Soils are more than a pile of dirt!

https://www.soils.org/stickers

Soils are an organized mixture of organic & mineral matter created by the interplay of five soil forming factors.

$$s = f\,(cl, o, r, p, t \ldots)$$

Jenny 1941

Two types of rock weathering

Two types of chemical weathering

$$\underbrace{2NaAlSi_3O_8}_{\text{Na- feldspar}} + 2H_2CO_3 + 9H_2O \Rightarrow \underbrace{2Na^+ + 2HCO_3^- + 4H_4SiO_4}_{\text{Soluble Components}} + \underbrace{AL_2SiO_5(OH)_4}_{\text{kaolinite}}$$

$$\underbrace{CaCO_3}_{\text{limestone}} + H_2CO_3 \Rightarrow \underbrace{Ca^{++} + 2HCO_3^-}_{\text{Soluble Components}}$$

Bowen Reaction Series

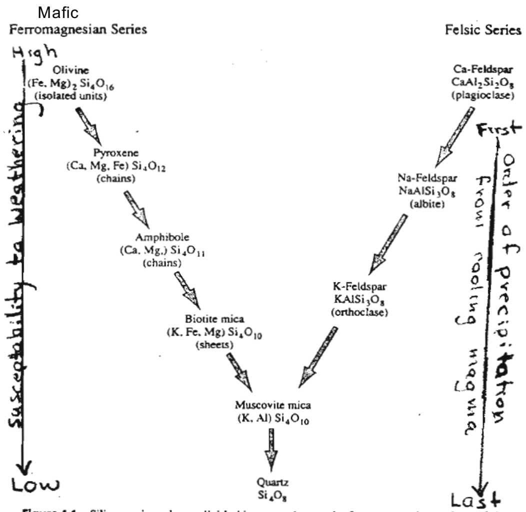


Figure 4.1 Silicate minerals are divided into two classes, the ferromagnesian series and the felsic series, based on the presence of Mg or Al in the crystal structure. Among the ferromagnesian series, minerals that exist as isolated crystal units (e.g., olivine) are most susceptible to weathering, while those showing linkage of crystal units and a lower ratio of oxygen to silicon are more resistant. Among the felsic series, Ca-feldspar (plagioclase) is more susceptible to weathering than Na-feldspar (albite) and K-feldspar (orthoclase). Quartz is the most resistant of all. This weathering series also follows the order in which these minerals are precipitated during the cooling of magma. Schlesinger 1991

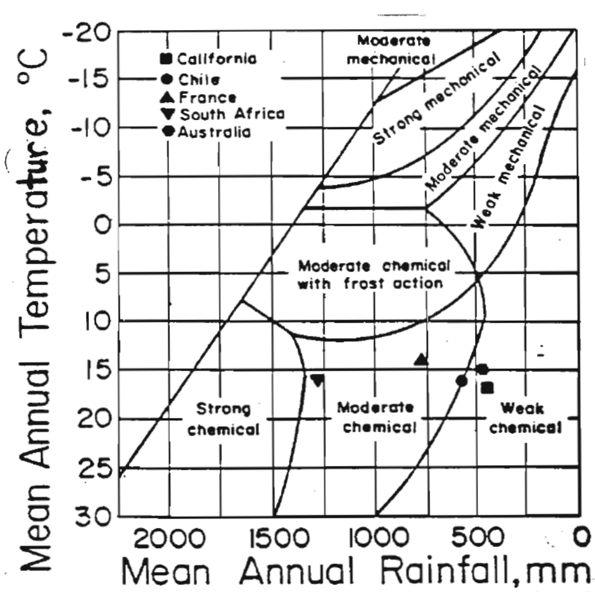


Figure 3--Relative mechanical and chemical weathering rates as influenced by mean annual temperature and rainfall (adapted from Peltier 1950).

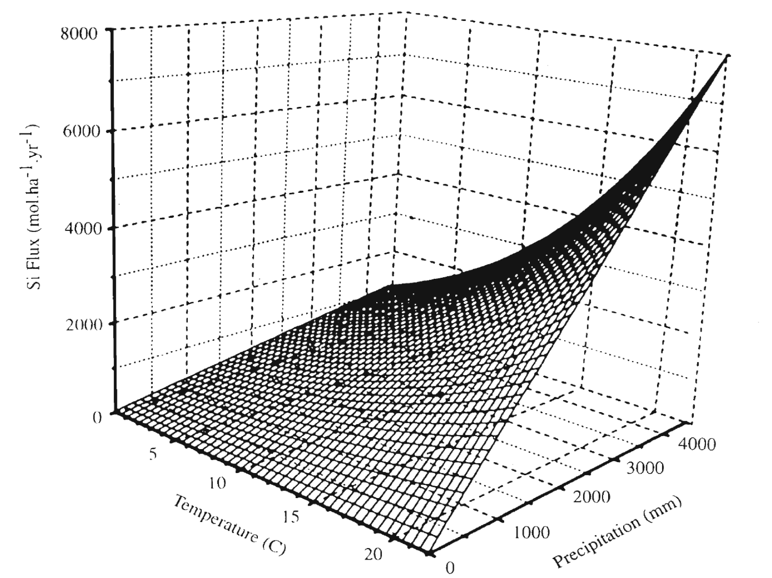


Figure 4.2 Loss of silicon (SiO_2) in runoff as a function of mean annual temperature and precipitation in various areas of the world. Modified from White and Blum (1995).

Table 4.8 Chemical and Mechanical Denudation of the Continents

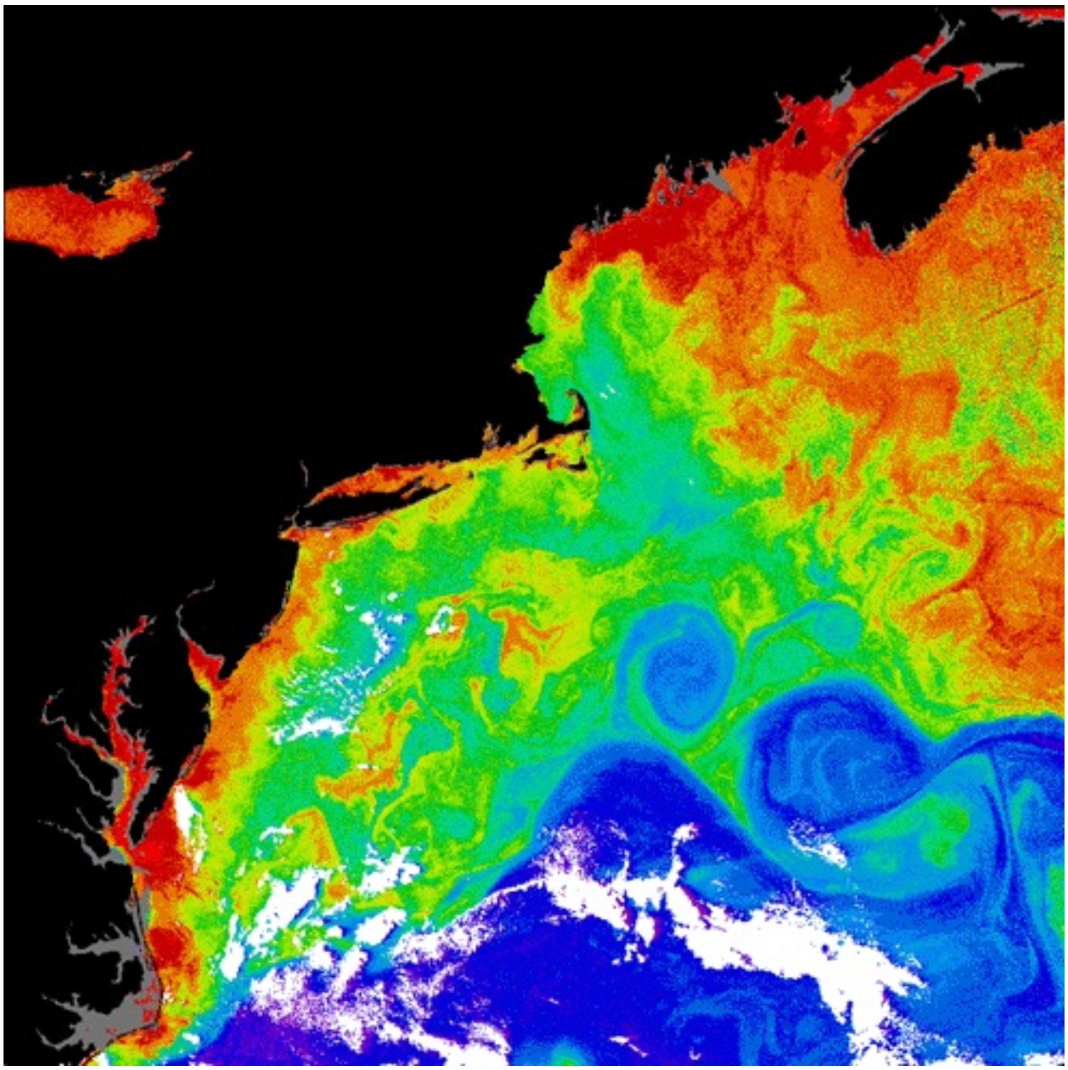
	Chemical Denudation[a]		Mechanical Denudation[b]		Ratio
Continent	Total (10^{14}g/yr)	Per Unit Area (Mg/km²/yr)	Total (10^{14}g/yr)	Per Unit Area (Mg/km²/yr)	Mechanica / Chemical
North America	7.0	33	14.6	84	2.1
South America	5.5	28	17.9	100	3.3
Asia	14.9	32	94.3	304	6.3
Africa	7.1	24	5.3	35	0.7
Europe	4.6	42	2.3	50	0.5
Australia	0.2	2	0.6	28	3.0
Total	39.3		135.0		3.4

[a] From Garrels and MacKenzie (1971).
[b] From Milliman and Meade (1983).

Schlesinger 1991

Categories of chemical reactions in soil

Denudation is a connection between the land and oceans



Composition & ways to classify soils

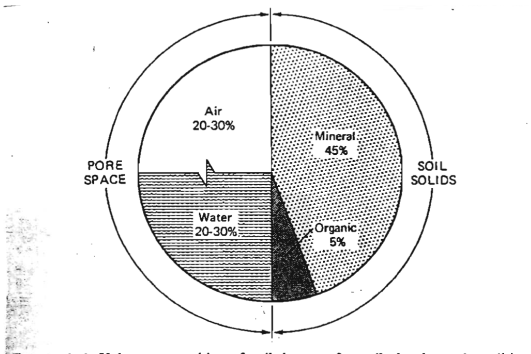


FIGURE 1:4. Volume composition of a silt loam surface soil when in good condition for plant growth. The air and water in a soil are extremely variable, and their proportion determines in large degree its suitability for plant growth. Brady 1974

Parent Material Source & Deposition Site

1. Sedentary	Still at original site	Residual
2. Transported	Gravity	Colluvial
	Water	Alluvial, Marine, Lacustrine
	Ice	Glacial
	Wind	Aeolian

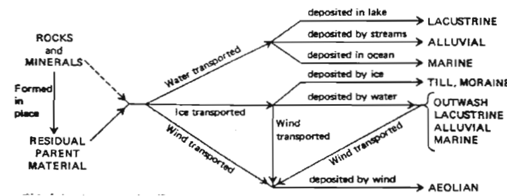


FIGURE 11:3. How various kinds of parent material are formed, transported, and deposited. Brady 1974

Soil Orders Defined by their Profiles

Table 20–1 Major orders of soil recognized by the U.S. Soil Conservation Service

Name	Description
Alfisols	(So named because of their content of aluminum, Al, and iron, Fe.) Quite well developed horizons, with a thin humus layer and bases accumulated in the B horizon. Includes the former gray-brown podzols.
Aridisols	(From the Latin *aridus*, dry.) Water unavailable to plants for long periods; little organic matter; may have clay, gypsum, or carbonate horizons, the carbonate horizon usually within 30 cm of the surface; high base content; reddish to light gray or brown. Includes the former red desert soils and sierozems.
Entisols	(From the Latin *ent-*, existing.) Lack horizons; dominated by mineral materials; young soils. Includes azonal and alluvial soils.
Histosols	(From the Greek *histos*, tissue.) Very high organic matter; brown. Includes half-bog and bog soils, peats, mucks.
Inceptisols	(From the Latin *inceptum*, beginning.) A chemically diverse group containing relatively young soils with little production and movement of clays; horizons not well developed; texture finer than that of loamy sand; humid climates. Includes the former weak podzols, humic gley, and brown forest soils.
Mollisols	(From the Latin *mollis*, soft.) Black or dark brown surface layer of soft or crumbly consistency; often deep; may have a clay or carbonate horizon; rich in bases. Found under semihumid grasslands and forests with well-developed understories. Includes the former chernozems, prairie soils, and rendzinas.
Oxisols	(From the French *oxyde*, oxide.) Old, highly weathered tropical soils; rich in iron oxides and hydeous aluminum silicate; sometimes rich in humus; low in silica. Includes the former laterites and some latosols.
Spodosols	(From the Greek *spodos*, wood ash.) Leaf litter over a humus-rich layer, beneath which is a light (often grayish or whitish) A_2 horizon. Below that is a reddish and black B horizon, the *spodic horizon*, rich in extractable aluminum and iron. Includes well-developed podzols.
Ultisols	(From the Latin *ultimus*, last.) Old soils of humid, usually warm climates; strongly leached, with much clay formed and moved to the B horizon; low base content. Includes the former red and yellow podzols, and some laterites and latisols.
Vertisols	(From the Latin *verto*, to turn.) Clay soils; dark in color; forming characteristic deep, wide cracks on drying. Includes the former grumosol and smolnitza.

Texture

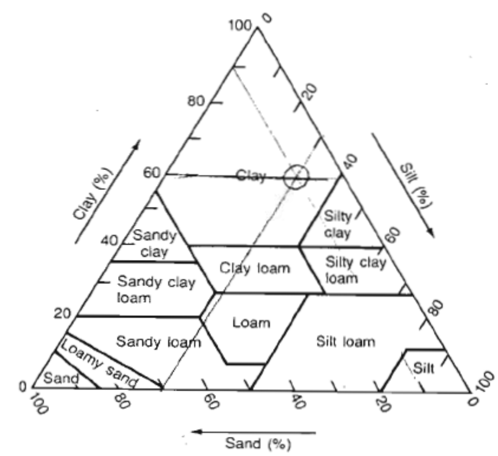
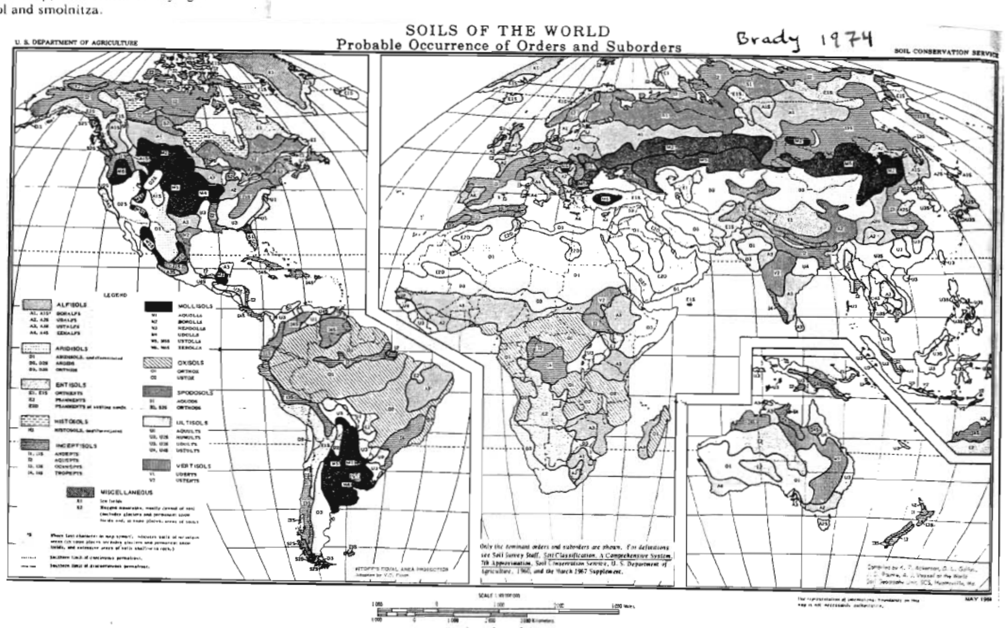


FIGURE 6-2

Soil classification by texture. (From Janick et al. Data from U.S. Department of Agriculture.)

Ehrlich et al. 1977



Soil texture is important because

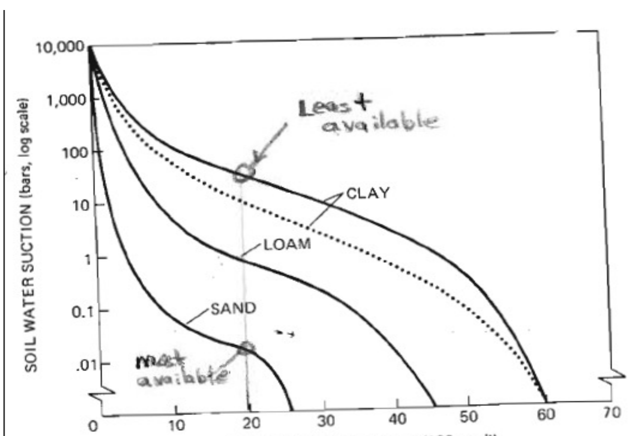
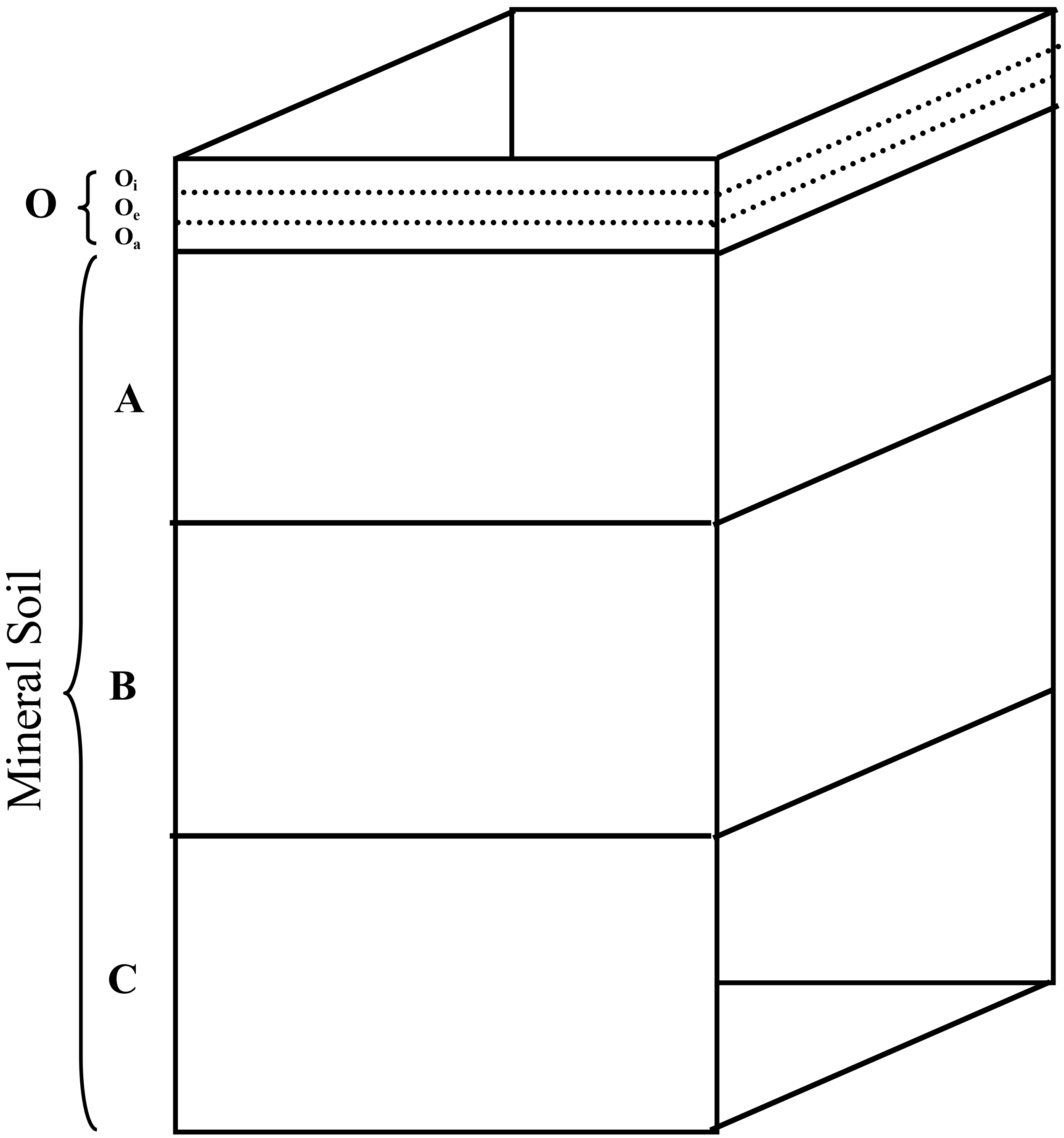
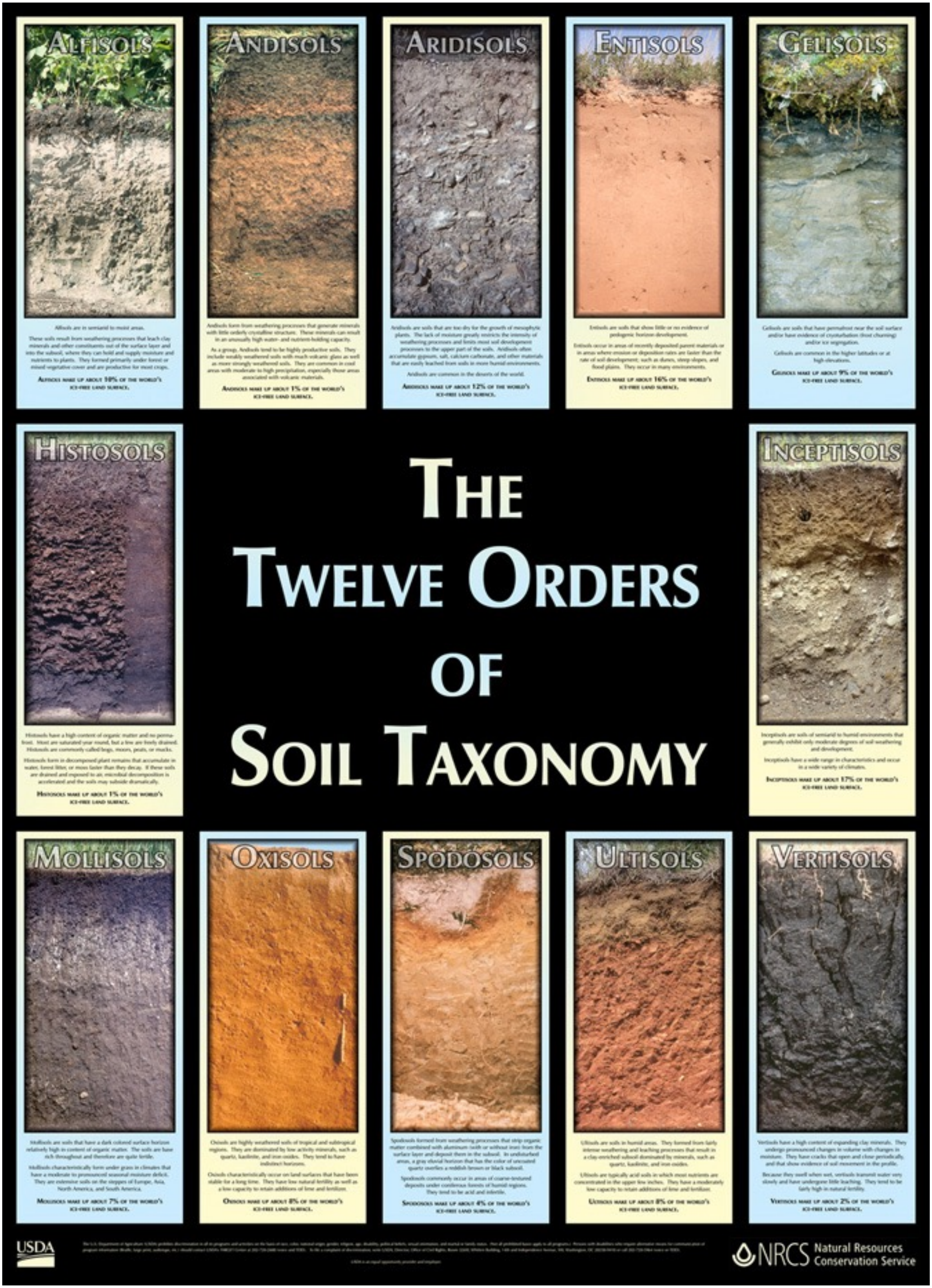
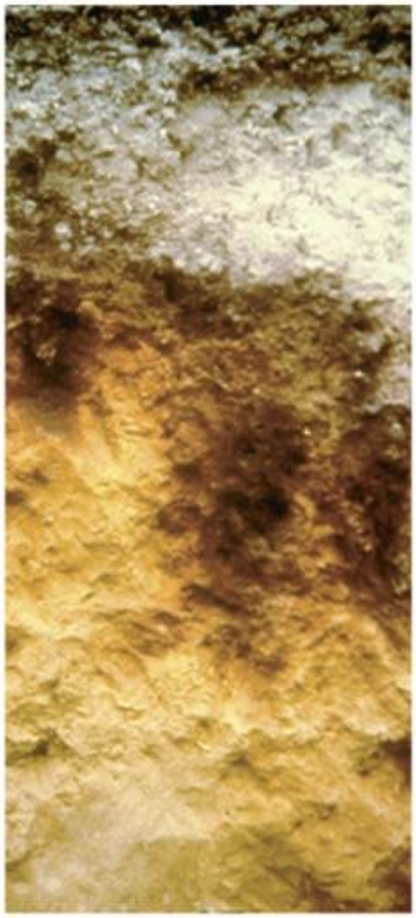


FIGURE 7:7. Soil moisture suction curves for three representative mineral soils. The solid lines show the relationship obtained by slowly drying completely saturated soils. The dotted line for the clay soil is the relationship expected when a dry soil is wetted. The difference between the two clay lines is due to *hysteresis*. Brady 1974

Soil profiles consist of horizontal layers called horizons



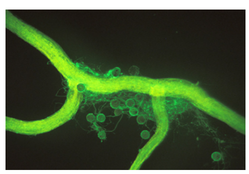

Alfisols
Alfisols are in semiarid to moist areas.
These soils result from weathering processes that leach clay minerals and other constituents out of the surface layer and into the subsoil, where they can hold and supply moisture and nutrients to plants. They formed primarily under forest or mixed vegetative cover and are productive for most crops.
Alfisols make up about 10% of the world's ice-free land surface.
Andisols
Andisols form from weathering processes that generate minerals with little orderly crystalline structure. These minerals can result in an unusually high water- and nutrient-holding capacity.
As a group, Andisols tend to be highly productive soils. They include weakly weathered soils with much volcanic glass as well as more strongly weathered soils. They are common in cool areas with moderate to high precipitation, especially those areas associated with volcanic materials.
Andisols make up about 1% of the world's ice-free land surface.
Aridisols
Aridisols are soils that are too dry for the growth of mesophytic plants. The lack of moisture greatly restricts the intensity of weathering processes and limits most soil development processes to the upper part of the soils. Aridisols often accumulate gypsum, salt, calcium carbonate, and other materials that are easily leached from soils in more humid environments.
Aridisols are common in the deserts of the world.
Aridisols make up about 12% of the world's ice-free land surface.
Entisols
Entisols are soils that show little or no evidence of pedogenic horizon development.
Entisols occur in areas of recently deposited parent materials or in areas where erosion or deposition rates are faster than the rate of soil development; such as dunes, steep slopes, and flood plains. They occur in many environments.
Entisols make up about 16% of the world's ice-free land surface.
Gelisols
Gelisols are soils that have permafrost near the soil surface and/or have evidence of cryoturbation (frost churning) and/or ice segregation.
Gelisols are common in the higher latitudes or at high elevations.
Gelisols make up about 9% of the world's ice-free land surface.
Histosols
Histosols have a high content of organic matter and no permafrost. Most are saturated year round, but a few are freely drained. Histosols are commonly called bogs, moors, peats, or mucks.
Histosols form in decomposed plant remains that accumulate in water, forest litter, or moss faster than they decay. If these soils are drained and exposed to air, microbial decomposition is accelerated and the soils may subside dramatically.
Histosols make up about 1% of the world's ice-free land surface.
The Twelve Orders of Soil Taxonomy
Inceptisols
Inceptisols are soils of semiarid to humid environments that generally exhibit only moderate degrees of soil weathering and development.
Inceptisols have a wide range in characteristics and occur in a wide variety of climates.
Inceptisols make up about 17% of the world's ice-free land surface.
Mollisols
Mollisols are soils that have a dark colored surface horizon relatively high in content of organic matter. The soils are base rich throughout and therefore are quite fertile.
Mollisols characteristically form under grass in climates that have a moderate to pronounced seasonal moisture deficit. They are extensive soils on the steppes of Europe, Asia, North America, and South America.
Mollisols make up about 7% of the world's ice-free land surface.
Oxisols
Oxisols are highly weathered soils of tropical and subtropical regions. They are dominated by low activity minerals, such as quartz, kaolinite, and iron oxides. They tend to have indistinct horizons.
Oxisols characteristically occur on land surfaces that have been stable for a long time. They have low natural fertility as well as a low capacity to retain additions of lime and fertilizer.
Oxisols make up about 8% of the world's ice-free land surface.
Spodosols
Spodosols formed from weathering processes that strip organic matter combined with aluminum (with or without iron) from the surface layer and deposit them in the subsoil. In undisturbed areas, a gray eluvial horizon that has the color of uncoated quartz overlies a reddish brown or black subsoil.
Spodosols commonly occur in areas of coarse-textured deposits under coniferous forests of humid regions. They tend to be acid and infertile.
Spodosols make up about 4% of the world's ice-free land surface.
Ultisols
Ultisols are soils in humid areas. They formed from fairly intense weathering and leaching processes that result in a clay-enriched subsoil dominated by minerals, such as quartz, kaolinite, and iron oxides.
Ultisols are typically acid soils in which most nutrients are concentrated in the upper few inches. They have a moderately low capacity to retain additions of lime and fertilizer.
Ultisols make up about 8% of the world's ice-free land surface.
Vertisols
Vertisols have a high content of expanding clay minerals. They undergo pronounced changes in volume with changes in moisture. They have cracks that open and close periodically, and that show evidence of soil movement in the profile.
Because they swell when wet, vertisols transmit water very slowly and have undergone little leaching. They tend to be fairly high in natural fertility.
Vertisols make up about 2% of the world's ice-free land surface.
USDA
NRCS Natural Resources Conservation Service



Soil Organic Matter (SOM)

Different compounds decay at different rates

Discovery (in 1996) of the glycoprotein glomalin suggests that it may create a strong link between biota & some important soil properties



- Produced by hyphae of AM fungi
- May account for ~25% of soil C
- Persists 7-24 years
- Enhances abundance of soil aggregates

Photograph by Jim Richardson

Organically farmed soils (at left) have a more cohesive structure, which results in less silty runoff than found with conventionally farmed soils (at righ
These samples come from the Farming Systems Trial at the Rodale Institute near Kutztown, Pennsylvania. For 28 years, a plot of land there has been
managed organically: Researchers rotate crops regularly, grow cover crops in winter, and apply no chemical fertilizers or pesticides. Laboratory analys
shows that organically managed soils produce lots of glomalin, a gluey protein that helps earth hold its ground.

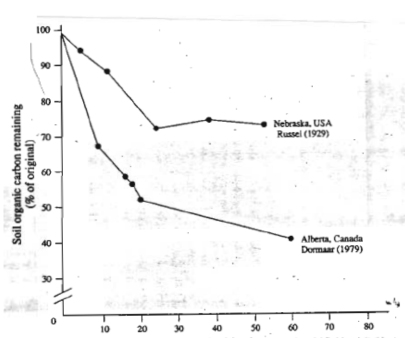


Figure 5.18 Decline in soil organic matter following conversion of native soil to agriculture for two grassland soils. Schlesinger 1991

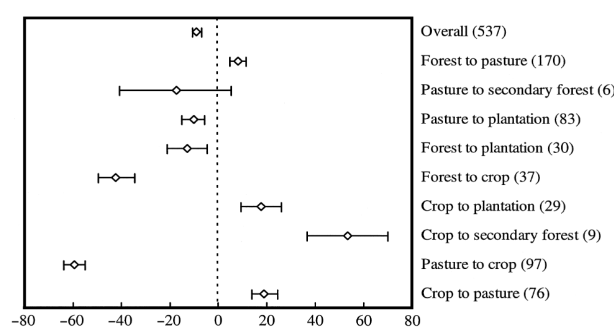


Fig. 1 Soil carbon response to various land use changes (95% confidence intervals are shown and numbers of observations are in parentheses).

Guo and Gifford 2002

Soil chemistry is influenced by clay minerals and SOM

Secondary Clay Minerals

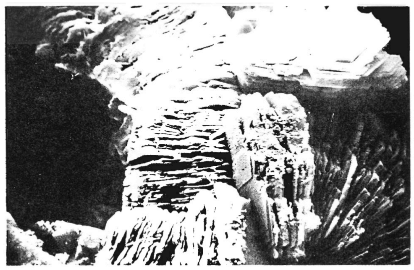
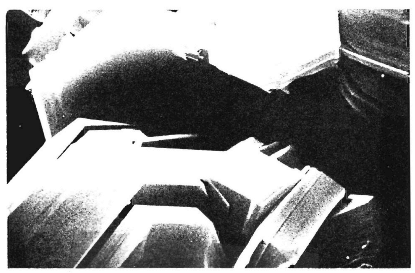


FIGURE 4:1. Crystals of four silicate clay minerals found in soils. (*Above*) Kaolinite from Illinois magnified about 1,600 times (note hexagonal crystal upper right). (*Below*) Dickite from Kansas magnified about 9,000 times. (*Opposite above*) Illite from Wisconsin magnified about 15,000 times. (*Opposite below*) Montmorillonite from Wyoming magnified about 18,000 times. [*Scanning electron micrographs courtesy Dr. Bruce F. Bohor, Illinois State Geological Survey.*]



Brady 1974

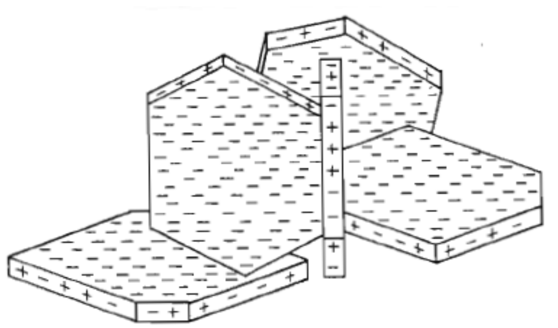
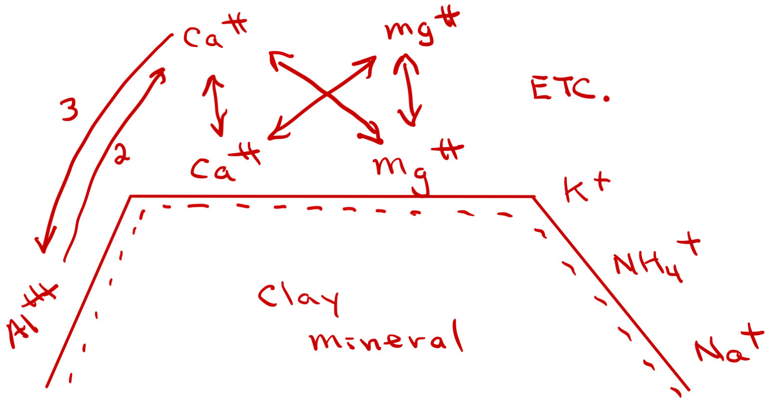
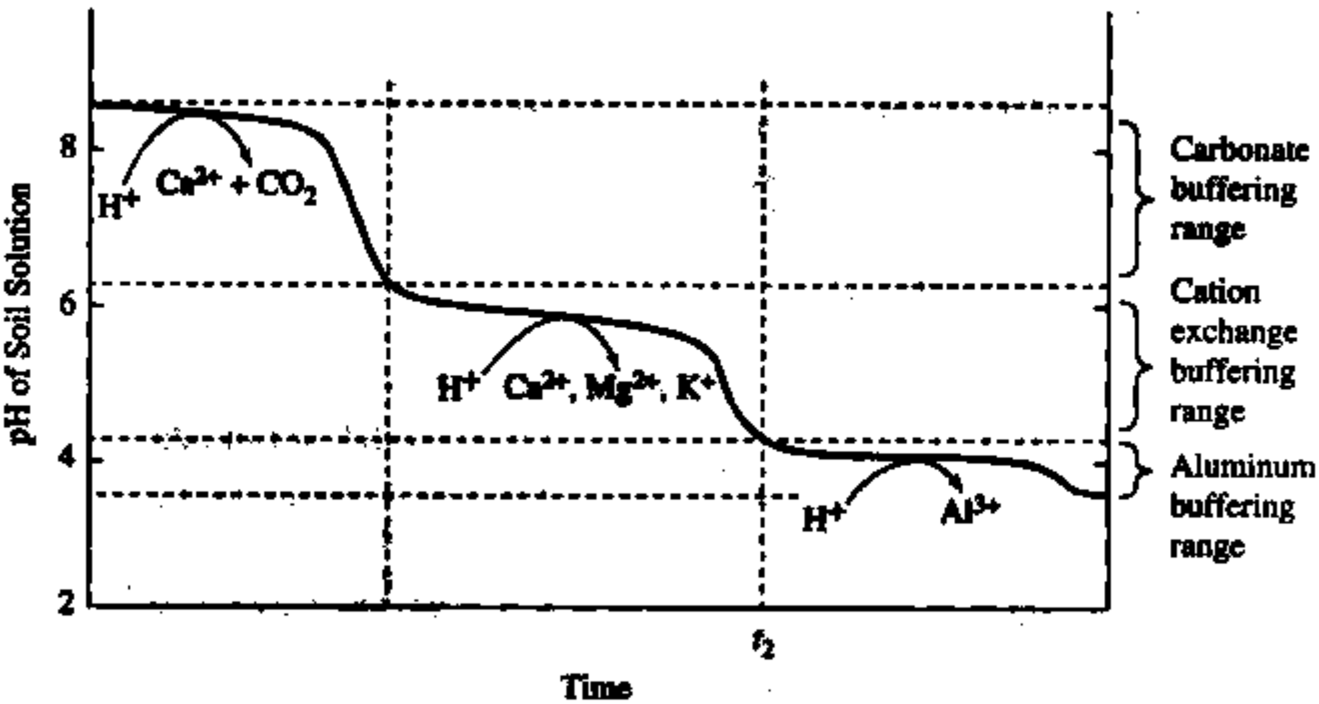


Figure 16-8. An idealized group of clay particles representing the **card house** effect in soil structure in which positive charges on edge positions are attracted by negative charges on the broad surfaces. The negative charges provide exchange sites for cations, and are thus a storage facility. (Reprinted by permission of McGraw-Hill Book Co. from *Soils and Soil Fertility* by Thompson and Troeh, 1973.) Barbour et.al. 1980

Soil Chemistry
(CEC & pH Buffering)



Decline in soil pH over time in response to atmospheric acid inputs.



From: Spiro, T.G., and W. M. Stigliani. 2003.
Chemistry of the environment.
Page 301. 2nd edition. Prentice Hall, Upper Saddle River, NJ

Stages of buffering if present in soils

1) Acidic rain can be neutralized if calcium carbonate is present

Limestone: $CaCO_3 + H_2SO_4$ --> $CaSO_4 + H_2CO_3$
$CaCO_3 + 2HNO_3$ --> $Ca(NO_3)_2 + H_2CO_3$

The calcium sulfate is soluble in water and hence the limestone dissolves and crumbles.

H_2CO_3 --> CO_2 gas + H_2O

The original acid (hydrogen ions) have been converted to water in these reactions.

2) Cation exchange buffering is limited by the number of exchange sites occupied by Na^+, K^+, NH_4^+, Ca^{++}, Mg^{++}

3) *Aluminum buffering is rarely depleted b/c Al containing minerals are common in soils.*

When pH drops below 4.2, H^+ dissolves the Al-containing minerals.

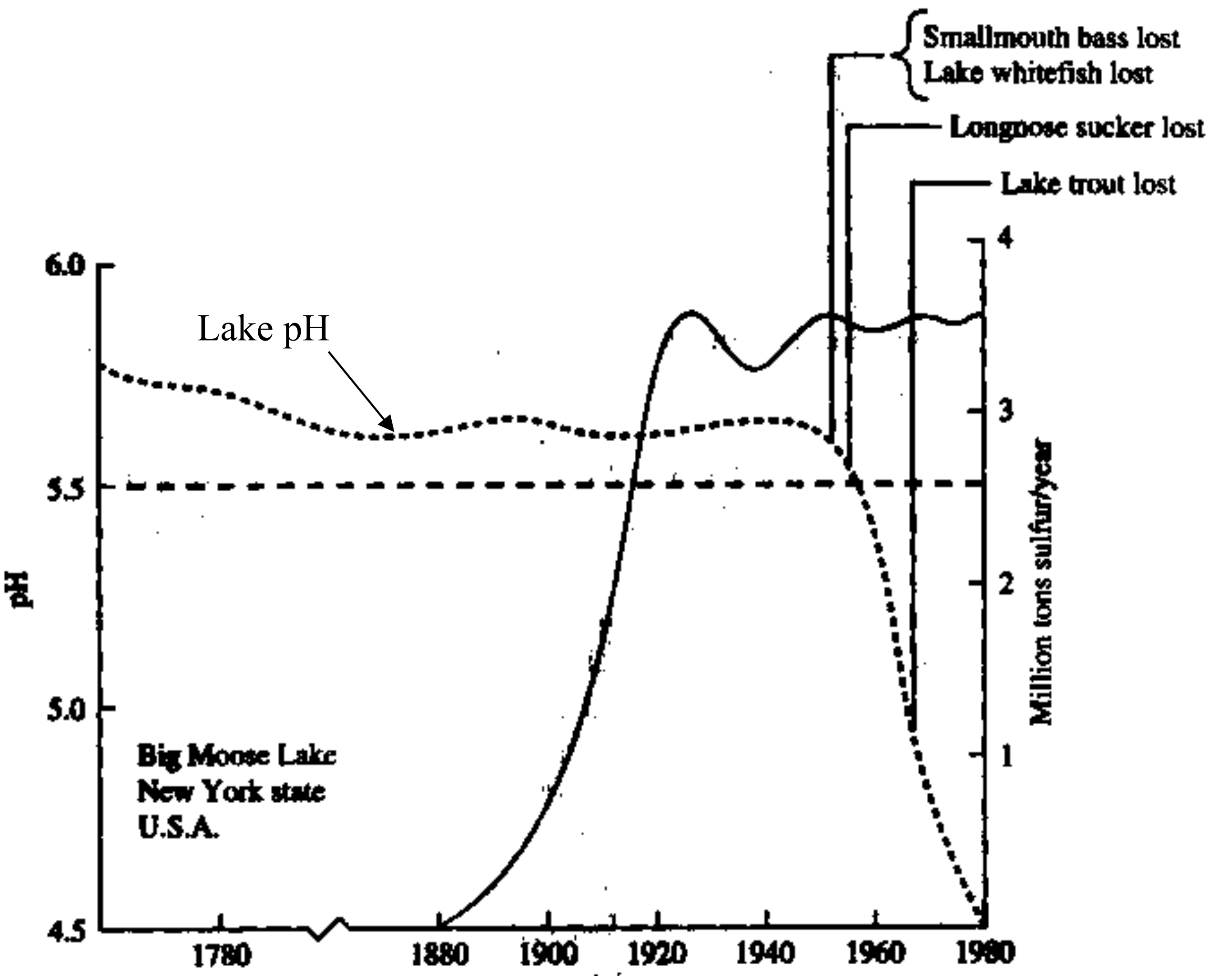
$$\mathbf{Al_2Si_2O_5(OH)_{4kaolinite} + 6H^+ = 2Al_3{}^+{}_{aq} + 2H_4SiO_{4aq} + H_2O}$$

$$\mathbf{NaAlSi_3O_{8plagioclase} + 4H^+ + 4H_2O = Na^+{}_{aq} + Al^{3+}{}_{aq} + 3H_4SiO_{4aq}}$$

$$\mathbf{Al(OH)_{3gibbsite} + 3H^+ = Al^{3+}{}_{aq} + 3H_2O}$$

Al^{3+} can be toxic to plants and aquatic organisms.

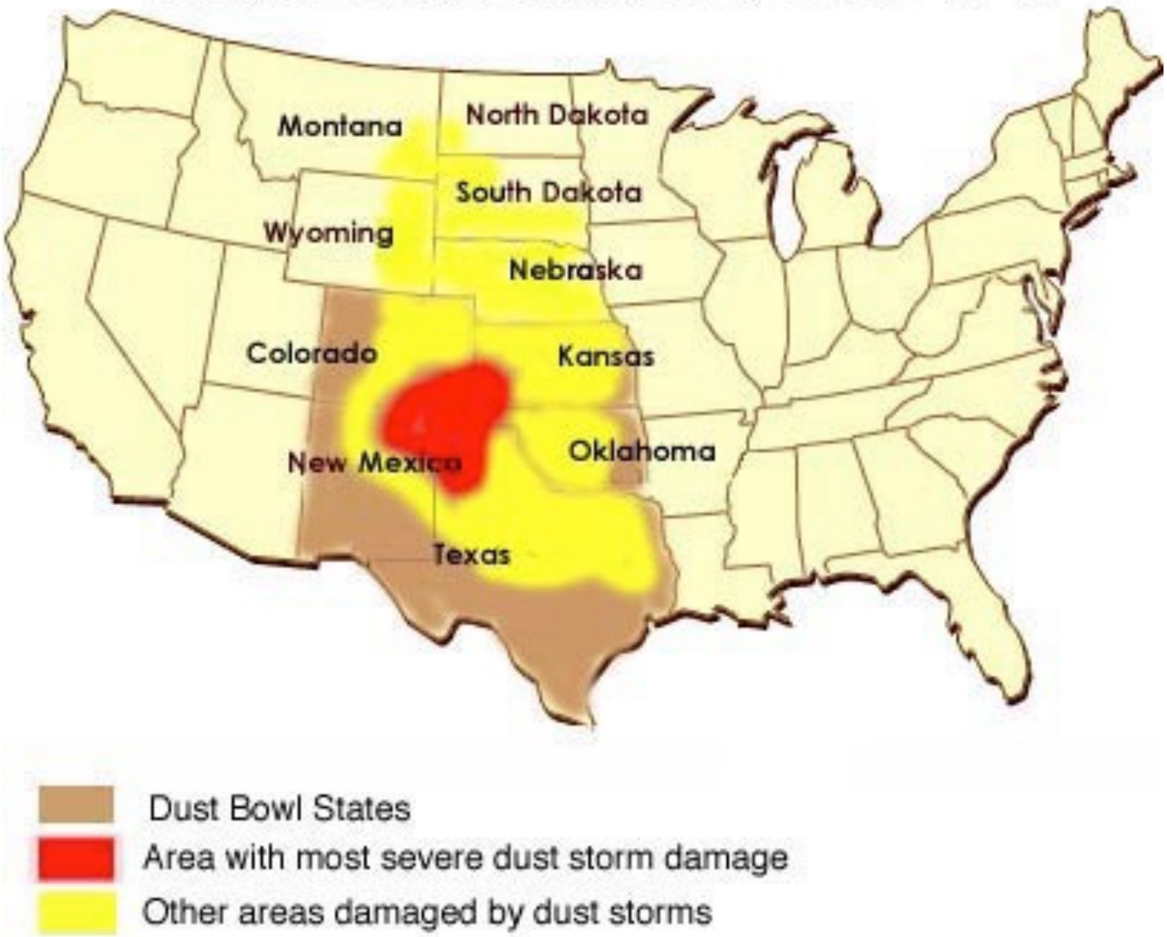
Polluting activities may be far displaced in time from their environmental effects.



Dashed line: lake pH, Solid line: upwind SO_2 emission from the U.S. industrial midwest.

The Dust Bowl

DUST STORM DAMAGE, 1930-1940



Soil Erosion – U.S. case study

May 1934	Topsoil blown off the Great Plains reaches ships 200 miles offshore in the Atlantic
1935	Soil Conservation Service (SCS) established after dust from the Great Plains seeped into congressional hearing room
Dust Bowl	~89 million acres of cropland destroyed (9 million) or damaged
1954-1956	Wind erosion damaged more land than in the 1930s
c.a. 1988	"Enough topsoil erodes … each day to fill a line of dump trucks … 3,5000 miles long …" *Miller 1988*

Table 13-8 *Increases in sediment yield due to human activity*

Situation	Magnitude of increase
In large rivers, generally	3.5 times
In small rivers, generally	8
Forest clearance, Cameron Highlands, Malaysia	5
From erosion of forest roads, Idaho	200–500
Forest clearance, South Island, New Zealand	up to 100
Coon Creek, Wisconsin 1870–1930	10
Cultivation on forest land, Java	2
Trinidad	9
Ivory Coast	18
Tanzania	5
Urbanization in rainforest area, Malaysia	20

Douglas 1990
in Turner et al. 1990

~9 fold ?

Land use affects erosion rates both locally & globally!

Table 4.13 Rates of erosion associated with construction and urbanization

Location	*Land use*	*Source*	*Rate (t km^{-2} yr^{-1})*
1 Maryland, USA	Forest	Wolman (1967)	39
	Agriculture		116–309
	Construction		38,610
	Urban		19–39
2 Virginia, USA	Forest	Vice et al. (1969)	9
	Grassland		94
	Cultivation		1,876
	Construction		18,764
3 Detroit, USA	General non-urban	Thompson (1970)	642
	Construction		17,000
	Urban		741
4 Maryland, USA	Rural	Fox (1976)	22
	Construction		37
	Urban		337
5 Maryland, USA	Forest and grassland	Yorke and Herb (1978)	7–45
	Cultivated land		150–960
	Construction		1,600–22,400
	Urban		830
6 Wisconsin, USA	Agricultural	Daniel et al. (1979)	<1
	Construction		19.2
7 Tama New Town, Japan	Construction	Kadomura (1983)	c.40,000
8 Okinawa, Japan	Construction	Kadomura (1983)	25,000–125,000

Goudie 2000

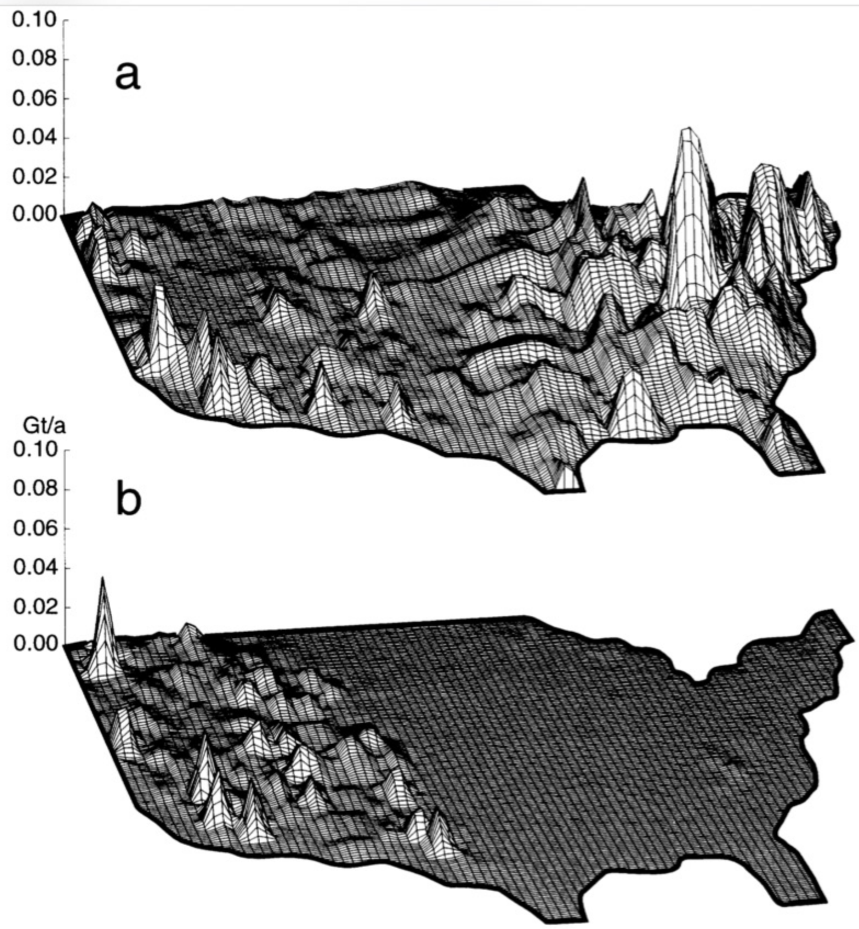


Figure 1. Maps of the United States showing, by variations in peak height, the rates at which earth is moved in gigatonnes per annum in a grid cell measuring 1° (latitude and longitude) on a side, by (a) humans, and (b) rivers

If we do things differently, we can get different results.

Table 5. Annual soil loss (tons per hectare) by crop and technology in the United States.

Technology	State	Soil loss (tons ha^{-1})
Corn		
Conventional, continuous (*131*)	MO	47
Conventional, plow-disk (*132*)	IN	47
Conventional, plow-disk (*132*)	OH	27
Conventional, continuous (*133*)	PA	20
Conservation, rotation (*133*)	PA	7
Conservation, contour (*57*)	IL	6
Conservation, no-till (*134*)	MS	0.3
Soybeans		
Conventional (*135*)	MS	36
Conservation, rotation (*135*)	MS	9
Conservation, no-till (*67*)	GA	0.02
Cotton		
Conventional (*136*)	MS	91
Conservation, no-till (*136*)	MS	1.3
Wheat		
Conventional (*137*)	WA	22
Conservation, mulch (*138*)	MS	1.7
Natural vegetation		
Undisturbed grass (*18*)	KS	0.07
Undisturbed forest (*139*)	NH	0.02

Pimentel et al. 1995

The link between human welfare and soils has been recognized for a long time

"As water wears away stones and torrents wash away the soil, so you destroy man's hope" Job 14:19

Photograph by Jim Richardson

In northern China's Loess Plateau the edges of terraced fields routinely collapse down steep gullies. Farming on this fragile silt contributes to one of the world's highest erosion rates.

National Geographic
Sept. 2008

And it's likely to continue into the future

"With eight billion people, … We're simply not going to be able to keep treating it like dirt"

David Montgomery
Univ. of Washington

"The land takes care of us as we care for it ..."

Cletus Reed
80-yr old
Iowan farmer

Photograph by Jim Richardson

National Geographic
Sept. 2008