U3A Geology

Geology of the regolith

Introduction

- Regolith → blanket of unconsolidated and secondarily cemented, heterogeneous earth materials covering solid bedrock
- regolith materials can be broadly sub-divided into either in-situ or, transported materials e.g. alluvial, colluvial lacustrine sediments
- includes soil, broken and altered rocks and related materials
- regolith on Earth originates from weathering and biological processes
- uppermost part of regolith that typically contains organic matter is conventionally referred to as soil between the soil and the bedrock are two zones called the pedolith and saprolith

Regolith

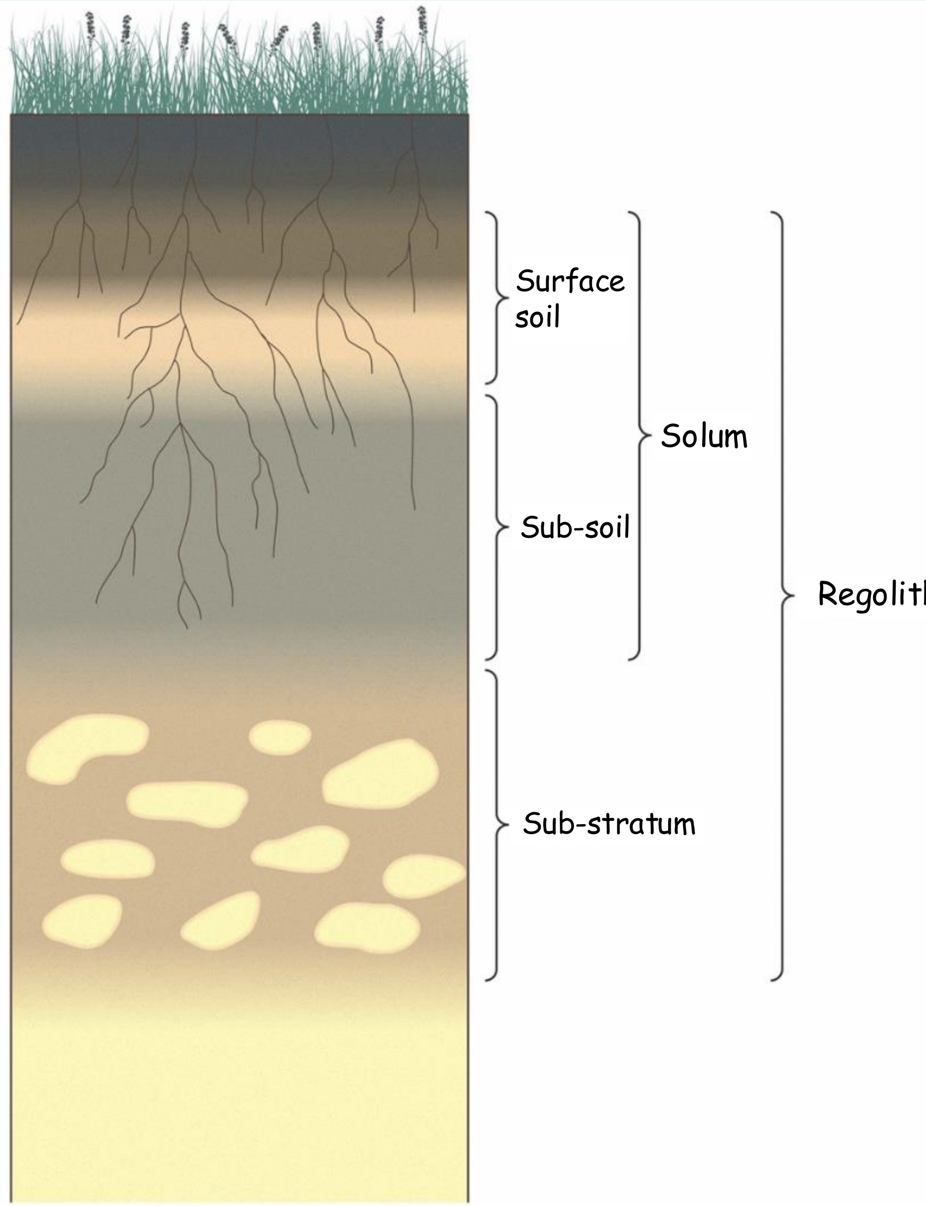
- The regolith of a region is a product of a long term weathering history
- leaching and dispersion are dominant during initial phase of weathering under humid conditions
- regoliths vary from a few metres to >150m thick
- regoliths on steep slopes and uplifting regions are generally shallow
- deeply weathered regoliths are widespread in inter-tropical belt particularly on continental landmasses between 35°N and 35°S

Formation of deeply weathered regolith

- Conditions for formation of deeply weathered regolith include moderate relief to allow leaching products of chemical weathering
- a second condition is long periods of tectonic stability, tectonic activity and climate partly erode regolith
- rocks weather at ~20m per million years → deep regoliths require several million years to develop
- the third condition is humid tropical to temperate climate → enable reactions to react more rapidly
- deep weathering can occur in cooler climates but over longer periods

Soil regolith profile (Huggett 2023)

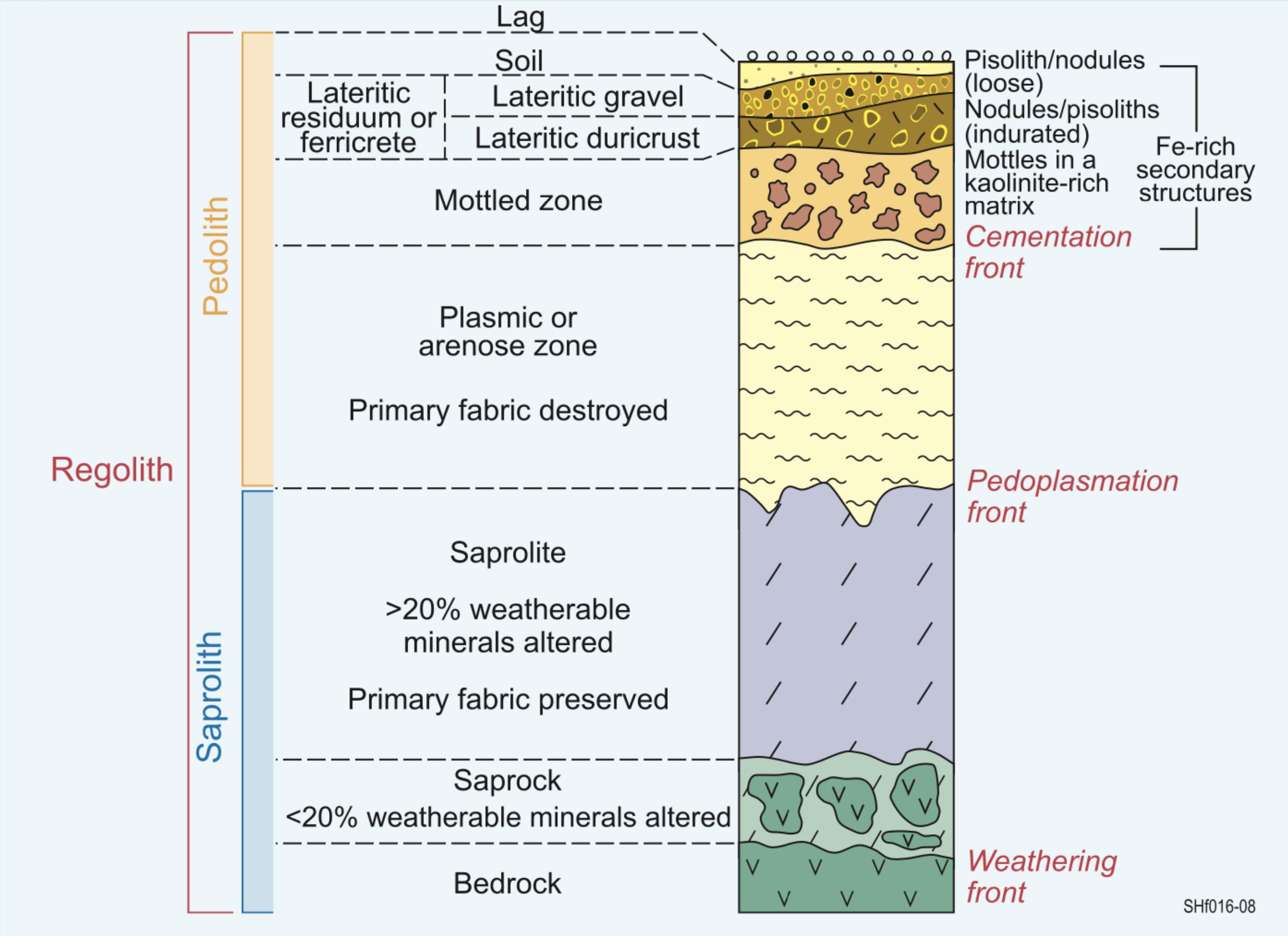
Organic horizons	O1 Litter
	O2 Decomposed animal and plant remains
Mineral horizons (the solum, the upper part of which is the topsoil)	A Humic horizon
	E Eluvial horizon
	B Illuvial horizon
Mineral horizon (substrate)	C Unconsolidated material from which the solum may have been formed (sometimes called parent material). Part of the regolith
Consolidated bedrock	R Largely unweathered rock



Soil regolith

- Solum → upper part of soil profile where layers have undergone soil forming processes
- Humic horizon → sub-surface layer with significant accumulation of organic matter, often alongside Fe and Al compounds
- Eluvial horizon → characterised by removal of materials e.g. clay, Fe, Al and organic matter through eluviation → light coloured zone
- Illuvium horizon → horizon that is enriched by addition of materials from overlying horizons

Lateritic regolith profile (Eggleton 2001)



Pedolith

- Pedolith → upper part of regolith profile → characterised by weathering products that have lost their fabric
- introduction of salts or colloids into one horizon from another by downwards percolating water
- the principal horizons are the plasmic (clay) zone mottled zone and lateritic residuum
- subdivision of the pedolith is based on replacement of primary fabrics and concentration of elements, primarily Fe and Si
- mottled zone and lateritic residuum are caused by local segregation and accumulation of Fe

Saprolith

- Saprolith → lowest part of regolith profile in which the primary fabric is retained
- fabrics imply pseudomorphism in which original minerals are replaced or partially replaced by alteration products without change of fabric
- there is little or no change in volume of material
- principal horizons are saprock and saprolite with saprolite comprising at least two-thirds of the weathered profile

Lag

- Lag → accumulated coarse, unconsolidated, resistant rocky material
- left behind by erosional processes like wind, water and ice
- forms a surface layer called a lag deposit

Lag

Sturt Stony desert, South Aust.

Gossan

- Gossan → intensely oxidised weathered or decomposed rock, usually at upper part of ore deposit or mineralised vein
- in most gossans, the iron cap is composed of Fe-oxide and quartz, often in the form of boxwork
- in other cases, hematite, limonite, goethite and jarosite exist as pseudomorphs replacing primary ore minerals
- some gossans are black and contain Mn-oxides such as pyrolusite, manganite and psilomelane
- Broken Hill ore deposit discovered through recognition of outcropping gossan

Gossan

Gossan outcrop, Iron Mountain Cu-Fe deposit, Californiorna

Laterite

- Laterite → soil type rich in Fe and Al normally formed in hot and wet tropical areas
- nearly all laterites are rusty red coloured because of high Fe content
- they form from intense weathering of underlying parent rocks with the leaching out of more soluble cations (e.g. Na, K, Mg)
- thick laterite layers are porous and slightly permeable may be aquifers in some rural areas

Laterite

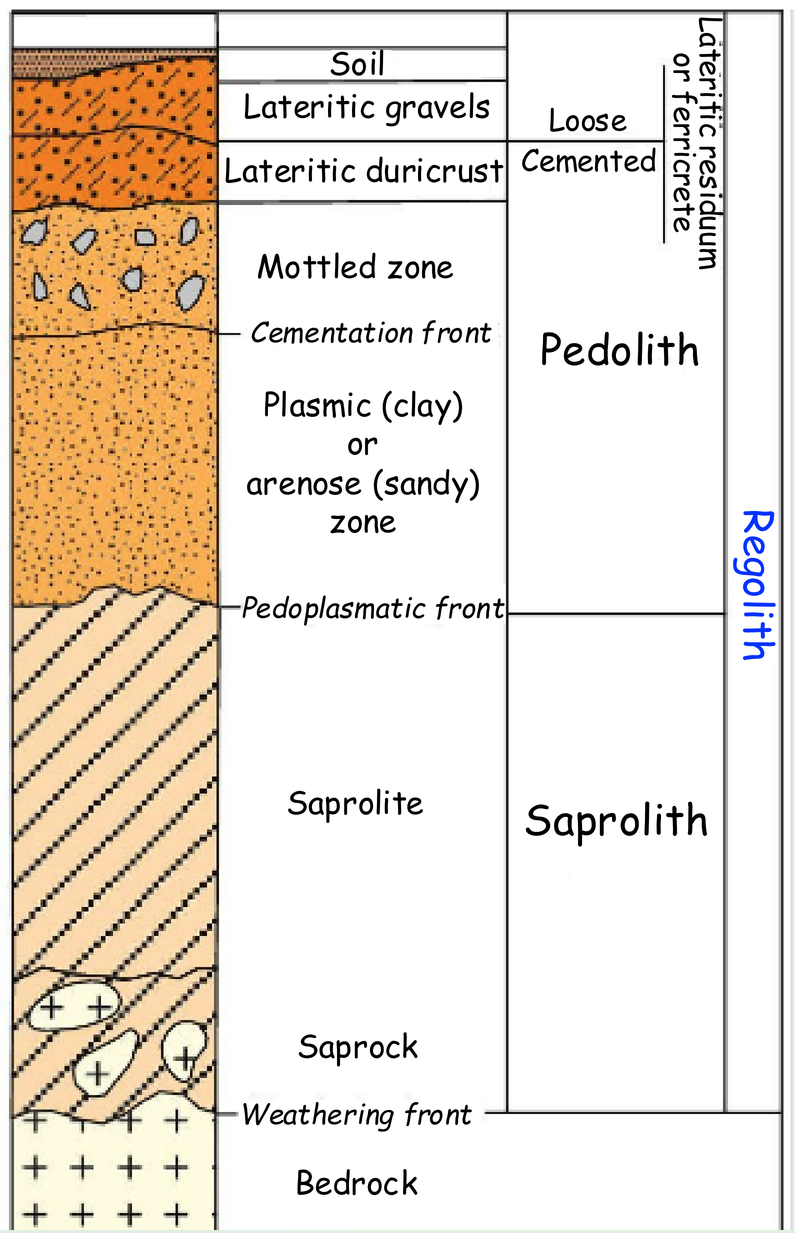
- Laterites are a source of Al (bauxites) and Ni (Ni laterites)
- formed from leaching of parent sedimentary, metamorphic and igneous rocks
- residues of leaching → insoluble oxides, hydroxides and sulphates of Fe, Al and Si under elevated temperature conditions
- an essential feature for formation of laterite is repetition of wet and dry seasons
- rocks are leached by percolating rainwater in wet season, resulting solution brought to surface by capillary action
- easily leached ions (Na, K and Mg) washed away next wet season

Regolith (lateritic profile)

- Laterite may be used to refer to ferricrete at top of complete weathering profile or more informally to describe entire profile
- beneath the ferricrete is a mottled zone, an active profile close to the water table
- above the water table is a zone of active weathering because it is in contact with abundant moisture and oxygen
- the active weathering front is located some distance below the water table and marks the boundary between fresh and weathered rock (saprock)

Laterite profile

Regolith (lateritic profile)



Ferruginous zone

- In the ferruginous zone, nodules and pisoliths are abundant and may be cemented to form duricrust
- zone is composed dominantly of secondary oxides and oxy-hydroxides of Fe (goethite, hematite, maghemite), hydroxides of Al (e.g. gibbsite, boehmite) and kaolinite [($AlSi_2O_5(OH)_4$]
- consists of loose lateritic gravels and/or lateritic duricrust
- lateritic gravels are the unconsolidated component of lateritic residuum → commonly overlie the lateritic duricrust
- the gravels consist of nodules, pisoliths and fragments in the size range 2-64mm

Duricrust (hardpan)

- Duricrust → hard indurated layer on or near soil surface
- duricrust can range in thickness from a few cm to several metres
- duricrusts typically form by accumulation of soluble minerals deposited by waters that have moved upward, downward or laterally by capillary action
- precipitation of duricrust commonly assisted by evaporation in arid conditions
- there are different types of duricrust; ferricrete (dominated by Fe-oxides); alcrete (bauxite) dominated by Al; silcrete (by Si); calcrete (by $CaCO_3$); gypcrete (by gypsum)

Duricrust (hardpan)

Hardpan capping, Buckley's breakaway, WA

Breakaway

- Breakaway → eroded cliff or slope often located at the edge of a mesa or plateau where harder, more resistant rock layers (duricrust), cap softer underlying layers
- over time, erosion of softer material causes cap rock to fracture and crumble resulting in colourful escarpments

Buckley's breakaway, WA

Silcrete

- Silcrete is strongly silicified, indurated regolith, generally of low permeability and commonly having a conchoidal fracture
- silcretes represent complete or near complete silicification of a precursor regolith horizon by the infilling of interstices with silica
- silcretes are common in the arid regions of Australia and Africa, often forming resistant cap rock
- silcrete is extremely hard and was used by the Australian aborigines for stone tool manufacture

Silcrete

Silcrete, Snowy River, NSW

Calcrete (or caliche)

- Calcrete (also called caliche) is a shallow layer of soil or sediment cemented by the precipitation of $CaCO_3$
- $CaCO_3$ first precipitates as small grains on sedimentary particles as grain coatings thicken → adjacent grains cemented together
- calcrete is a common feature of arid or semi-arid areas throughout the world it has a diversity of origins
- major process of forming calcrete begins when $CaCO_3$ is leached from upper soil horizons, precipitates deeper to form calcrete
- some calcrete forms by upward movement of water through capillary action → as water evaporates → minerals precipitate

Calcrete (caliche)

Calcrete outcrop, Texas, USA

Ferricrete

- Ferricrete → hard, erosion-resistant layer of sedimentary rock, usually conglomerate or breccia that has been cemented into duricrusts by Fe-oxides

- Fe-oxide cements are derived from the oxidation of percolating Fe-salt solutions

- ferricretes form at or near the land surface and may contain sediments that have been transported from outside the immediate area of the deposit

Ferricrete

Ferricrete , Niger

Ferricrete, Ranworty, UK

Alcrete

- Alcretre → also known as aluminocrete is a type of duricrust formed by the accumulation of Al-oxides and hydroxides
- particularly common in seasonally-wet humid to sub-humid tropical environments
- form through leaching of more mobile elements (K, Na, Mg) from weathering profiles
- alcrete is closely related to bauxite with extremely high concentrations of Al being classified as bauxite

Regolith – mottled zone

- The mottled zone lies just below the duricrust
- mottling is composed of different coloured patched materials, generally red/brown with grey/white matrix
- mottled zone is predominantly kaolinite and hematite or goethite increasing cementation by hematite towards top of zone
- mottles have sharp, distinct or diffuse boundaries
- mottles typically range in size from 10-100mm but may reach several metres in size
- mottling can develop in both plasmic and saprolite zones

Regolith – mottled zone (Bronzewing, WA)

Mottled zone, Bronzewing open pit

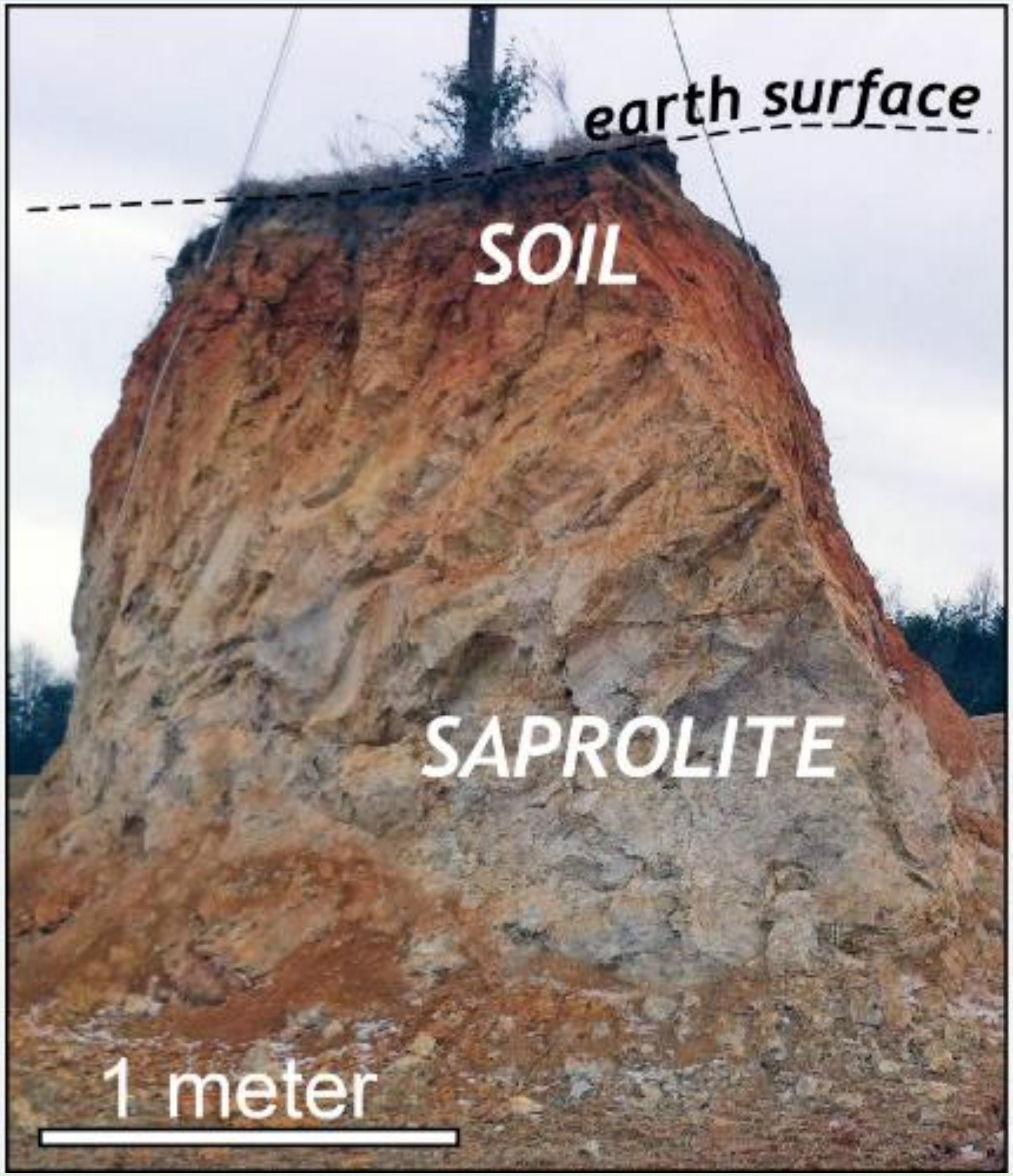
Plasmic zone

- Plasmic zone → mesoscopically homogenous layer of weathering profile dominated by clay or silty clay
- characterised by its pale colour, presence of clay minerals, particularly kaolinite with dispersed Fe oxides
- transitional zone between mottled zone and saprolite produced by loss of fabric without significant chemical and mineralogical changes
- loss of lithic fabric caused by solution and authigenesis of minerals and mechanical processes (shrinking, swelling of clay)
- plasmic zone not always present

Saprolite

- Saprolite → chemically weathered bedrock that forms in lower zones of regolith profiles → preserved fabric
- saprolite has more than 20% of weatherable minerals altered
- more intense weathering results in a continuous transition from saprolite to laterite
- in lateritic regoliths, saprolite may be overlain by upper horizons of residual laterite
- weathering formed kaolinitic [$Al_2SiO_5(OH)_4$] saprolites
- iron compounds are primary colouring agents in saprolite e.g. goethite yellow (fine), brown (coarse)

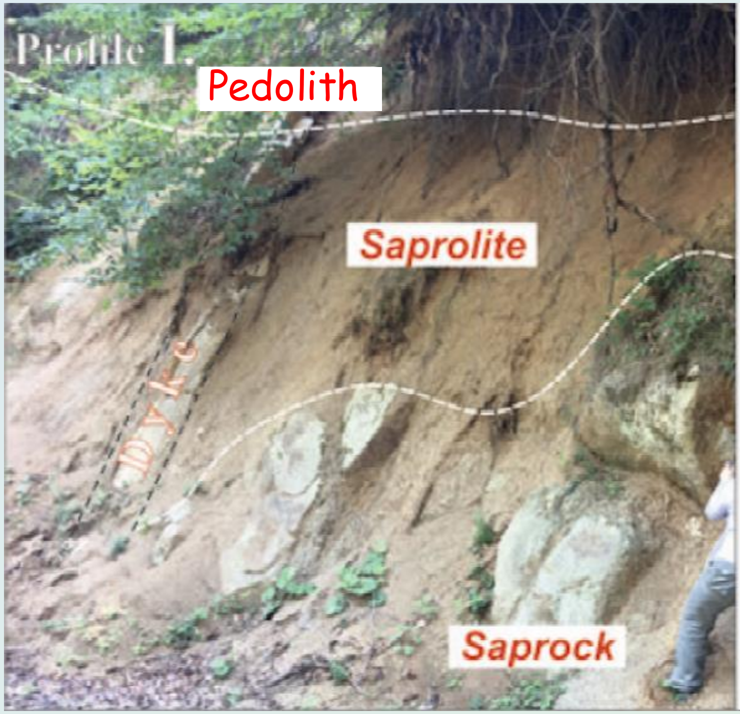
Saprolite

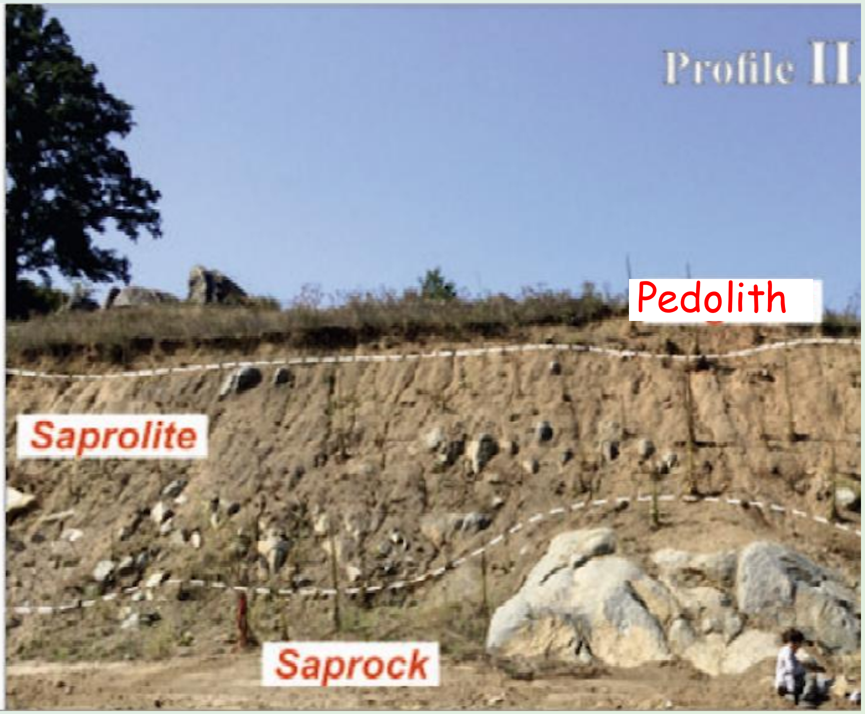


Saprock

- Saprock → compact, slightly weathered rock of low porosity, with <20% of the weatherable minerals altered
- weathering occurs along mineral boundaries, cleavages, joints, shears and fractures
- first signs of weathering are generally oxidation of sulphides and carbonates or breakdown of feldspars
- upper and lower boundaries may be sharp or gradational
- may vary markedly in depth and thickness over short distances and with only minor lithological changes

Saprock


Profile I.
Pedolith
Saprolite
Dyke
Saprock


Profile II.
Pedolith
Saprolite
Saprock

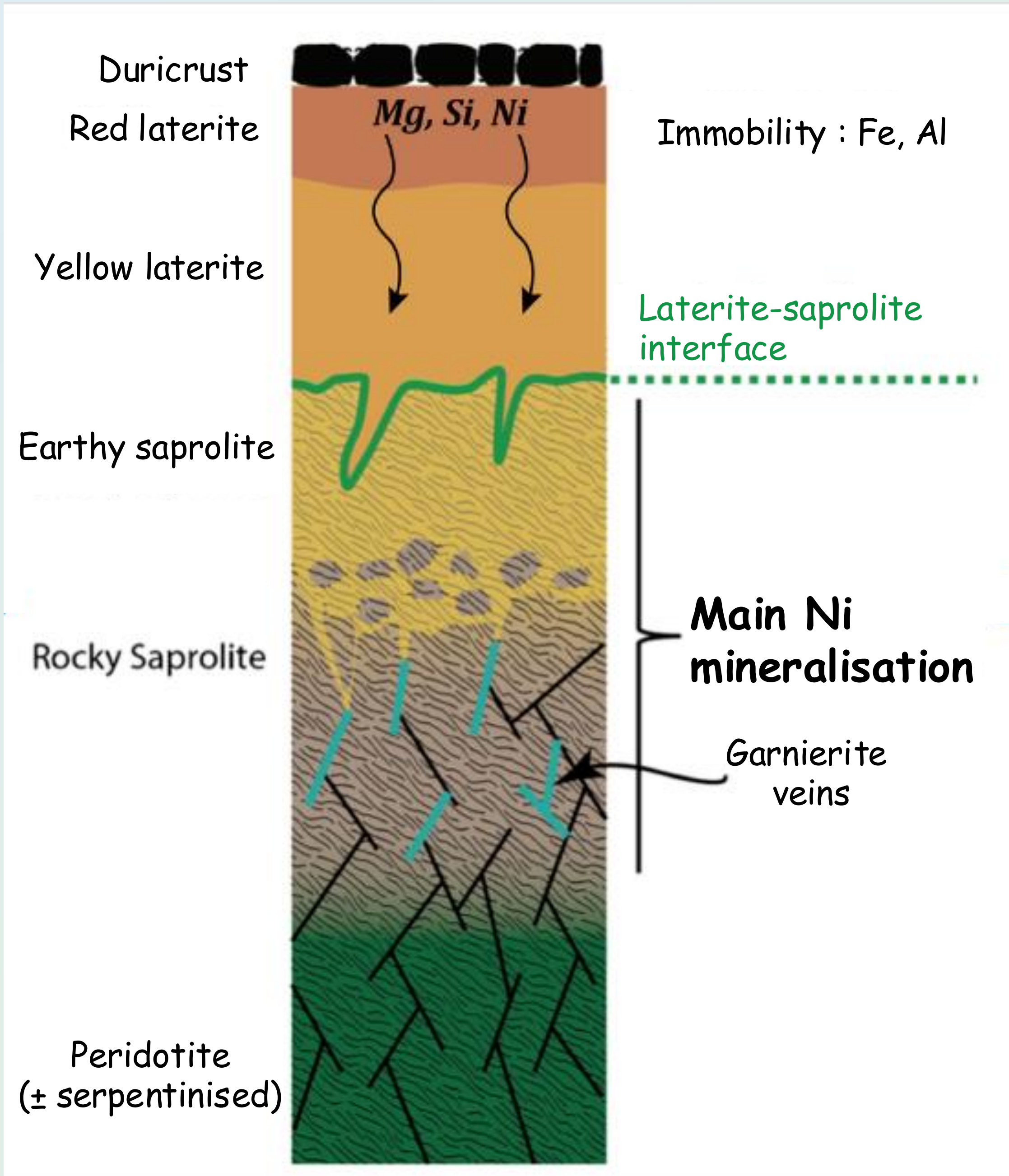
Nickel laterite deposits

- Ni-laterite deposits are surficial weathered rind formed on weathered ultramafic rocks
- they account for 73% of the world continental Ni deposits
- formed by intensive weathering of olivine-rich ultramafic rocks e.g. dunite, peridotite, komatiite and serpentinised derivatives
- serpentinite consists mainly of the Mg silicate serpentine $\{Mg_6[Si_4O_{10}](OH_8\}$ and contains 0.03% Ni
- primary Ni content is strongly enriched in course of laterisation
- two types of lateritic Ni ore recognised: (1) limonite types
  (2) silicate types

Ni laterite

Ni laterite in outcrop, New Caledonia

Typical laterite profile New Caledonia (Ulrich 2010)



Ni laterite character

- Ni laterite deposits are very large tonnage deposits in the range of 20Mt of 1% Ni
- they are composed of long tabular bodies over several hundred metres long but only tens of metres thick
- deposits consist of predictable weathering profiles that includes five zones
- from the base upwards they are unweathered ultramafic bedrock, saprolite, clay-rich, limonite zone and ferricrust

Types of Ni-laterite deposits

- Limonitic type deposits are highly enriched in Fe due to strong leaching of Mg and Si
- they comprise mainly goethite containing 1-2% Ni
- Silicate type (saprolite type) Ni ore forms beneath the limonite zone
- it contains 1.5-2.5% Ni and consists largely of Mg-depleted serpentine
- there are minor amounts of the mineral garnierite [$(Mg,Ni)_3Si_4O_{10}(OH)_2.2H_2O$] with a high Ni content (20-40%)
- all Ni in silicate zone → leached down from overlying goethite zone

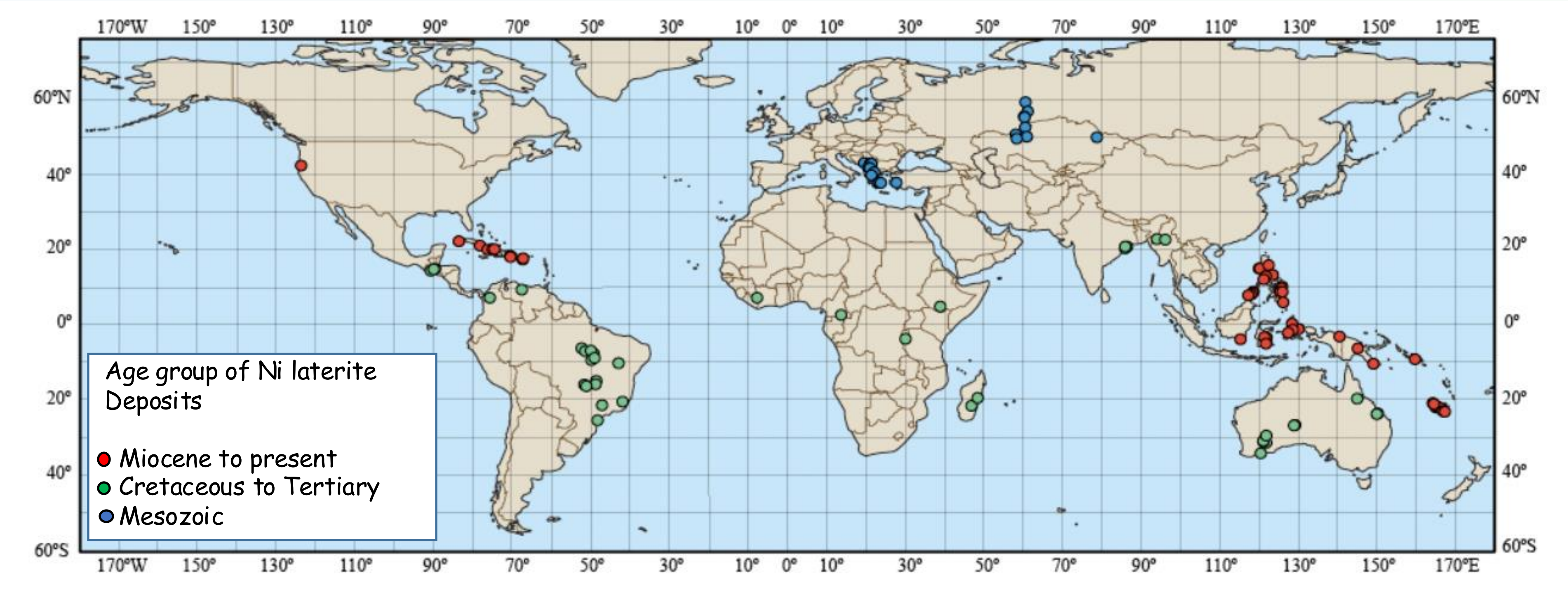
Ni- laterite zones

- In saprolite zone, Ni is contained in hydrous Mg silicates consisting of serpentines, chlorite, sepiolite and garnierite (Mg-hydroxides)
- Ni in limonite zone occurs within Fe-oxides goethite and hematite
- saprolite and limonite zones tend to contain higher grades of Ni and can range from 1.5-3% and 1.2-1.7% respectively
- clay zone is rich in Ca, Na, Mg, Fe and Al forming clay minerals called smectites that contain trace amounts of Ni
- factors affecting and producing Ni-laterites include original rock the soil develops from, climate, rate of weathering, drainage of groundwater and tectonic setting

Location of Ni laterite deposits

- Majority of Ni laterite deposits tend to occur within parallels 23.5° north and south of the equator
- these are areas that are within warm, tropical environments where chemical and mechanical weathering occurs
- the majority of Ni laterite deposits are located in New Caledonia, Western Australia, Indonesia and South America
- New Caledonia contains 21% of world's laterites, Australia 29%, Philipinnes 17% and Indonesia 12%
- some deposits occur outside of tropical belt including Oregon, and the Ural Mountains, Russia

Global Ni laterite deposits



The most notable Ni laterite deposits in Australia are the Murrin Murrin and Wingellina areas in WA and Greenvale in Qld

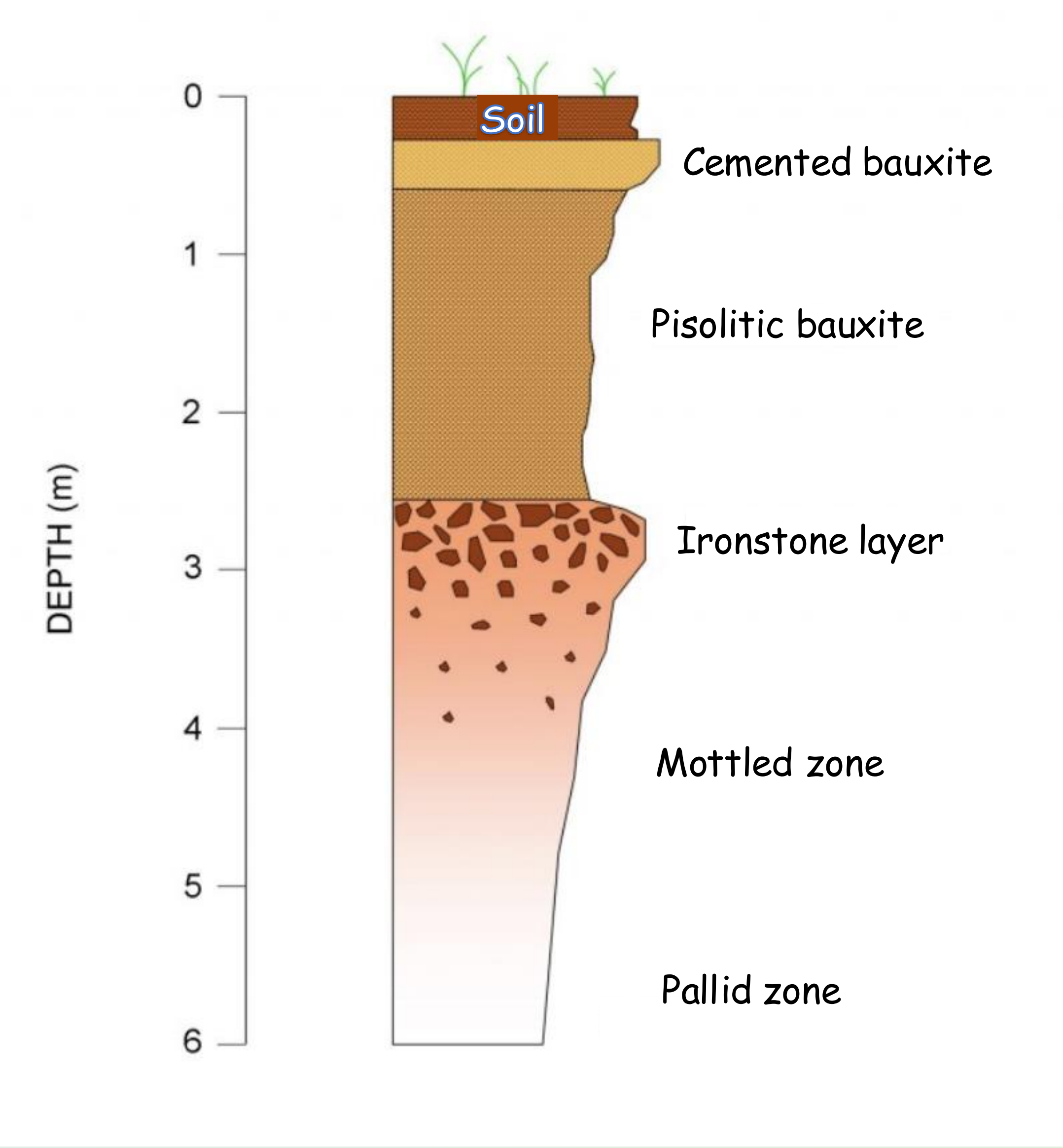
Bauxite

- Most of the world's Al is mined from lateritic bauxite deposits
- bauxite is composed mainly of hydrated alumina minerals (e.g. gibbsite) in newer tropical deposits
- in older subtropical, temperature deposits, the main minerals are boehmite [$Al(OH)_3$] and some diaspore
- weathering of Si-rich rocks sees mobile elements such as Ca, Na, K and Mg leached while immobile elements Al, Fe, Ti and Zr remain
- after millions of years what is left is a laterite that is either Fe-rich or Al-rich

Lateritic bauxite profile

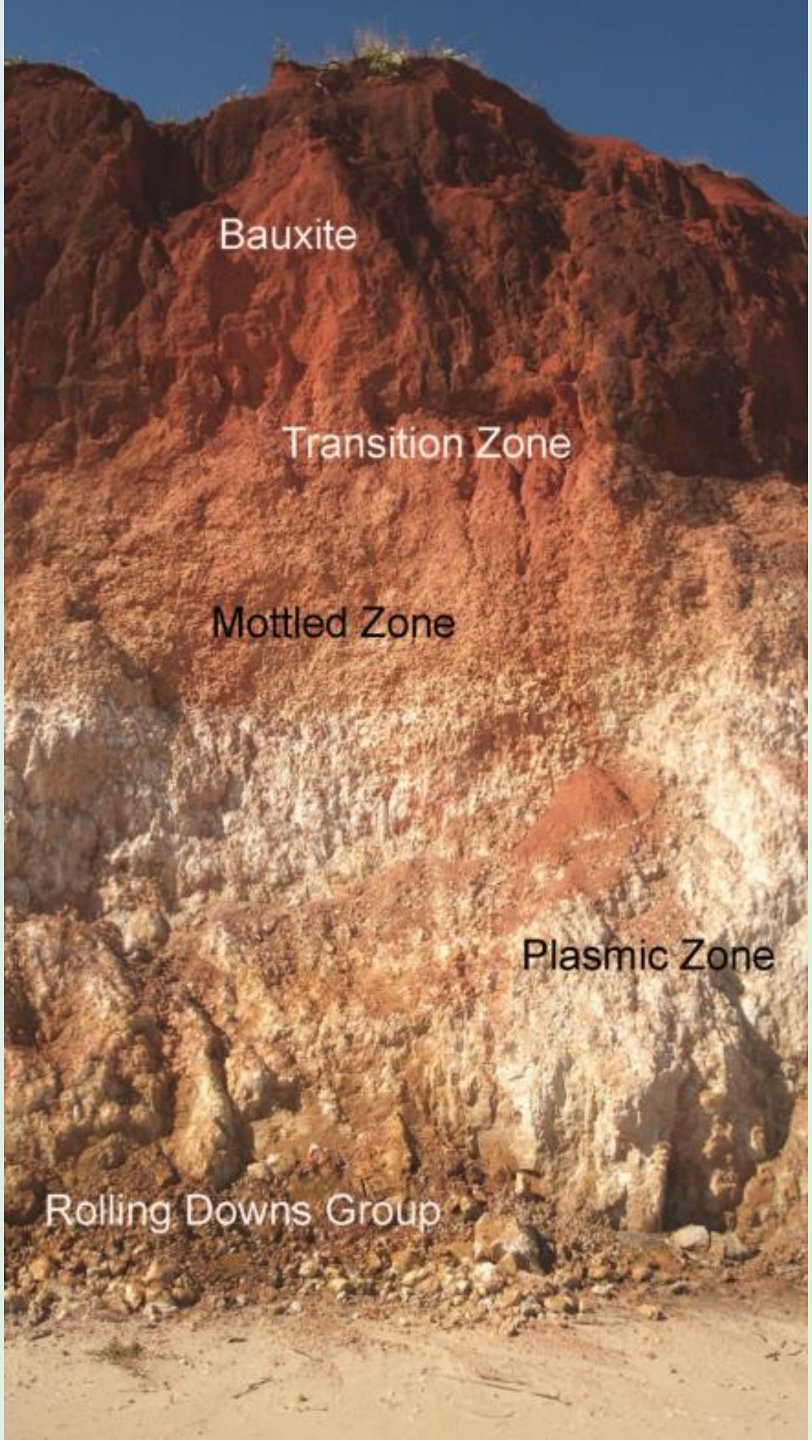
- The profile consists of a relatively thin layer of soil overlying a horizon of cemented pisolitic bauxite (alcrete)
- underlying cemented bauxite is a layer of loose pisolitic bauxite 1-2m thick (main pisolite mineral → gibbsite)
- below pisolitic bauxite is a nodular ironstone layer → Fe, kaolin rich
- beneath the ironstone layer the profile becomes progressively less nodular and more mottled
- mottled zone has reddish patches containing hematite and goethite
- at greater depths kaolinite dominates, the name pallid zone is given to the lowest part of profile

Bauxite profile (Tilley 2008)



Regolith profile- Weipa

- Weipa plateau experiences monsoonal climate → weathering to depth of ~30m
- organic-rich topsoil ~0.5m thick overlies red soil horizon up to 5m thick
- red soil consists of fine bauxite → transported and redeposited
- bauxite horizon → mostly loose pisoliths, minor cemented bauxite
- forms thin laterite gravel → 0.5-12m thick → continuous over many km



Pisolitic bauxite

- Pisolitic bauxite is composed of spherical concretionary grains with kaolinic cores and aluminium hydroxide cortices
- pisolith core is typically reworked parts of other bauxite material
- all pisoliths are concentrically layered with 2 to >10 cortices; most commonly 3-6
- their external appearance bears no relationship to inner fabric
- pisoliths grow after release from clay matrix by addition of successive layers (cortices) of fine-grained gibbsite, boehmite and hematite

Pisolitic bauxite