Short Course for Northern Star Resources

YILGARN REGOLITH AND LANDSCAPE

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The Yilgarn Craton surface regolith

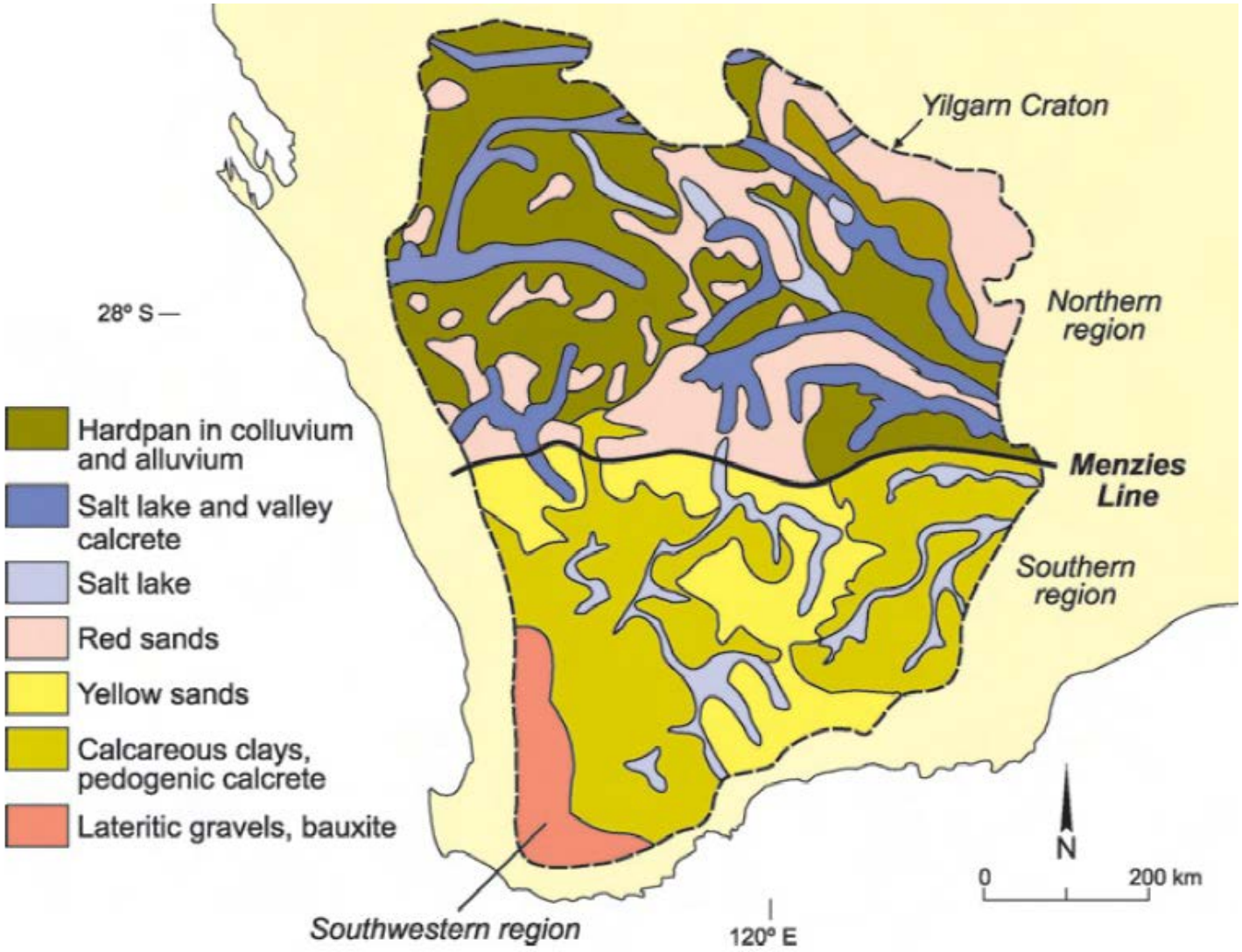
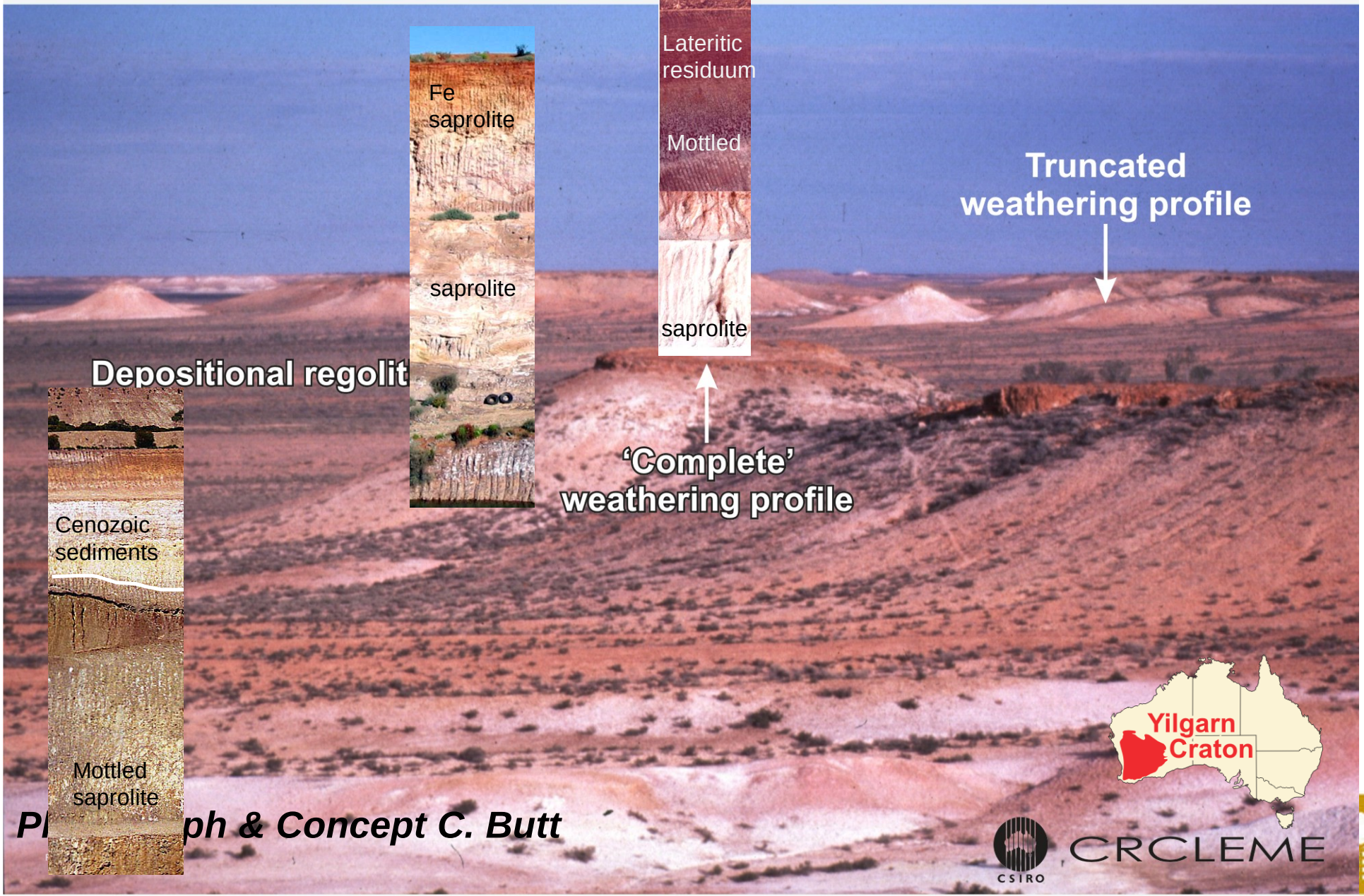


Image: Churhward & Anand, 2000

Regolith-landforms: Variable Regolith



Pl ph & Concept C. Butt

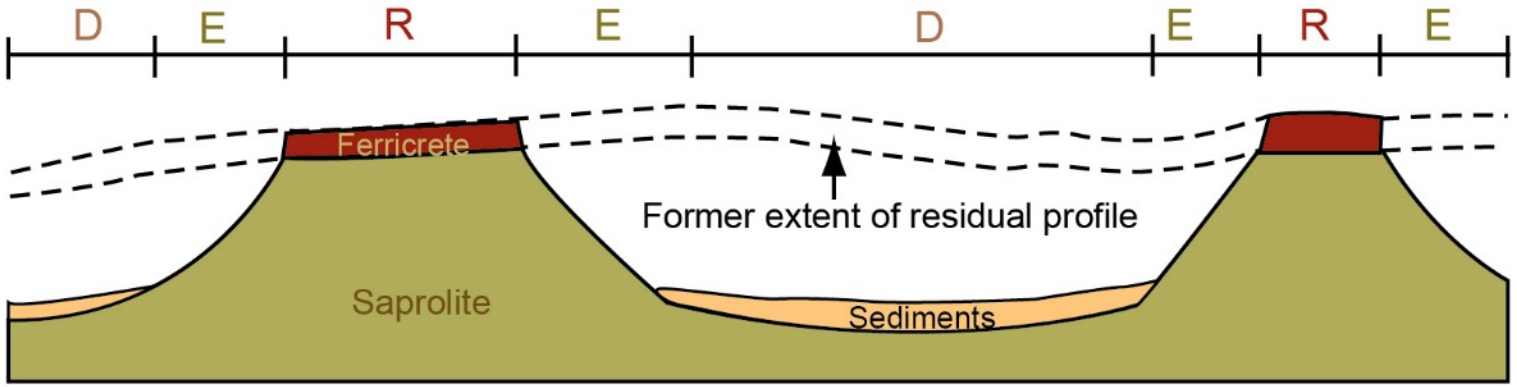
CSIRO CRCLEME

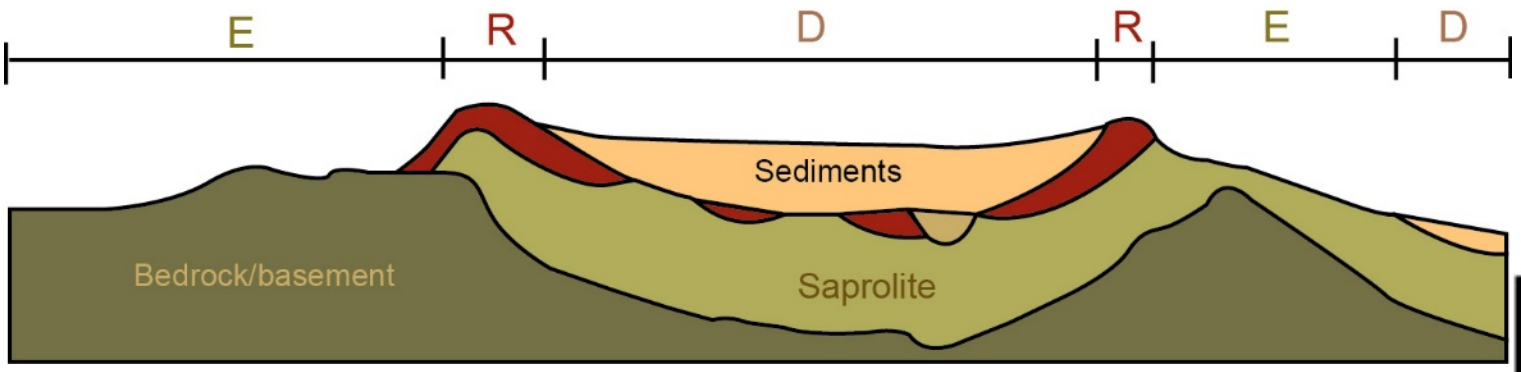
Relict – Erosional – Depositional Scheme

R – lateritic gravel and duricrust dominated terrane

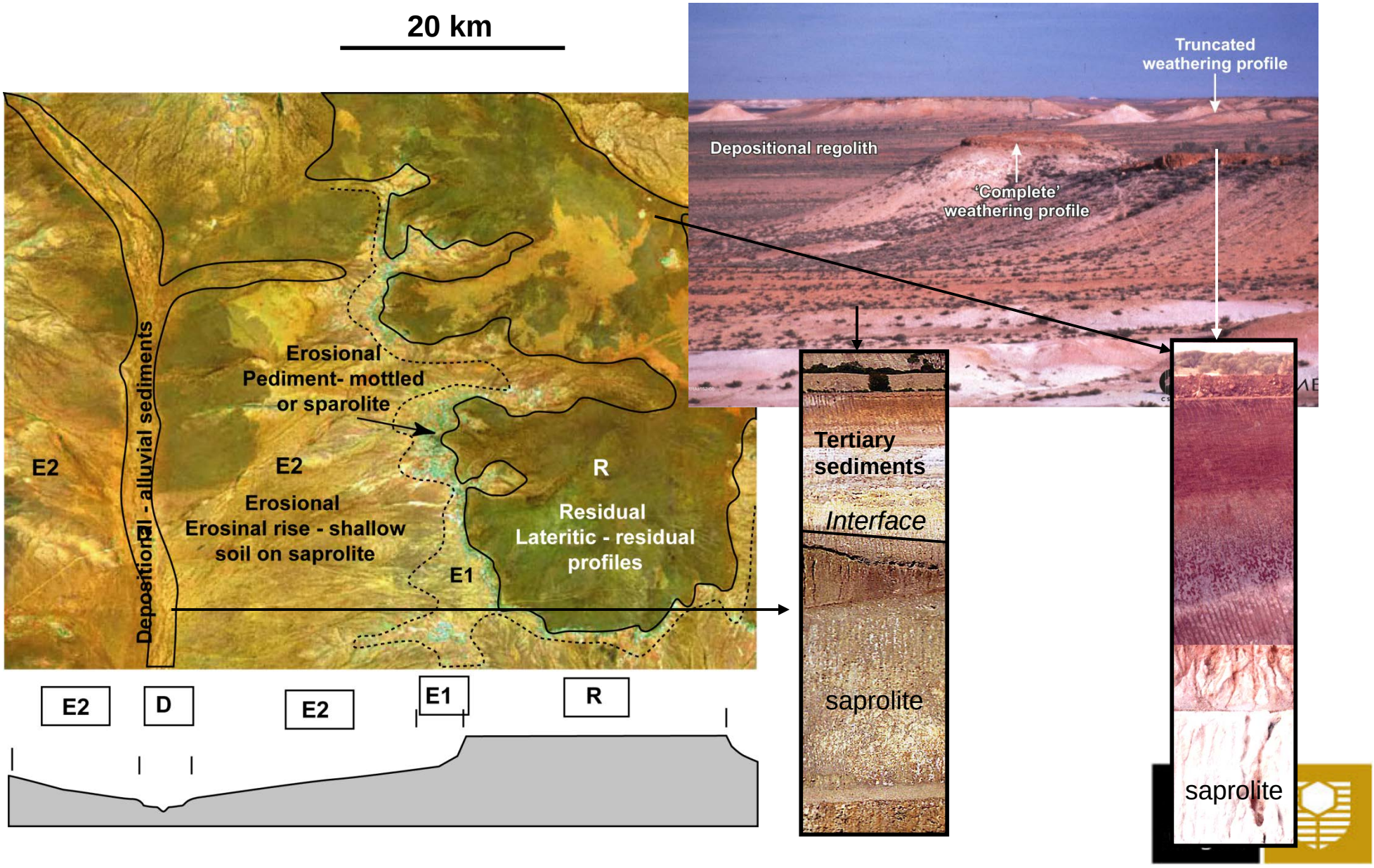
E – Saprolite, shallow soil and bedrock dominated terrane

D – Sediment dominated terrane

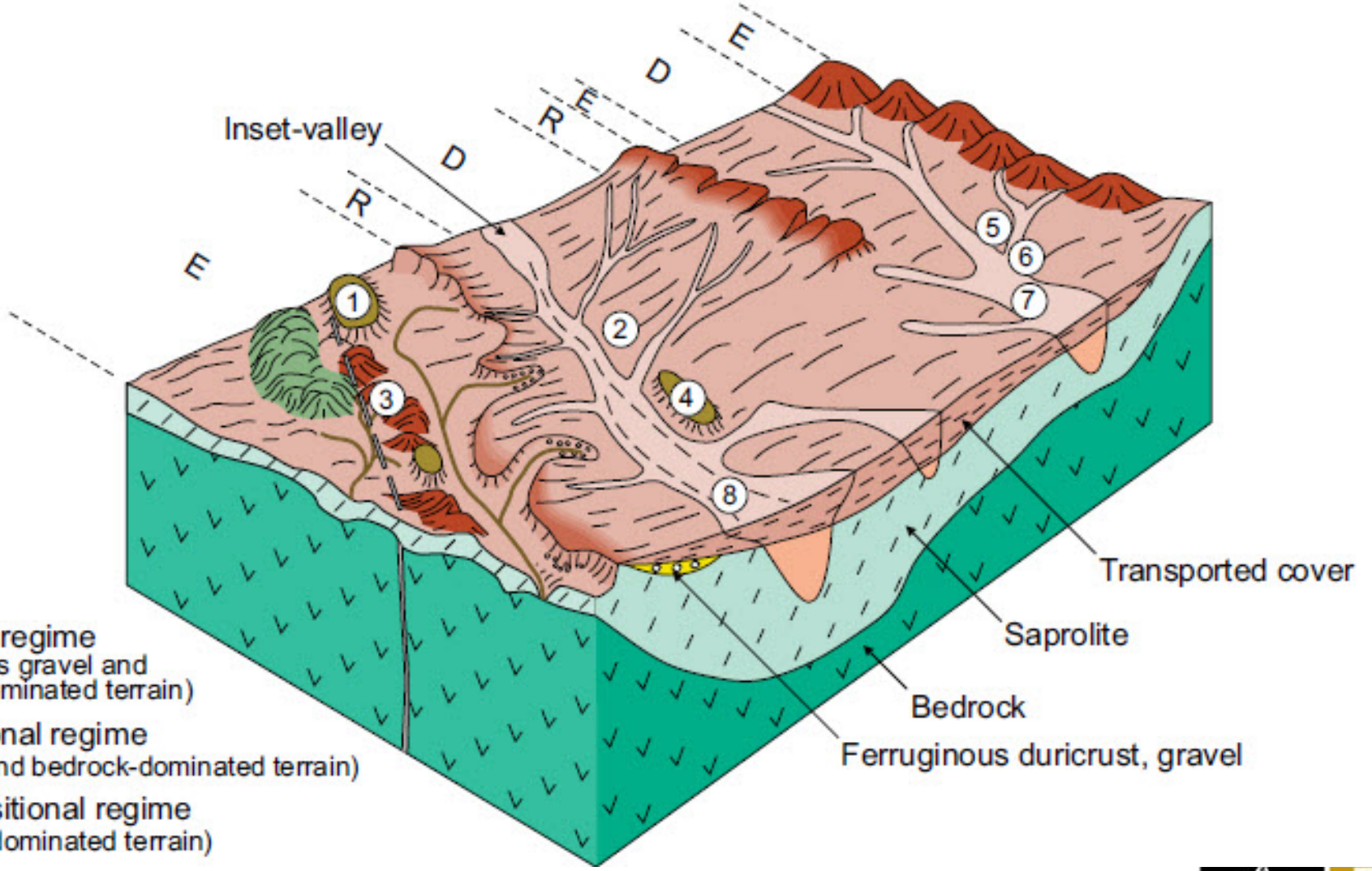




Remote Sensing & Regolith-landforms

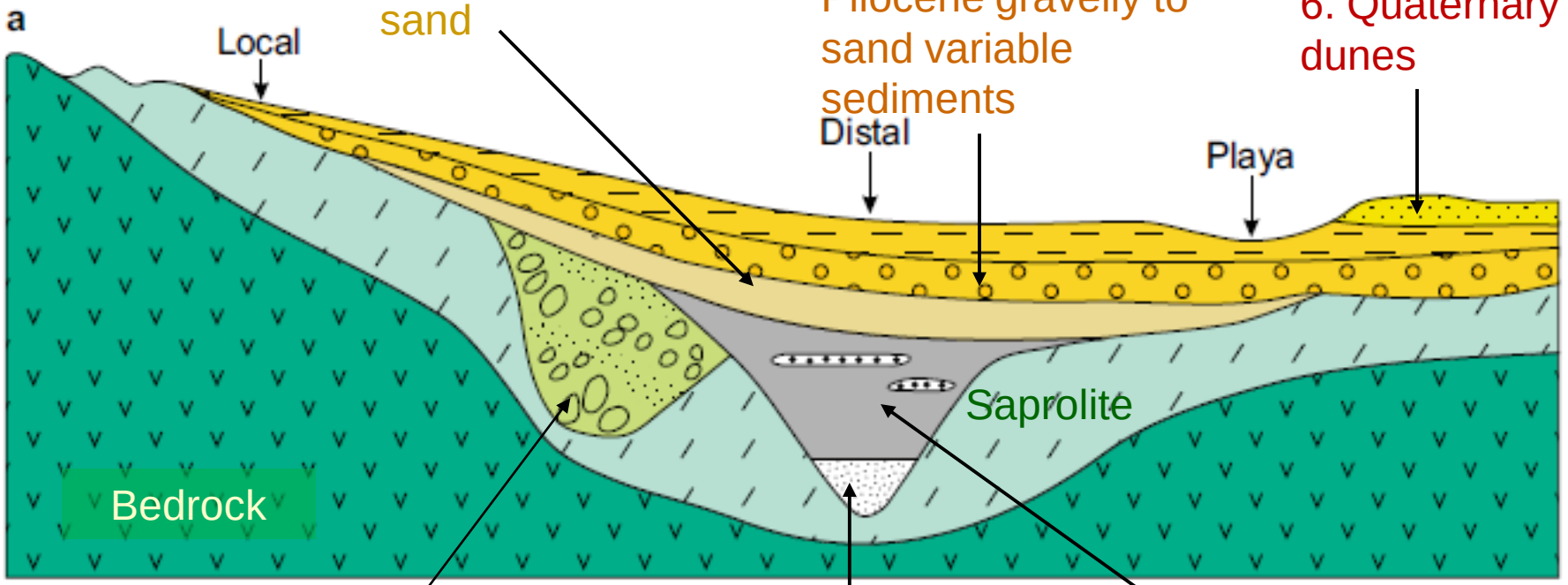


Regolith-landforms of Northern Yilgarn



From Anand & Butt (2010)

Main Phanerozoic Sediment relationships – Transported regolith



4. Miocene gravelly sand

5. Miocene to Pliocene gravelly to sand variable sediments

6. Quaternary sand dunes

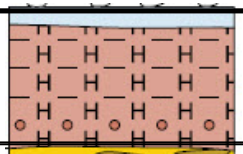
1. Permian boulder clays, grits, sandstone

2. Paleocene *Wollabur* gravel & sandstone

3. Miocene *Perkolli shale* (clays & lenses of gravel)

From Anand & Butt (2010)

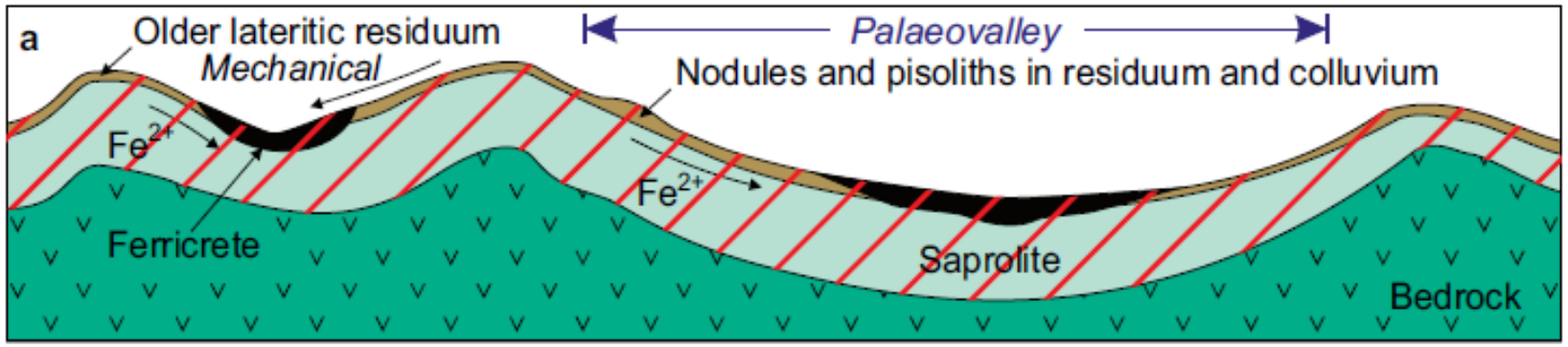
Stratigraphy of transported regolith in the Yilgarn

Lithology Age		Regolith Unit	Description	Interpreted depositional environment
Pleistocene		Hardpan	Sandy clay to clay sand with Fe gravel	Aeolian, fluvial, colluvial
Pliocene		Nodular ferricrete	Sandy clay with clay spherites	Overbank deposits
Early Eocene to Mid Miocene		Fe gravel + clay	Granule to pebble, hematite + maghemite	Fluvial, colluvial
		Megamottled clay	White to cream clay with quartz, kaolinite, lignite	Overbank – shallow wetland
		Fe pisolitic clay	Grey clay with kaolinite, smectite	
		Gravel + sand	Fe gravel & sand, vein quartz	Fluvial channel
Permian		Mottled mudstone Sandstone	Mudstone to sandstone with conglomerate base	Glacial outflow
Archean		Saprolite		

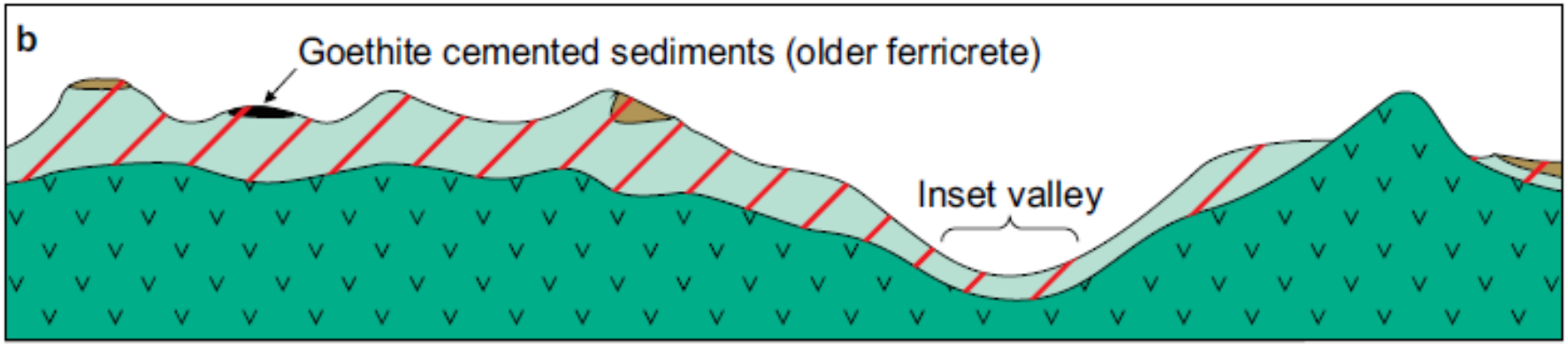
Compiled from Dusci (1994), deBrokert (2002), Anand et al. (2013)

Weathering history and landscape evolution - 1

Late Permian to Cretaceous – extension weathering with stable landsurface conditions



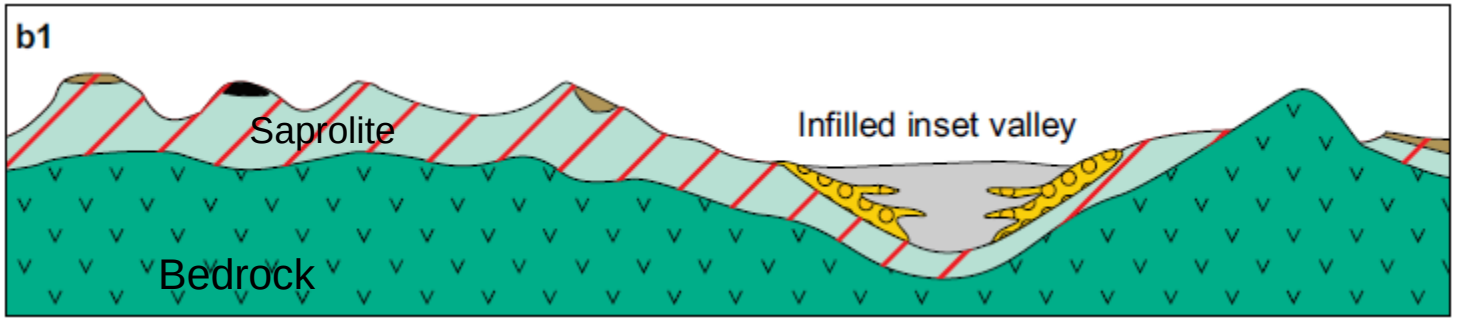
Late Cretaceous to Eocene – drop in sea-levels (base level change) caused inset valleys to develop in the landscape with erosion



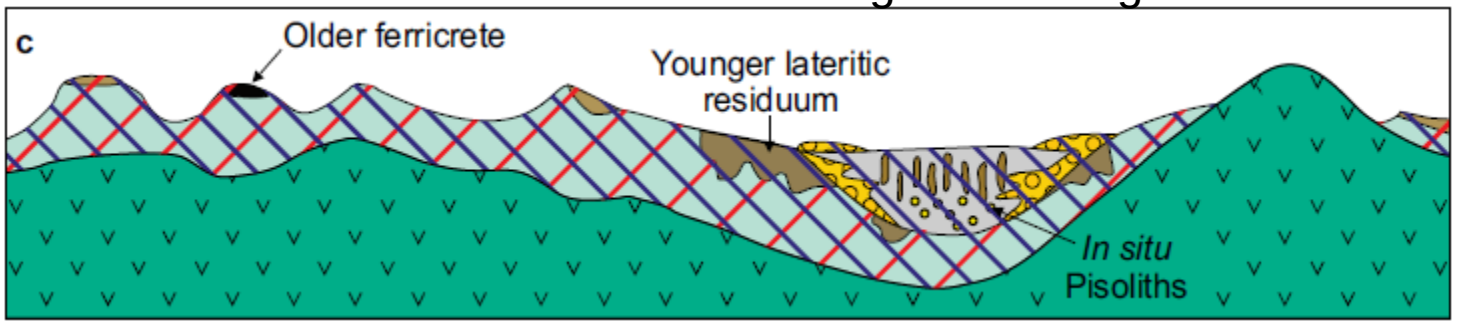
After Anand & Butt (2010)

Weathering history and landscape evolution - 2

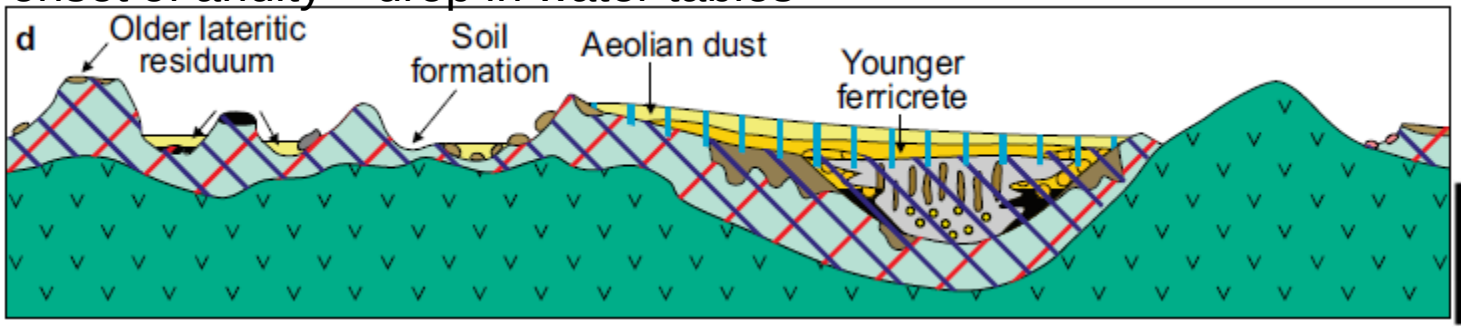
Mid Eocene - Miocene filling of inset valleys due higher sea-levels

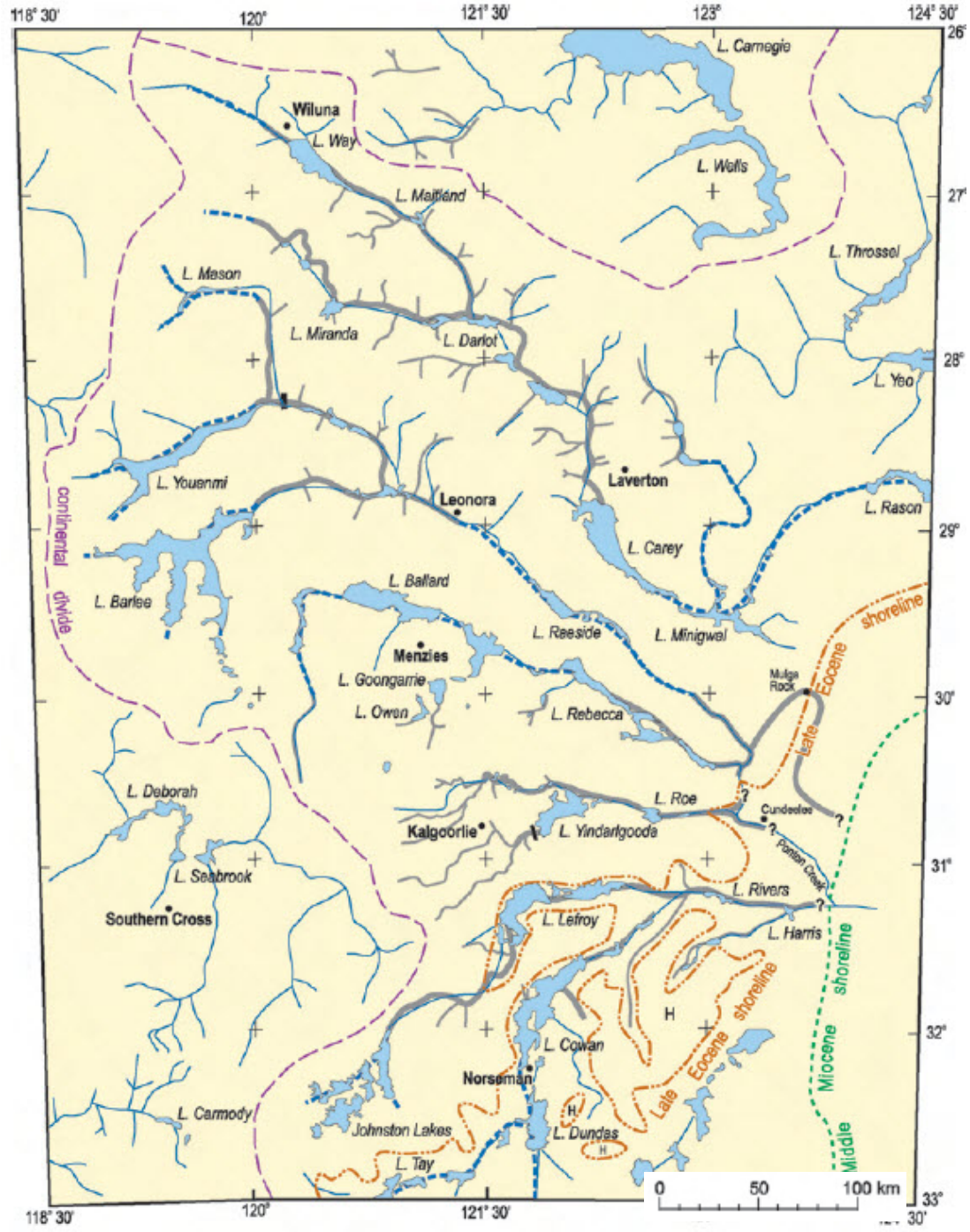


Mid-Miocene –stable conditions favouring weathering



Late Miocene –to current – local erosion and sedimentation and onset of aridity – drop in water tables





Yilgarn Inset valley paleochannel fills

Salt lakes

Paleodrainage

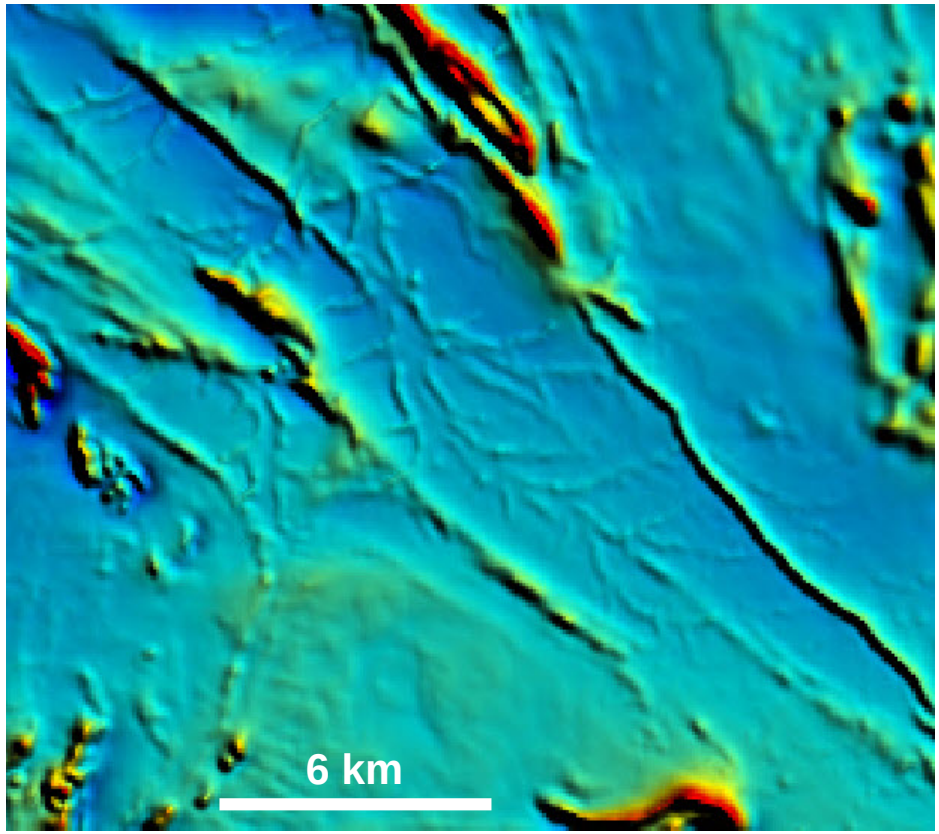
Trunk inset valley fill

Trunk inset valley fill (inferred)

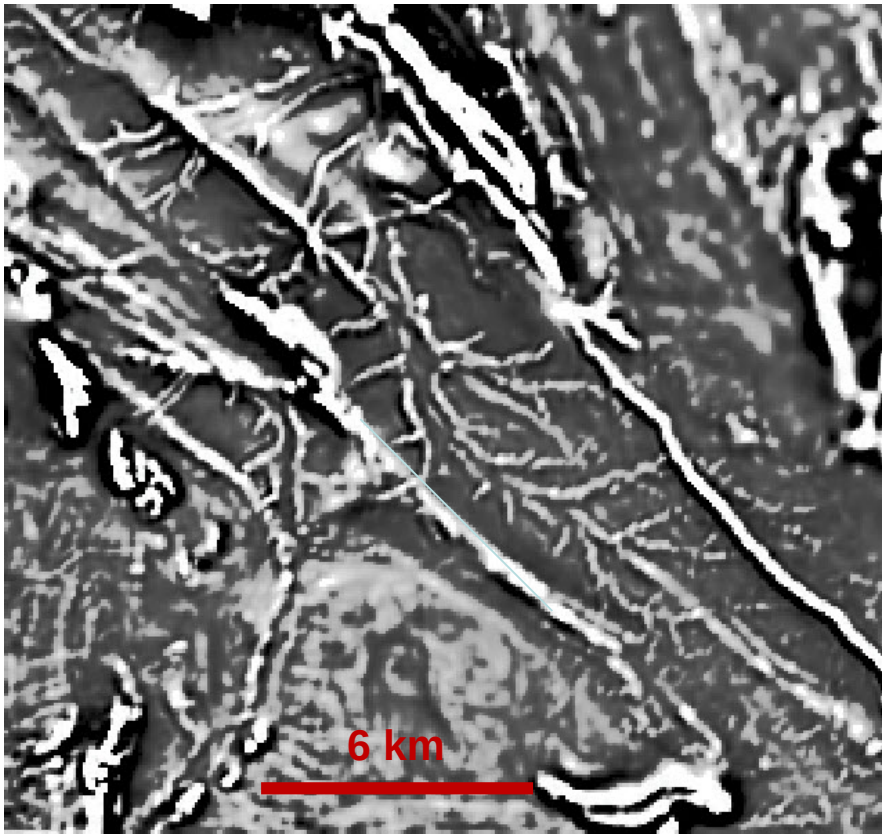
After de Brokert (2002), compiled from Kern & Commander (1993)

Yilgarn Inset Valley Paleochannels - Magnetics

RTP – southeast of Laverton

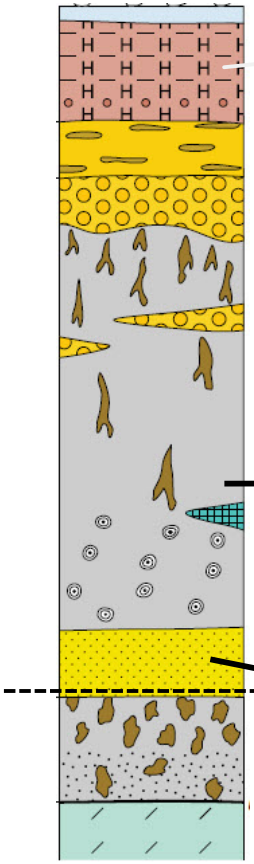


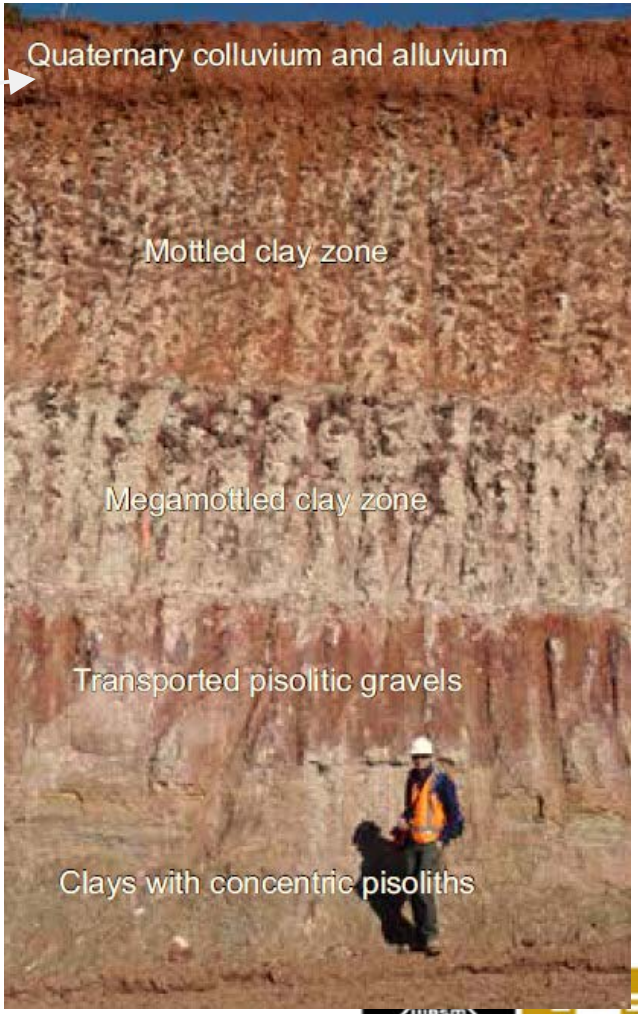
1VD – 30 km southeast of Laverton



Paleochannel sediments that have maghemite bearing pisolites show up on magnetic survey images – distributary channel form

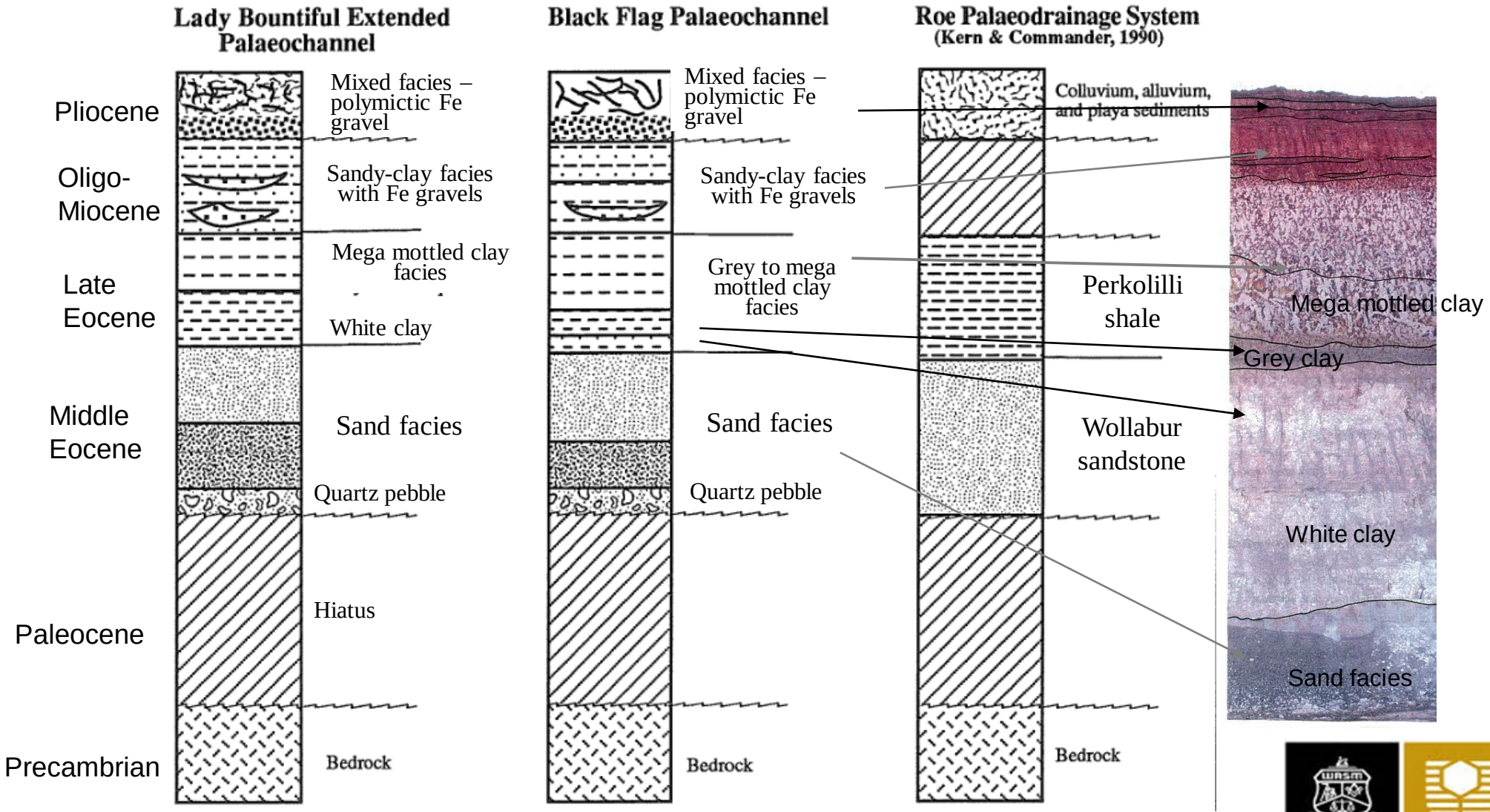
Paleochannels (Inset-valley fills)





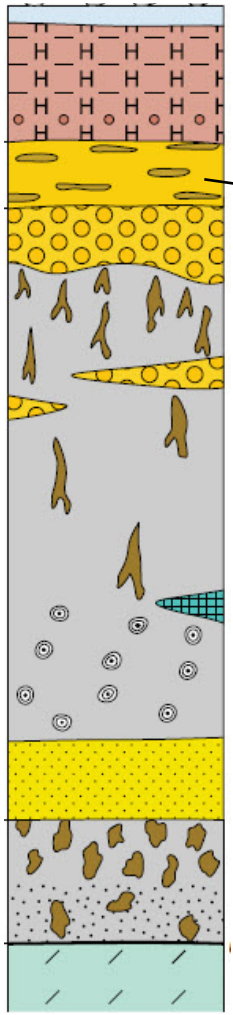
Images: Ravi Anand

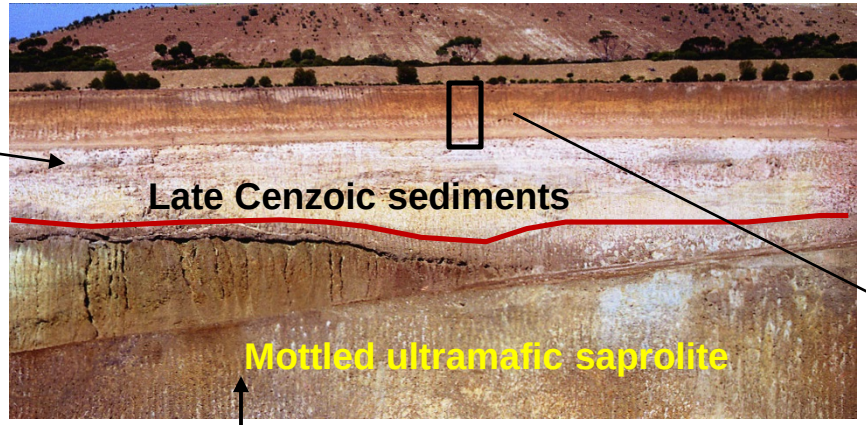
Inset valley paleochannel fill stratigraphy

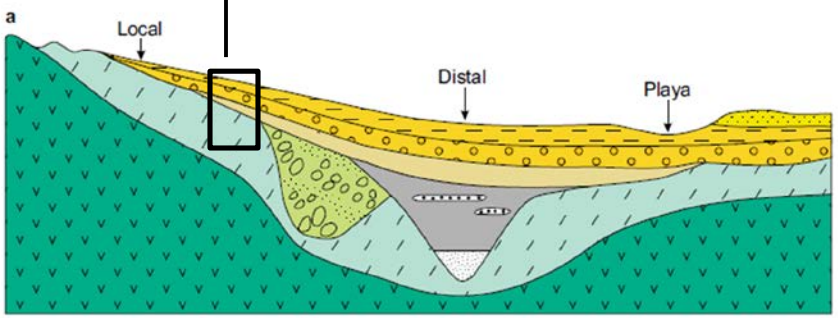


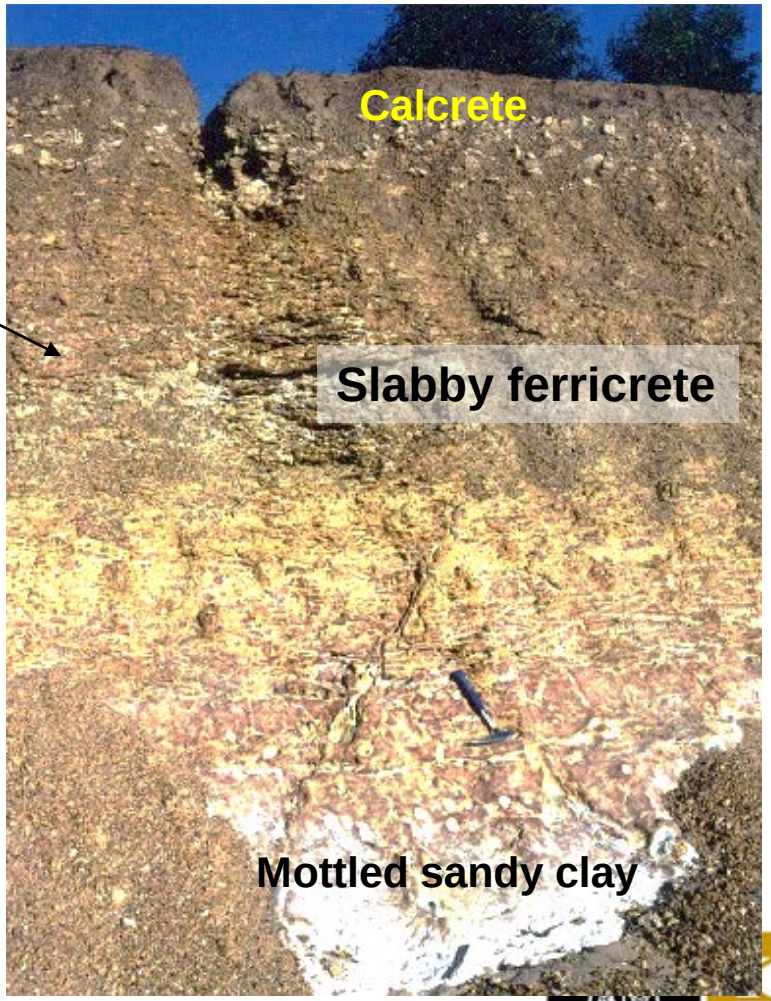
From Dusci (1994)

Late Cenozoic sediments & regolith



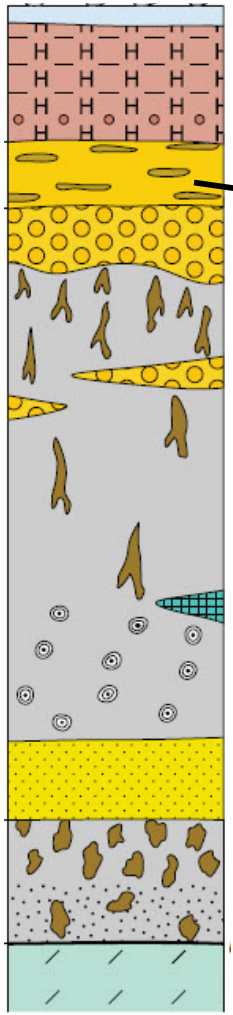


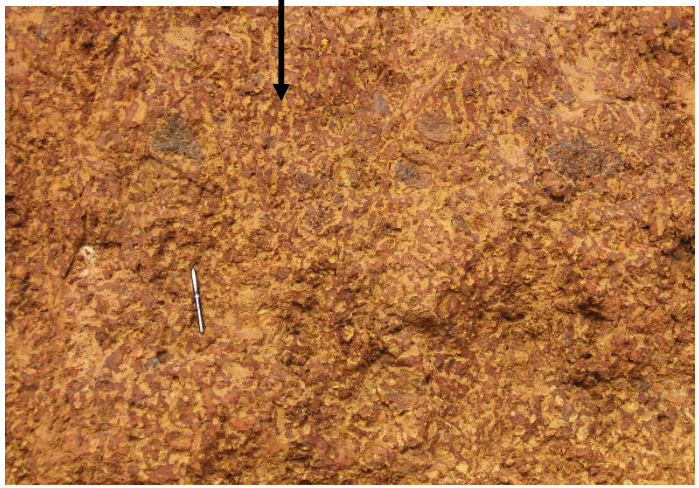




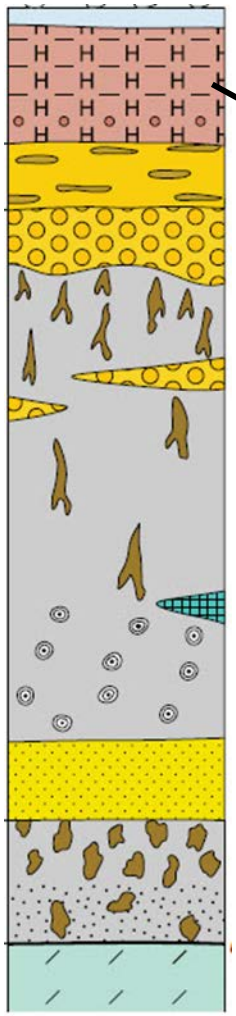
Stratigraphic column from Anand & Butt (2010)

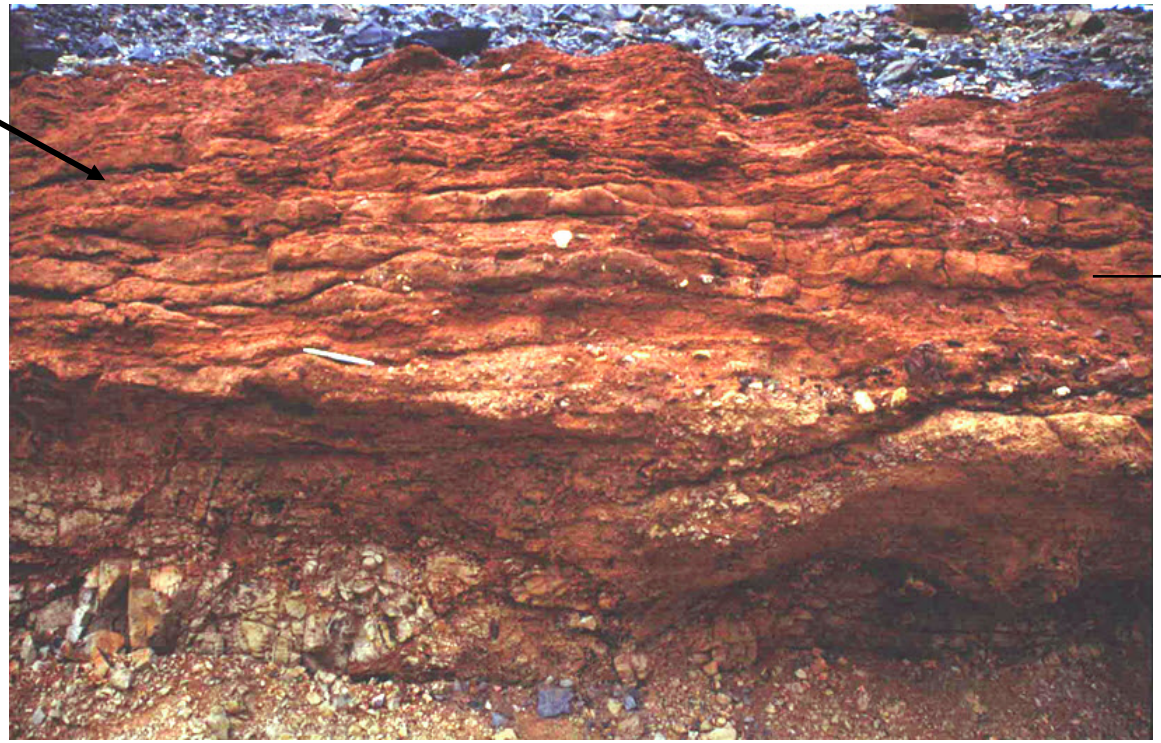
Late Cenozoic sediments & regolith

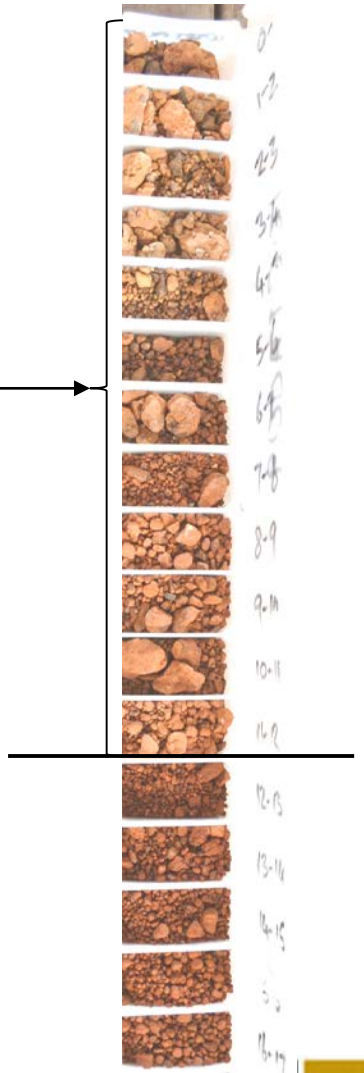




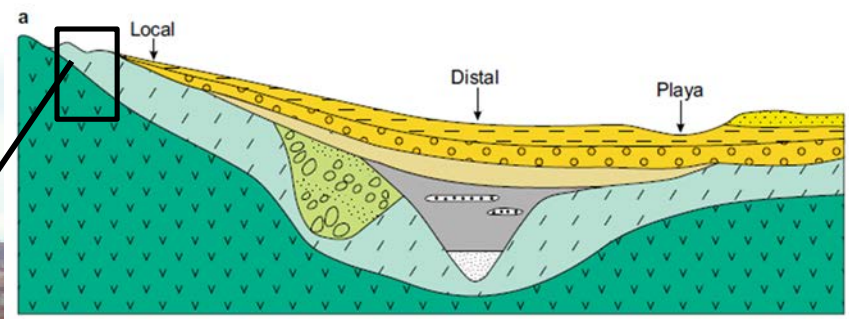
Pleistocene sediments - hardpan

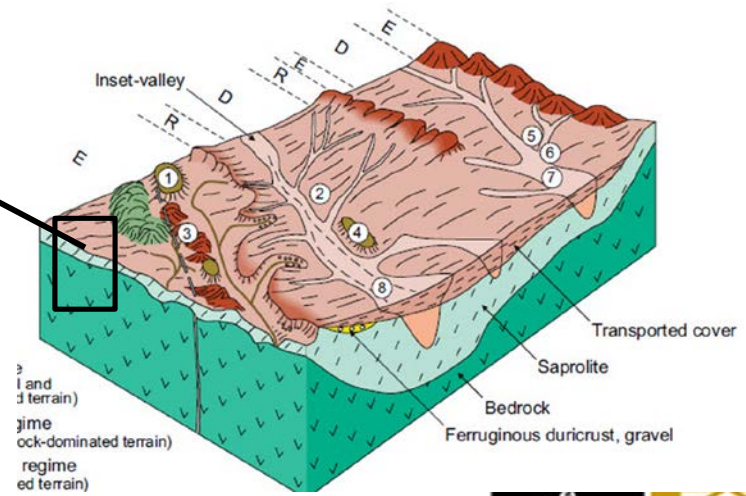




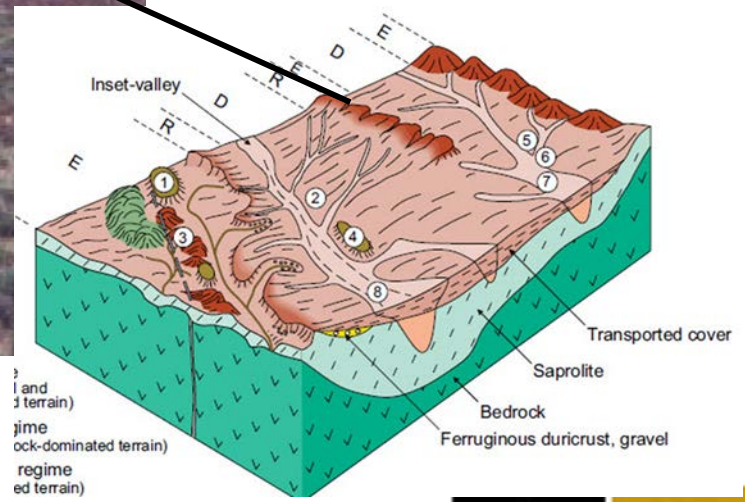


Regolith-Landform relationships
Erosional rises/low hills



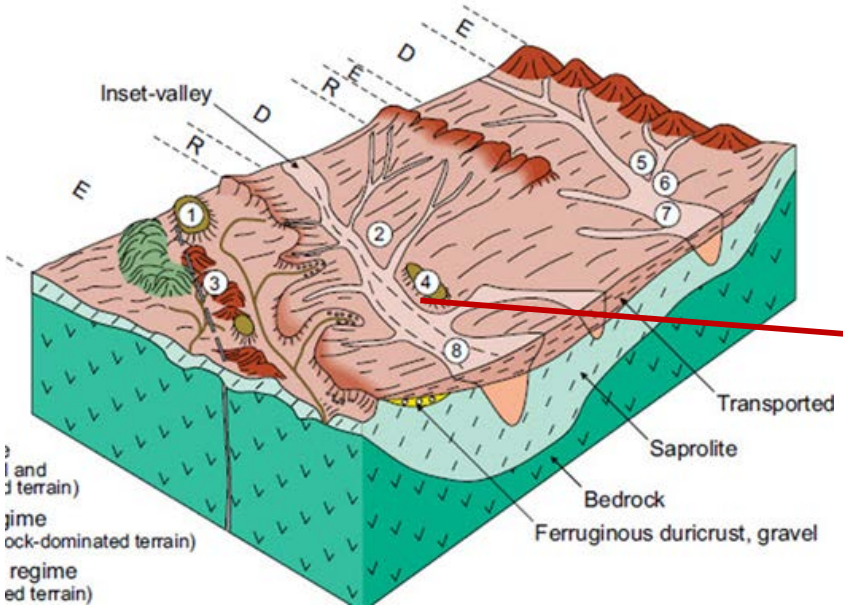


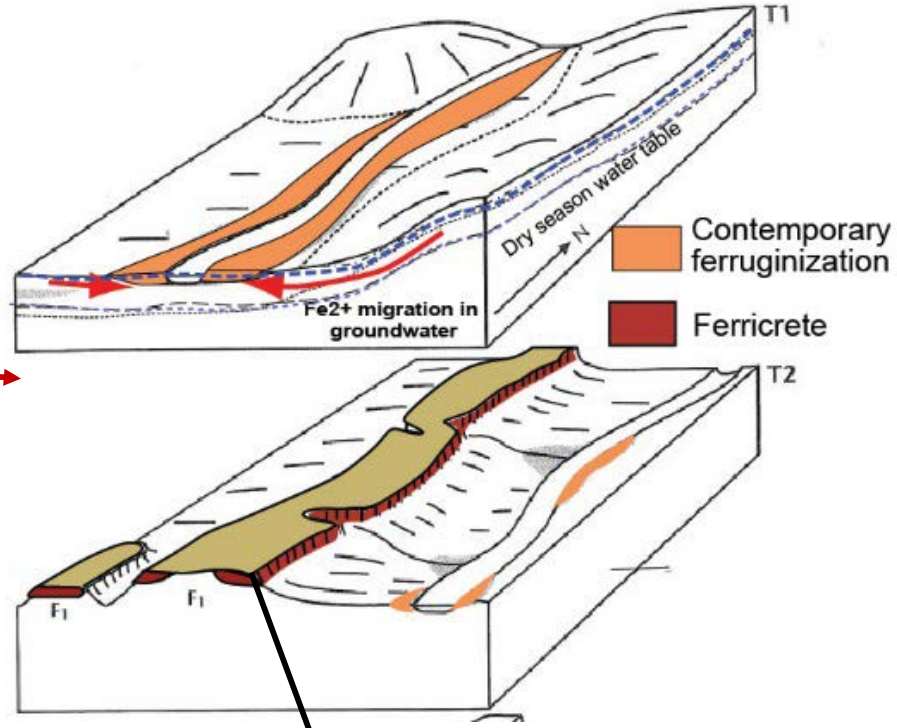
Regolith-Landform relationships
Erosional - Breakaways



Regolith-landform relationships

Relief Inversion in landscapes

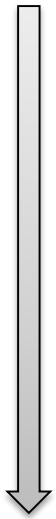




Profile modifications across the Yilgarn-
Onset of aridity

Profiles have mineralogical & geochemical characteristics of present climate superimposed on those from previous one

Humid



Iron oxides	Acid	Ferruginous duricrust, ferricrete
Silica	Acid	Pedogenic silcrete
Aluminosilicates	Acid-nuetral	Hardpan
Silica	Acid-neutral	Hardpan, groundwater silcrete
Carbonates,	Alkaline	Calcrete, gypcrete
Halides, sulfates	Alkaline	Evaporites in playas, soils

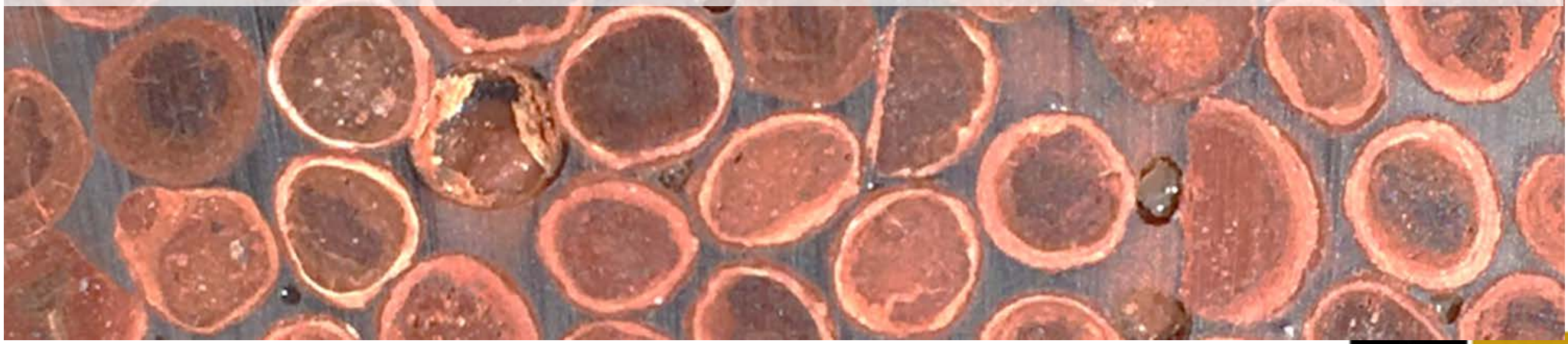
Arid

Lowering of water-table

Leaching of vadose zone under oxidizing & possibly saline conditions

Dehydration of hardening of phases

Regolith Minerals
Types, Nature & Significance



Types of regolith minerals

Phyllosilicates or Clay Minerals (layer silicates)

Smectites, kaolinite, illite, vermiculite & interstratified varieties of these

Framework Silicates – opal A & opal-CT, quartz

Oxides & hydroxides of Fe, Mn, Al & Ti

Geothite, hematite, maghemite (all Fe), gibbsite (Al), lithophorite (Mn)

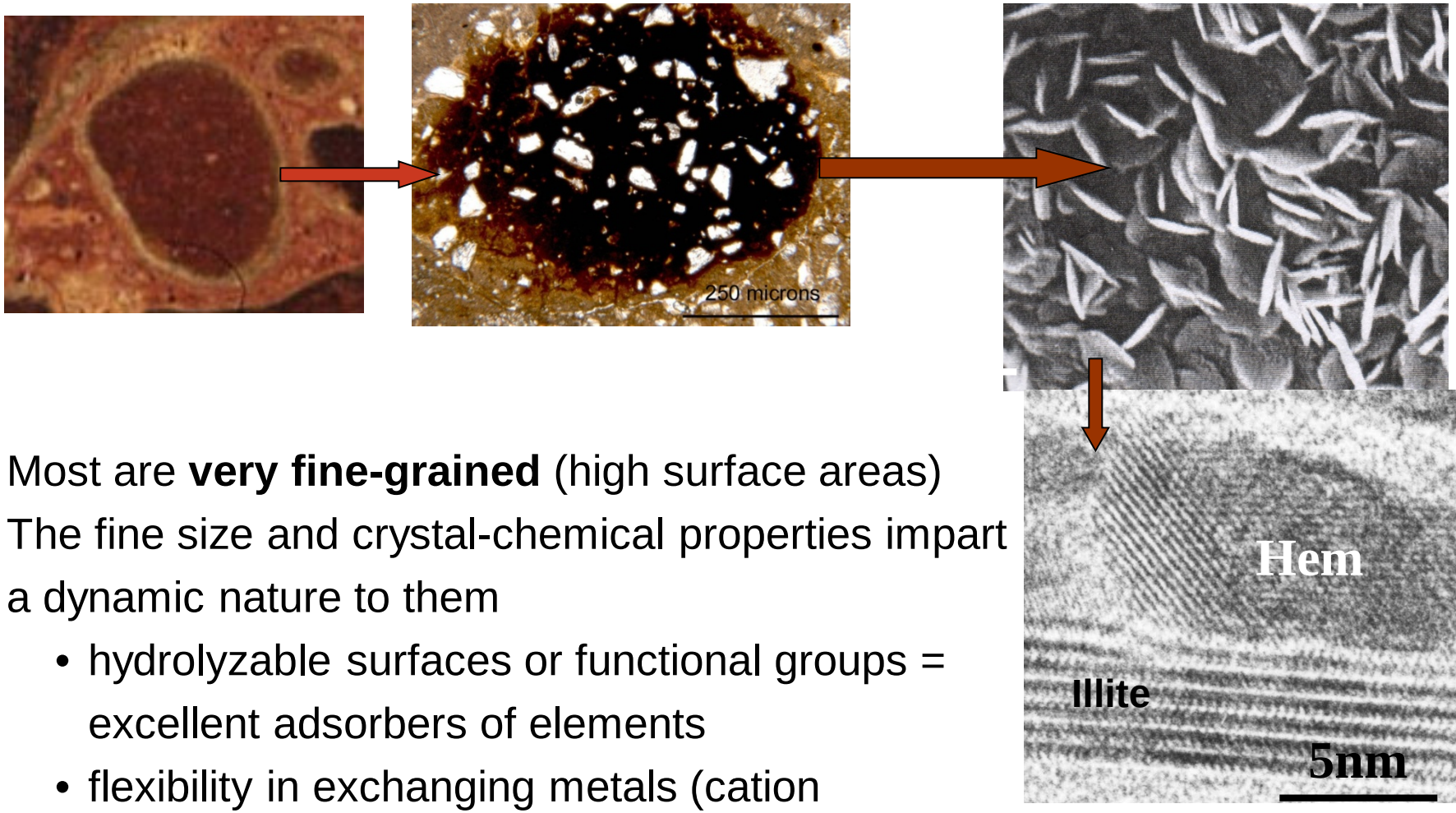
Sulfates - gypsum, jarosite, alunite

Carbonates – calcite, dolomite, magnesite

Chlorides - halite

Phosphates – crandalite, florencite, plumbogummite

Regolith Minerals – Fine Grained Mixtures



Most are **very fine-grained** (high surface areas)

The fine size and crystal-chemical properties impart a dynamic nature to them

- hydrolyzable surfaces or functional groups = excellent adsorbers of elements
- flexibility in exchanging metals (cation exchange)

Why identify, quantify and understand regolith minerals?

They provide clues to the **physio-chemical conditions** of the regolith such as pH, Eh, temperature, drainage, presence of anions

→ **Present & past environments and processes**

They regulate **trace** and **major element** mobility in the regolith and therefore impact on geochemistry of regolith, groundwaters and surface waters

→ **Mineral Hosts**

According to a geochemist, to interpret most forms of geochemical data- three rules apply: mineralogy, mineralogy and mineralogy!

Iron oxide types and their formation conditions

Hematite
Fe_2O_3

Red to reddish brown.

Favoured under **low water activity**, low Al activity, high organic matter and high temperature.

Forms due to transformation of ferrihydrite (rapid oxidation of Fe^{2+})

Goethite
FeOOH

Brownish-yellow.

High water activity, high organic matter, high Al activity and low temperatures.

Forms from oxidation of Fe^{2+}

Iron oxide types and their formation conditions

Maghemite

γ-Fe_3O_4

Dark brown to black. Magnetic. Forms by the oxidation of magnetite, or dehydration of lepidocrocite or heating of Fe hydroxides with organic matter. Highly weathered regolith & forest fires

Lepidocrocite

γ-FeOOH

Orange-brown. Polymorph of goethite (different structure same composition). Forms by slow oxidation of Fe^{2+}. Found in seasonally anaerobic but non-calcerous soils by slow oxidation

Magnetite

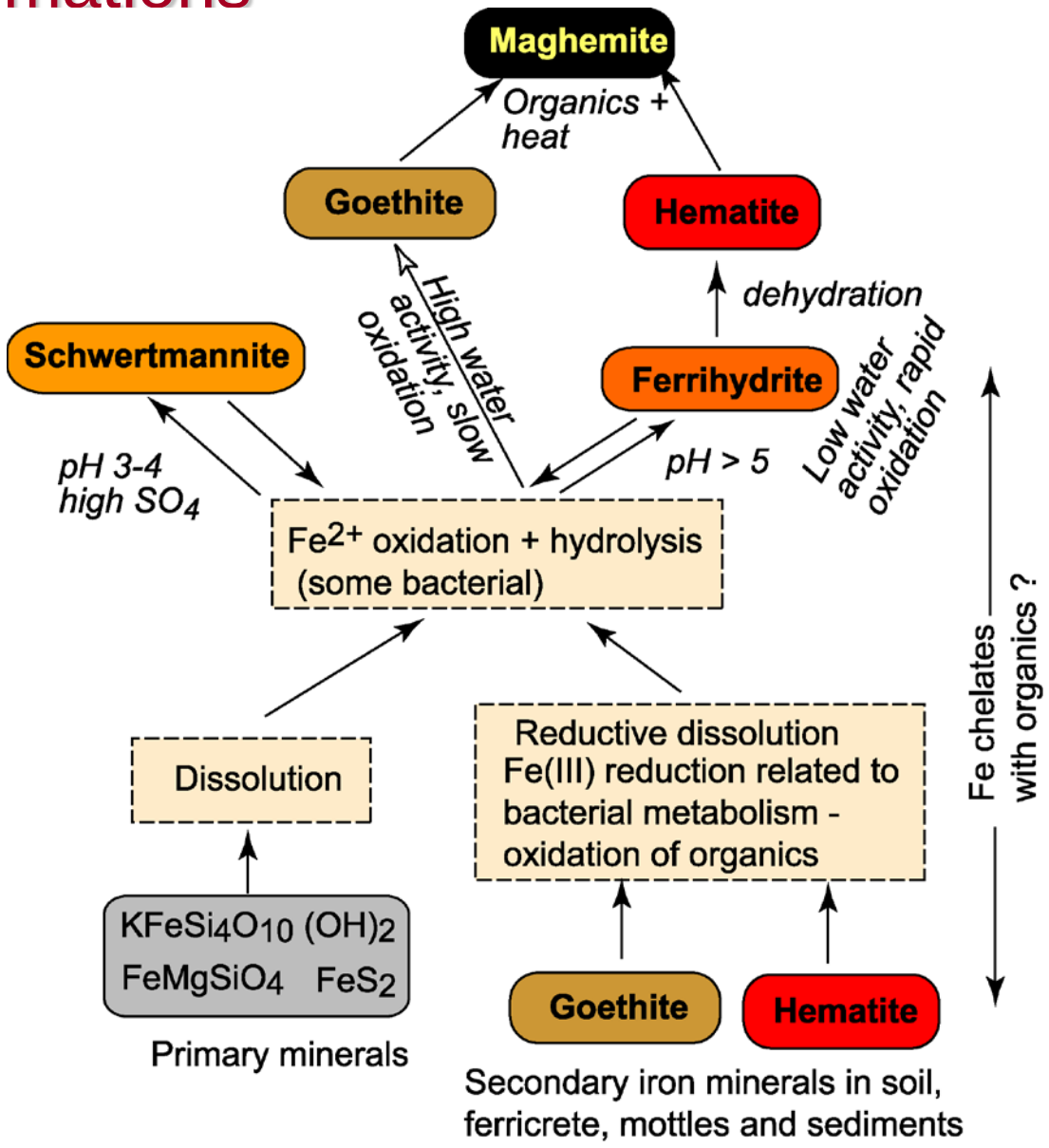
Fe_3O_4

Black. Magnetic. Inherited from parent rock or forms in reducing conditions or via magnetotactic bacteria. Submerged soils

Iron oxide formation, dissolution and transformations

Once formed, iron oxides transform via two processes

- Via **dissolution** and **reprecipitation** as another oxide
- Via **structural rearrangement of** another oxide where the structure reorganizes to a new one

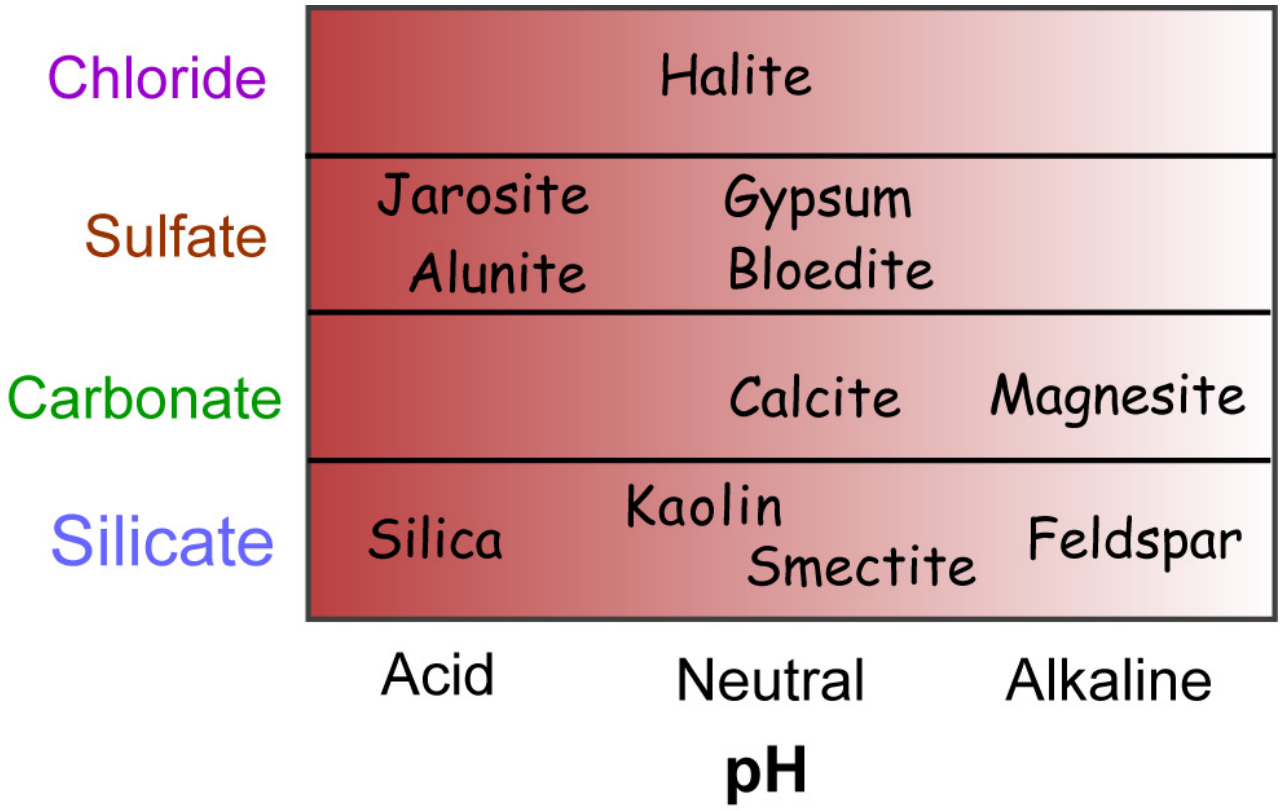


Modified after Bigham et al (2001)

Minerals & regolith environments

pH vs Anions

The presence of specific minerals provides information on pH and type of dominant anion present in the system



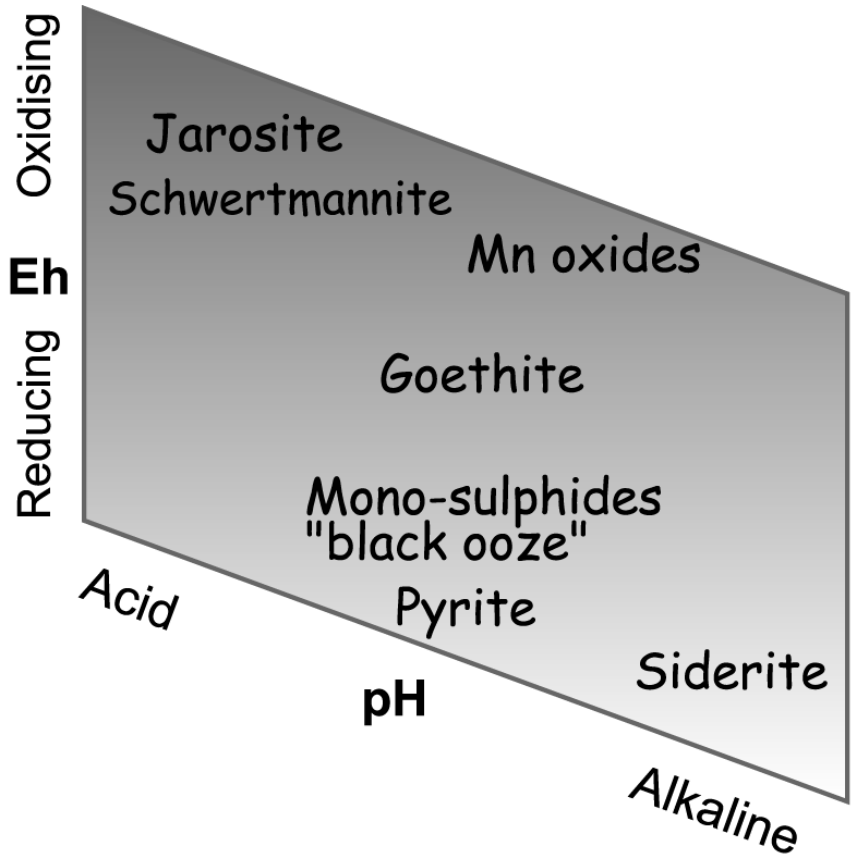
Modified – Taylor & Eg

Minerals & regolith environments

pH vs Eh (redox condition)

Iron oxides, iron-sulfates, iron sulfides and carbonate minerals are indicators of pH and redox (oxidizing or reducing) conditions

Sulfide weathering
Acid sulfate soils
Acid Mine Drainage
Salt Lakes
Wetlands
Constructed drains



Modified after Taylor & Eggleton (2001)

Minerals & regolith environments

Profile Drainage (& Climate)

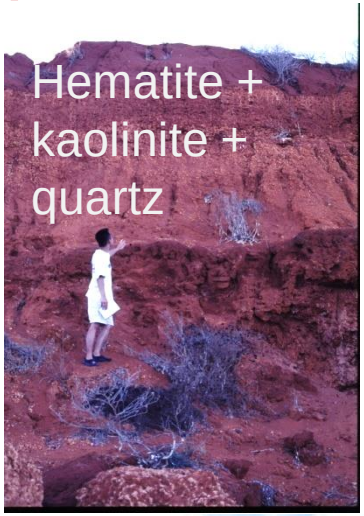
Impeded or slow groundwater flow results in **smectite-carbonate-goethite** association

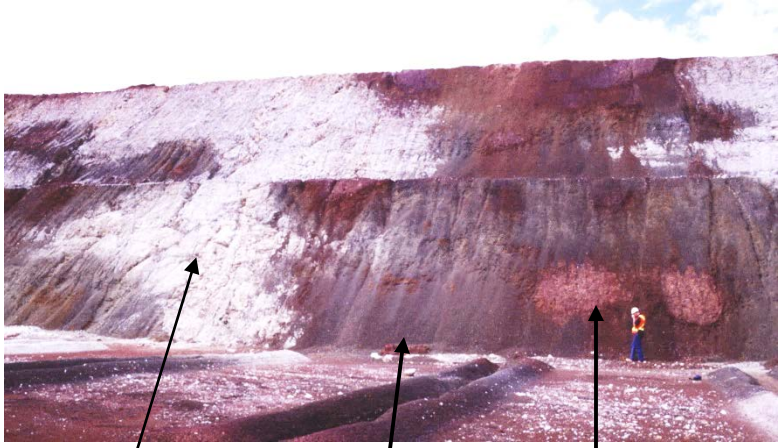
Free flow (well-drained) results in most stable assemblage -**kaolinite-hematite**

Need to consider climate and drainage together

- e.g. smectites may indicate aridity and/or impeded drainage

Well drained, dry





Wet vs Dry

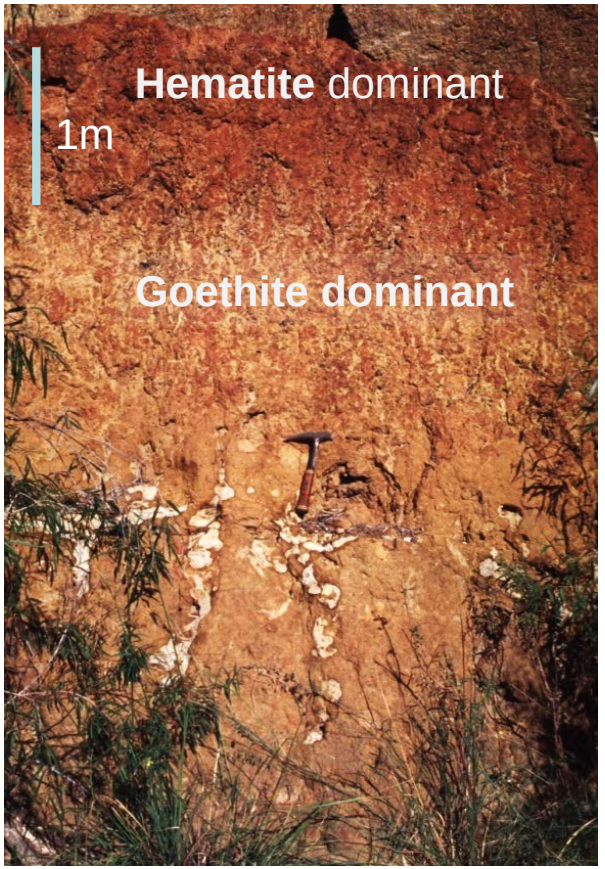
Use iron oxides as indicators

Goethite (yellow-brown)– high water activity

Hematite (red to dark red) – low water activity

This association provides **wet** vs **dry** environmental information on

- Micro – fine mottles
- Profile – brown mottles below red soil
- Landscape – red crests versus yellow valleys
- Regional scale - red areas versus yellow

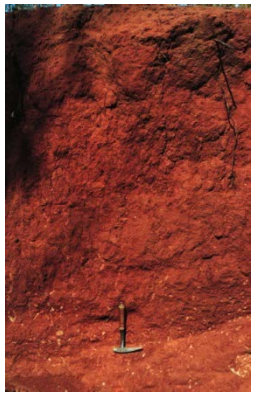


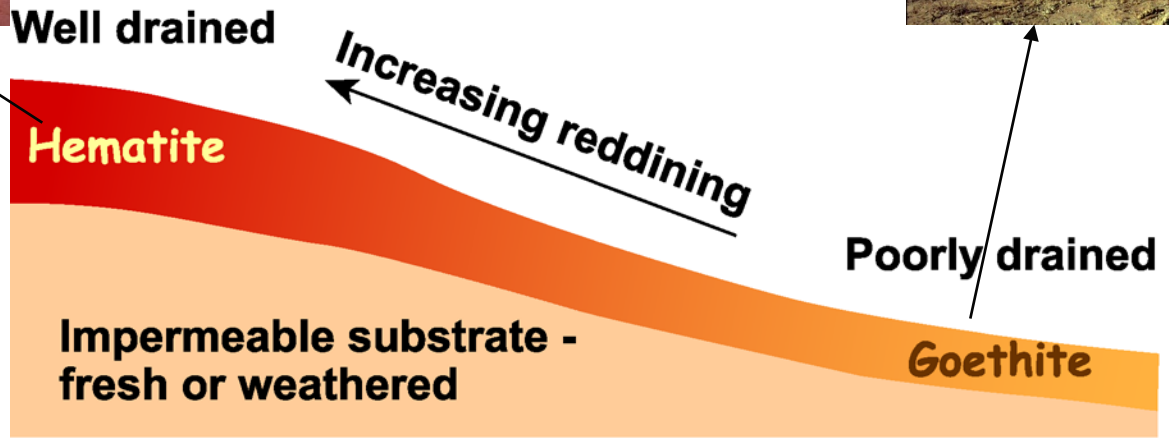
Drainage & Landsacpe

Local regolith environment is dictated by landscape position because landscape position controls drainage

Generally, hill crests are drier because they are well drained

Valleys are wetter because poorly drained



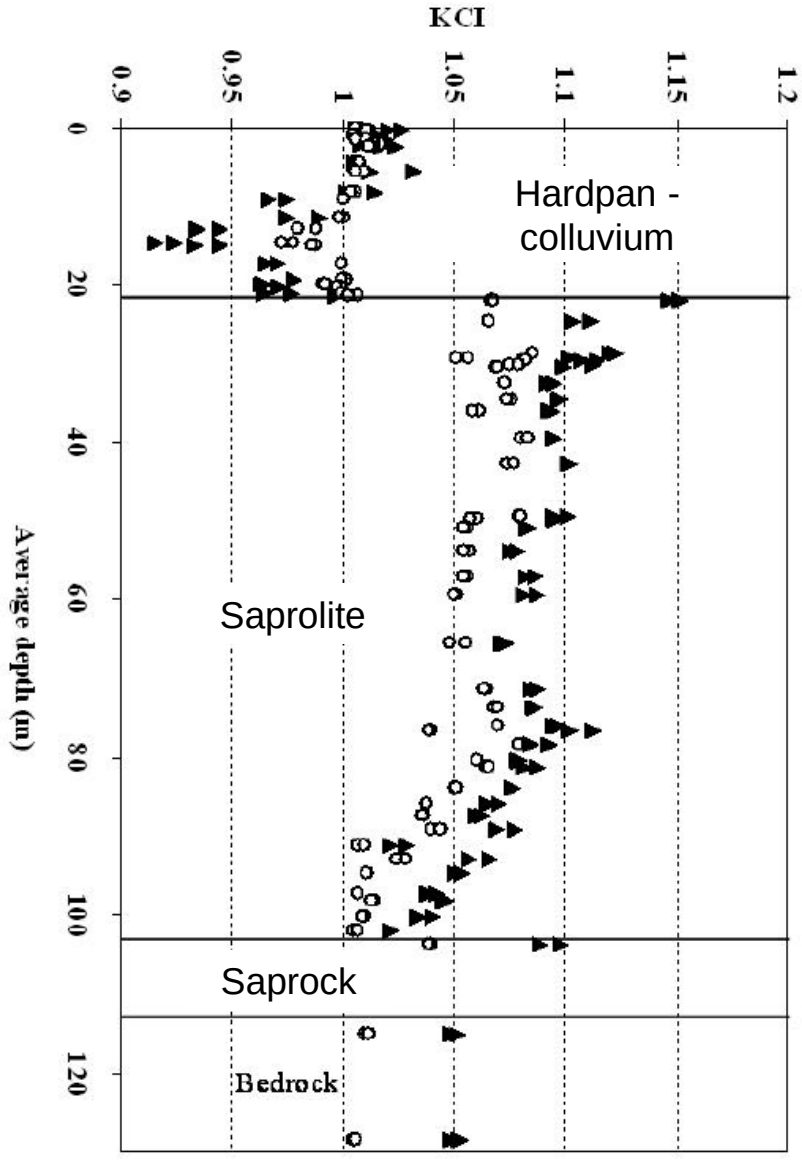


In Situ vs Transported

Kaolinite “Crystallinity”

- Kaolinite “crystallinity” or disorder
- Kaolinite Crystallinity Index (KCI) determined via reflectance spectra (ASD or HyLogger) using kaolinite doublet
- *In situ* = well crystalline (ordered)
- Transported = poorly crystalline

However, not always true



After Phang (2000)