Pasture Yields in Oil-Contaminated Soils from the Petroleum Producing Region of Southeastern Mexico

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BACKGROUND

- In the southern Gulf of Mexico region there are ~600 Ha (1,500 acres) of contaminated pasture lands
- The mineral resource is a public good, but on private property
- The property owner does not receive royalties from the petroleum production, plots are small
- Social conflicts due to contamination, inadequate clean-up
- Important to understand relationship between petroleum concentration and pasture production in different kinds of soil

→cleanup criteria

→remediation strategies and techniques

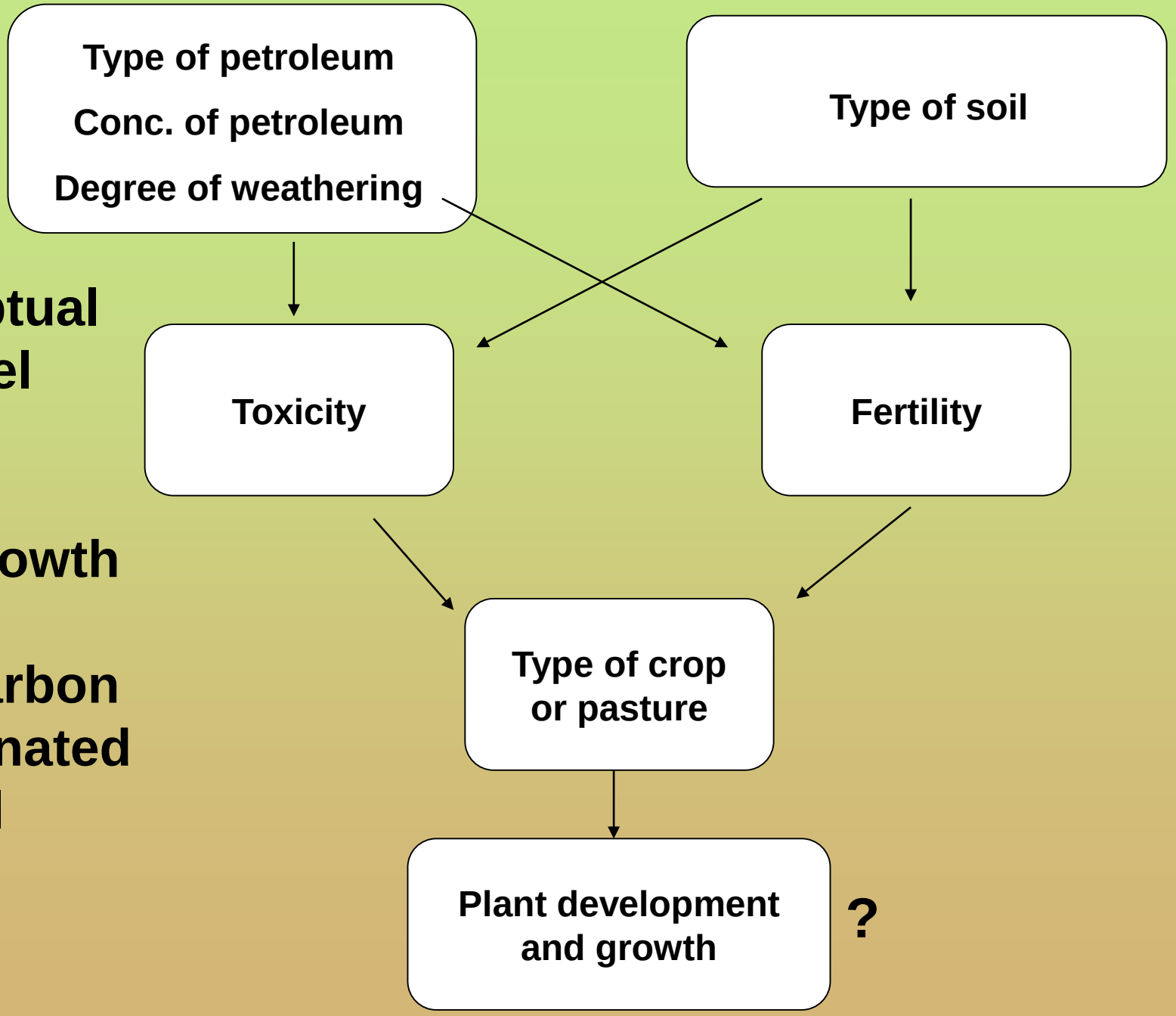
SISTEMATIC EVALUATION

- **Previous study using 5 soil types common in petroleum producing region of SE Mexico, and 4 petroleum types**
- **Contamination of soil at different concentrations**
  - **Measurement of acute toxicity (Microtox), and subchronic toxicity (28 d earthworm)**
  - **Measurement of impacts to soil fertility: water repellency, soil moisture, compaction, complemented with *in situ* weathering experiments**
- **Current study looks at actual pasture yields at different concentrations**

UJAT

Conceptual Model

Plant Growth in Hydrocarbon Contaminated Soil



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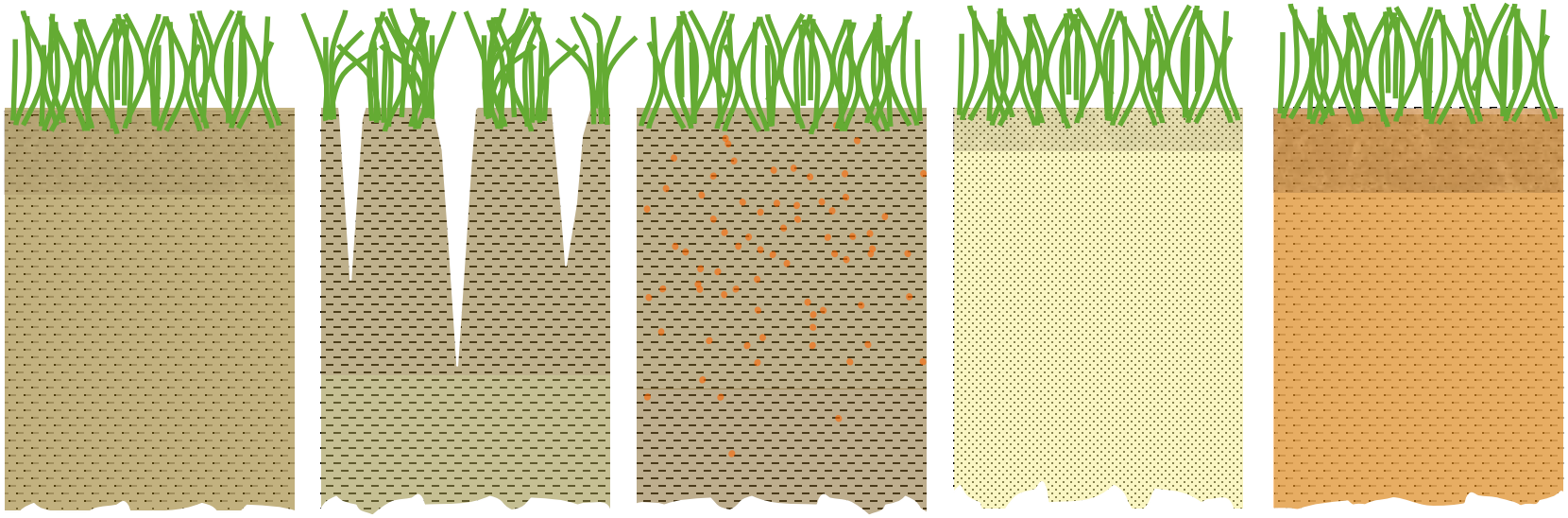


FAO:	FLUVISOL	VERTISOL	GLEYSOL	ARENOSOL	ACRISOL
USDA:	FLUVENT	VERTISOL	GLEYSOL	PSAMMENT	ULTISOL

• rich alluvial soil • medium texture • good internal drainage • aerobic conditions	• gilgai microrelief • high clay content • smectite clays: high shrink-swell capacity • poor internal drainage	• seasonally flooded • high clay content • smectite clays: high shrink-swell capacity • poor internal drainage	•coastal sandy soil •very low clay and silt content •excessive internal drainage	• weathered soil from Pleistocene Terrace • sandy-clay texture • clays: kaolinites and Fe/Al oxides, – no shrink swell capacity
cacao, bananas, maize, pasture, sugarcane, chilies, tomatoes, etc.	pasture, some maize	pasture, savannah oak (Macuilís)	pasture, coconuts	pasture, pineapple, citrus, sugarcane

Soils Used in Study

PREVIOUS OBSERVATIONS

Impacts of petroleum contamination in soil are affected by:

- **Type of Petroleum:**
  - **→lighter crudes are more acutely toxic (but temporary)**
  - **→heavier crudes are more likely to impact fertility:**
    - **polar groups lead to formation of HC laminates**
      - **→water repellency/soil moisture**
    - **polar groups appear to form agglomerations**
      - **→soil compaction**
    - **recovery may be very, very slow**

Formation of Oily Laminates

Non-polar Hydrocarbons

Slightly polar Hydrocarbons

Natural organic material (charged/polar/non-polar)

Mineral Fraction (negative charge)

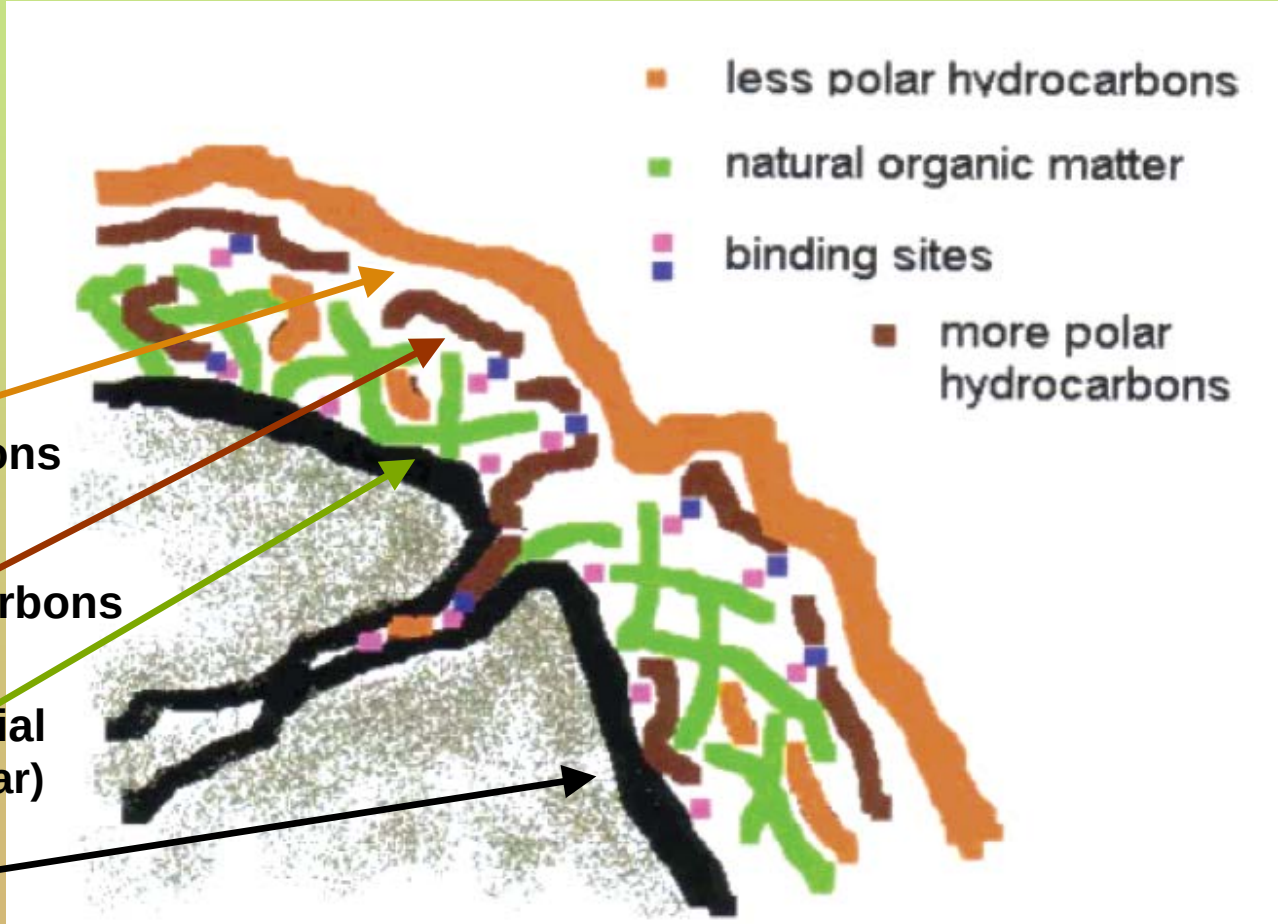
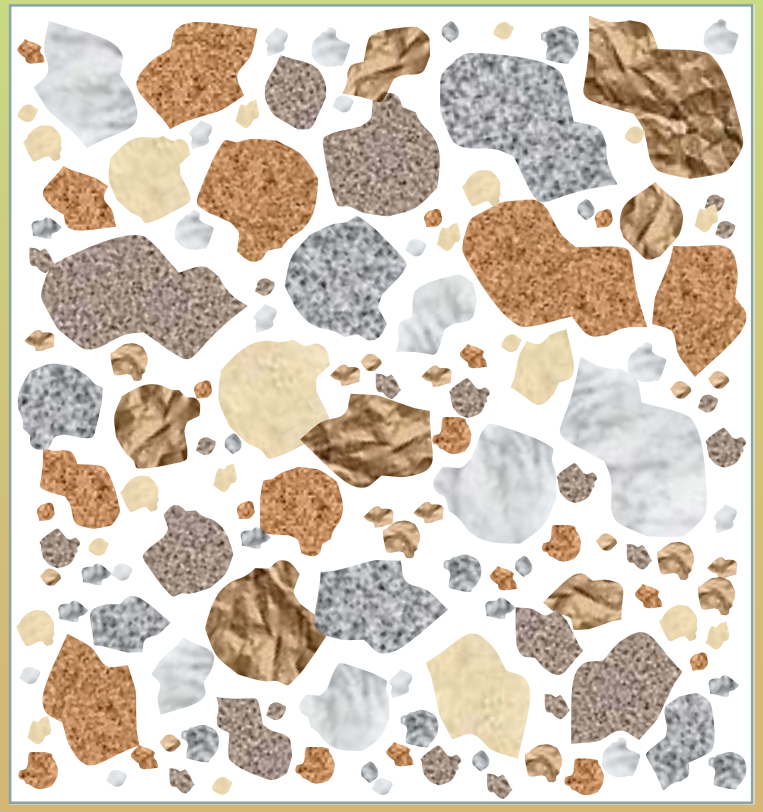


FIGURE 6. Model of the interaction between natural soil organic matter (NOM) and the diagenetic products of petroleum contamination that generates water repellency.

From Litvina *et al.* 2003

Formation of Oily Agglomerations

Agglomeration of soil particles by weathered or extra-heavy petroleum



- Un contaminated soil particles

Formation of Oily Agglomerations

Agglomeration of soil particles by weathered or extra-heavy petroleum

- **Oil contaminated soil particles**
- stickiness of heavy oil causes particles to stick together
- Agglomeration into larger particles
  - Loss of available surface area
  - Loss of field capacity
  - Loss of cation exchange capacity
- **Leads to compaction and loss of porosity**
  - Reduction in water infiltration
  - Reduction in gas exchange
  - Reduction in root penetration

PREVIOUS OBSERVATIONS

Impacts of petroleum contamination in soil are affected by:

- **Type and abundance of soil clays:**

  smectites: high surface area, expansive (in brown-grey soils)

  →reduce toxicity (low bioavailability)

  →very little water repellency (lots of reactive surface area)

  →very little compaction (shrink-swell properties)

  non-smectites: kaolinites, amorphous Fe/Al oxides lower surface area, non-expansive (in red-clay soils)

  →med. toxicity (more bioavailability)

  →med. water repellency (less reactive surface area)

  →a lot of compaction (no shrink-swell properties)

PREVIOUS OBSERVATIONS

Impacts of petroleum contamination in soil are affected by:

- **Type and abundance of soil clays:**

  very sandy soils: practically no clay (<1%)

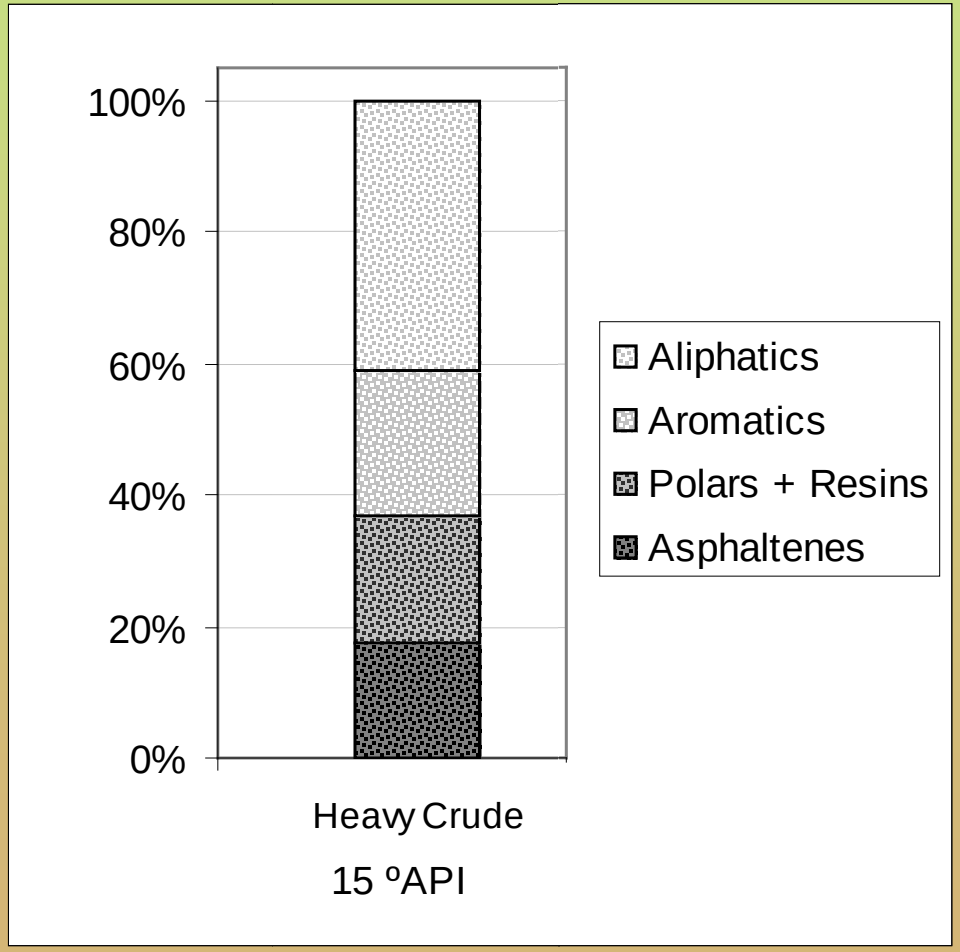
  →med-high toxicity (almost complete bioavailability)

  →high water repellency (very little reactive surface area)

  →no compaction (absence of clays:
  → basically no aggregates)

Methods

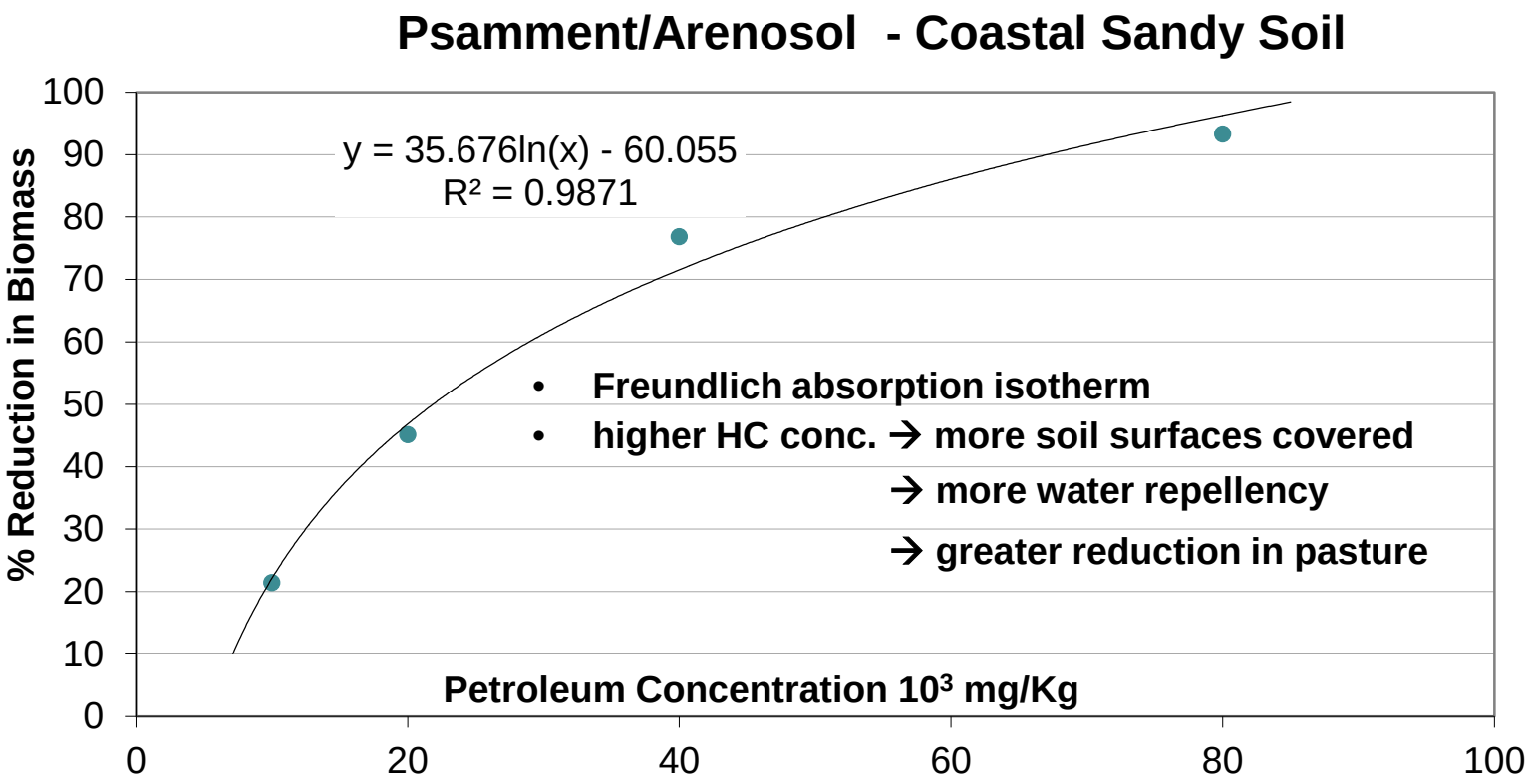
- **Soils contaminated at 1, 2, 4 and 8% with <u>heavy crude</u>, plus uncontaminated control**
  - **simulates old spills**
  - **lots of polar functional groups**
  - **still fluid at ambient temperature**



Methods

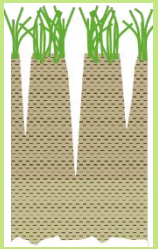
- **Soils contaminated at 1, 2, 4 and 8% with heavy crude, plus uncontaminated control**
- **Soil placed in cut-off 2L plastic containers with perforated bottoms**
- **Planted with Humidicola grass (*Brachiara humidicola*) stolons (5 per treatment unit)**
- **After initial stabilization cut, grass was cut every month down to 7 cm and dried in an oven at 60°C**
- **Reduction in dry biomass averaged over 6 month period and compared to petroleum concentration in all five soils**
- **Dose-response curves generated for each soil**

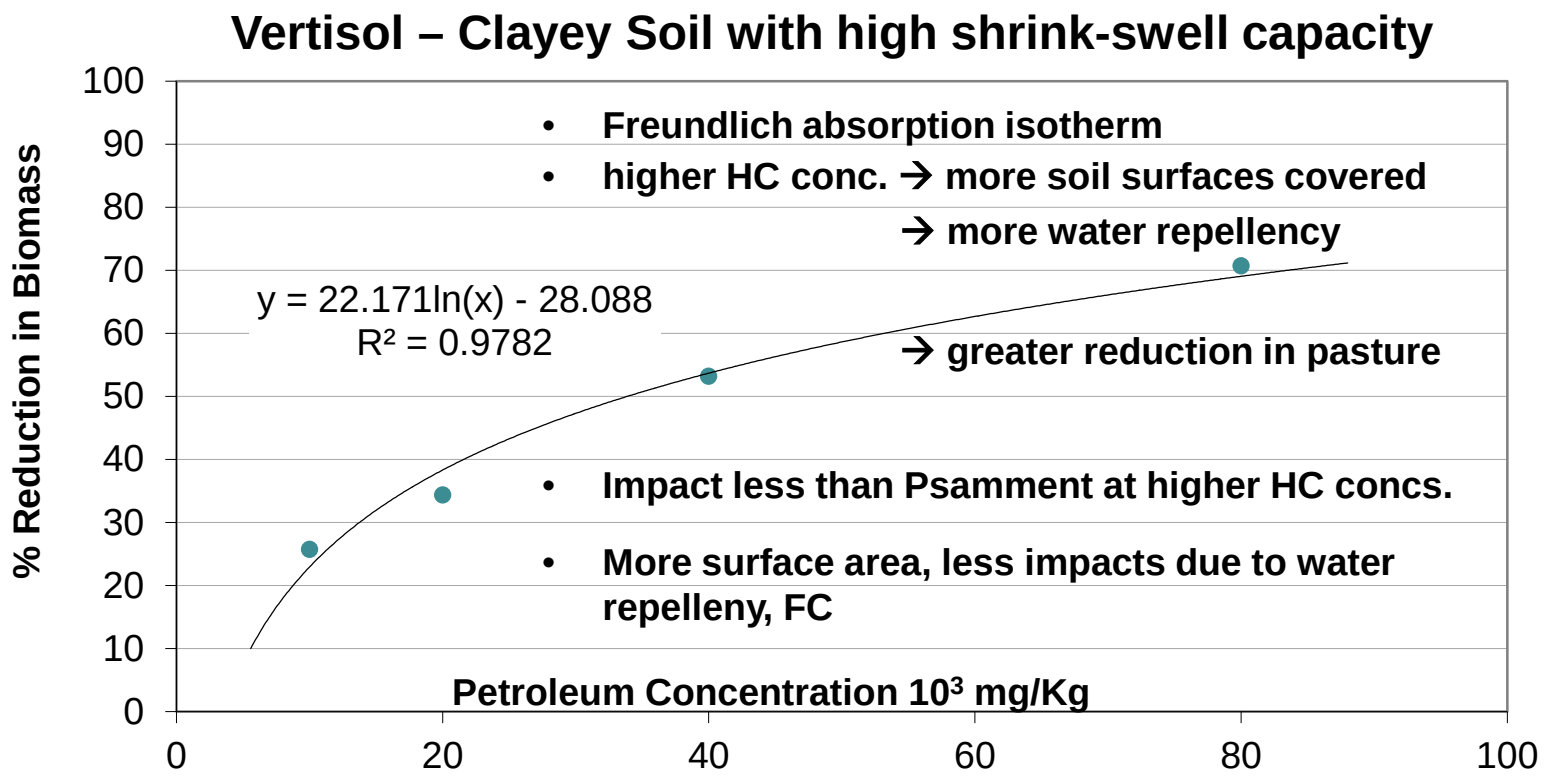
Dose-Response Curve: Psamment



- Practically no clay, no compaction: impacts due to water repellency, FC
- At 1% TPH, 22% pasture reduction! (compare to norms in TX, LA, etc.)
- (original studies on waste pits – bentonite - with base oil – diesel)
- To reduce impacts to only 10%, need to reduce HC conc. to 7,100 mg/Kg

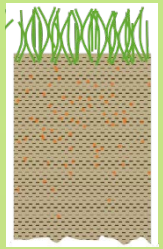
Dose-Response Curve: Vertisol



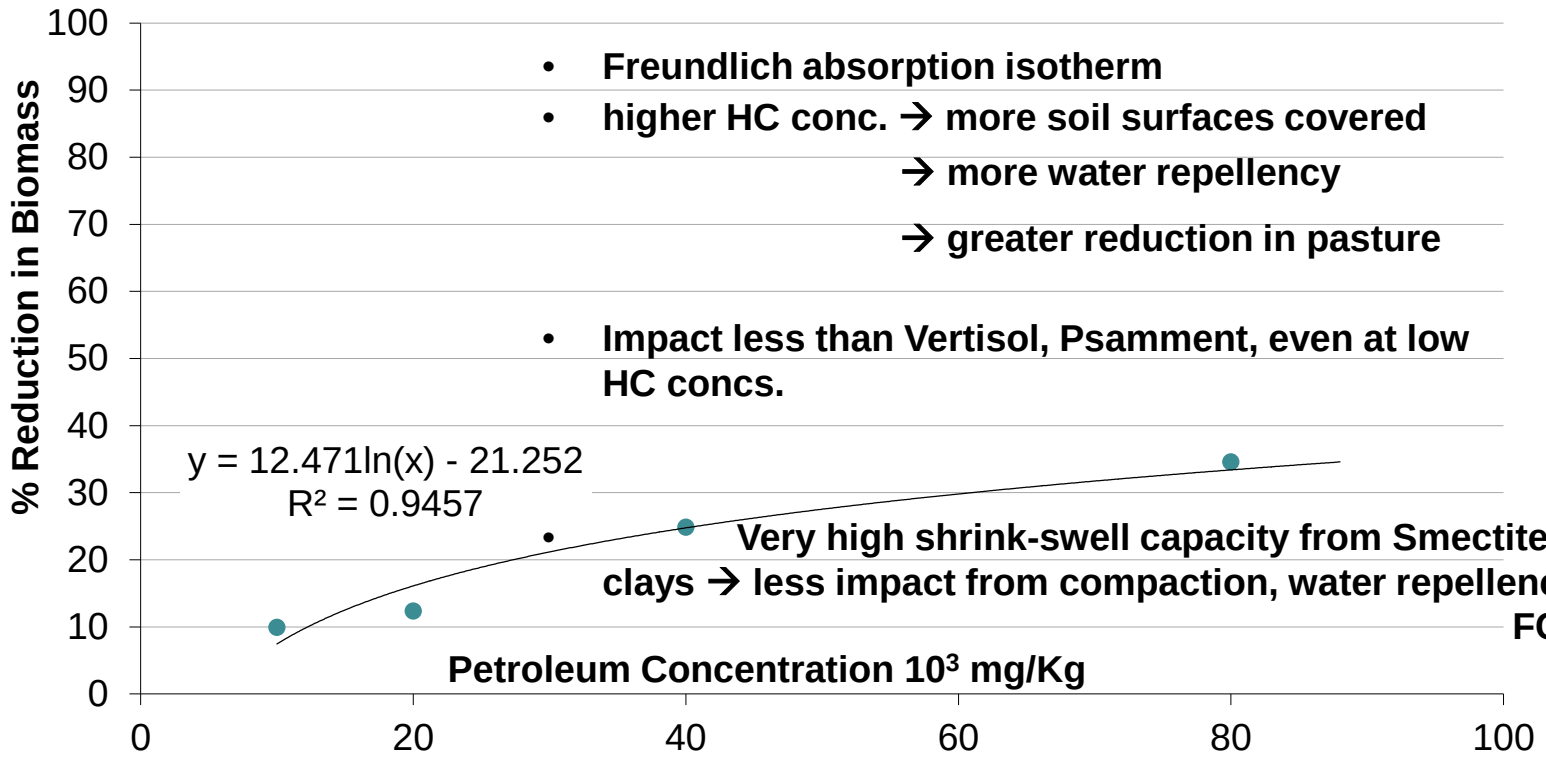


- However with clay may be some compaction also
- At 1% TPH, 23% pasture reduction! (compare to norms in TX, LA, etc.)
- To reduce impacts to only 10%, need to reduce HC conc. to 5,600 mg/Kg
- At low HC concs. impacts are similar to Psamment (some compaction?)

Dose-Response Curve: Gleysol



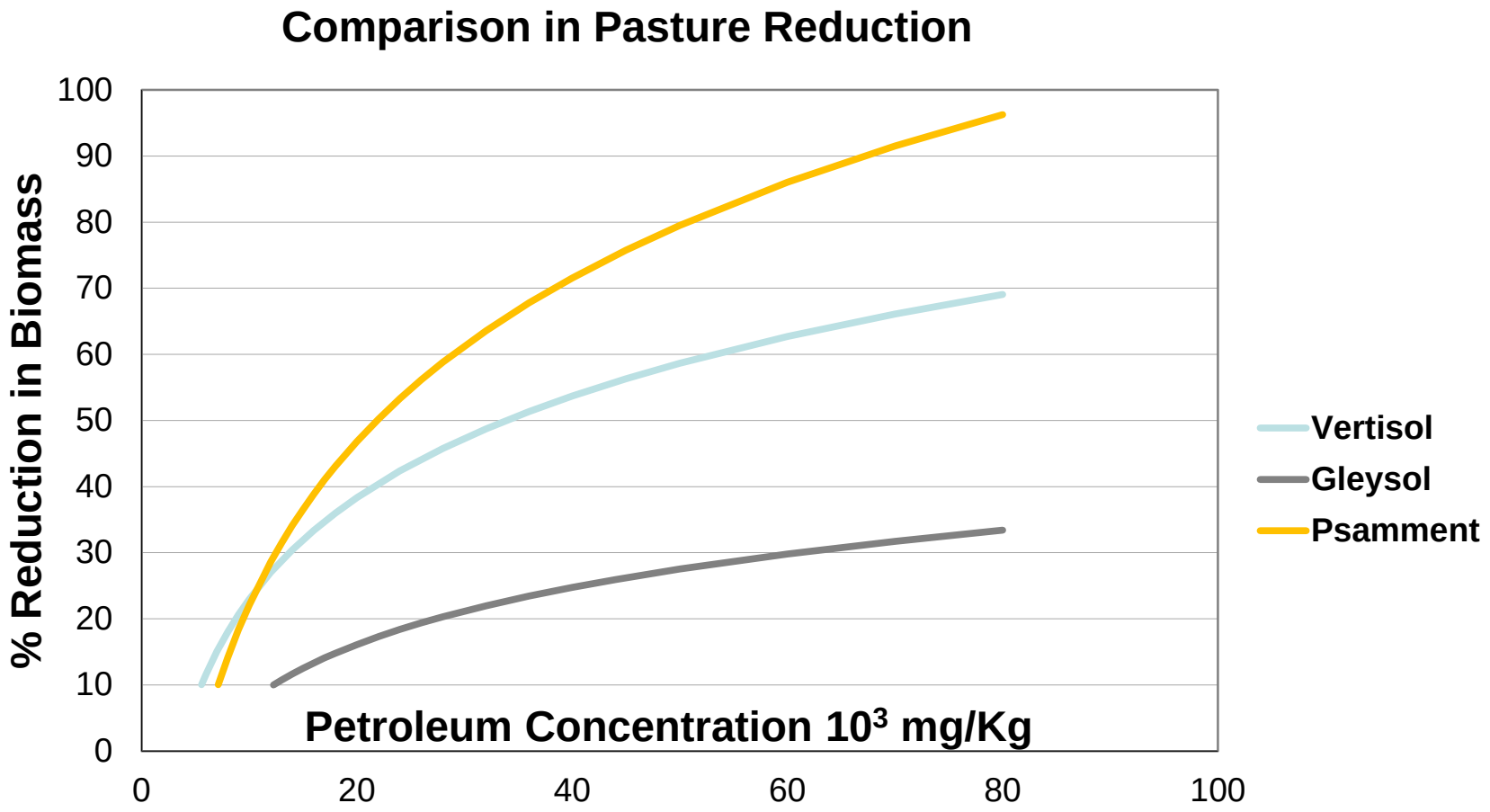
Gleysol – Clayey Marshy Soil



- **Freundlich absorption isotherm**
- **higher HC conc. → more soil surfaces covered**
  → more water repellency
  → greater reduction in pasture
- **Impact less than Vertisol, Psamment, even at low HC concs.**
- **Very high shrink-swell capacity from Smectite clays → less impact from compaction, water repellency, FC, etc.**

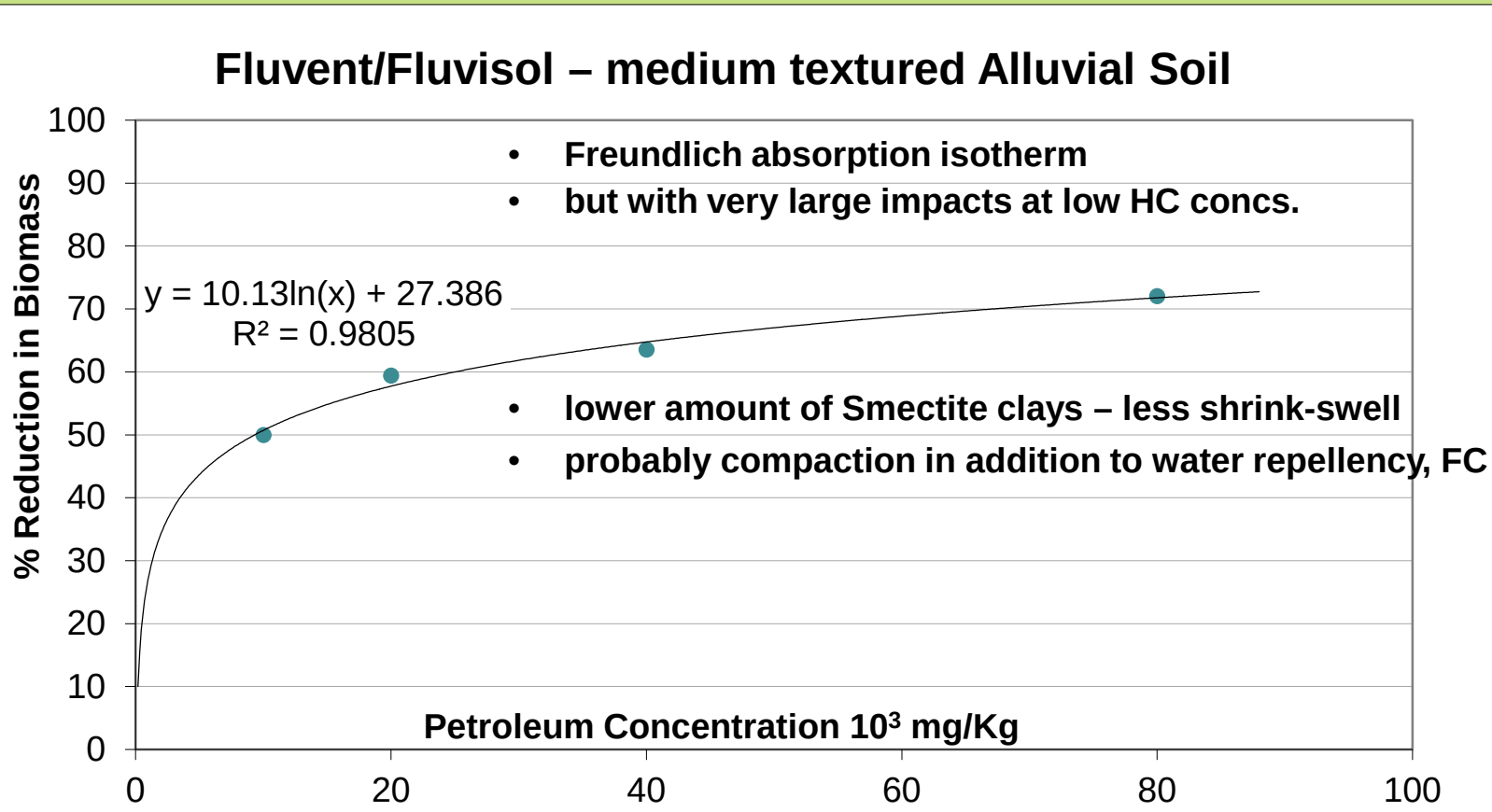
- **At 1% TPH, 7.5% pasture reduction – Ok (similar to waste pits – bentonite)**
- **To reduce impacts to only 10%, need to reduce HC conc. to 12,300 mg/Kg**
- **Very low impacts even at 2% TPH.**

Dose-Response Curves: Clayey vs. Sandy Soils



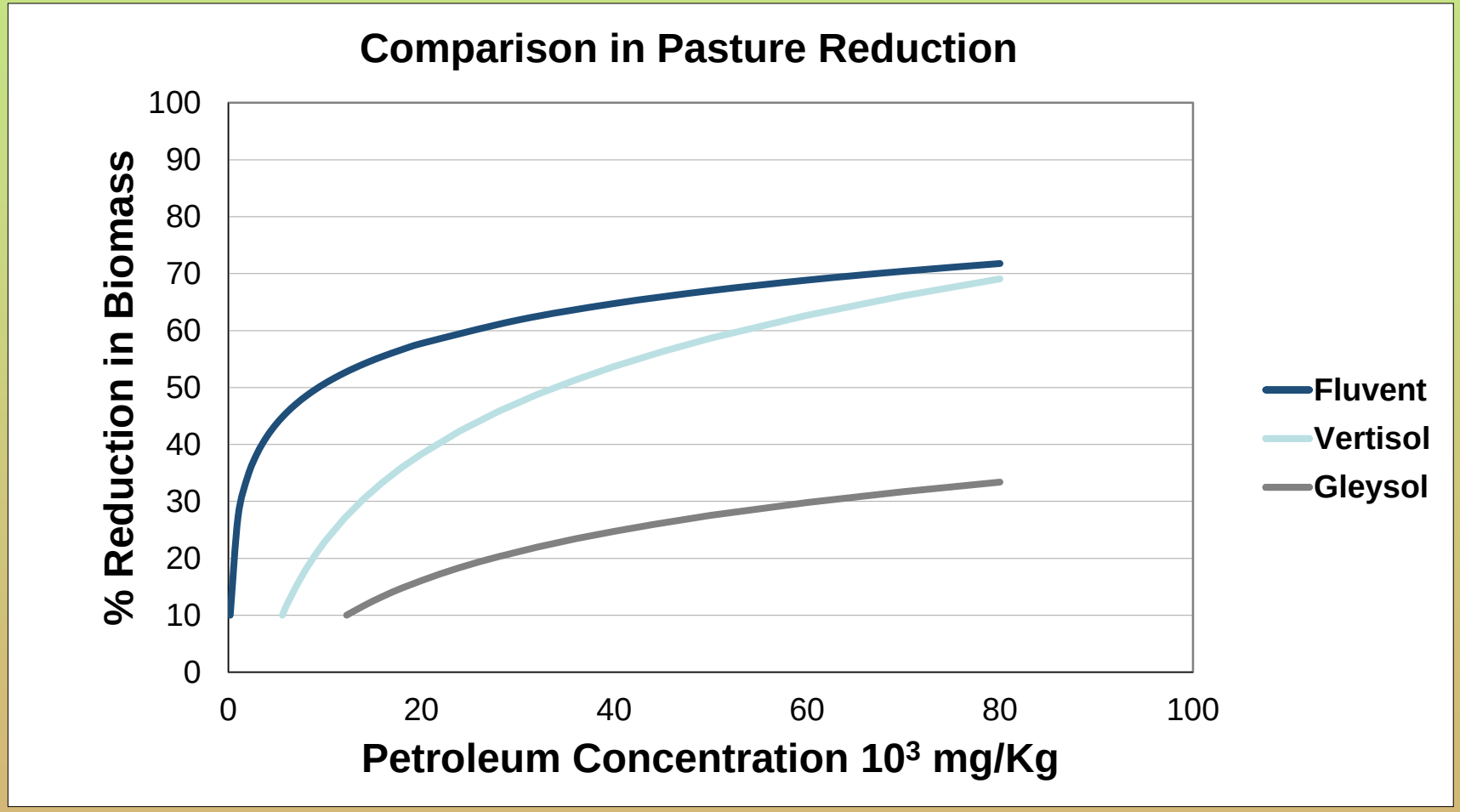
- Freunlich absorption isotherms – surface area impacts?
- Greater impacts in soil with less clay?
- Probably some compaction also in Vertisol, most notable a low HC concs.

Dose-Response Curve: Fluvent



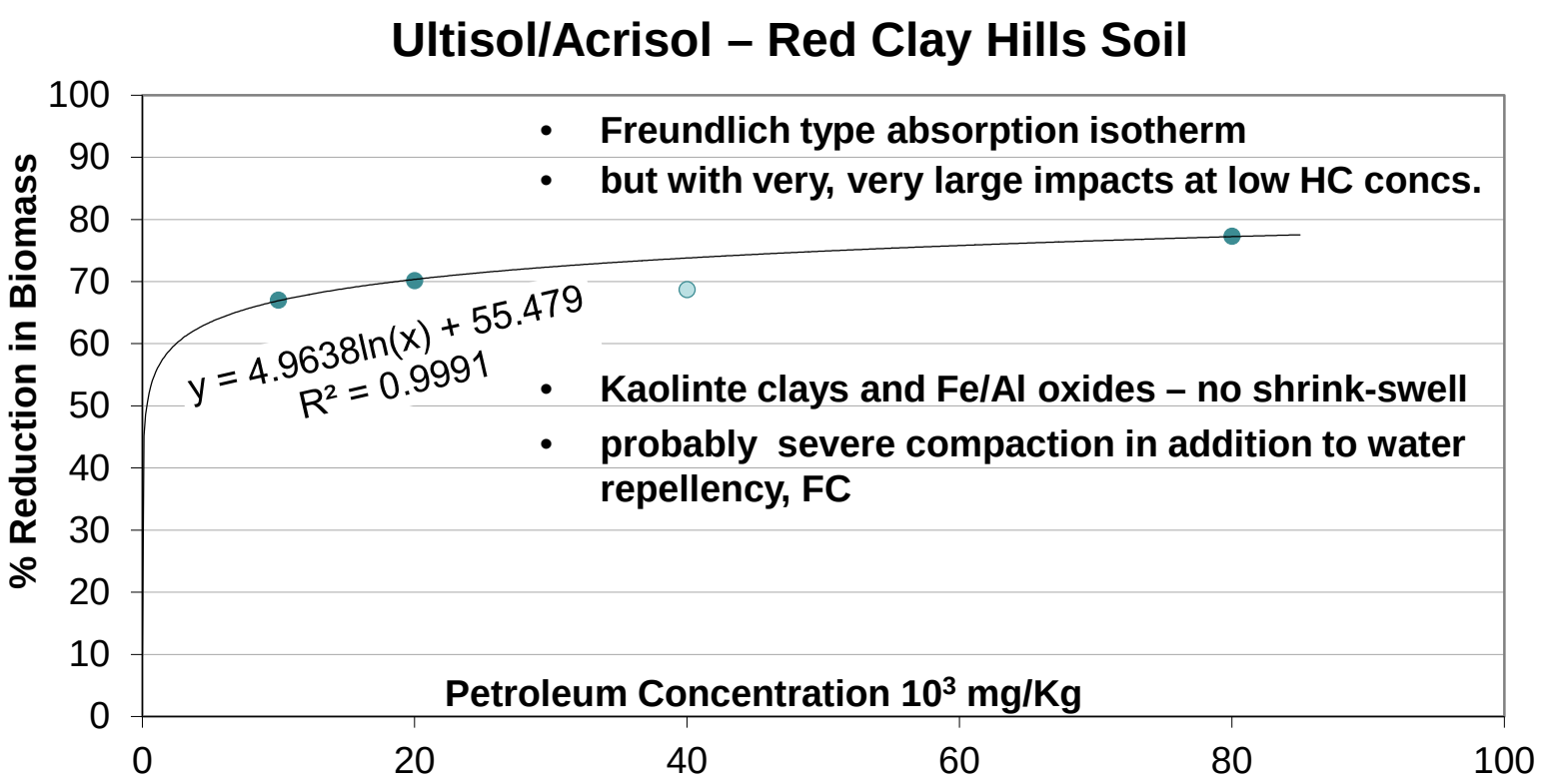
- At 1% TPH, 51% pasture reduction!
- To reduce impacts to only 10%, need to reduce HC conc. to ~200 mg/Kg!
- Alternatives? (reduce compaction, increase FC, etc.)

Dose-Response Curves: Alluvial Soils



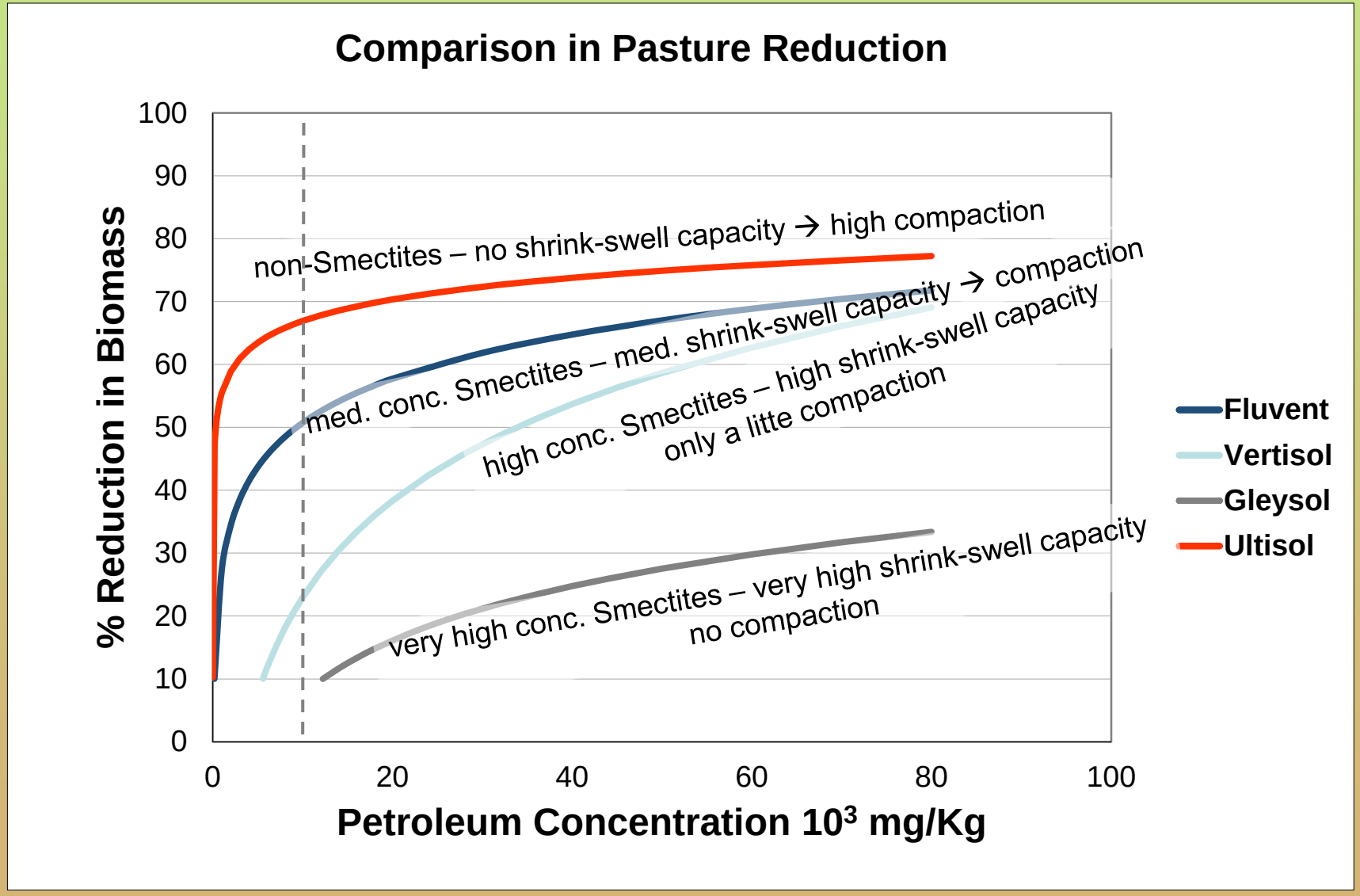
- Fluvent shows much greater impacts at low concentrations
- Formation of oily laminates + agglomeration? (compaction)

Dose-Response Curve: Ultisol

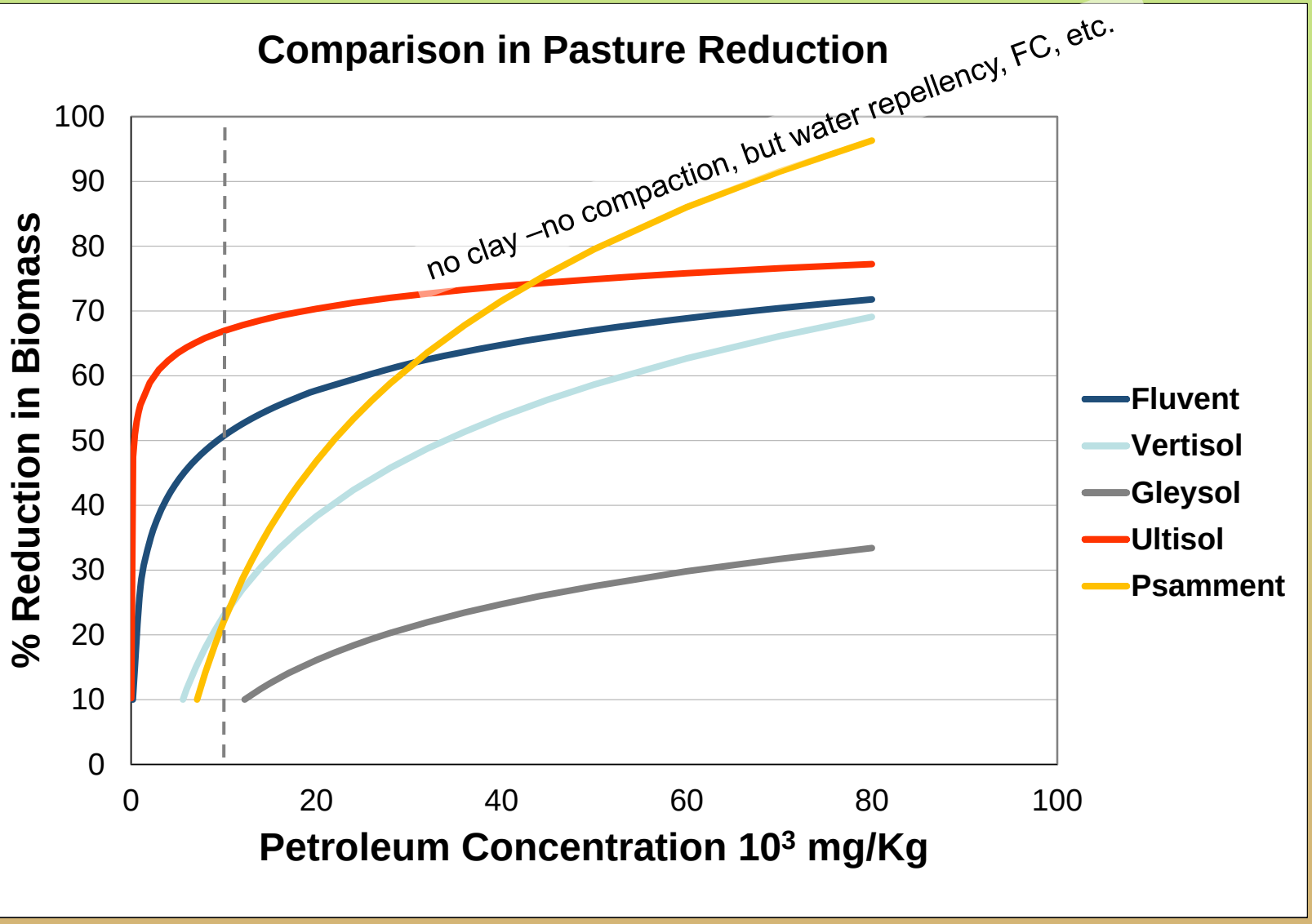


- At 1% TPH, 67% pasture reduction!
- To reduce impacts to only 10%, need to reduce HC conc. to <100 mg/Kg!
- Alternatives? (reduce compaction, increase FC, etc.)

Dose-Response Curves: Soils with Clay



Dose-Response Curves: Soils with Clay vs. Sandy Soil



CONCLUSIONS

Impacts of petroleum contamination in soil are affected by:

- **Type and abundance of soil clays:**
  - **no clay → no compaction**
    (but water repellency, FC problems)
  - **high amount of Smectite clays → large shrink-swell capacity**
    → partially mitigates compaction problems
  - **low or no Smectite clays → little or no shrink-swell capacity**
    → high to very high compaction
    → water repellency, FC also

CONCLUSIONS

Original studies in 1970s and 80s were based on treated drilling mud pits:

→ **lots of Smectite clay (Bentonite)**

→ **HC with low polarity (diesel vs. heavy oil)**

→ **1% rule used out of context**

- **For some marshy soils with high Smectite clay content - OK**
- **For other soils may need to lower level to < 100 mg/Kg to still maintain 90% pasture production**

CONCLUSIONS

- Better strategy: leave moderate concentration (1%?) but use secondary criteria for final site remediation/restoration
    - water repellency
    - compaction
- If water repellency is too high (sandy soil), treat by alkaline desorption and organic amendments to increase FC
- If compaction is too high, treat with organic amendments
- Easier to remedy symptoms of petroleum contamination than reduce concentrations to very low values ($$$)
- Longer term recovery? (1 – 3 years?)
- Important to monitor compaction, water repellency

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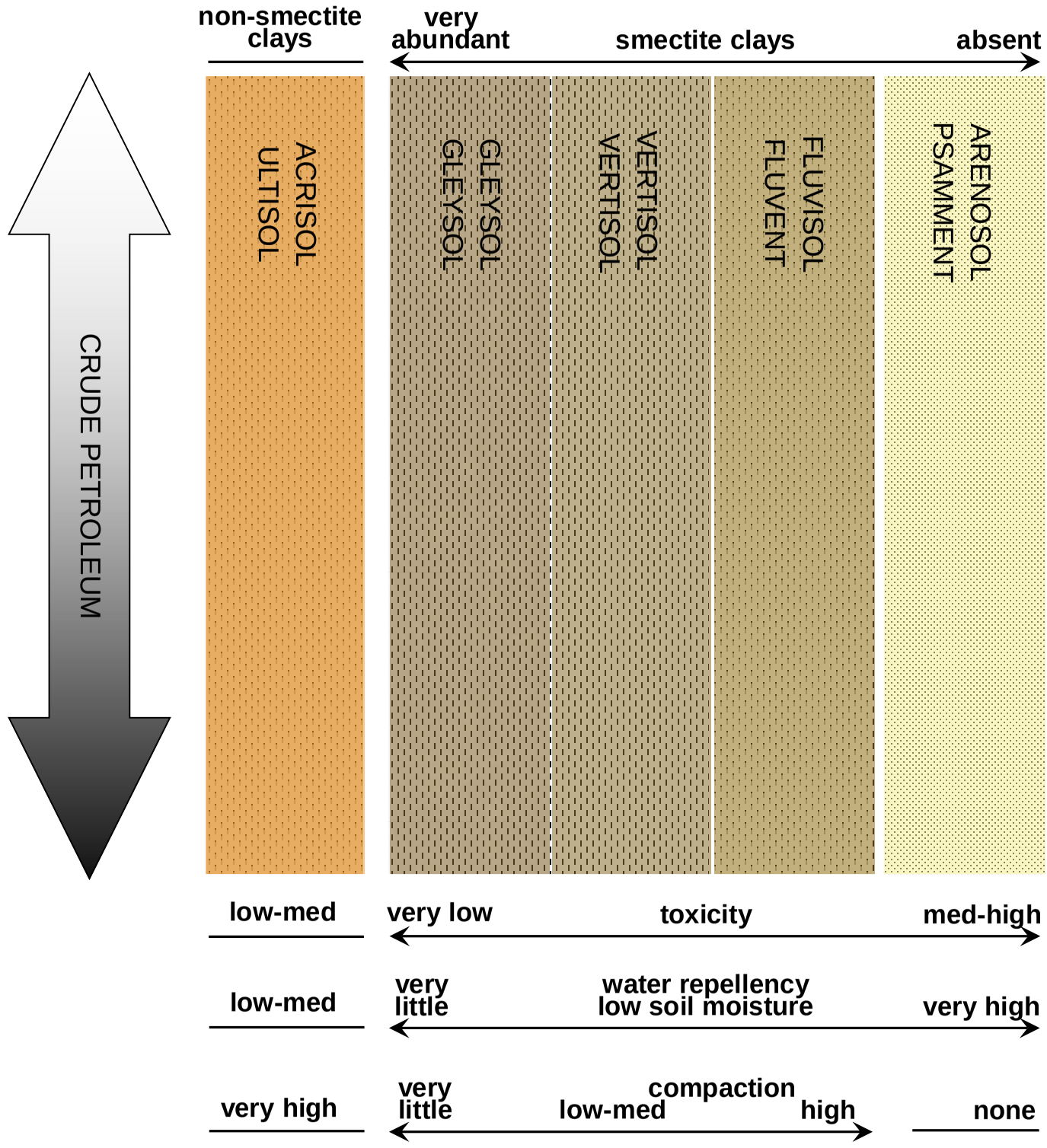
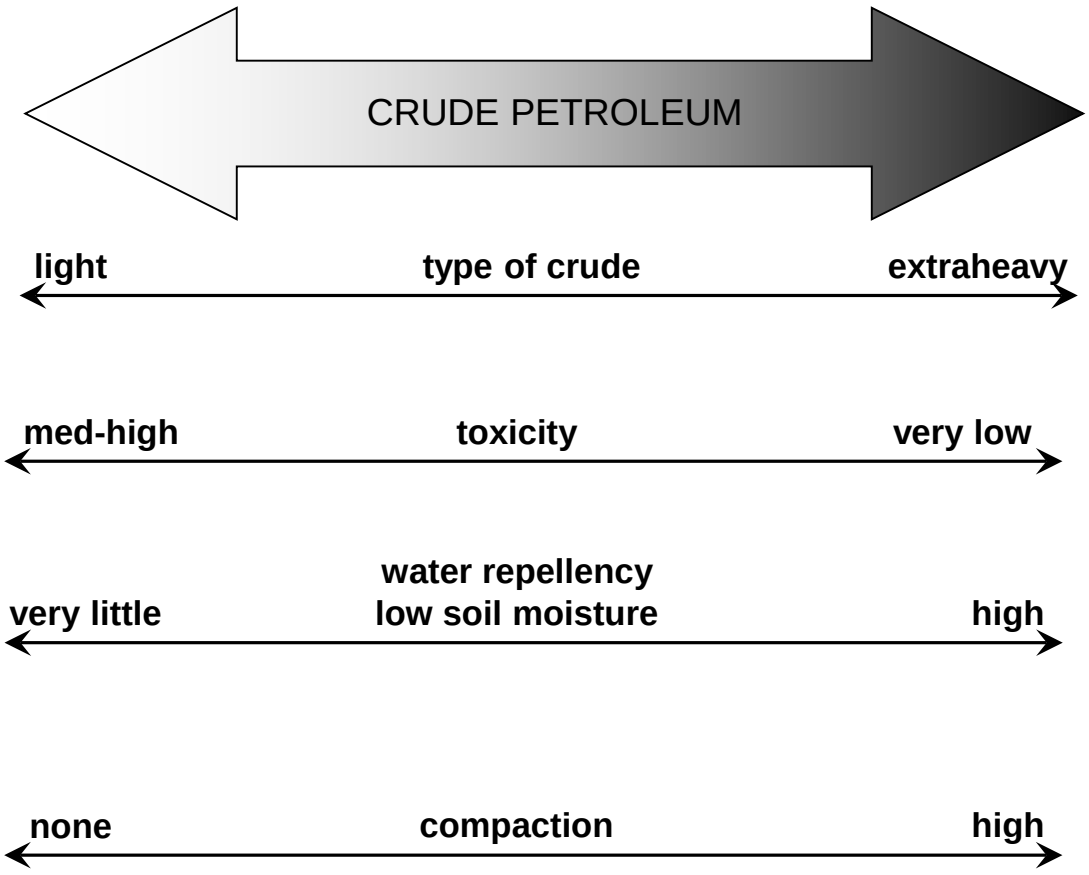
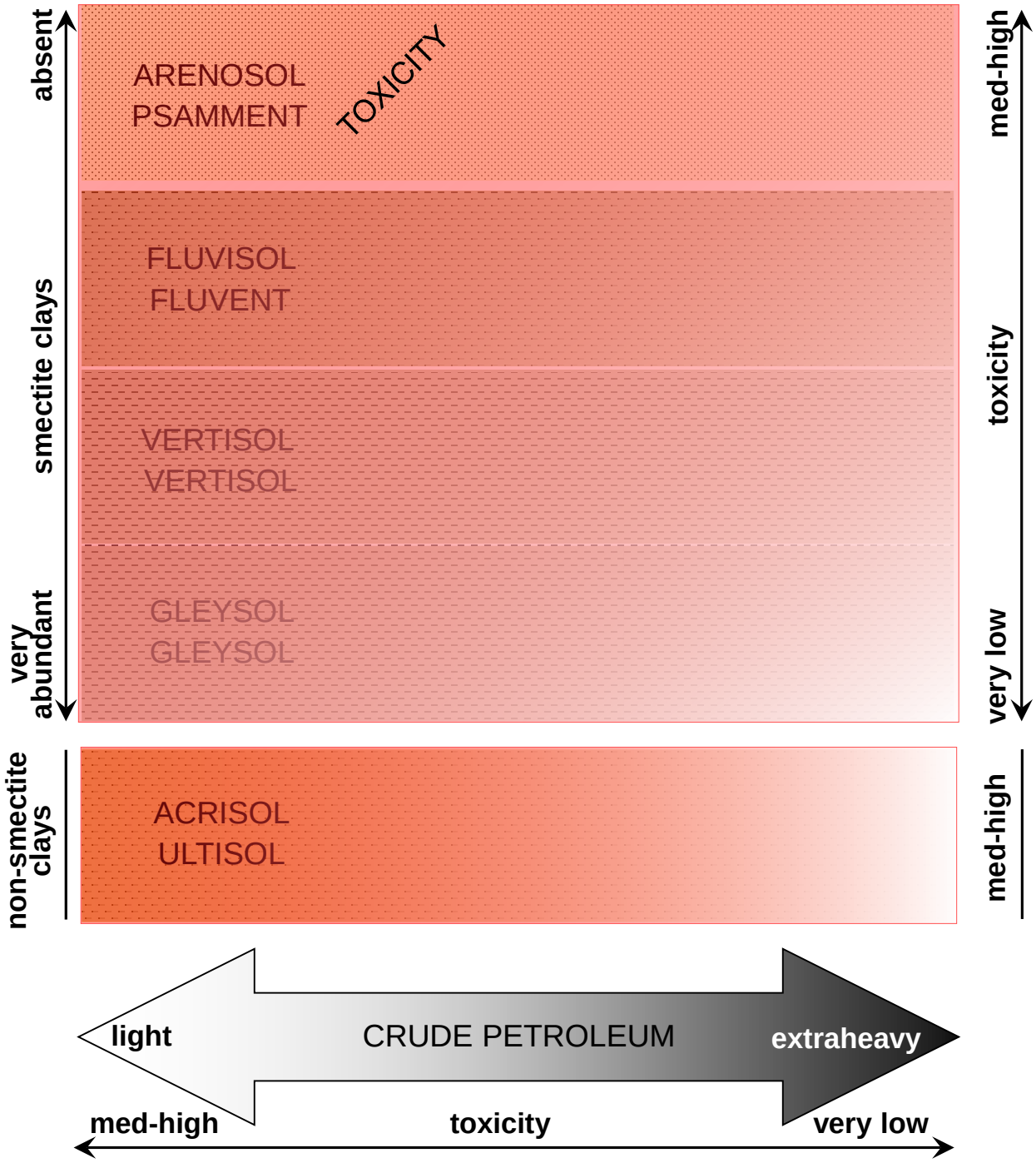
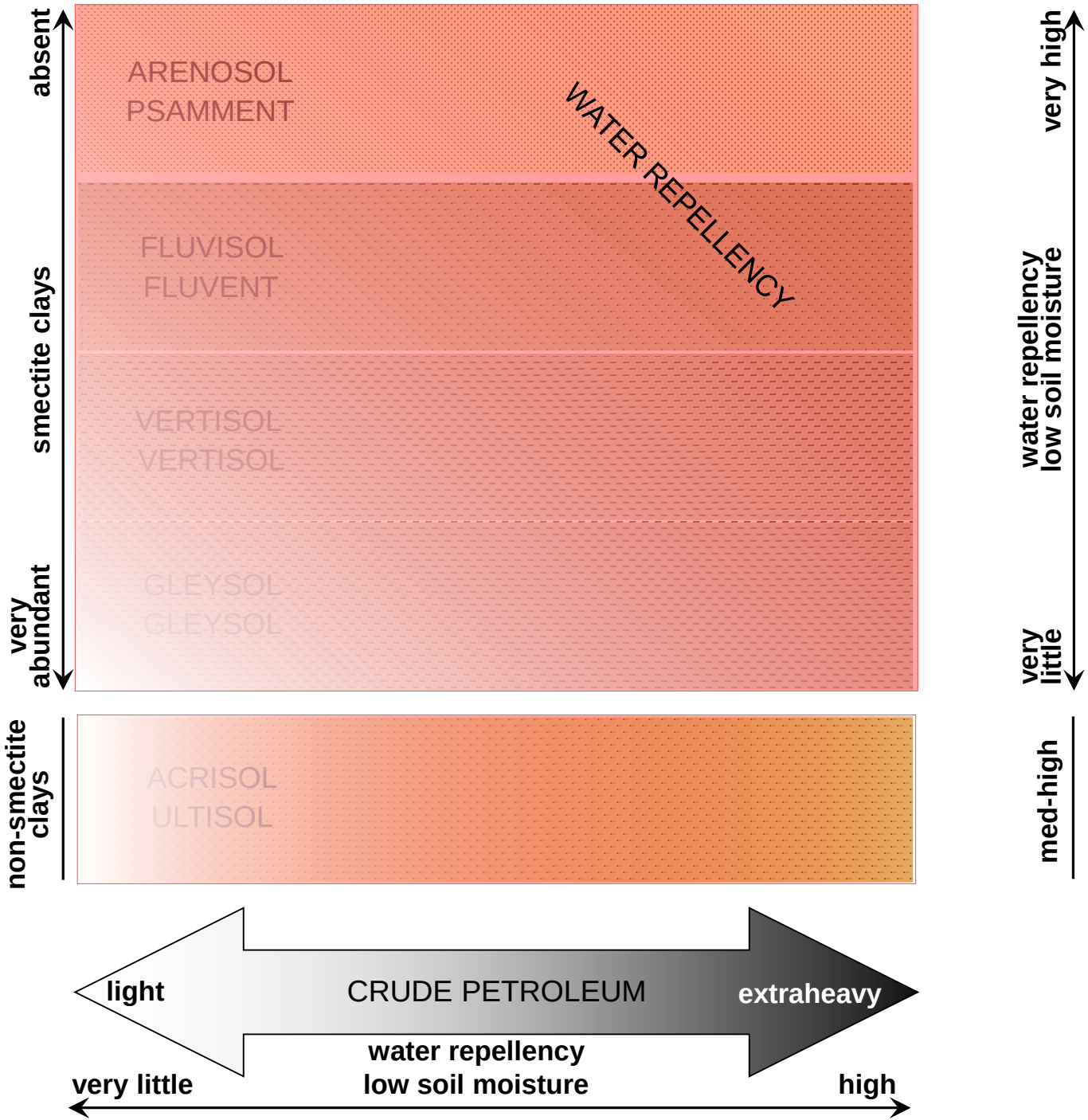
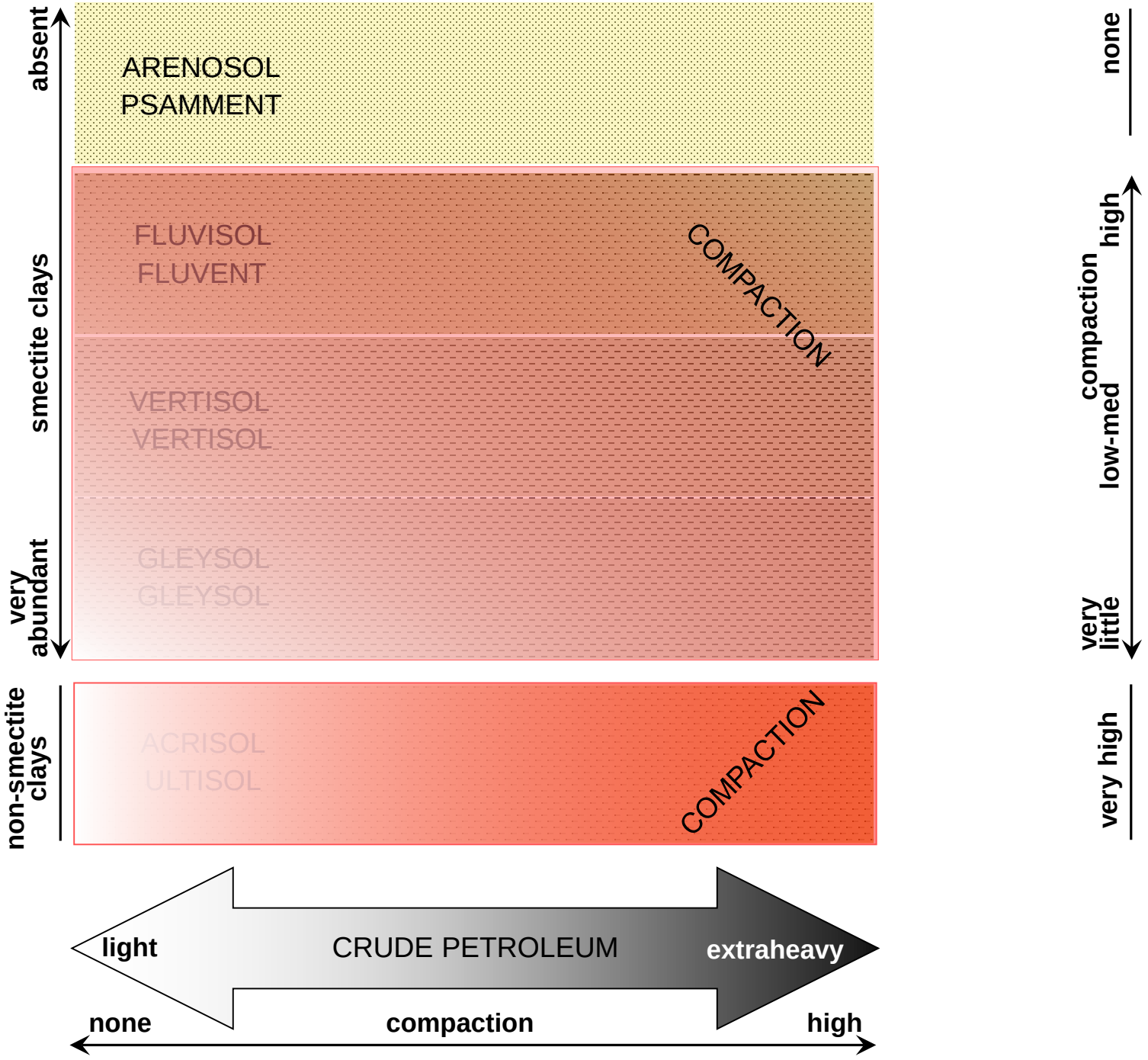

non-smectite clays
very abundant
smectite clays
absent
CRUDE PETROLEUM
ACRISOL
ULTISOL
GLEYSOL
GLEYSOL
VERTISOL
VERTISOL
FLUVISOL
FLUVENT
ARENOSOL
PSAMMENT
low-med
very low
toxicity
med-high
low-med
very little
water repellency
low soil moisture
very high
very high
very little
compaction
low-med
high
none


CRUDE PETROLEUM
light
type of crude
extraheavy
med-high
toxicity
very low
water repellency
very little
low soil moisture
high
none
compaction
high


absent
smectite clays
very abundant
ARENOSOL
PSAMMENT
TOXICITY
FLUVISOL
FLUVENT
VERTISOL
VERTISOL
GLEYSOL
GLEYSOL
med-high
toxicity
very low
non-smectite clays
ACRISOL
ULTISOL
med-high
light
CRUDE PETROLEUM
extraheavy
med-high
toxicity
very low


absent
smectite clays
very abundant
ARENOSOL
PSAMMENT
FLUVISOL
FLUVENT
VERTISOL
VERTISOL
GLEYSOL
GLEYSOL
WATER REPELLENCY
very high
water repellency
low soil moisture
very little
non-smectite clays
ACRISOL
ULTISOL
med-high
light
CRUDE PETROLEUM
extraheavy
water repellency
low soil moisture
very little
high


absent
ARENOSOL
PSAMMENT
none
smectite clays
FLUVISOL
FLUVENT
COMPACTION
VERTISOL
VERTISOL
compaction
high
low-med
very abundant
GLEYSOL
GLEYSOL
very little
non-smectite clays
ACRISOL
ULTISOL
COMPACTION
very high
light
CRUDE PETROLEUM
extraheavy
none
compaction
high