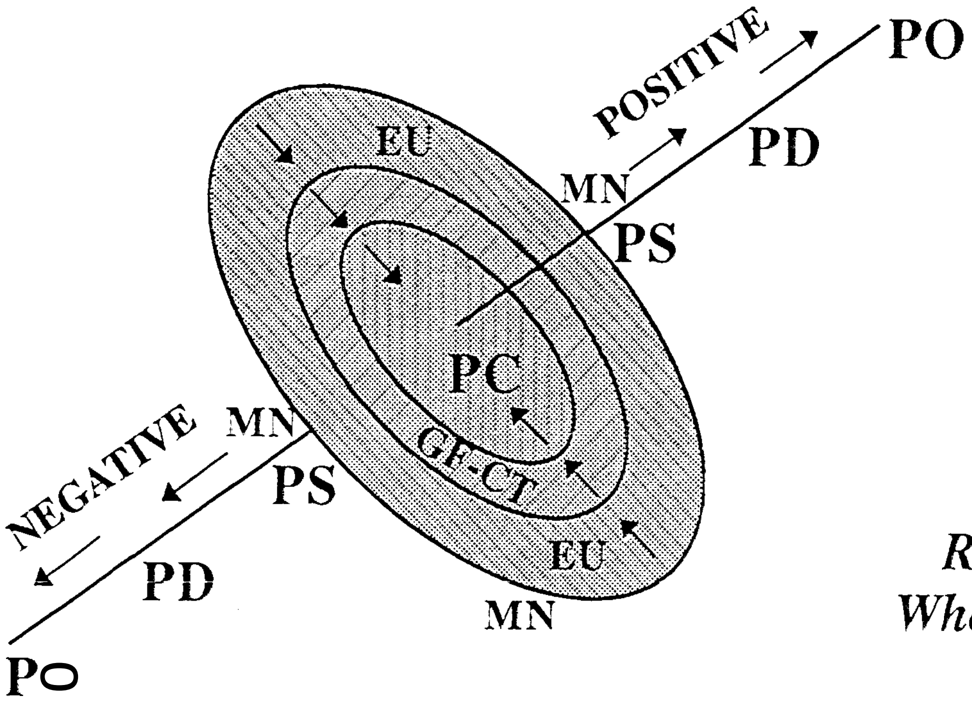
Figure 1



Related Distribution Patterns
Where Cohesive Forces Dominate

KEY

MN = Monic
GF = Gefuric
CT = Chitonic
EU = Enaulic
GF-CT = Gefuric-Chitonic
PC = Close Porphyric
PS = Single-Space Porphyric
PD = Double-Space Porphyric
PO = Open Porphyric
→ = Direction of volume change, positive or negative as shown



Related Distribution Patterns
Where Adhesive Forces Dominate