EXPLORATION GEOCHEMISTRY IN DEEPLY WEATHERED ENVIRONMENTS

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OUTLINE

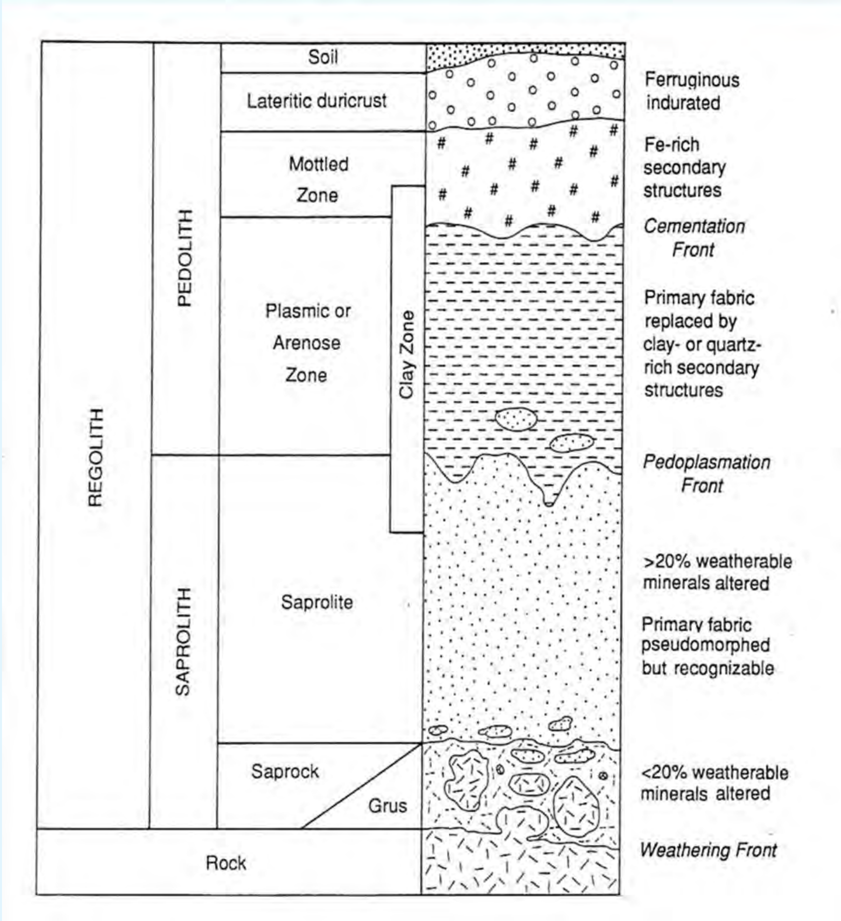
- Regolith geochemistry
- Background to regolith
- Case studies
  - Western Australia
  - Suriname
  - Sudan
- Summary

REGOLITH GEOCHEMISTRY

- Many elements are unstable at the Earth's surface and will be redistributed through both mechanical and chemical means during weathering.
- Transported geochemical anomalies provide false geochemical anomalies (false positives), whereas zones of chemical depletion within the regolith profile may result in false negatives.
- Requires the correct identification of regolith materials and an understanding of landscape evolution.
- Challenging environments to work in but include some of the most prospective terrains for mineral exploration.

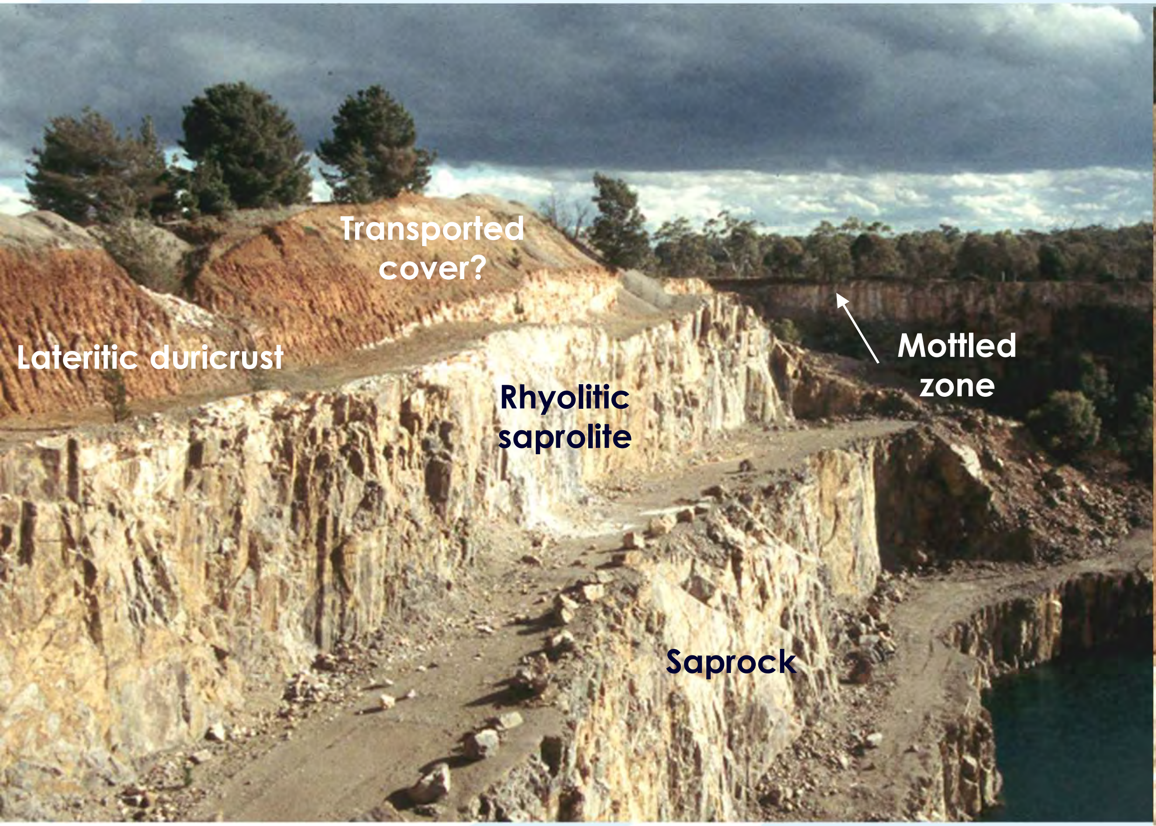
IDEALIZED REGOLITH PROFILE

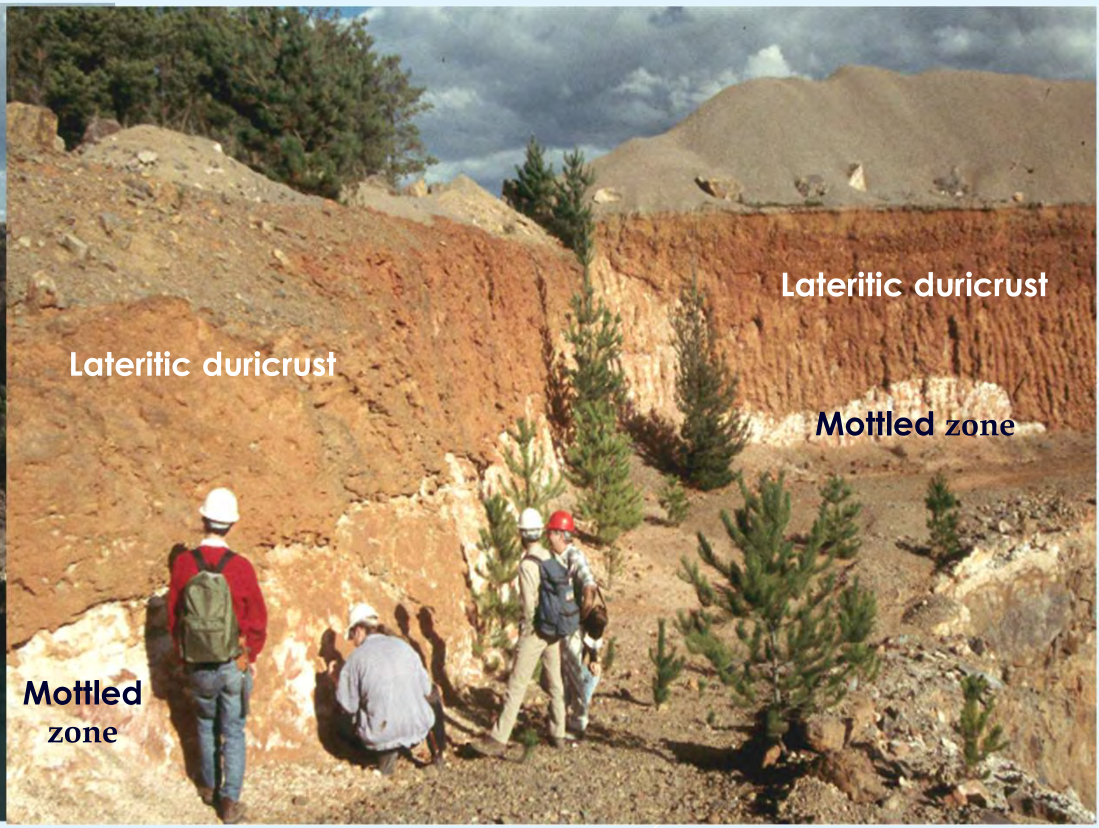
- Pedolith (no preserved primary textures)
  - soil
  - lateritic duricrust (lateritic residuum)
  - mottled zone
  - clay zone (plasmic or arenose zone)
- Saprolith (primary textures preserved)
  - saprolite
  - saprock/grus
- Fresh rock



(From Robertson & Butt, 1997)

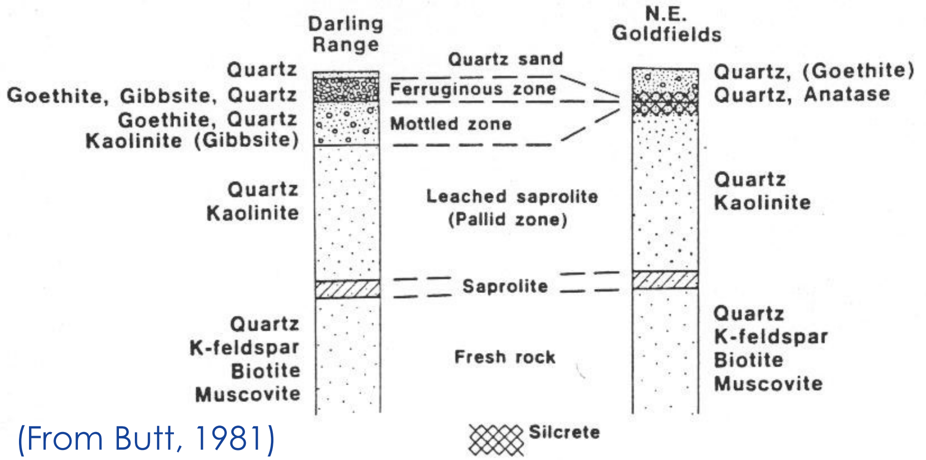
BORAL QUARRY, WESTERN VICTORIA, AUSTRALIA





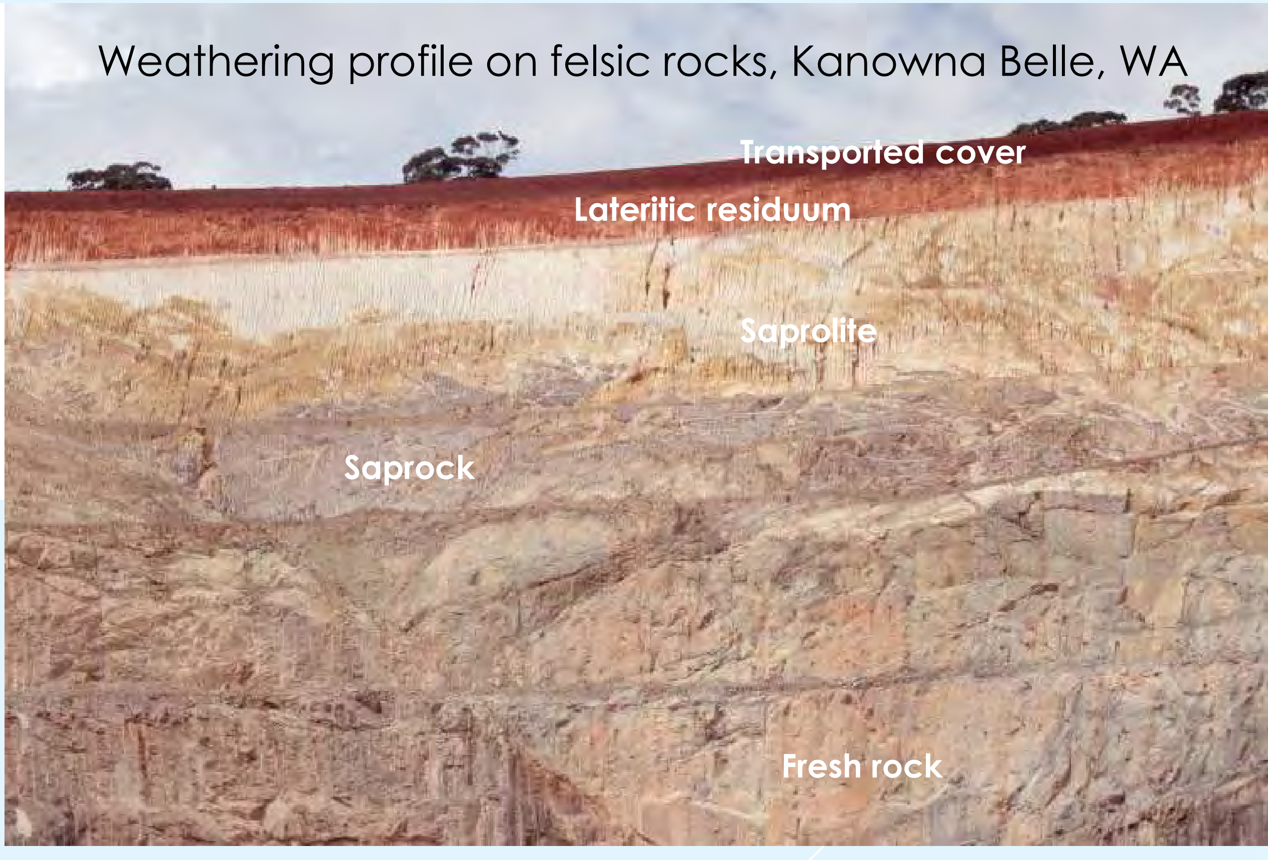
- Fresh rock may be 10s of metres, if not >100 m below ground surface

WEATHERING PROFILES ON FELSIC ROCKS

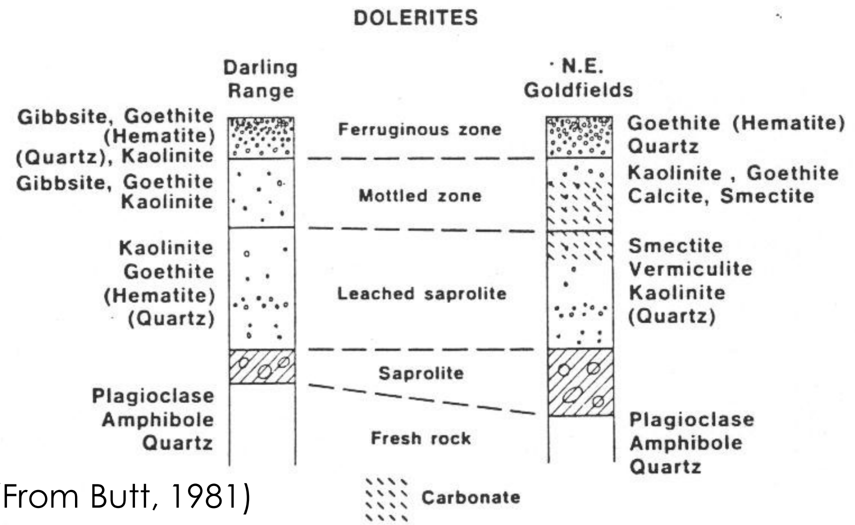


(From Butt, 1981)

High Rainfall **Low Rainfall**



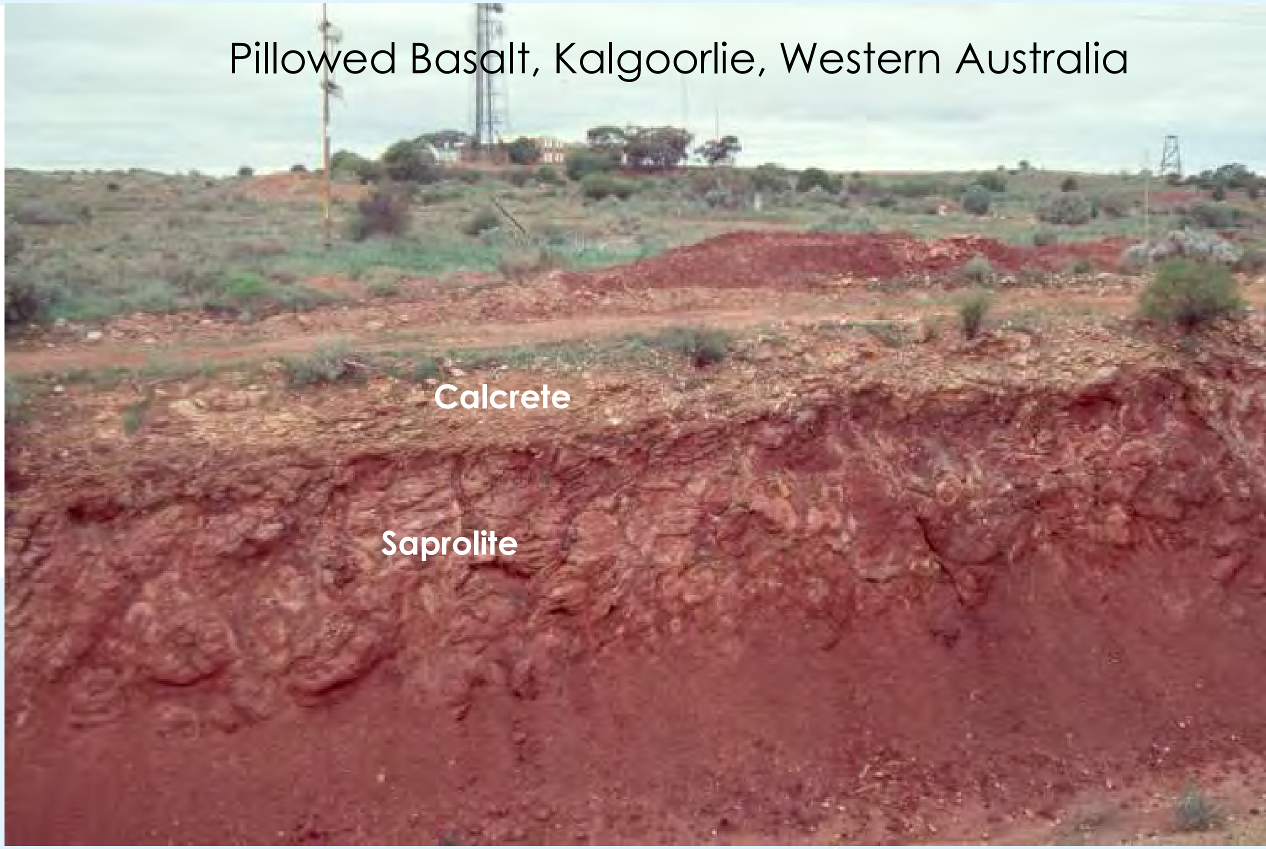
WEATHERING PROFILES ON MAFIC ROCKS



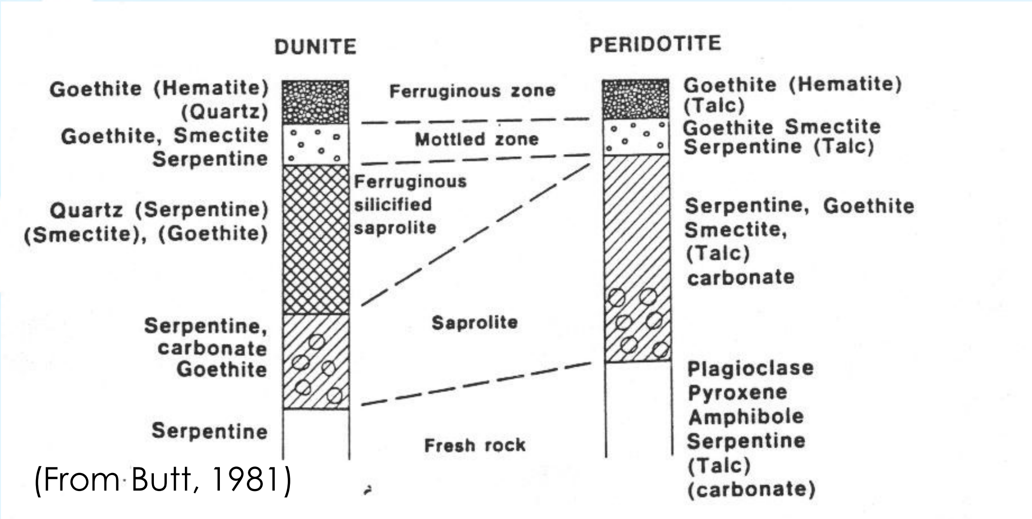
(From Butt, 1981)

High Rainfall **Low Rainfall**

Mottled, nodular duricrust, Golden Mile Dolerite, Mt. Percy, WA



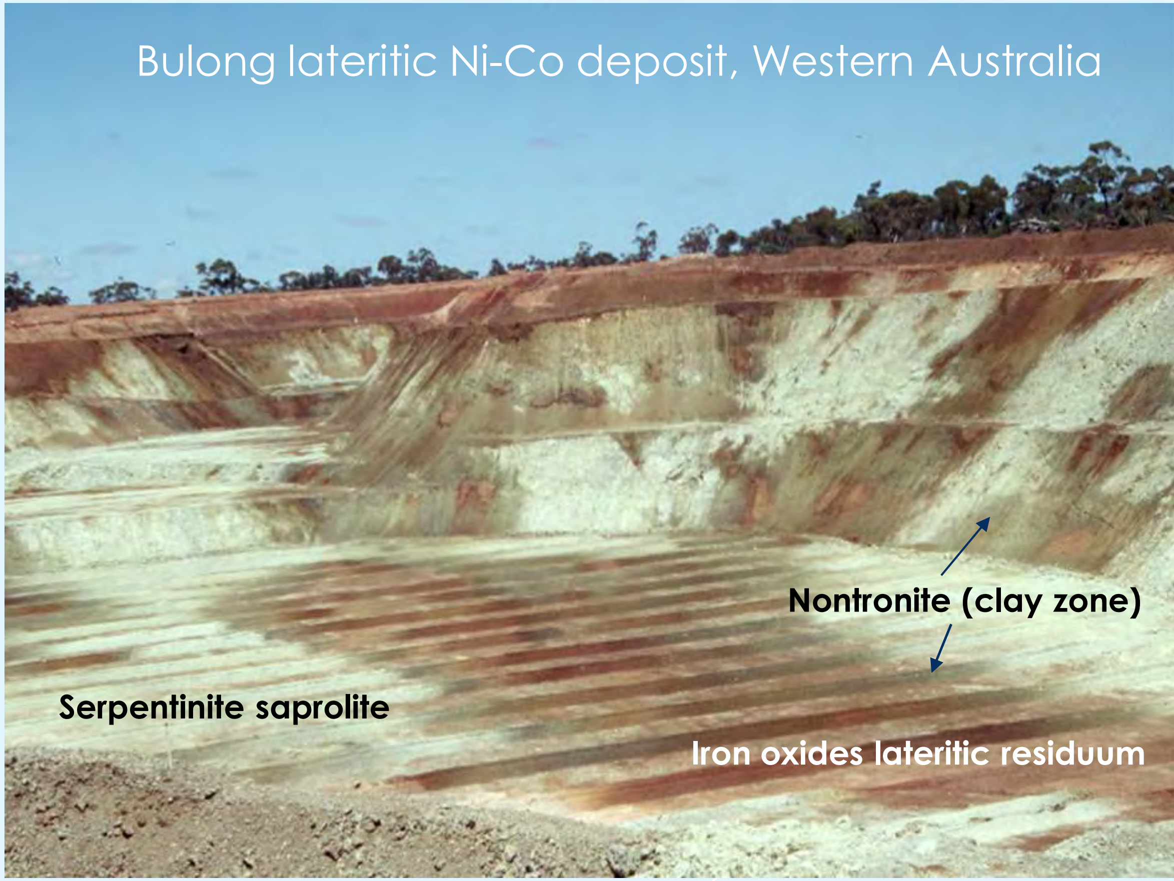
WEATHERING PROFILES ON ULTRAMAFIC ROCKS



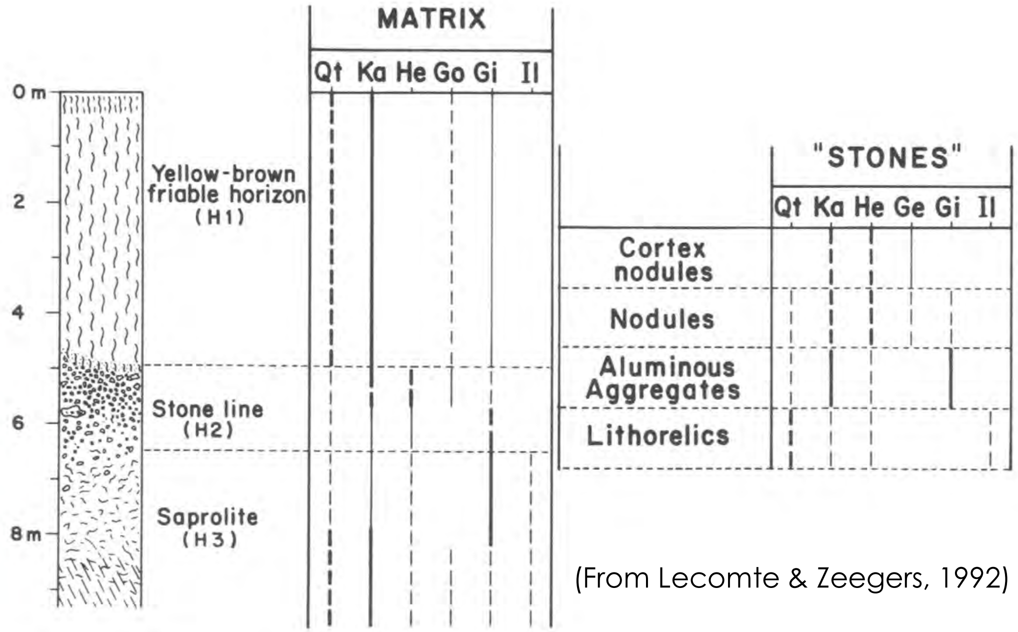
(From Butt, 1981)

Oxide-dominant Clay-dominant

- Mineralology is ultimately dependent on whether the ultramafic rocks are orthocumulates or adcumulates, and the distribution may be structurally-controlled.



STONE LINES AND FERRALITIC SOIL

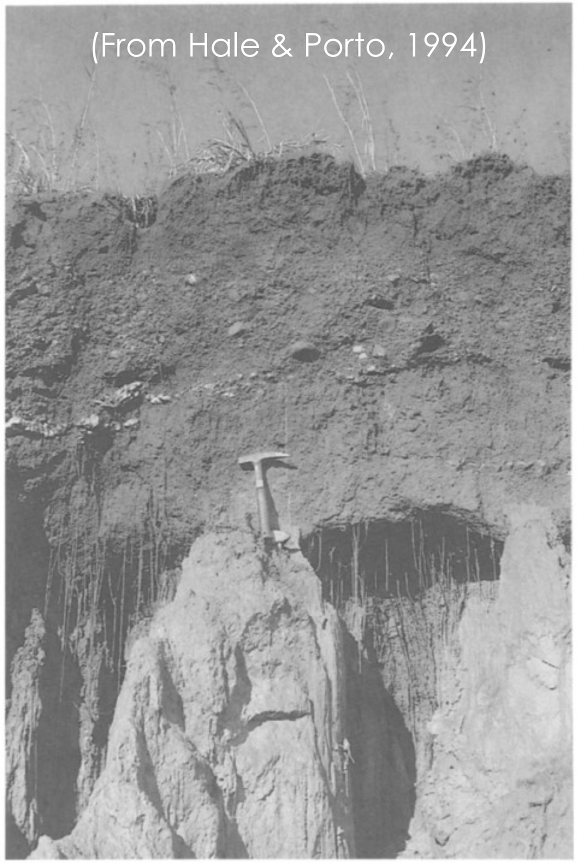


(From Lecomte & Zeegers, 1992)

Pedolith

Stone line

Saprolith

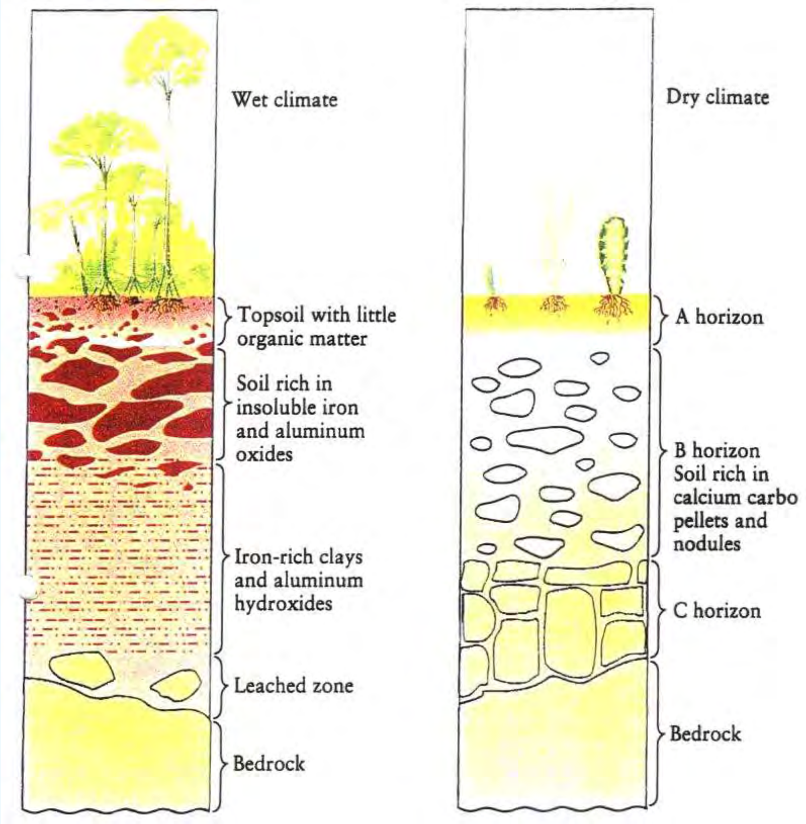


(From Hale & Porto, 1994)

- Stone lines may mark a break between the pedolith and saprolith

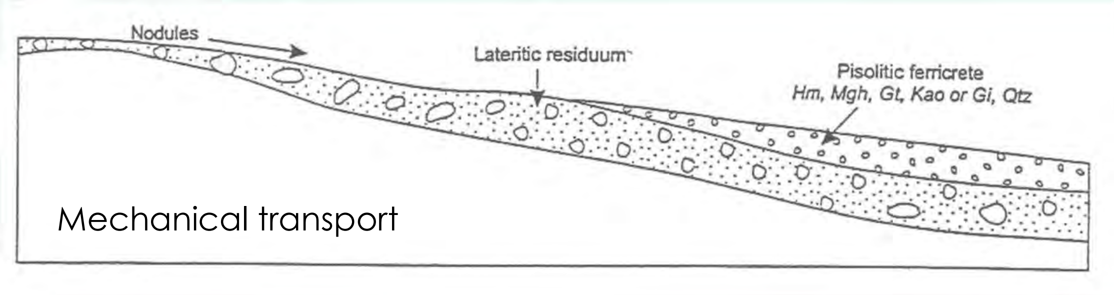
EFFECTS OF CLIMATE CHANGE

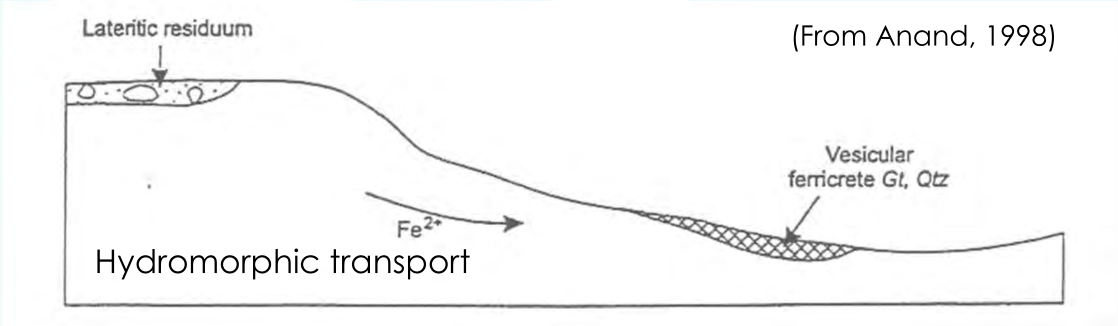
- To a more humid climate
  - Increased leaching
  - Degradation of earlier regolith units
- To a less humid climate
  - Similar effects to uplift; decreased leaching
- To a semi-arid or arid climate
  - Erosion from uplands; deposition in valleys
  - Lowering of the water table; dehydration
  - Decreased leaching; saline groundwater
  - Precipitation of silica and alkali elements



(From Anand et al., 1997)

INVERTED TOPOGRAPHY - 1



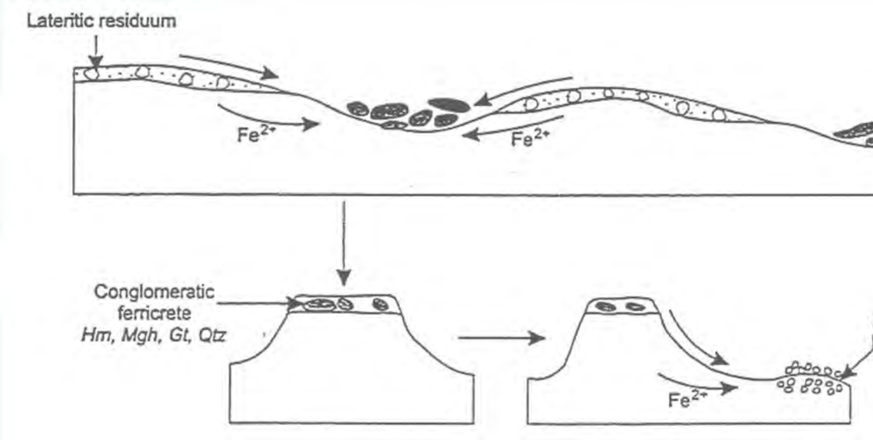


(From Anand, 1998)

- Fe tends to be hydromorphically and physically transported into low-lying areas where ferricrete can form through oxidation of reduced Fe

TELE GEO

INVERTED TOPOGRAPHY - 2

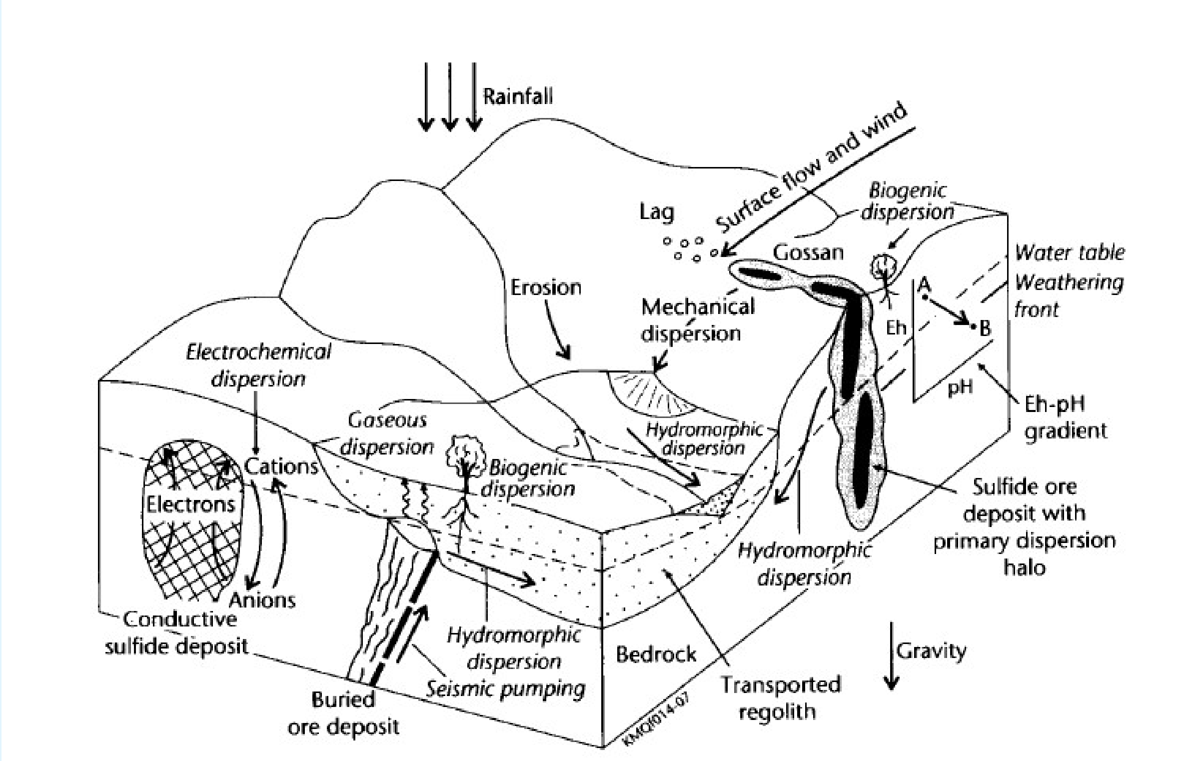


(From Anand, 1998)

- This resistant layer then protects the underlying saprolith from erosion during landscape evolution
- Not restricted to arid or tropical environments

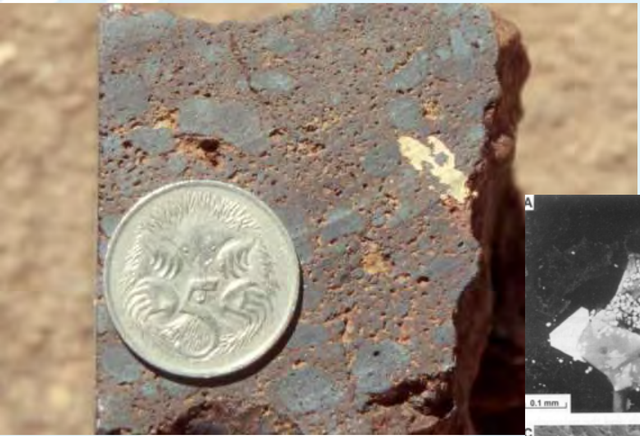
SUPERGENE PROCESSES

- A wide variety of supergene processes act upon mineralization within the regolith, including:
  - Formation of electrochemical cells;
  - Development of Eh and pH gradients across the water table, which may rise and fall with climate/uplift;
  - Hydromorphic, mechanical and biogenic dispersion; and
  - Dissolution and re-precipitation of metals (supergene enrichment)

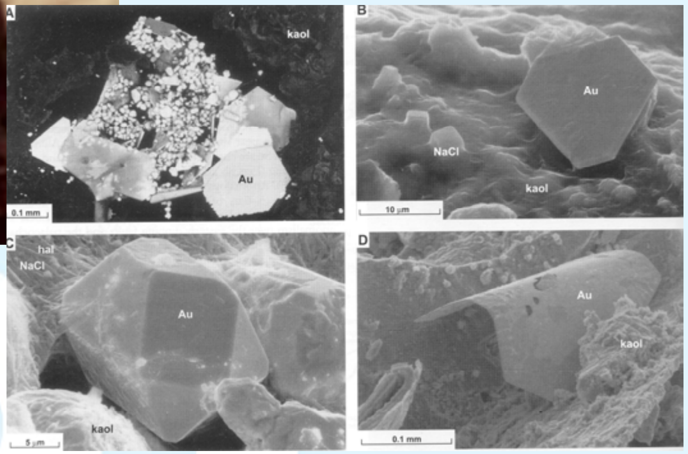


(From McQueen, 2009)

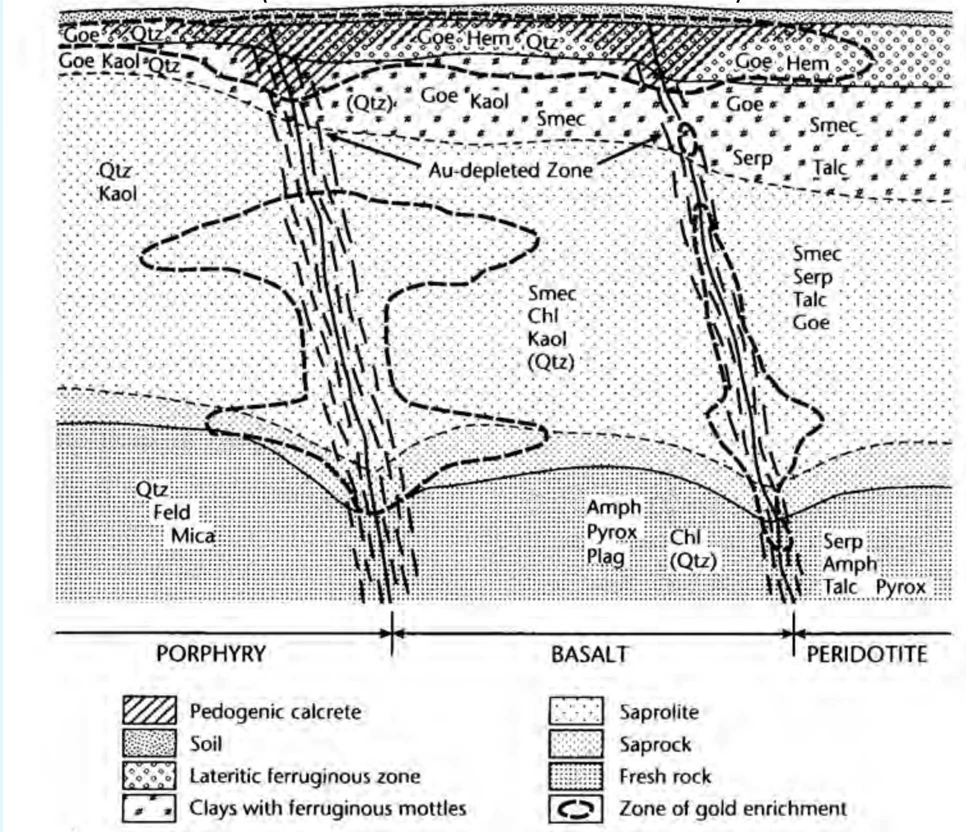
SUPERGENE GOLD



(From Lawrance, 2001)



(From McQueen & Scott, 2009)

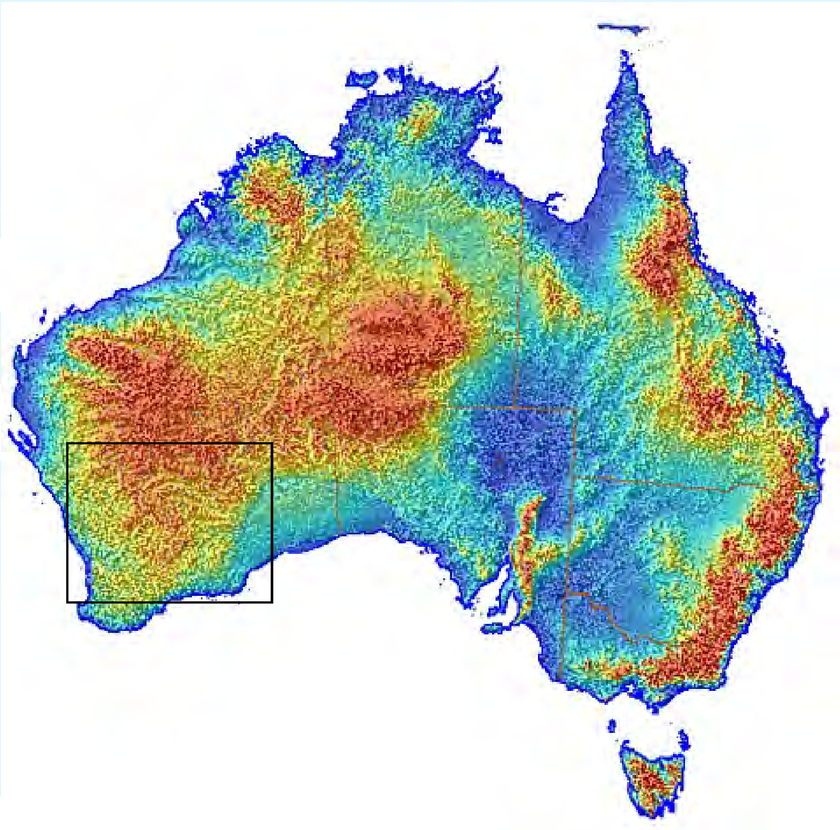


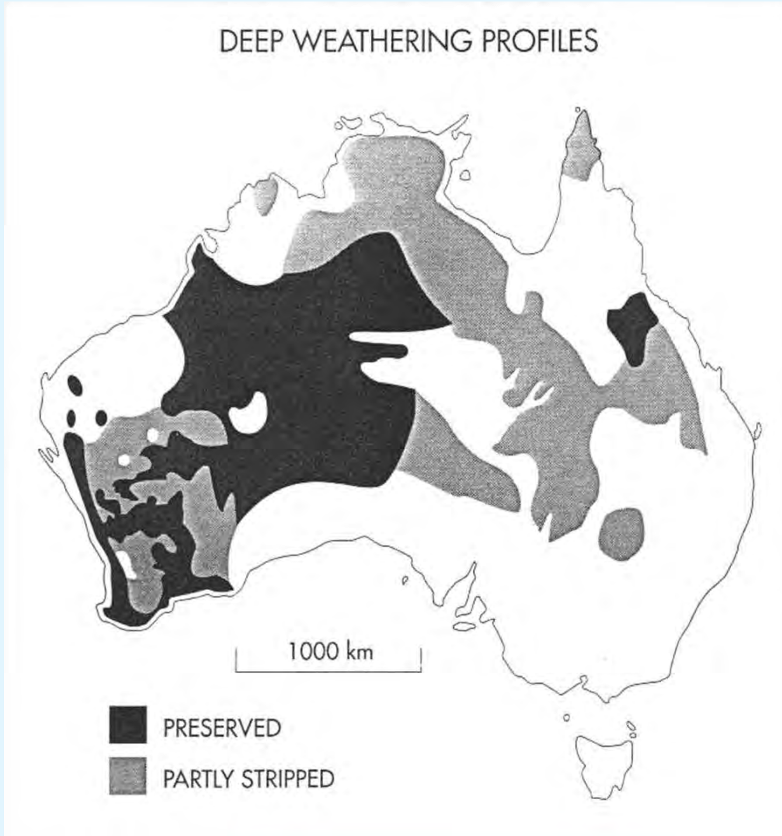
- The dissolution and migration of Au may produce a shallow zone of depletion, with re-precipitation of high-fineness Au close to the current and/or former water table(s).

CASE STUDY 1 – WESTERN AUSTRALIA

Semi-arid weathering environment

PRESERVATION OF DEEPLY WEATHERED ENVIRONMENTS

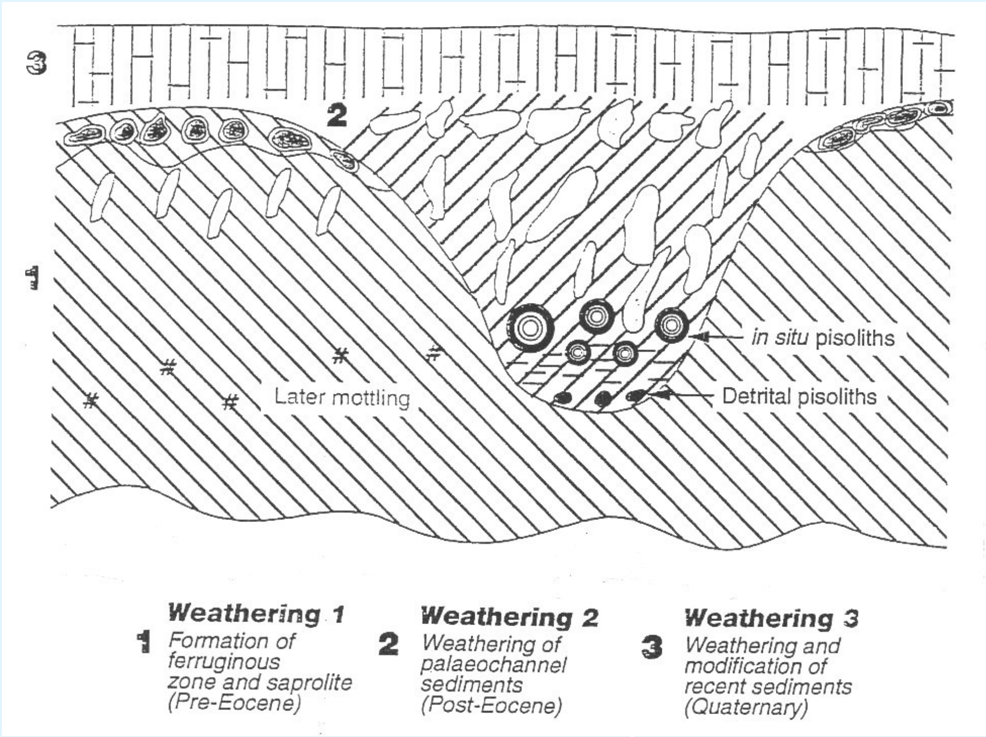




- Although deeply weathered, the complete regolith profile is not preserved in all places

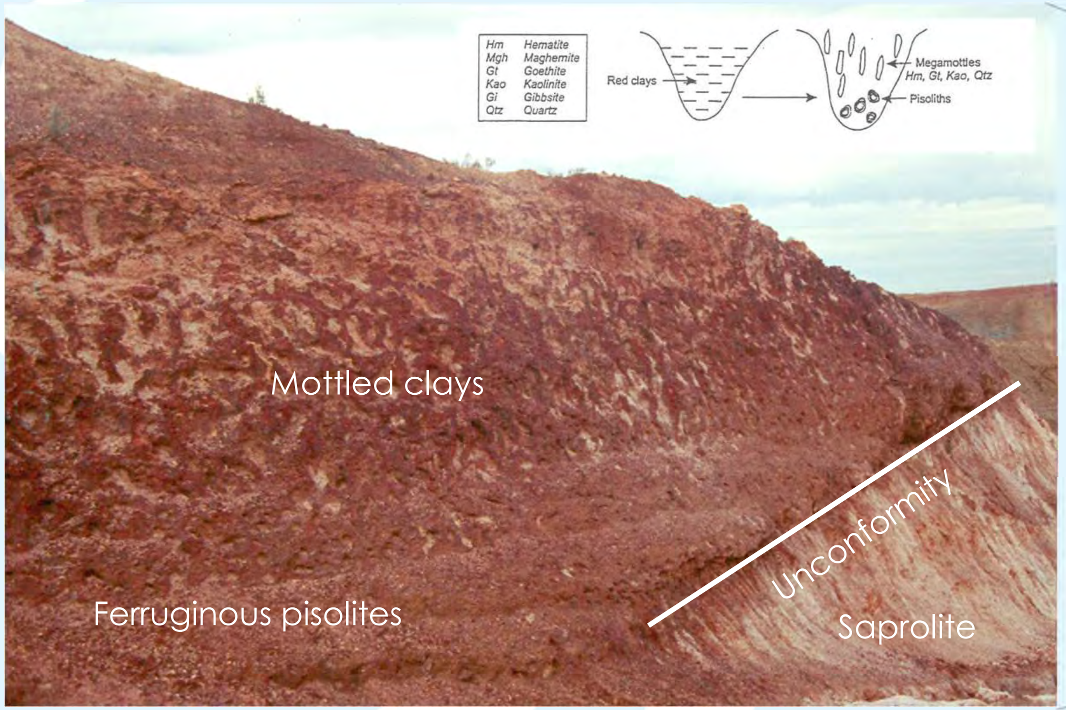
SOUTH YIGARN CRATON, WESTERN AUSTRALIA

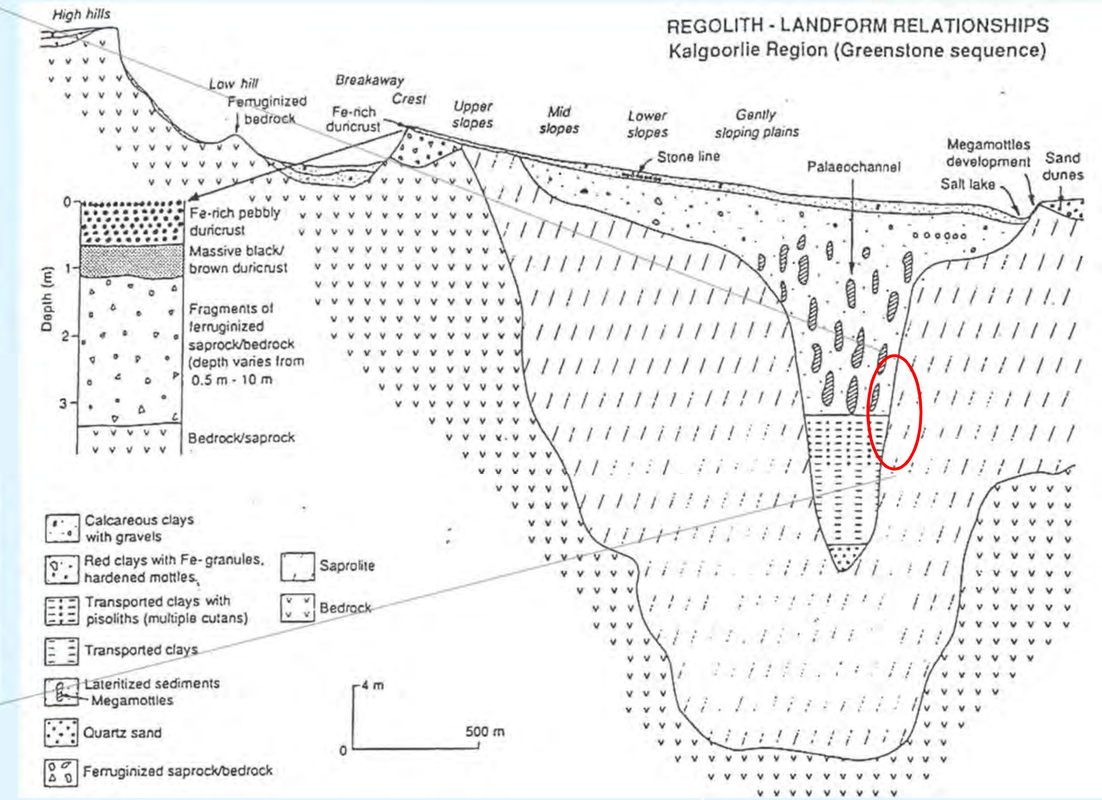
- Pre-Eocene deep weathering in a humid climate and formation of ferricrete and silcrete.
- Eocene incision of the landscape; formation of paleo-channels, possibly related to final break-up of Gondwana.
- In-fill of drainage and deep weathering of paleo-channel fill.
- Weathering of Recent sediments under arid conditions to form calcrete and further incision.



(From Anand, 1998)

PRE-EOCENE TO EOCENE HISTORY





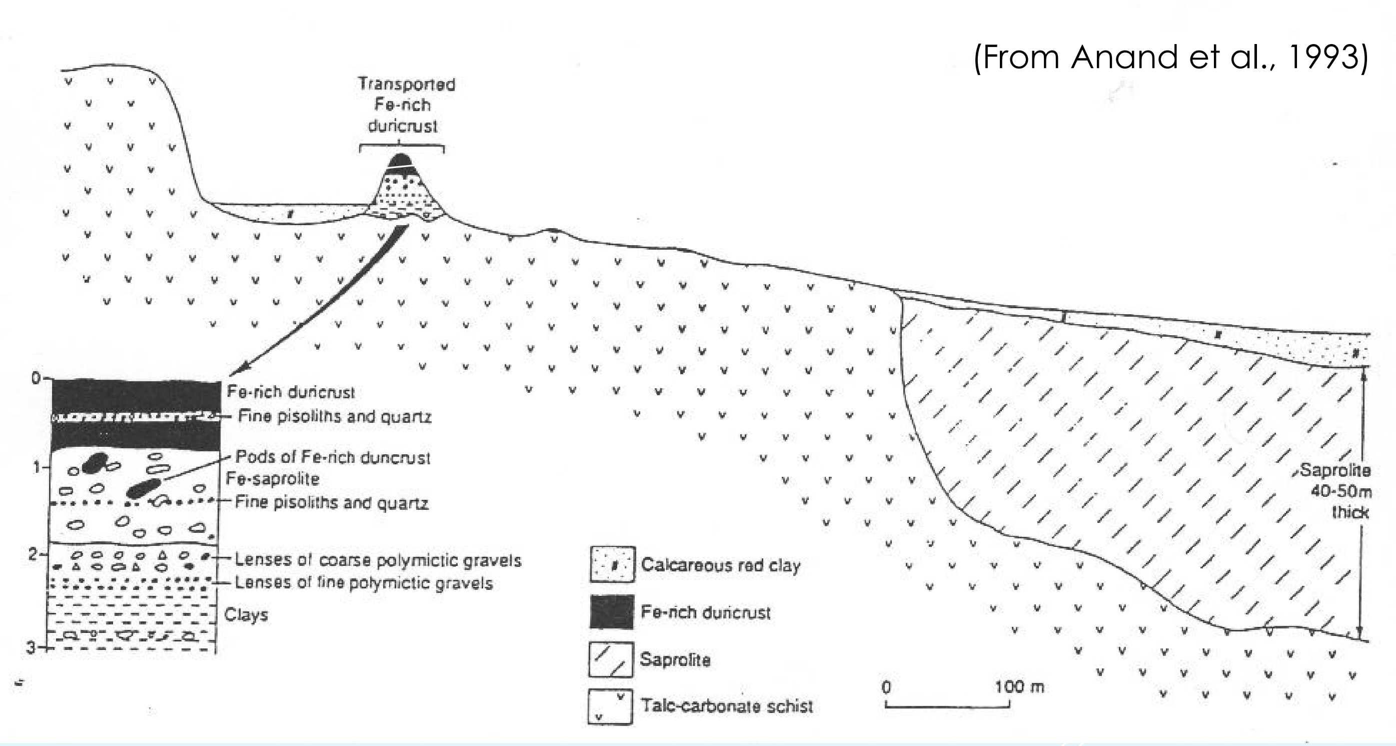
- Paloeochannels in the southern Yilgarn craton may contain both paleo-placer and supergene Au

(From Anand et al., 1993)

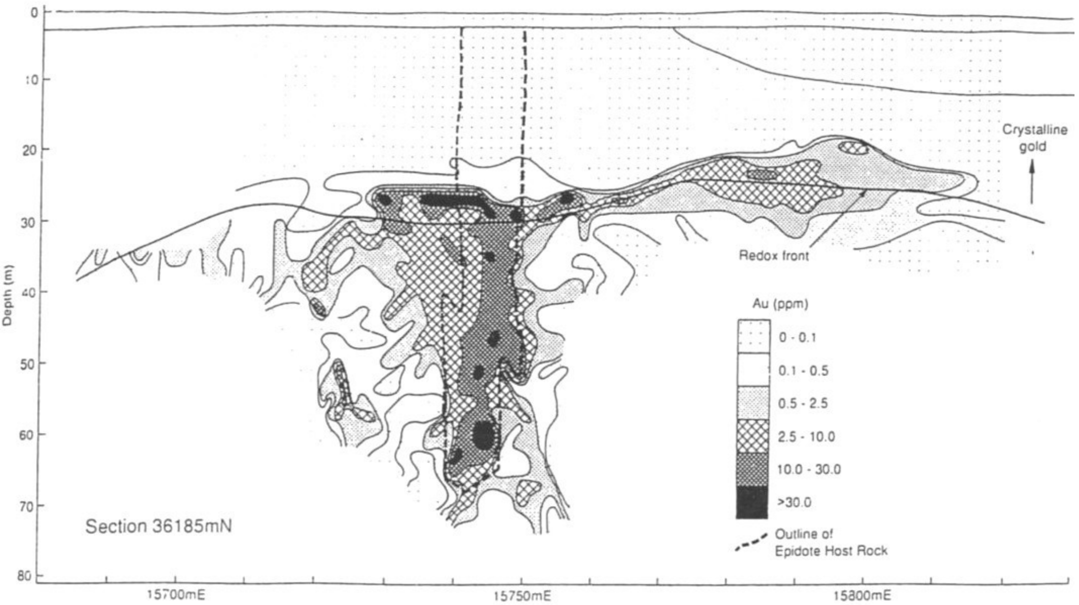
TELE GEO

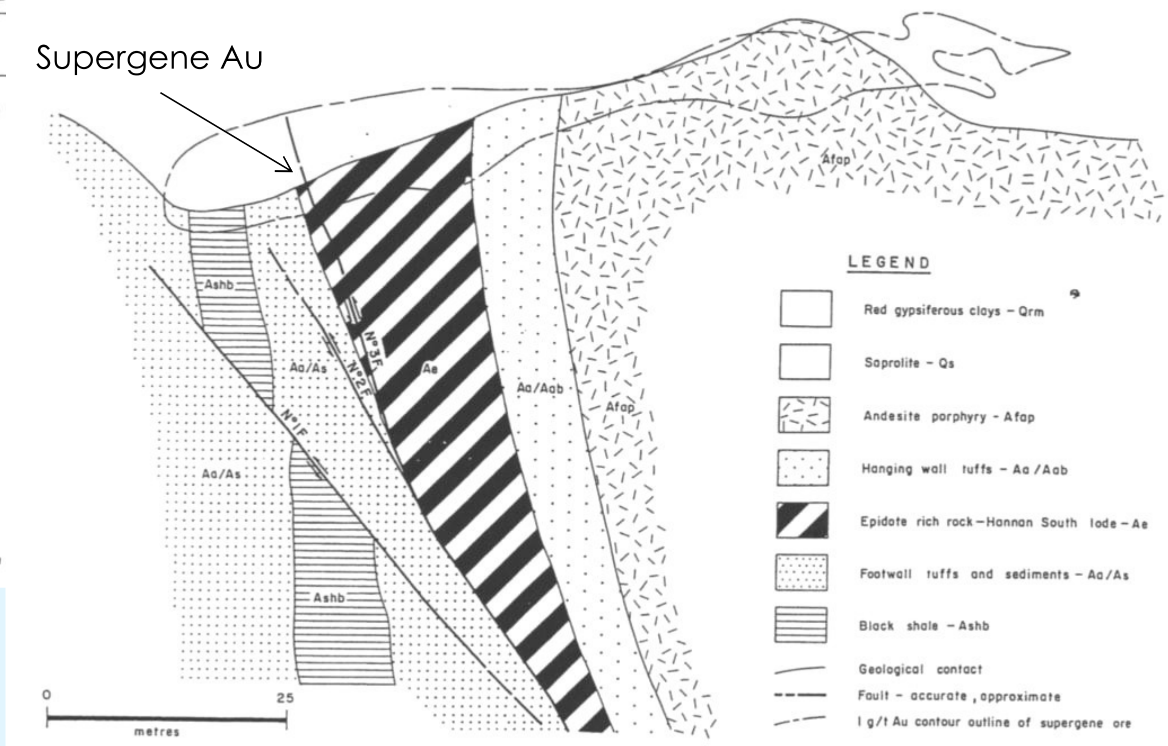
MIOCENE TO RECENT HISTORY

- Recent changes in climate have resulted in:
  - Reduced leaching;
  - Drop in water tables;
  - Dehydration of profiles;
  - Increased salinity and acidity of groundwater;
  - Precipitation of calcite in the soil; and
  - Inverted topography.



HANNONS SOUTH GOLD DEPOSIT

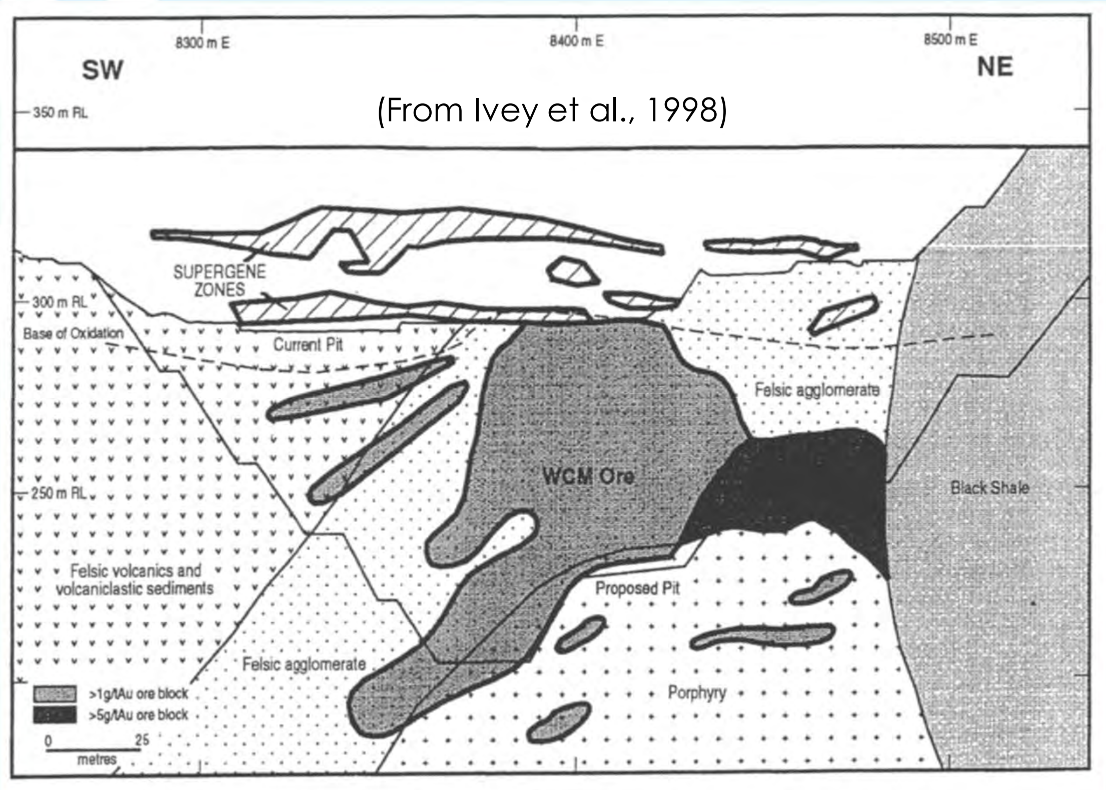




- Supergene Au has been mobilized laterally away from the primary sulphide deposit

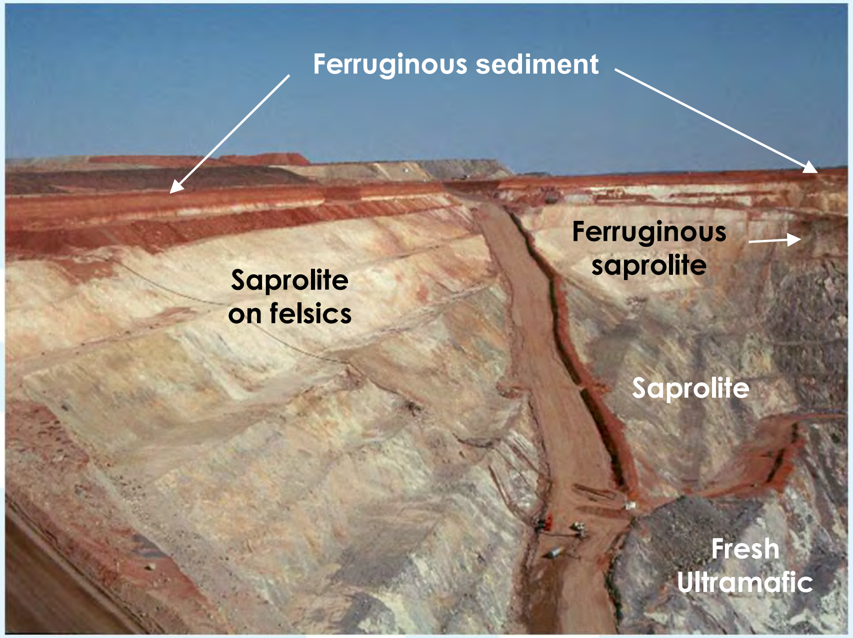
(From Schiller & Ivey, 1990)

BINDULI GOLD DEPOSIT

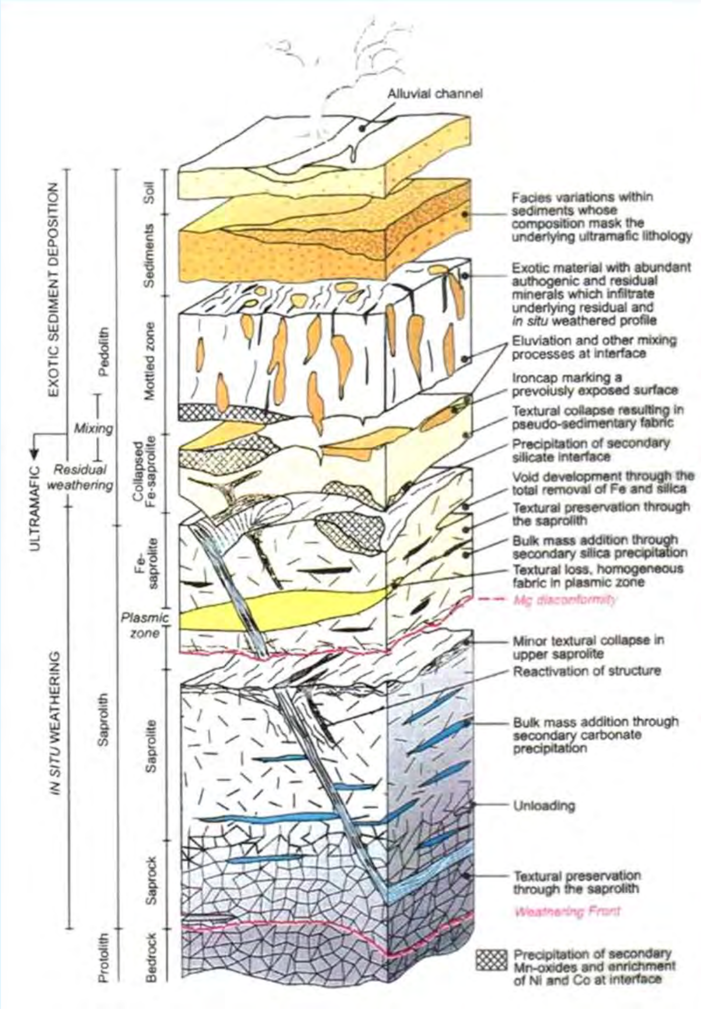


- Two supergene blankest formed at Binduli, perhaps in response to fluctuating water tables

SUPERGENE NICKEL – MT. KEITH, WESTERN AUSTRALIA

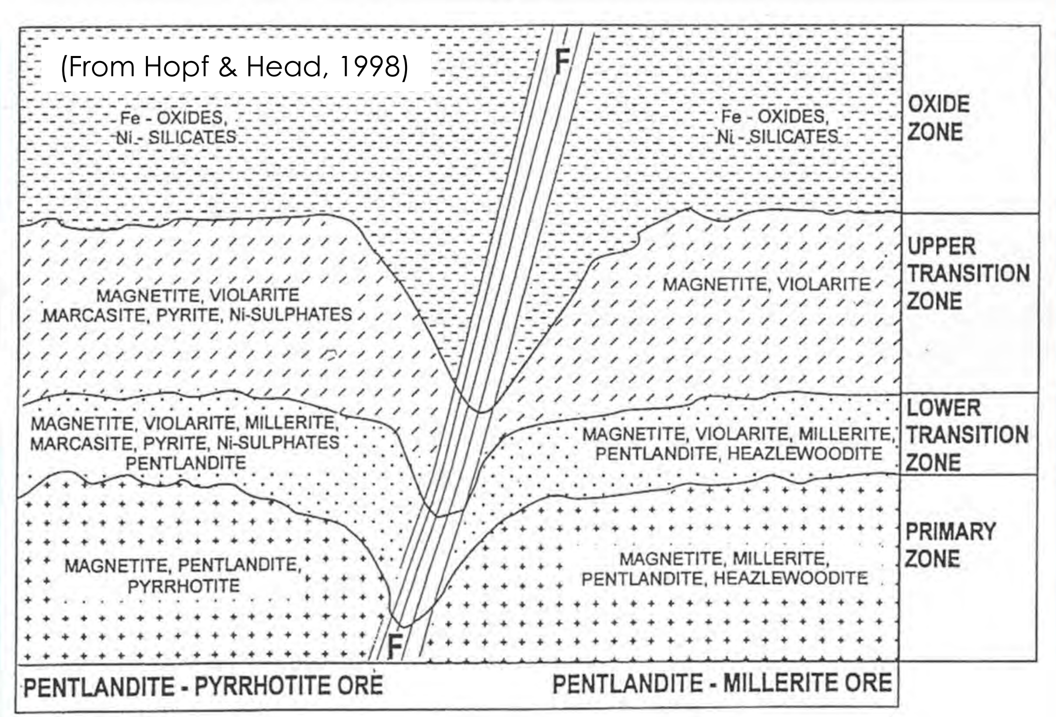


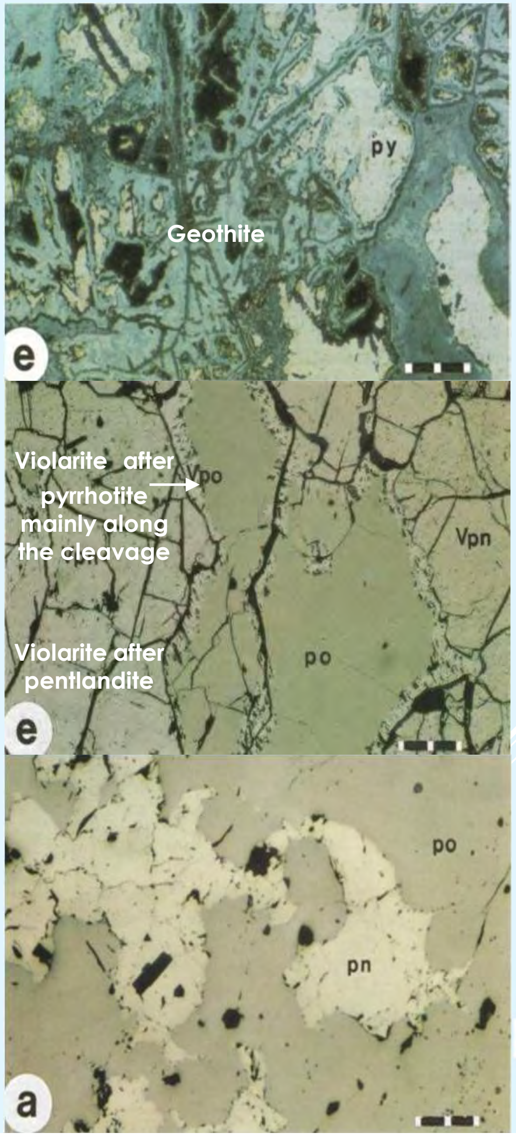
- The regolith profile at Mt Keith is complex and complicated by the presence of overlying sediments
- Although supergene Ni occurs at Mt. Keith, production was from the fresh sulphide zone



(After Brand & Butt, 1998)

WEATHERING OF NICKEL SULPHIDES





(From Roberts & Travis, 1986)

- Ni-gossans may be identifiable geochemically
- Remnant textures may be preserved deeper in the profile

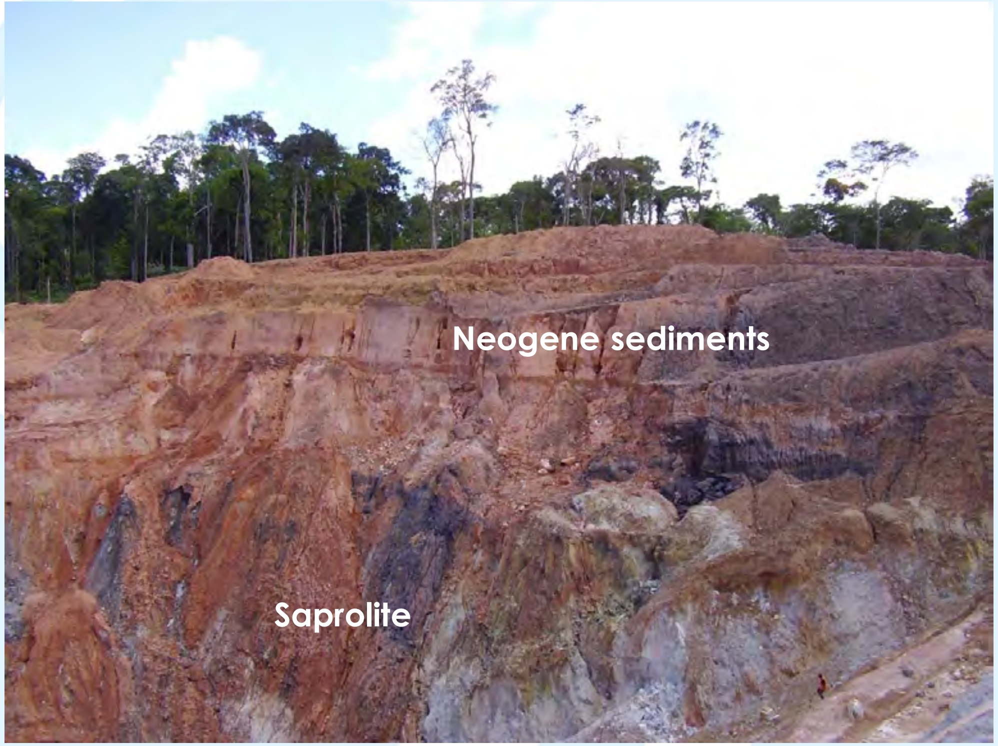
CASE STUDY 1 CONCLUSIONS

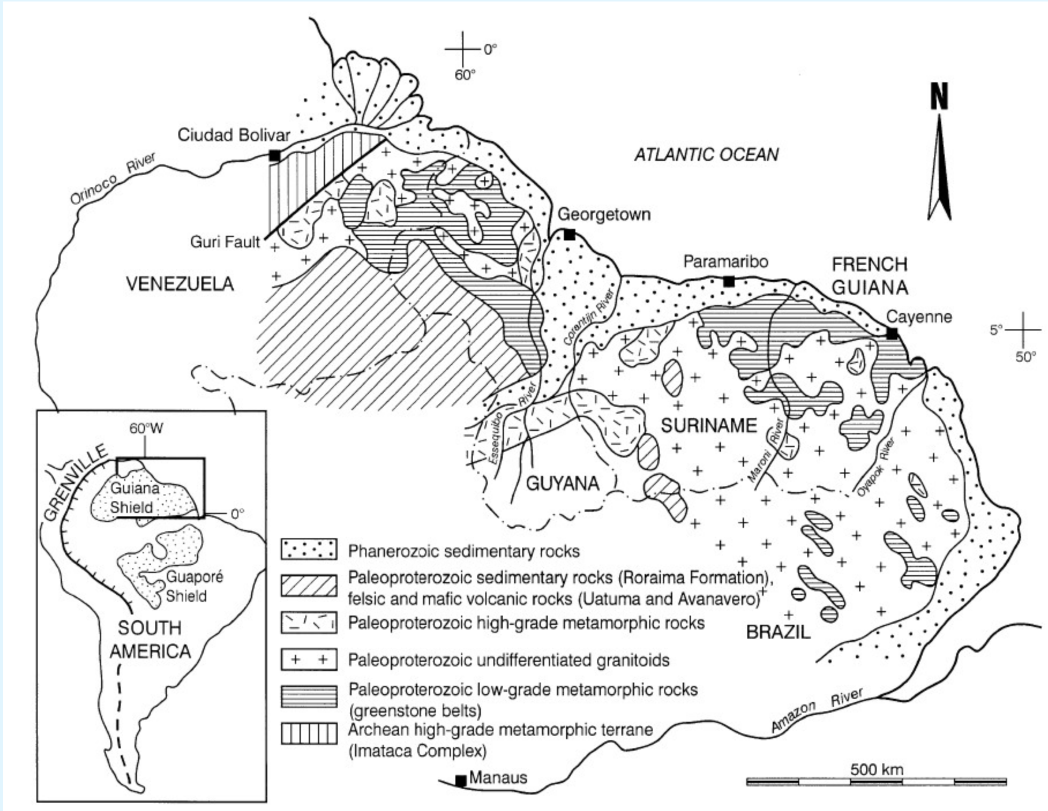
- The southern Yilgarn Craton of Western Australia has experienced a complex weathering and landscape evolution history involving:
  - Deep weathering;
  - Incision of the weathered profile followed by in-fill of paleochannels;
  - Continued weathering of bedrock areas and paleochannels; and
  - A shift to an arid climate and continued erosion.
- Near-surface mineral deposits have undergone oxidation and remobilization by both mechanical and chemical means resulting in:
  - Depletion of metals in parts of the regolith profile;
  - The generation of transported false geochemical anomalies; and
  - Precipitation of metals during supergene enrichment, sometimes laterally displaced from the primary mineral deposit

CASE STUDY 2 – SURINAME, SOUTH AMERICA

Wet tropical weathering environment

GUIANA SHIELD GEOLOGY



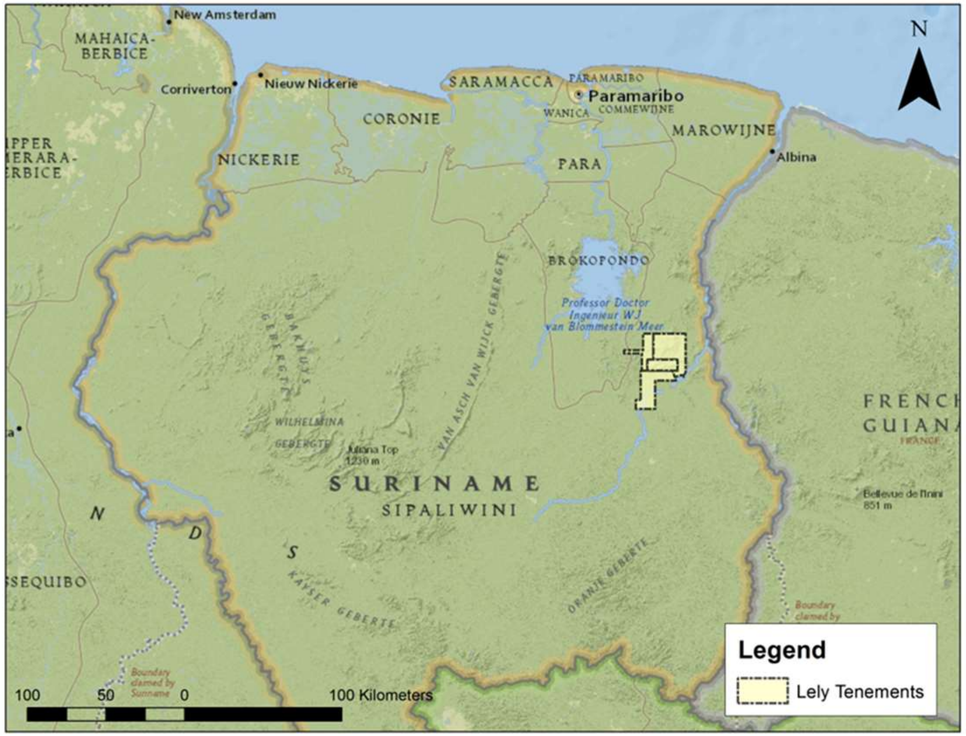


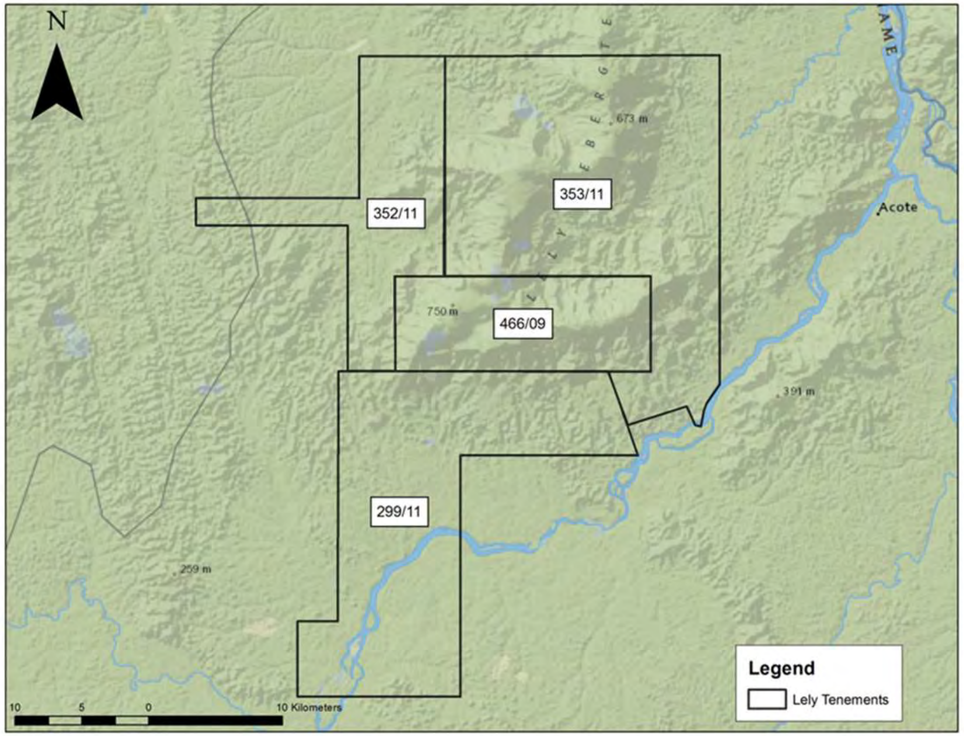
- Deeply weathered Precambrian craton, with profiles locally truncated and in part covered by unconsolidated recent sediments near the coast

(From Voicu *et al.*, 2001)

LELY PROJECT

GRASSALCO
We bring prosperity to the surface



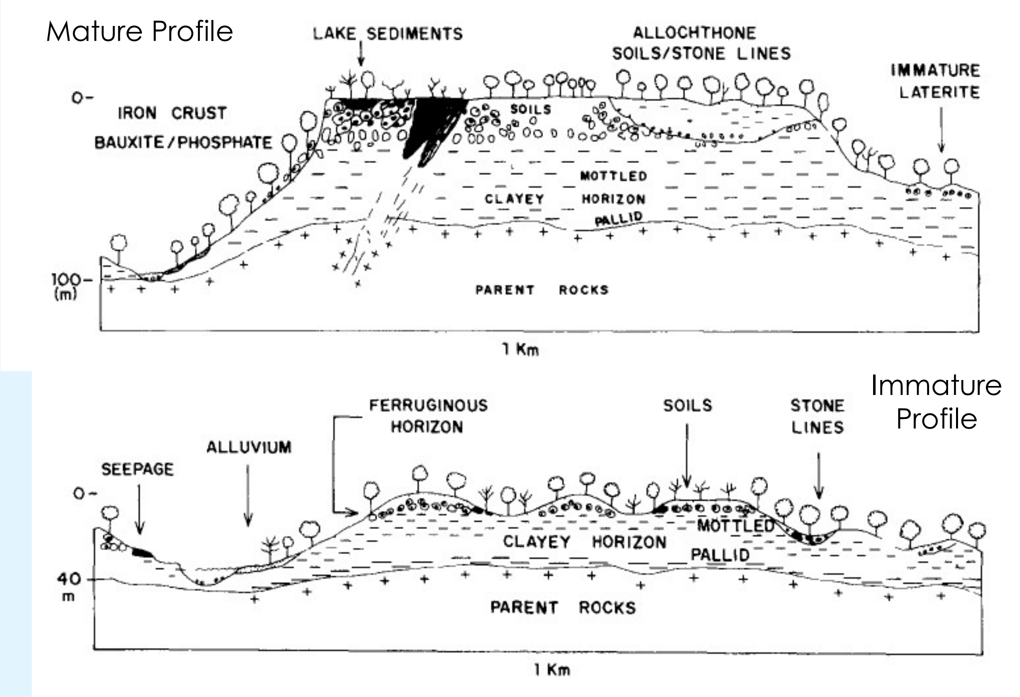


- The Lely mountains consist of the remnant of an elevated plateau

TELE GEO

SOUTH AMERICAN LANDSCAPE EVOLUTION

- Development of a complete lateritic profile on a mature landscape (peneplain) during the Paleogene
  - Velhas cycle in central Brazil
  - Associated with a high water table
- Incision of the Velhas surface during the Pleistocene
  - Fall in relative groundwater levels
  - Degradation of the lateritic duricrust through soil formation (ferralitic soils)



LELY MOUNTAINS FERRICRETE PLATEAU

- A thick band of ferricrete caps the Lely plateau and has prevented erosion of the underlying pedolith and saprolith

FERRALITIC SOILS

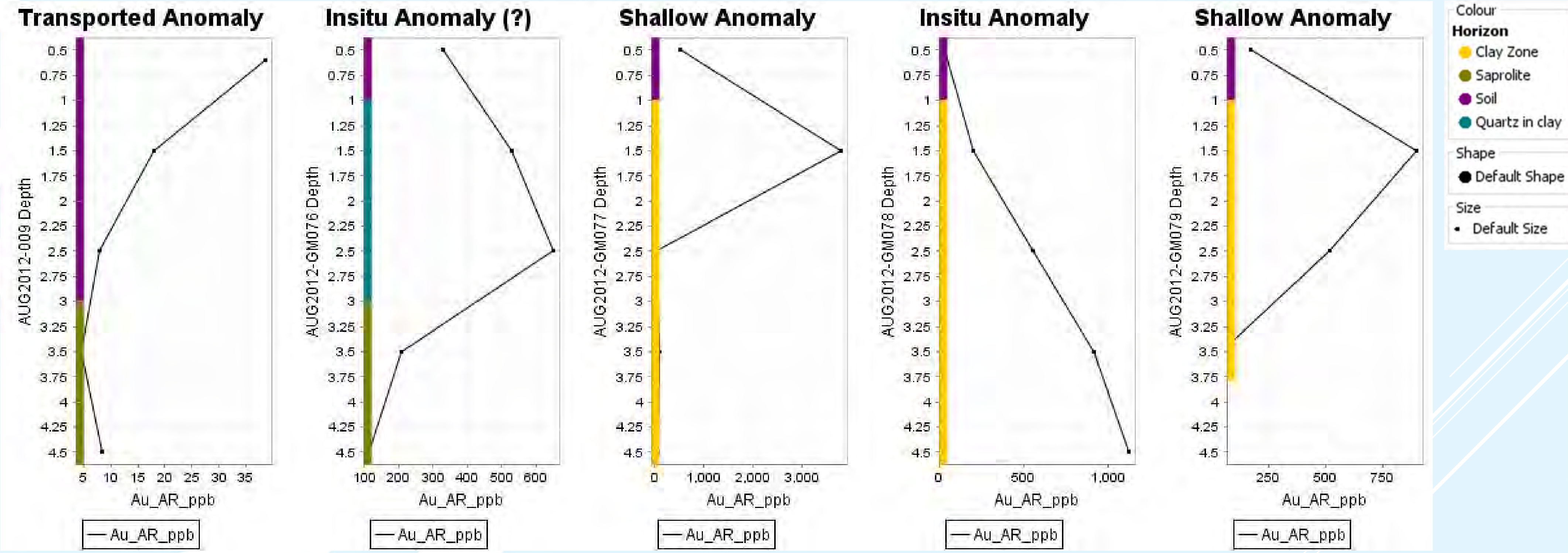
- Ferralitic soils develop on all substrates

SOIL SAMPLE FOLLOW-UP

- Soil samples followed up by hand augering down to bedrock (saprolite)

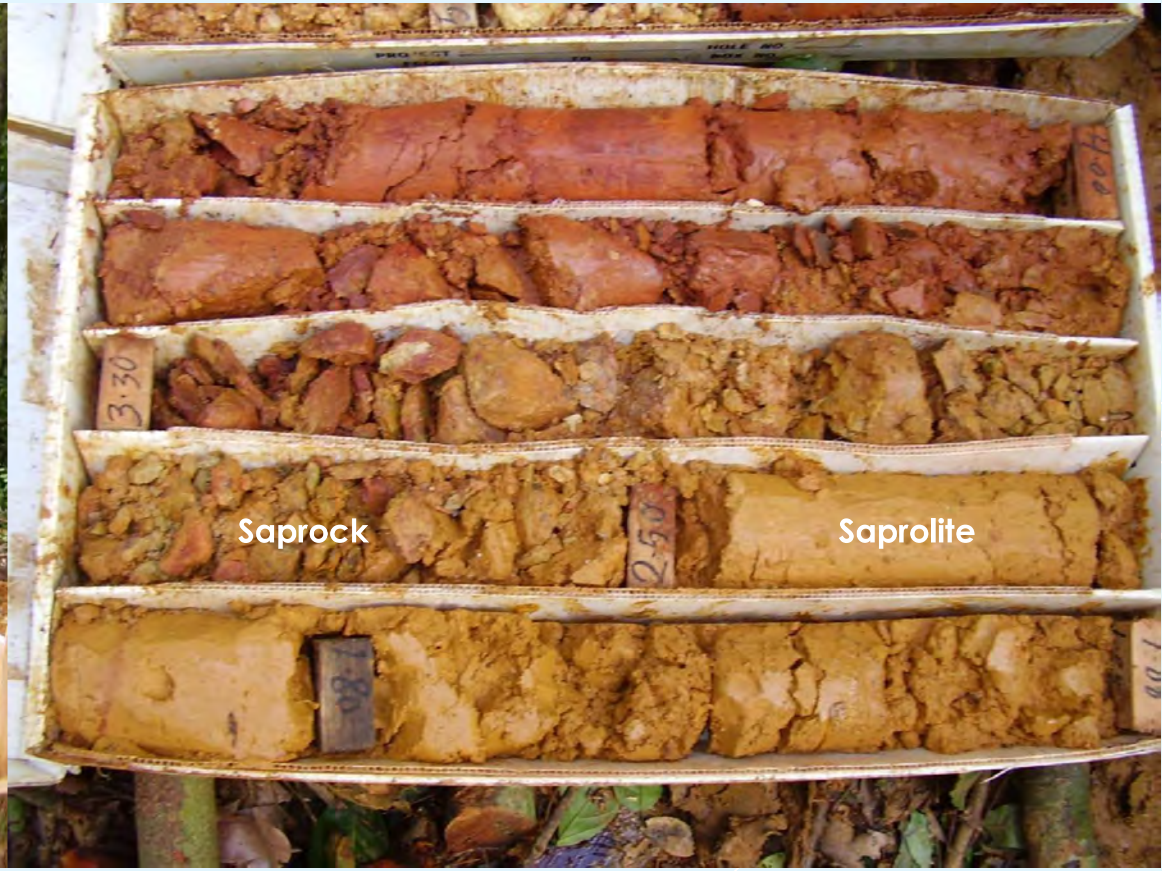
TELE GEO

INTERPRETATION OF AUGER GOLD DATA



- Whether a auger sample is a viable *in situ* exploration target requires the collection of data from a profile and an interpretation of regolith

DIAMOND DRILLING



- Drilling from ridges allowed access for man-portable drill rigs and drilling directly into saprolite and saprock

TELE GEO

CASE STUDY 2 CONCLUSIONS

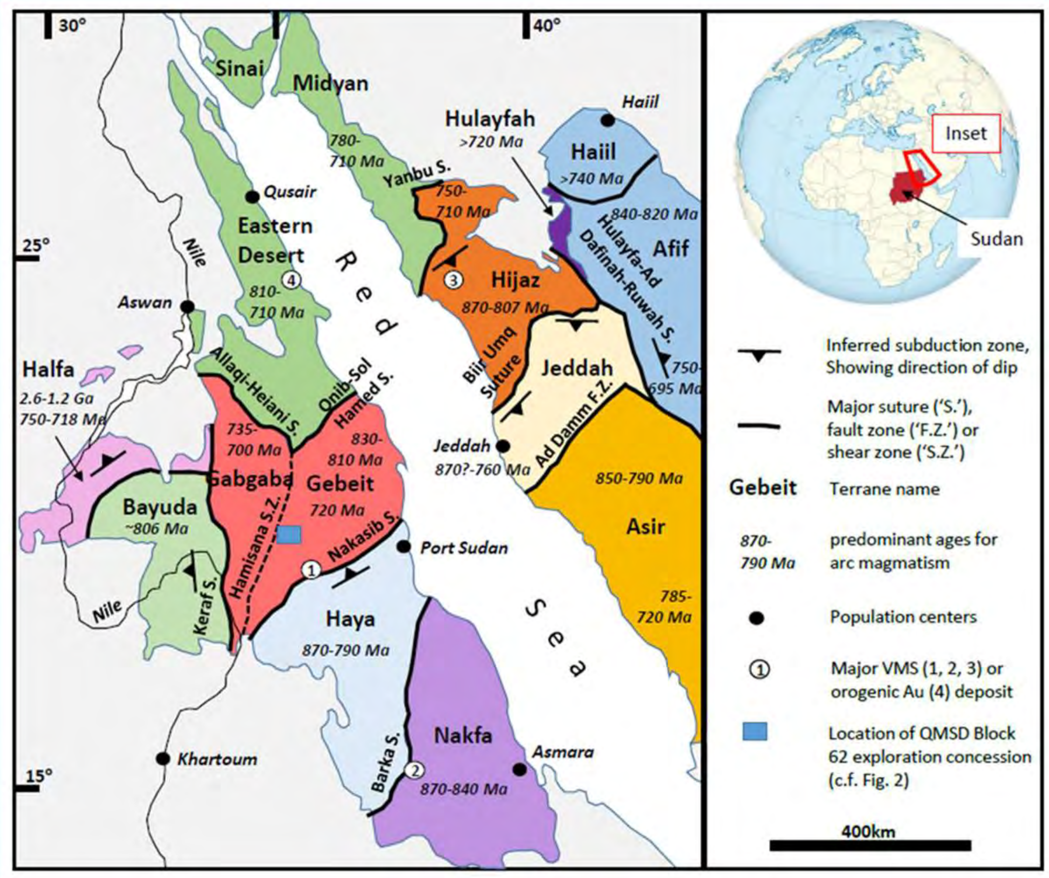
- Northern South America contains remnants of a Mesozoic plateau that was locally covered with ferricrete and which subsequently preserved the underlying regolith profile (including bauxite) to form inverted topography.
- The ferricrete dominating the top of the Lely plateau is not locally-derived and does not contain anomalous gold.
- Anomalous gold in pedolith and saprolith samples only occurs at surface on the flanks of Lely Mountain where the ferricrete capping has been eroded away.
- It must be established whether geochemical data from ferrilitic soils reflect the underlying bedrock below a stone line; down hole auger profiles must be collected.

CASE STUDY 3 – SUDAN, AFRICA

Arid environment

ARABIAN-NUBIAN SHIELD GEOLOGY

- The Jebel Ohier porphyry Cu-Au deposit formed at ca 730 Ma in the Proterozoic Arabian-Nubian Shield located in the Red Sea Hills of northeast Sudan.
- Cu-Au mineralization consisting of magnetite-pyrite-chalcopyrite-bornite is associated with a quartz vein stockwork.
- Supergene Cu is developed but it is Au shedding from the deposit that has been mined since ancient (Nubian) times.



(From Bierlein et al., 2016)

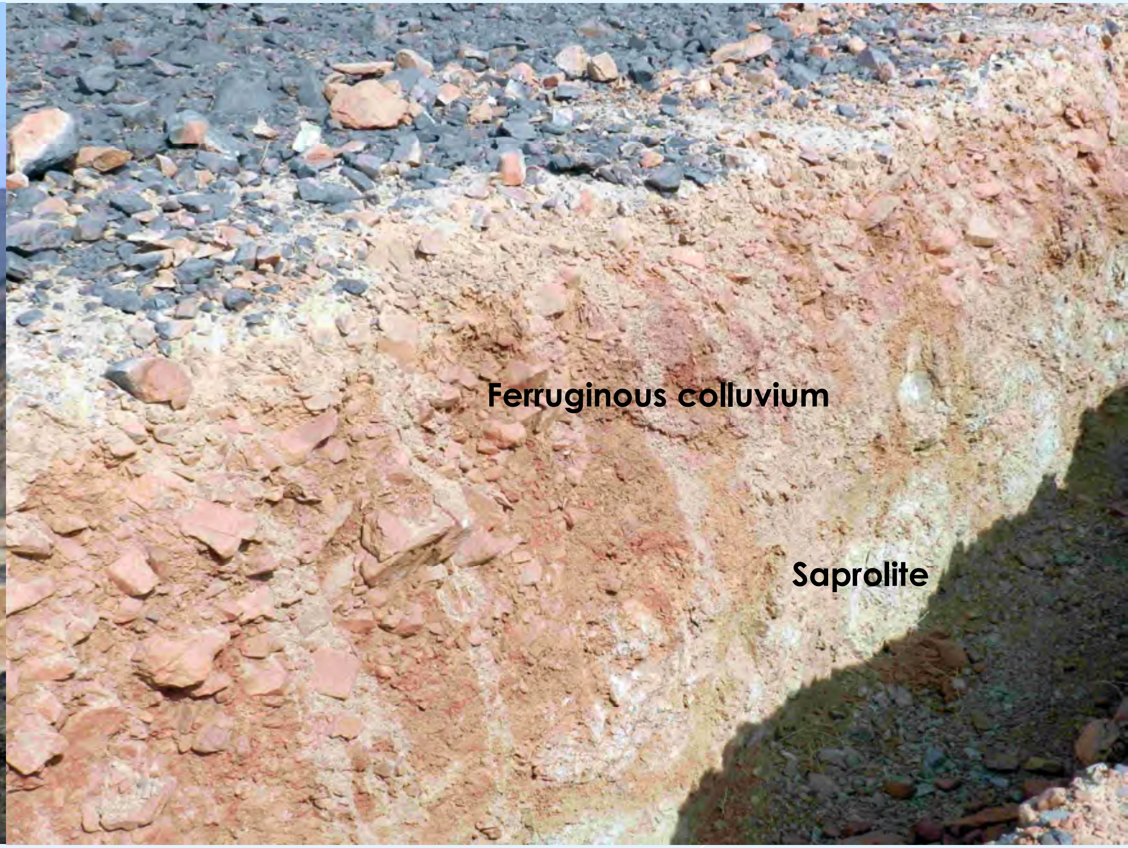
RED SEA HILLS TOPOGRAPHY

- Present day topography can be related to flank uplift related to the opening of the Red Sea during the Neogene.
- No soil development per se (lithosols), with valleys choked by aeolian sand.
- Relatively fresh rock occurs along topographical highs.
- The area is traversed by numerous wadis that contain water infrequently.

EXPOSED BEDROCK

- Outcrop varies from relatively fresh towards the Red Sea to deeply weathered further inland, particularly in the vicinity of the Jebel Ohier porphyry Cu-Au deposit

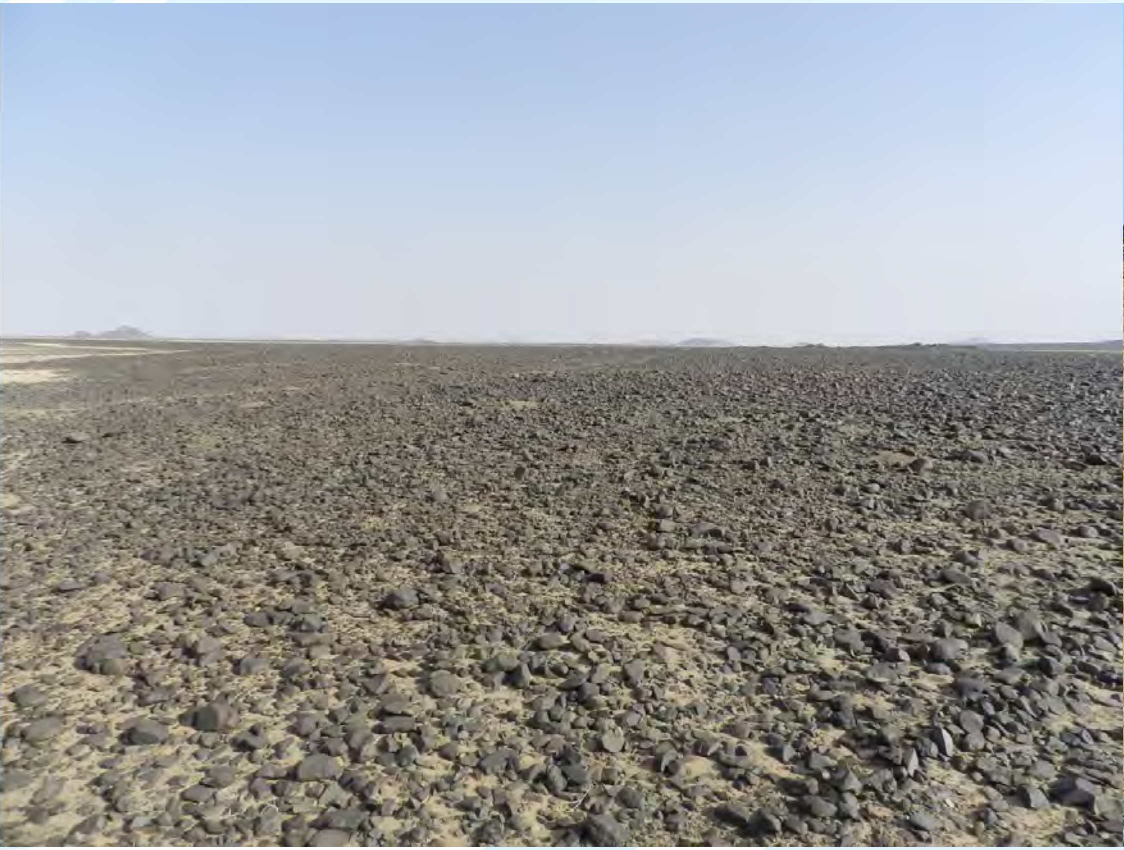
COLLUVIAL SOILS



- Near-surface material is transported in areas with relief; trenched for access to bedrock

TELE GEO

DEFLATIONARY PLAIN



- Clasts covered by desert varnish sit directly on saprock

DESERT VARNISH

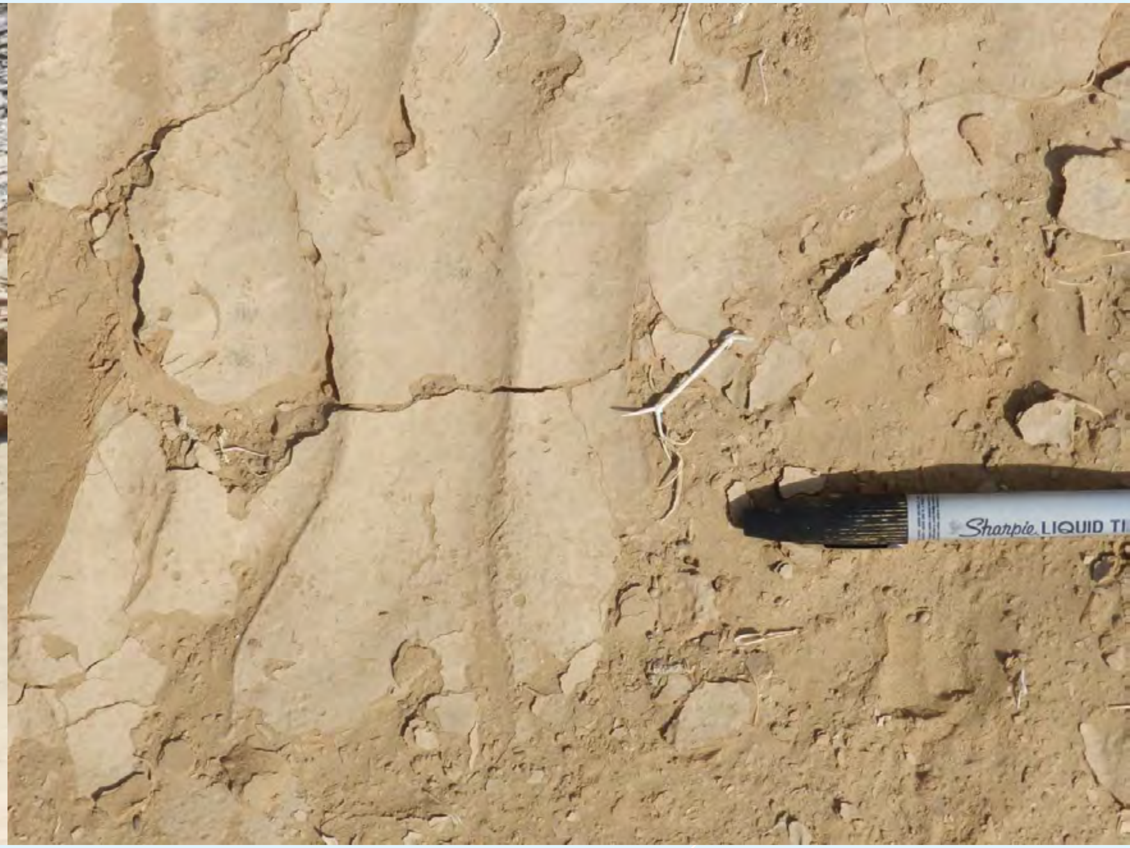
- Rock clasts are covered with a microscopic layer of Mn & Fe oxides +/- clay that has been hardened by the heat to form a desert varnish

TELE GEO

STREAM SEDIMENT SAMPLING

- Poorly consolidated stream sediment occurs along wadis in traps behind small shrubs

OVERBANK SEDIMENTS



- Overbank deposits are well developed after major rainfall events, and show evidence of water transport

AEOLIAN SAND

- By contrast, the aeolian sand is unconsolidated!

CASE STUDY 3 CONCLUSIONS

- Although deeply weathered in places, geologically recent exhumation of bedrock in the region of the Red Sea hills of northern Sudan has exposed fresh rock and saprolite.
- Deep weathering is facilitated by the presence of primary sulphides in the bedrock, for example at the Jebel Ohier porphyry Cu-Au deposit.
- Colluvium is widespread and overprinted by weathering to produce ferruginous deposits; mass wasting may be facilitated by the presence of hydrothermal alteration in the bedrock.
- In spite of the arid nature of the region, stream sediments generated by intermittent stream flows provide an effective and easily attainable sample medium for regional geochemical surveys.

SUMMARY

- Exploration geochemistry in deeply weathered environments requires an understanding of regolith materials and landscape evolution.
- Most metals are unstable at the Earth's surface and will be both chemically and mechanically transported during weathering.
- Supergene process may produce both zones of metal enrichment and metal depletion, sometimes laterally-displaced from the primary mineral deposit.
- Changes in climate and erosional base level result in modification to, and truncation of, regolith profiles.