

THE SOLID PHASE

In this section we will examine the functional properties of the soil solid phase. The solid phase includes: **rock and mineral fragments, secondary minerals, and organic materials.** These materials are derived from parent material via fragmentation and weathering, aerial deposition of mineral and organic particles, and through the biosynthesis and decomposition of plant and animal tissue.

Our major interest is in the reactive materials with a high surface area, but we will begin with a brief description of the organization and properties of the larger mineral fragments followed by a discussion of the organic materials in soils.

Inorganic Materials

Composition - Not to surprisingly, soils reflect the materials from which they are made. Parent material for the mineral fraction of soils are normally the primary aluminosilicate minerals. As the name implies, these minerals are made from aluminum, silicon and oxygen. Taken together these elements account for approximately 82 % of the earth's crust by weight. On a mass basis, the importance of O, and Si is easily appreciated. The average composition of the earth's crust is given below.

Average chemical composition of the earth's crust

Element	% by weight	Element	% by weight
O	46.5	Ca	3.6
Si	27.6	Mg	2.1
Al	8.1	Na	2.8
Fe	5.1	K	2.6

In soil minerals, both Si and Al are found as small, highly charged cations (Al^{3+} and Si^{4+}), which coordinate with the larger O anion (O^{2-}) to form silica tetrahedron and the aluminum octahedron. In both of these structures, the small central ions are surrounded by either four or six O^{2-} or OH^- . In essence this "hides" the cations and exposes the O or OH groups to solution. On a volume basis, the larger anions dominate the soil forming minerals and also soil minerals.

OXYGEN DOMINANCE IN SILICATE MINERALS

Element	O	Si	Al	K
Mineral	VOLUME %			
Quartz	98.7	1.3		
K - feldspar	87.1	0.9	0.9	11.1
Muscovite - mica	89.9	0.6	1.9	7.6

Consequently, the surface chemistry in soils is dominated by the reactions that occur on oxide and hydroxide- rich surfaces. These surfaces are extremely hydrophilic and therefore are always bathed in layers of adsorbed water molecules surrounded by varying volumes of "bulk" water. Adsorbed water has properties that differ from bulk water.

In this section we will examine the architecture of important soil minerals and soil forming minerals. First we will begin with the primary minerals and then progress to the secondary layer silicates and oxy-hydroxides.

Primary Minerals in Soils

Primary minerals are made from the building blocks of Al octahedra and Si tetrahedra. Differences in minerals are related to the way in which these elements are arranged and how they share edges or faces and compensate for the charges in the minerals.

Primary minerals are formed in high temperature and high pressure environments from the elements which are most abundant. As we have already seen, O, Si, Al, are most abundant. From a structural view, they are arranged in either tetrahedral or octahedral structures. Whether octahedra or tetrahedra form depends on the size of the cation and anion and has been related to the radius ratio. In general the ratio $r_{\text{central}}/r_{\text{coordinated}}$ determines crystal geometry, however for soil forming minerals, oxygen anions are so common that the ratio $r_{\text{M}^+}/r_{\text{O}^-}$ is the important consideration. The coordination is essentially the number of oxygens or hydroxides that can crowd around a central cation with out excessive repulsion. The size effect is formalized in the Goldschmidt Radius Ratio. The electrical attraction between the cation and the anion is defined by Coulomb's Law. As long as the ions of opposite charge are separated, the system has energy that can be extracted by moving the ions closer together until they touch. As the ions touch, the system energy is a minimum because moving the nuclei closer together must deformed the atoms and this would require energy.

Coordination in soil minerals with different cations and oxygen expressed as the Goldschmidt ratio r_c/r_o ,
from Pauling 1960, Ahrens 1952 and Schulze 1989.

Three fold Coordination $r_c/r_o = 0.155 - 0.225$		Four-fold Coordination $r_c/r_o = 0.225 - 0.414$		Six-fold Coordination $r_c/r_o = 0.414 - 0.732$		Eight-fold Coordination $r_c/r_o > 0.732$	
B ³⁺	0.16	Be ²⁺	0.25	Al ³⁺	0.36	Sr ²⁺	0.80
		P ⁵⁺	0.25	Fe ³⁺	0.46	La ³⁺	0.81
		Si ⁴⁺	0.30	Fe ²⁺	0.53	Pb ²⁺	0.86
		Al ³⁺	0.36	Mn ³⁺	0.47	K ⁺	0.95
				Mn ²⁺	0.57	Ba ²⁺	0.96
				Mg ²⁺	0.47		
				Ca ²⁺	0.71		
				Zn ²⁺	0.52		
				Li ⁺	0.49		
				Na ⁺	0.69		
				Pb ⁴⁺	0.60		

Pauling, L. 1960. *The Nature of the Chemical Bond*, 3rd. Ed. Cornell University Press. Ithaca, NY. 644 pp.

Ahrens, L.H. 1952. *The use of ionization potentials*. *Geochim. Cosmochim. Acta*. 2: 155 - 169.

Schulze, D.G. 1989. *An Introduction to Soil Mineralogy*. In. *Minerals in Soil Environments*. 2nd Ed. J.B. Dixon and S.B. Weed Eds. Soil Sci. Soc. America. Madison, Wisc. pp. 1244

Note that Al can be found in both four-fold and six-fold coordination. Four and six-fold coordination result in geometric figures represented by a tetrahedron and an octahedron respectively. These geometric units are the basic building blocks for most primary and secondary soil minerals.

Common Soil Forming Primary Minerals

Rocks are an assemblage of primary minerals in a more or less consistent proportion. Figure 2.1 shows the mineralogical composition of rocks based on mineralogy and crystal size. Minerals in these rocks are composed of silica tetrahedra and aluminum octahedra. In some of the silica tetrahedra, Si is replaced by Al and the charge deficit is balanced by monovalent or divalent cations. Similarly, in the octahedra, Al may be replaced by Mg or other divalent cations. This replacement also generates a charge deficit that must be balanced by cations that are not an integral part of the octahedral or tetrahedral network.

Arrangement of the silica tetrahedra and the sharing of oxygen among tetrahedra is used to classify primary minerals. A classification scheme, based on the arrangement of silica tetrahedra, is outlined below. In addition to being a useful system of classification, the sharing of oxygens and the resulting structures are correlated with the ease of weathering. A greater number of shared oxygens and more covalent linkages in the minerals are associated with a greater resistance to weathering. Weathering rates are also correlated with the temperature of precipitation in melts. Figure 2.2 depicts the relationship between mineral formation and temperature in melts.

Figure 2.1. Classification of rocks based on mineral composition and texture.

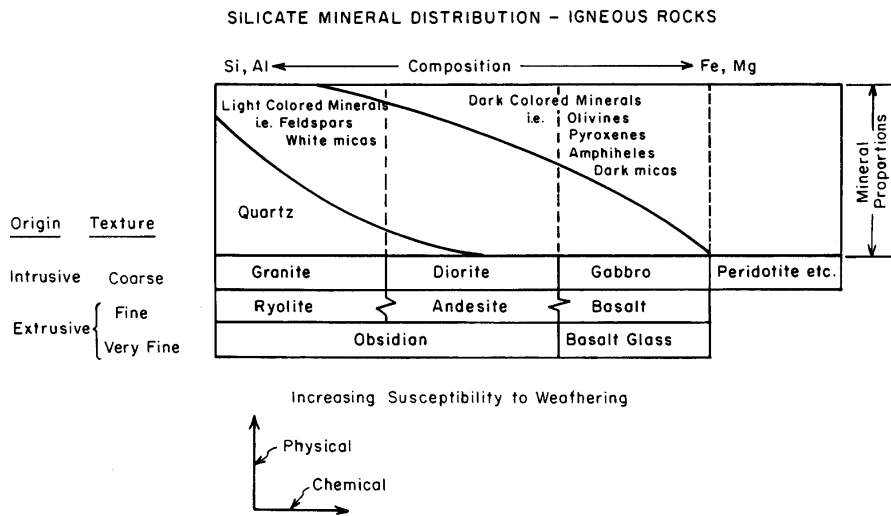
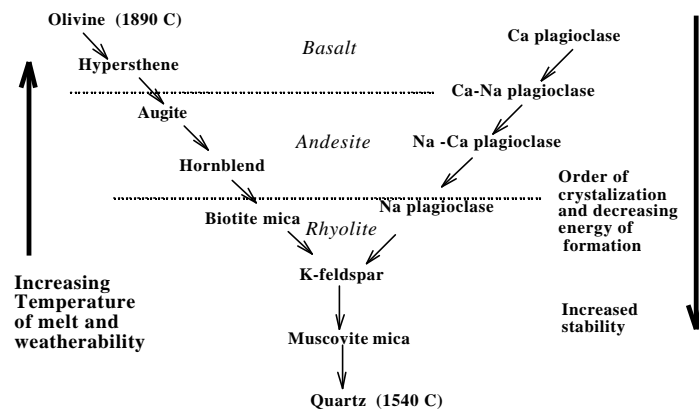


Figure 2.2 The arrangement of minerals in relation to temperature of precipitation in melts. Modified from Goldich, 1938 and Bohn et al. 1985.



SOIL MINERALS ACCORDING TO STRUCTURAL ARRANGEMENT OF TETRAHEDRA

A. Independent tetrahedra (nesosilicates)

1. Olivines (Fe,Mg)₂ SiO₄
 - a. Isomorphous series end-members
 1. fayalite Fe₂SiO₄
 2. forsterite Mg₂SiO₄
 - b. Compact, physically strong
 - c. Chemically reactive because Fe and Mg are readily exposed at crystal faces.
 - d. Alter to serpentine, magnetite, goethite, magnesite, opal.

B. Chains of tetrahedra (inosilicates)

1. pyroxenes - single chains
 - a. augite (Na, Ca)(Fe,Mn,Zn,Mg)(Si,Al)₂O₆
2. amphiboles - double chains
 - a. hornblende (Ca,Na)_{2.26}(Mg,Fe,Al)_{5.15}(Si,Al)₈ O₂₂(OH)₂
3. weathering proceeds parallel to chains

C. 3-dimensional network of tetrahedra (tectosilicates) with each oxygen bonded to 2 Si atoms

1. Quartz - SiO₂ - 3-dimensional network of tetrahedra with no Al proxying
2. feldspars - Al proxying for Si, $1/4 < \text{Al/Si} + \text{Al} < 1/2$
 - a. plagioclase feldspars
 1. albite, ... anorthite mineral series
 2. albite NaAlSi₃O₈
 3. anorthite CaAl₂Si₂O₈
 - b. potassic feldspars
 1. orthoclase, microcline - KAlSi₃O₈

D. 2-dimensional sheets of tetrahedra and octahedra (phyllosilicates)

1. mica – primary minerals but may be found in the <2 um fraction of soils and are therefore clay sized.
 - a. No proxying in octahedral or tetrahedral sheets, & no "charge balancing" cations -- pyrophyllite (D), Talc (T)

D forms are dioctahedral; 2 out of 3 octahedral positions occupied by the "coordinating" cation, usually Al³⁺

T forms are trioctahedral; 3 out of 3 octahedral positions occupied by the "coordinating" cation, usually Mg²⁺ or Fe²⁺
 - b. proxying of Al for Si in tetrahedral sheet, muscovite (D), biotite (T)
2. Secondary sheet minerals - "clays"
 - a. 1:1 Tetrahedral to Octahedral sheets (Kandites)
 - b. 2:1 Tetrahedral to Octahedral sheets (Smectites)
 - c. 2:1:1 or 2:2 Tetrahedral to octahedral sheets (Chlorites)
3. Amorphous materials
4. Zeolites
- 5.. Allophane and imogolite
6. Interstratified minerals

LAYER SILICATE NOMENCLATURE***I. One to one layer silicates (1:1)**

- A. Kaolin (kandite) group $(\text{Si}_4)^{\text{IV}}(\text{Al}_4)^{\text{VI}}\text{O}_{10}(\text{OH})_8$
1. Dioctahedral
 - a. Kaolinite
 - b. Metahalloysite
 - c. Halloysite $(\text{Si}_4)^{\text{IV}}(\text{Al}_4)^{\text{VI}}\text{O}_{10}(\text{OH})_8 \cdot 4 \text{H}_2\text{O}$
- B. Serpentine group $(\text{Si}_4)^{\text{IV}}(\text{Mg}_6)^{\text{VI}}\text{O}_{10}(\text{OH})_6$
1. Trioctahedral
 - a. Antigorite
 - b. Crysotile
 - c. Lizardite

II. Two to one layer silicates (2:1)

- A. Montmorillonite (smectite) group
1. dioctahedral
 - a. Montmorillonite $\text{X}_{0.66}(\text{Si}_8)^{\text{IV}}(\text{Al}_{3.34}\text{Mg}_{0.66})^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 - b. Biedellite $\text{X}_{0.66}(\text{Si}_{7.34}\text{Al}_{0.66})^{\text{IV}}(\text{Al}_4)^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 - c. Nontronite $\text{X}_{0.66}(\text{Si}_{7.34}\text{Al}_{0.66})^{\text{IV}}(\text{Fe}_4^{3+})^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 2. Trioctahedral
 - a. Saponite $\text{X}_{0.66}(\text{Si}_{7.34}\text{Al}_{0.66})^{\text{IV}}(\text{Mg}_6)^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 - b. Hectonite $\text{X}_{0.66}(\text{Si}_8)^{\text{IV}}(\text{Mg}_{5.34}\text{Li}_{0.66})^{\text{VI}}\text{O}_{20}(\text{OH})_4$
- B. Vermiculite group
1. Dioctahedral
 2. Trioctahedral $\text{X}_{0.7-1}(\text{Si}_{6-5.6}\text{Al}_{2-3.5})^{\text{IV}}(\text{Mg}_{3.5-6}\text{Fe}^{3+}, \text{Al}_{2.5-1})^{\text{VI}}\text{O}_{20}(\text{OH})_4$
- C. Mica group
1. Dioctahedral
 - a. Muscovite $\text{K}_2(\text{Si}_6\text{Al}_2)^{\text{IV}}(\text{Al}_4)^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 - b. Margarite $\text{Ca}_2(\text{Si}_4\text{Al}_4)^{\text{IV}}(\text{Al}_4)^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 2. Trioctahedral
 - a. Biotite $\text{K}_2(\text{Si}_{6-5}\text{Al}_{2-3})^{\text{IV}}(\text{Mg}, \text{Fe}^{2+}, \text{Al})_6^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 - b. Clintonite $\text{Ca}_2(\text{Si}_{2.5}\text{Al}_{5.5})^{\text{IV}}(\text{Mg}, \text{Al})_6^{\text{VI}}\text{O}_{20}(\text{OH})_4$
- D. _____ group
1. Dioctahedral
 - a. Pyrophyllite $(\text{Si}_8)^{\text{IV}}(\text{Al}_4)^{\text{VI}}\text{O}_{20}(\text{OH})_4$
 2. Trioctahedral $(\text{Si}_8)^{\text{IV}}(\text{Mg}_6)^{\text{VI}}\text{O}_{20}(\text{OH})_4$

III. Two to two layer silicates (2:2 or 2:1:1)

- A. Chlorite group $(\text{Mg}, \text{Fe}, \text{Al})^{\text{IV}}(\text{OH})_{12}(\text{Si}, \text{Al})^{\text{VI}}(\text{Mg}, \text{Al}, \text{Fe})_6^{\text{VI}}\text{O}_{20}(\text{OH})_4$

IV. Short range order aluminosilicates

- A. Allophane
- B. Imogolite

* Modified from Dr. L. Whittig handouts

Important Mineral Surfaces in Soils

Soil minerals are important because they may have high surface area (colloids) and because they furnish ions to solution either via dissolution or because they are charged and participate in "exchange" reactions. For these reasons we need to know which soil minerals are important and their properties. Important soil minerals are listed below along with their surface area, cation exchange capacity (CEC), and type of charge developed.

Important soil minerals and their properties.

Layer silicates Minerals	Surface Area	CEC*	Charge type**
Kaolinite	10 - 20	10 - 150	PD?
Montmorillonite	600 - 800	900 - 1200	PERM, PD
Vermiculite	600 - 800	1200 - 1500	PERM, PD
Chlorites	70 - 150	100 - 400	PERM,PD
Oxides & Hydrous Oxides			
Aluminum	20 - ?	var	PD
Iron	2 - 200	var	PD
Manganese	30 - 500	var	PD
Amorphous silicates			
Allophane	145 -	200 -700	PD
Imogolite	1000	200 - 700	PD
Organic materials			
Organics		1000 - 4000	PD

* CEC = cation exchange capacity (mmol(+) kg⁻¹)

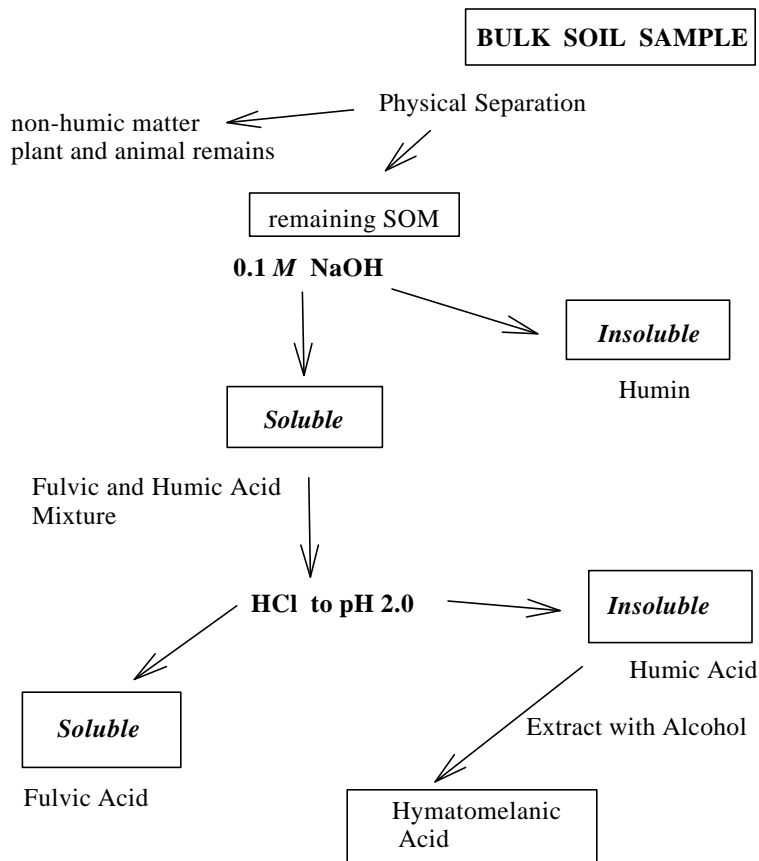
** PD = pH dependent charge, PERM = structural permanent charge

Organic Materials

Organic matter in soil comes from several sources including plants and animals as well as the decomposition products from these sources. Other sources include airborne dusts, and applied chemicals. In soils the wide array of organic materials exists in different particle sizes with different degrees of decomposition and this translated into organics with differing solubilities and functional grouping. Soil organics may be separate discrete phases or they may be intimately associated with mineral surfaces.

The classical separation or extraction of soil organic matter is shown in the diagram below in which a soil sample is faced with strong base and shaken under nitrogen. The soluble phase is filtered and acidified to pH 2 with mineral acid. The soluble phase remaining after acidification is called **fulvic acid** and the insoluble phase is called humic acid. These are operationally defined fractions of the soil organic matter. As might be expected fulvic and humic acids have different properties to complement their differences in solubility.

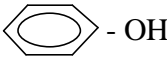
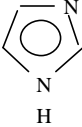
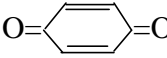
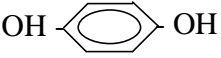
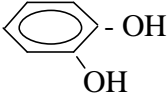
Figure 2.2. Fractionation scheme for soil humic substances.



Fulvic and humic acids are not specific compounds, but mixtures of different compounds of varying molecular weight and properties. Generally speaking, fulvic acids are lower in molecular weight and more highly oxidized than humic acids. Although the structure of fulvic and humic acid are unknown, a good deal of research has found that both of these polymers contain a number of important functional groupings that influence soil properties and reactions such as cation exchange, buffering, chelation and adsorption.

Function Groups on SOM

Important Functional Groups in Humic Substances

Amino	$R - NH_2$	Ether	$R-CH_2-O-CH_2-R'$
Amide	$R - \overset{\text{O}}{\parallel} C - NH_2$	Ester	$R-C-O-R'$
Amine	$R - CH_2NH_2$	Alcoholic OH	$R-OH$
Aldehyde	$R-HC = OH$	Phenolic OH	 - OH
Carbonyl	$R - \overset{\text{O}}{\parallel} C - R'$	Imidazole	
Carboxyl	$R - \overset{\text{O}}{\parallel} C - OH$	Quinone	
Enol	$R - \overset{\text{O}}{\parallel} C = CH - OH$	Hydroquinone	
Ketone	$R - \overset{\text{O}}{\parallel} C - R'$	Catechol	
Keto Acid	$R - C - COOH$		
Imino	$= NH$		
Imine	$R - CH = NH$		

CHARGE DEVELOPMENT

One of the most important aspects of soil colloids is the charge that they carry. This charge is either; 1) a permanent aspect of the mineral which was incorporated during formation or subsequently modified by weathering or 2) a charging of the surface O or OH groups as solution pH changes. The former is called permanent charge and the latter is called pH dependent charge. Among the common soil minerals, only the layer silicates (excluding kaolinite) have permanent charge. This charge arises by atomic proxying in the structure where a cation of lower charge substitutes for either Si^{4+} or Al^{3+} in octahedral or tetrahedral positions. This substitution results in a charge deficit (fewer cationic charges compared to anionic charges) and negative charge on the clay which is directly dependent on the amount

of substitution. In addition to the permanent charge layer silicate clays and the other soil solids can develop charge by protonation or deprotonation of the surface O and OH groups. Since this pH dependent charge is a protonation or deprotonation reaction it can be described by standard methods used in acid base chemistry. The restriction on this approach is the knowledge of the dissociation constant for the surface O or OH species which will vary with the coordination number and the coordinating cation as well as the salt content of the bathing solution.

As a first approximation to estimating the dissociation of the surface group and solution acids we may use the well known Henderson - Hasselbalch equation that has been used extensively to evaluate and make pH buffer solutions. (*The derivation is given in appendix 2 - a*)

$$\text{pH} = \text{pK}_{\text{diss}} - \log \frac{(\text{HA})}{(\text{A}^-)}$$

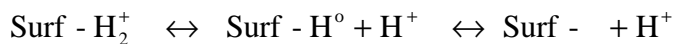
HA is the protonated form of a simple acid and A⁻ is the conjugate of the acid. pK_{diss} is the log of the acid dissociation constant.

Surface Charge

Knowing K_{diss} one may calculate the fraction of dissociated sites on surfaces and infer something about the charge characteristics of the colloid. But it is also possible to protonate a surface group generating a positive charge as illustrated below.



Combining the dissociation and association reactions for surface sites (S^{\cdot}) shows that surface charge depends on pH or $[H^+]$ and the number of surface sites (S) which are protonated or deprotonated.



The total number of sites (capacity) and the dissociation constants for the reactions vary from mineral to mineral. Figure 2.4 illustrates the effect of pH on the charge of a layer silicate edge. The same reactions can occur on any hydroxyl or oxide surface such as iron and aluminum oxides. It is important to note that the solution pH is not controlled by the association or dissociation of the edge, but is imposed by some other external control.

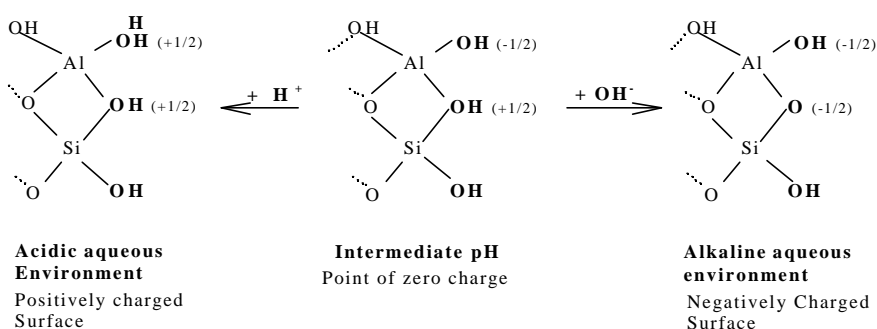
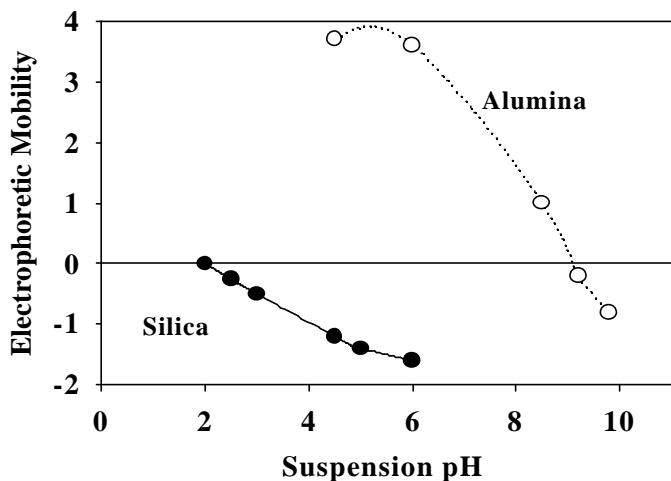


Figure 2.4. Charge development on clay edges in relation to solution pH.

Surface charge can be demonstrated experimentally by electrophoresis. In this technique, colloids are suspended between two electrodes charged to a given potential. The migration velocity direction of the particles in the electric field can be observed. Figure 2.5 is a graph of the migration velocity of silica and alumina particles in solutions of differing pH. At low pH the colloid is positively charged, while at high pH the particles exhibit a negative charge. The point where the "net" charge is zero is termed the **zero point of charge (zpc)**. It may also be called the point of zero charge (pzc). As the particles' net charge change from positive to negative, the particles are said to exhibit a **charge reversal**.

Charge reversal and charge are dependent on the acid strength of the oxide/hydroxide minerals or surface groups. Acid strength is determined by the coordinating cation, crystallinity of the mineral and other factors. Alumina and silica have zpc's which differ by 7 pH units. These differences in charge characteristics are important variables affecting exchange reactions and sorption from soil solutions.

Figure 2.5. *The electrophoretic mobility of alumina and silica in suspension of differing pH.* Taken from D. Stiger (1975). *Physical Chemistry: Enriching topics from Colloid and Surface Science.* H. van Olphen and K. J. Mysels ed. Theorex, La Jolla, Ca. page. 304.



The point of zero charge for several soil minerals varies from about 2 to 9 as shown.

Mineral	PZC
Aluminum oxide	9.1
Aluminum trihydroxide	5.0
Iron Oxide	6 – 8
Manganese oxides	
Birnessite	1.8 – 2.5
Pyrolusite	7.3
Hausmannite	7.3
Silicon oxide	2.0
Kaolinite	4.5
Montmorillonite	2.5

Soil organic materials develop charge wholly by ionization of functional groups. Among the most important groups are the carboxyl, hydroxyl, phenolic, and amino acid. Figure 2.6 and 2.7 show how CEC (soil charge) of several soils and organic C to changes in relation to solution pH.

Figure 2.6. The cation exchange capacity of soils in relation to pH. From Pratt and Bair. *Hilgardia* 33:695.

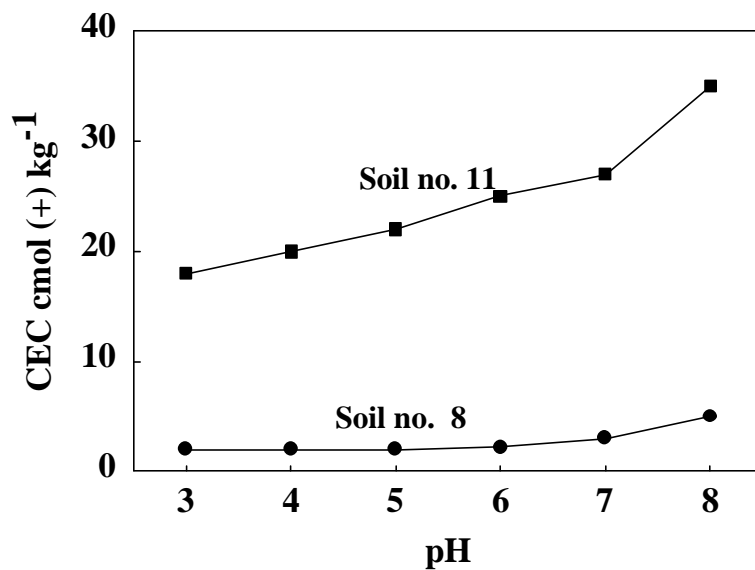
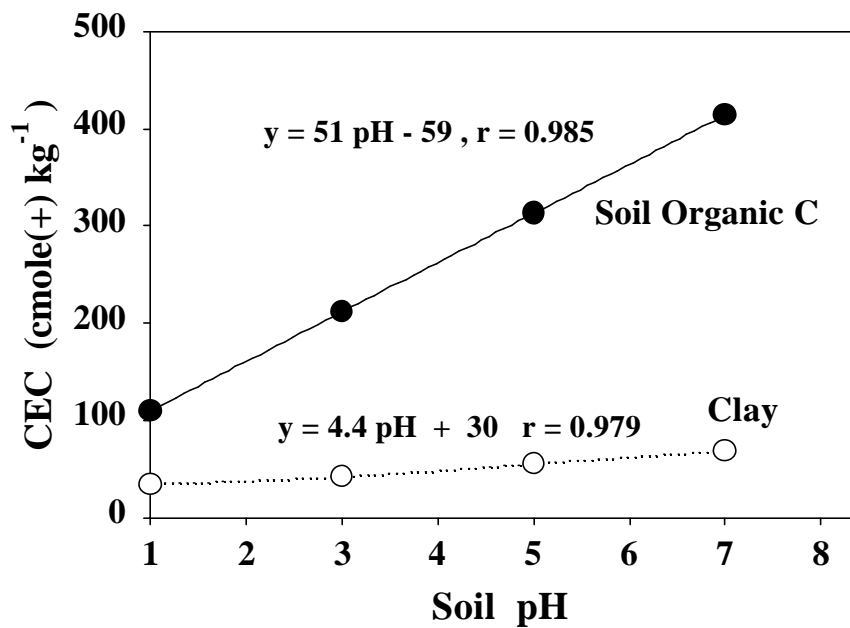


Figure 2.7. Cation exchange capacity of clay and soil organic matter in relation to pH. From Helling, et al. *Soil Science Society of America Proceedings*. 28:517-520.



Appendix 2-a. Derivation and application of the Henderson Hasselbach Equation

We will derive this equation for the monoprotic acid HA. The equilibrium reaction is:



Assuming the equilibrium constant for the reaction is known:

$$K_{diss} = \frac{(\text{H}^+)(\text{A}^-)}{\text{HA}} \quad (2)$$

Since the relationship to pH is required, we first solve for H^+ :

$$(\text{H}^+) = \frac{K_{diss}(\text{HA})}{(\text{A}^-)} \quad (3)$$

taking the logarithm of both sides:

$$\log (\text{H}^+) = \log K_{diss} + \log \frac{(\text{HA})}{(\text{A}^-)} \quad (4)$$

multiplying by -1 gives:

$$-\log(\text{H}^+) = -\log K_{diss} - \log \frac{(\text{HA})}{(\text{A}^-)} \quad (5)$$

defining $-\log [X]$ as pX and remembering that $-\log \text{H} = \text{pH}$ we have the final result

$$\text{pH} = \text{p}K_{diss} - \log \frac{(\text{HA})}{(\text{A}^-)} \quad (6)$$

This relationship is quite useful because if the pK of the acid is known, the ratio of the dissociated species (A^-) to HA can be estimated. Note that this ratio changes by a factor of 10 for each unit change in pH. Thus, the ratio changes by a factor of 10 for each pH unit increase or decrease. If the pH equals the pK then the ratio is 1 and the term is equal to zero. When $\text{pH} = \text{p}K$, there is an equal molar mixture of the protonated and deprotonated forms of the acid. Regardless of the complexities of a solution, this relationship will always be true. If the dissociation constants of a polyprotic acid are different by at least a factor of 100, the simple monoprotic relationship can be applied to the individual dissociation steps.

REVIEW QUESTIONS

1. Aluminosilicates dominate the solid phase of most soils. Why is this observed? What other secondary minerals would you expect in soils? What are the charge characteristics of these groups?
2. Loosely speaking, a ion in soil solution sees the world as a monotone of oxygen and/or hydroxyls. Why is the world of the cation so restricted?
3. How do soil minerals develop positive and negative charge?
4. Why does oxygen occupy such a large volume in soil minerals?
5. How does the pK of edge groups relate to charge on clays?
6. What is the Henderson-Hasselbalch Equation? How can it be used to find protonated or deprotonated species?
7. What are the most important functional groups in SOM?
8. What happens to the charge on soil minerals as pH increases?
9. Why do some clays shrink and swell while others do not?
10. Soils formed from ultrabasic materials are higher in clays, Ca, Mg, and Fe than those formed from acid igneous rocks. Why?
11. Mica has a balancing cation ratio of 2 per formula as we discussed it, while vermiculite has a ratio of 0.7 to 1.0 per formula and smectites have a ratio of 0.66 per unit. What does this mean in terms of exchange capacity and potential exchange capacity?
12. Does atomic proxying always develop a charge imbalance?
13. What are allophane and imogolite? What types of soils often contain these minerals?
14. Highly weathered tropical soils, are high in gibbsite and iron and relatively low in silica. What would explain this observation?
15. How is Bragg's Law used to distinguish among the various layer silicates?
16. What factors affect the stability of primary minerals?
17. Chlorites have less exchange capacity than the 2:1 minerals that they resemble. Why? soil particle size decreases, the proportion of primary minerals to secondary minerals decreases. Why?
18. What are the ways that silica tetrahedra can be arranged in primary and secondary minerals?
19. At high pH the electrophoretic mobility of Goethite is negative and it is positive at low pH, while the electrophoretic mobility of montmorillonite is negative at both high and low pH. Why?
20. What is fulvic and humic acid? Humin?

21. What are some major differences between fulvic and humic acids?
22. How does the pK of edge groups relate to charge on clays?
23. Silica is usually found in four fold coordination while Al is most often in four fold coordination but may be found in six fold coordination. What affects this coordination number?
24. Gibbsite is a close packed arrangement of hydroxyls coordinated with aluminum. The octahedral sheet in clay minerals is not close packed. Why?
25. What is a chelate? Why is chelation important for soil organic matter?
26. What is the relationship between electrical conductivity and concentration?

TERMS

PZC	atomic proxying	isomorphous substitution	gibbsite
apical oxygen	octahedral	tetrahedral	EC
permanent charge	pH -dependent charge	electrophoretic mobility	Goethite
mica	kandite	smectite	chlorite
feldspar	pyroxene	amphibole	olivine
Henderson-Hasselbalch	2:2	2:1	1:1
smectities	kandites	Chlorites	Radius ratio
montmorillonite mica		Charge reversal	pK