April 17, 2015
農学国際特論Ⅰ

陸域環境

ー土壌生成･水資源･熱収支ー

Terrestrial Environment (2)

-World soils (soil genesis), Water resources, Physical environment of soil-

東京大学 大学院農学生命科学研究科
農学国際専攻　国際情報農学研究室 溝口　勝

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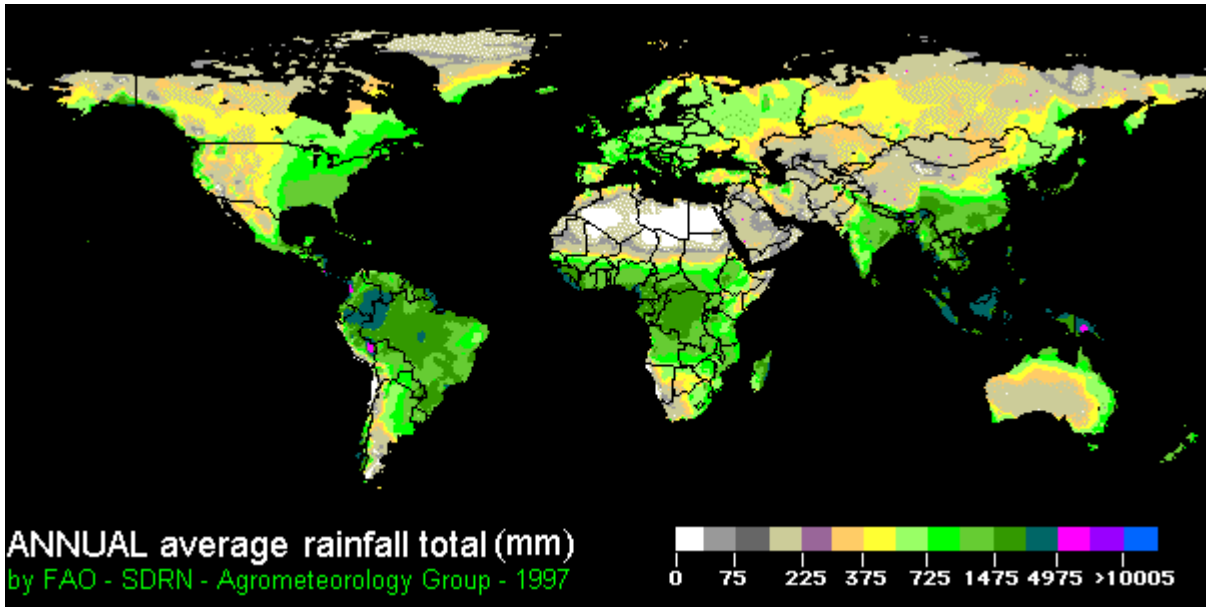
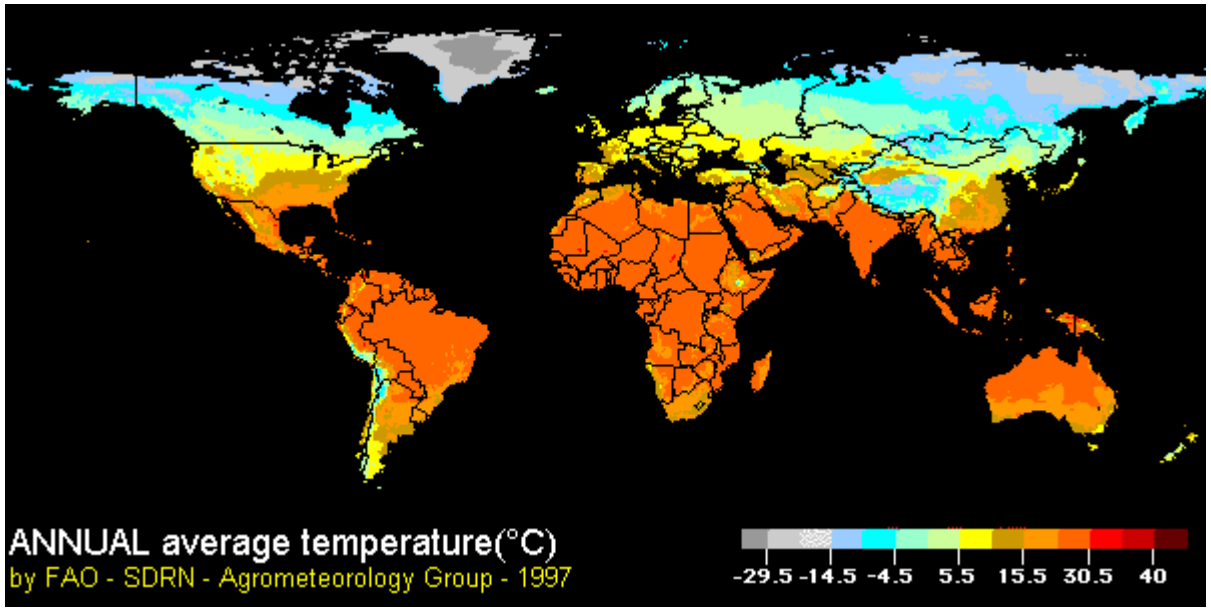
降水量
Precipitation

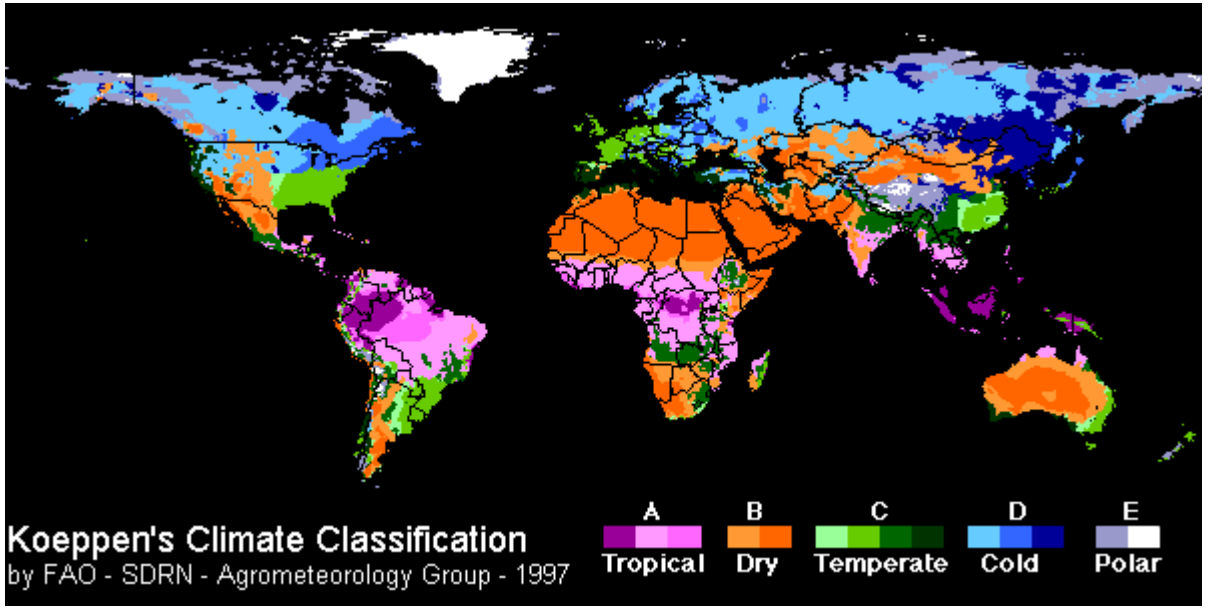


気温
Temperature

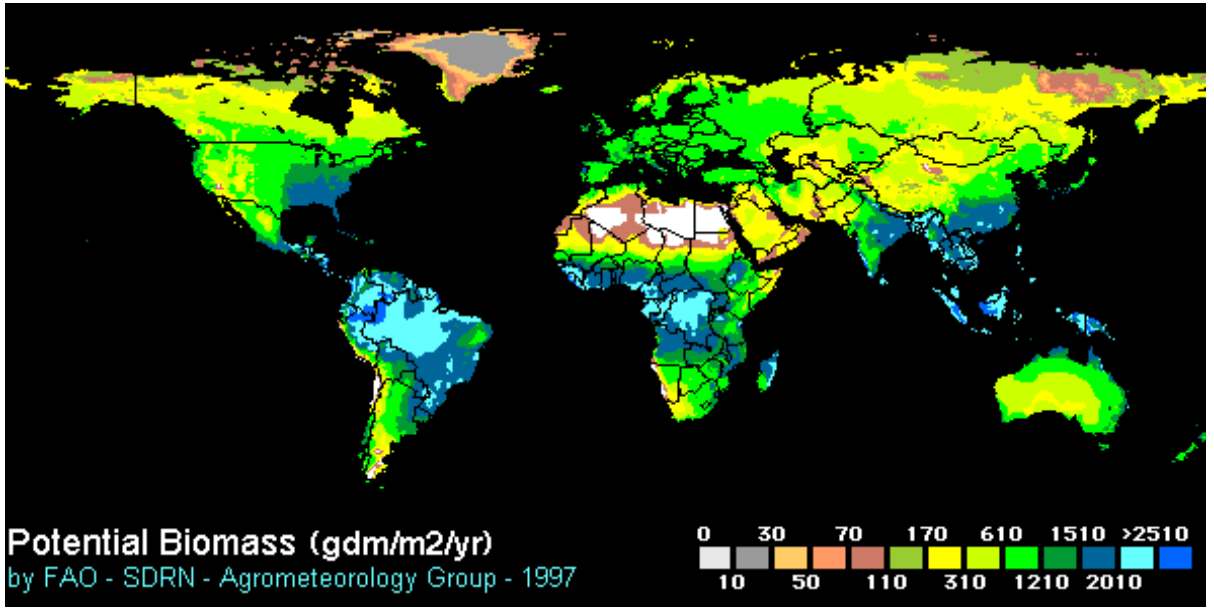


http://www.fao.org/WAICENT/FAOINFO/SUSTDEV/EIdirect/CLIMATE/EIsp0002.htm

気候区分
Climate
classification



植生区分
Vegetation
classification



http://www.fao.org/WAICENT/FAOINFO/SUSTDEV/EIdirect/CLIMATE/EIsp0002.htm

講義の要点
Main point of the lecture

- 生産と環境のための土壌
  - 土壌は土地固有の資源として，農業生産や環境保全のために重要である
- Soil for the production and environment
  - Soil is important for agricultural production and environmental conservation as a resource of intrinsic land

- 土壌学の基礎
  - 土壌生成は生物過程を含む5つの生成因子による
  - 土壌は主として土粒子（固相）・水（液相）・空気（気相）によって構成される
  - 世界の土壌は12のパターン分類される
- Fundamentals of soil science
  - Soil formation is generated by five factors including biological process
  - Soil is mainly composed of three phases, such as soil particles (solid phase) , water(liquid phase) and gas phase(air)
  - The world's soils are classified into 12 patterns

講義の内容
Contents of the lecture

- 水資源：水文学
  - 降水量
- 地表面の熱収支
- 土壌生成
  - 土壌断面
  - 世界の土壌

- Water resources : Hydrology
  - Precipitation
- Heat balance of the ground surface
- Soil formation
  - Soil profile
  - The world's soil

水文学（hydrology）

- 定義
  - 地球上の水循環を対象とする地球科学の一分野
  - 主として、陸地における水をその循環過程から、地域的な水のあり方・分布・移動・水収支等に主眼をおいて研究する科学
- Definition
  - A field of earth science that target the water cycle on Earth
  - Scientific research focuses on nature of regional water, distribution, movement, water balance from the circulation process on earth
- 研究対象
  - 水の供給源としての降水の地域的・時間的分布特性、蒸発、浸透、陸水や地下水の移動等
- Research interests
  - As a source of water, regional characteristics and temporal distribution of precipitation, evaporation, infiltration, and movement of land water and groundwater

Definition of hydrology(1964, UNESCO)
水文学の定義（1964，ユネスコ）

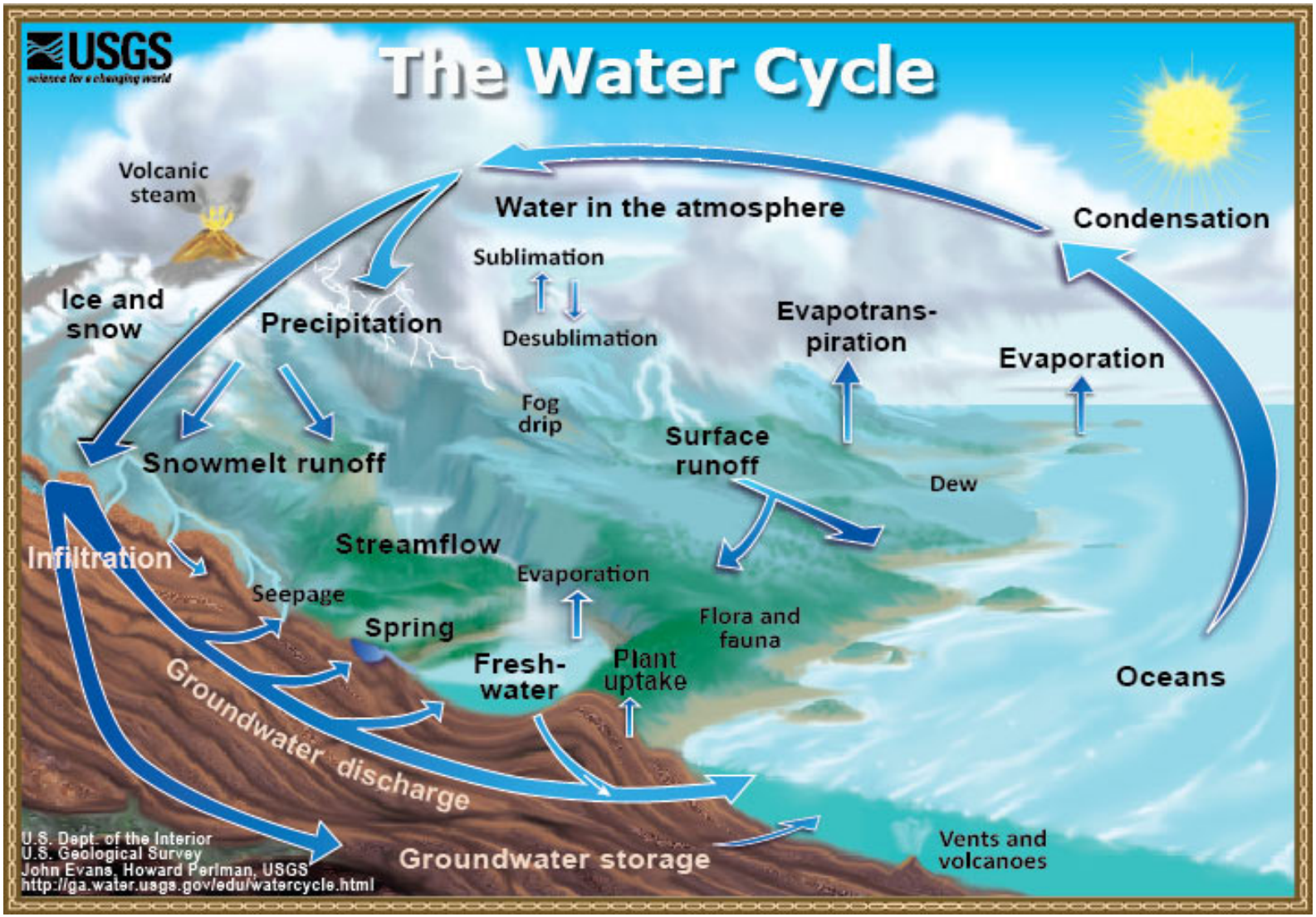
- Hydrology is the science which deals with the waters of the earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the physical and biological environment, including their responses to human activity. Hydrology is a field which covers the entire history of the cycle of water on the earth

- 水文学とは地球の水、それらの発生、地球上における循環と分布、それらの物理的および化学的な特性と、人類の活動に対する反応を含む物理学的および生物学的な環境への相互作用を扱う科学である。水文学は地球上における水の循環の歴史全体を包括する分野である。

地球における水の大循環
General circulation of water in the Earth

http://upload.wikimedia.org/wikipedia/commons/d/d5/Watercyclejapanese.jpg

The Water Cycle



http://ga.water.usgs.gov/edu/watercycle.html

水収支式（hydrological equation）

$$P - R - G - E - T = \Delta S$$

P：降水量　R：流出量　G：地下水量　　E：蒸発量

T：蒸散量　ΔS：貯留量

P: Precipitation, R: Runoff, G: Ground water,

E:Evaporation, T: Transpiration, ΔS :Storage

地球の放射収支

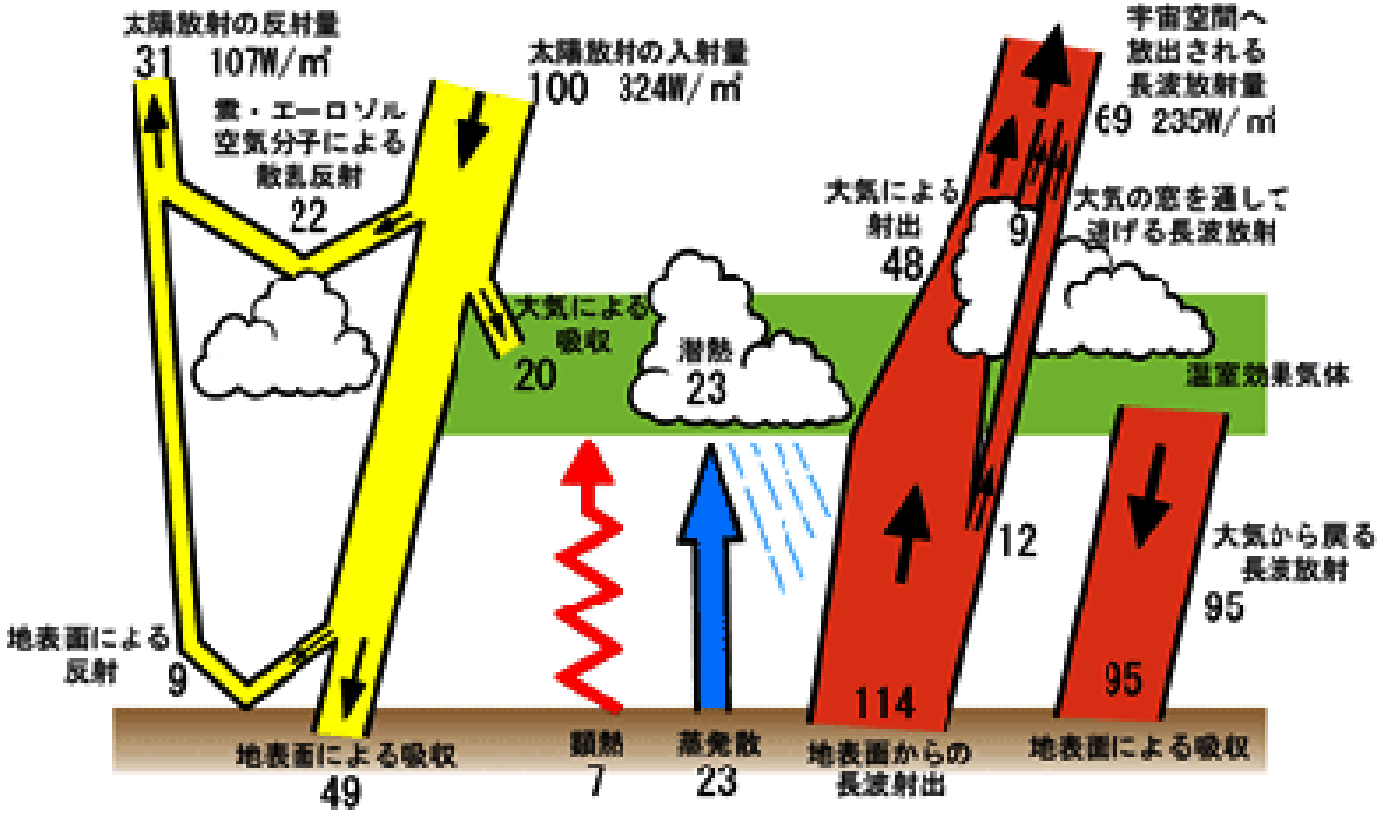
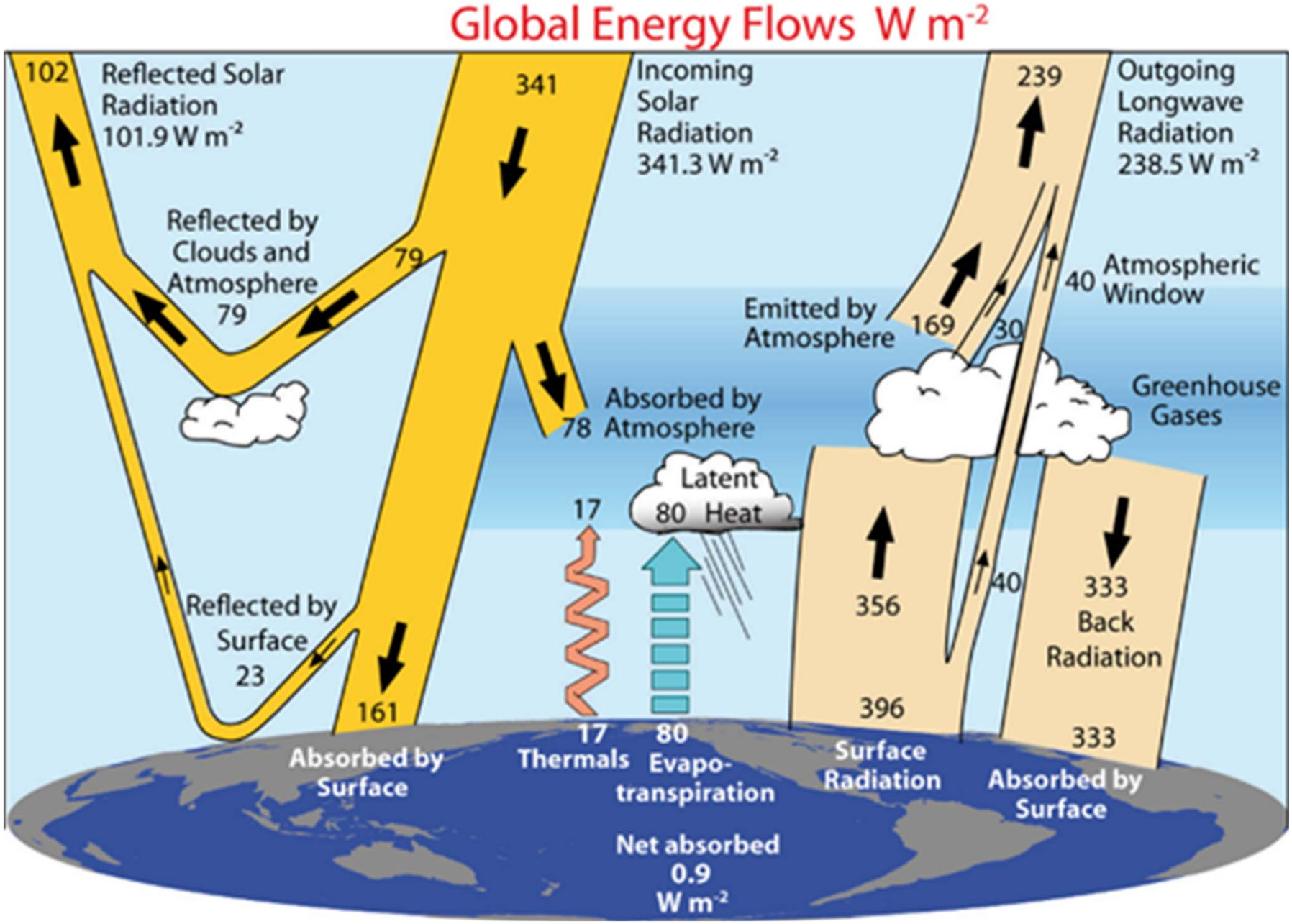


図 1　地球の放射収支

http://kobam-hp.web.infoseek.co.jp/meteor/energy-balance.html



http://hal.astr.ucl.ac.be/textbook/chapter2_node8.xml

地表面の熱収支
Heat balance of the ground surface

放射収支の式 (Radiation balance equation)

$$Rn = S\downarrow + S\uparrow + L\downarrow + L\uparrow$$

S:短波放射　　L:長波放射

S:Shortwave radiation, L:Long-wave radiation

熱収支の式　(Heat balance equation)

$$Rn = G + H + Le$$

G : 地中熱流量（地中への熱の移動）
H : 顕熱フラックス（気温変化による）
Le : 潜熱フラックス（蒸発による水蒸気熱移動）
G:Geothermal heat flow(Movement of heat to the ground)
H: Sensible heat flux (due to changes in temperature)
Le:Latent heat flux (Heat transfer due to evaporation of water vapor)

土壌学の定義　(wikipedia)

- 土壌学（どじょうがく、Soil science）は、地球の表層にある、天然資源としての土壌についての学問分野である。土壌学では、土壌生成, 土壌分類、土壌パターンのマッピングなどを研究対象とし、物理学、化学、生物学、資源価値などといった側面からのアプローチが行われる。特に資源価値の側面からは、土壌の利用や管理についても研究される。

- 土壌学の主な分野として、土壌の構造や化学的特性、形態、分類を扱うペドロジーと、生物（特に植物）による土壌の影響を扱う栽培土壌学という2つの分野がある。どちらも土壌学の一分野であるが、これらの分野名は土壌学という分野と特に区別されずに用いられることもある。土壌学は、土壌学を専門とする土壌学者のみが研究対象としているわけではなく、工学者、農耕学者、化学者、地理学者、生物学者、生態学者、微生物学者、林学者、公衆衛生学者、考古学者、また地域計画の専門家など、さまざまな分野の研究者が土壌学の発展に貢献している。

Definition of soil science (wikipedia)

- **Soil science** is the study of soil as a natural resource on the surface of the earth including soil formation, classification and mapping; physical, chemical, biological, and fertility properties of soils; and these properties in relation to the use and management of soils.
- Sometimes terms which refer to branches of soil science, such as pedology (formation, chemistry, morphology and classification of soil) and edaphology (influence of soil on organisms, especially plants), are used as if synonymous with soil science. The diversity of names associated with this discipline is related to the various associations concerned. Indeed, engineers, agronomists, chemists, geologists, physical geographers, ecologists, biologists, microbiologists, sylviculturists, sanitarians, archaeologists, and specialists in regional planning, all contribute to further knowledge of soils and the advancement of the soil sciences.
- Soil scientists have raised concerns about how to preserve soil and arable land in a world with a growing population, possible future water crisis, increasing per capita food consumption, and land degradation.

http://en.wikipedia.org/wiki/Soil_science

土壌学の学問分野
Disciplines of soil science

(wikipedia)

- 環境土壌学
- ペドロジー
  - ペドメトリックス
  - 土壌生成
  - 土壌多様性
  - 土壌形態学
  - 土壌微形態学
  - 土壌分類
  - USDA土壌分類
- 土壌生物学
  - 土壌微生物学
- 土壌化学
  - 土壌生化学
  - 土壌鉱物学
- 土壌物理学
  - 土壌伝達関数
  - 土質力学
  - 土木工学
  - 水文土壌学
- 栽培土壌学
- 土壌調査

日本土壌肥料学会

- 土壌物理
- 土壌化学・土壌鉱物
- 土壌生物
- 植物栄養
- 土壌生成・分類・調査
- 土壌肥沃度
- 肥料・土壌改良資材
- 環境
- 社会・文化土壌学

Soil Science Society of America

- Soil Physics
- Soil Chemistry
- Soil Biology & Biochemistry
- Soil Fertility & Plant Nutrition
- Pedology
- Soil & Water Management & Conservation
- Forest, Range, and Wildland Soils
- Nutrient Management & Soil & Plant Analysis
- Soil Mineralogy
- Wetland Soils
- Soils & Environmental Quality

土壌学が応用される分野

Field of soil science will be applied (wikipedia)

- 土壌を用いた廃棄物の活用
  - 浄化システム
  - 厩肥
  - 汚泥処理
- 危機に瀕した区域の特定と環境保護
  - 湿地、流域
  - 環境変動の影響を受けやすい土壌
  - 生物多様性、生息地保護の観点からみて重要である土壌
- 土地利用の管理
  - 林学
  - 農耕学
    - 肥料管理
    - 灌漑設備
  - 放牧
- 水質管理
  - 豪雨管理
  - 堆積物と侵食の制御
- 損傷を受けた土壌の復元、レメディエーション
  - 鉱山の再生利用
  - 洪水、豪雨による浸食
  - 土壌汚染
- 維持可能な資源利用
  - 表土の保全

- Utilization of waste using soil
  - Clarification system
  - Feedlot manure
  - Sludge treatment
- Environmental protection of specific areas where the endangered
  - Wetlands, watershed
  - Soil susceptible to environmental changes
  - Soil is important from the perspective of biodiversity, protection of habitat
- Management of land use
  - Forestry
  - Agronomic
    - Manure management
    - Irrigation facilities
  - Grazing
- Water quality management
  - Heavy rain management
  - Sediment and erosion control
- Restoration of damaged soil, bioremediation
  - Reclamation of mine
  - Flood erosion, due to heavy rainfall
  - Soil contamination
- Sustainable resource use
  - Conservation of topsoil

土の生産力の解釈の歴史

History of the interpretation of soil productivity

土の科学（久馬一剛）p.69より

- 17世紀初め
  - ヴァン・ヘルモントの実験（植物栄養の水説）
- 18世紀
  - タル（イギリス；土粒子説）
  - ウォレリウス（スウェーデン；腐植説）ー「地脂」
  - デイヴィ（イギリス）、テーア（ドイツ）ー腐植説
- 1840
  - リービッヒ（ドイツ）ー無機栄養説
  - 「農芸化学」の創立
    - 土は植物栄養の貯留場所との認識

- Early 17th century
  - Van Helmont experiment
  - Theory of water for plant nutrition
- 18th century
  - Tal (UK; theory of soil particles)
  - Valerius (Sweden; humus theory) - "fat land"
  - Davy (UK), Thaer (Germany) - humus theory
- 1840
  - Liebig (Germany)
    - Theory of Inorganic nutrition
  - Founding of "agricultural chemistry"
    - Soil is recognized as a storage of plant nutrition

土壌の概念(The concept of soil)

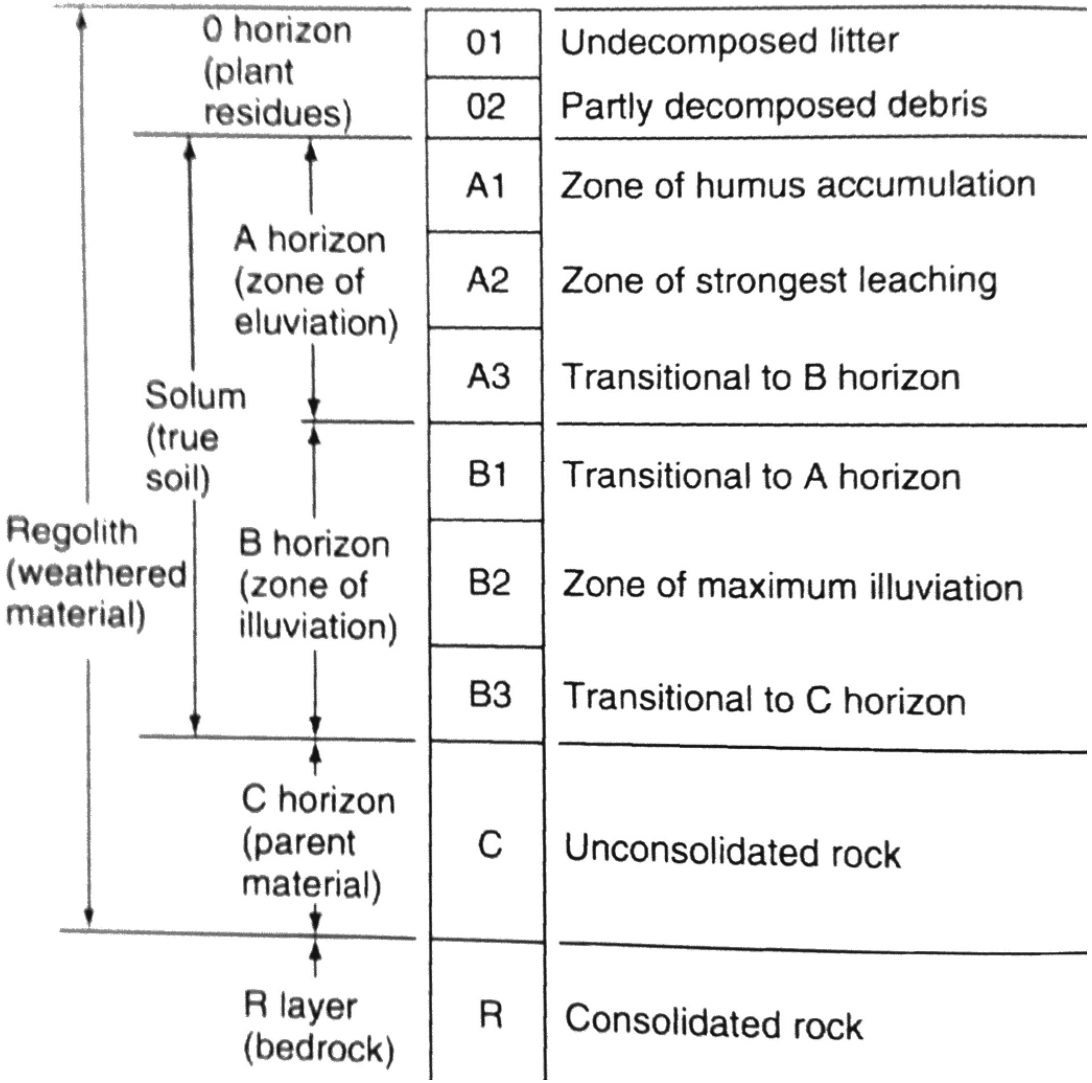
土の科学（久馬一剛）より

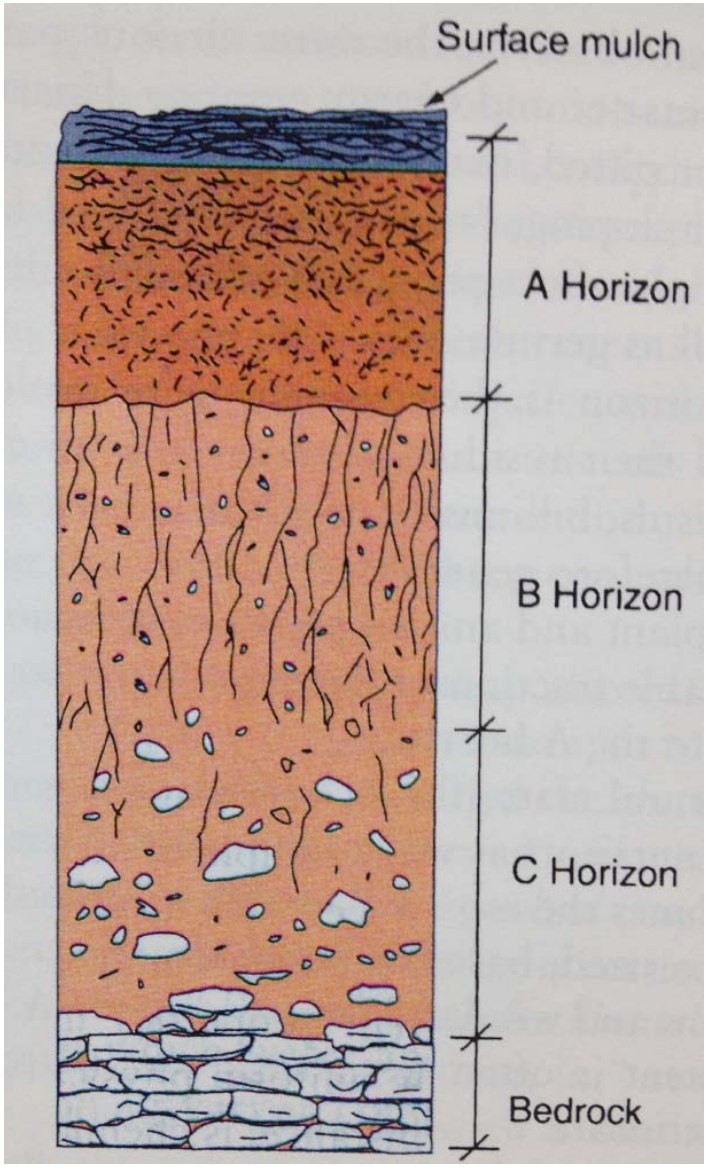
- 19世紀まで
  - 土壌は「岩石の破砕、あるいは風化などによって形成されたもの」
  - 植物への養分供給源
- ドクチャーエフ（1883；ロシアの黒土,Russian Chernozem)
  - 土壌は「生物などを介した過程によって変化している地球上の自然体(natural body)」
  - 土壌生成因子（5つ）が重要
    - 気候、生物、起伏、母材、時間

- Until the 19th century
  - Soil is something formed by weathering or fracturing of the rock
  - Source of nutrients to plants
- Dokuchaev (1883; black soil of Russia, Russian Chernozem)
  - Soil is natural body on Earth, which has changed by a process such as through the organism
  - Five soil formation factors are important
    - Climate, Organisms, Relief, Parent material, Time

$$s=f(Cl, O, R, P, T)$$

Soil Profile horizons（層位）





after D. Hillel(2008), p.24

Process of soil formation
土壌生成過程

- Podzolization　ポドソル化作用
- Leaching　洗脱作用
- Calcification　石灰集積作用
- Ferralization　鉄アルミナ富化作用
- Salinization　塩類集積作用
- Solodization　アルカリ化作用

After E.M.Bridges(1970), pp.21-25

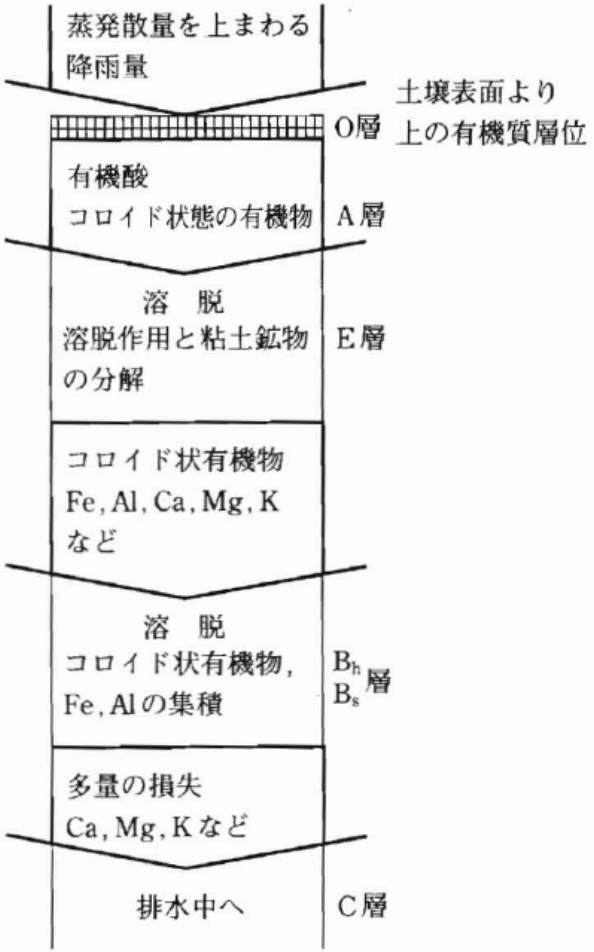


図2－4　ポドゾル化作用の過程
（ブリッジズ，1990を一部改変）

Fe：鉄，Al：アルミニウム，Ca：カルシウム，Mg：マグネシウム，K：カリウム，B_h：有機物に富むB層，B_s：鉄やアルミニウムの酸化物が集積したB層，O層・A層・E層・B層・C層については後述，図中の矢印は水の移動方向を示す

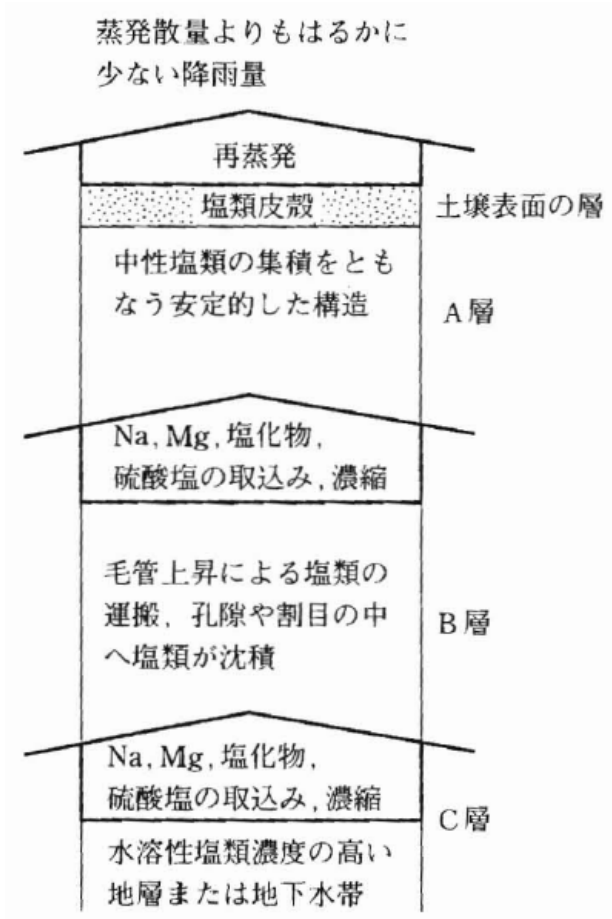
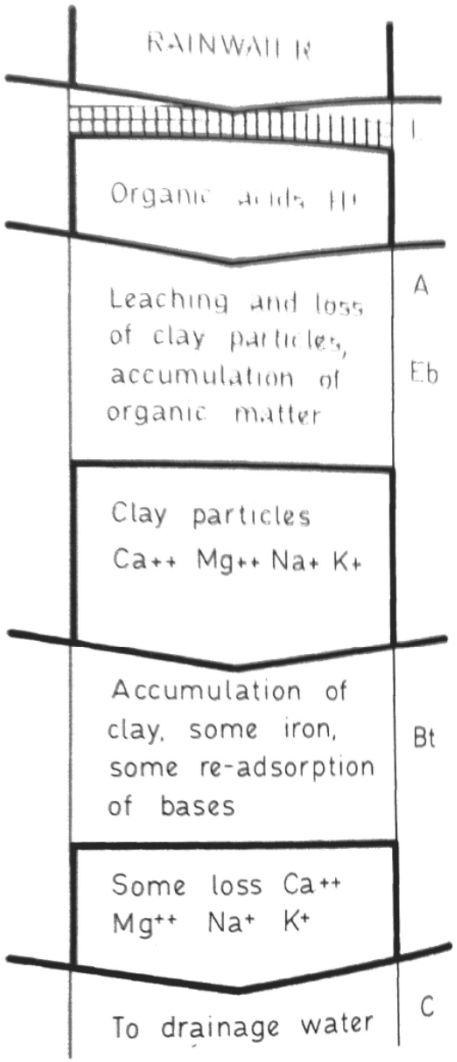


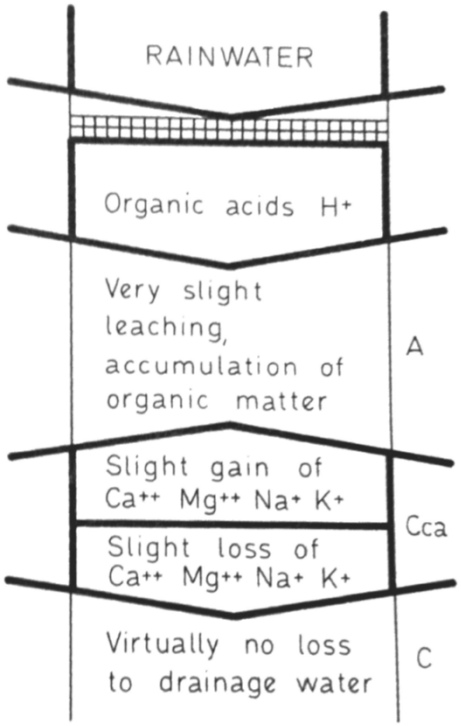
図2－6　塩類集積作用の過程
（ブリッジズ，1990を一部改変）

Na：ナトリウム，他は図2－4と同じ

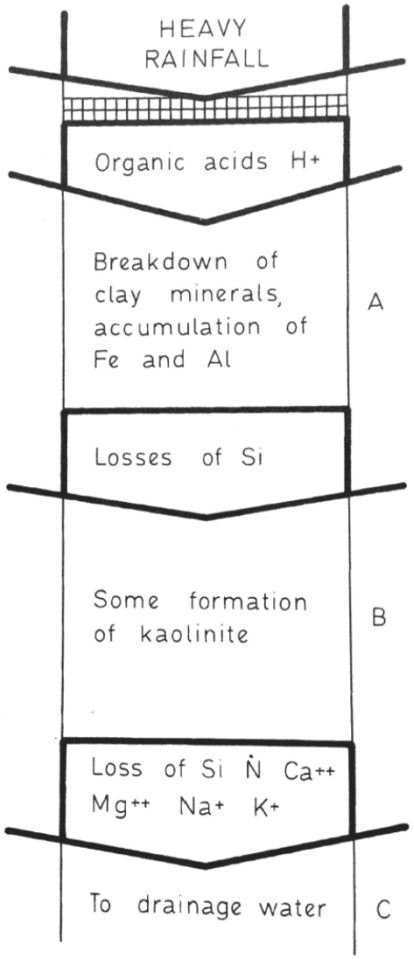
土壌学の基礎（松中照夫）p.21,23より



Leaching
洗脱作用

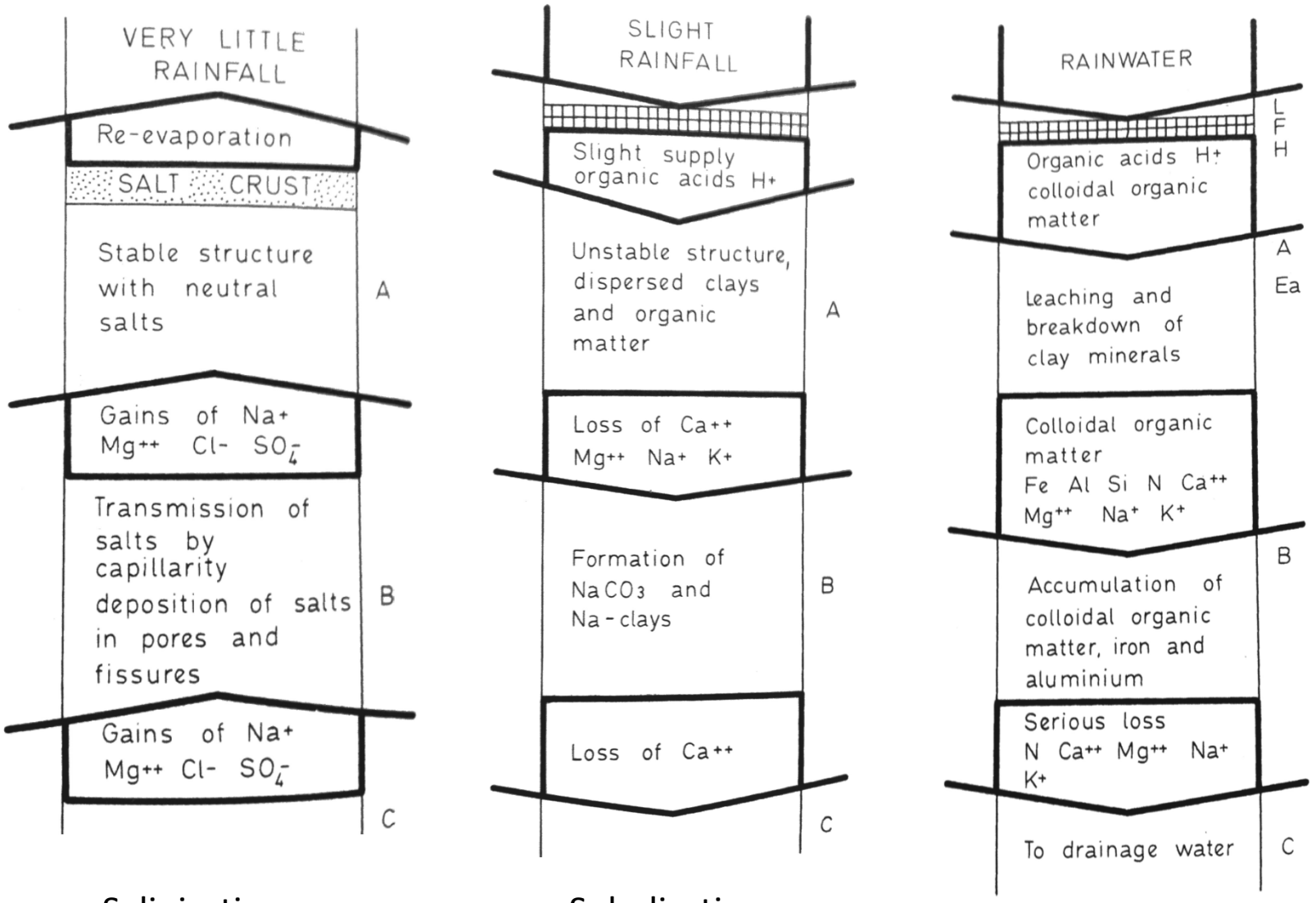


Calcification
石灰集積作用



Ferralization
鉄アルミナ富化作用

After E.M.Bridges(1970), pp.21-25



Salinization
塩類化作用

Solodization
アルカリ化作用

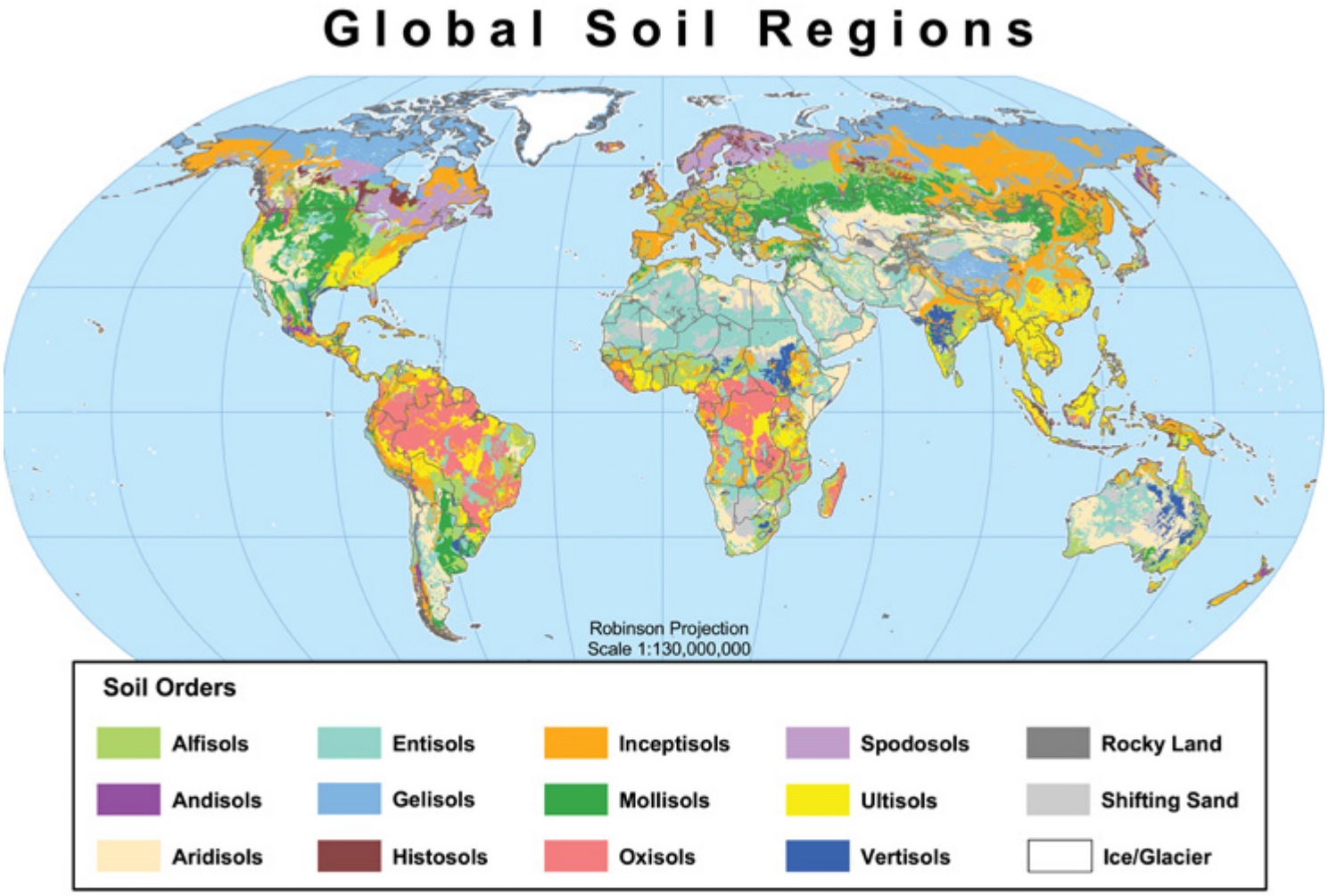
Podzolization
ポドゾル化作用

After E.M.Bridges(1970), pp.21-25

Various soil and colors



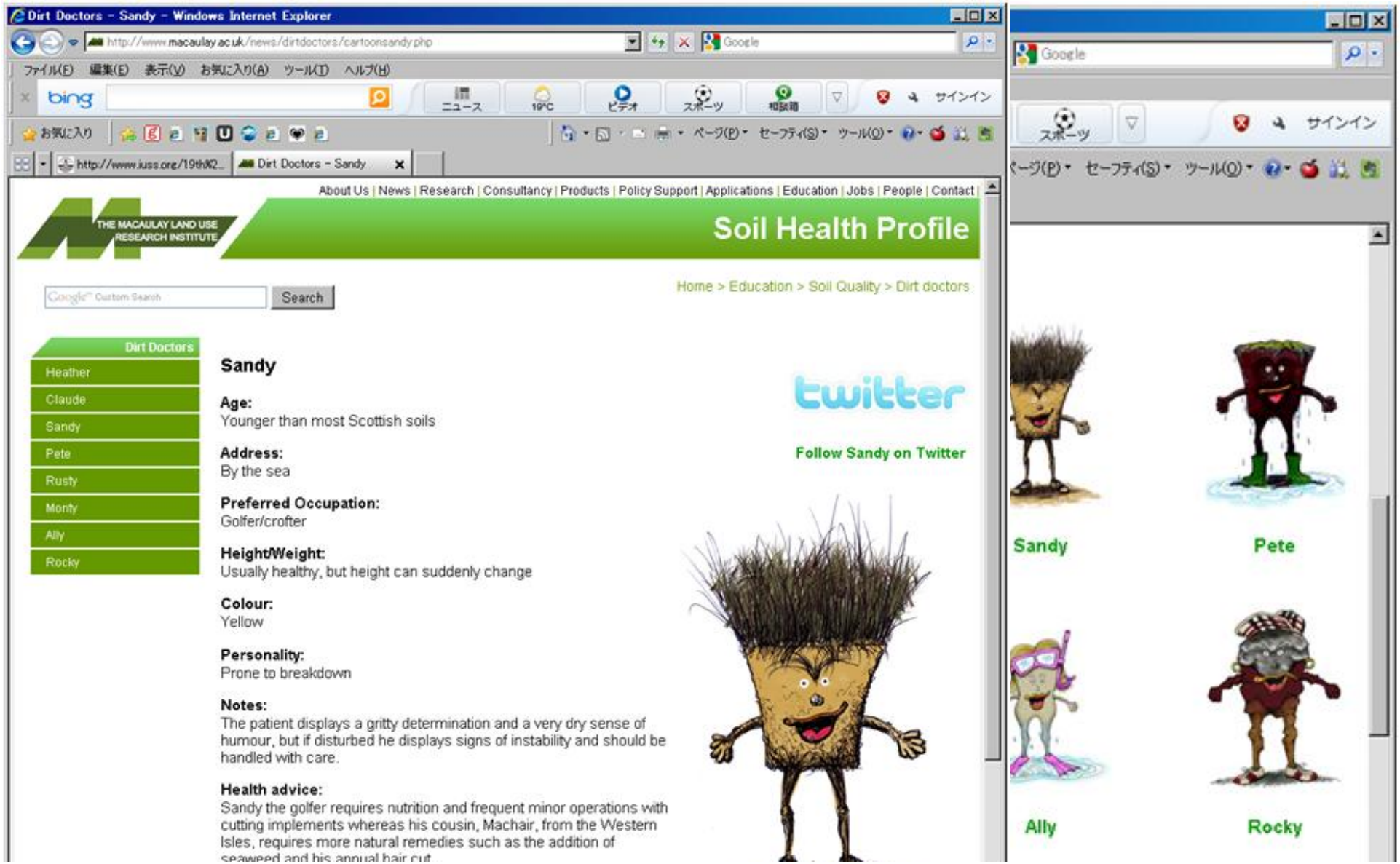

Soil Taxonomy



http://soils.usda.gov/use/worldsoils/mapindex/order.html

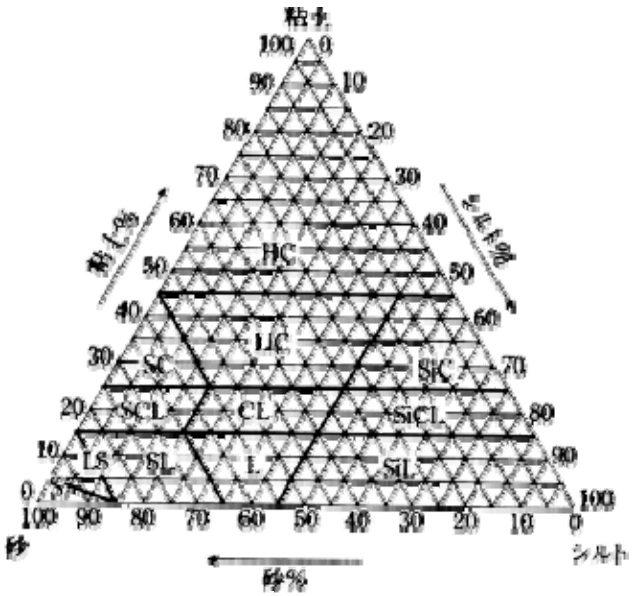
Attracting young people to soil

- “Dirt Doctor”



Fundamentals of Soil properties

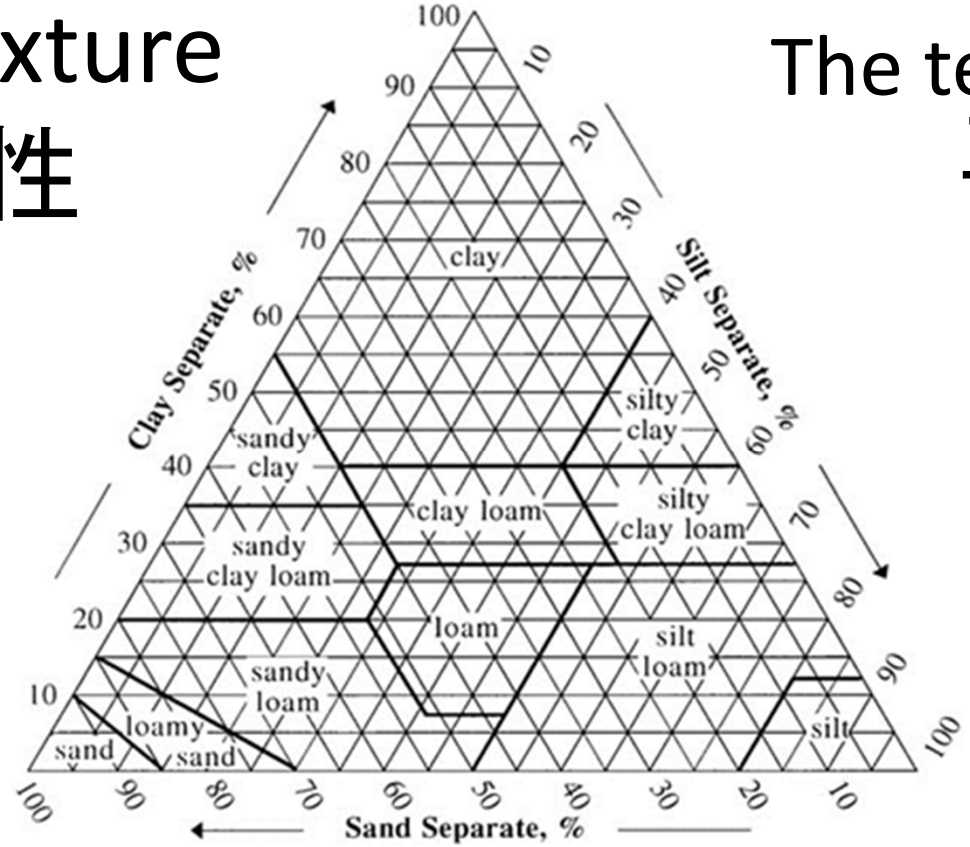
- What is soil made of?
  - Soil particles, water, air
- Classification of soil particles
  - Classified according to the size
  - Sand, silt, clay (<2 μm)

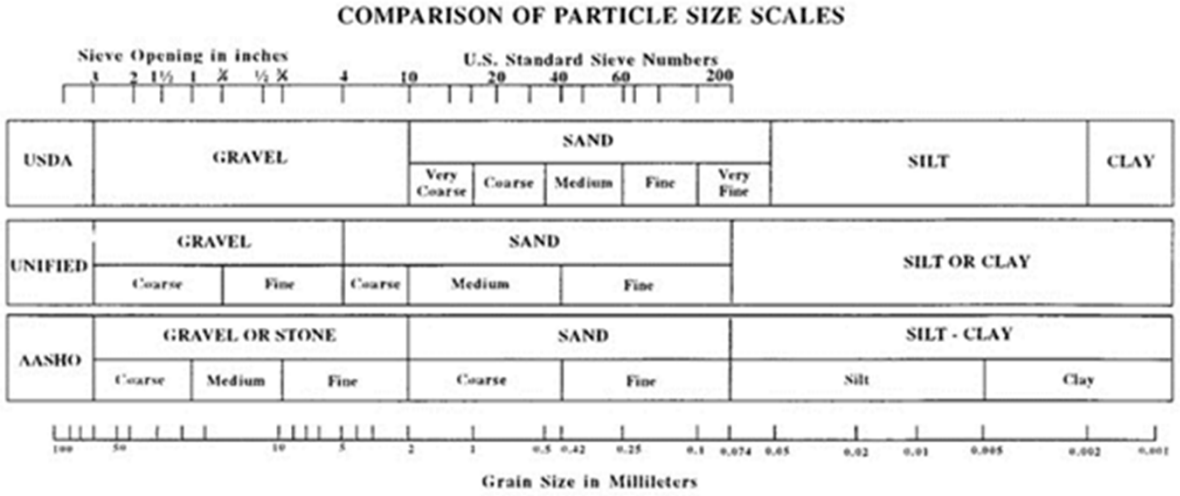


- Nature of the clay
  - muddy when it contains a lot of water
  - hard when it is dry
  - muddy water contains clay

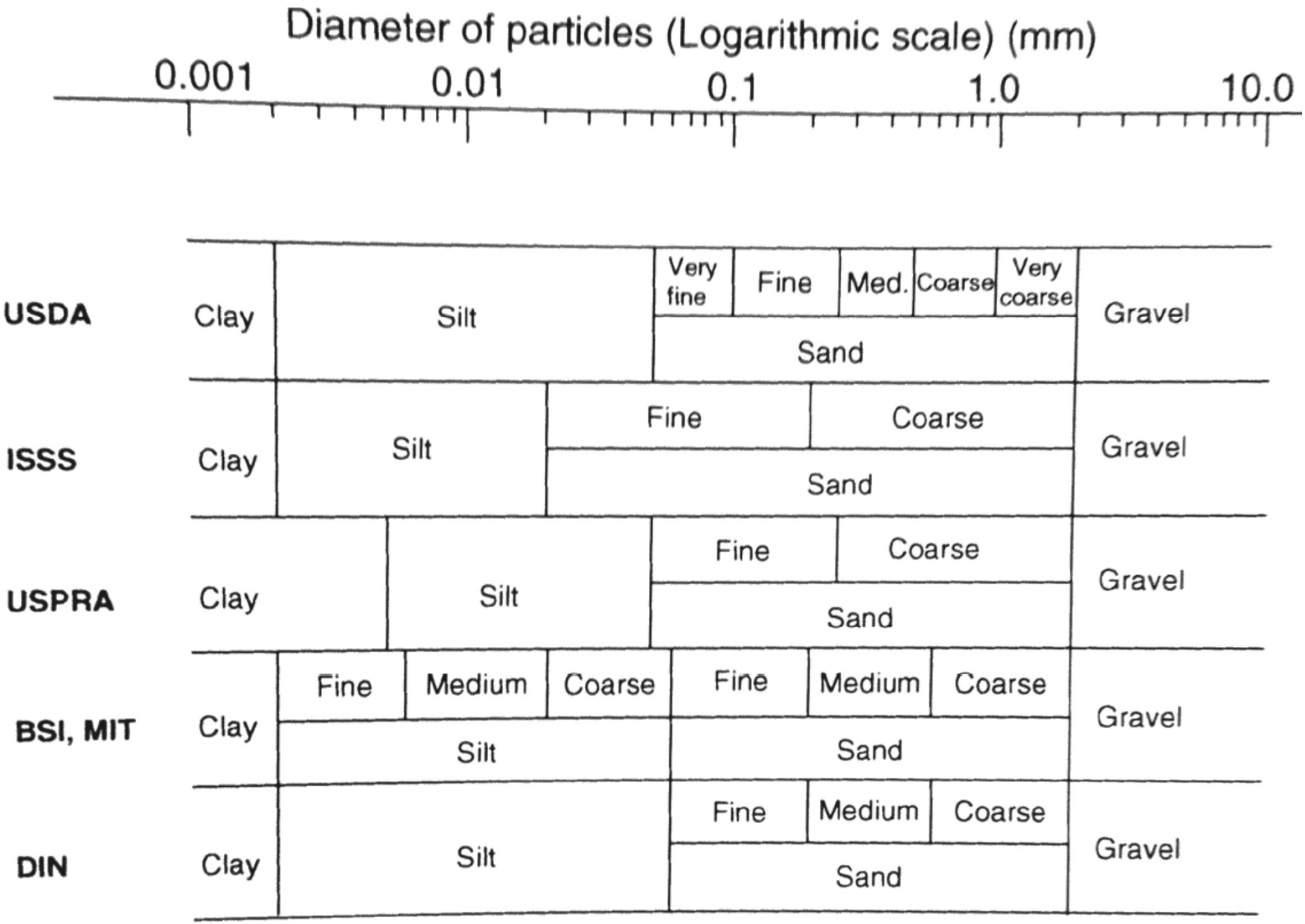
Soil Texture
土性

The textural triangle
三角座標



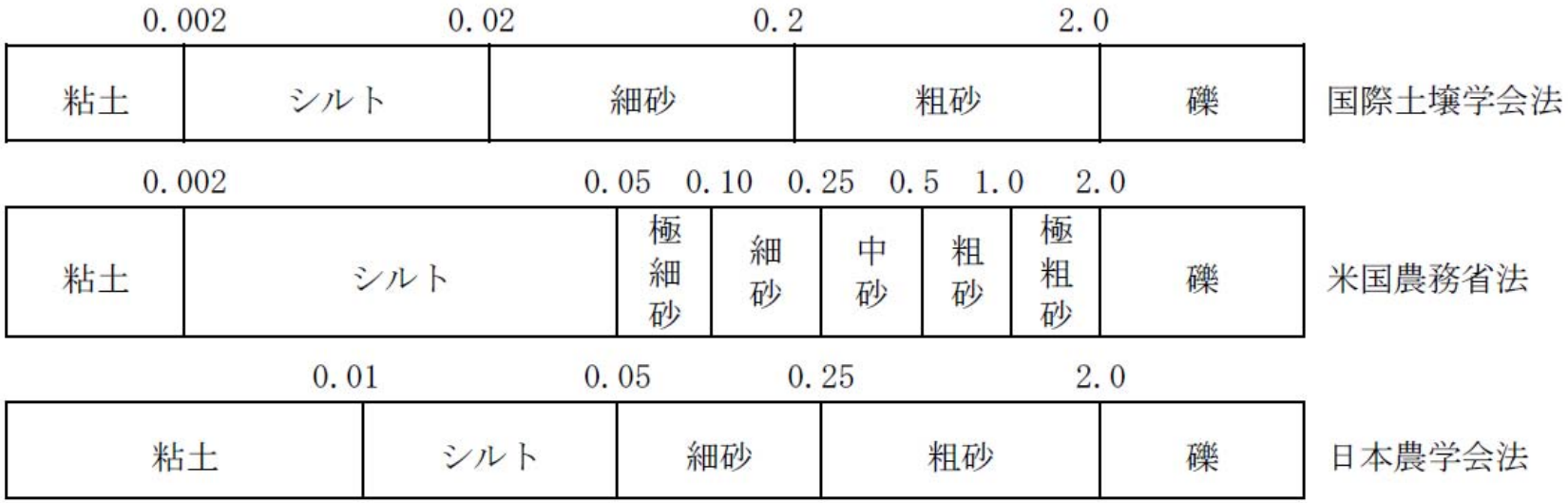


Classification of textural fractions



after D. Hillel(2008), p.57

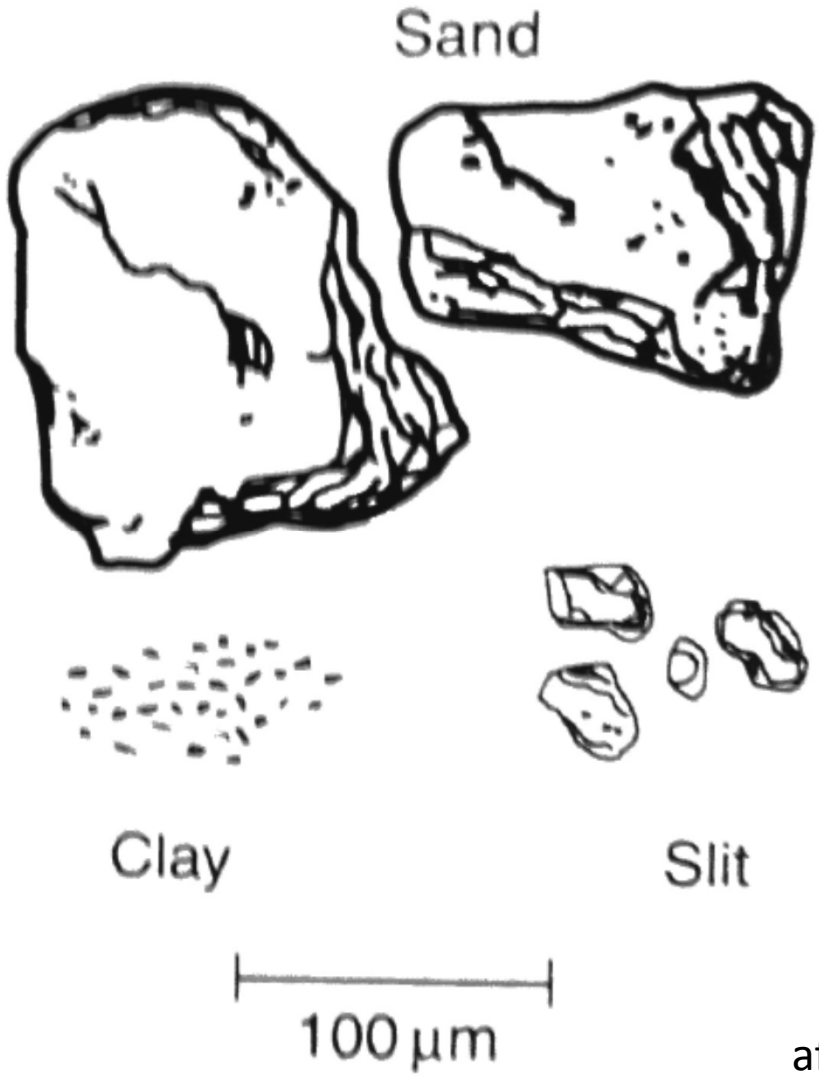
土壌の粒度区分



粒径（mm, 対数目盛）

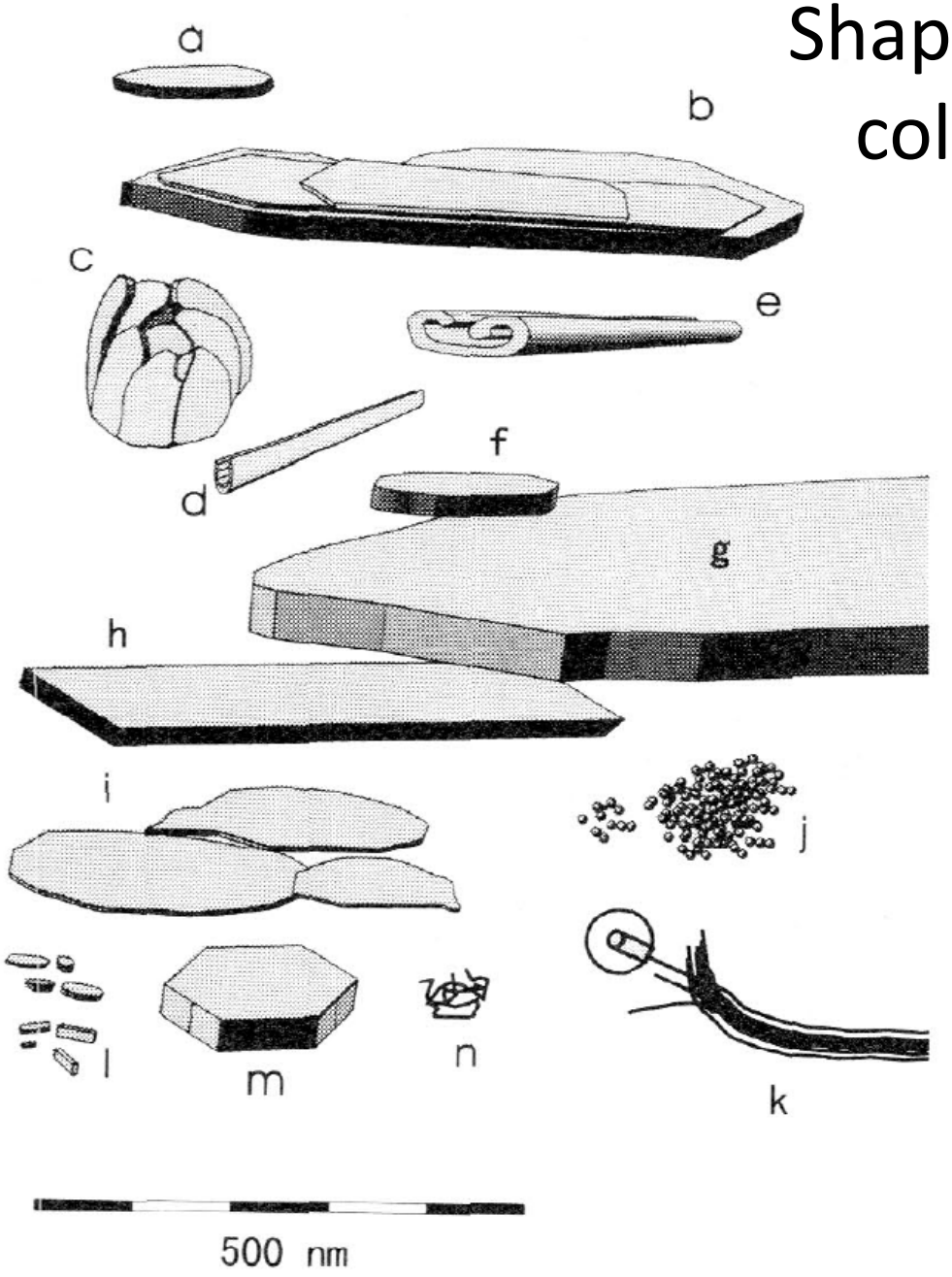
最新土壌学（久馬一剛）p. 40より

Comparative sizes of sand, silt and clay



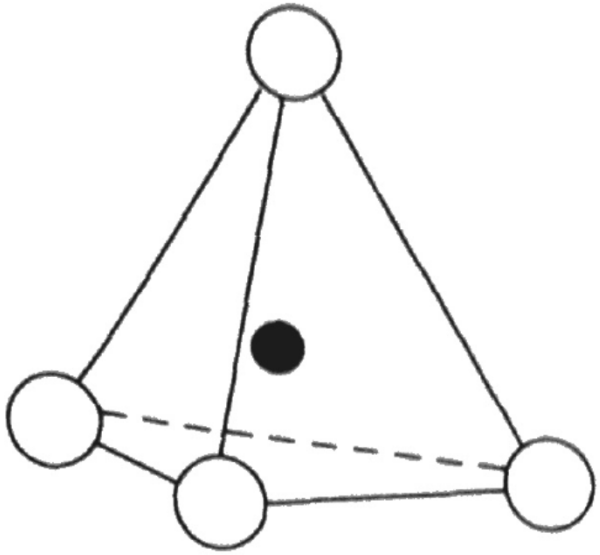
after D. Hillel(2008), p.57

Shape and size of Soil colloidal particles

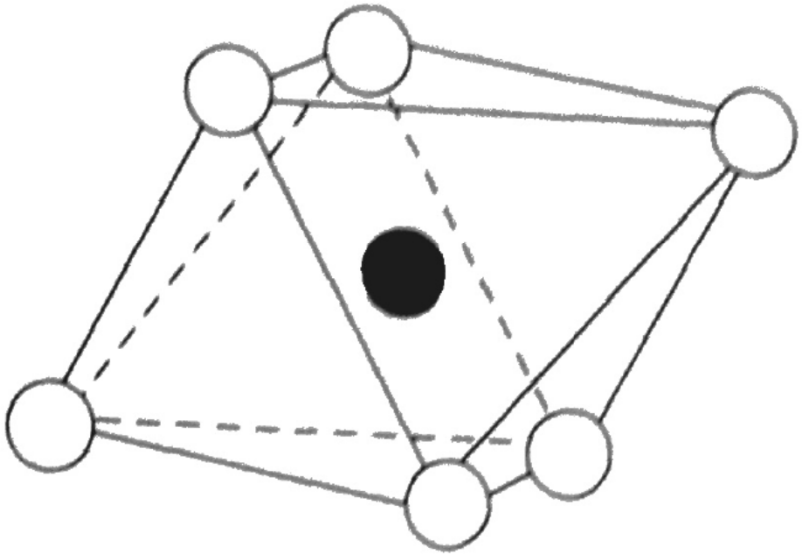


a. カオリナイト/caolinite
b. カオリナイト/
c. ハロサイト/harosite
d. ハロサイト
e. ハロサイト
f. イライト/ilite
g. バーミュキュライト /vermuculite
h. スメクタイト/smectite
i. スメクタイト
j. アロフェン/alophen
k. イモゴライト/imogolite
l. ヘマタイト・ゲータイト /hemasite/geortite
m. ギブサイト/gibsite
n. 腐植酸/humuin

The structural units of aluminosilicate clay minerals
アルミノケイ酸塩

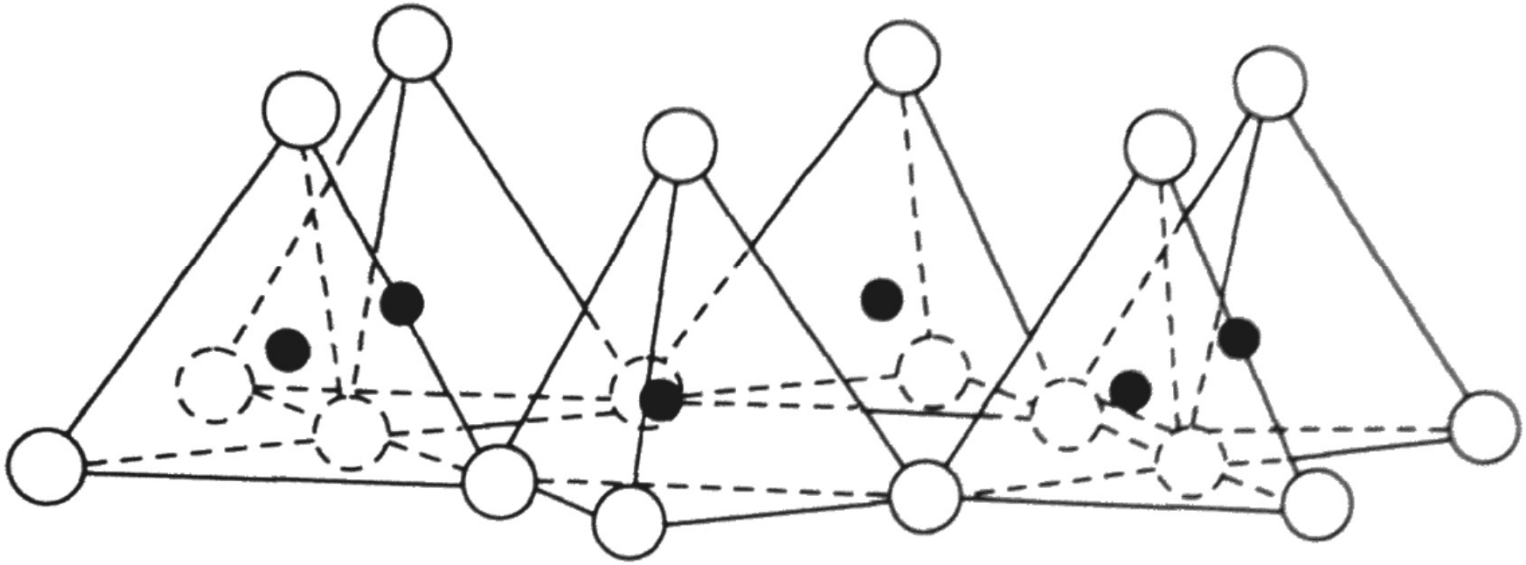


a tetrahedron of oxygen atoms
surrounding a silicon ion

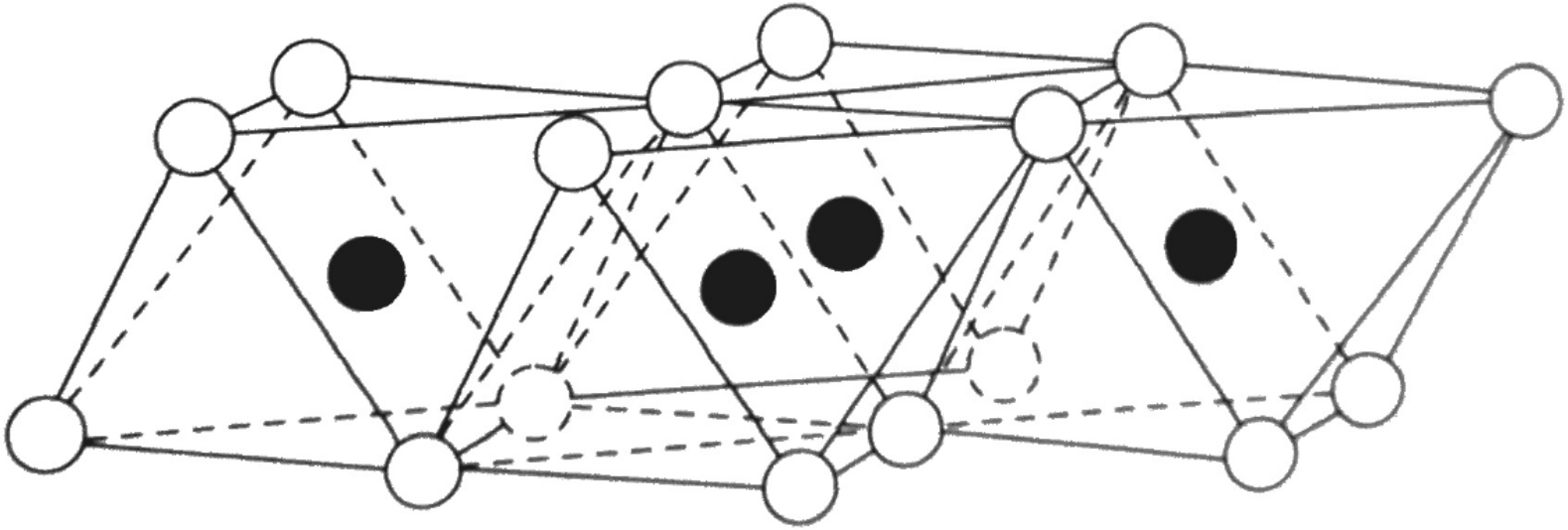


an octahedron oxygens
or hydroxyls enclosing
an aluminum ion

after D. Hillel(2008), p.63



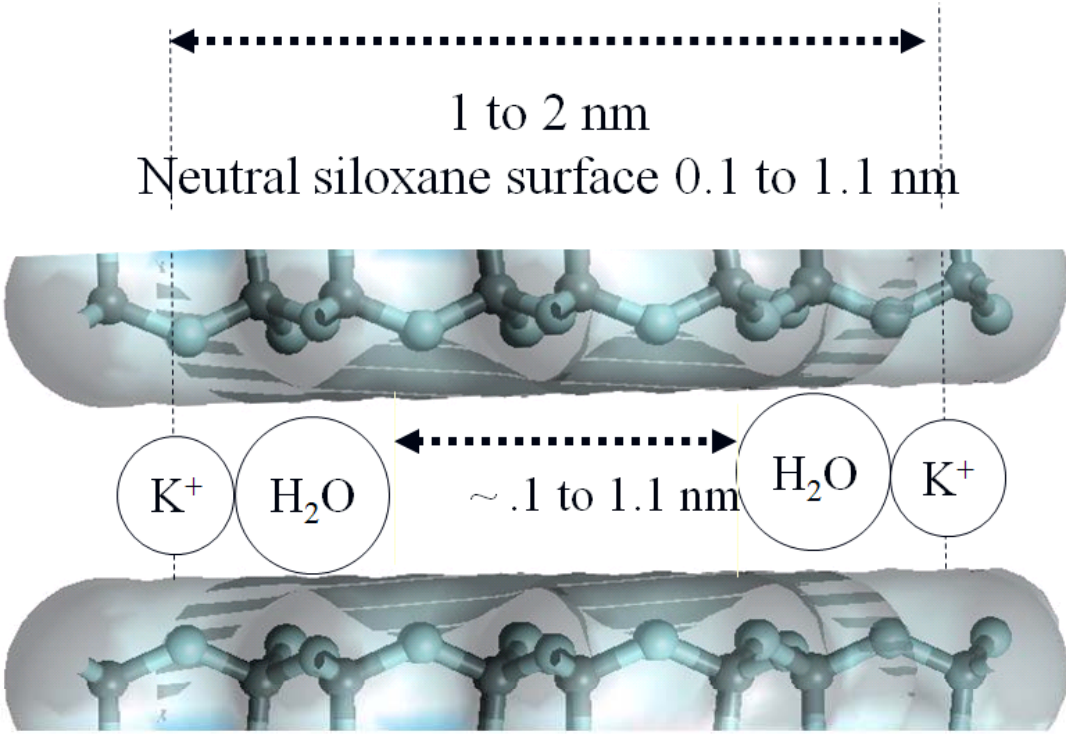
Hexahedral network of tetrahedra forming a silica sheet

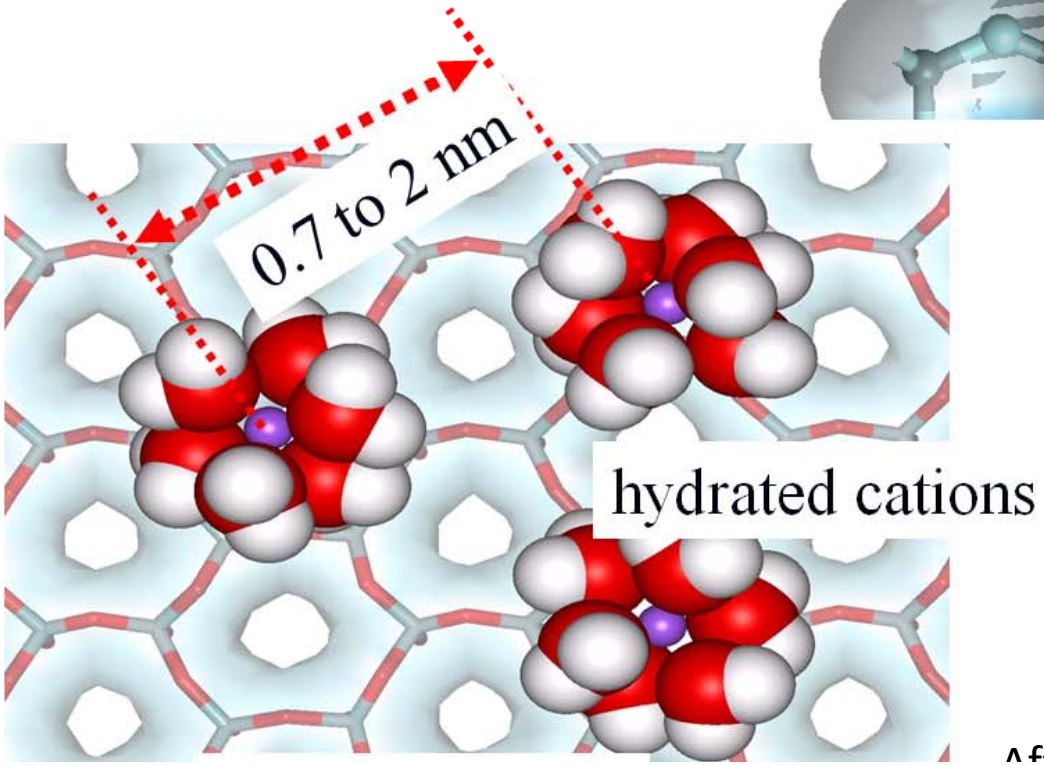


Structural network of octahedra forming an alumina sheet

after D. Hillel(2008), p.63

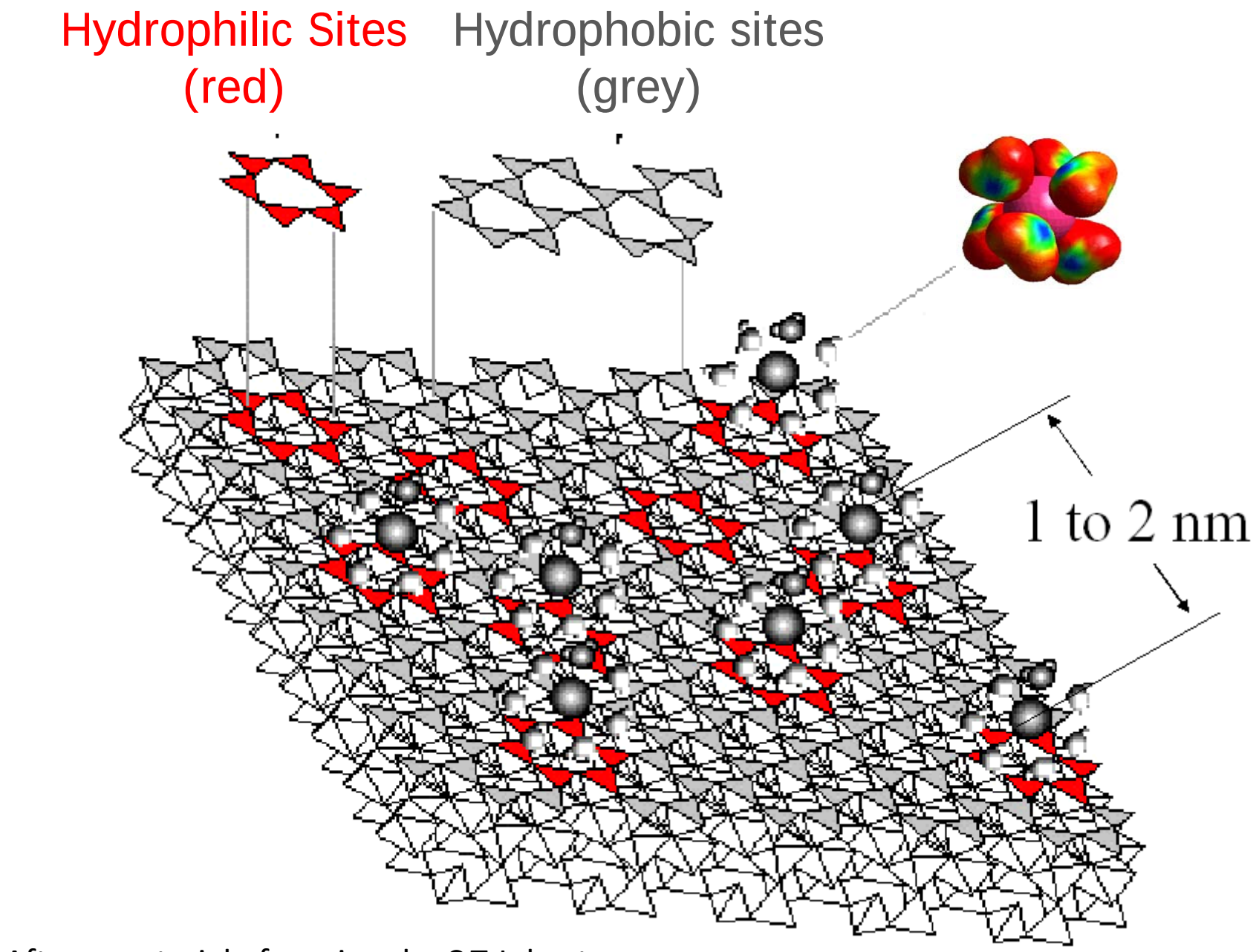
Radioactive cesium and clay





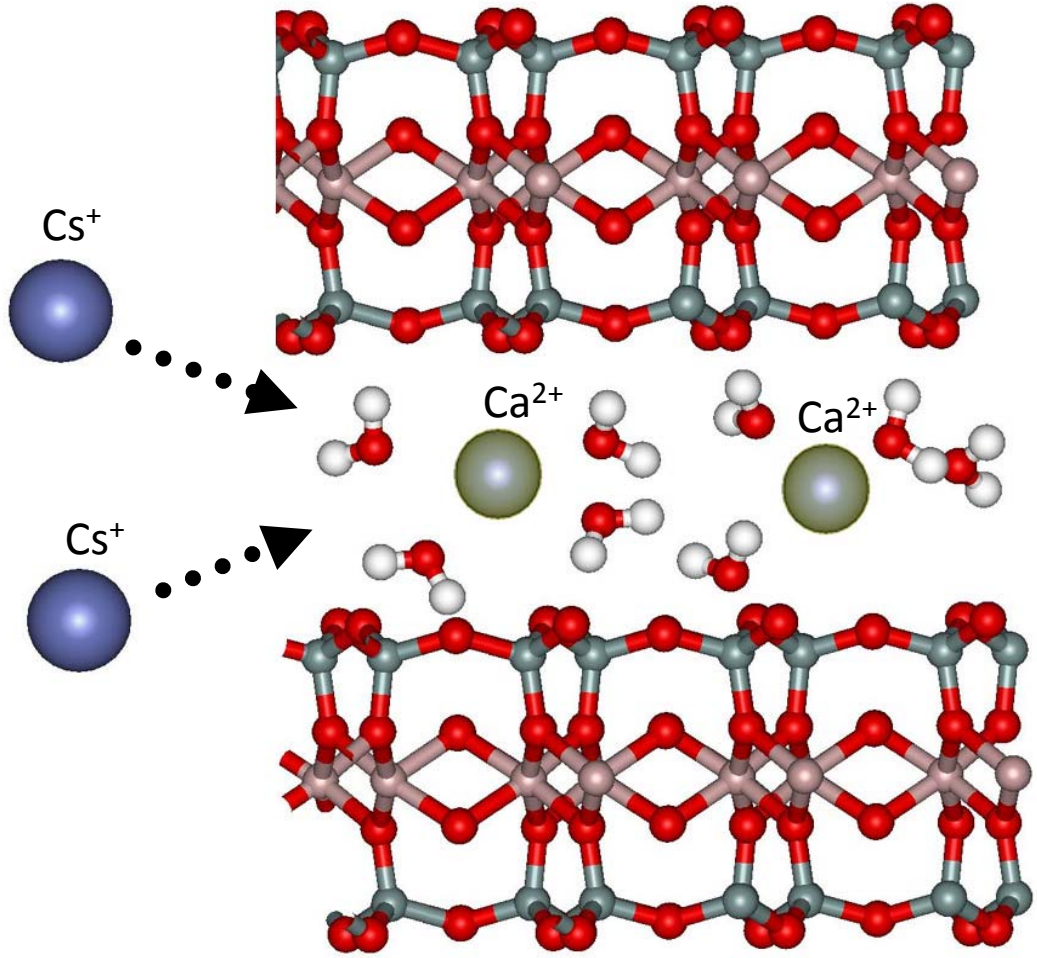
Cation exchange and cation fixation

After a material of seminar by C.T. Johnston



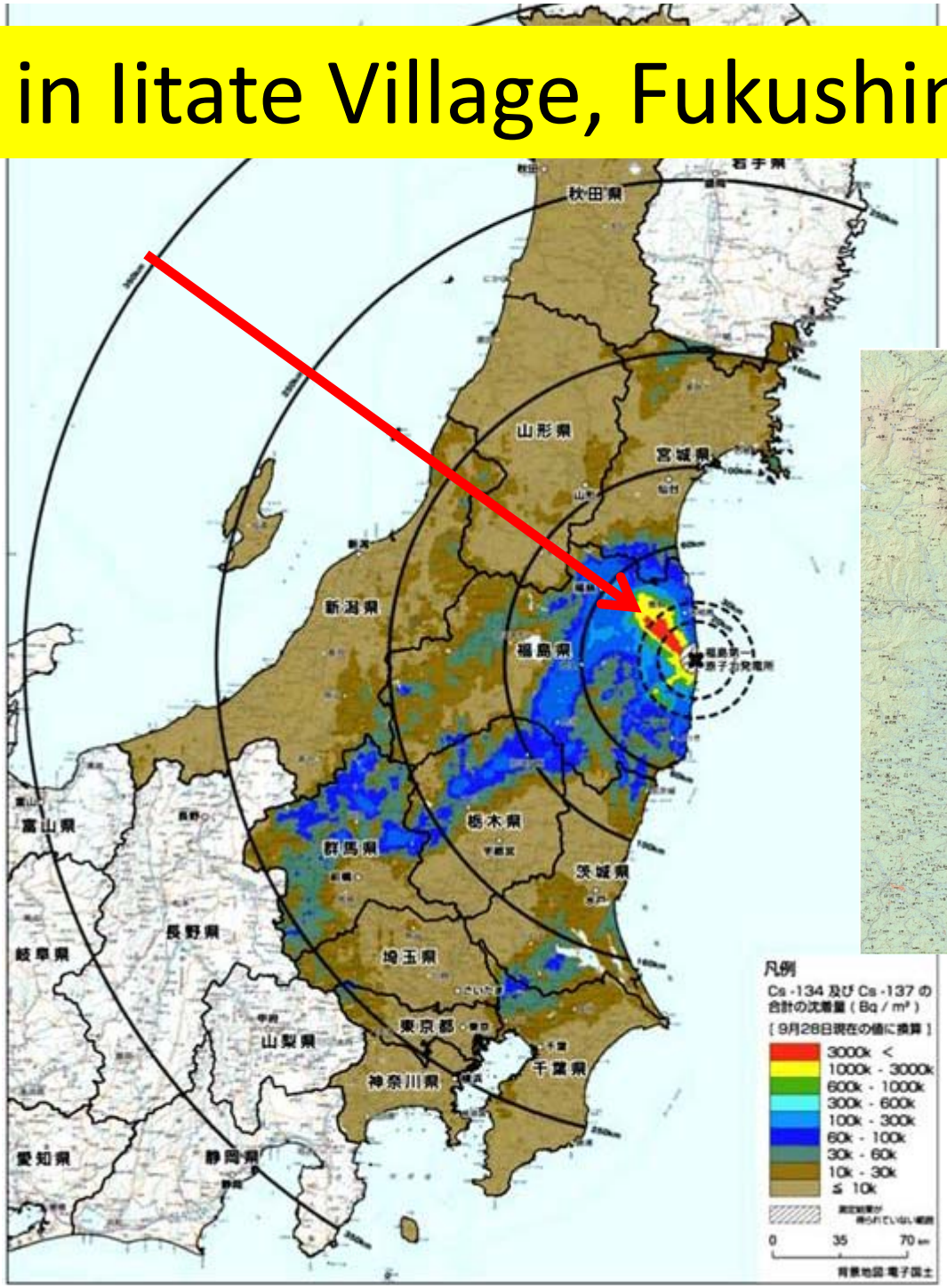
After a material of seminar by C.T Johnston

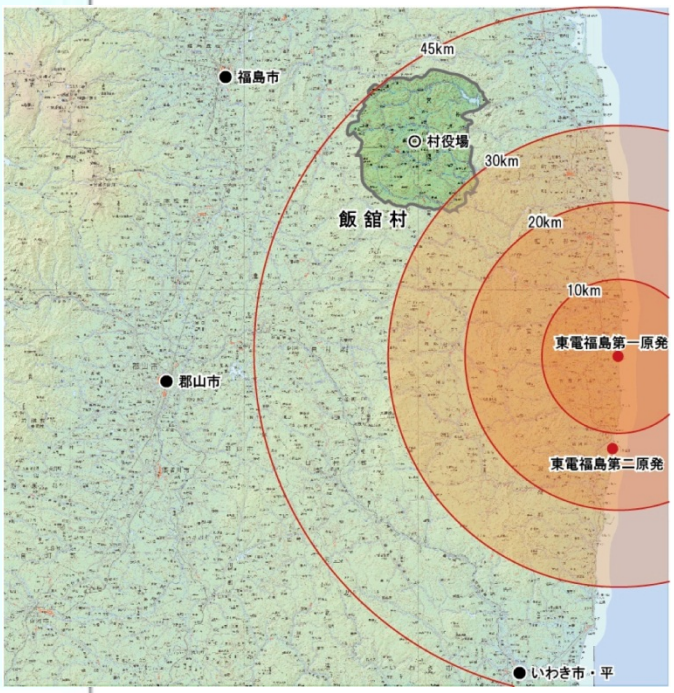
Cation exchange of Ca^{2+} by Cs^{+}



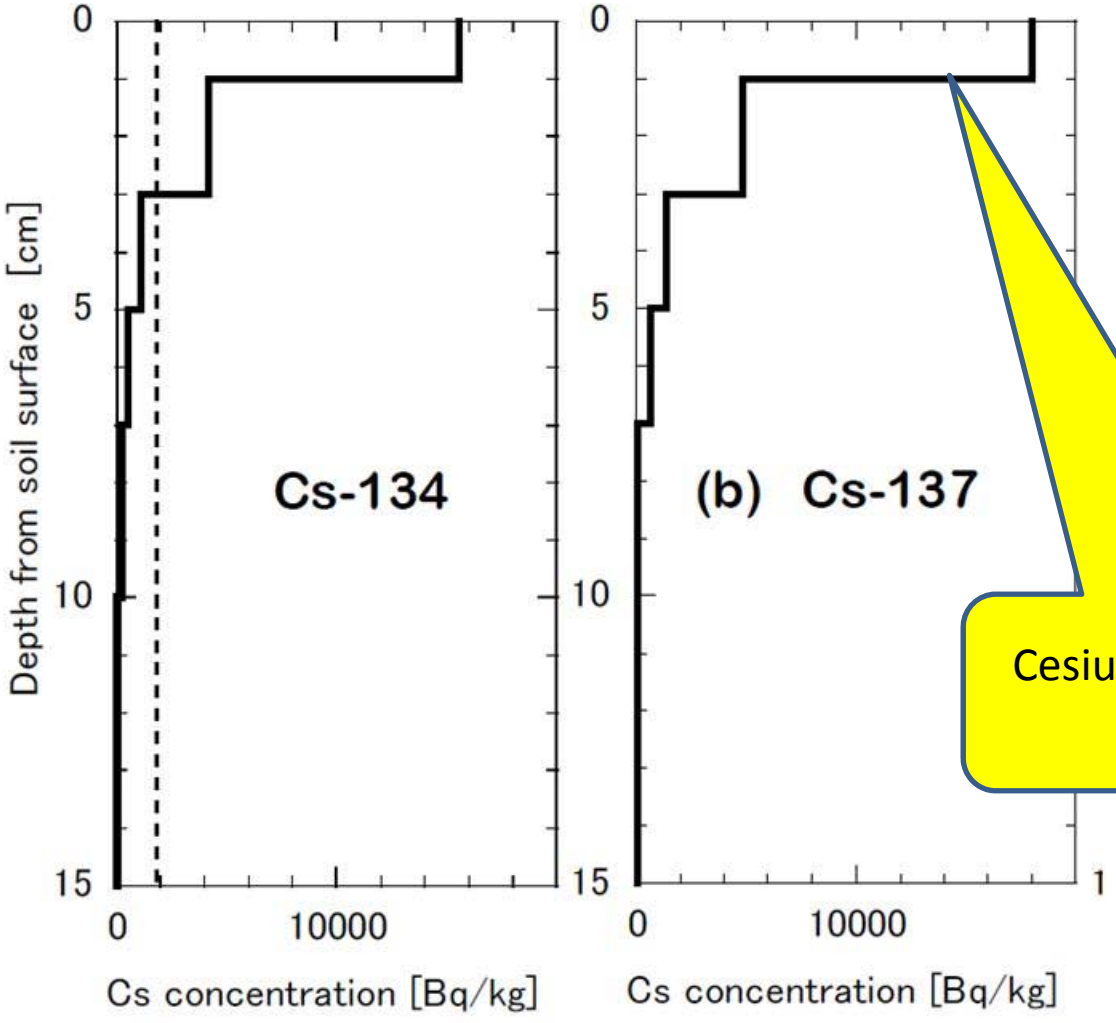
Johnston et al., Langmuir 17(12) 3712-3718

Soil in Iitate Village, Fukushima Prefecture





Radioactive Cesium Conc. in paddy soil (2011.5.24)



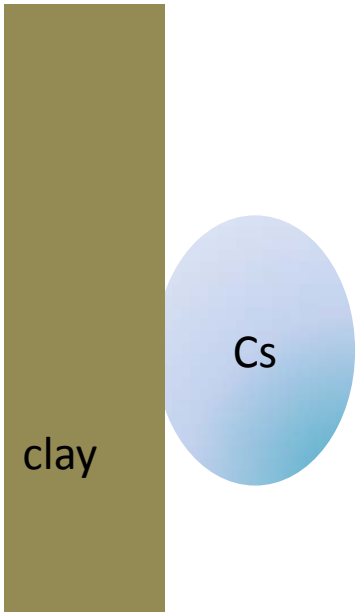
Cesium is adsorbed in a few cm layer of top soil

Shiozawa, et.al: Vertical Concentration Profiles of Radioactive Cesium and Convective Velocity in Soil in a Paddy Field in Fukushima, RADIOISOTOPES, 60, 323-328 (2011)

How should we deal with rice paddies?

How to think of radioactive cesium

- Regard as a complex of cesium and clay particles
  - Clay colloid
- Note the movement of the clay
- Think the removal of the clay
  - Absorbing radioactive cesium



Measurement of radiation dose on a slope near the Iitate Village office (2011.6.25; Mizoguchi and Noborio)

2.5 µSv/h

3.5 µSv/h

7.0 µSv/h

Radiation dose was higher at the bottom of the slope than at the top of the slope

Radiation level is high at the border between road and grass where clay particles stop

Stripping topsoil method

農林水産省

Official decontamination methods by Government

MAFF

Ministry of Agriculture, Forestry and Fisheries

From August, 2012

Soil puddling method

Deep plowing method

Where will contaminated soil ?

（June 24, 2012）

How to remediate soil contaminated by radioactive substances

(1)Soil puddling method

(2) Stripping topsoil method

(3) Inversion tillage method

(4) Stripping frozen topsoil method

Stripping test of frozen topsoil (January 8, 2012)

5 cm thick frozen soil as a plate

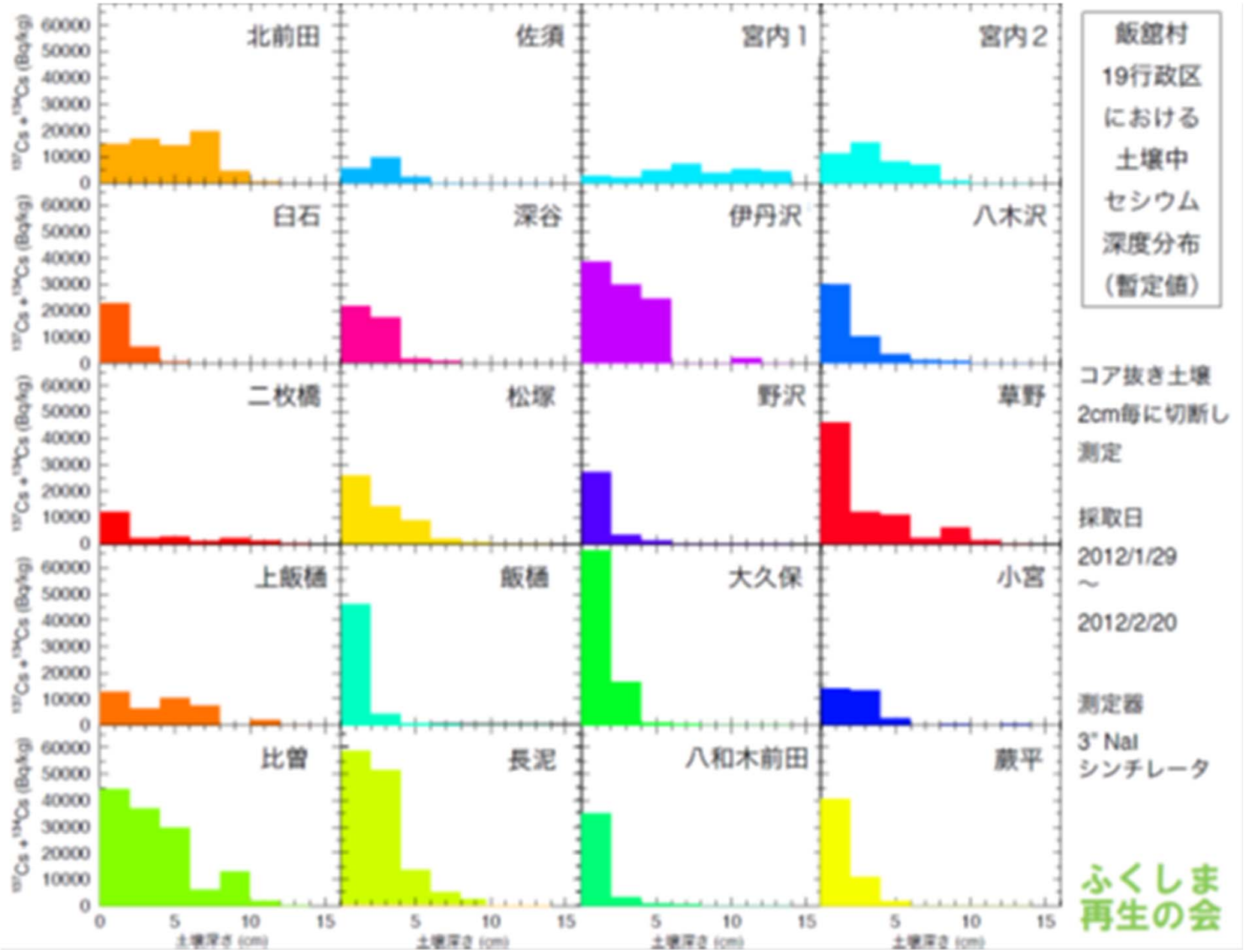
1.28μSv/h → 0.16μSv/h

Soil survey in snow storm

田畑の汚染状況の調査

(2012年2月～)

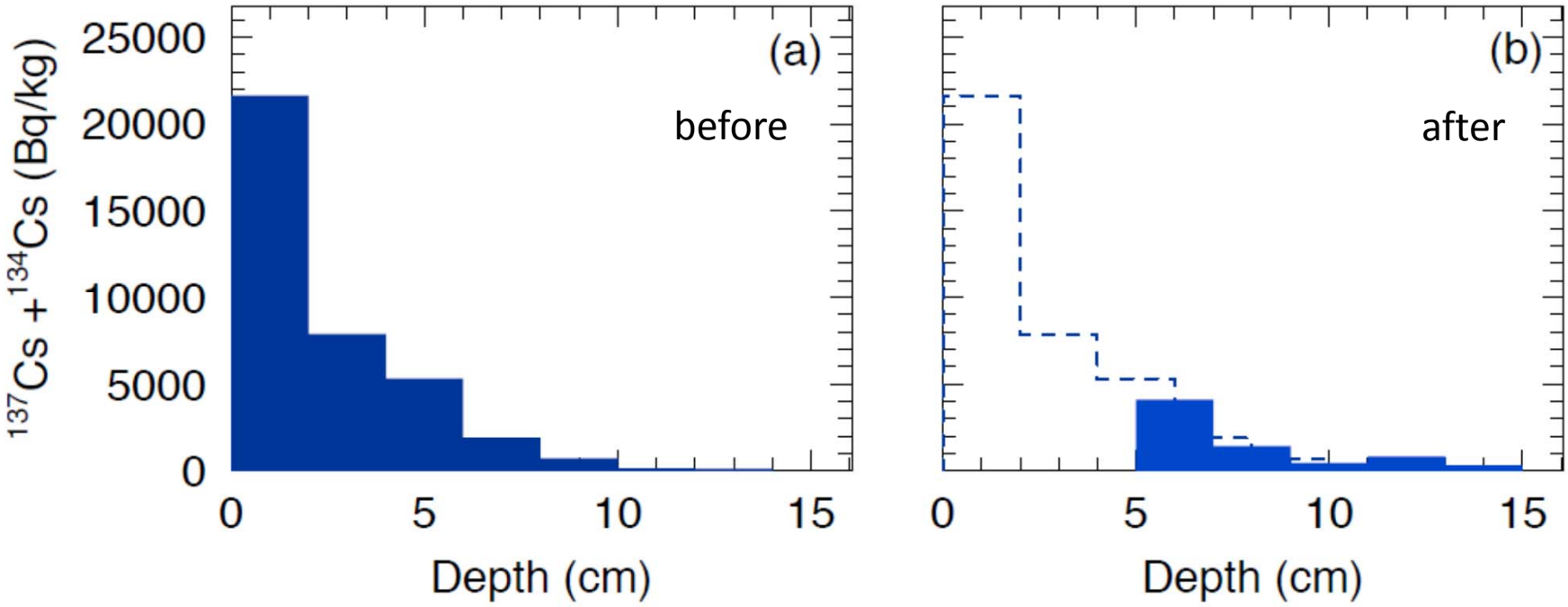
Distribution of radioactive cesium in paddy soil in 19 regions in Iitate village
(Resurrection of Fukushima, 2012)



Rotary weeder method that was tested by a volunteer group（April 2012）

Amount of radioactive cesium profiles before/after rotary weeder operation

(Resurrection of Fukushima, 2012)



ふくしま再生の会　　http://www.fukushima-saisei.jp/

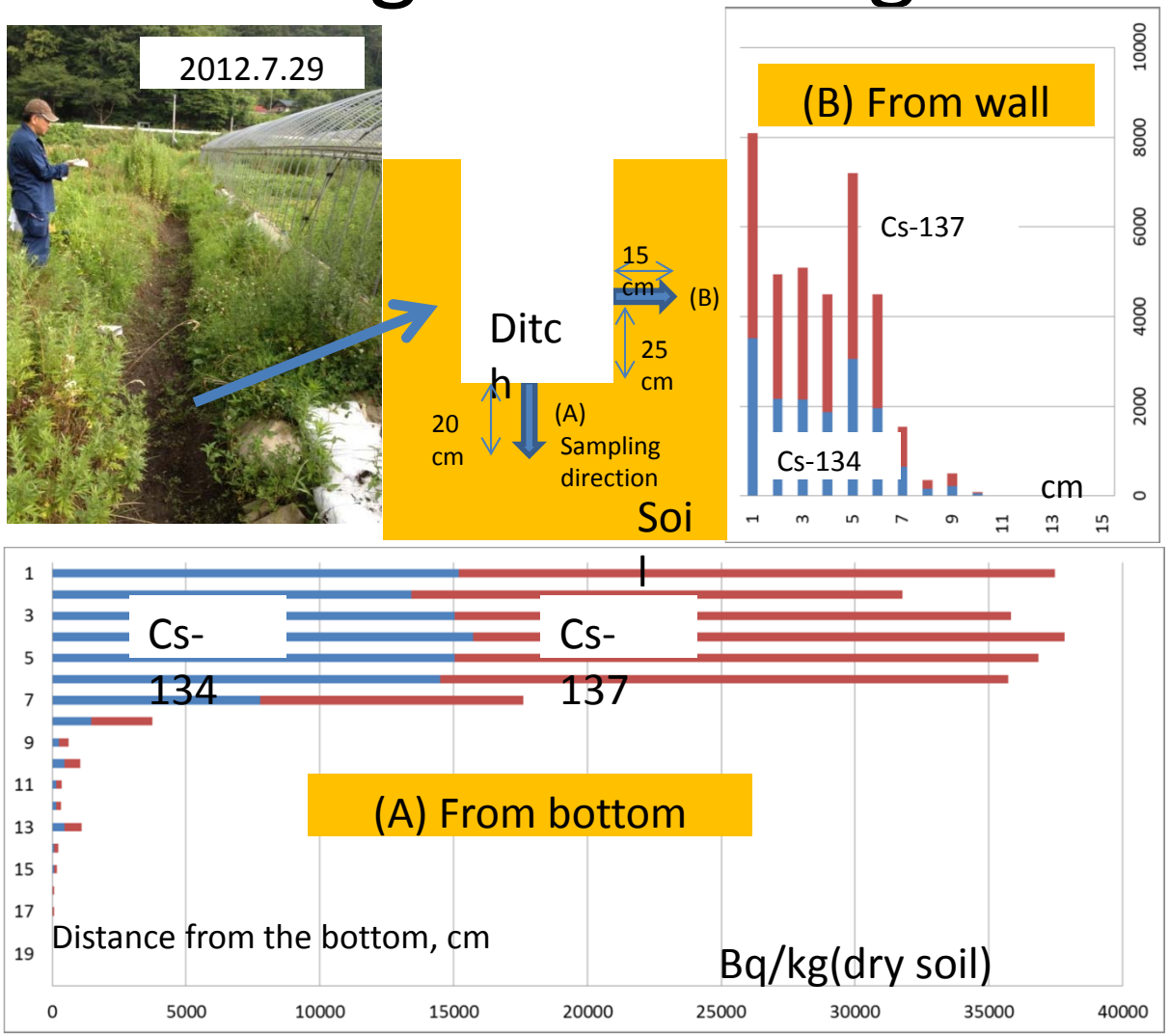
2012.4.29　Flash out muddy water

2012.6.24　Muddy water infiltrated into the ground

2012.8.26　soil sampling for the measurement of cesium concentration of soil

2012.8.26　clay crack on the ground

Concentration of radioceasium of soils surrounding the drainage ditch



Filtration of muddy water using sand

Fresh water comes out when muddy water is poured in the sand. When this operation is repeated, fresh water becomes slow to comes out. Clay particles with radioactive cesium are also trapped in the sand by this principle. (Right: fresh water, Left: muddy water)

Soil paddling method for decontamination of rice field

Komiya, Iitate (May 18, 2013)

References
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- 土壌学の基礎 （松中照夫） 2003, 農文協
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Homework
レポート課題

1. Explain why radiation dose was higher at the bottom of the slope than at the top of the slope in page 43.

2. Find your favorite page from “2015 International Year of Soils” and explain the reason why you like the page.

http://www.fao.org/soils-2015/en/