國立中央大學地球科學系
GP3087 Sedimentary Geology

Instructor: 林殿順

This course introduces the principles of sedimentology and stratigraphy. Topics will be covered are: origin and transport of sedimentary materials, physical properties of sedimentary rocks, composition, classification, and diagenesis of sedimentary rocks, depositional environments, and principles of stratigraphy and basin analysis. This course includes a two-day field training in SW Taiwan.

Course Outline

Part I: Origin and Transport of Sedimentary Materials

1. Weathering and soils
2. Transport and deposition of siliciclastic sediments

Part II: Physical Properties of Sedimentary Rocks

3. Sedimentary textures
4. Sedimentary structures

Part III: Composition, Classification, and Diagenesis of Sedimentary Rocks

5. Siliciclastic sedimentary rocks
6. Carbonate sedimentary rocks
7. Other chemical/biochemical and carbonaceous sedimentary rocks

Part IV: Depositional Environments

8. Continental (terrestrial) environments
9. Marginal-marine environments
10. Siliciclastic marine environments
11. Carbonate and evaporite environments

Part V: Stratigraphy and Basin Analysis

12. Lithostratigraphy
13. Sequence and magnetic stratigraphy
14. Biostratigraphy
15. Chronostratigraphy and geologic time
16. Basin Analysis, Tectonics, and Sedimentation

Textbook

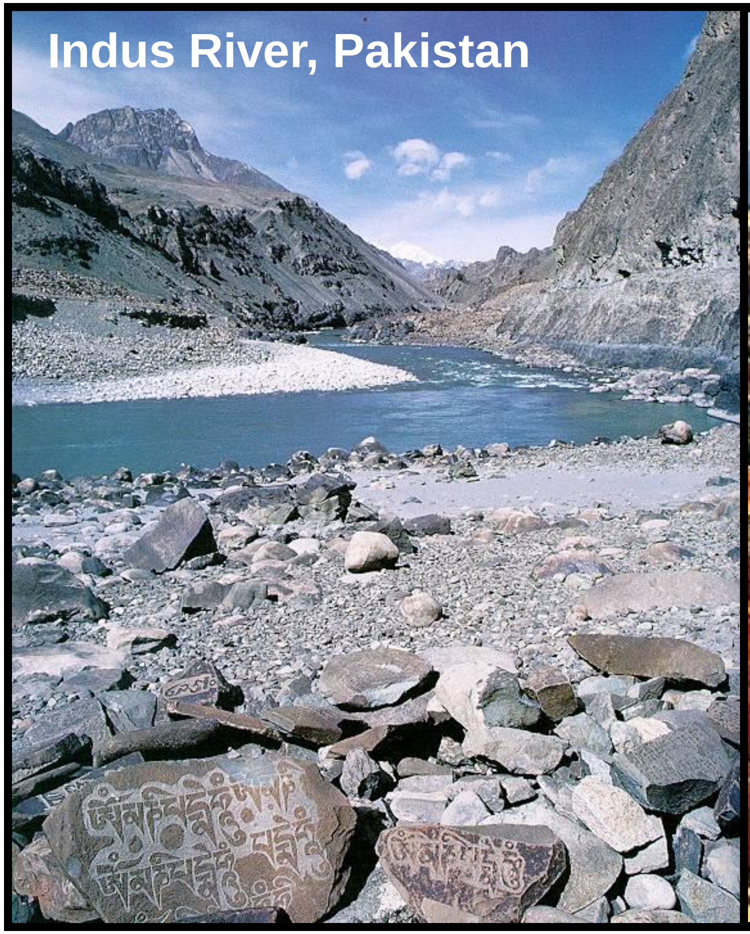
Boggs, S., Jr., 2006, *Principles of Sedimentology and Stratigraphy*, fourth edition: Prentice Hall, New Jersey, 662 pp.

Course Schedule

Class: 20 September ~ 8 November 2012; Midterm exam: 15 November 2012
Class: 22 November 2012 ~ 10 January 2013; Final exam: 17 January 2013
Field trip: 15 ~16 December 2012 (Southwest Taiwan, 曾文溪、七股潟湖)

Grading: Midterm exam 35%; Final exam 35%;
Field trip 20%; Assignments 10%

Chapter 1. Weathering and Soils



Indus River, Pakistan

Bryce Canyon, Utah

Mechanical **Chemical**

How sediments are made and landscapes formed

Photos from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

1.1 Introduction

Weathering

岩石因物理崩解、化學與生物作用而形成殘餘的固態物質與溶解(dissolved)的化學物質的過程稱為風化作用。

Regolith(表岩屑)

The loose layer of broken rock and mineral fragments on the surface.


Soil forming from rock breakdown

Erosion

Transport of regolith and the wearing down of bedrock

Photo from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

The Rock Cycle

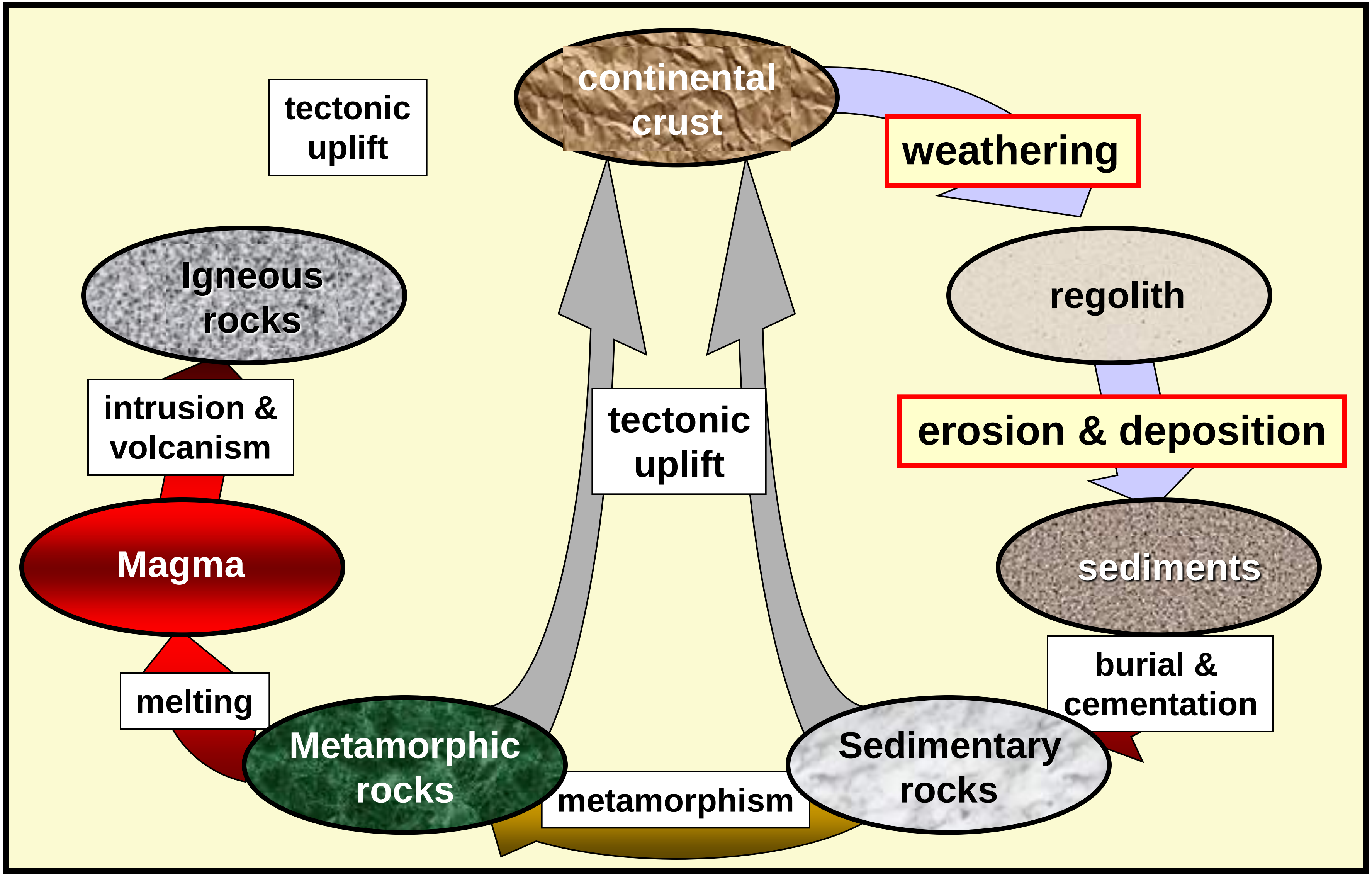


Figure from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

1.2 Subaerial weathering processes

1.2.1 Physical Weathering

The physical breaking of rocks into small particles

- **Freeze-thaw (frost) weathering (ice wedging)**
- **Isolation (thermal) weathering**
- **Salt weathering**
- **Wetting and drying**
- **Stress-release weathering**

Jointed Sandstone
Point Lobos, CA

Most mechanical weathering exploits JOINTS, pre-existing fractures in the rock

Photos from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

Freeze-thaw cycles: Ice wedging

The physical breaking of rocks into small particles

Water creeps into cracks during warm weather; it then expands as it freezes (about 9%)

This puts great pressure on the rocks

Fig. 1.1 Large, angular blocks of rock generated by **freeze-thaw weathering** of thin-bedded sandstones and mudstones of the Canning formation (Paleocene) exposed along the Canning River, Arctic National Wildlife Refuge, Alaska.

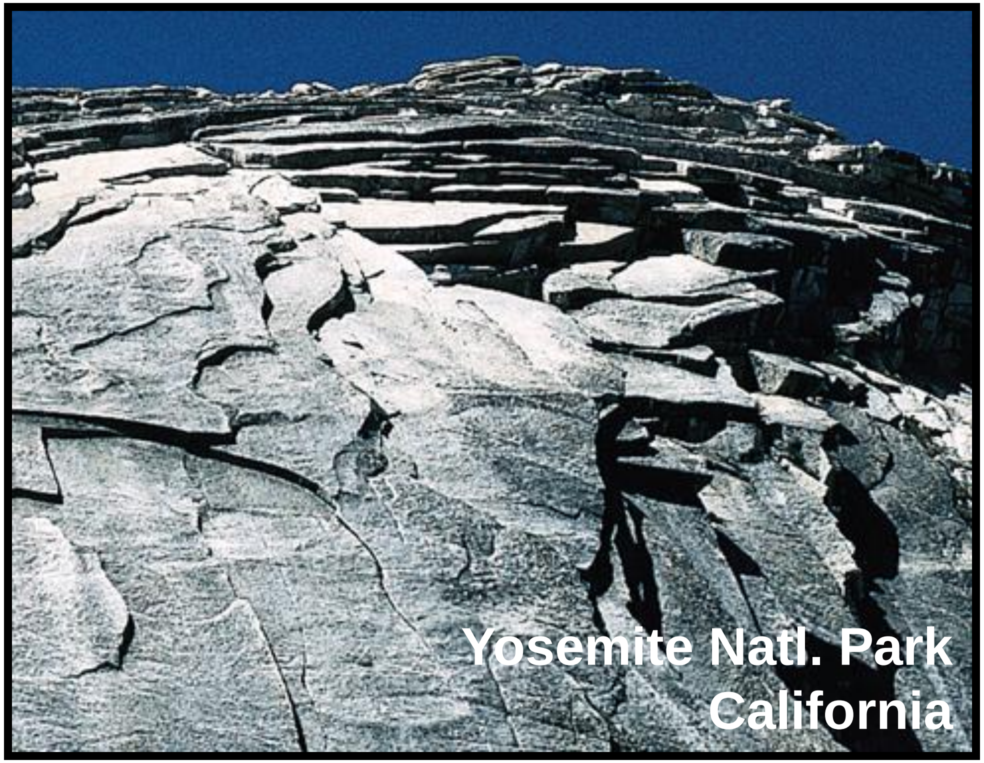
Ice wedging is important:

- **Arctic climates**
- **Temperate climates**
- **High altitudes (mountains)**

Release of overburden pressure

Large, thin sheets of rock that fall off bedrock

Upward rebound of the rocks creates tensile stresses, causing fractures to develop that are oriented nearly parallel to the topographic surface.


Yosemite Natl. Park
California

Photos from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

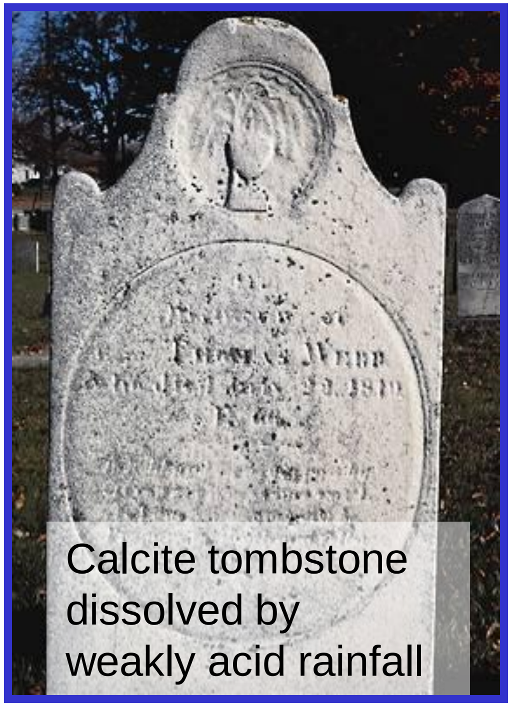
Spheroidal weathering is smaller-scale weathering of roughly massive rock masses, cut by intersecting joints, causing layers or “skins” to spall off to produce spheroidal cores.

Fig. 1.2 Spheroidal weathering in granite. Note low successive, thin layers of weathered rock are spalled off to produce a spheroidal core.

Weathering exploits joint surfaces:
Example from Penghu basalts

1.2.2 Chemical Weathering

Chemical weathering alters both the chemical and mineralogical composition of rocks.



Calcite tombstone dissolved by weakly acid rainfall

Oxidation of iron in soils
Hawaiian

Alan H. Strahler

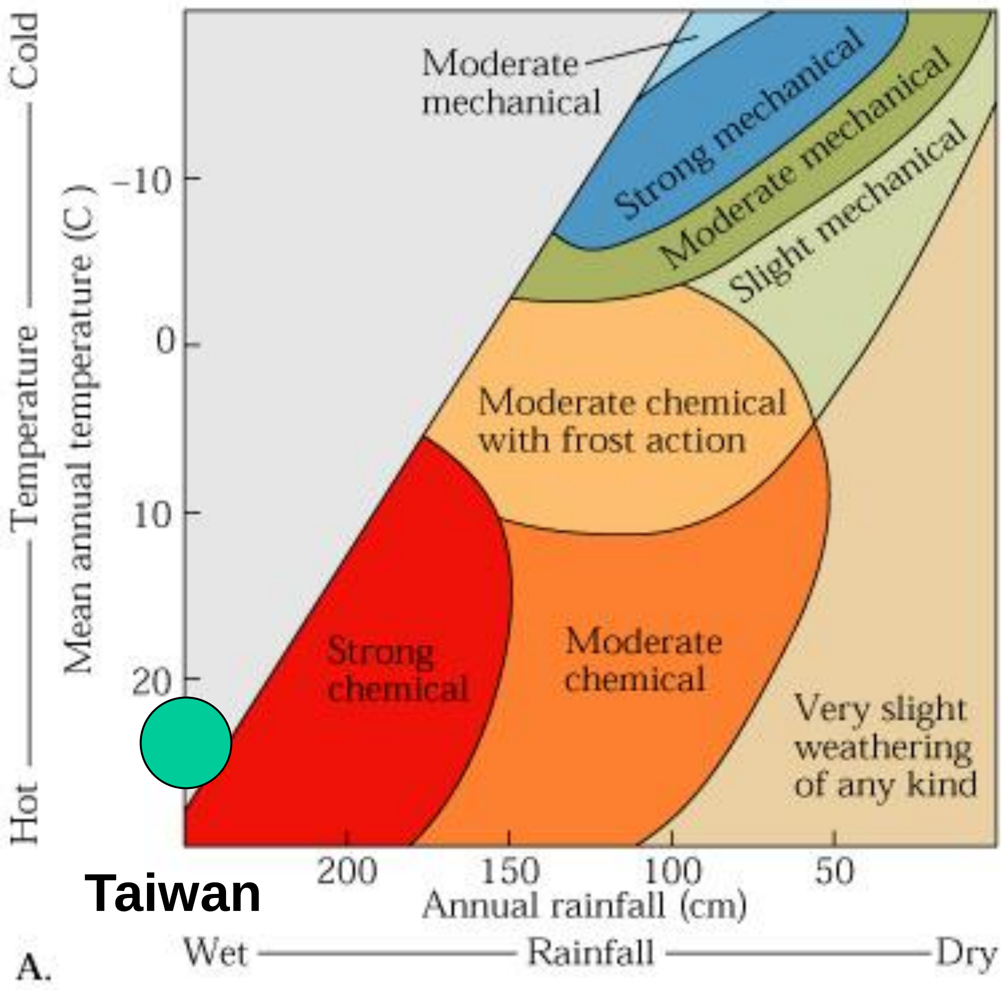
A. Simple solution (congruent dissolution)

B. Hydrolysis (水解)

C. Oxidation (氧化)

D. Others: Hydration (水合), Ion exchange (離子交換), Chelation

Chemical Weathering: Climate



Climate affects chemical weathering strongly

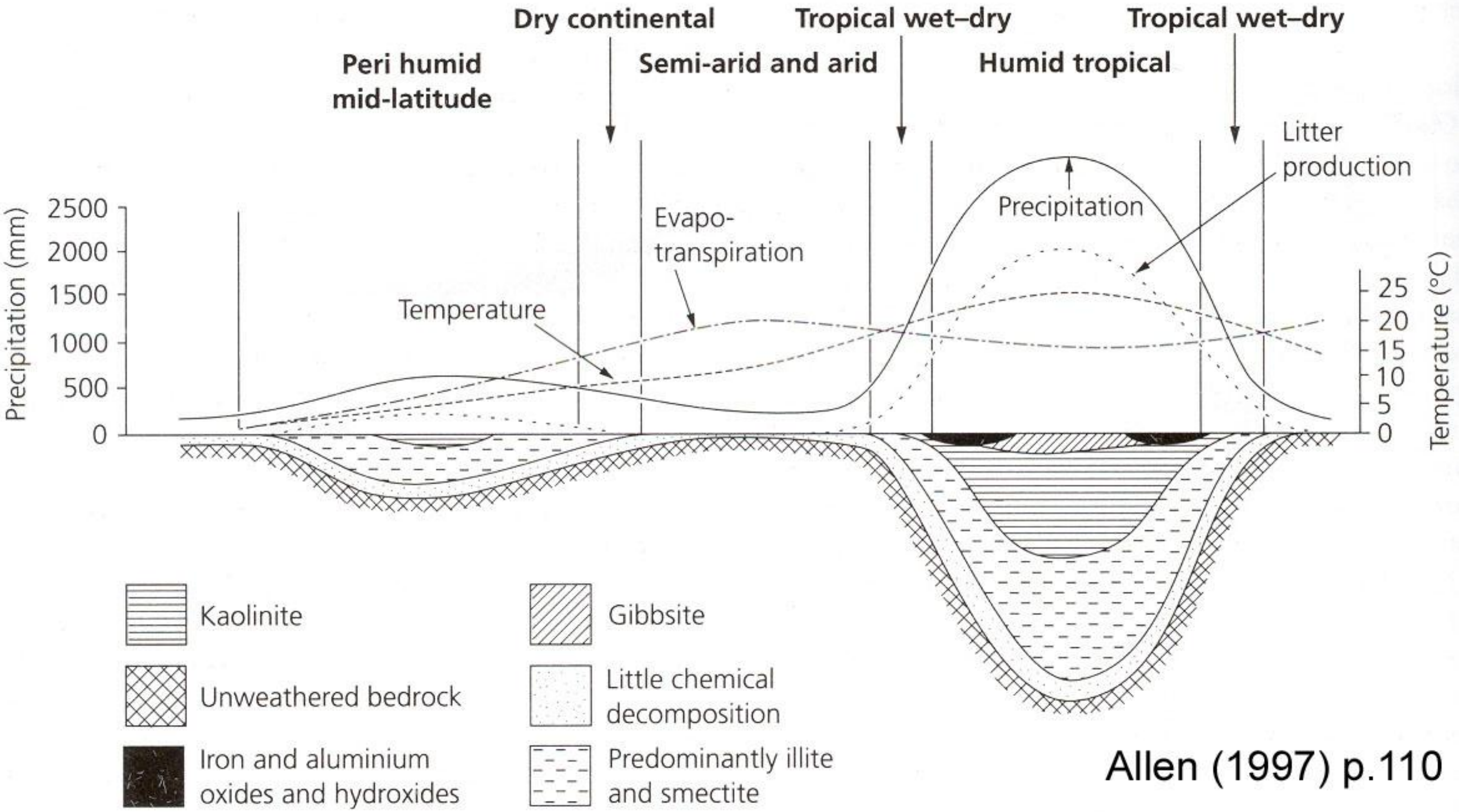
- **More water**
- **More vegetation**
- **More soils**
- **Hotter Temperatures**

Happens in any oxygenated environment (air, most water)

台灣平均雨量為250 cm/yr

Figure from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

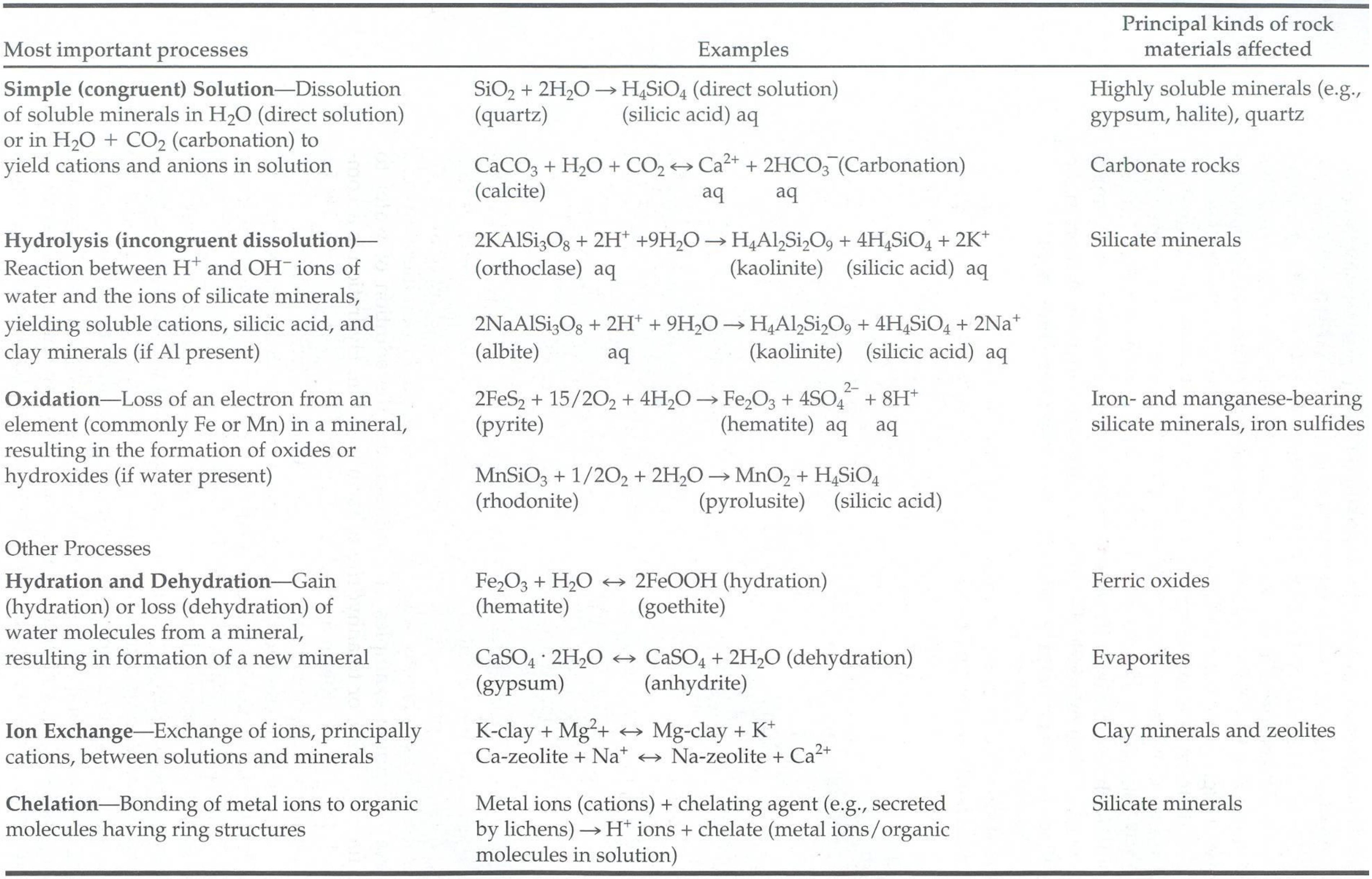
Chemical weathering products vs. climate



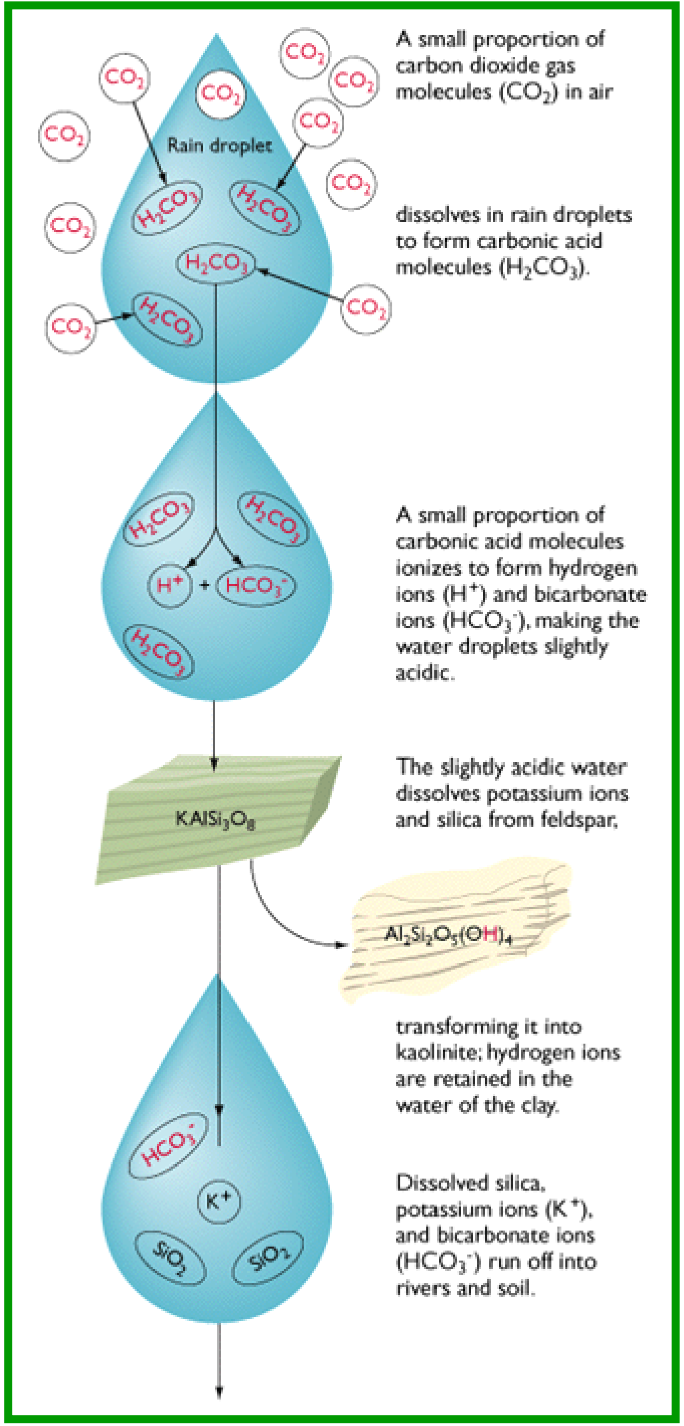
Allen (1997) p.110

Fig. 3.9 Latitudinal zonation of regolith thickness and type. Modified from Strakhov (1967) [10].

Table. 1.1 Principal processes of chemical weathering



Most important processes	Examples	Principal kinds of rock materials affected
Simple (congruent) Solution—Dissolution of soluble minerals in H_2O (direct solution) or in $H_2O + CO_2$ (carbonation) to yield cations and anions in solution	$SiO_2 + 2H_2O \rightarrow H_4SiO_4$ (direct solution) (quartz) (silicic acid) aq	Highly soluble minerals (e.g., gypsum, halite), quartz
	$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$ (Carbonation) (calcite) aq aq	Carbonate rocks
Hydrolysis (incongruent dissolution)—Reaction between H^+ and OH^- ions of water and the ions of silicate minerals, yielding soluble cations, silicic acid, and clay minerals (if Al present)	$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow H_4Al_2Si_2O_9 + 4H_4SiO_4 + 2K^+$ (orthoclase) aq (kaolinite) (silicic acid) aq	Silicate minerals
	$2NaAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow H_4Al_2Si_2O_9 + 4H_4SiO_4 + 2Na^+$ (albite) aq (kaolinite) (silicic acid) aq	
Oxidation—Loss of an electron from an element (commonly Fe or Mn) in a mineral, resulting in the formation of oxides or hydroxides (if water present)	$2FeS_2 + 15/2O_2 + 4H_2O \rightarrow Fe_2O_3 + 4SO_4^{2-} + 8H^+$ (pyrite) (hematite) aq aq	Iron- and manganese-bearing silicate minerals, iron sulfides
	$MnSiO_3 + 1/2O_2 + 2H_2O \rightarrow MnO_2 + H_4SiO_4$ (rhodonite) (pyrolusite) (silicic acid)	
Other Processes		
Hydration and Dehydration—Gain (hydration) or loss (dehydration) of water molecules from a mineral, resulting in formation of a new mineral	$Fe_2O_3 + H_2O \leftrightarrow 2FeOOH$ (hydration) (hematite) (goethite)	Ferric oxides
	$CaSO_4 \cdot 2H_2O \leftrightarrow CaSO_4 + 2H_2O$ (dehydration) (gypsum) (anhydrite)	Evaporites
Ion Exchange—Exchange of ions, principally cations, between solutions and minerals	K-clay + Mg^{2}+ ↔ Mg-clay + K^+ Ca-zeolite + Na^+ ↔ Na-zeolite + Ca^{2+}	Clay minerals and zeolites
Chelation—Bonding of metal ions to organic molecules having ring structures	Metal ions (cations) + chelating agent (e.g., secreted by lichens) → H^+ ions + chelate (metal ions/organic molecules in solution)	Silicate minerals



A small proportion of carbon dioxide gas molecules (CO_2) in air dissolves in rain droplets to form carbonic acid molecules (H_2CO_3).

A small proportion of carbonic acid molecules ionizes to form hydrogen ions (H^+) and bicarbonate ions (HCO_3^-), making the water droplets slightly acidic.

The slightly acidic water dissolves potassium ions and silica from feldspar, transforming it into kaolinite; hydrogen ions are retained in the water of the clay.

Dissolved silica, potassium ions (K^+), and bicarbonate ions (HCO_3^-) run off into rivers and soil.

B. Hydrolisis

水解作用指由氫(H^+)或氫氧根(OH^-)離子取代原來礦物的其他元素(如K^+, Na^+, Ca^{2+}, Mg^{2+})，而形成新的礦物。水解作用有CO_2加入，則稱為碳酸化作用(Carbonation)。

NEEDS WATER TO OCCUR!

CO_2和水作用產生H^+與HCO_3^-形成弱酸性

$2KAlSi_3O_8$（orthoclase)＋$2H^+$＋$9H_2O$ $\longrightarrow$

$Al_2Si_2\ O_5(OH)_4$ (kaolinite)＋$4H_4SiO_4$(*aq*) ＋$2K^+$

Weak acids strip cations out of minerals

This is the main process of:

- weathering silicates
- making clays

Figure from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

石灰岩的化學風化作用主要是碳酸化作用(Carbonation)

Sinkhole
Winter Park, Florida

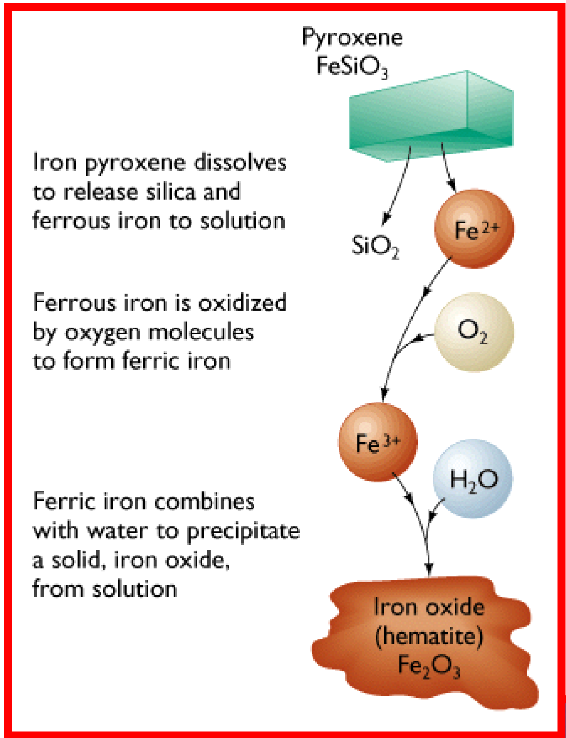
Tower Karst China

$$H_2CO_3 + 2CaCO_3 \longleftrightarrow Ca^{2+} + 2HCO_3^-$$

若CO_2多則反應向右，石灰岩溶解，形成卡斯特(karst)地形與鐘乳石洞或滲穴(sinkhole)；若CO_2少反應向左，碳酸鈣沉澱，形成鐘乳石。在乾燥氣候下，碳酸鈣於土壤中沉澱，形成鈣質結礫岩(calcrete)。

Photos from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

C. Oxidation



Loss of an electron from an element (commonly Fe or Mn) in a mineral, resulting in the formation of oxides or, if water is present, hydroxides.

$$4FeSiO_3 + O_2 \longrightarrow 2Fe_2O_3 + 4SiO_2$$

pyroxene **hematite**

$$Fe^{2+} \longrightarrow Fe^{3+} + e^-$$

Monument Valley Arizona

Oxidation of iron in soils Hawaiian

Photos from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

D. Other chemical weathering processes: Hydration

某些礦物可將水分子(H_2O)納入其結晶格內，如此結晶內的孔隙加大，使此水化合物更容易受風化。另外，礦物體積膨脹之後，岩石的內部壓力加大，可以導致岩石破碎。

$$2Fe_2O_3 + 3H_2O \longrightarrow 2Fe_2O_3.3H_2O$$

Hematite 赤鐵礦

Limonite 褐鐵礦

Photo from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

Products of oxidation

氧化物(Oxides)與氫氧化物(hydroxides)合稱為三氧化鋁鐵(sesquioxides)

Si的氧化物	石英、非晶質矽石(amorphous silica)、蛋白石質矽石(opaline silica)
Al的氫氧化物	Gibbsite(三水鋁石Al(OH)$_3$, boehmite(軟水鋁石γAl(OH)$_3$) 一水硬鋁石(diaspore, αAlO(OH))
Fe的氧化物與氫氧化物	Hematite (赤鐵礦Fe_2O_3), Magnetite (磁鐵礦,Fe_3O_4), goethite(針鐵礦αFe(OH))
Ti的氧化物	Anatase (銳鈦礦,TiO_2)

Hematite

Goethite

Bauxite（**鋁土礦**）, the principal ore of aluminum, is a rock mixture consisting mostly of several hydrous aluminum oxide minerals, including boehmite, diaspore, gibbsite, and impurities such as QUARTZ, CLAY MINERALS, and iron hydroxides.

Example five Al-minerals that weather to form bauxite: kaolinite, muscovite, biotite, hornblende, feldspar.

Bauxite

Chemical Weathering: Clay Minerals

Generated strictly as a weather product by many types of chemical weathering

$$KAlSi_3O_8 + 2H^+ + 12H_2O \longleftrightarrow KAl_3Si_3O_{10}(OH)_2 + 2K^+ + 6H_4SiO_4$$

K-spar **Muscovite Clay**

Hydrolysis + Hydration

$$2KAl_3Si_3O_{10}(OH)_2 + 2H^+ + 3H_2O \longleftrightarrow 3Al_2Si_2O_5(OH)_4 + 2K^+$$

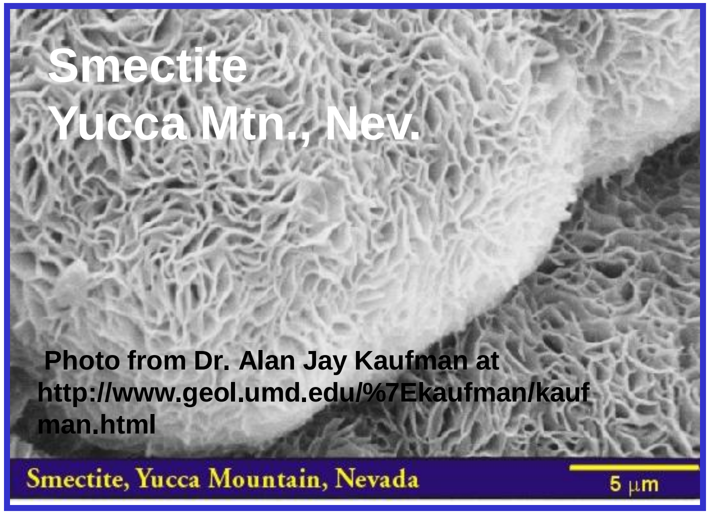
Muscovite Clay **Kaolinite Clay**

Hydrolysis + Hydration

$$Al_2Si_2O_5(OH)_4 + 5H_2O \longleftrightarrow 2Al(OH)_3 + 2H_4SiO_4$$

Kaolinite Clay **Gibbsite Clay**

Hydrolysis + Hydration



Smectite
Yucca Mtn., Nev.

Photo from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

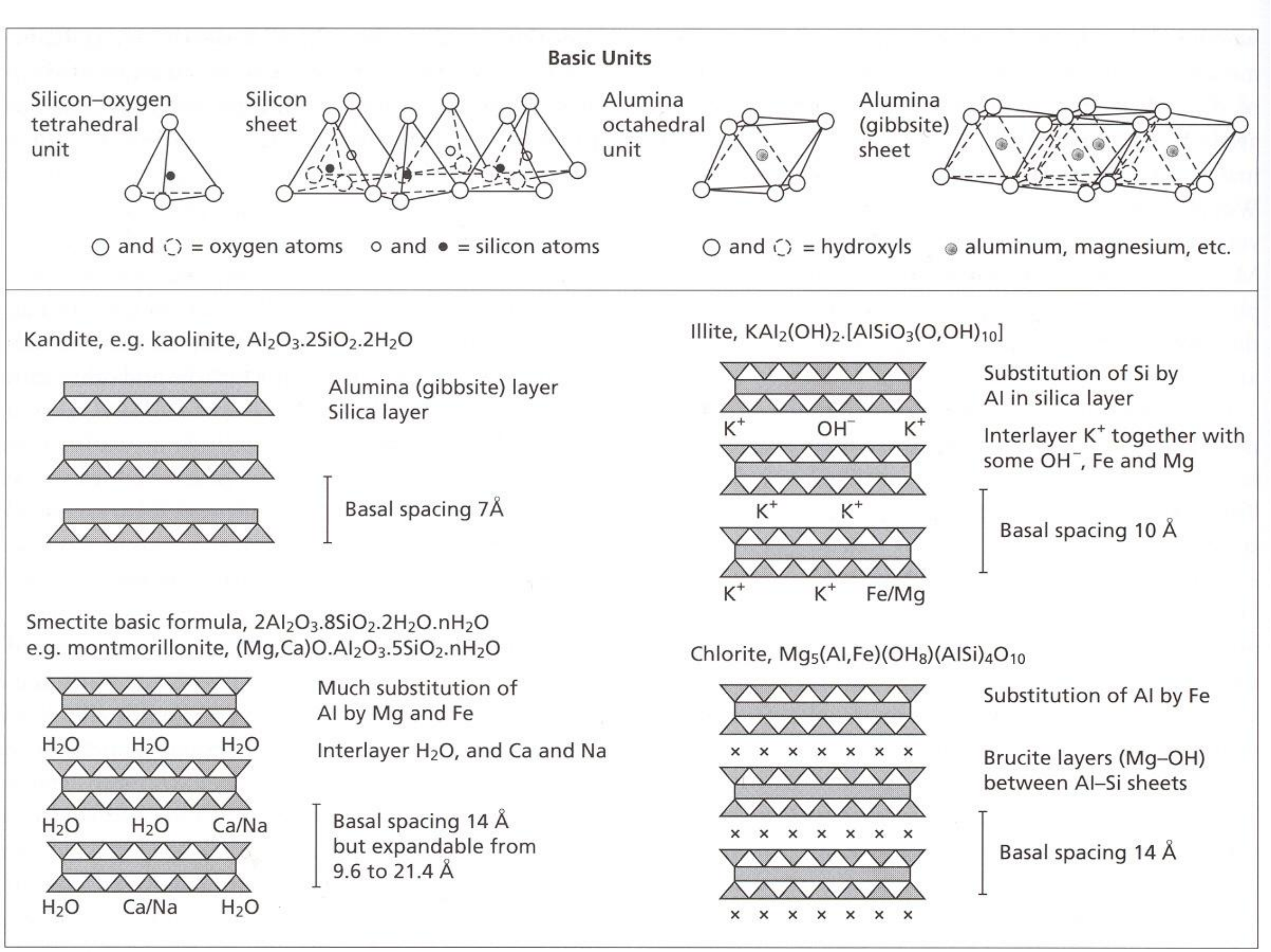
Kaolinite

Clay Minerals

黏土礦物基本上是含氫氧根(OH-)或水(H_2O)之鋁矽酸鹽，其中有些礦物會有Mg, Fe取代Al的現象。屬葉狀矽酸鹽(phyllosilicates)。

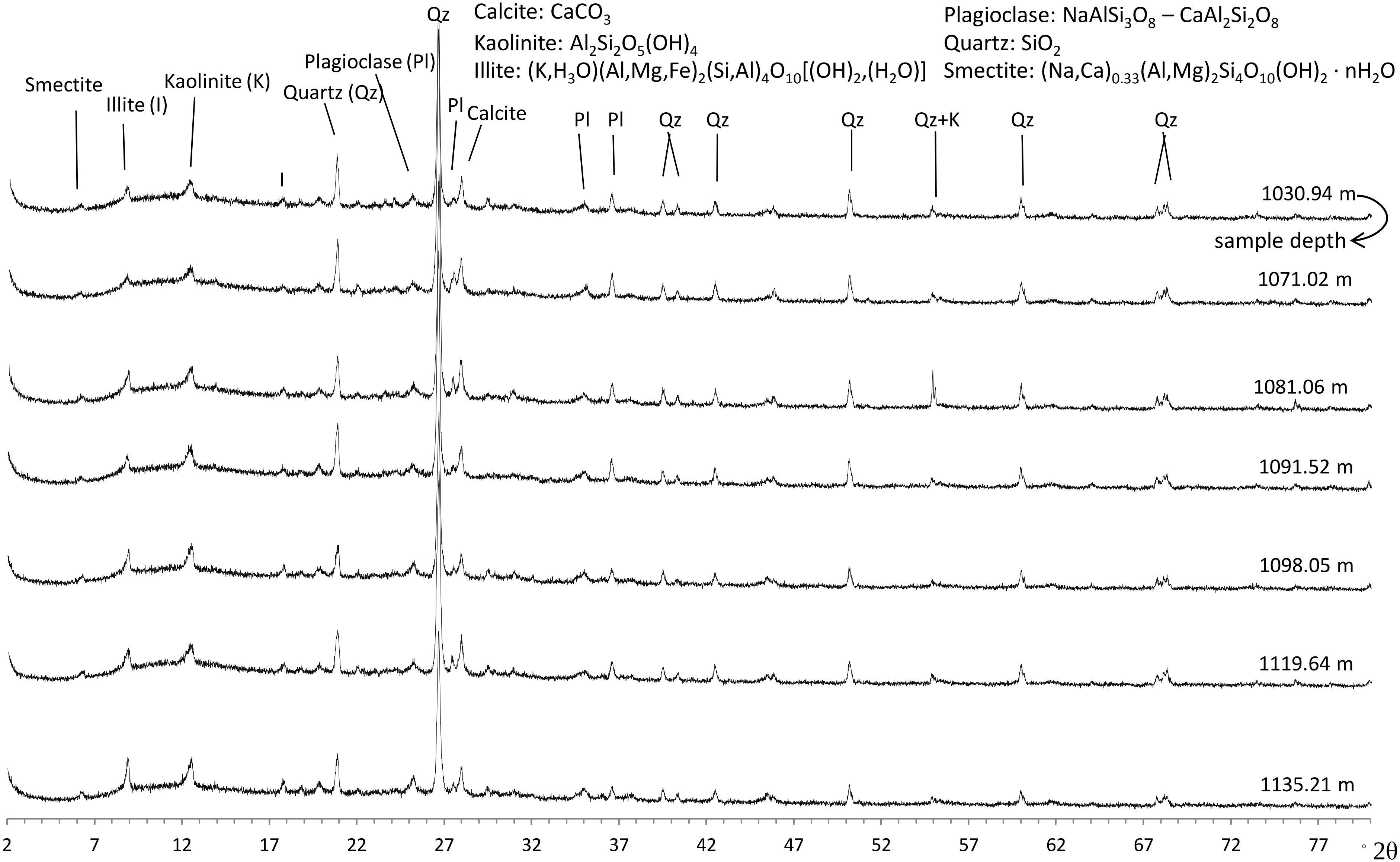
礦物群	化學成分	主要礦物	四面體(tetrahedral)層：八面體(octahedral)層	附註
Kandite group	含水、鋁矽酸鹽 hydrous aluminium silicate	Kaolinite(高嶺石$Al_2Si_2O_5(OH)_4$), halloysite (禾樂石 $Al_2Si_2O_5(OH)_4.nH_2O$)	1:1	
Illite group	含水、鉀矽酸鹽	Illite(伊萊石$(K,H_3O)(Al, Mg,Fe)_2(Si,Al)_4O_{10}(OH)_2.H_2O$)	2:1	illite最常見的黏土礦物
Smectite group	複合、含水、鎂鋁矽酸鹽	Montmorillonite(蒙脫石,大約化學式$(Al，Fe, Mg, Zn, Ca, Na)_4(Si_4O_{10})_2(OH)_4.nH_2O$)；vermiculite(蛭石,$Mg_3(Si, Al)_4(OH)_2.4.5H_2O[Mg]_{0.35}$)	2:1	Expandable clay
Chlorite group	Hydrous silicate of Al, Fe and Mg	Chlorite (綠泥石,$(Mg,Fe)_3(Si,Al)_4O_{10}).(Mg,Fe)_3(OH)_6$)	2:2	主要是非風化產物、常見於變質岩(如綠色片岩)與火成岩(Mg-Fe矽酸鹽的換質產物)
Mixed-layer group	混成黏土	Illite-montmorillonite mixed-layers		

Structures of clay minerals



Tucker (2001) p.98

note: gibbsite layer: 由Al-O/OH組成的八面體層片稱之，因gibbsite(水鋁石) 的化學是為$Al(OH)_3$
Brucite layer: 由Mg-O/OH組成的八面體層片稱之，因brucite(水鎂石)化學式為$Mg(OH)_2$
上圖Chlorite部分，x成一行表示brucite layer故為2:2
上圖層間的陽離子，很容易於風化或成岩過程中被leached out of the clay mineral by percolating waters.



Calcite: $CaCO_3$
Kaolinite: $Al_2Si_2O_5(OH)_4$
Illite: $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$

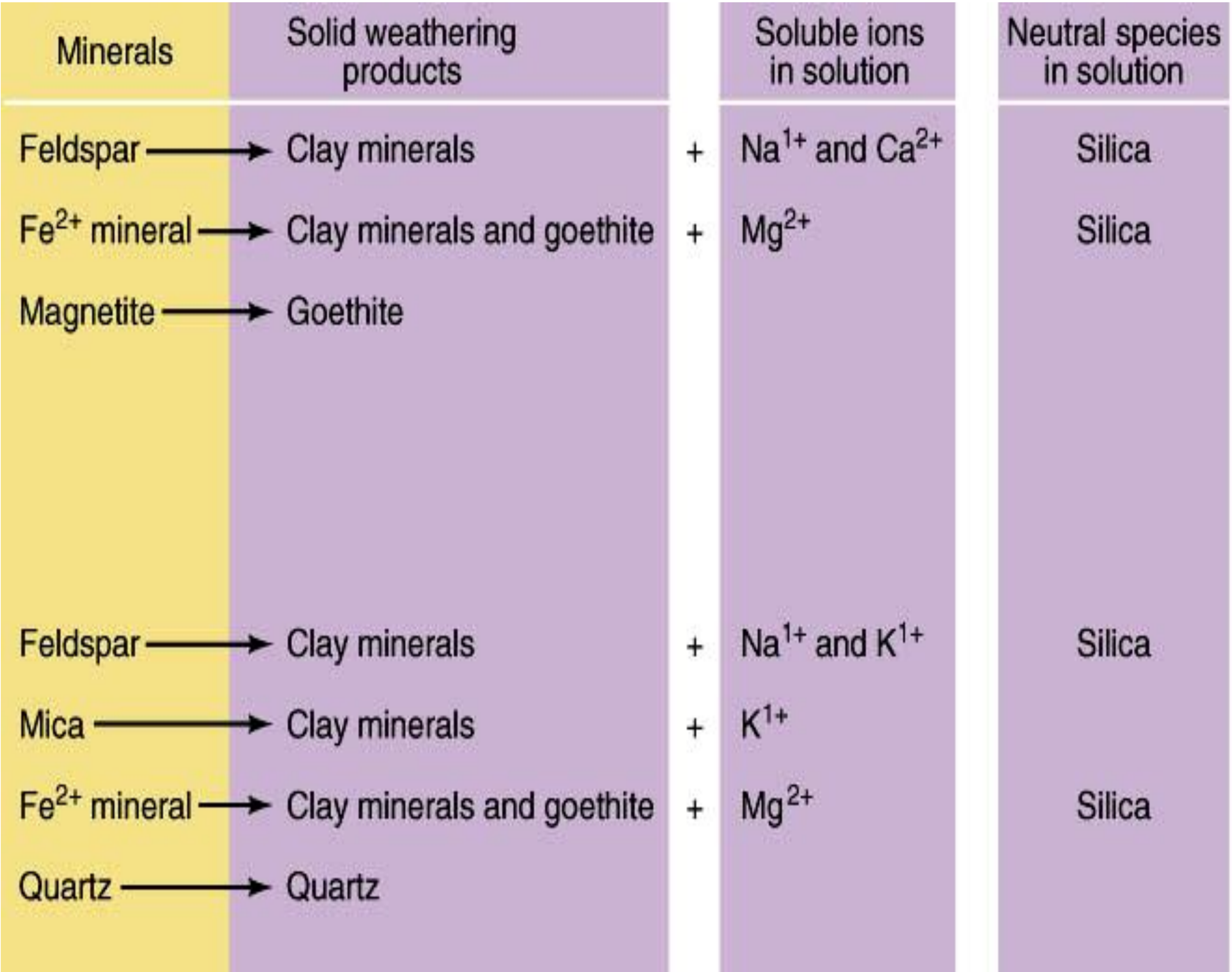
Plagioclase: $NaAlSi_3O_8 - CaAl_2Si_2O_8$
Quartz: SiO_2
Smectite: $(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$

XRD diffractograms of shale samples (bulk rock Chinshui Shale) from TCDP-A borehole, Taichung

Effects of Chemical Weathering on Basalt and Granite

Basalt

Granite



Minerals		Solid weathering products		Soluble ions in solution	Neutral species in solution
Feldspar	→	Clay minerals	+	Na^{1+} and Ca^{2+}	Silica
Fe^{2+} mineral	→	Clay minerals and goethite	+	Mg^{2+}	Silica
Magnetite	→	Goethite			
Feldspar	→	Clay minerals	+	Na^{1+} and K^{1+}	Silica
Mica	→	Clay minerals	+	K^{1+}	
Fe^{2+} mineral	→	Clay minerals and goethite	+	Mg^{2+}	Silica
Quartz	→	Quartz			

1.2.3 Weathering Rate

Goldich's weathering series vs. Bowen's reduction series:

unstable

stable

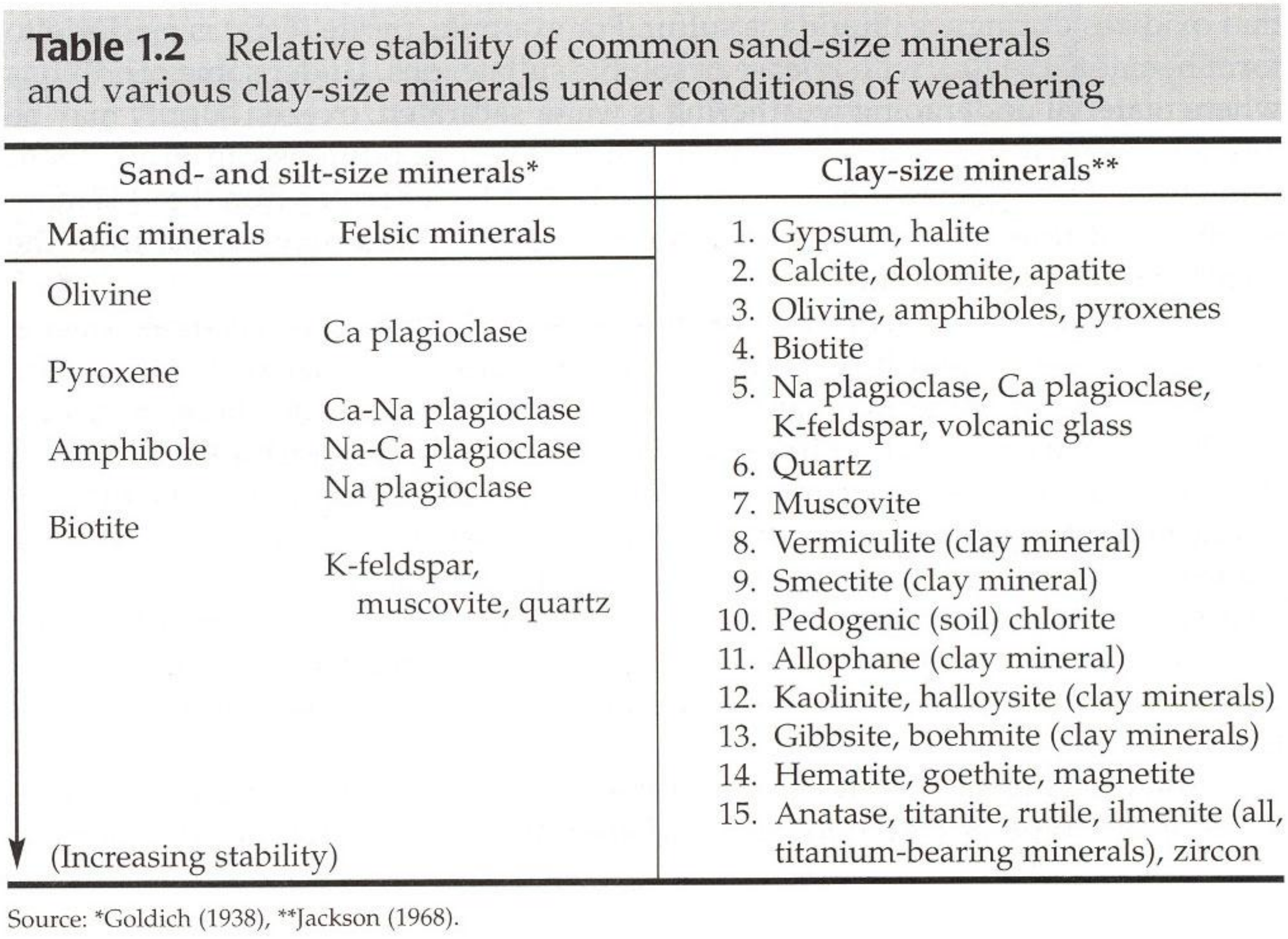


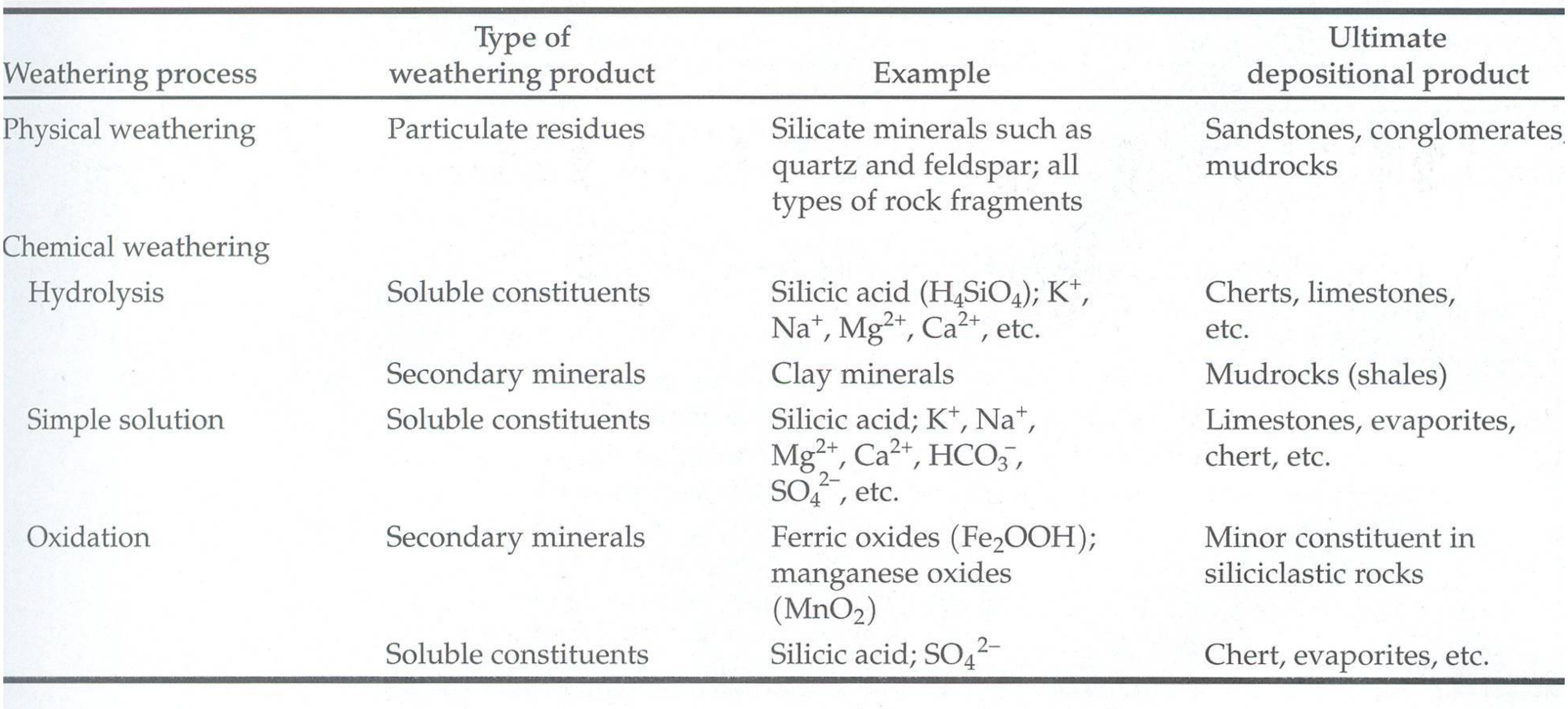
Table 1.2 Relative stability of common sand-size minerals and various clay-size minerals under conditions of weathering

Sand- and silt-size minerals*		Clay-size minerals**
Mafic minerals	Felsic minerals	
Olivine		1. Gypsum, halite
	Ca plagioclase	2. Calcite, dolomite, apatite
Pyroxene		3. Olivine, amphiboles, pyroxenes
	Ca-Na plagioclase	4. Biotite
Amphibole	Na-Ca plagioclase	5. Na plagioclase, Ca plagioclase, K-feldspar, volcanic glass
	Na plagioclase	6. Quartz
Biotite		7. Muscovite
	K-feldspar, muscovite, quartz	8. Vermiculite (clay mineral)
		9. Smectite (clay mineral)
		10. Pedogenic (soil) chlorite
		11. Allophane (clay mineral)
		12. Kaolinite, halloysite (clay minerals)
		13. Gibbsite, boehmite (clay minerals)
		14. Hematite, goethite, magnetite
(Increasing stability)		15. Anatase, titanite, rutile, ilmenite (all, titanium-bearing minerals), zircon

Source: *Goldich (1938), **Jackson (1968).

1.2.4 Products of subaerial weathering

Table. 1.3 Principal kinds of products formed by subaerial weathering processes and the types of sedimentary rocks ultimately formed from these products.



Weathering process	Type of weathering product	Example	Ultimate depositional product
Physical weathering	Particulate residues	Silicate minerals such as quartz and feldspar; all types of rock fragments	Sandstones, conglomerates, mudrocks
Chemical weathering			
Hydrolysis	Soluble constituents	Silicic acid (H_4SiO_4); K^+, Na^+, Mg^{2+}, Ca^{2+}, etc.	Cherts, limestones, etc.
	Secondary minerals	Clay minerals	Mudrocks (shales)
Simple solution	Soluble constituents	Silicic acid; K^+, Na^+, Mg^{2+}, Ca^{2+}, HCO_3^-, SO_4^{2-}, etc.	Limestones, evaporites, chert, etc.
Oxidation	Secondary minerals	Ferric oxides (Fe_2OOH); manganese oxides (MnO_2)	Minor constituent in siliciclastic rocks
	Soluble constituents	Silicic acid; SO_4^{2-}	Chert, evaporites, etc.

Products of weathering:
A. siliciclastic sedimentary rocks

矽質沉積岩占75%的地球表面沉積物。

風化作用造成的固態物質，經常以石英為主，稱為矽質顆粒(siliciclastic grains)，由這些顆粒造成的沉積岩稱為矽質沉積岩。矽質沉積岩包括礫岩、砂岩、頁岩等。

Note: 這些風化而來的固態物質也經常來自陸地，所以他們也稱為陸源顆粒(terrigenous grains)。

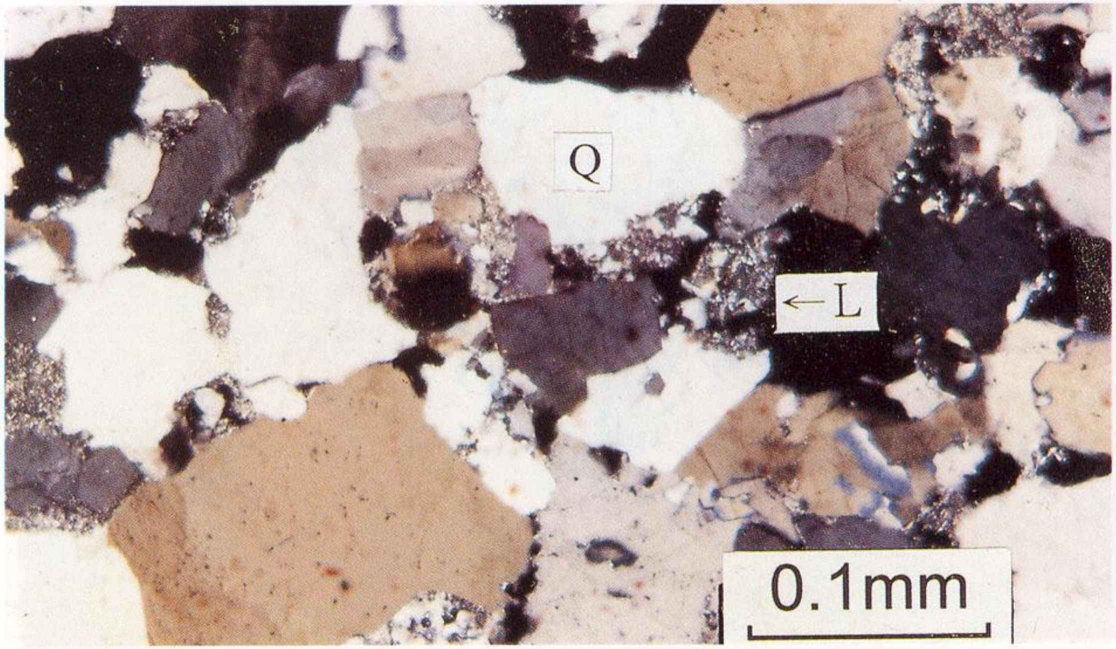


圖3-26　石英砂岩岩象

顯微鏡下的白冷層石英砂岩，由石英(Q)和少許岩屑(L)組成。顆粒多次角形，淘選度佳。由於受過深埋，所以顆粒間有些微的壓溶現象，形成齒狀穿插的邊緣 (南投縣水里鄉)。

鄧屬予(1997)

Weathering products


海岸山脈--大港口層（2003 中央大學野地野外實習）

Gravel- or sand-sized products:
e.g, conglomerates and
sandstones

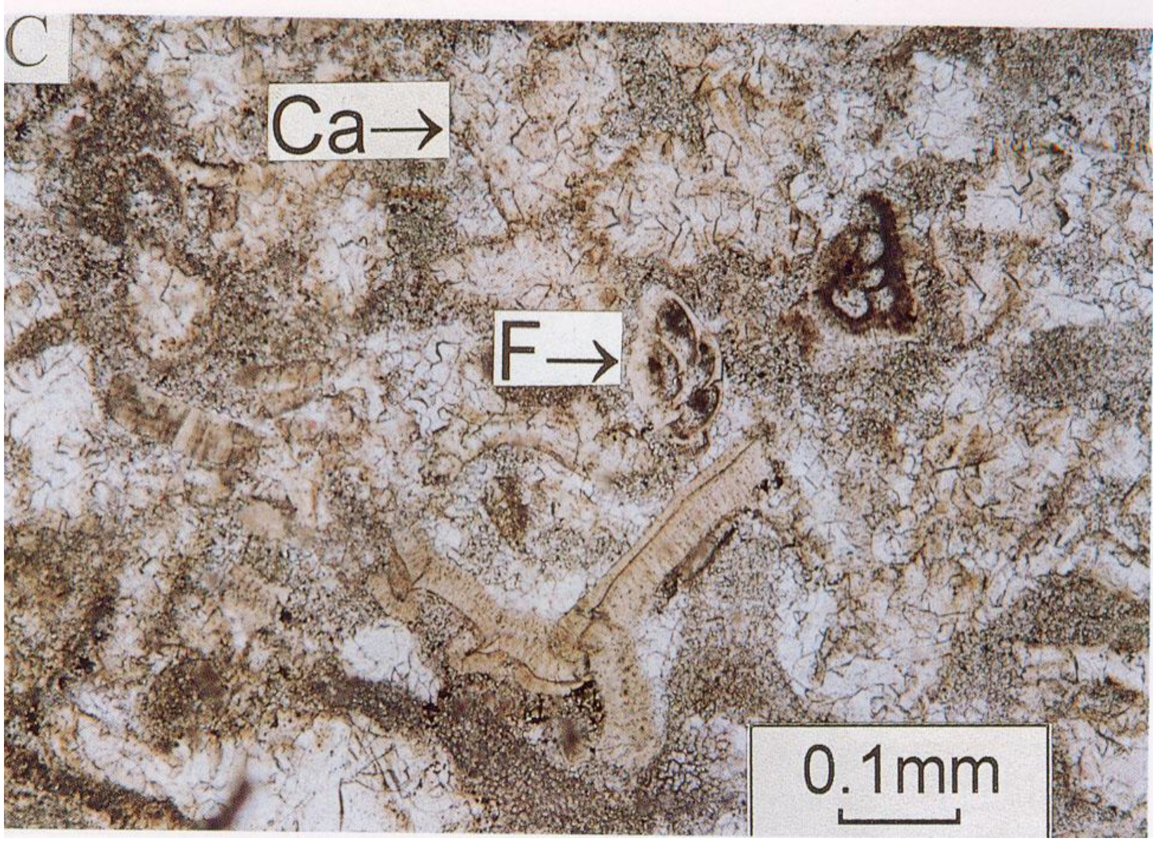
Clay-sized products:
Mudstone or shale


恆春-- 四重溪層(2003 中央大學野地野外實習)

Products of weathering:
B. Chemical/biochemical sedimentary rocks

化學/生物化學沉積岩
占25%的地球表面沉積物。

風化作用造成的溶解物(如Ca, Mg, Si)到達湖或海時，因化學或生物化學作用，將這些溶解物轉化成固態，形成沉積物。如石灰岩(limestone)、燧石(chert)、蒸發岩(evaporite)等。



Limestone (半屏山石灰岩)

鄧屬予(1997)

1.3 Submarine weathering processes and products

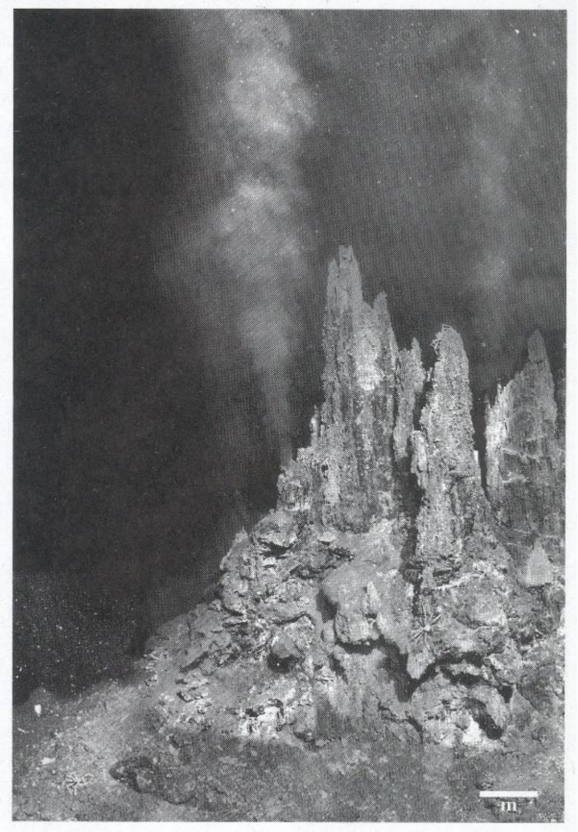


Fig. 1.3 A multiple-orifice black smoker, Faulty Towers complex, Mothra hydrothermal vent field, Endeavour Segment, Juan de Fuca ridge. The constructional chimneys in the foreground were built by precipitation of sulfides and other minerals from heated water issuing from the vents at temperatures exceeding 250°C.

1. Interaction of seawater with hot oceanic rocks along mid-ocean ridge; Magnesium, sulfate, and sodium ions are removed from seawater, whereas elements such as iron, manganese, silicon, potassium, lithium, and strontium are enriched in the seawater. Products at oceanic hot springs: sulfide (pyrite, $FeS2$, chalcopyrite, $CuFeS2$), sulfate and oxides.
2. Low-temperature (<20°C) alteration of volcanic rocks and sediments on the ocean floor. Products: smectite clay mineral, zeolite, chlorite.

Submarine weathering process is important for changes in composition of seawater owing to ion exchange during the reaction of seawater with basalts.

1.4 Soils

1.4.1 Soil-forming processes

1. **Additions to the ground surface** - precipitation of dissolved ions in rainwater; influx of solid particles such as windblown dust; addition of organic matter from surface vegetation.
2. **Transformations**

a. Decomposition of organic matter within soils to produce organic compounds.

b. Weathering of primary minerals; formation of secondary minerals, including iron oxides.

3. **Transfers**

a. Movement of solids or suspended material downward from one soil horizon to a lower horizon by groundwater percolation (eluviation).

b. Accumulation of soluble or suspended material in a lower horizon (illuviation).

c. Transfer of ions upward by capillary movement of water and precipitation of ions in the soil profile.

4. **Removals**: removal of substances still in solution to become part of the dissolved constituents in groundwater or surface water.
5. **Bioturbation of soil** - soil disruption by animals and plants.

Soils

Photo from Dr. Alan Jay Kaufman at
http://www.geol.umd.edu/%7Ekaufman/kaufman.html

Important soil-forming processes

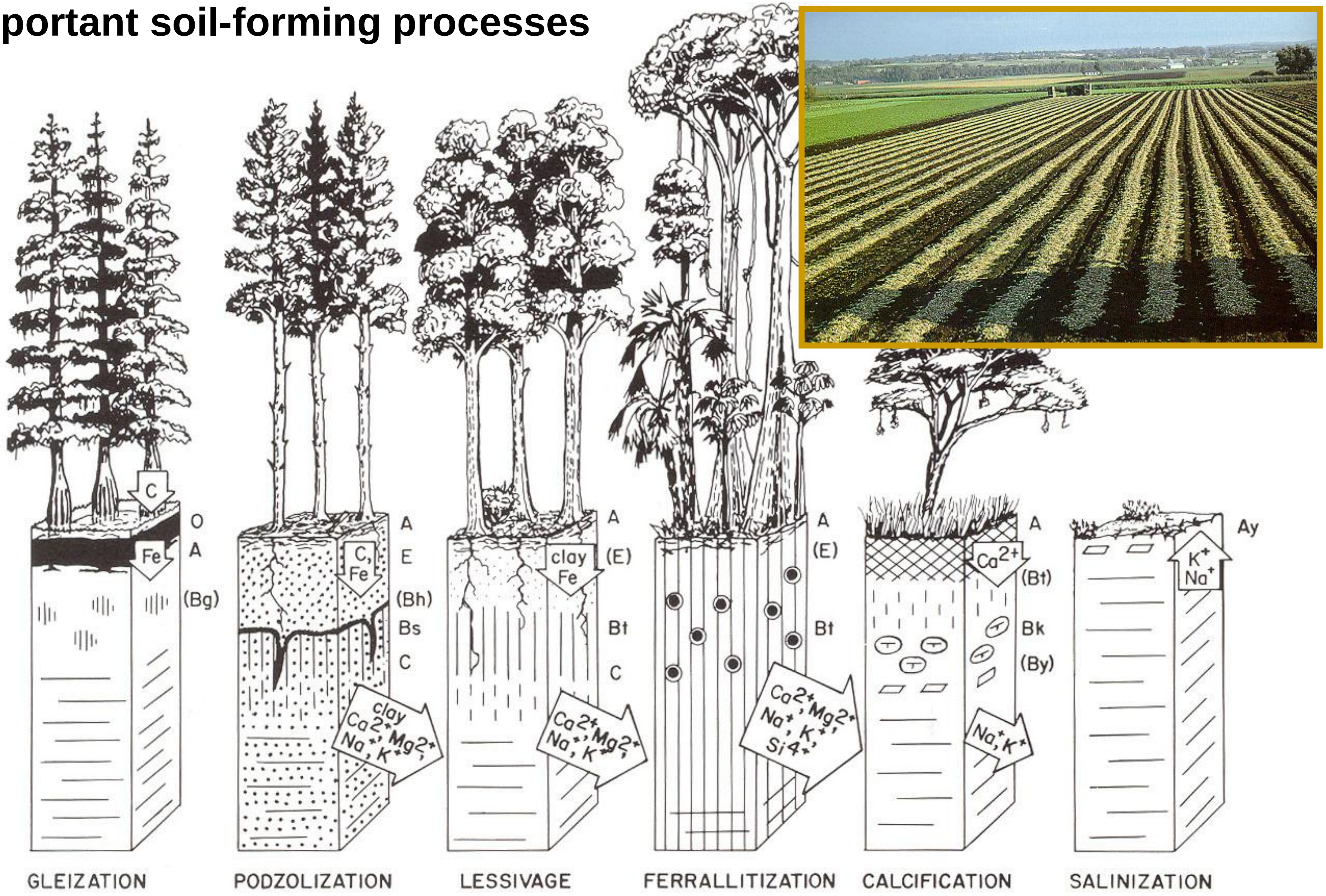
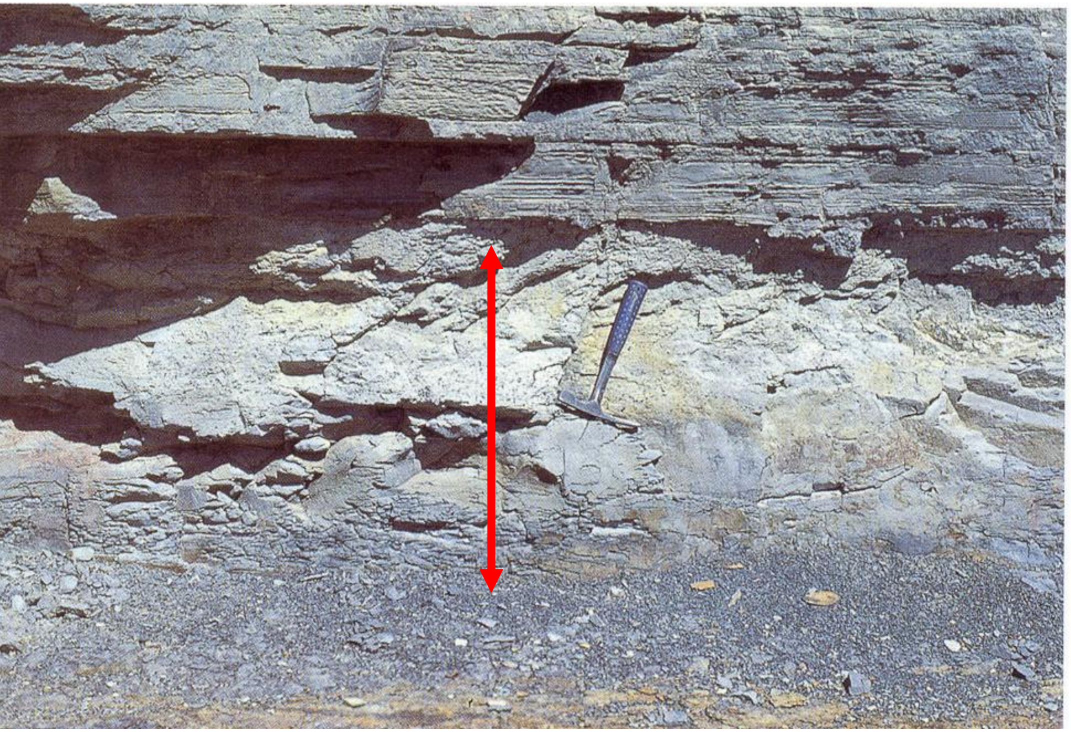


Figure 1.17. Common soil-forming regimes (from Retallack, 1990a, *Soils of the past*, fig. 4.12, with permission of Chapman & Hall)

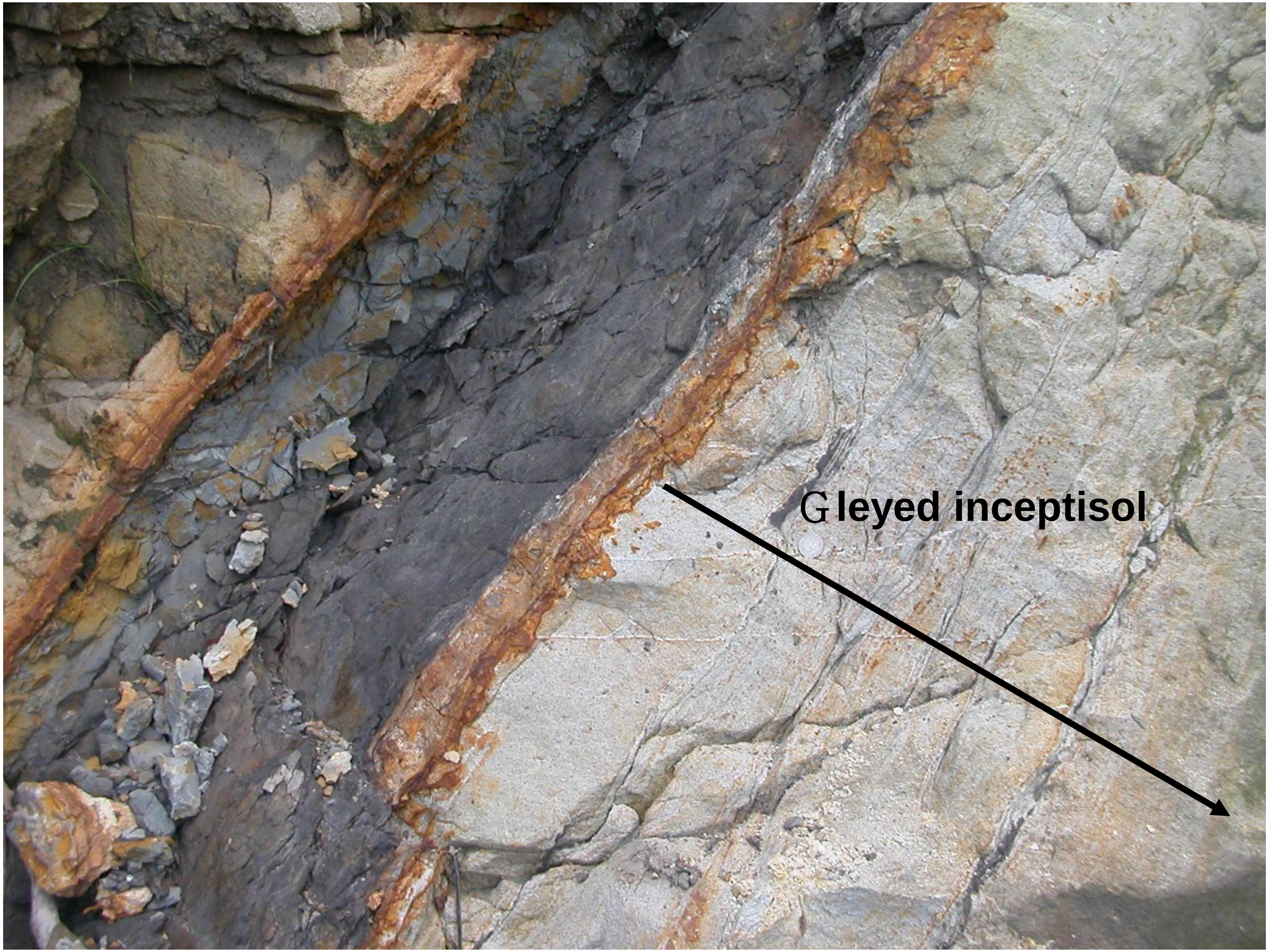
Gleization (潛水灰化作用)

在缺(低)氧的泡水土壤中(waterlogged soil) ，使Fe^{3+}還原成Fe^{2+} ，形成藍灰色或綠灰色土壤的作用 。

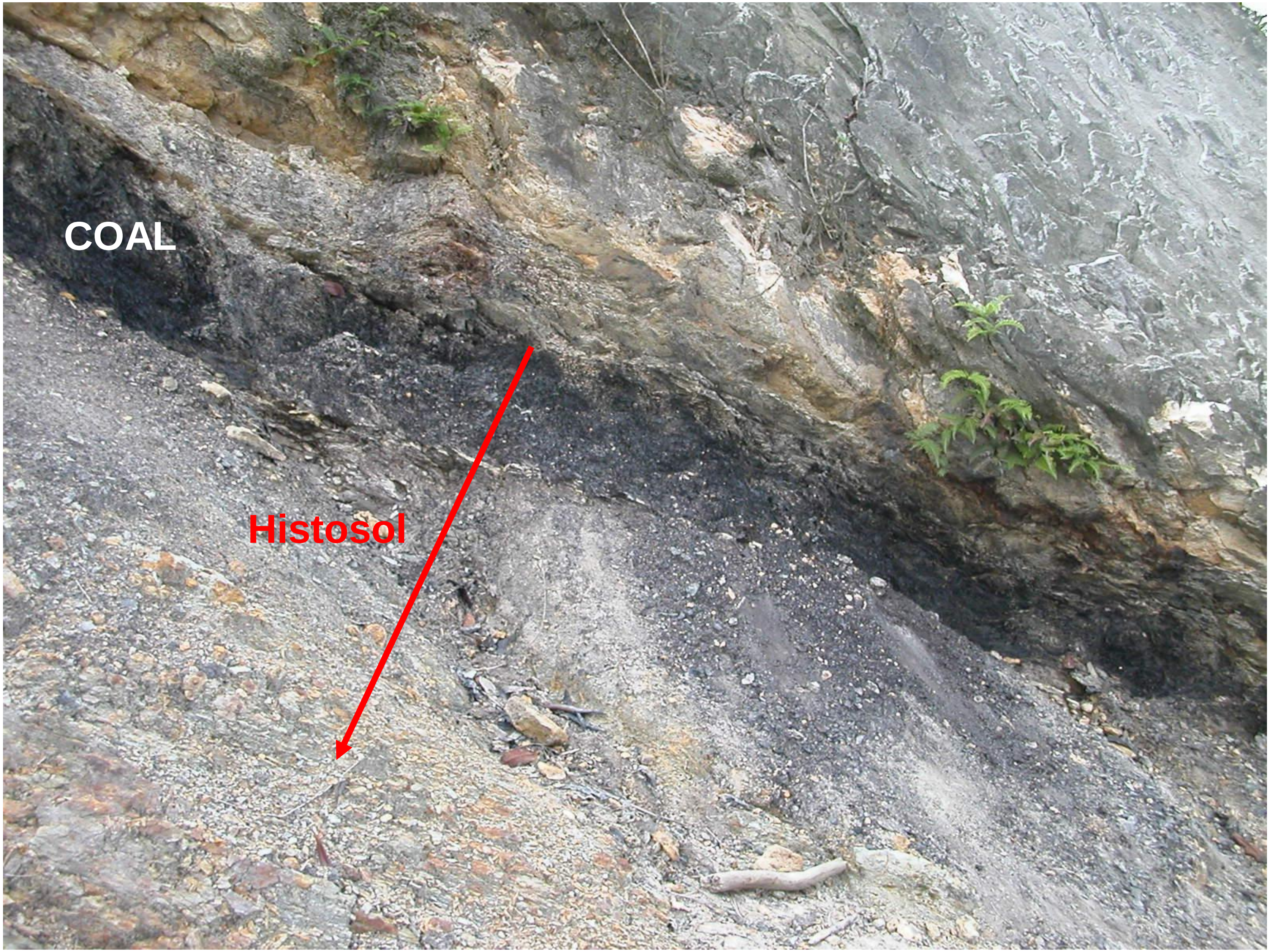


Colour photo 100. **Gleyed Inceptisol.** The massive claystone below the bedded siltstones is a paleosol with abundant siderite and the blue-grey to purple-grey colour that is characteristic of waterlogged soils. Such colours and minerals of reducing chemical conditions are called gley features. Stagnant water in the profile has allowed preservation of much organic matter, including recognizable root traces and faecal pellets. However, it was not always waterlogged, as can be seen from deeply penetrating root traces, burrows like those of earthworms (see Colour photo 19), and profile differentiation into a light-coloured surface over a purple and clayey subsurface horizon. This horizon differentiation has not completely obscured relict bedding, so the paleosol was an Inceptisol, and in view of its gleyed nature, an Aquept. This is the Turimetta clay eroded phase paleosol in the Early Triassic, Garie Formation, south of Bilgola Beach, New South Wales, Australia (Retallack, 1976, 1977). Hammer handle for scale is 25 cm long.

Retallack (1997)



東坑層(苗栗明德水庫)



東坑層（苗栗明德水庫）

Podzolization (灰化作用)

酸性淋溶作用(leaching)，使表層的Al、Fe、有機質往下傳輸。本作用造成表層殘留石英，底層則聚集三氧化鋁鐵(sesquioxides)或有機質。

Lessivage (澱積作用)

將黏土由表層(A層)往下搬運至B層的裂隙澱積。本作用造成B層含較多的黏土，且顏色較表層為淺。

Calcification (鈣化作用)

在半乾燥到亞潮濕(subhumic)的氣候區內，碳酸鈣形成結核、聚集成帶，造成calcrete 。

Ferrallitization (or laterization 紅鋁鐵礦化)

強烈與深部風化，造成厚層、成分均勻的土壤剖面。土壤富含黏土與三氧化鋁鐵。

Near the front entrance of National Central University

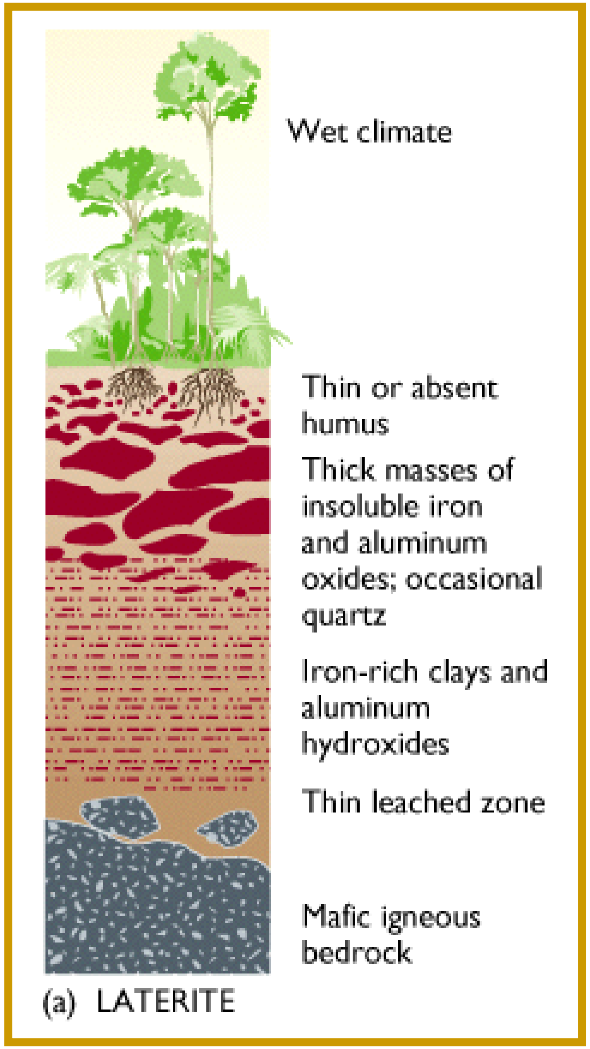
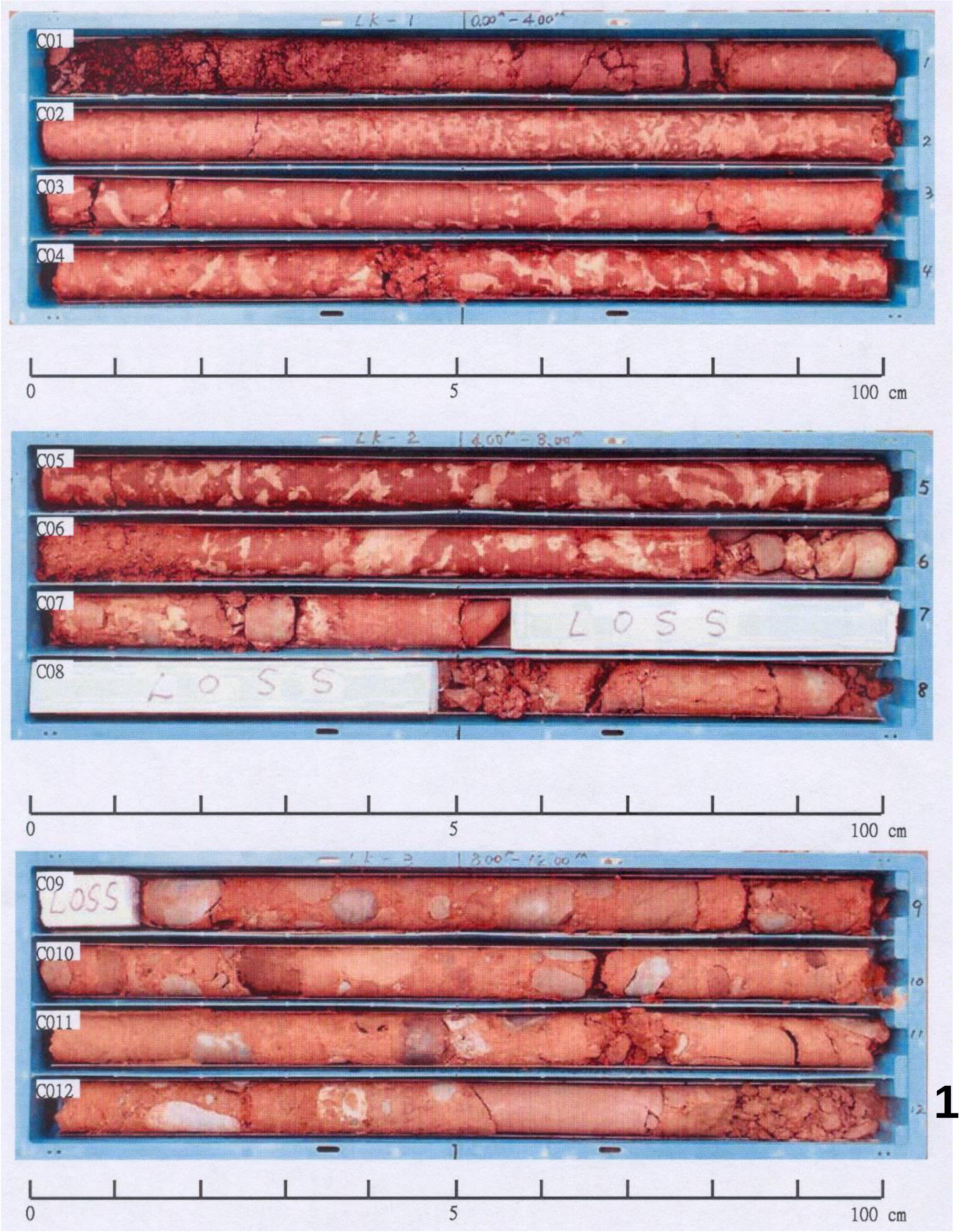


Figure from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

1.4.2 Soil profiles and soil classification

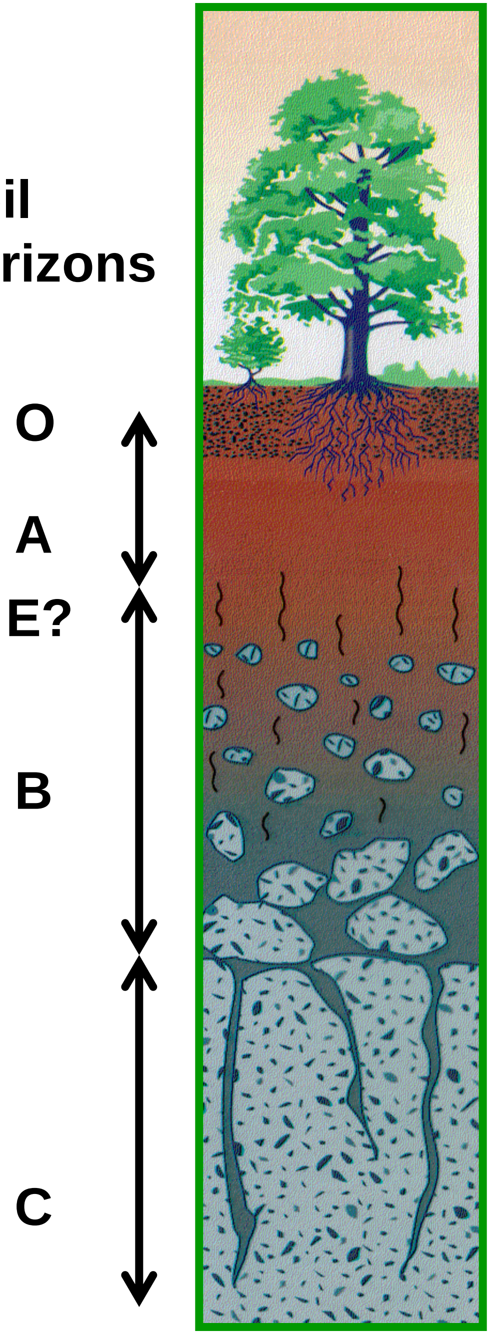


林口台地紅土剖面

Soil Profile

O horizon: 有機質層(e.g. coal)
A horizon: 表土層(屬洗出層)
B horizon: 底土層(屬洗入層)
C horizon: 被岩層

Soil horizons



Topsoil	**Organic processes**
Soil leached of soluble minerals; rich in clay and insoluble minerals and organic matter	**Hydrolisis and Oxidation**
Little organic mater; dissolved minerals from A horizon precipitated	**Hydrolisis New Minerals**
Bedrock cracked and weathered	**Mechanical weathering**

Figure from Dr. Alan Jay Kaufman at http://www.geol.umd.edu/%7Ekaufman/kaufman.html

1.4.3 Paleosols

Paleosols in the Miocene Penghu basalts

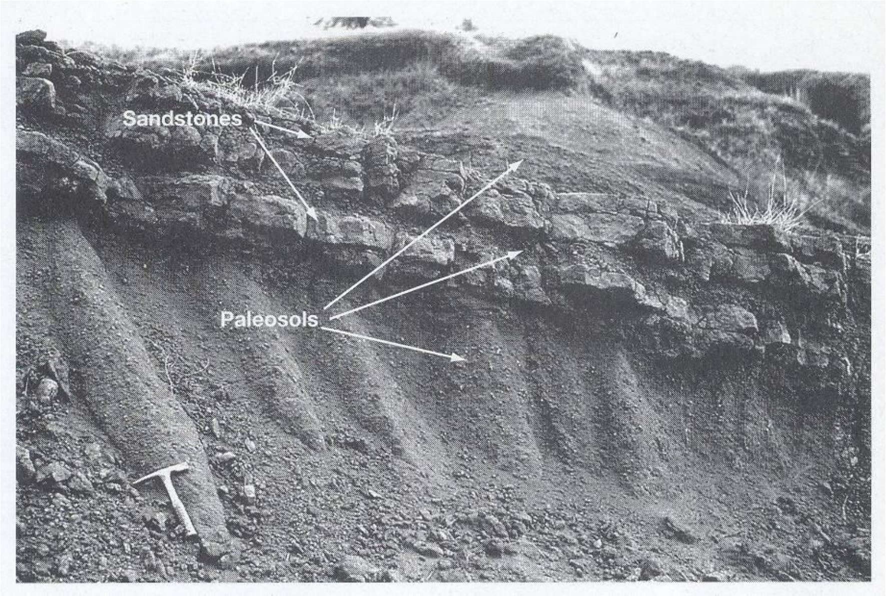


Fig. 1.7 Red paleosols exposed below bedded sandstones in the Middle Miocene, Chinji Formation, Siwalik Group, in a creek bed 3 km south of Khaur, Potwar Plateau, Pakistan. The hammer is 25cm long.

1.4.4 Recognition of paleosols

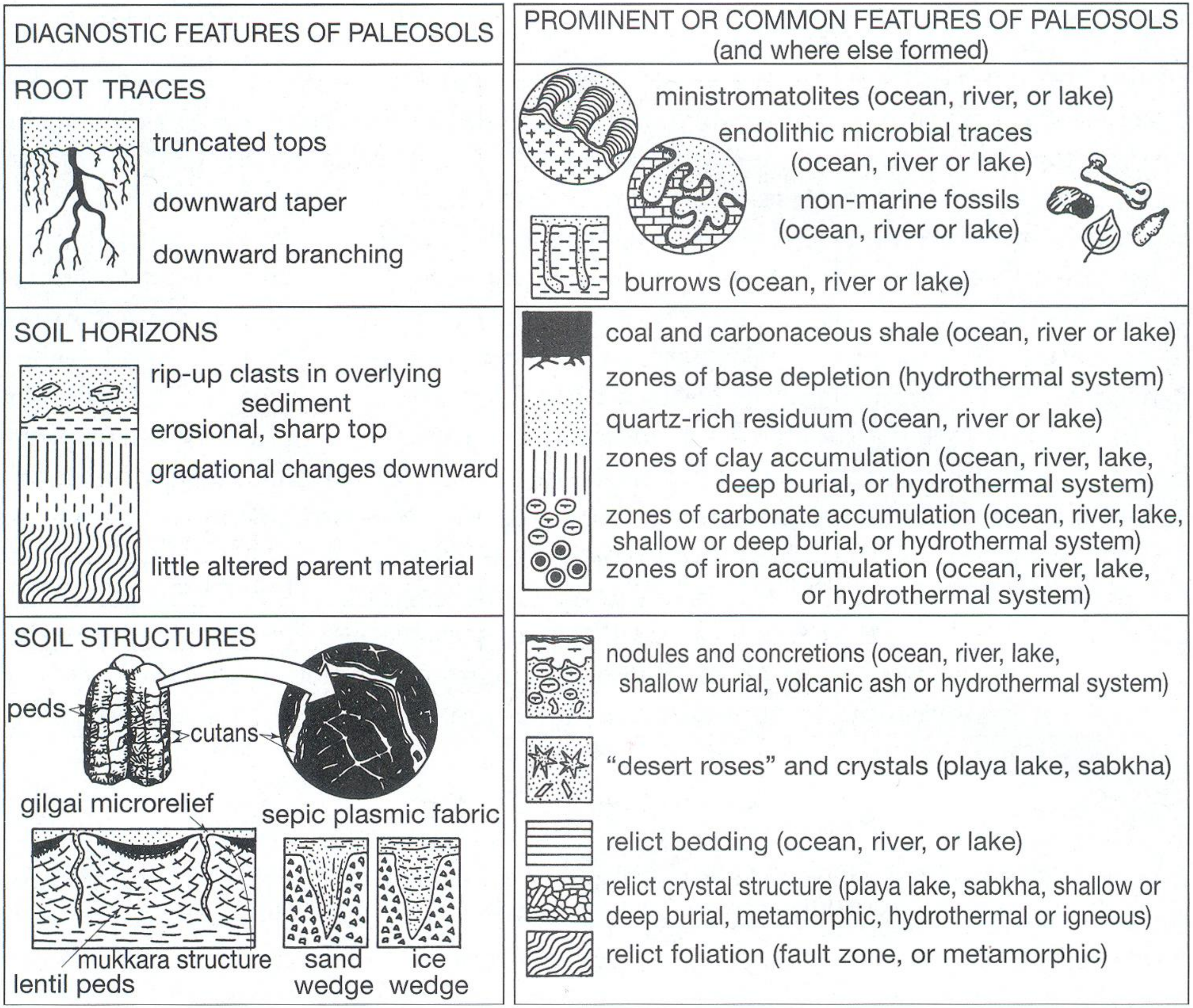
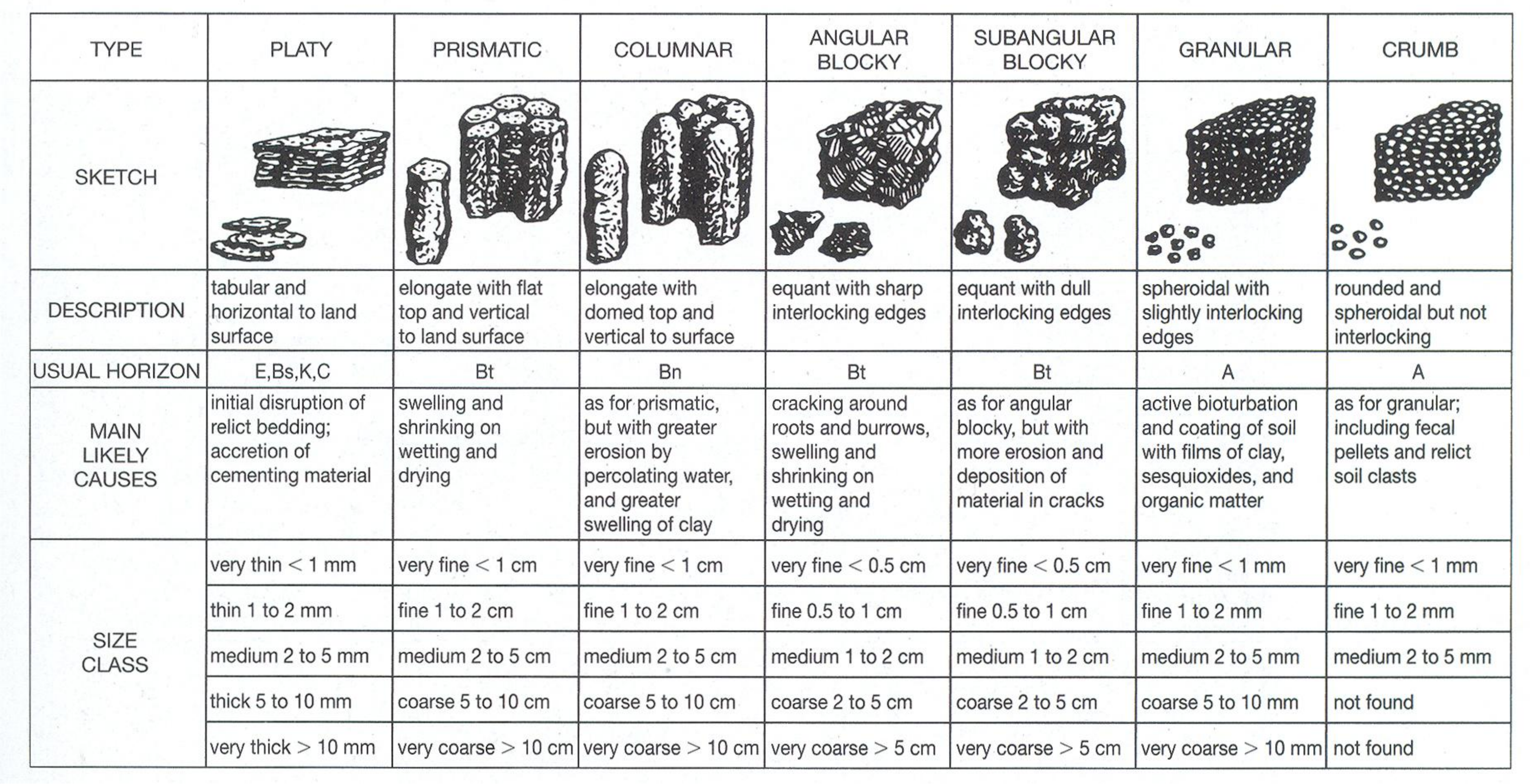


Fig. 1.4 Characteristic and common features useful in recognition of paleosols.

Root traces – one of the indicators for paleosol

Fig. 1.5 An example of root traces in a paleosol. The original organic matter has been partially replaced by iron oxides. Early Miocene, Molalla Formation, western Oregon.



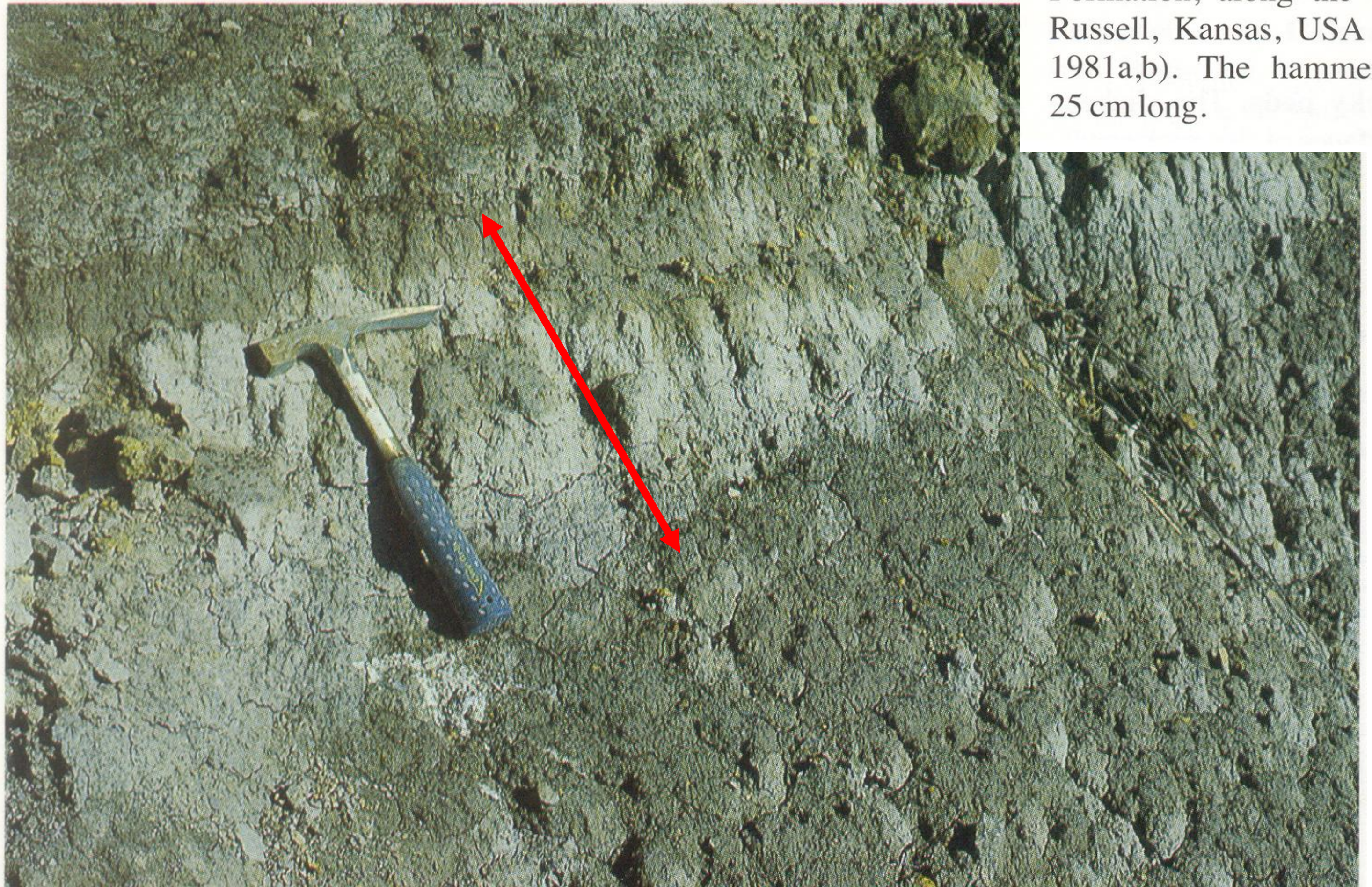
TYPE	PLATY	PRISMATIC	COLUMNAR	ANGULAR BLOCKY	SUBANGULAR BLOCKY	GRANULAR	CRUMB
SKETCH							
DESCRIPTION	tabular and horizontal to land surface	elongate with flat top and vertical to land surface	elongate with domed top and vertical to surface	equant with sharp interlocking edges	equant with dull interlocking edges	spheroidal with slightly interlocking edges	rounded and spheroidal but not interlocking
USUAL HORIZON	E,Bs,K,C	Bt	Bn	Bt	Bt	A	A
MAIN LIKELY CAUSES	initial disruption of relict bedding; accretion of cementing material	swelling and shrinking on wetting and drying	as for prismatic, but with greater erosion by percolating water, and greater swelling of clay	cracking around roots and burrows, swelling and shrinking on wetting and drying	as for angular blocky, but with more erosion and deposition of material in cracks	active bioturbation and coating of soil with films of clay, sesquioxides, and organic matter	as for granular; including fecal pellets and relict soil clasts
SIZE CLASS	very thin < 1 mm	very fine < 1 cm	very fine < 1 cm	very fine < 0.5 cm	very fine < 0.5 cm	very fine < 1 mm	very fine < 1 mm
	thin 1 to 2 mm	fine 1 to 2 cm	fine 1 to 2 cm	fine 0.5 to 1 cm	fine 0.5 to 1 cm	fine 1 to 2 mm	fine 1 to 2 mm
	medium 2 to 5 mm	medium 2 to 5 cm	medium 2 to 5 cm	medium 1 to 2 cm	medium 1 to 2 cm	medium 2 to 5 mm	medium 2 to 5 mm
	thick 5 to 10 mm	coarse 5 to 10 cm	coarse 5 to 10 cm	coarse 2 to 5 cm	coarse 2 to 5 cm	coarse 5 to 10 mm	not found
	very thick > 10 mm	very coarse > 10 cm	very coarse > 10 cm	very coarse > 5 cm	very coarse > 5 cm	very coarse > 10 mm	not found

Fig. 1.6 Characteristics of various kinds of soil peds.

Colour photo 38. **Blocky peds.** The slickensided purplish black surfaces of this rock specimen are former cutans of iron-manganese oxides (mangans) which define a coarse angular blocky ped. The greenish grey interior of the ped is visible to the upper right, where it has broken open. This rock specimen is from the gleyed subsurface (Bg) horizon of an Aquept paleosol in the late Eocene (Duchesnean North American Land Mammal "Age"), upper Clarno Formation in the red hill west of Hancock Field Station, near Clarno, Oregon, USA (Retallack, 1991c,d). Scale is in centimetres and millimetres.

Colour photo 39. **Slickensided clay skins.** The randomly arranged striated surfaces of this rock specimen are compacted clay skins which define very coarse angular blocky peds. The grey/pink mottling is probably due to burial gleization and hydroxide dehydration during burial of a formerly yellow-brown soil. This rock specimen is from the upper Bt horizon of the Interior clay paleosol, a Paleudalf from the late Eocene (Chadronian North American Land Mammal "Age"), Chadron Formation, in the Pinnacles area of Badlands National Park, South Dakota, USA (Retallack, 1983a). Scale is in millimetres.

Colour photo 40. **Prismatic peds.** The light coloured layer around the hammer is vertically jointed from abundant prismatic peds. This paleosol and others like it supported mangal vegetation within a large tide-dominated delta. Brackish water molluscs have been found in them (Colour photo 21). The prismatic peds are in a Bw horizon beneath a dark carbonaceous A horizon in a Sulfaquent paleosol from the mid-Cretaceous (Cenomanian), upper Dakota Formation, along the Saline River north of Russell, Kansas, USA (Retallack & Dilcher, 1981a,b). The hammer handle for scale is 25 cm long.



Retallack (1997)

Colour photo 5. **Drab-haloed root traces.** Drab-haloes of light green silt surround deeply penetrating root traces and are conspicuous in the red oxidized matrix of the paleosol. They probably formed early during burial of the soil as the root decomposed anaerobically. The paleosol is an Eutrochrept in the Late Devonian (Frasnian), Oneonta Formation, Catskill magnafacies, in road cuts along interstate highway I88 near Unadilla, New York, USA (Gordon & Bridge, 1987). Hammer for scale has a handle 25 cm long.

南莊層(苗栗)

Pedogenic carbonates (calcrete) from the Upper Carnian Raibl Formation, Dolomites, Southern Alps (Italy) showing columnar internal structures in a green to reddish mudstone matrix reflecting a change in paleogroundwater table.

Photo by: Lorenz Keim, Front cover of “Sedimentology 2004, v.51/1”