INTRODUCTION TO REGOLITH GEOLOGY

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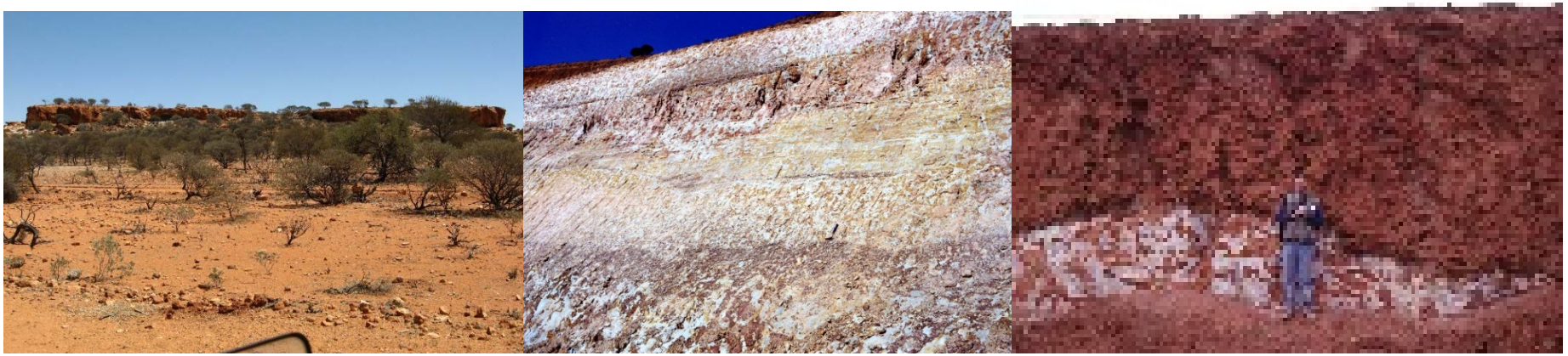


What is Regolith?

Regos – cover *Lithos* - rock

"Crap" on the surface! Chocolate icing on your rock cake!

Entire unconsolidated or recemented cover overlying fresh rock, that has formed by *weathering, erosion, deposition* of the older material.

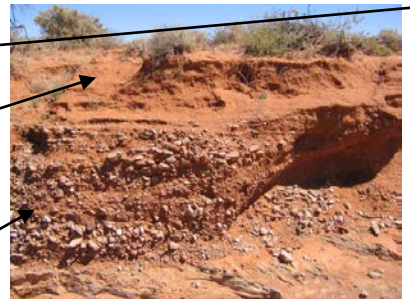
Weathered rock - saprolite

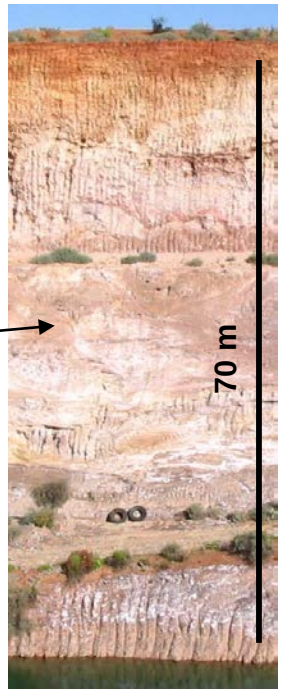
Weathered material unlike rock – soils, mottled materials

Unconsolidated clastic sediments – alluvium, colluvium, dunes, etc.

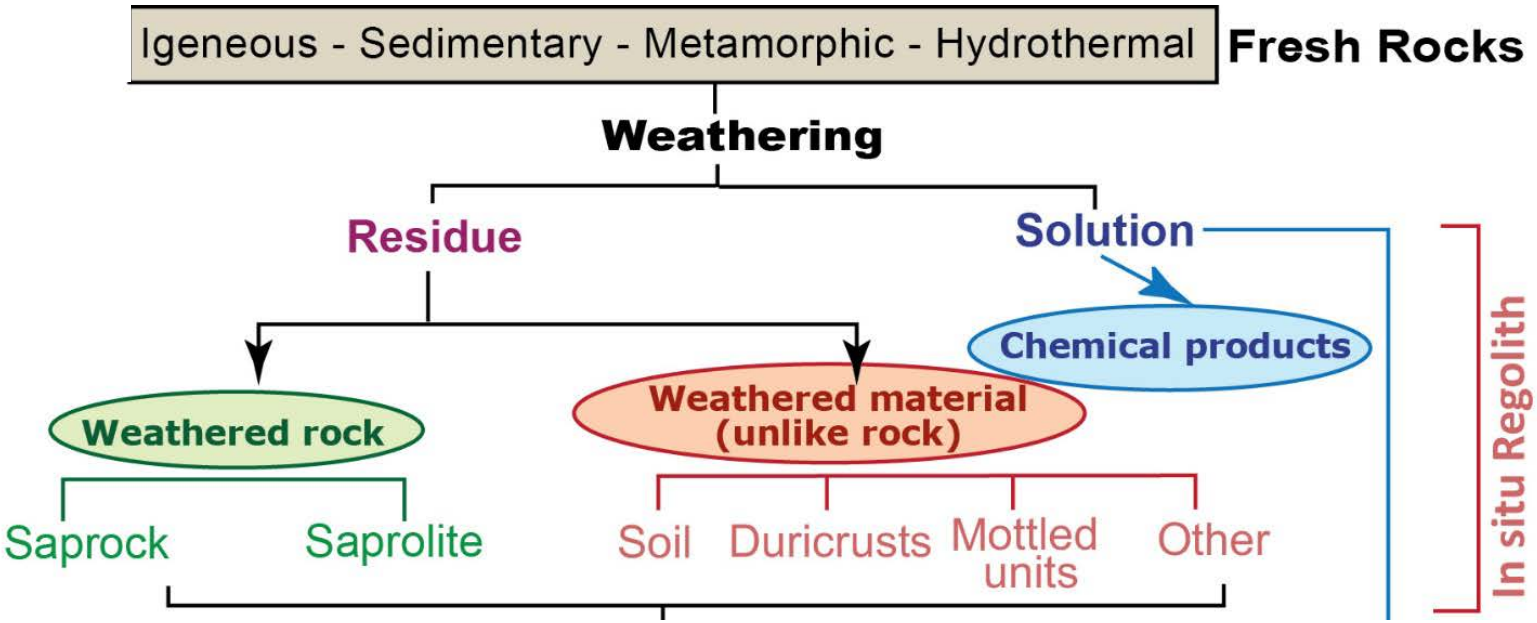
Recemented sediments & soil – cretes or duricrusts

Chemical sediments near surface – gypsum, halite (evaporites)

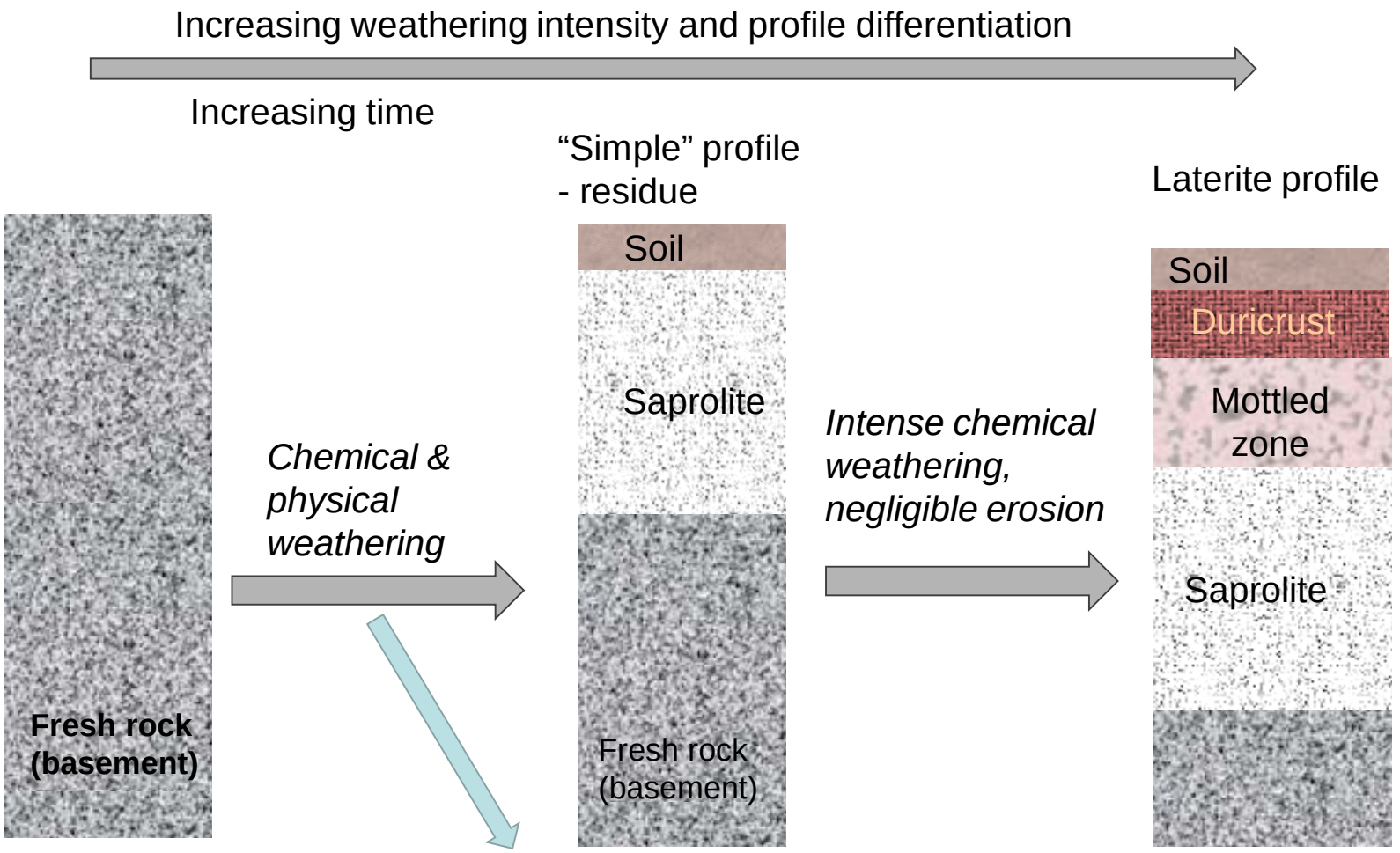




Regolith Materials & Formative Processes

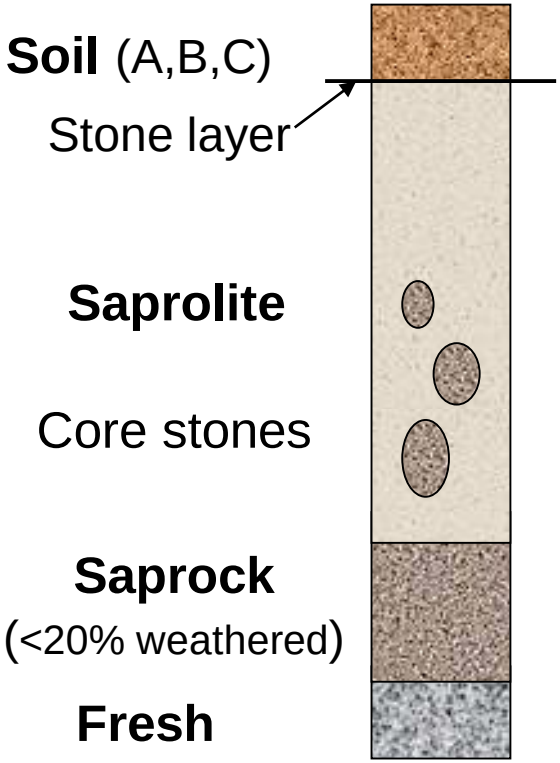


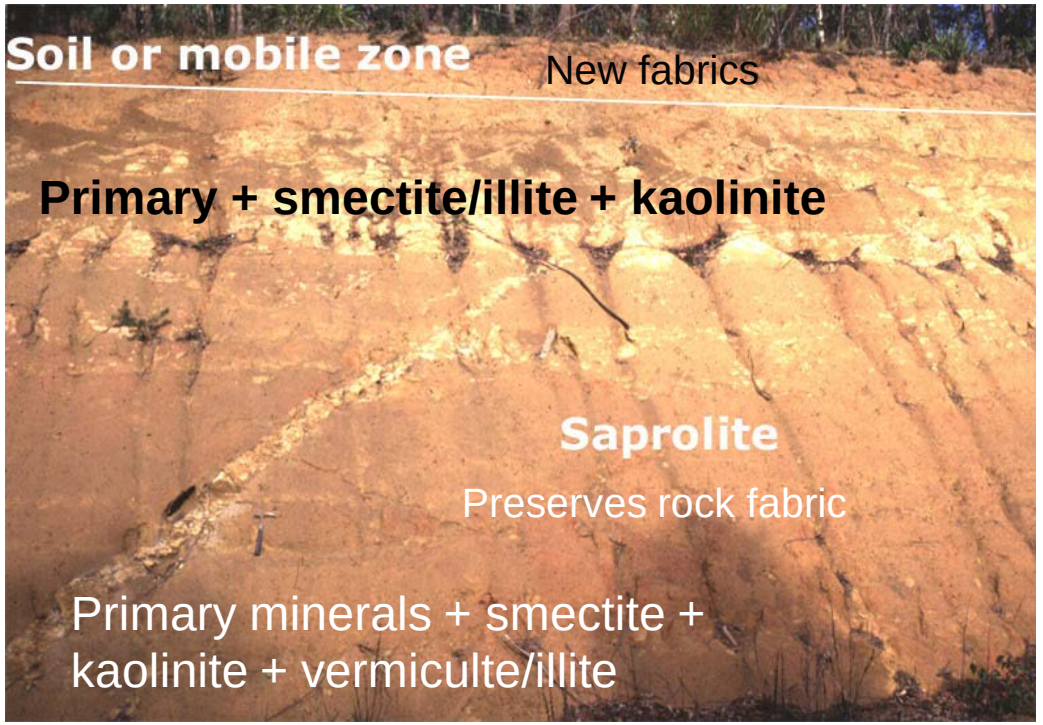
Evolution of weathering profiles



"Soluble" ions released in solution to ground & surface waters (solutes)

A “simple” weathering profile



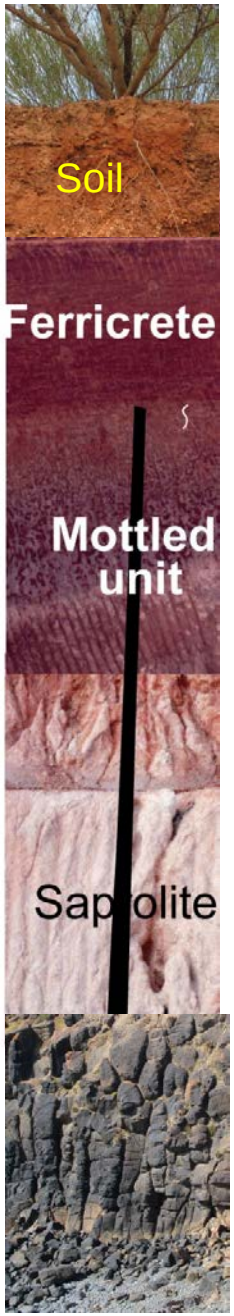


Processes that create and modify weathering profiles:

Chemical weathering :solution processes (dissolution-precipitation; redox; complexation; adsorption); Vegetation;

Physical weathering: Bioturbation; Mechanical

“Classic” laterite profile



Soil – horizons, bio-mantle is the uppermost zone of regolith in which plant roots & fauna live; likely to have horizons

Duricrust – Indurated & with secondary fabrics
Fe-Al-Si-Ca cements
Mottled zone – generally red patches (Fe oxides) in grey matrix (kaolinite) “Redox Front”

Saprolite – weathered rock that retains rock fabric (Kaolin, smectite, illite; If ferruginized – Fe oxides/hydroxides)

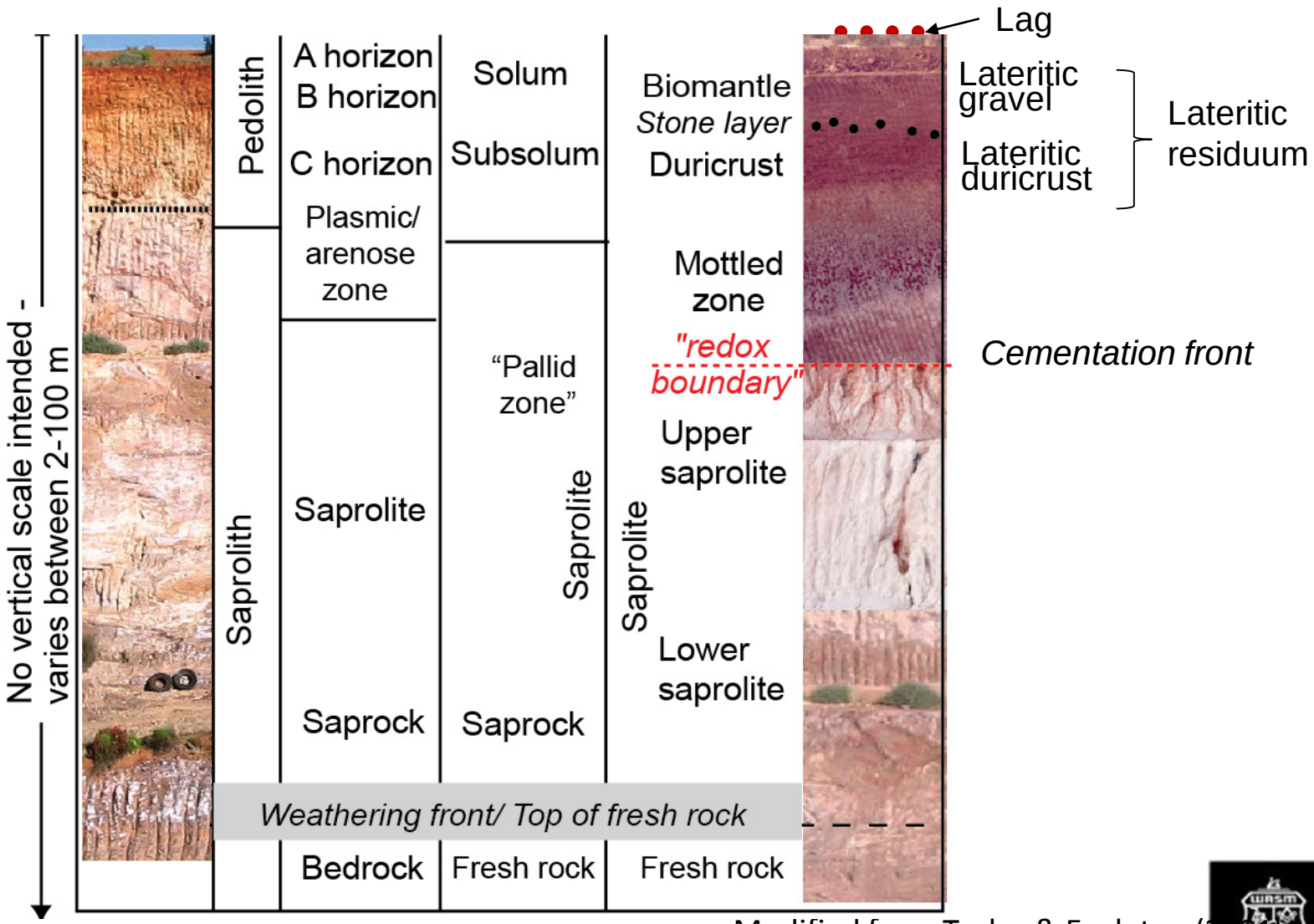
→ “Pallid” or leached

(Mottled; Ferruginized; Silicified)

Saprock – partly weathered rock fabric retained (<20% weathered)

Fresh Rock

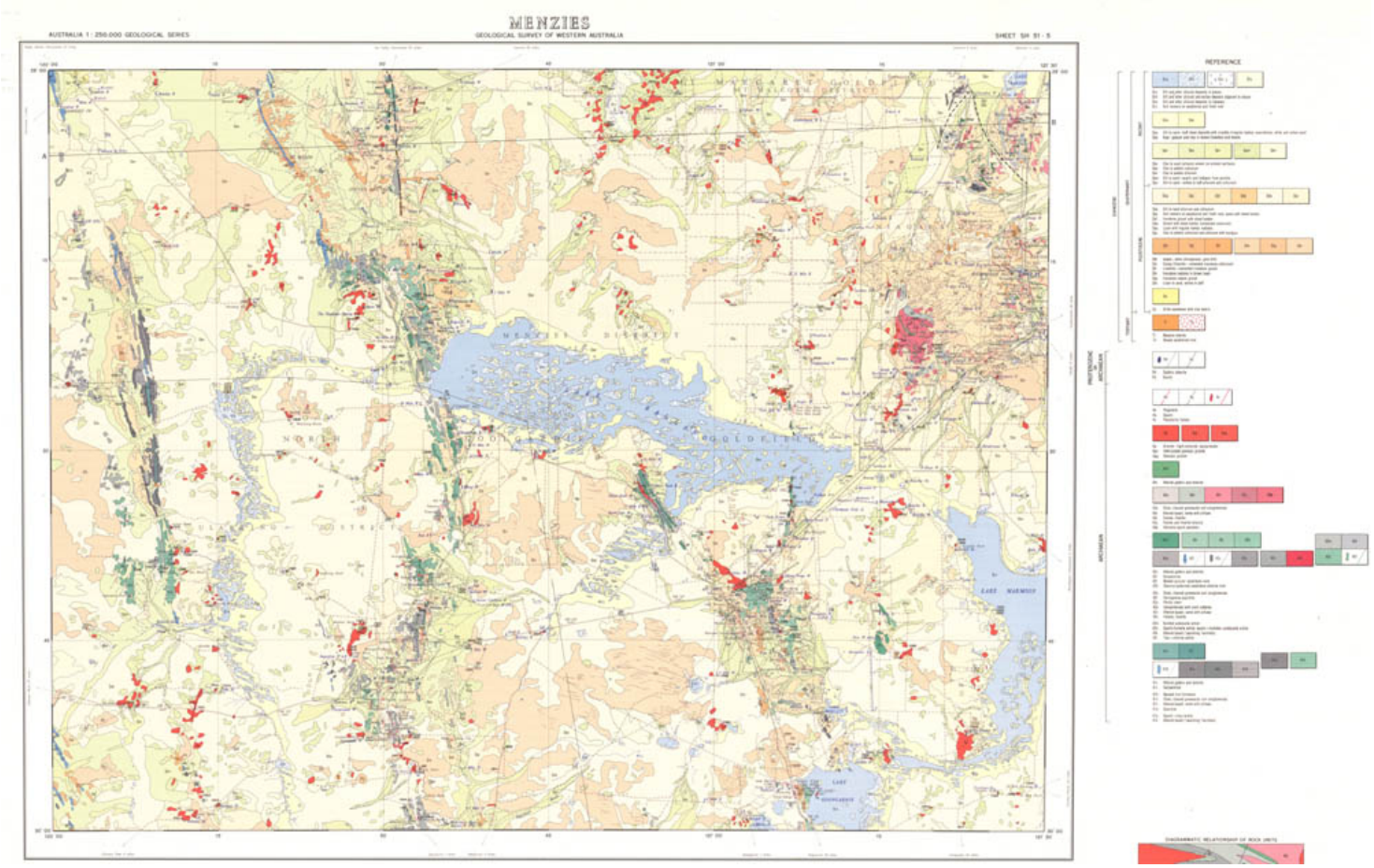
Weathering profile terminology



Modified from Taylor & Eggleton (2

Why bother studying the crap on the surface ?

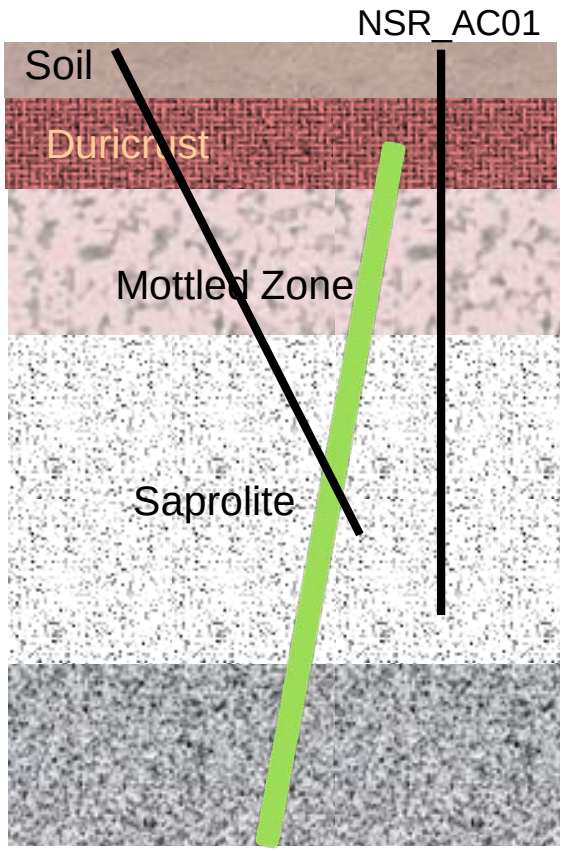
Australia is covered with it. Yellow colours on a map – they are everywhere! (foe & friend)



What lies beneath? How do you explore in “yellow/blue” terrains?

Why bother studying the crap on the surface ?

Every surface exploration drillhole starts in the regolith and most RAB/AC holes end in the regolith!

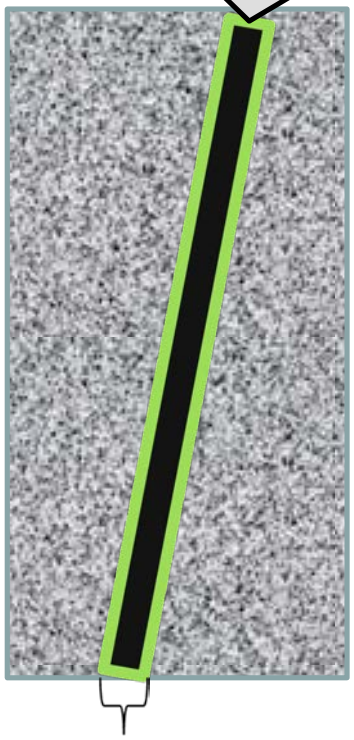


- How do I log it?
- How can I make use of it during exploration?
  - Specific units
  - Metal concentrations

Why bother studying the crap on the surface ?

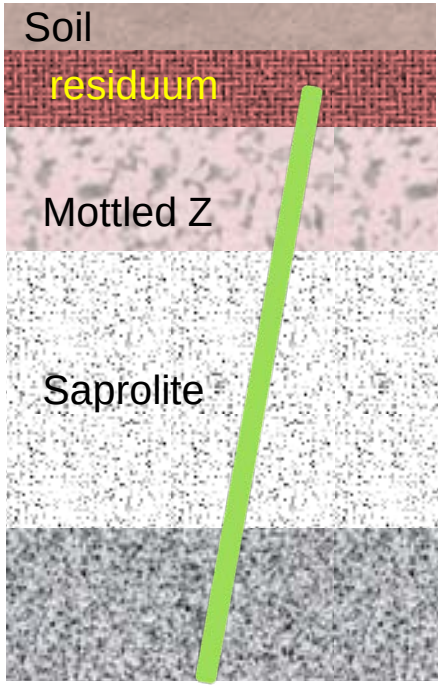
Metals disperse from primary ore deposit and make **wider** *secondary dispersion* footprint in the regolith - allows efficient target generation

Geological & geochemical expression at surface

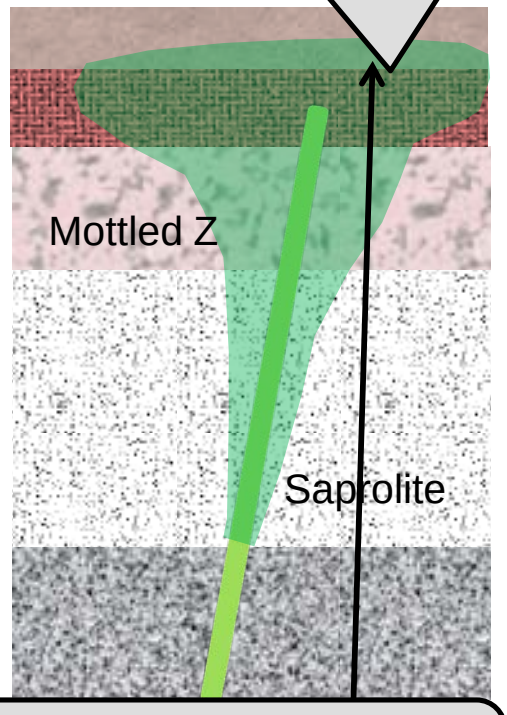


Primary mineralization footprint

What is the expression in regolith or surface sediment covered regions?



Wider geochemical expression in regolith makes target identification efficient



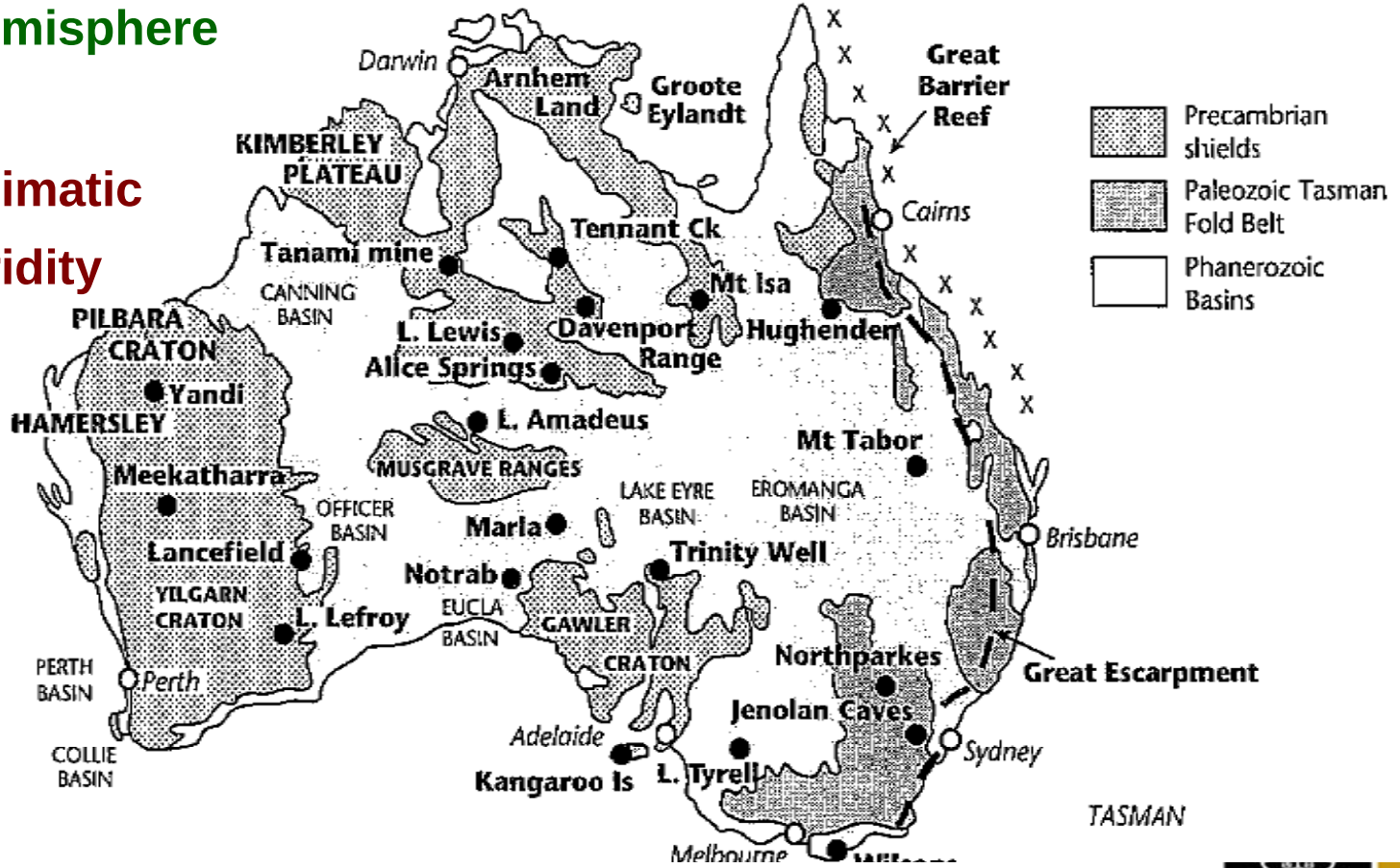
Wider secondary footprint near surface can be used to identify target to drill

Why has Australia been **unlucky** to have this crap develop and persist on it?

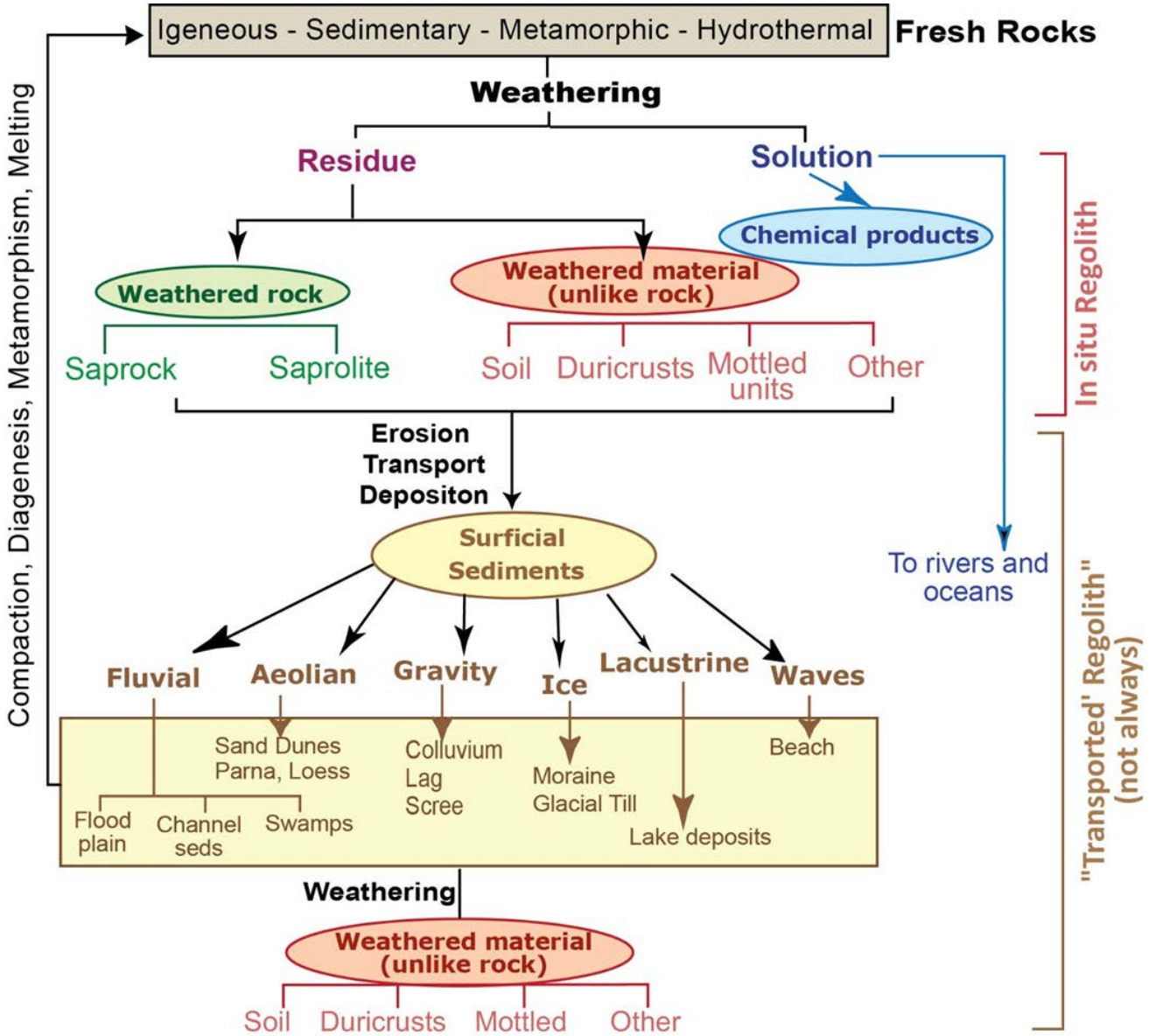
1 Escaped erosive force of Quaternary glaciation unlike Northern Hemisphere

2 Minimal post Paleogene orogeny

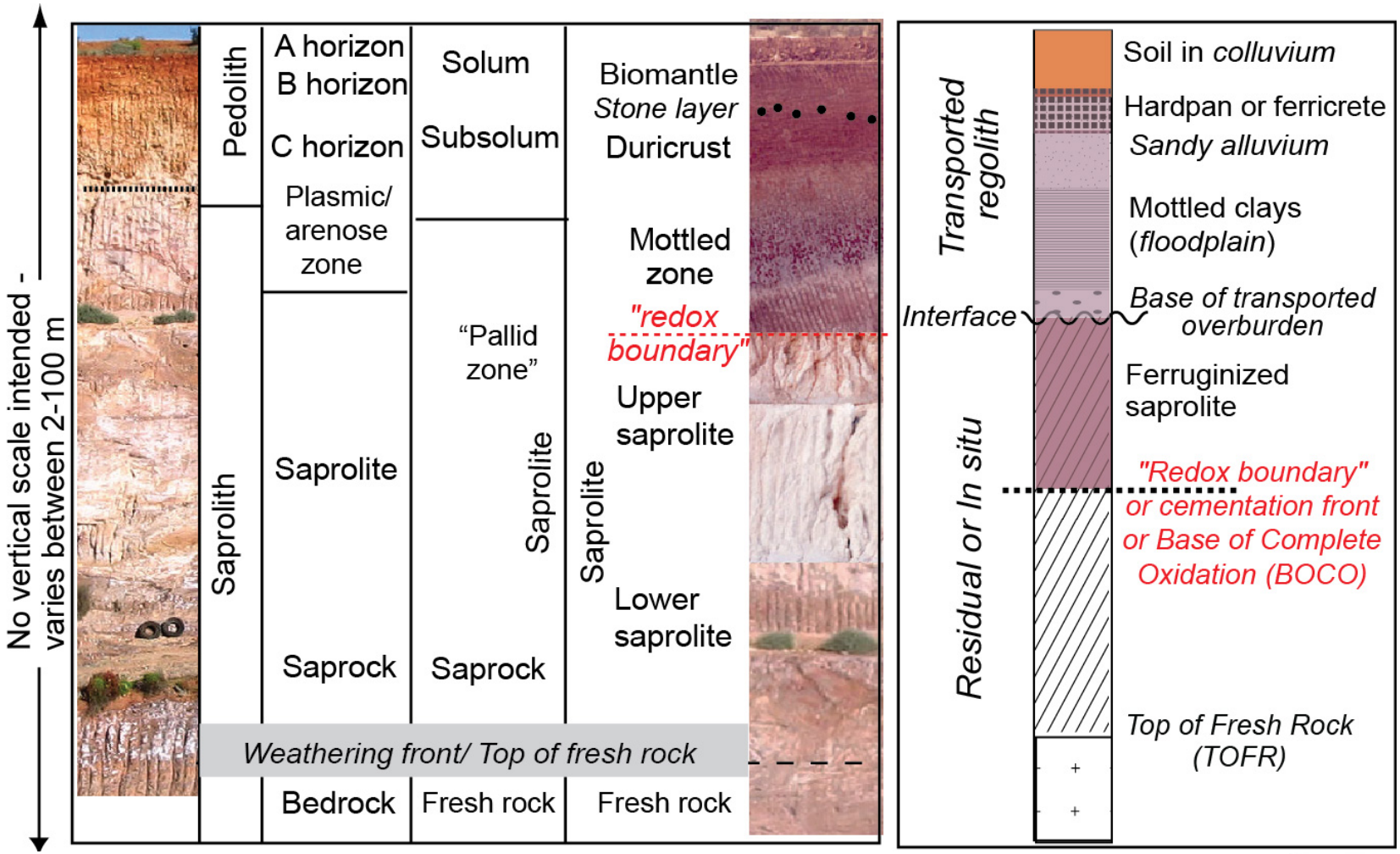
3 Neogene climatic Evolution - aridity



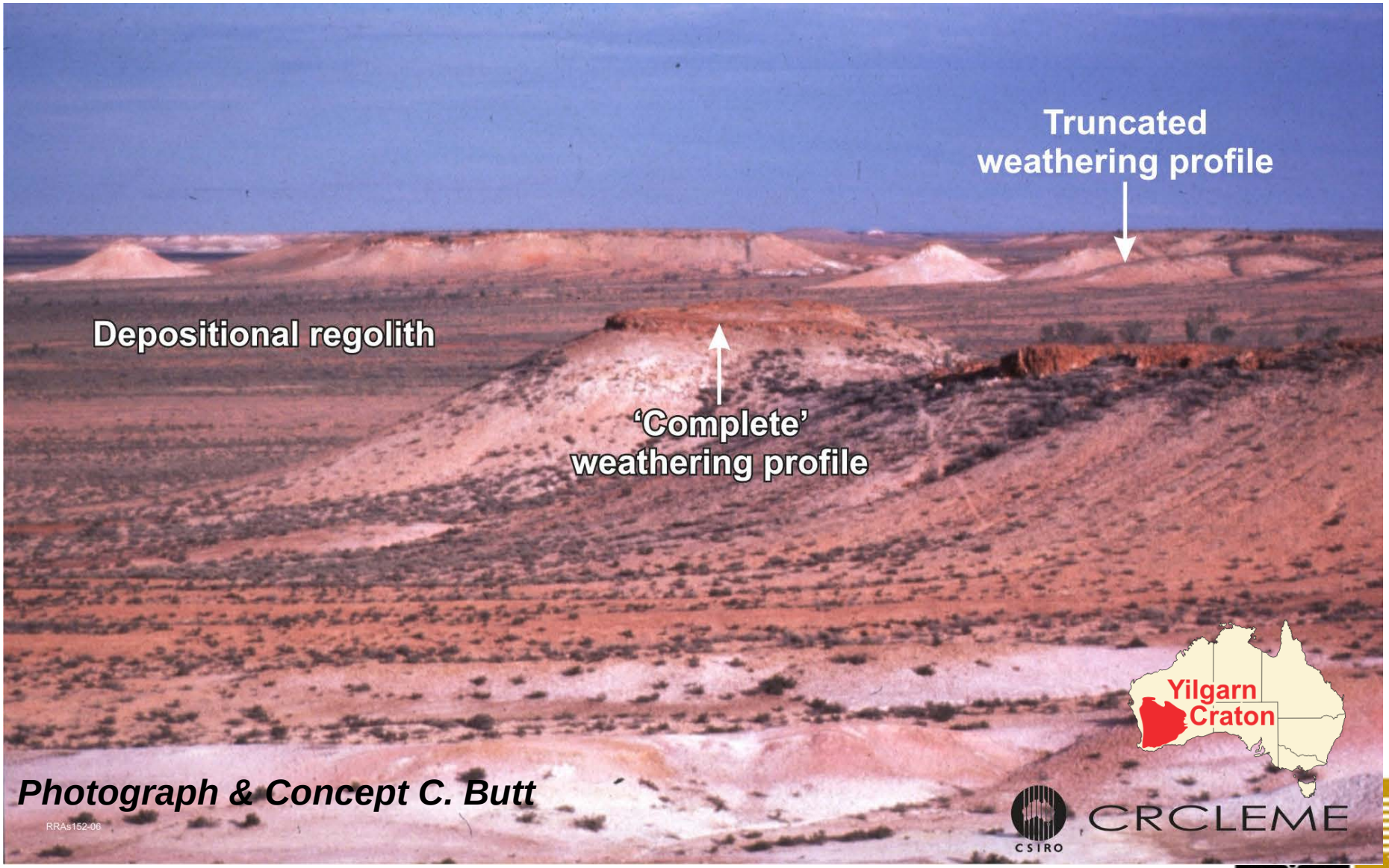
Regolith Materials - In situ vs Transported



Regolith Profile Terminology - Transported

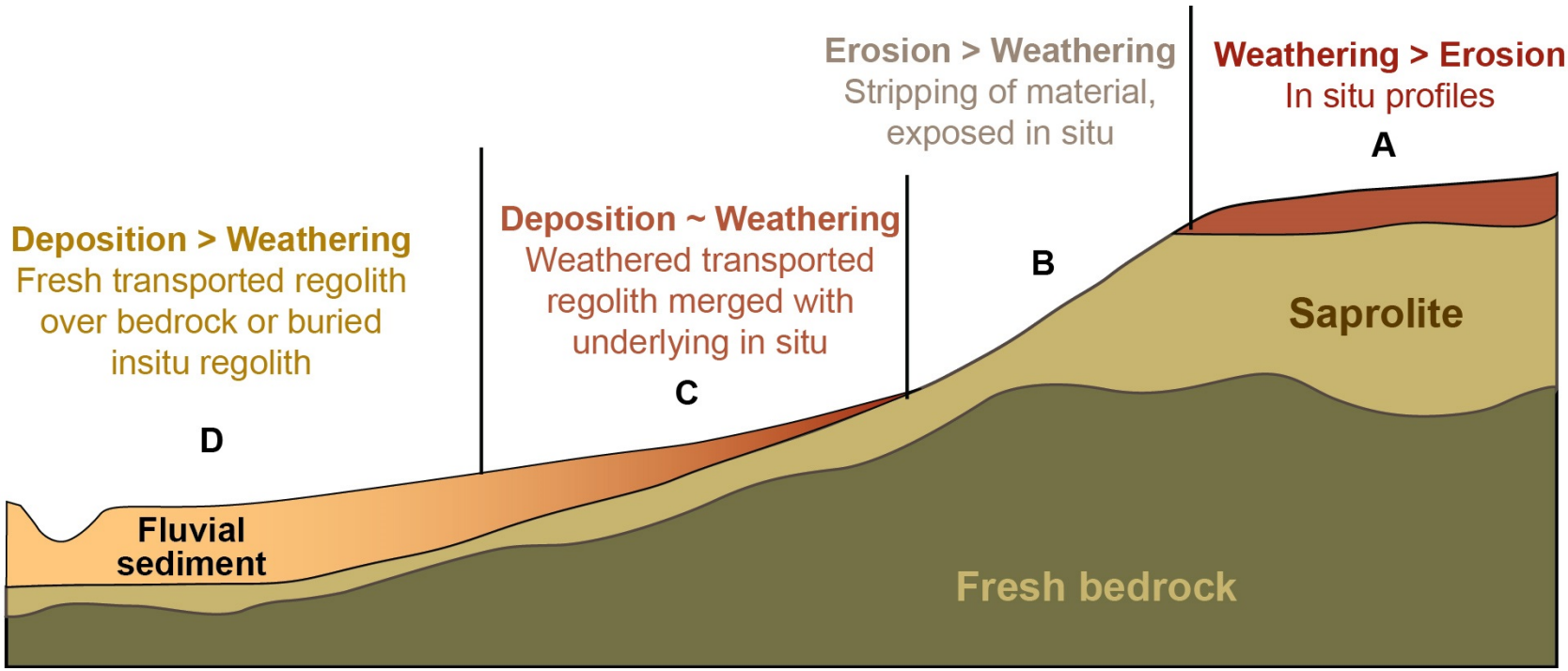


Regolith-landforms: Variable Regolith In situ vs Transported

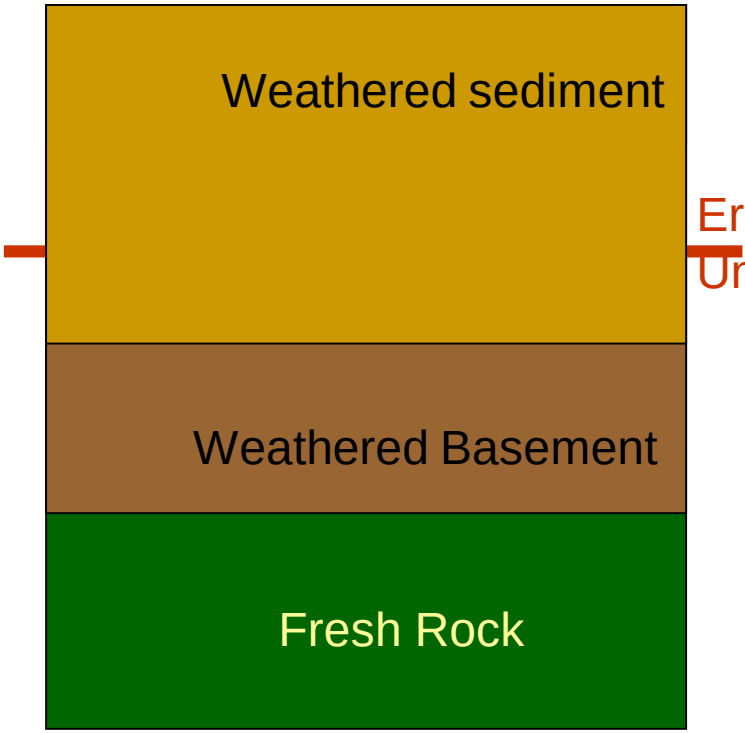


Regolith in landforms
In situ vs Transported

Regolith in the landscape evolves as a function of intensity of weathering (in situ or residual), erosion and deposition (transport)



Weathering, weathering profiles & landscape events



Surface landscape events in 1D

1 Weathering of basement

2 Erosion of surface

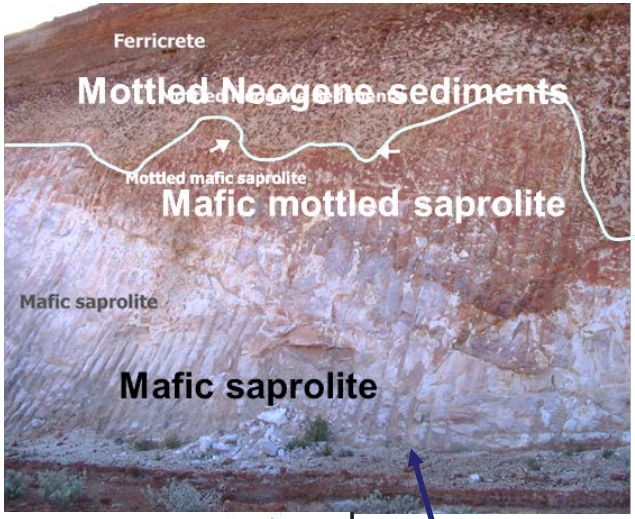
3 Deposition of sediment

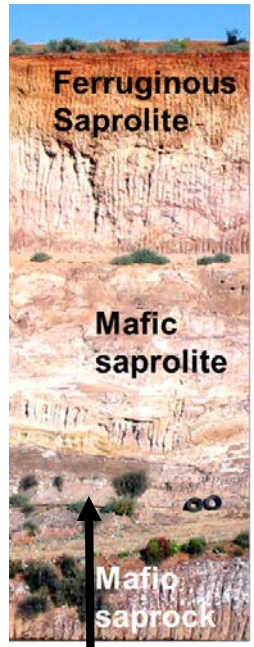
4 Weathering of sediment Unconformity still recognizable

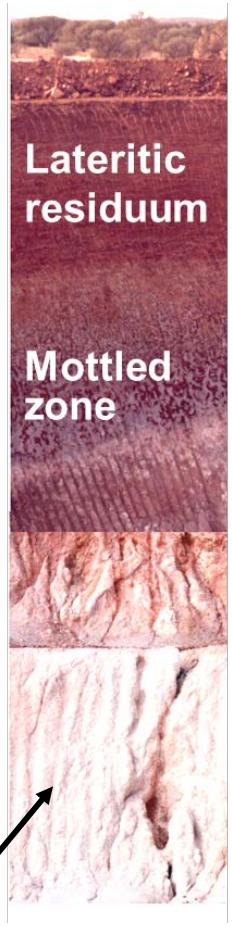
5 Deeper weathering of sediment obscures unconformity – landscape event unrecognizable

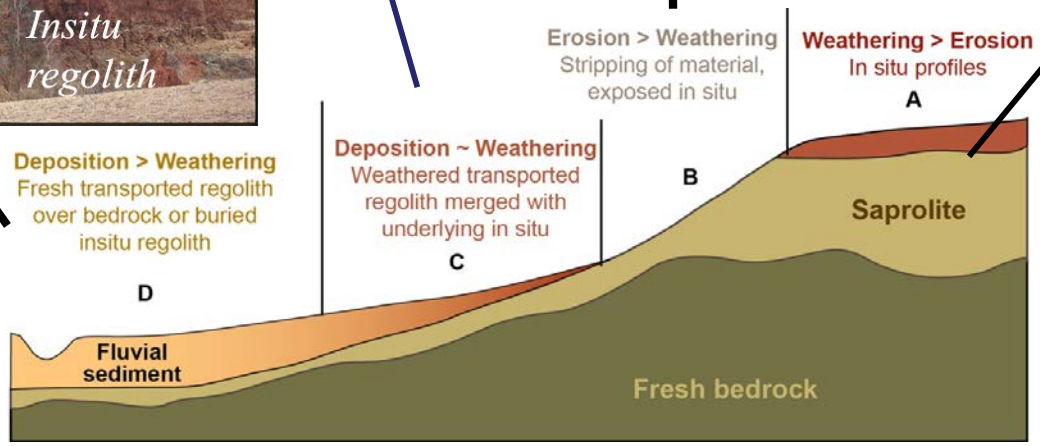
Need to unravel landscape events in weathering profiles in 1D and 2D

In situ vs Transported - 3

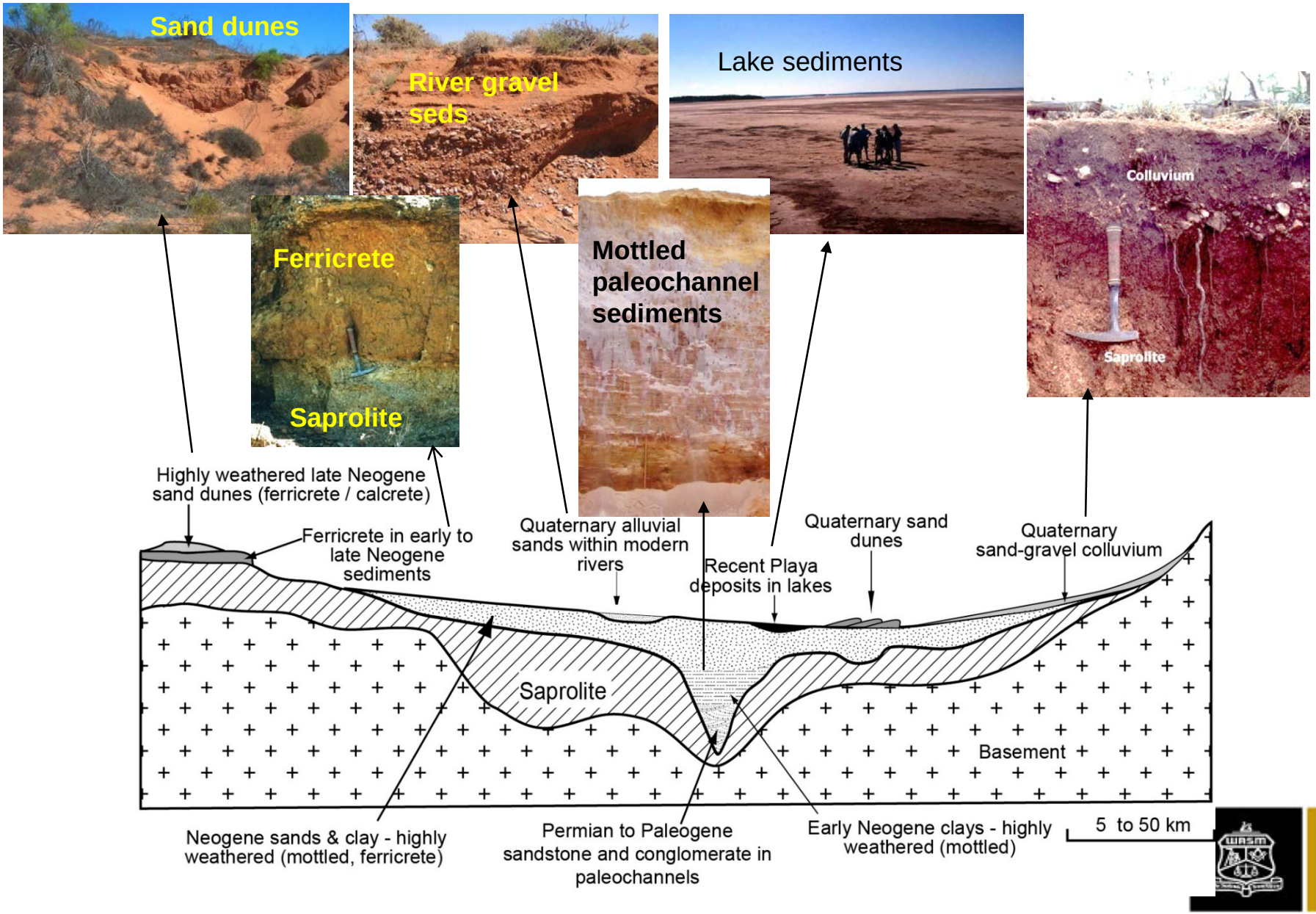






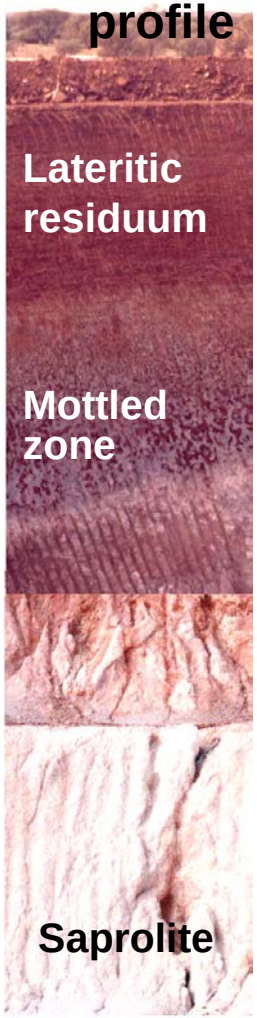


Transported Regolith Materials within the Landscape



“Classic” weathering profiles – a few neglected but critical points

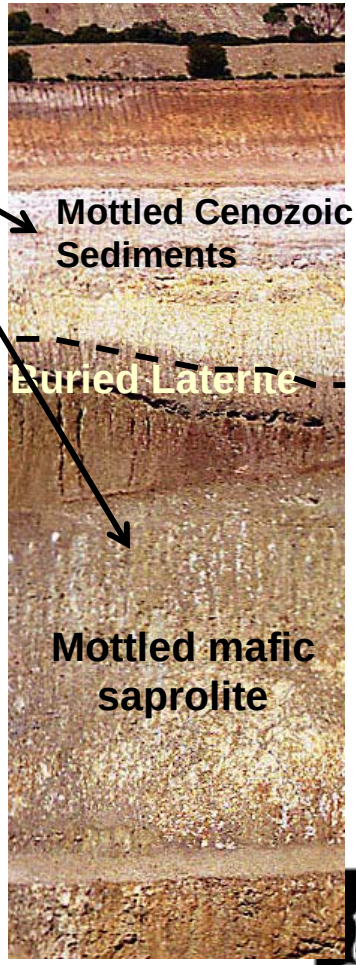
“Classic” lateritic profile



Not all zones of the “classic” laterite profile are present and any zone can crop out at surface

Regolith material units do not form in a sequence and some can repeat

Unconformity or interface



Thickness of zones can vary within 10s of meters

Changes during Weathering

Replacement of soluble ions by protons (H)

Primary

- Feldspar $(K,Na,Ca)AlSi_3O_8$
- **Pyroxene $(Mg,Ca,Fe)SiO_3$**
- Amphibole $(Ca,Mg,Fe)Si_8O_{22}(OH)_2$
- **Olivine $(Mg,Fe)_2SiO_4$**
- Mica $(K,Fe)Al_3Si_3O_{10}(OH)_2$

Ca^{2+}, Na^+, Mg^{2+} & K^+
Released as solutes

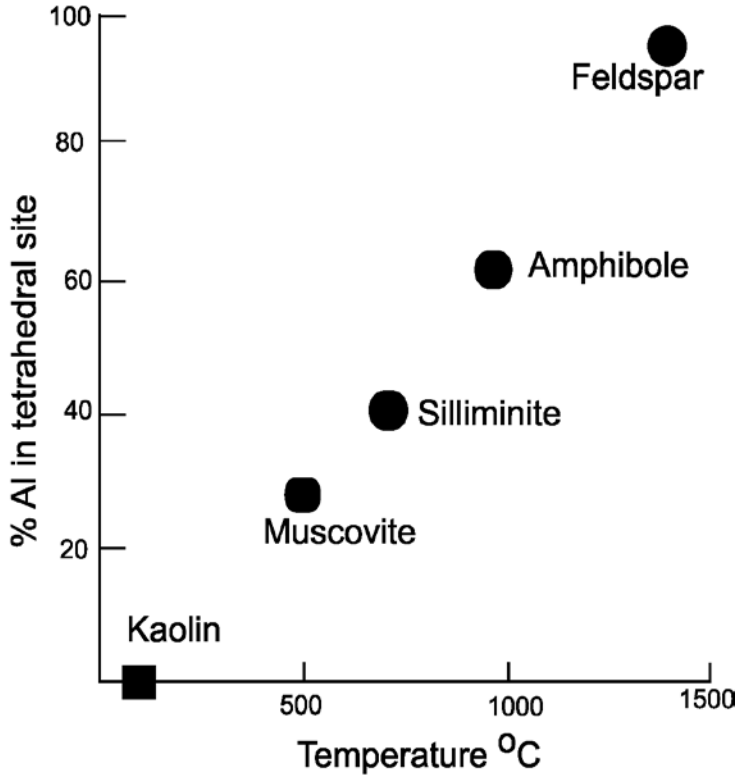
Secondary

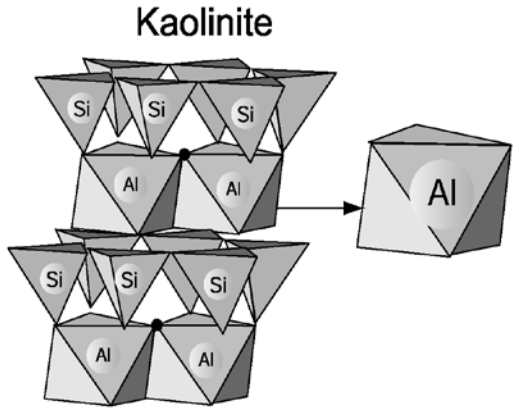
- Kaolinite $Al_2Si_2O_5(OH)$
- **Smectite $(Ca,Mg,Fe)AlSi_3O_{10}(OH)_2.H_2O$**
- Illite $KAl_3Si_3O_{10}(OH)_2$
- **Goethite FeOOH**
- **Hematite Fe_2O_3**

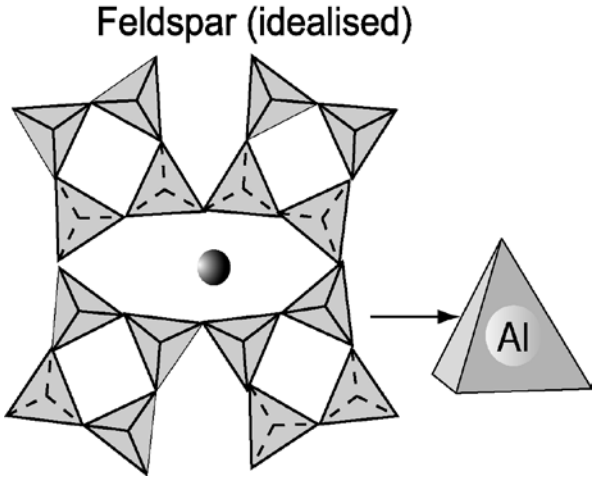
H^+ & H_2O

Changes during Weathering

Change of Al coordination on weathering





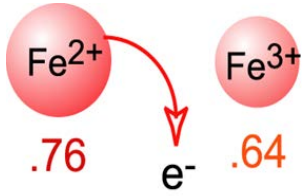


Change from four fold (tetrahedral) to six-fold (octahedral) on weathering

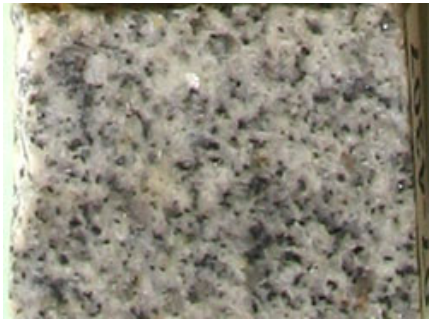
Changes during Weathering

Oxidation of Fe (& Mn)

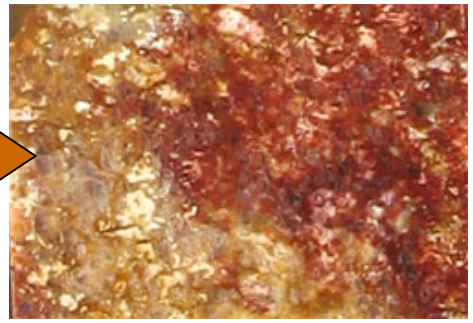
- Oxidation & reduction accomplished by **electron transfer**
- Oxidation – loss of electrons; Reduction – gain of electrons
- Fe^{2+} in biotite, pyroxenes, amphiboles, olivine, pyrite
- Oxidation: higher charge Fe^{3+}, smaller ionic radii
- Fe^{3+} - combines readily with O^{2-} to form oxides and hydroxides = goethite, hematite, maghemite, lepidocrocite, ferrihydrite
- Fine grained > reddish-brown hues



Fe^{2+} in biotite & amphiboles
Coarse grained minerals

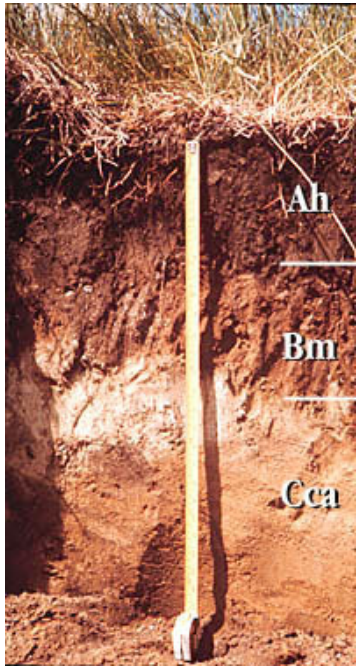


Fe^{3+} in hematite & goethite
Very fine grained minerals

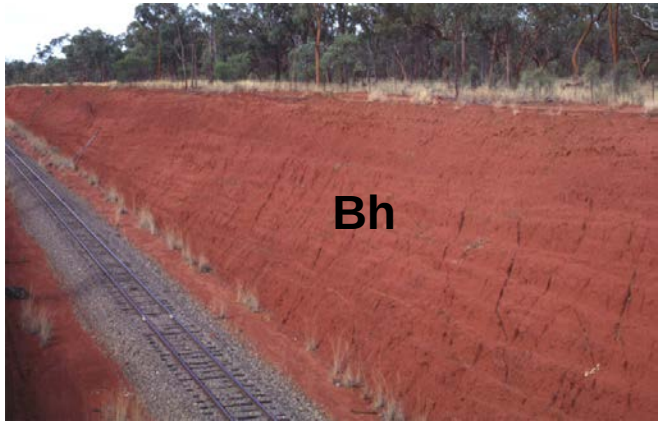


Soil & Biomantle

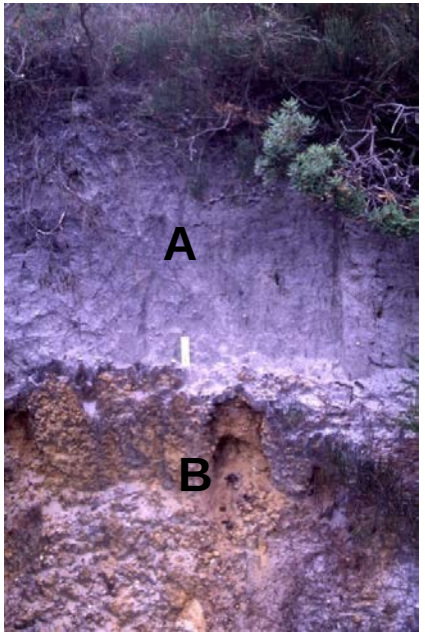
Soil profile terminology



Deep ferrosol



Podzol – leached A

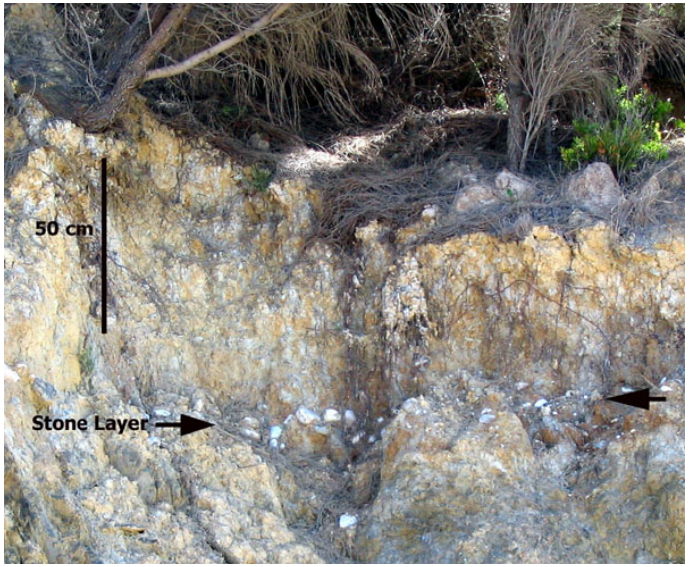


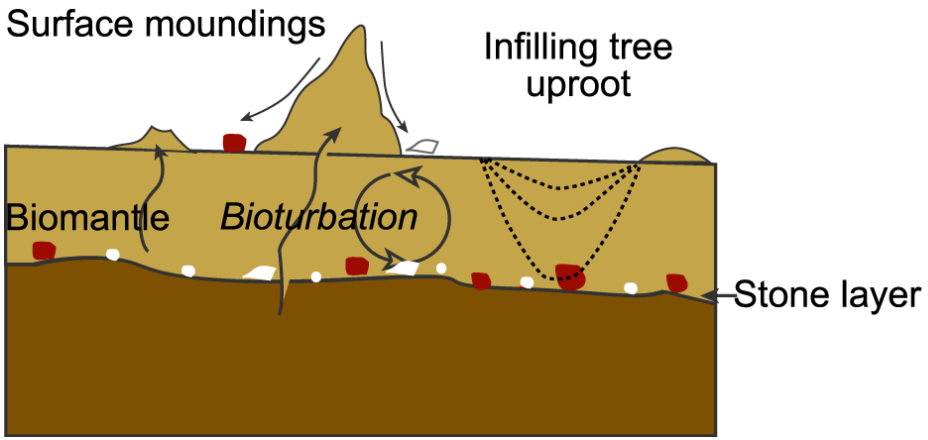
- Soil is the weathered material on the surface that is **biologically and biomechanically** active
- Described on horizons (colour), structure and texture
- Due to bioturbation (mixing in the biomantle), difficult to apply principle of superposition

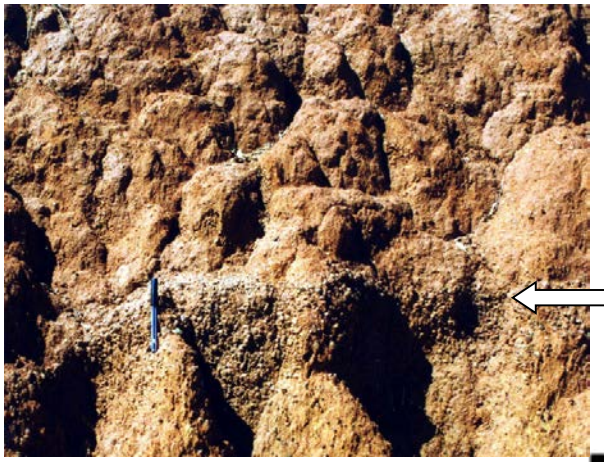
Stone Line or Stone Layer

Signifies either

- **Unconformity (erosion)**
- **Depth of past or current bioturbation**
- **Heavier particles sink on soil mixing**



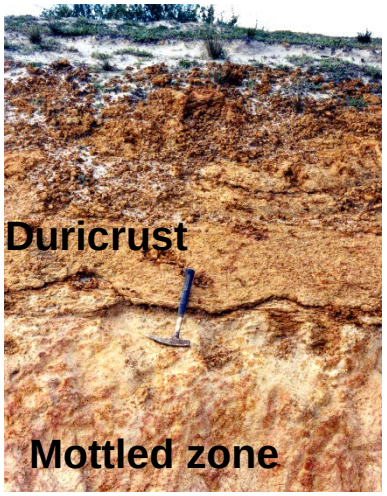




Stone layer

Duricrusts

- Iron, calcium, aluminium, silica cemented surface or near surface material (indurated)
- Diverse terminology and classification based on
- **Morphology**
  - Fabrics such as pisolithic, nodular, vermiform etc. Descriptive and preferred classification
- **Genesis: Mode of origin = Interpretive**
  - Pedogenic (vadose) or soil based and
  - Groundwater. Only use when sure of origin.



Many duricrusts - Ferricretes/laterites and calcretes are great sample media for a range of commodities – Au, Ni, base metals – and surface, subsurface & buried sampling success

Iron Duricrusts
Laterite, Ferricrete…

Laterite

- Most common reference to iron indurated material but also referred to red or yellow gravelly soils and mottles. Best reserved for upper parts of profile

Lateritic residuum

- Collective term for upper ferruginous material (indurated and/or loose) of a laterite profile

Lateritic duricrust

- Iron cemented massive or different fabric material forming the upper parts of laterite profile

Lateritic gravel

- Loose iron rich segregations (pisolites, nodules)

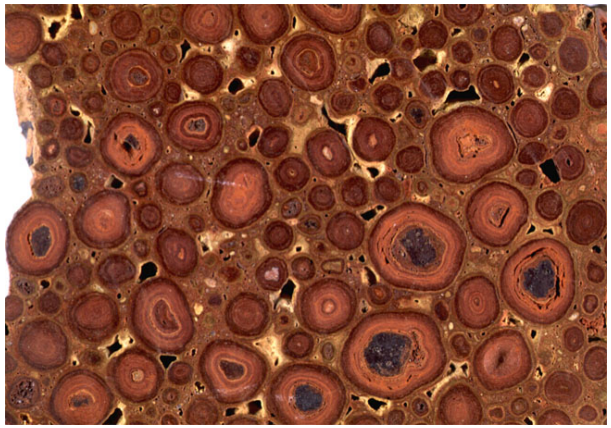
Ferricrete

- Regolith, specially sediments, cemented by iron oxides

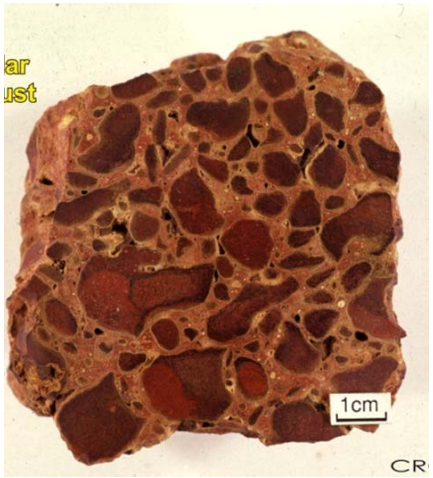
Most cemented by Fe-oxides: hematite, goethite & maghemite

Iron duricrust: Lateritic Residuum/Ferricrete
Classification Morphological – based on fabrics

Pisolitic



Nodular



Vermiform

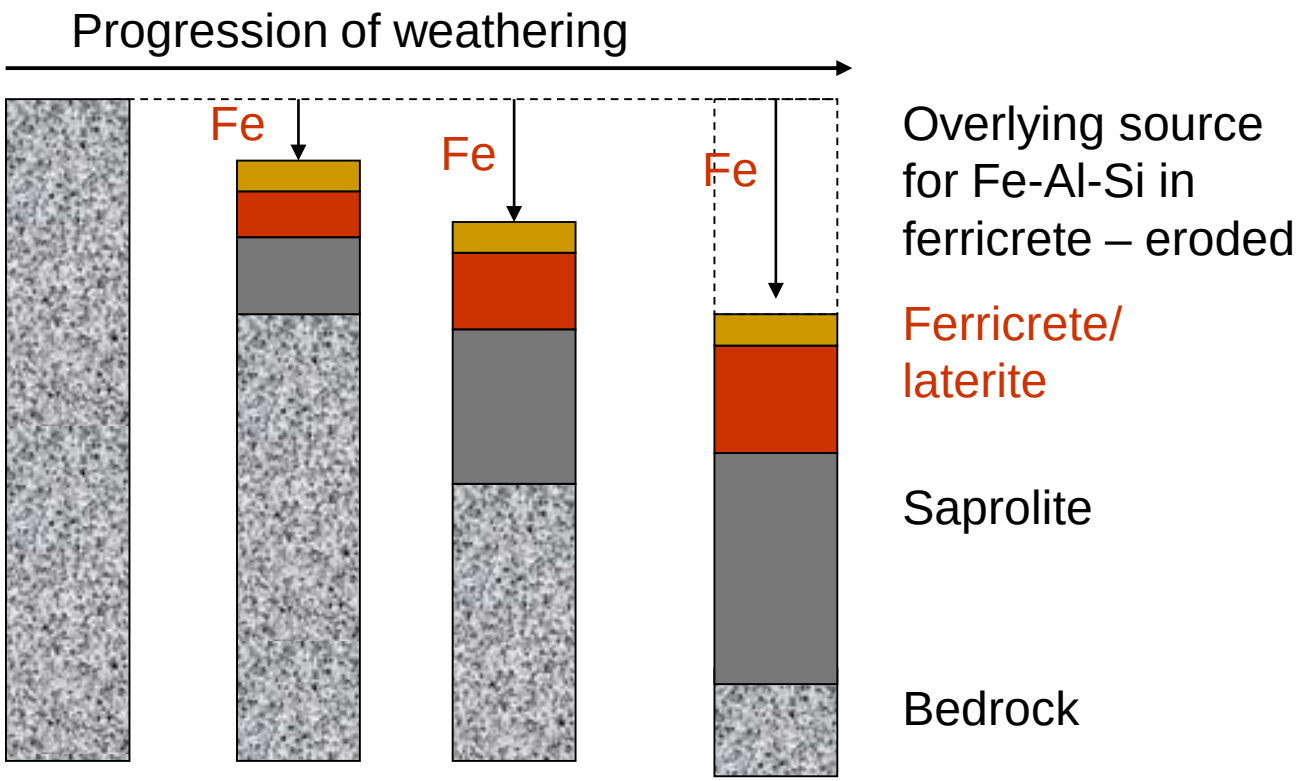
Compound

Vesicular

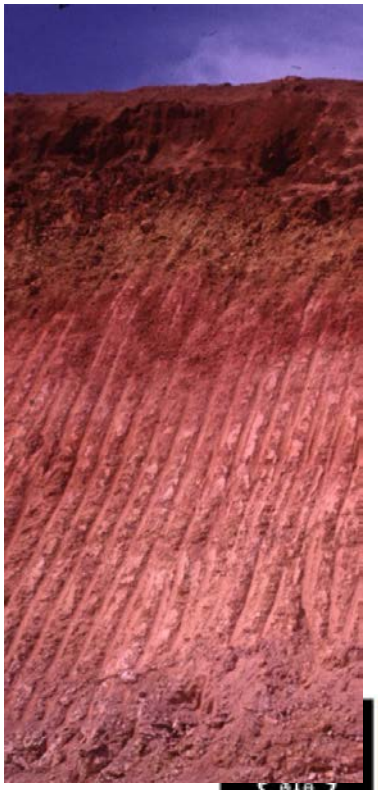
Ferricrete/Laterite genesis – Model 1

In situ weathering and profile lowering mechanism

In situ or residual weathering, vertical movement of Fe and concentration with landscape lowering – relative & vertical absolute accumulation of Fe (and Al & Si)

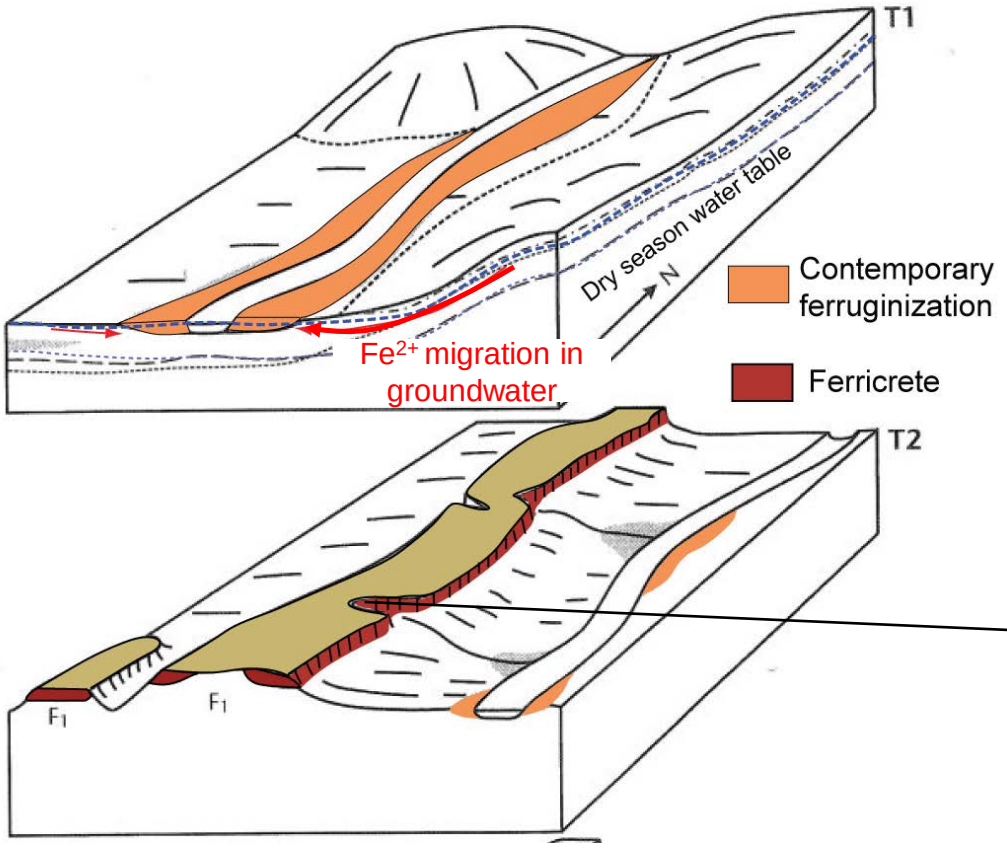


Modified after McFarlane 1983 & Taylor & Eggleton 2001



Ferricrete/Laterite Genesis – Model 2
Lateral Migration Theory

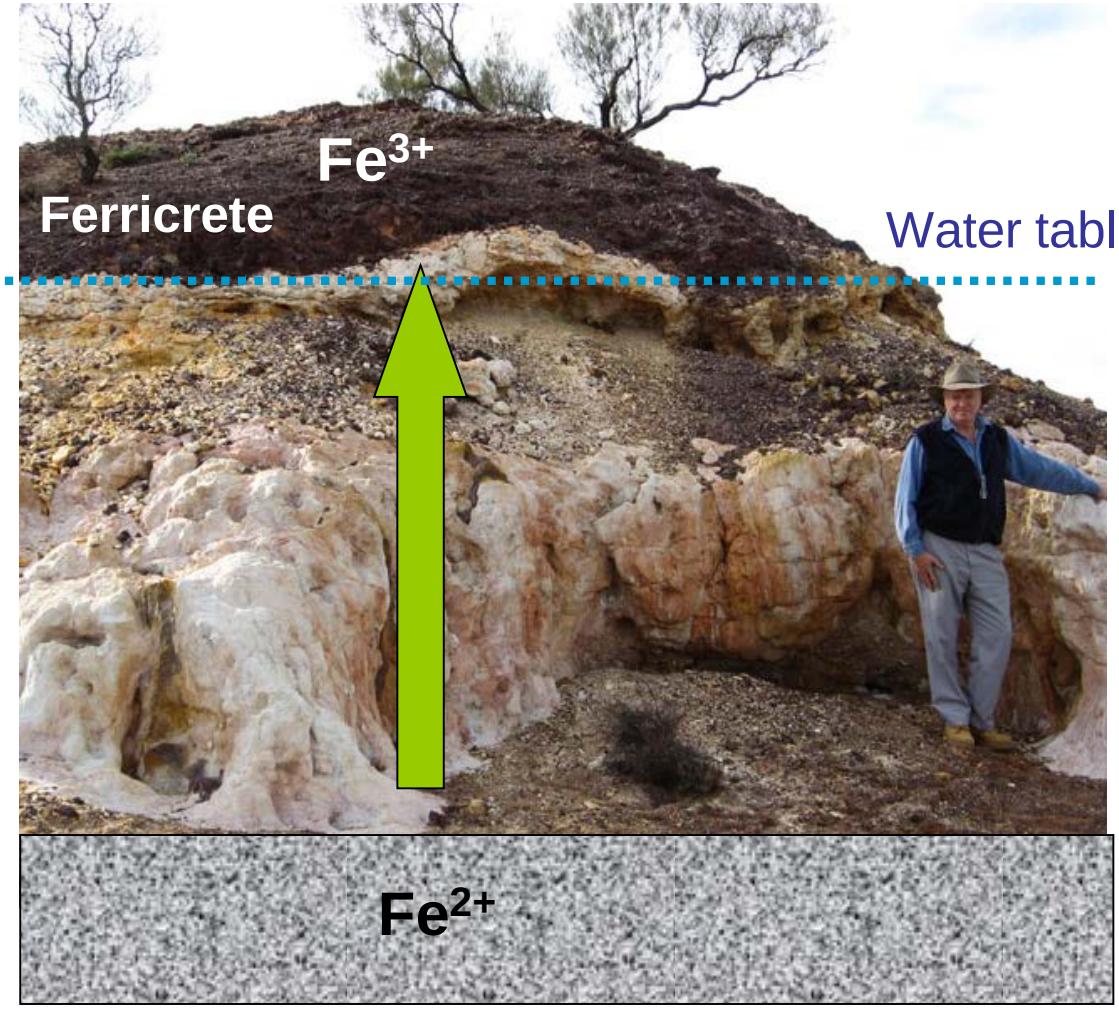
Lateral migration of iron and precipitation with cementation – lateral absolute accumulation (also mostly within sediments)



Modified after Taylor (2008)

Ferricrete/Laterite Genesis – Model 3

Upward diffusion theory



Fe^{2+} released from primary minerals at weathering front diffuses upwards to oxidizing conditions at water table and oxidizes to Fe^{3+} and precipitates as Fe oxides & hydroxides - cements

Duricrusts

Silcrete

Material cemented by silica

- Micro quartz, opal A, opal CT

Two main genetic types

- Pedogenic and Groundwater

Sand quartz cemented by micro crystalline silica or pure cement

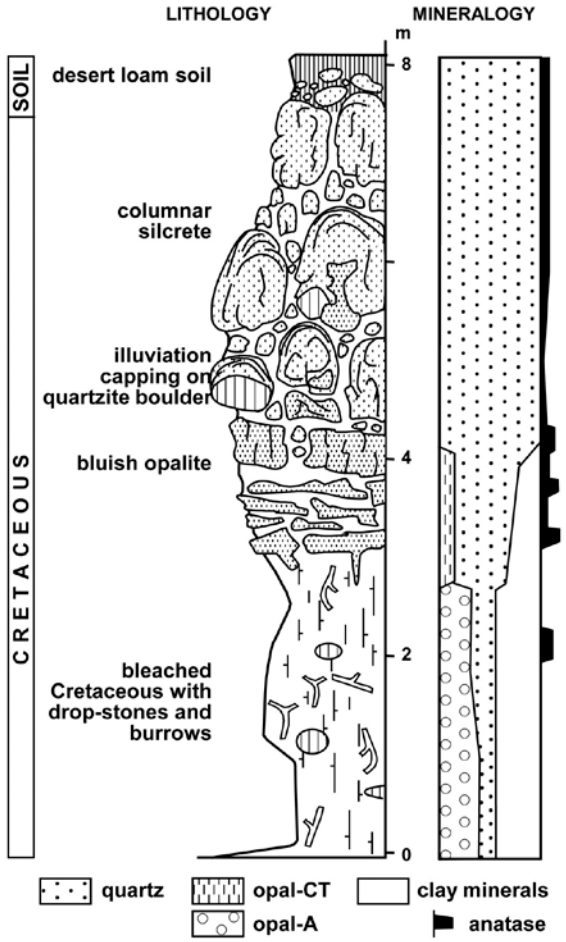
Common duricrust around Australia

Hard to extremely hard

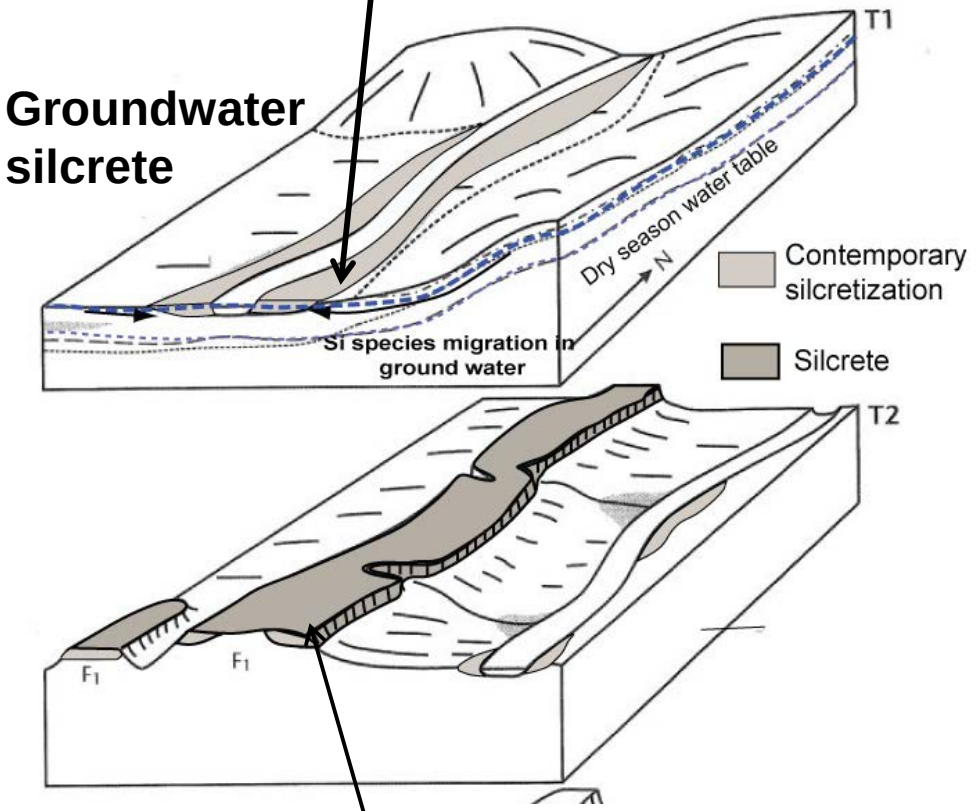
Silcrete Genesis

Pedogenic silcrete

Leaching of silica downwards from upper Si bearing units to form silica concentrations in regolith



Silica migrates from higher locations to valleys via groundwater & precipitates/cements sediments on pH change & evaporation



Subsequent erosion removes softer adjoining highs leaving the hard silcrete as caps (past channels)

Duricrusts

Calcretes

Materials cemented by calcium carbonate dominantly calcite, but also dolomite

Morphological classification

Nodular - Massive - Laminar - Rhizocrete

Genetic classification

Pedogenic - Capillary

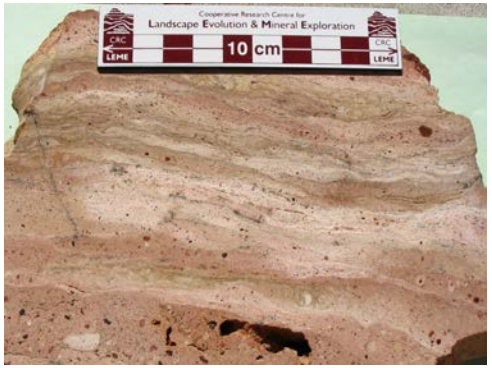
Phreatic (groundwater) - Gravitational

Generally restricted to soil or just below soil, but can be found deeper above saprolite

Nodular to bouldery

Rhizomorphic

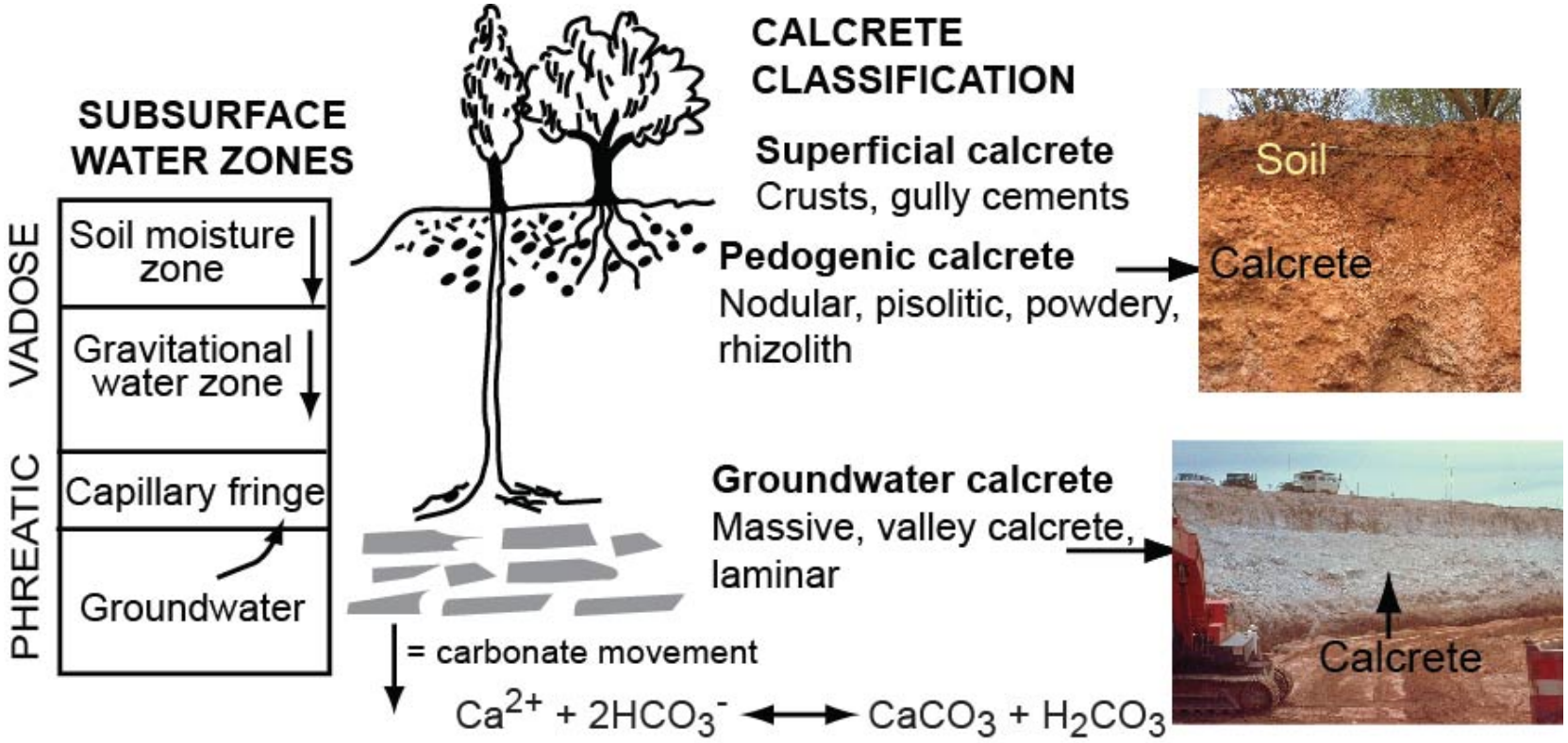
Laminar



Valley (groundwater) calcrete

Duricrusts

Calcrete Formation – hydrological setting



- **High evaporation & evapotranspiration = carbonate precipitation**
- **CO_2 degassing (removal) = carbonate precipitation**
- **Groundwater flow to valleys and precipitation of carbonate on evaporation**

Redoximorphic Features

Mottles & Mottled zones

Mottle zones of laterite profiles

Mineralogy

Red: Hematite > Goethite ~ Kaolinite

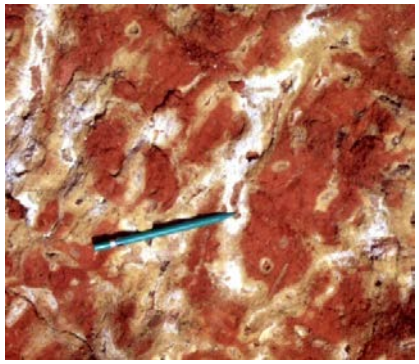
Yellow/brown: Goethite > Kaolinite

Grey: Kaolinite

- Fine (<1 cm)
- Coarse (1-3 cm)
- Mega-mottles (>3 cm)

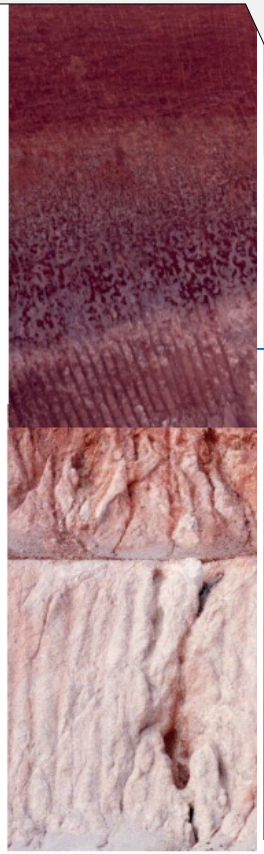
Red matrix – grey mottles

Mottles around roots!



Redoximorphic feature formation

Oxygen gradient created by O_2 being consumed by oxidizing organic matter



As water table recedes, parts to oxidise first attract Fe^{2+} and oxidise it

Oxidizing
High Eh

Permanent water table fluctuating zone

Redox Front

Parts that remain saturated longer, depleted in Fe

Permanently saturated zone

Fe^{2+} (Mn^{2+}) diffuse upwards along oxygen gradient to oxygenated water

Which other elements?

Reducing
Low Eh

Redoximorphic feature (mottles & ferricrete) formation in profile – duration and depth/height of saturation!

Morphology

Nodules pisolites

Small – coarse mottles

Coarse to mega mottles

Increasing duration of saturation

Red brown hardpans

- Hard indurated material – mostly alluvium and colluvium, cemented by dominantly Si & Al (koalinite, micro-quartz) and minor Fe and Mn oxides
- Platy or blocky structure with sub-horizontal Al-Si laminations
- Cement is generally fine grained kaolin and amorphous Si with minor goethite
- Range in thickness from 1 – 10 m

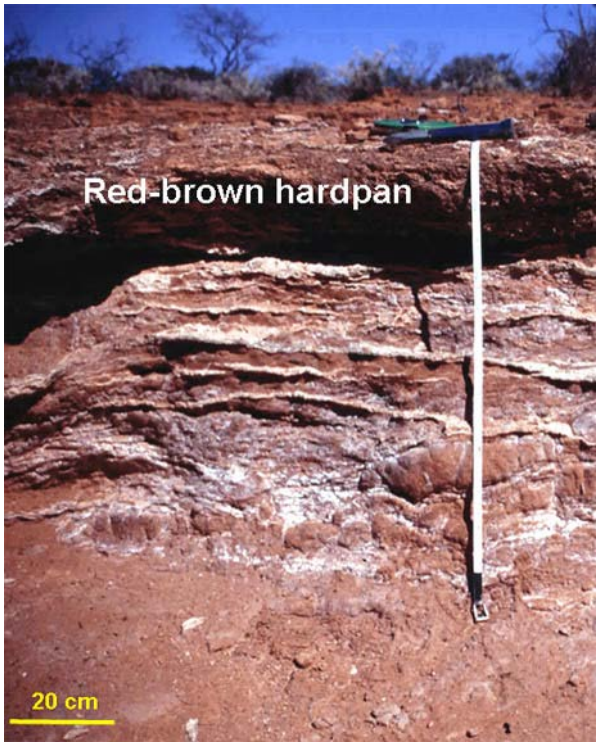
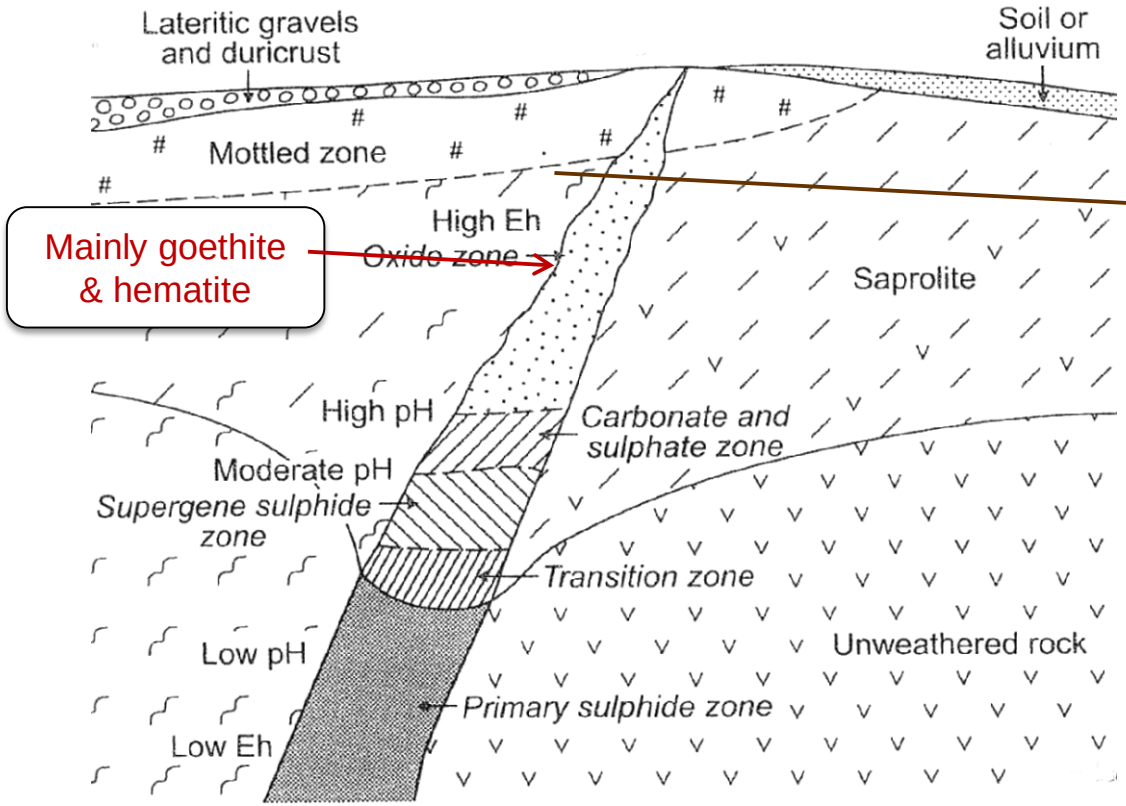


Image: A Mazhiznan

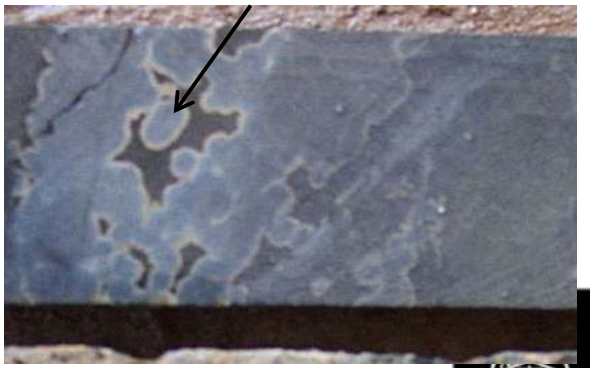
Gossans
Sulfide weathering products



"Typical" gossan profile. From Scott (2001)

Boxwork fabric

Colloform fabric



Lag

Indicative of subsurface saprolite

Saprolite close to surface

Indicative of subsurface nodular/pisolitic ferricrete/laterite

Likely transported