Table 1-2. Common nonsilicate minerals in soils.

Mineral class	Mineral	Chemical formula
Halides	Halite	$NaCl$
Sulfates	Gypsum	$CaSO_4 \cdot 2H_2O$
	Jarosite	$KFe_3(SO_4)_2(OH)_6$
Sulfides	Pyrite	FeS_2
Carbonates	Calcite	$CaCO_3$
	Dolomite	$CaMg(CO_3)_2$
	Nahcolite	$NaHCO_3$
	Trona	$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$
	Soda	$Na_2CO_3 \cdot 10H_2O$
Oxides and Hydroxides		
Aluminum	Gibbsite	$Al(OH)_3$
	Nordstrandite	$Al(OH)_3$
	Boehmite	$AlOOH$
	Diaspore	$AlOOH$
	Corundum	Al_2O_3
Iron	Hematite	Fe_2O_3
	Goethite	$FeOOH$
	Lepidocrocite	$FeOOH$
	Maghemite	Fe_2O_3
	Ferrihydrite	$Fe_5O_7(OH) \cdot 4H_2O$
	Magnetite	Fe_3O_4
Manganese	Lithiophorite	$(Al,Li)MnO_2(OH)_2$
	Birnessite	variable
	Hollandite	$Ba_2Mn_8O_{16}$
	Pyrolusite	MnO_2
	Todorokite	variable
	Manganite	$MnOOH$
Titanium	Rutile	TiO_2
	Anatase	TiO_2
	Ilmenite	$FeTiO_3$

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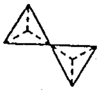
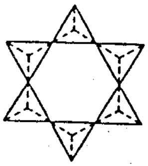
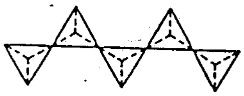
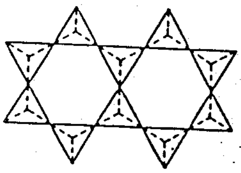
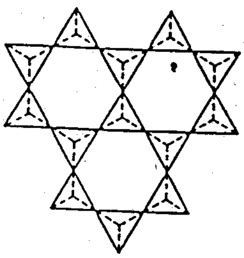
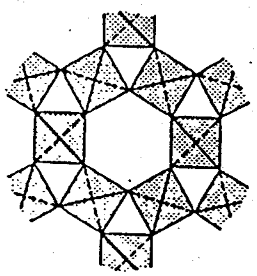
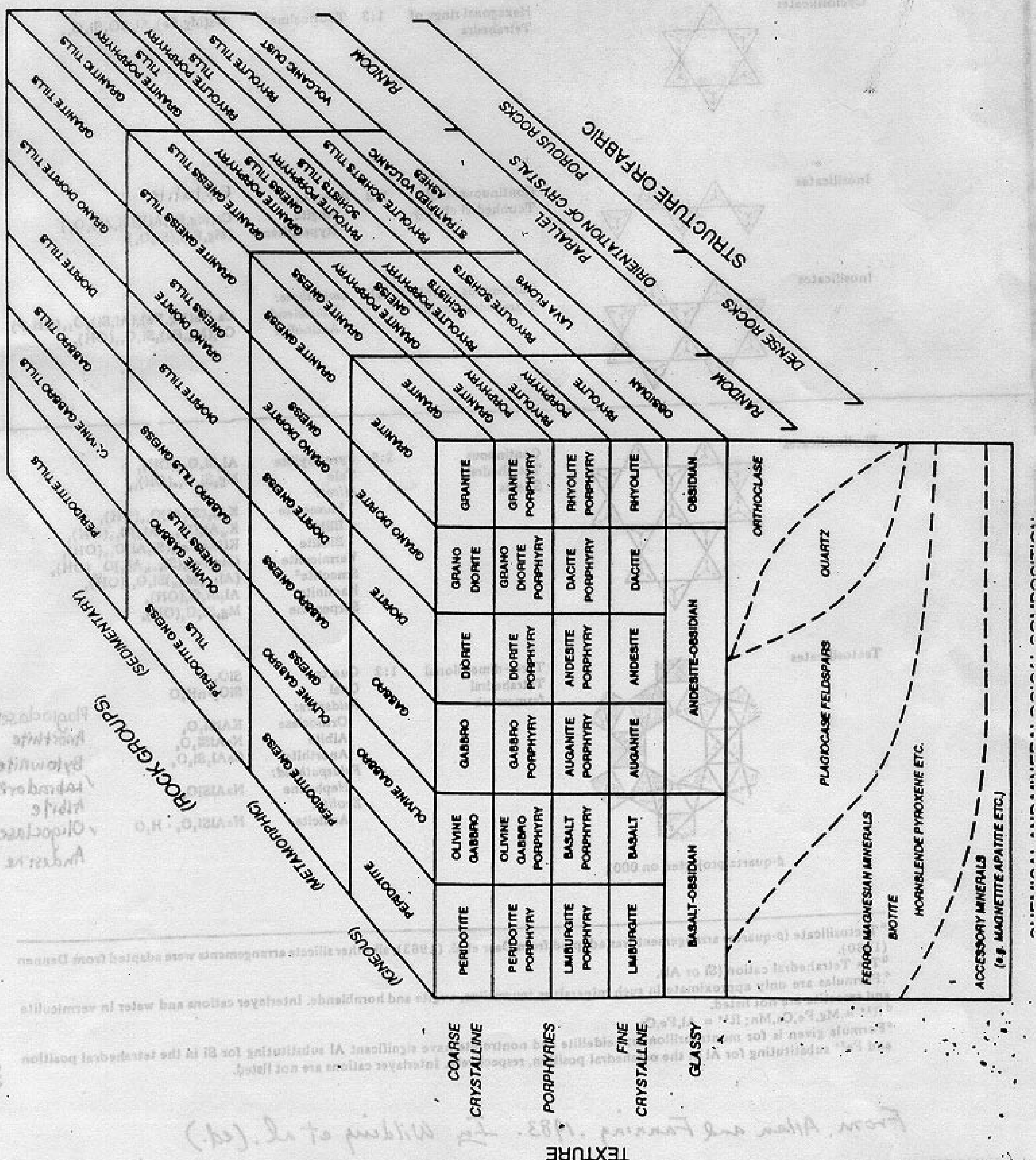
Silicate class	Arrangement of tetrahedra[a]	Structural group	T:O[b] ratio	Examples	Structural formula[c]
Nesosilicates		Independent Tetrahedra	1:4	Olivine	$(Mg,Fe)_2SiO_4$
				Zircon	$ZrSiO_4$
				Garnet	$R_3^{2+}R_2^{3+}(SiO_4)_3$[d]
				Sphene	$CaTi(SiO_4)O$
				Epidote	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$
Sorosilicates		Double Tetrahedra	2:7	Hemimorphite	$Zn_4(Si_2O_7)(OH)_2H_2O$
Cyclosilicates		Hexagonal rings of Tetrahedra	1:3	Tourmaline	$Na(Mg,Fe)_3Al_6BO_3Si_6O_{18}$
Inosilicates		Continuous single Tetrahedral chains	1:3	*Pyroxenes:*	Enstatite
				Augite	$Ca(Mg,Fe,Al)[(Si,Al)_2O_6]$
				Hypersthene	$(Mg,Fe)_2(Si_2O_6)$
Inosilicates		Continuous double Tetrahedral chains	4:11	*Amphibole:*	
				Hornblende	$Ca_2Na(Mg,Fe)_4(Al,Si)_8O_{22}(OH,F)_2$
				Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Phyllosilicates		Continuous Tetrahedral Sheets	2:5	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
				Talc	$Mg_3Si_4O_{10}(OH)_2$
				Micas:	
				Muscovite	$KAl_2(Si_3Al)O_{10}(OH)_2$
				Illite	$K_xAl_2(Si_{4-x}Al_x)O_{10}(OH)_2$
				Biotite	$K(Mg,Fe)_3(Si_3Al)O_{10}(OH)_2$
				Vermiculite	$(Mg,Fe)_3(Si_{4-x}Al_x)O_{10}(OH)_2$
				Smectite[e]	$(Al_{2-x}Mg_x)Si_4O_{10}(OH)_2$
				Kaolinite	$Al_2Si_2O_5(OH)_4$
				Serpentine	$Mg_3Si_2O_5(OH)_4$
Tectosilicates	 β-quartz projected on 0001	Three-dimensional Tetrahedral framework	1:2	Quartz	SiO_2
				Opal	$SiO_2 \cdot nH_2O$
				Feldspars:	
				Orthoclase	$KAlSi_3O_8$
				Albite	$NaAlSi_3O_8$
				Anorthite	$CaAl_2Si_2O_8$
				Feldspathoid:	
				Nepheline	$NaAlSiO_4$
				Zeolite:	
				Analcite	$NaAlSi_2O_6 \cdot H_2O$

Plagioclases Feldspars:
Anorthite
Bytownite
✓Labradorite
Albite
✓Oligoclase
Andesine

[a] Tectosilicate (β-quartz) arrangement was adapted from Deer et al. (1963); all other silicate arrangements were adapted from Dennen (1960).
[b] T = Tetrahedral cation (Si or Al).
[c] Formulas are only approximate in such minerals as tourmaline, augite and hornblende. Interlayer cations and water in vermiculite and smectite are not listed.
[d] R^{2+} = Mg,Fe,Ca,Mn; R^{3+} = Al,Fe,Cr.
[e] Formula given is for montmorillonite; beidellite and nontronite have significant Al substituting for Si in the tetrahedral position and Fe^{3+} substituting for Al in the octahedral position, respectively. Interlayer cations are not listed.

From Allen and Fanning. 1983. In Wilding et al. (ed.)



Plagioclase Feldspar
Anorthite
Bytownite
Labradorite
Albite
Oligoclase
Andesine

From Ahlan and Fanning. 1983. In Wilding et al. (ed.)

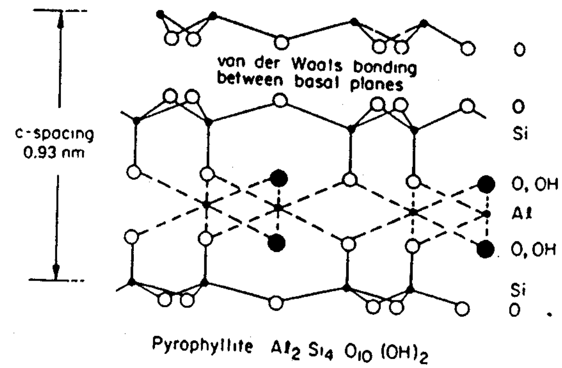


Fig. 4.5 Schematic structure of pyrophyllite. (From F. E. Bear (Ed.), *Chemistry of the Soil*. ACS Monograph Series No. 160, 1969.)

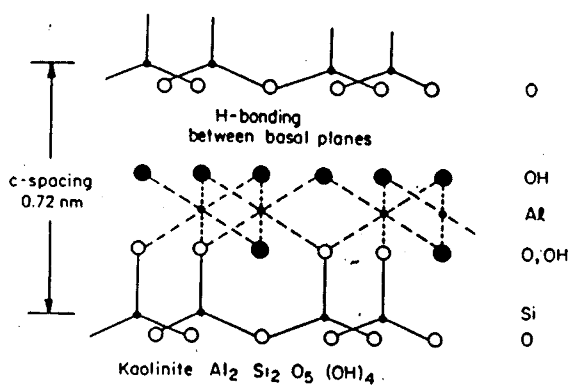


Fig. 4.4 Schematic structure of kaolinite. (From F. E. Bear (Ed.), *Chemistry of the Soil*. ACS Monograph Series No. 160, 1964.)

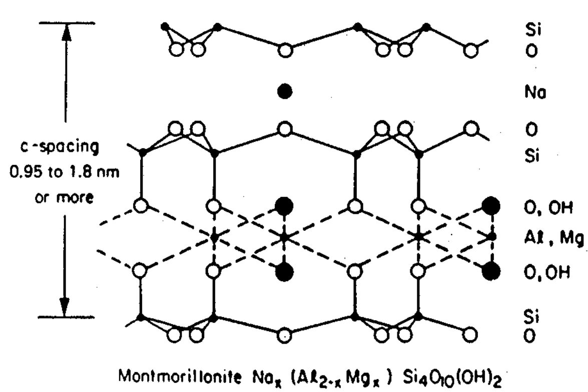


Fig. 4.7 Schematic structure of montmorillonite. (From F. E. Bear (Ed.), *Chemistry of the Soil*. ACS Monograph Series No. 160, 1964.)

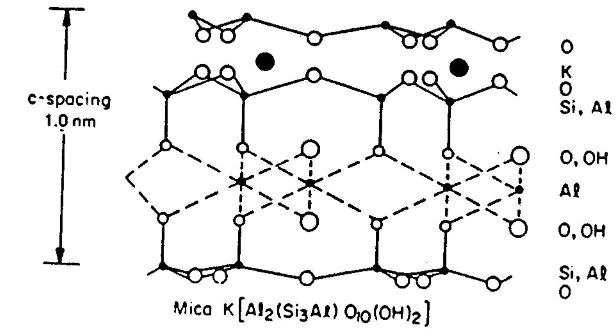


Fig. 4.9 Schematic structure of mica. (From F. E. Bear (Ed.), *Chemistry of the Soil*. ACS Monograph Series No. 160, 1964.)

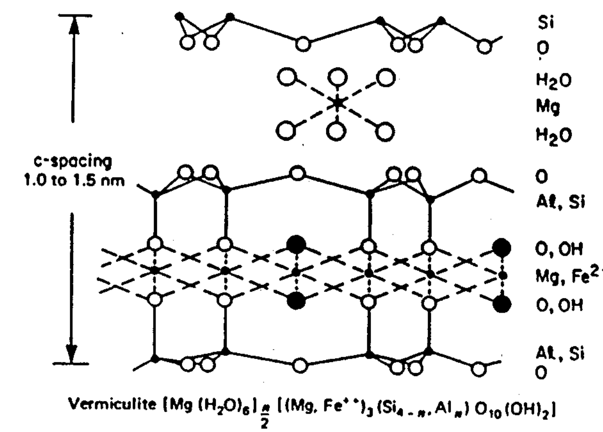


Fig. 4.8 Schematic structure of vermiculite. (From F. E. Bear (Ed.), *Chemistry of the Soil*. ACS Monograph Series No. 160, 1964.)

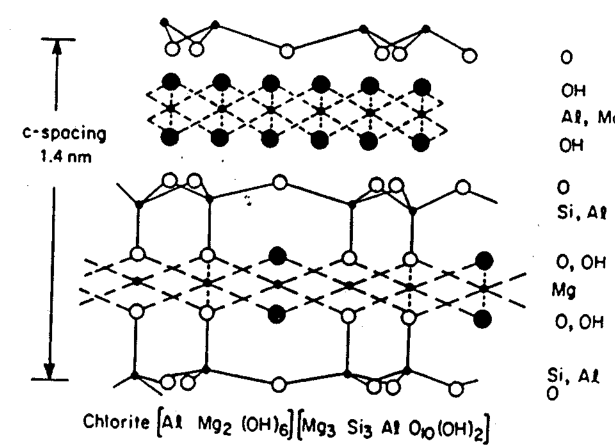


Fig. 4.6 Schematic structure of chlorite. (From F. E. Bear (Ed.), *Chemistry of the*

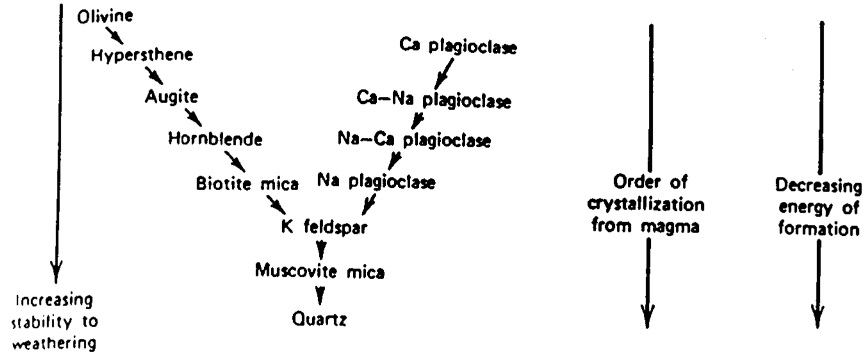


Fig. 3.2 Stability to weathering of some minerals in igneous and metamorphic rocks. (Adapted from S. S. Goldich, *J. Geology*, 46:38 (1938).)

Products of weathering.

Mineral	Residual Products	Material in Solution
Quartz	Quartz grains	Silica
Feldspars	Clay minerals	Silica K^+, Na^+, Ca^{2+}
Amphibole (hornblende)	Clay minerals Limonite Hematite	Silica Ca^{2+}, Mg^{2+}
Olivine	Limonite Hematite	Silica Mg^{2+}

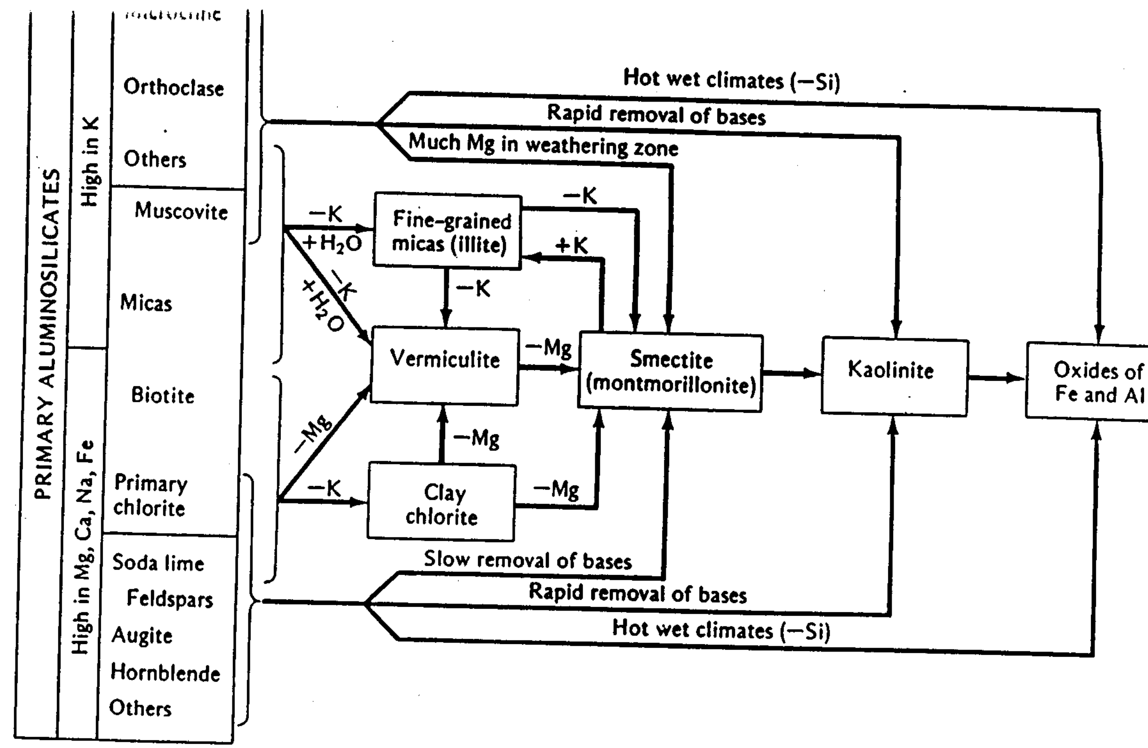
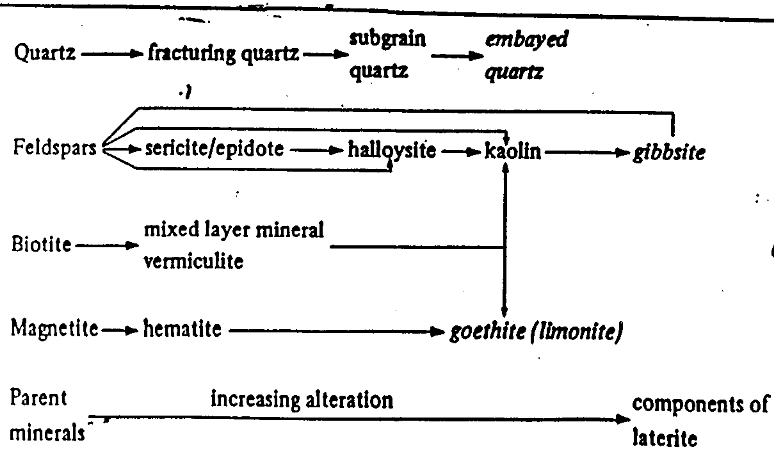
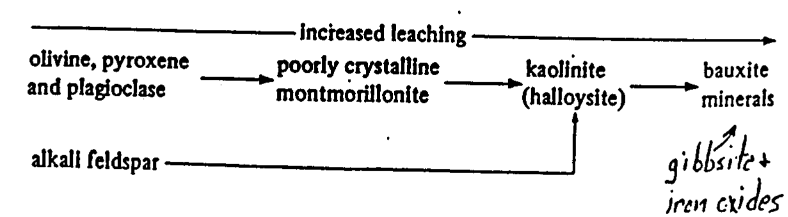


FIGURE 7.10
General conditions for the formation of the various layer silicate clays and oxides of iron and aluminum. Fine-grained micas, chlorite, and vermiculite are formed through rather mild weathering of primary aluminosilicate minerals, whereas kaolinite and oxides of iron and aluminum are products of much more intense weathering. Conditions of intermediate weathering intensity encourage the formation of smectite. In each case silicate clay genesis is accompanied by the removal of soluble elements such as K, Na, Ca, and Mg.

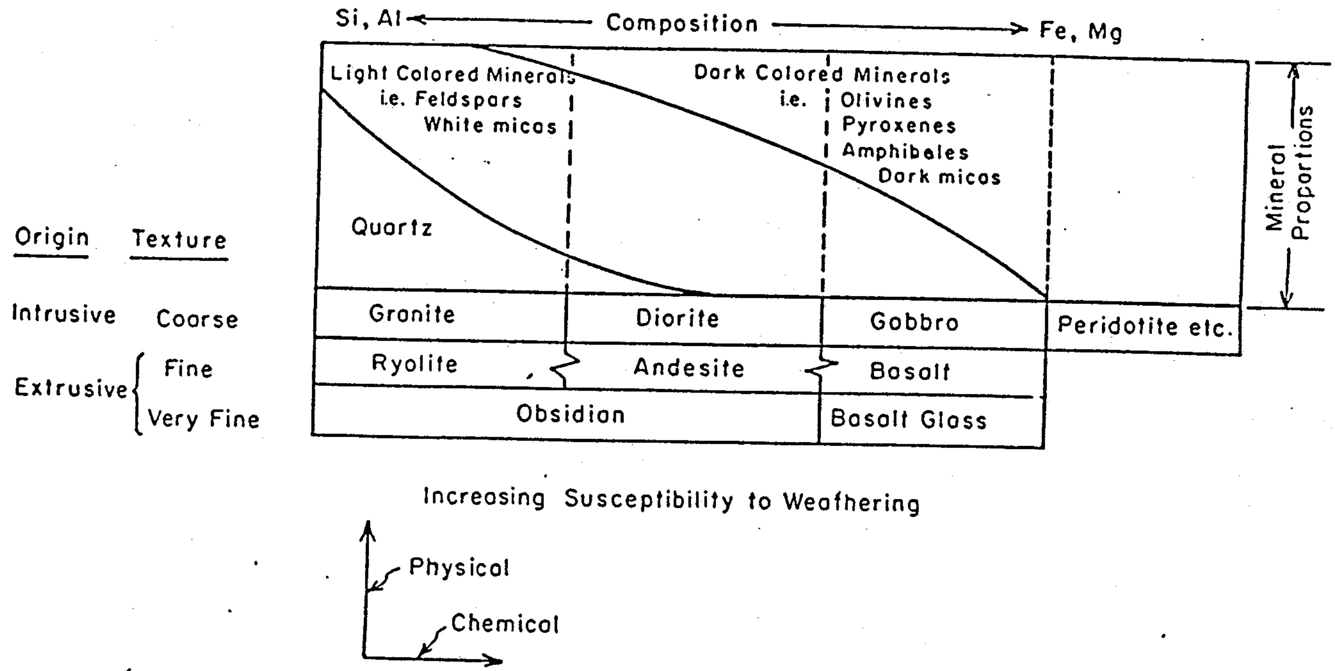


Weathering of Granite

Weathering of Basalt



SILICATE MINERAL DISTRIBUTION – IGNEOUS ROCKS



	CHIEF FELDSPAR ALKALI Potash Feldspars: Microcline or Orthoclase			ALKALI and SODA-LIME Orthoclase-Plagioclase	CHIEF FELDSPAR SODA-LIME Plagioclase			FELDSPARS ABSENT
Characteristic (essential) minerals	Quartz: 0–5%	Quartz: greater than 5%		No quartz	Quartz	No quartz	No quartz ±Olivine	No quartz Olivine Other Fe-Mg minerals
Percentage of silica	66–55%	75–65%	75–65%	65–50%	70–62%	65–50%	60–45%	50–30%
Family or clan	Syenite	Granite	Quartz monzonite	Monzonite	Quartz diorite	Diorite	Gabbro	Peridotite
PLUTONIC Characteristic texture 1 Granitic (megacrystalline)	Syenite	Granite Alaskite Granodiorite	Quartz monzonite	Monzonite	Quartz diorite	Diorite	Gabbro Anorthosite Norite	Peridotite Dunite
HYPABYSSAL 2. Porphyritic *Ground mass* a megacrystalline b microcrystalline *Phenocrysts*	Syenite porphyry (a mega-) Rhyolite porphyry (b micro-)	← Porphyries →						
VOLCANIC 3 Felsitic	Trachyte	Rhyolite	Quartz Latite	Latite	Dacite	Andesite (less than 50% dark minerals)	Basalt (greater than 50% dark minerals)	Various terms in wide use

TABLE 3.1
Common igneous rocks.

	Granitic	Andesitic	Basaltic	Ultramafic
Intrusive Extrusive	Granite Rhyolite	Diorite Andesite	Gabbro Basalt	Peridotite
Mineral Composition	Quartz Potassium feldspar Sodium feldspar	Amphibole Intermediate plagioclase feldspar Biotite	Calcium feldspar Pyroxene	Olivine Pyroxene
Minor Mineral Constituents	Muscovite Biotite Amphibole	Pyroxene	Olivine Amphibole	Calcium feldspar

← Increasing silicon content

Increasing iron content →

TABLE 4.1
Variations in properties among magmas of differing compositions.

Property	Basaltic	Andesitic	Granitic
Silica content	Least (~ 50)	Intermediate (~ 60)	Most (~ 70)
Viscosity	Least	Intermediate	Highest
Tendency to form lavas	Highest	Intermediate	Least
Tendency to form pyroclastics	Least	Intermediate	Highest
Density	Highest	Intermediate	Lowest
Melting point	Highest	Intermediate	Lowest
Typical minerals	Ca feldspar Pyroxene Olivine	Na feldspar Amphibole Pyroxene Mica	K feldspar Quartz Mica Amphibole

SOURCE: Modified from Peter Francis.

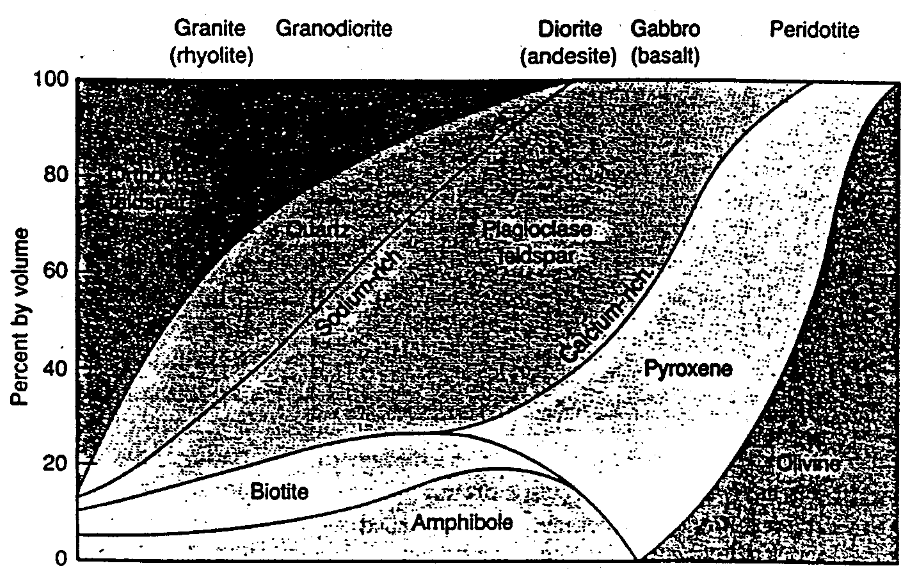


FIGURE 5.18 Classification of sedimentary rocks: inorganic detrital.

Composition	Grain-size Class and Diameter		Comments	Name	
Mainly quartz, feldspar, rock fragments, and clay minerals	gravel (> 2mm)		rounded grains	CONGLOMERATE	
			angular grains	BRECCIA	
	sand (0.0625–2.00, or 1/16–2, mm)		mostly quartz grains	QUARTZ SANDSTONE	SANDSTONE
			mostly feldspar grains	ARKOSE	
			mostly rock fragments	LITHIC SANDSTONE	
			mixed with much silt and clay	WACKE	
	mud	silt (0.0039–0.0625, or 1/256–1/16, mm)	nonfissile (compact)	SILTSTONE	MUDSTONE
			fissile (splits easily)	SHALE	
		clay (< 0.0039, or 1/256, mm)	nonfissile (compact)	CLAYSTONE	
			fissile (splits easily)	SHALE	

Composition	Comments	Grain-size	Name	
Mainly calcium carbonate, $CaCO_3$	shells or shell fragments (i.e., skeletal grains) well cemented to form dense rock	gravel (> 2 mm)	CALCIRUDITE	SKELETAL LIMESTONE
		sand (0.0625–2 mm)	CALCARENITE	
		silt (0.0039–0.0625 mm)	CALCISILTITE	
		clay (< 0.0039 mm)	MICRITE	
	shells or shell fragments (i.e., skeletal grains) poorly cemented to form porous, earthy rock	gravel (> 2 mm)	COQUINA	
		sand (0.0625–2 mm)	CALCARENITE	
		silt and clay (< 0.0625 mm)	CHALK	
	spherical grains with concentric laminations	< 2 mm	OOLITIC LIMESTONE	
	crystals fomed as inorganic chemical precipitates	coarse-grained (> 2 mm) to fine-grained (0.0039 mm)	CRYSTALLINE LIMESTONE	CHEMICAL LIMESTONE
		very fine grained (< 0.0039 mm)	MICRITE	
Mainly dolomite, $CaMg(CO_3)_2$	commonly altered from limestone	all sizes	DOLOSTONE	
Mainly varieties of quartz, SiO_2 (chalcedony, flint, chert, opal, jasper, etc.)	layers, lenses, nodules	microcrystalline or amorphous	CHERT	
Mainly halite, NaCl	crystals formed as inorganic chemical precipitates	all sizes	ROCK SALT	
Mainly gypsum, $CaSO_4 \cdot 2H_2O$	crystals formed as inorganic chemical precipitates	all sizes	ROCK GYPSUM	
Mainly plant fragments	brown and porous	all sizes	PEAT	
	black and nonporous	all sizes or dense with conchoidal fracture	BITUMINOUS COAL	

FIGURE 5.19 Classification of sedimentary rocks: chemical and biochemical.

Table 12.10
CLASSIFICATION OF TERRIGENOUS ROCKS[a] (COMPARE WITH FIG. 12.18 FOR SANDSTONE CLASSIFICATION)

GRAIN SIZE			COMPOSITION: Lithic fragments (e.g., chert, limestone, volcanic, granite)		COMPOSITION: Quartz	COMPOSITION: Feldspar
Cobble	Conglomerate (rounded), breccia (angular)	Cobble conglomerate (or breccia) (e.g., granite cobble conglomerate)			Quartz cobble conglomerate (or breccia)	
Pebble	Conglomerate (rounded), breccia (angular)	Pebble conglomerate (or breccia) (e.g., chert pebble conglomerate)			Quartz pebble conglomerate (or breccia)	
Granule	Conglomerate (rounded), breccia (angular)	Granule conglomerate (or breccia) (e.g., limestone granule conglomerate)			Quartz granule conglomerate (or breccia)	Feldspar granule conglomerate (or breccia)
Sand	Sandstone	**Wacke (>10% matrix)**	Lithic[1] wacke		Quartz wacke	Feldspathic[2] wacke
Sand	Sandstone	**Arenite (<10% matrix)**	Lithic arenite		Quartz arenite	Feldspathic[2] arenite
Silt	*(composition cannot be evaulated because of fine grain size)*					
Silt	Siltstone					
Mud	Mudstone—lacking fissility Shale—showing fissility					

[1]Dark, highly indurated lithic wackes are also referred to as greywackes.
[2]Red- or pink-colored feldspathic wackes and arenites can be referred to as arkoses.
[a]Modified after L. J. Suttner and J. Meyers, 1980, Field study of the petrology of sedimentary rocks in *Manual for Geologic Field Study of Northern Rocky Mountains*, Indiana University.

Table 12.6
CHEMICAL COMPOSITION OF AVERAGE IGNEOUS ROCK COMPARED WITH AVERAGE COMPOSITIONS OF SOME SEDIMENTARY ROCK TYPES[a]

	Average Continental Igneous Rock	Average Sandstone	Average Shale	Average Limestone
SiO_2	59.14	78.33	58.10	5.19
TiO_2	1.05	0.25	0.65	0.06
Al_2O_3	15.34	4.77	15.40	0.81
Fe_2O_3	3.08	1.07	4.02	0.54
FeO	3.80	0.30	2.45	—
MgO	3.49	1.16	2.44	7.89
CaO	5.08	5.50	3.11	42.57
Na_2O	3.84	0.45	1.30	0.05
K_2O	3.13	1.31	3.24	0.33
H_2O	1.15	1.63	5.00	0.77
P_2O_5	0.30	0.08	0.17	0.04
CO_2	0.10	5.03	2.63	41.54
SO_3	—	0.07	0.64	0.05
C(elemental)	—	—	0.80	—
Total	99.50	99.95	99.95	99.84

[a] After F. W. Clarke, 1924, Data of Geochemistry, *U.S. Geol. Surv. Bul.* 770.

TABLE 6. CLASSIFICATION OF METAMORPHIC ROCKS

A. FOLIATED

<table>
<tr><th colspan="3">TEXTURE</th><th colspan="6">COMPOSITION</th><th>ROCK NAME</th></tr>
<tr><td rowspan="4">ORIENTED GRAINS</td><td rowspan="3">NON-LAYERED</td><td>Very Fine Grained</td><td rowspan="3">CHLORITE</td><td rowspan="4">MICA</td><td rowspan="4">QUARTZ</td><td></td><td></td><td></td><td>SLATE</td></tr>
<tr><td>Fine Grained</td><td rowspan="3">FELDSPAR</td><td rowspan="3">AMPHIBOLE</td><td></td><td>PHYLLITE</td></tr>
<tr><td>Coarse Grained</td><td rowspan="2">PYROXENE</td><td>SCHIST</td></tr>
<tr><td>LAYERED</td><td>Coarse Grained</td><td></td><td>GNEISS</td></tr>
</table>

B. NON-FOLIATED

TEXTURE	COMPOSITION	ROCK NAME
Coarse Grained	Deformed Fragments of Any Rock Type	METACONGLOMERATE
Fine to Coarse Grained	Quartz	QUARTZITE
	Calcite or Dolomite	MARBLE