
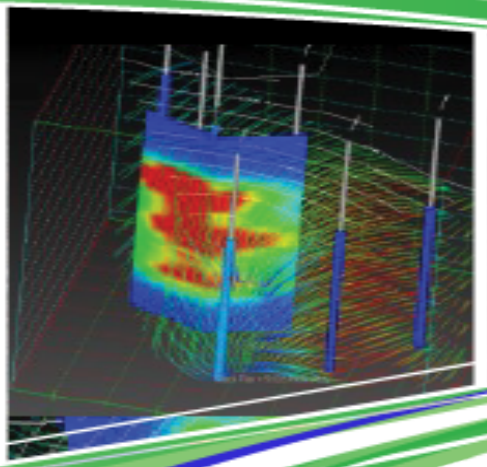


NARPM Presents…Focus on Geology

Fundamentals of Bedrock Characterization for Site Remediation

Concepts and Terminology

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EPA United States Environmental Protection Agency

26th NARPM Training Program

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Presentation Overview

- Selected Bedrock Concepts and Terminology
- Data Objectives for Remedial Investigations in Bedrock Terrains
- Brief Introduction to Bedrock Investigation Tools and Methods
- A few Words on Conceptual Site Models in Bedrock Environments
- *This Lecture provides introductory material for several follow-on lectures to be presented at NARPM in Chicago on August 26*

Selected Topics and Terminology to be Introduced

- What is “Bedrock” and how does it differ from other geologic deposits
- Bedrock-overburden transition zone
- Top of bedrock surface morphology
- Compositional variability of rock types
- Structural variability of rock types—layering, primary (compositional) layering, fracture style
- Fracture network mapping at appropriate scale of investigation
- Fractured Rock Hydrology—bulk flow in bedrock & identify/assess discrete fracture flow pathways
- Tools: fracture trace analysis, geologic mapping, surface & downhole geophysics, drilling, (with proper sequencing of methods)

Overview -- What is “Fractured Bedrock”

- What is Bedrock?
- Types of Bedrock

- What are Fractures?
- Types of Fractures

- Selected Characteristics of “Fractured Bedrock” Relevant to Site Remediation
  - E.g., Ability to hold and transmit water and contaminants

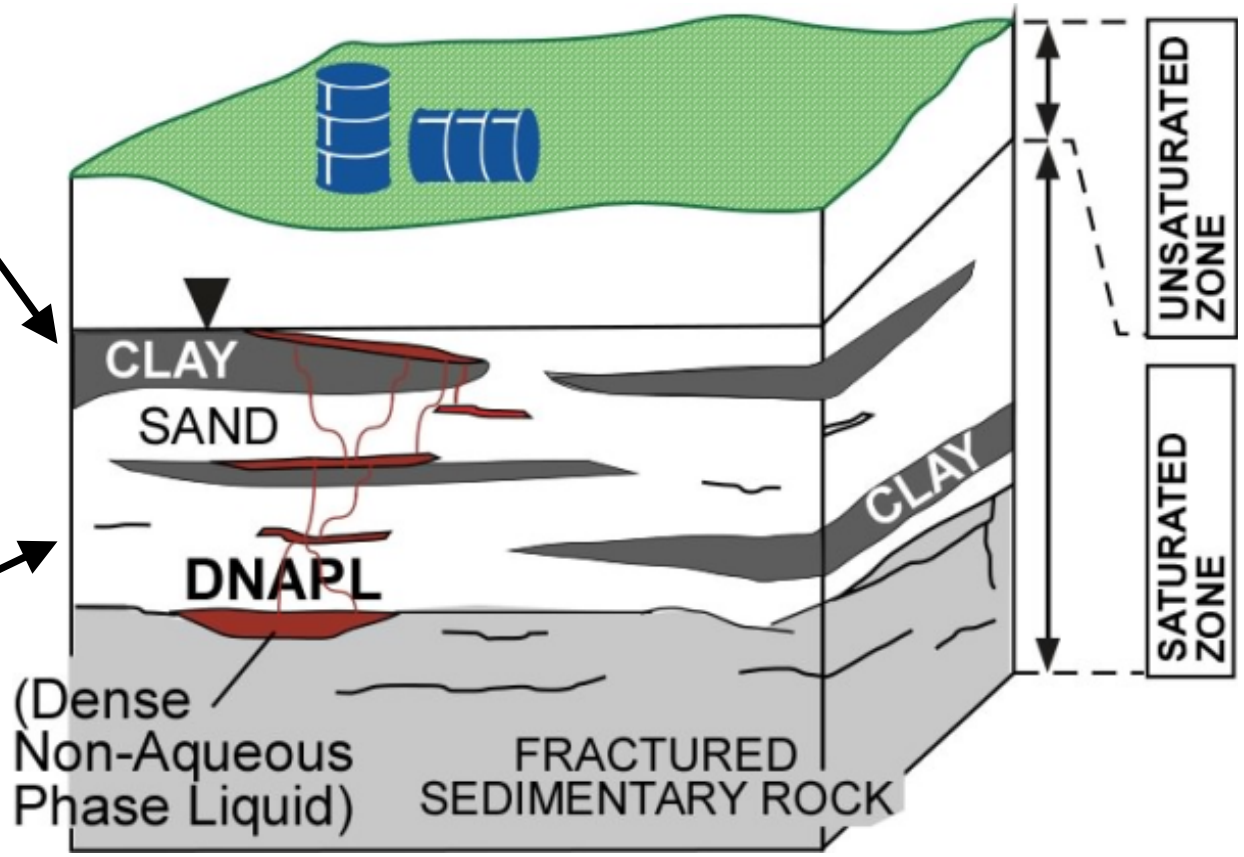
Dual Porosity in Unconsolidated Media

Immobile Porosity

Relatively low permeability bypassed by advective flow and dominated by diffusive flux

Mobile Porosity

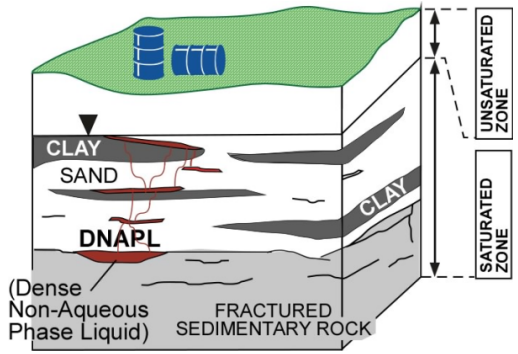
Relatively high permeability and dominated by advective flow

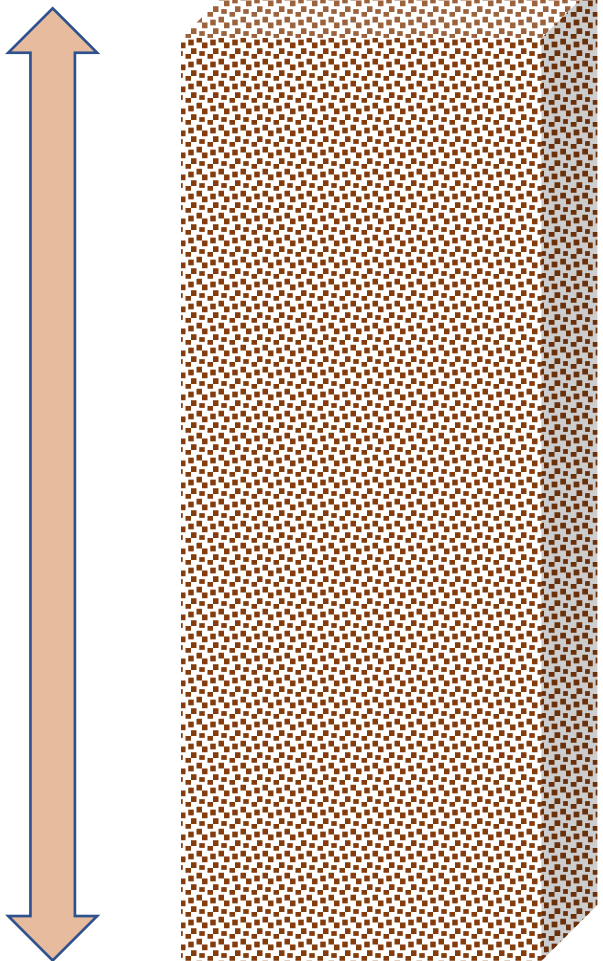


Source: Chuck Newell and Tom Sale

And now…..*for the rest of the story……*

BEDROCK !!!





Bedrock - *Some Important Characteristics*

- Chemistry
  - Bulk Chemistry
  - Trace Elements
- Mineralogy
  - Rock Forming Minerals
  - Trace Elements
- Denisity
- Porosity
- Permeability
- Texture
- Grain or crystal size
- Crystalline (from melt)
- Chemical precipitates
- Granular
  - Grains
  - cement

- Environment-specific
  - Water
  - Chemicals
- Geochemical Stability
- Weathering Processes

- Geophysical Properties
  - Electrical Conductivity
  - Magnetic Properties

- Ability to hold and transmit water and contaminants

Rock Definition: Naturally Occurring solid aggregate of one or more minerals or mineraloids

- No specific Chemical Composition
- Highly Variable Structure
- Physical Characteristics
- Consolidated

Types of Rock Forming Minerals

- SILICATES
- CHEMICAL PRECIPITATES
- METTALIC ORES AND MINERALS
- CLAY MINERALS

General Types of Rock-Forming Minerals (1)

- Silicates
  - Quartz (SiO2)
  - Feldspars (Aluminosilicates; Si, Oxygen, Al, + K,Na, or Ca)
  - Ferro magnesian Minerals (Si, Oxygen, Fe, Mg)
  - Phyllosilicates (layered); e.g., biotite, muscovite, “mica”
  - Aluminium Phyllosilicates (clay minerals)

(a)

(b)

Rock-Forming Minerals (2) Chemical Precipitates

- Carbonates
  - Calcite ($CaCO_3$)
  - Dolomite ($CaMg(CO_3)_2$)
- Evaporites
  - Gypsum ($CaSO_4 \cdot 2H_2O$
  - Anhydrite ($CaSO_4$)
  - Halite (bedded salt -NaCl)

Rock-Forming Minerals (3)
Ores

- Ores: useful minerals that can be extracted (at a profit)
- Oxides
  - Iron Ore (Hematite – Fe_2O_3)
  - Bauxite (Al_2O_3)
- Sulfides
  - Pyrite (FeS_2)
  - Chalcopyrite ($CuFeS_2$)
- Native elements
  - Gold (Au)
  - Silver (Ag)
  - Copper (Cu)

(f)

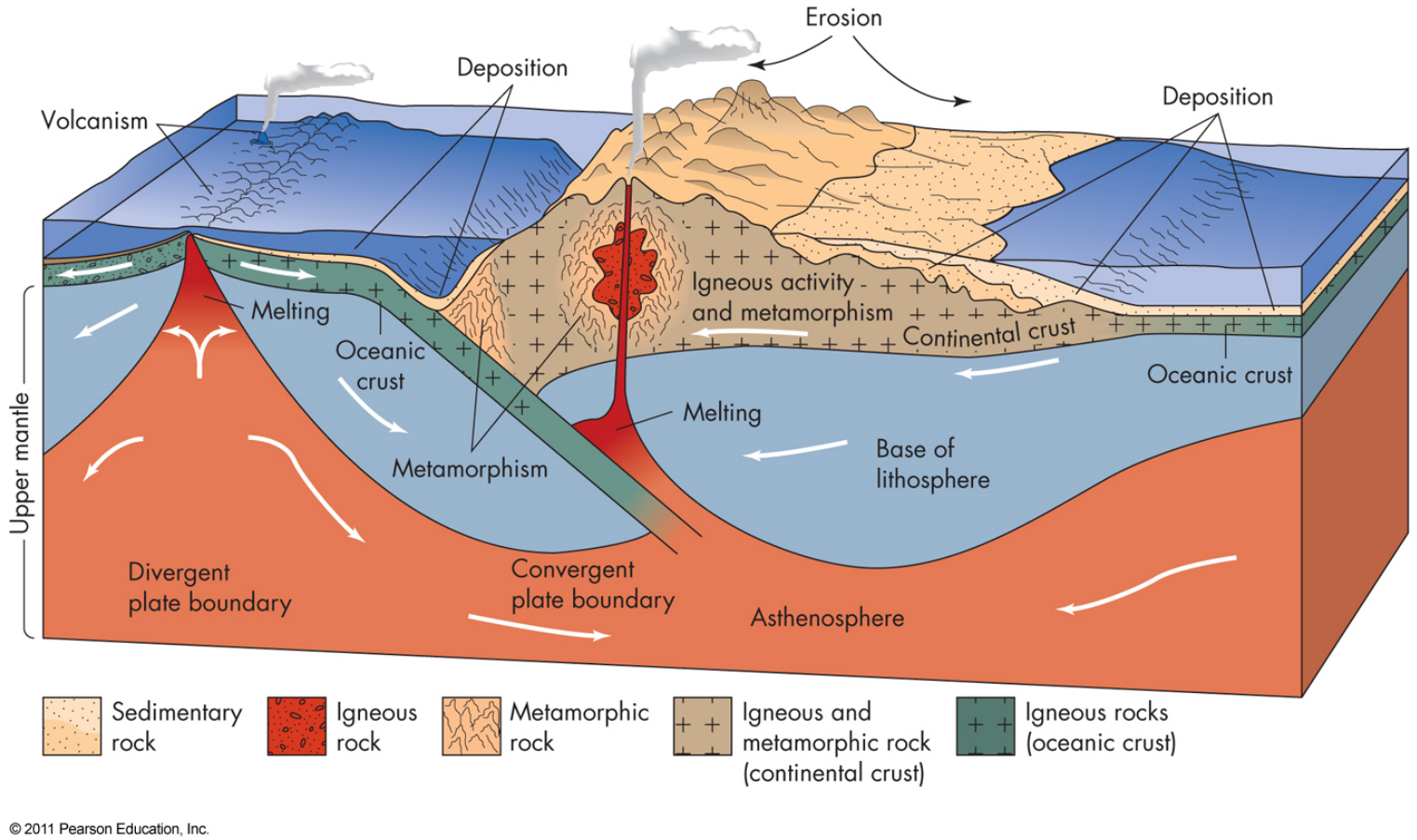
Clay Minerals

- Hydrous Aluminum phyllosilicates
- Weathering of feldspars
- Hydrothermal alteration
- E.g., Kaolinite
  - $Al_2Si_2O_5(OH)_4$

Densities of Common Rocks

Rock type	Density (gram/cm3)	Type of Crust	Comment
Water	1.0		
coal	1.1-1.4	continental	Upper crust; carbon rich
granite	2.6-2.7	continental	Silica-rich; upper crust
sandstone	2.2-2.8	continental	Upper crust
basalt	2.8-3.0	oceanic	Hi iron-magnesium
gabbro	2.7-3.3	oceanic	Chemical equivalent to basalt
peridotite	3.1-3.4	Upper mantle	Low silica content; “Ultra-mafic”

Environments of Rock Formation



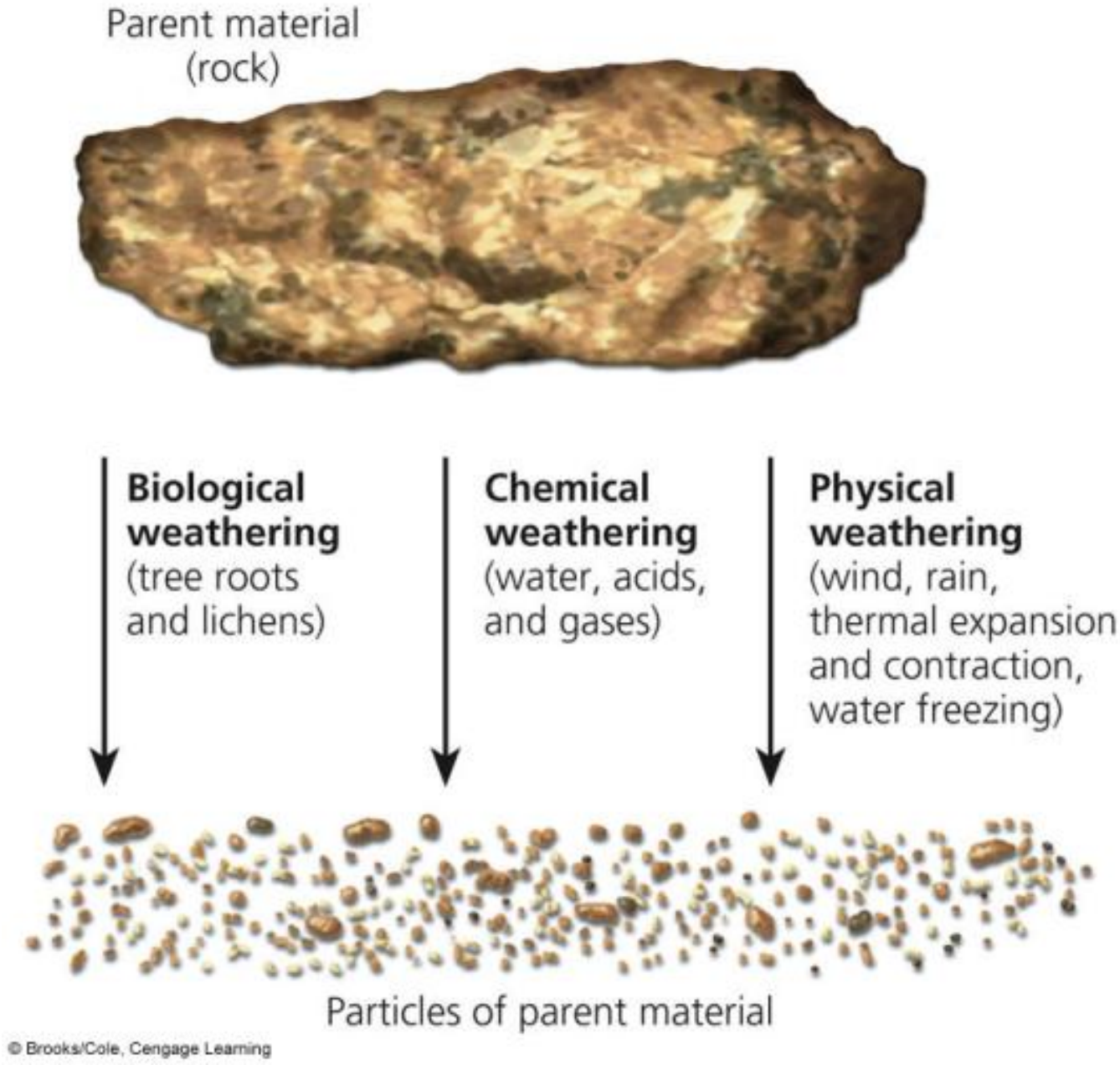
“Typical” New England Bedrock

- Igneous and Metamorphic
  - Most Rocks in NE
  - Silica-Rich
  - Heat and pressure
  - *Transformational loss of primary porosity and permeability*
  - Fractured
  - Porosity and permeability generally from Fractures (secondary)

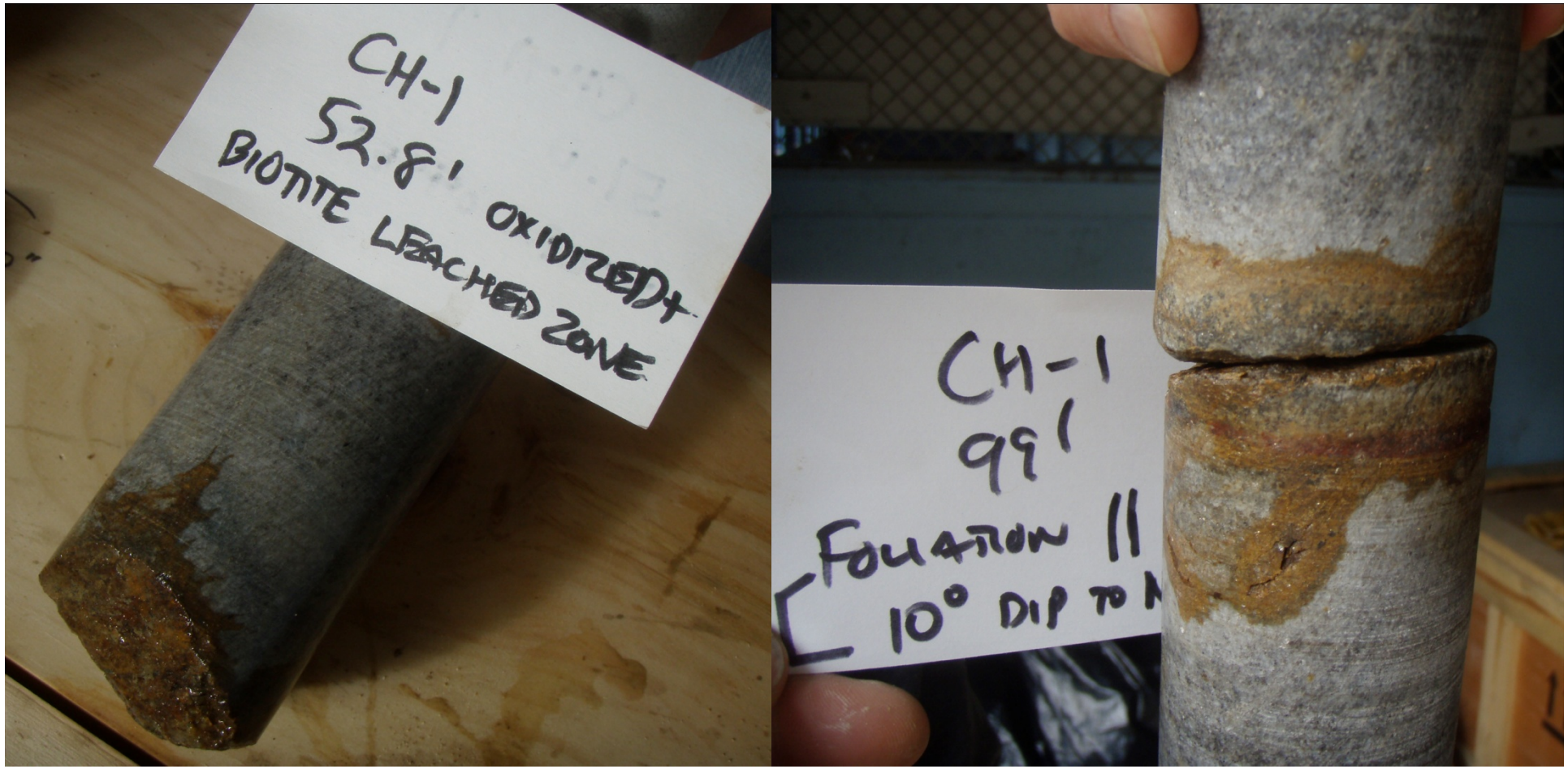
“Destructive” Earth Processes

- **Weathering**
  - Physical, Chemical, and Biological
- **Erosion**
  - Wind
  - Flowing water
  - Human activities
  - Glaciers

Weathering: Biological, Chemical, and Physical Processes

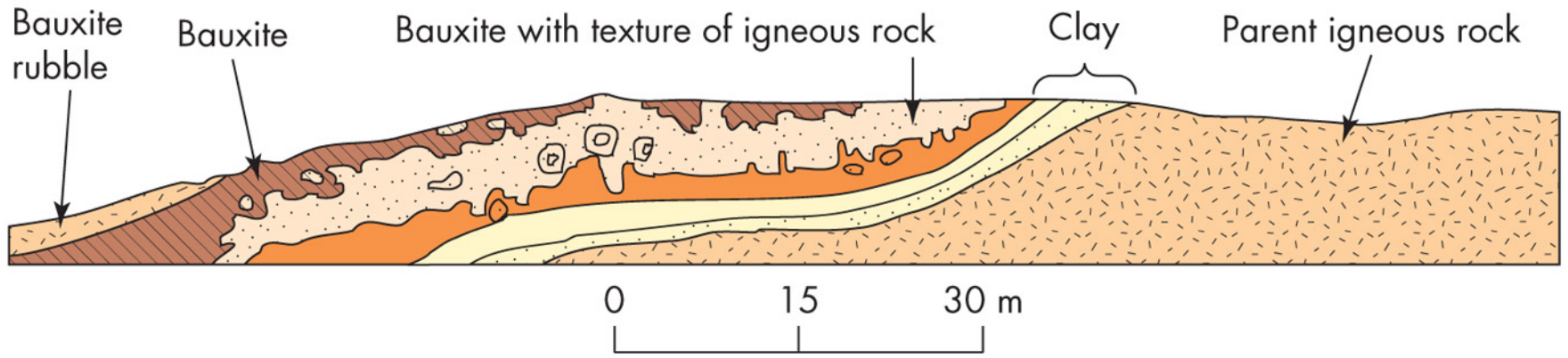


Chemical Weathering at depth in rock cores



Chemical Weathering *(on a small-scale)*

Chemical Weathering *(on a large scale)*



Carbonate Dissolution - Vermont

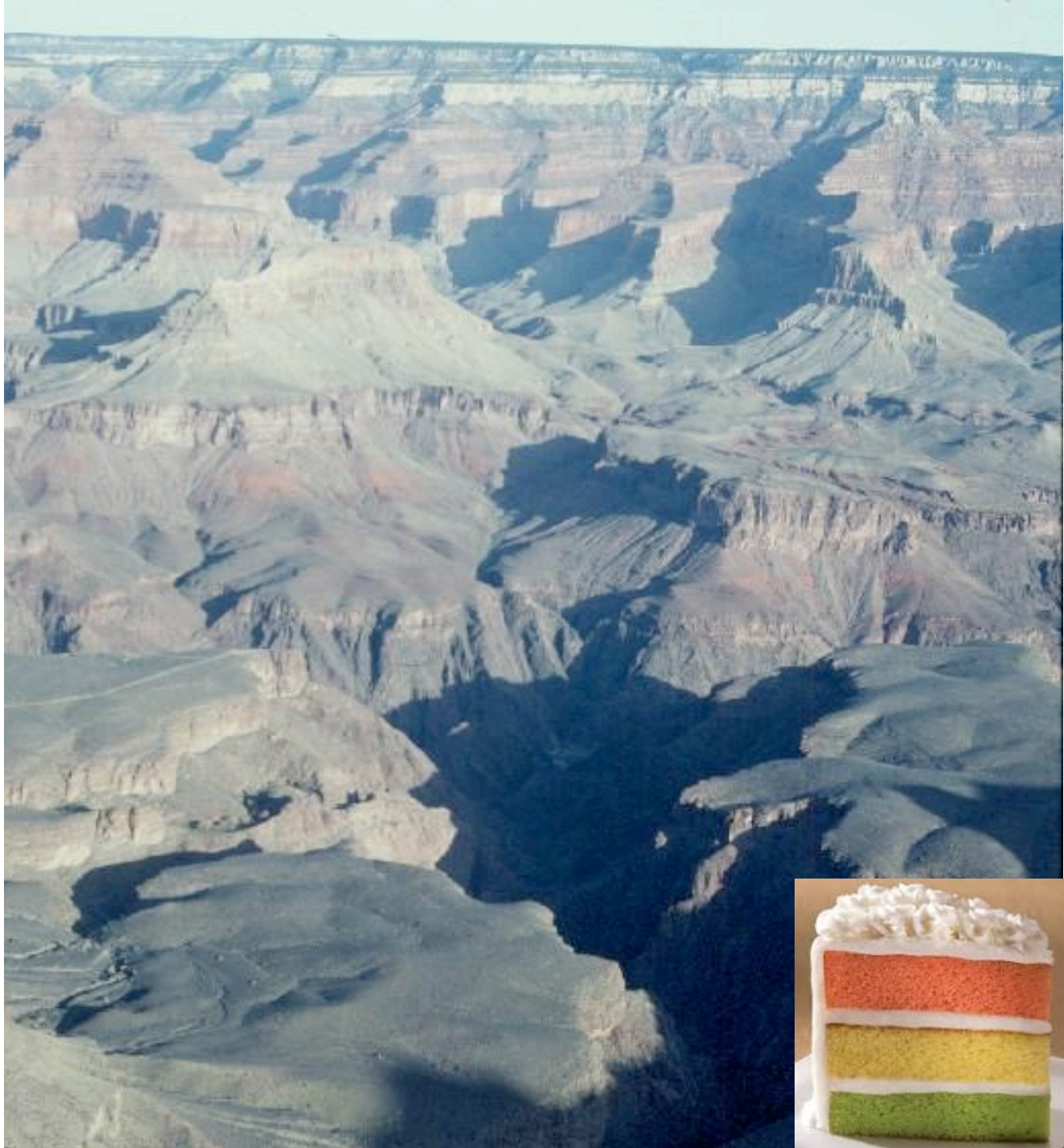
Geologic Structure and Fracturing

- Intrinsic Structure of Rock Masses
  - Composition layering
  - Foliation
  - Plutonic Bodies
  - Dykes

- Fracturing and Faulting
  - Forgotten Field of “Structural Geology”
  - Multiple Episodes Fracturing and Faulting

Primary Bedrock Fabric

- ***Compositional Layering***
  - Foliation
  - Bedding
  - Volcanic flows



Modes of Deformation and Styles of Fracturing

- Tectonic Forces
  - Compressional Tectonics
  - Extensional Tectonics
  - Paleo-tectonics
  - Neo-tectonics
  - Brittle
  - Ductile

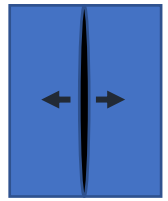
- Near-surface Forces
  - Fractures Related to Glaciation and Deglaciation
  - Brittle
  - Earth Tides

What is a “Fracture” – Basic Terminology

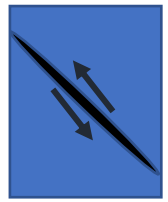
- Various crack-like features related to tectonics and lithology

- Fracture – general term, no slip

- Joint – formed by tensile loading, also no slip

B.  Joint

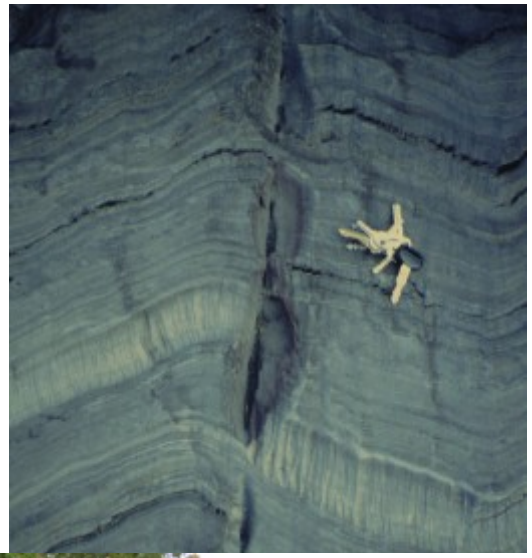
- Fault – Measureable displacement ; formed by compressional or tensile forces

 Fault

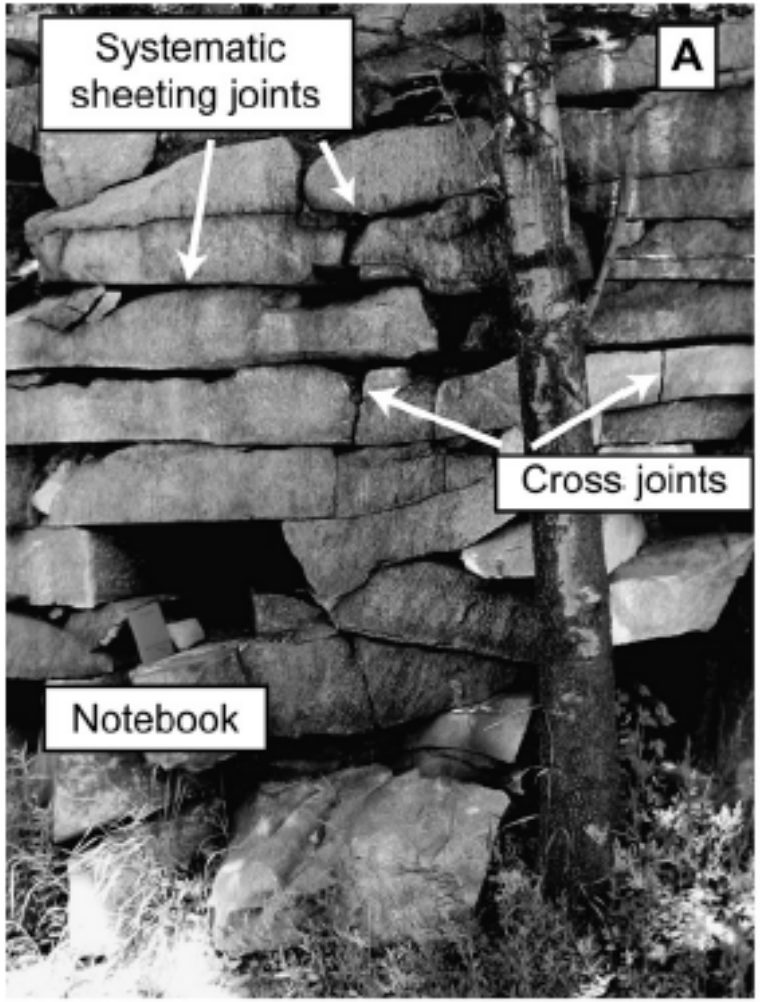
Fracture Types – Descriptive (Geometry)

- Sub-Horizontal Fracturing (Flat)
- Sub-vertical Fracturing (Steep)
- Moderately-dipping Structures (Everything else)
- Fracturing may or may not coincide with compositional layering

Steeply Dipping Fractures (Sub-Vertical)



Sub-horizontal “Sheeting Fractures”

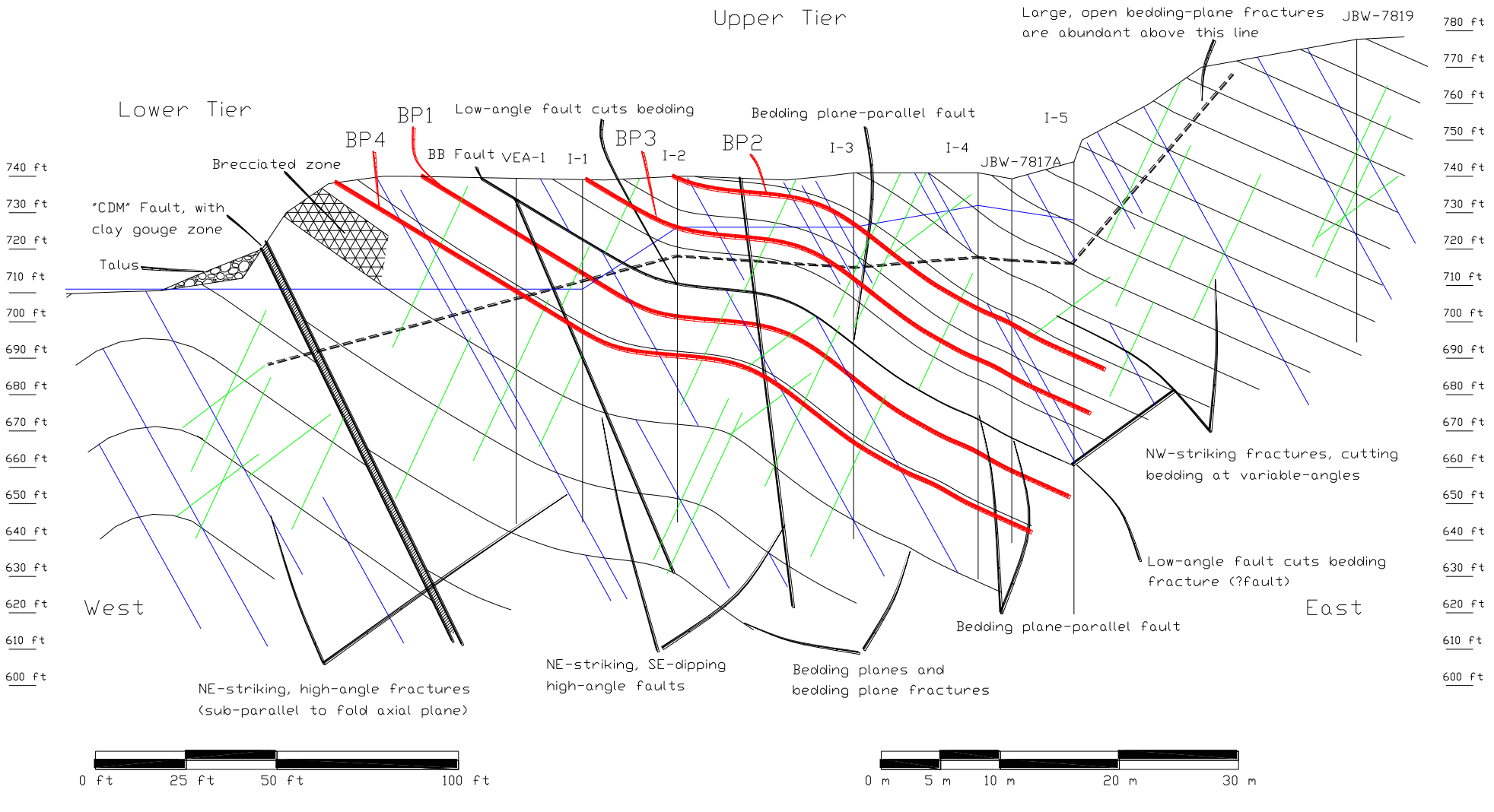


Source: Manda et. al. 2008

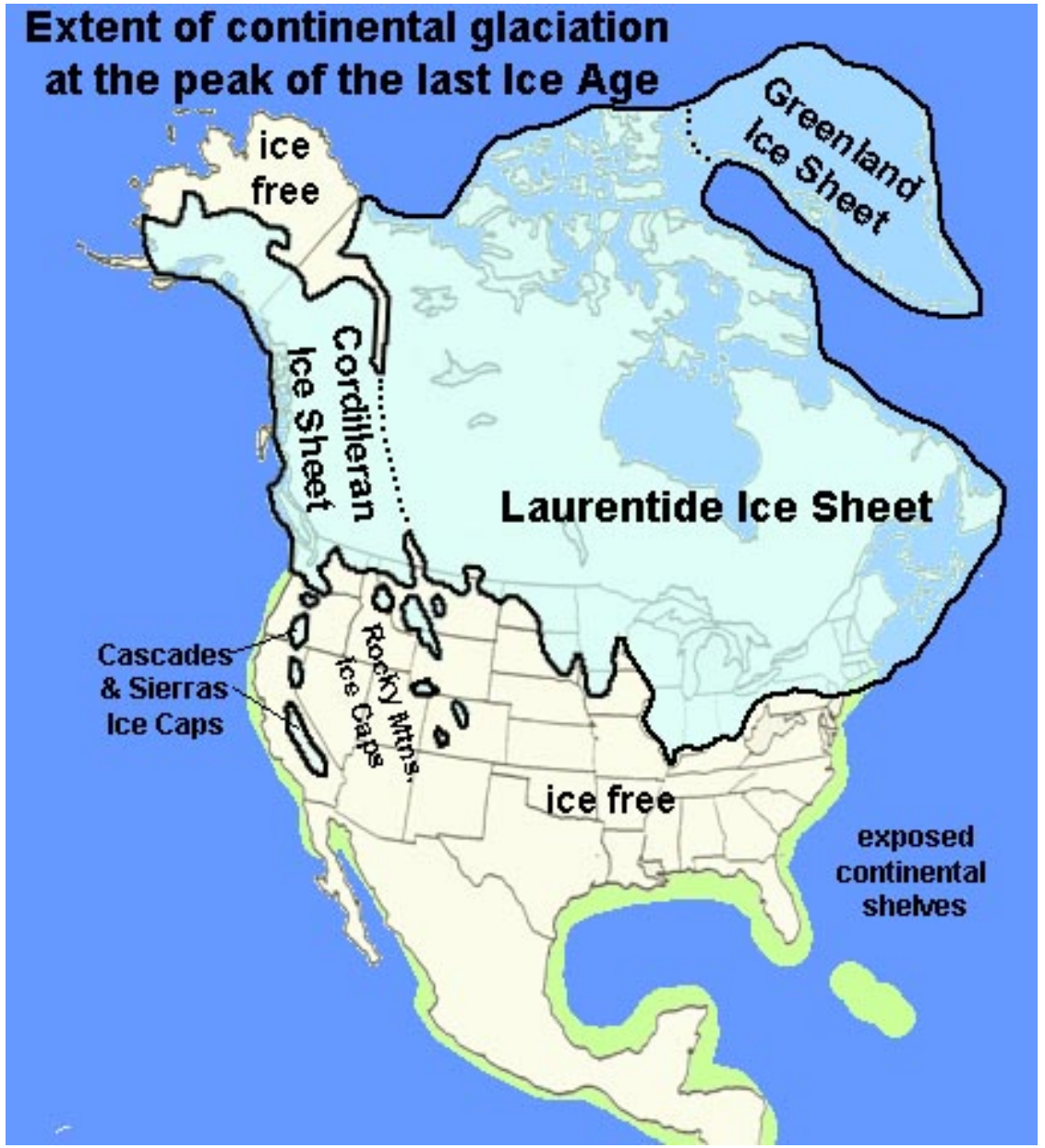
Vertical and Horizontal Fractures

Intersecting Steeply-Dipping Fractures/Faults with Inclined Bedding planes

Moderately-Dipping Fractures
Limestone, Maine



Extent of Late Pleistocene Glaciation in North America



Effects of Glaciation and Deglaciation

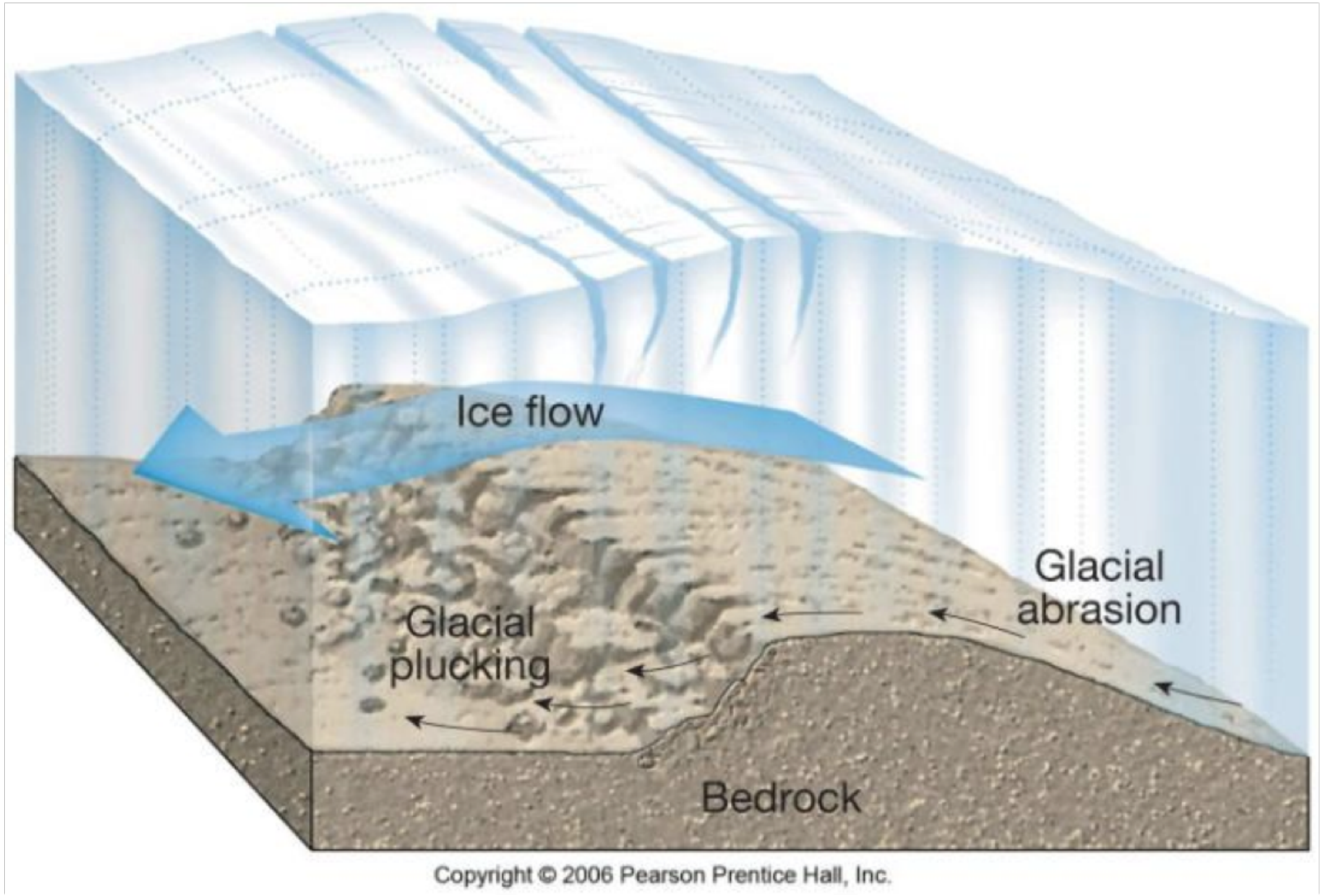
Glaciation

- Generally north-to-south Ice movement
- Scouring of Bedrock Surface
- Removal of highly weathered rock and saprolite
- **Scouring** accentuates valleys ("troughs") on bedrock surface in areas intense faulting and fracturing
- Removal of large rock mass ("Plucking") on down-ice sides of bedrock uplands

Deglaciation

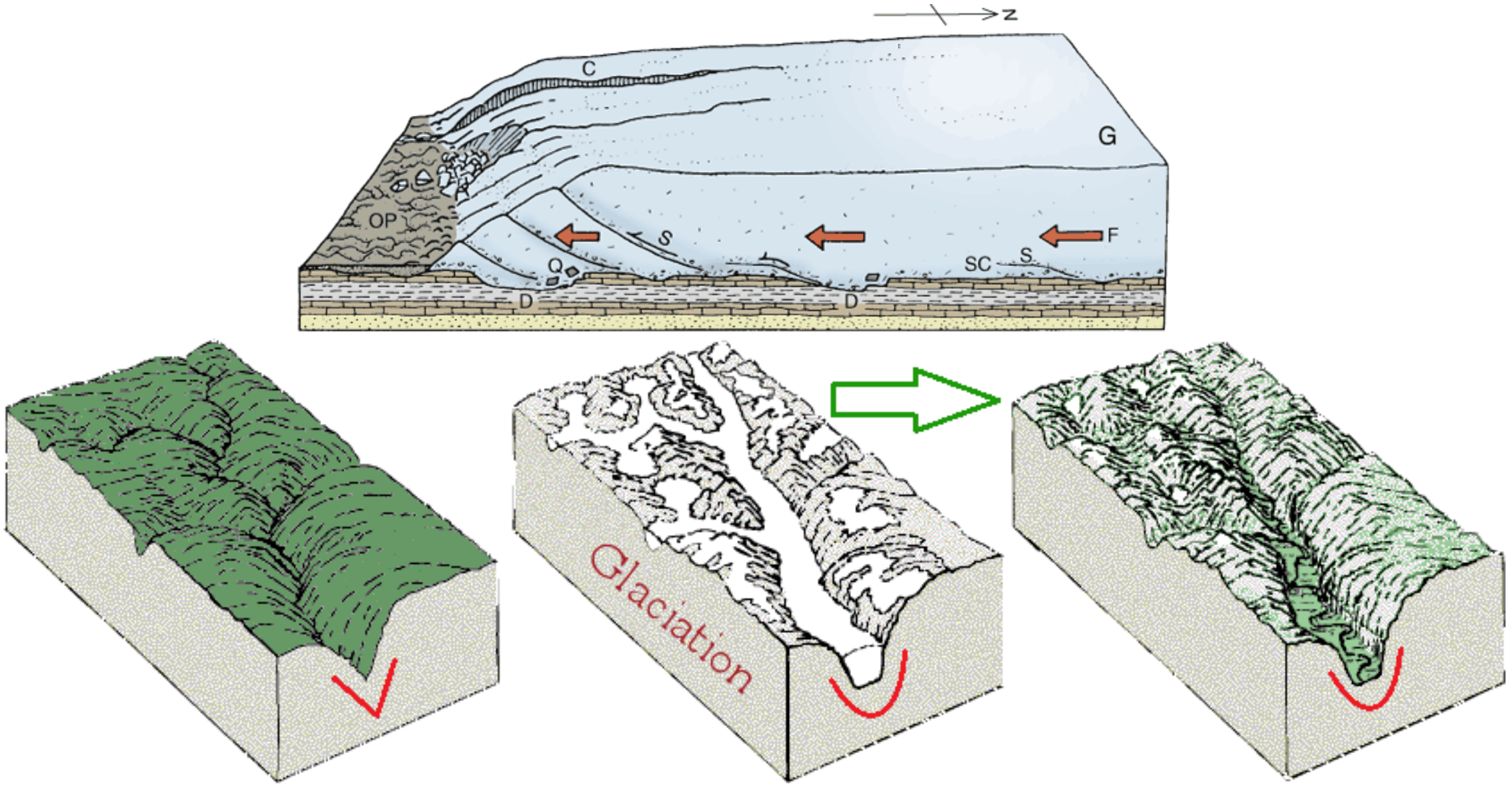
- Rapid melting of glaciers
- "instantaneous" removal of weight of 1 mile thickness of ice
- Rapid Depressurization of underlying rock mass
- Formation of stress relief joints in uppermost portion of bedrock
- "Sheeting joints"
- Isostatic adjustments

Glacial Scouring – Regional Scale

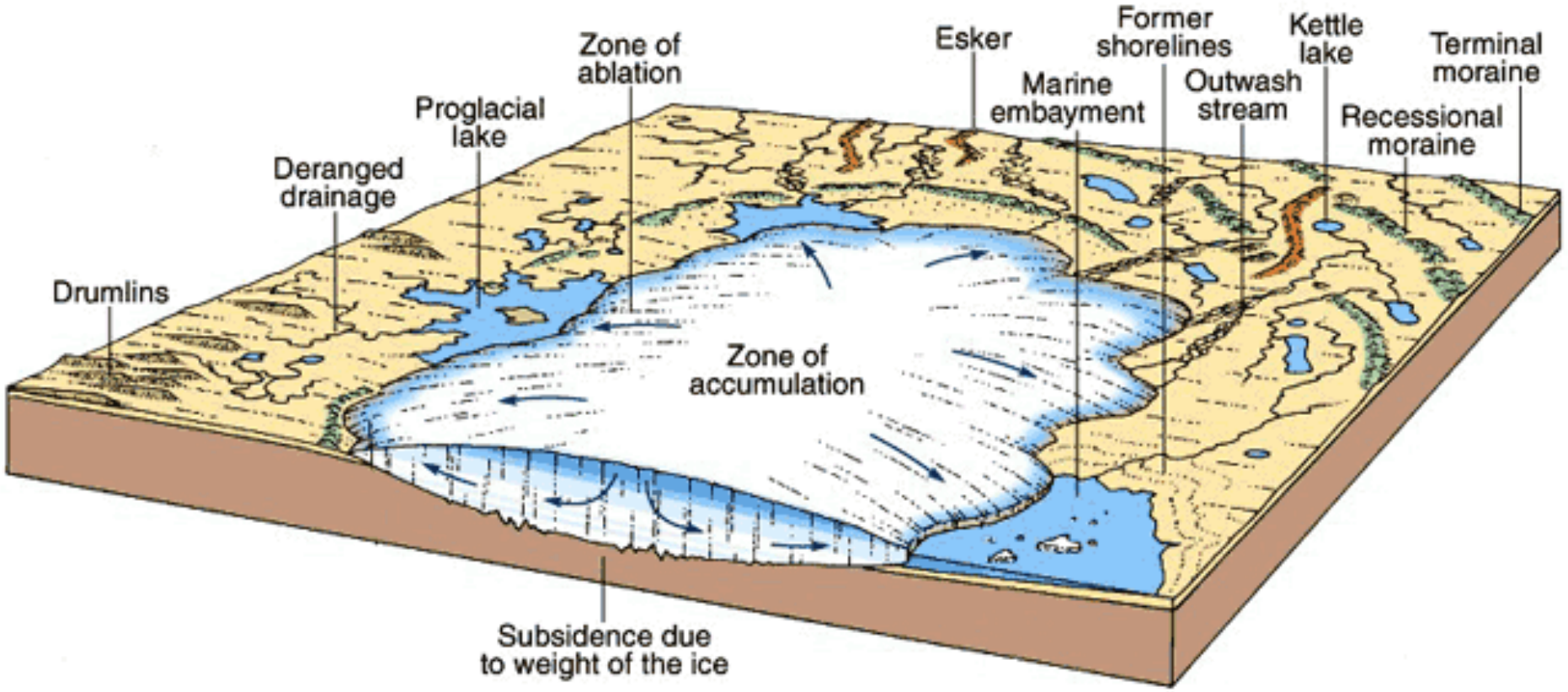


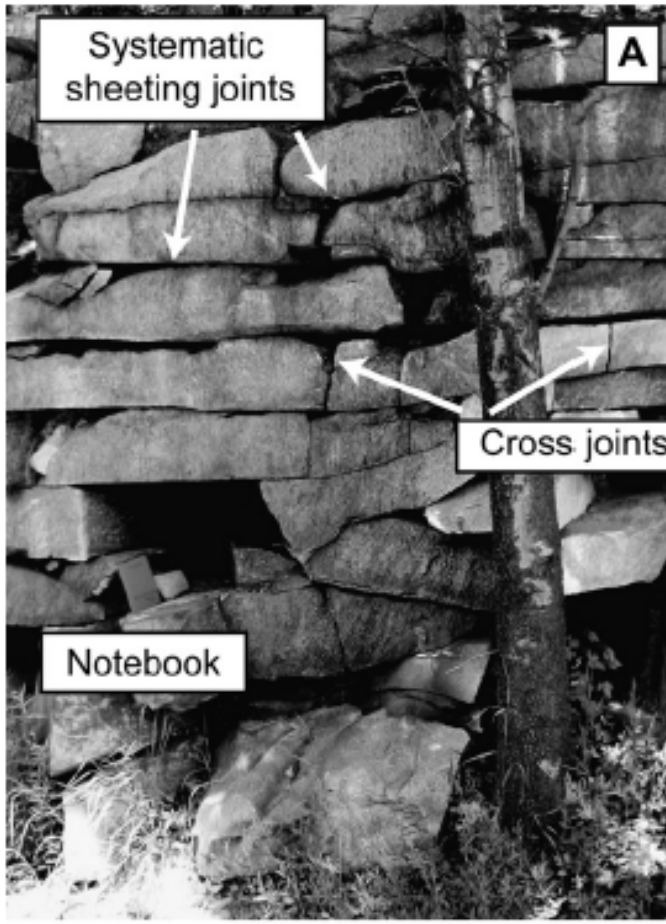
Glacial Scouring – Outcrop Scale

Glacially-scoured valley on Bedrock Surface

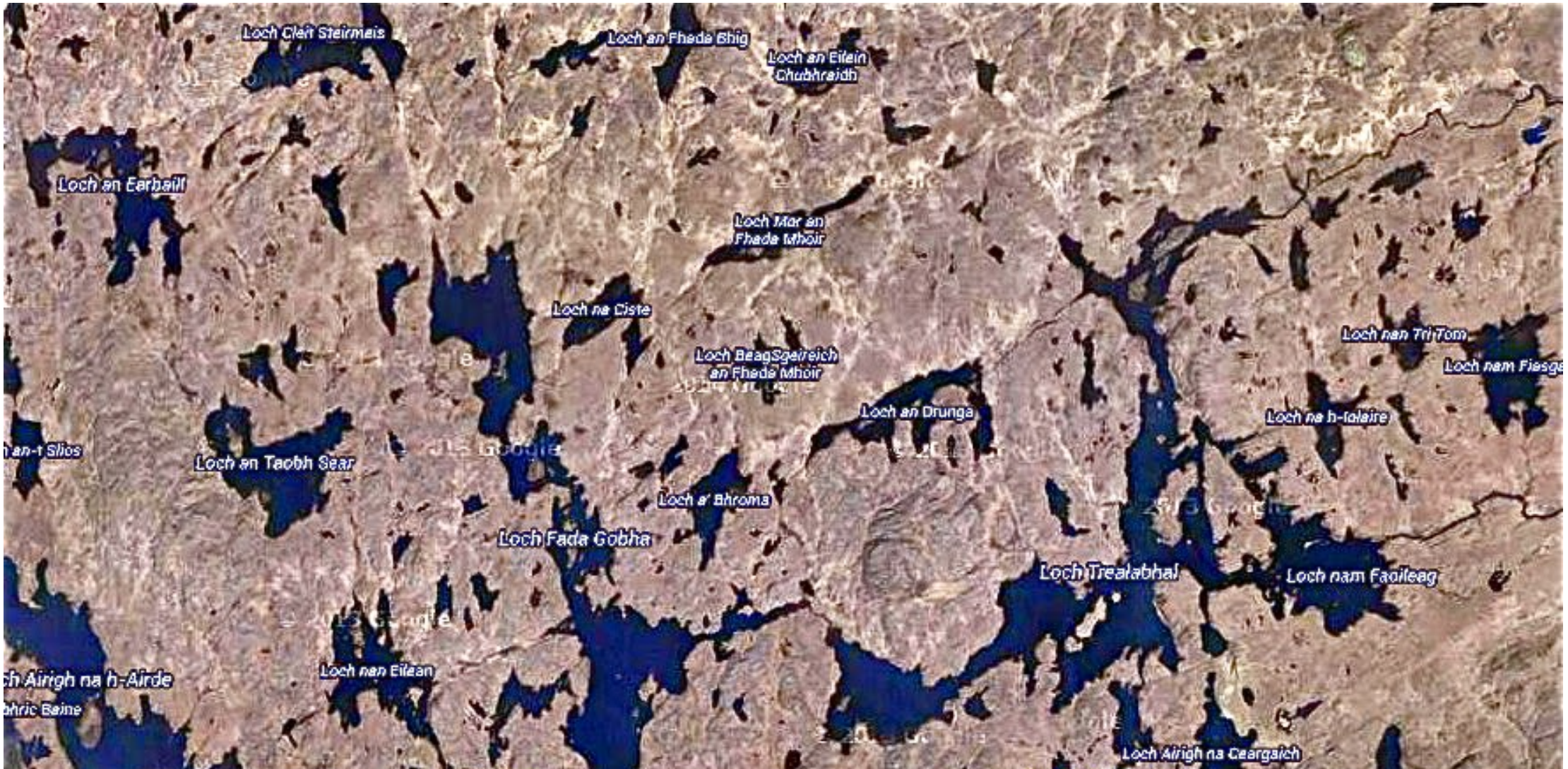


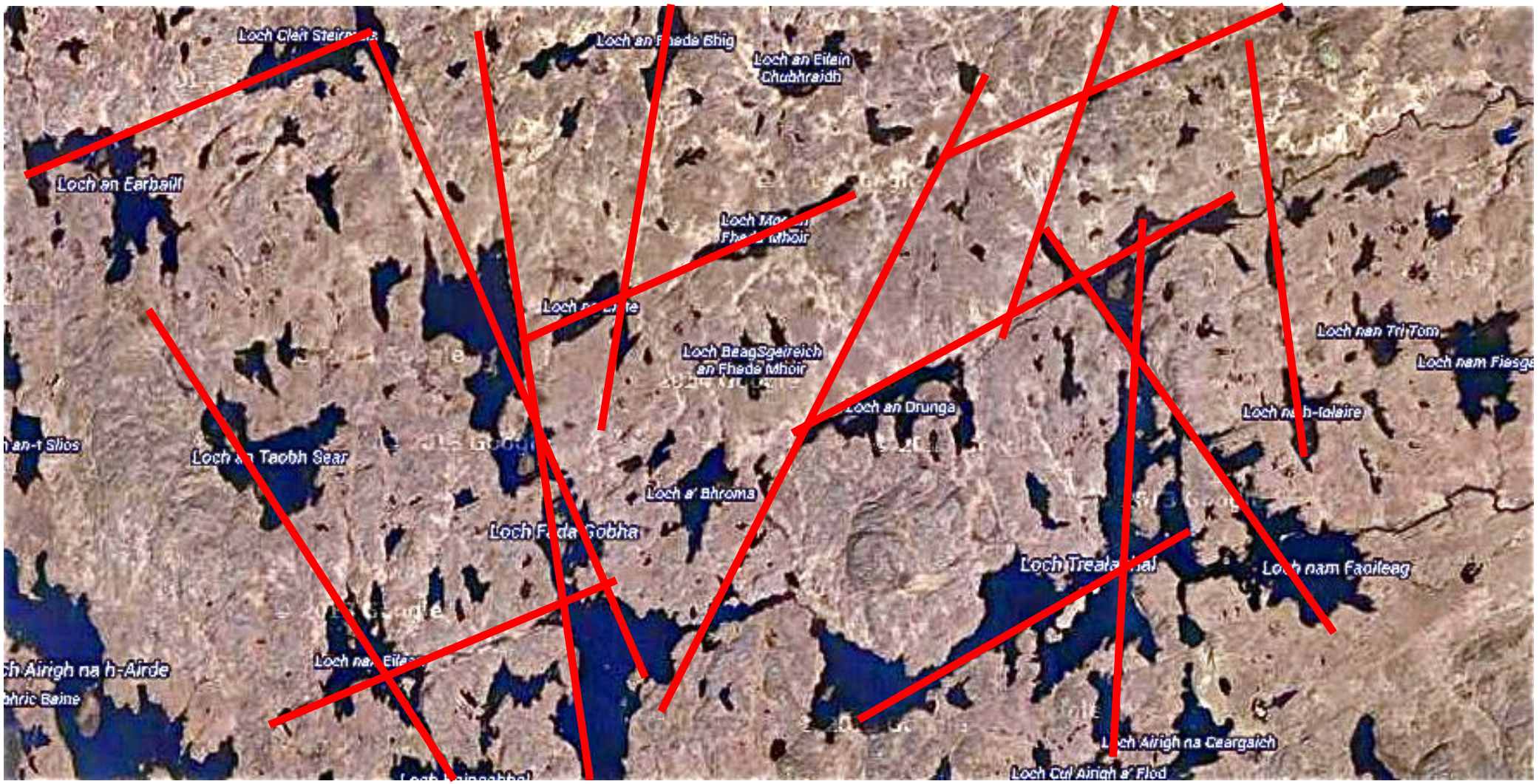
Stress-Relief Fractures

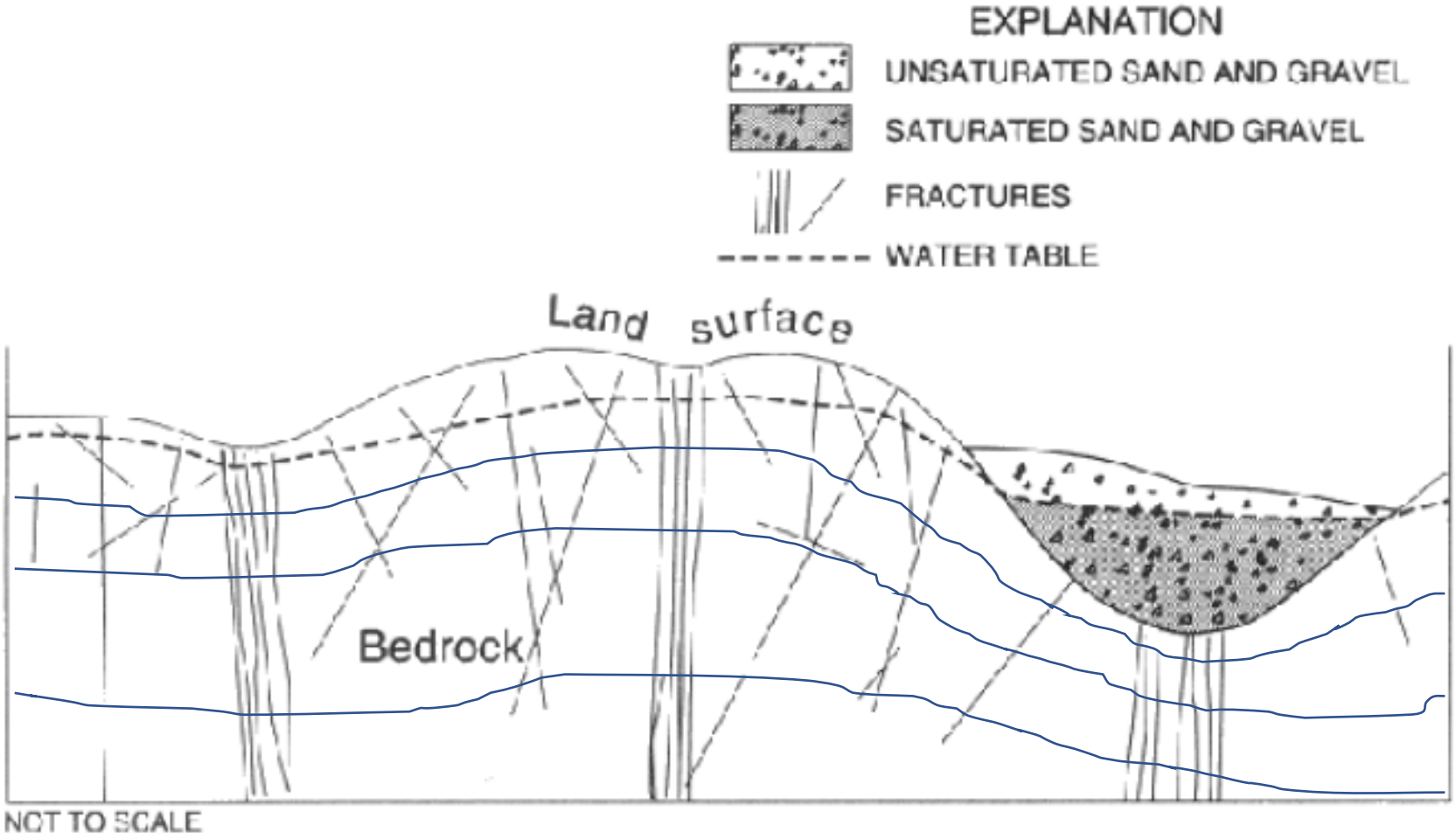


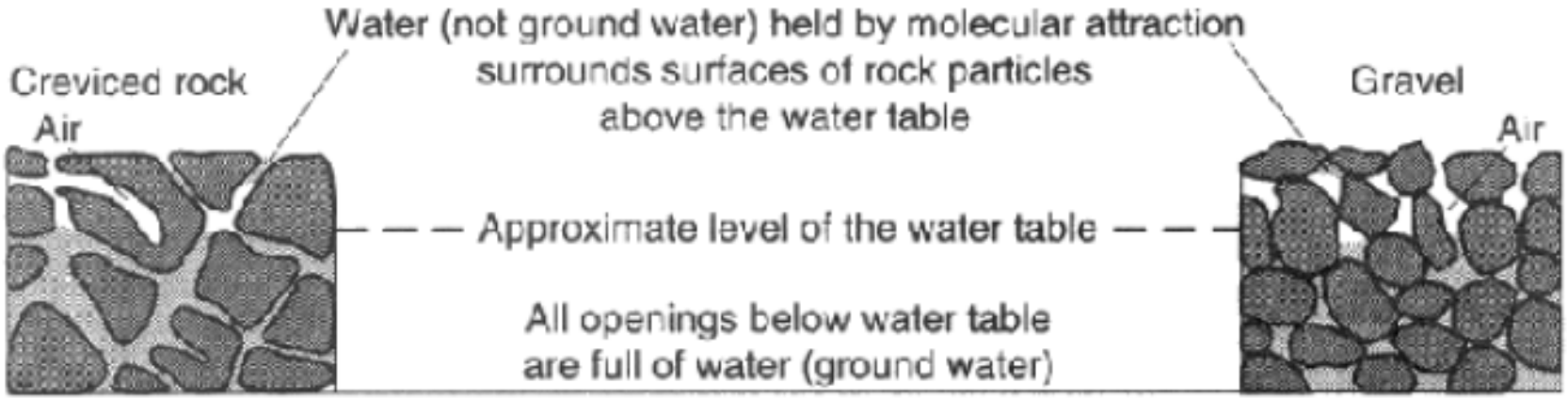


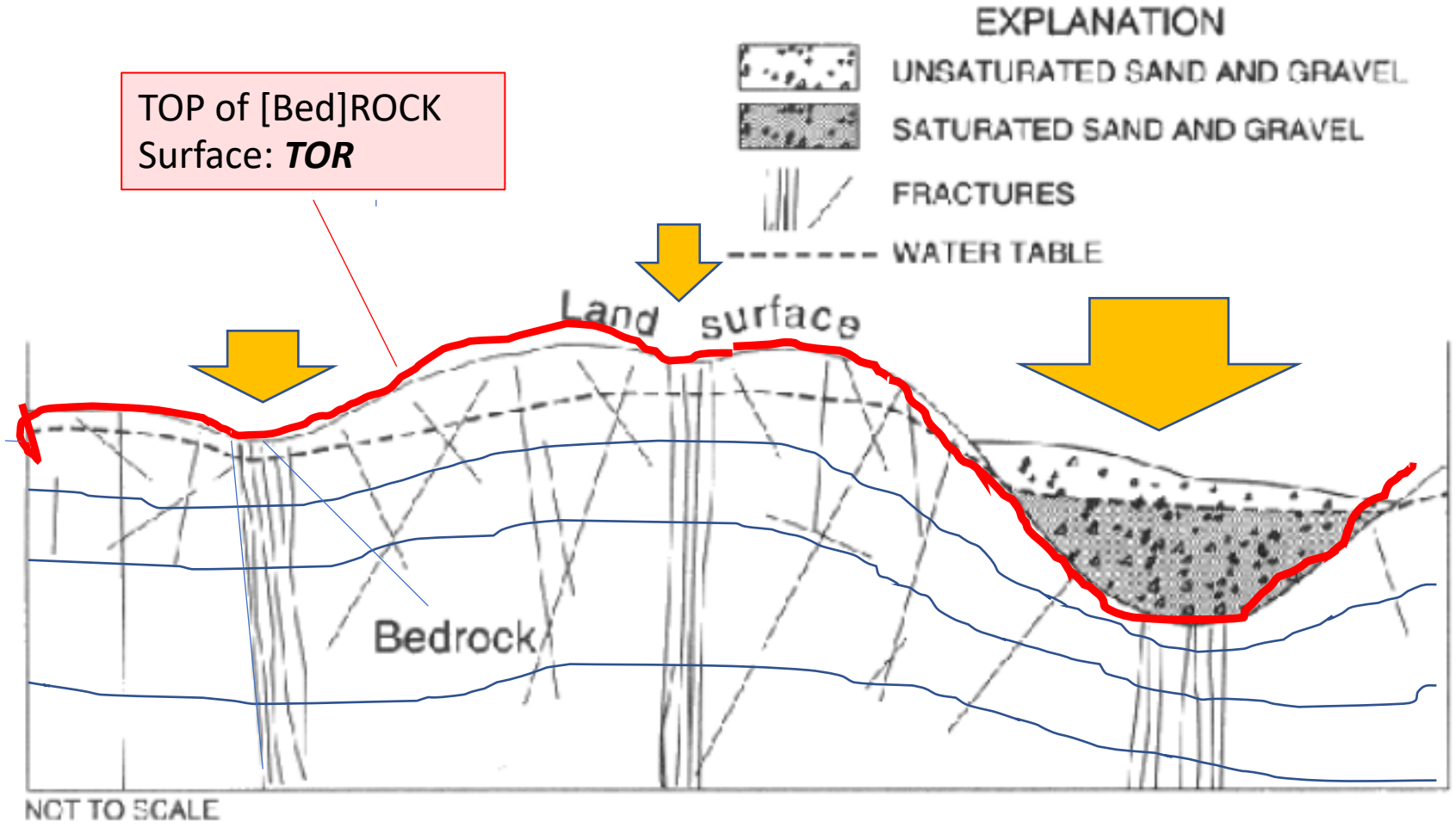
Regional Effects of Continental Glaciation

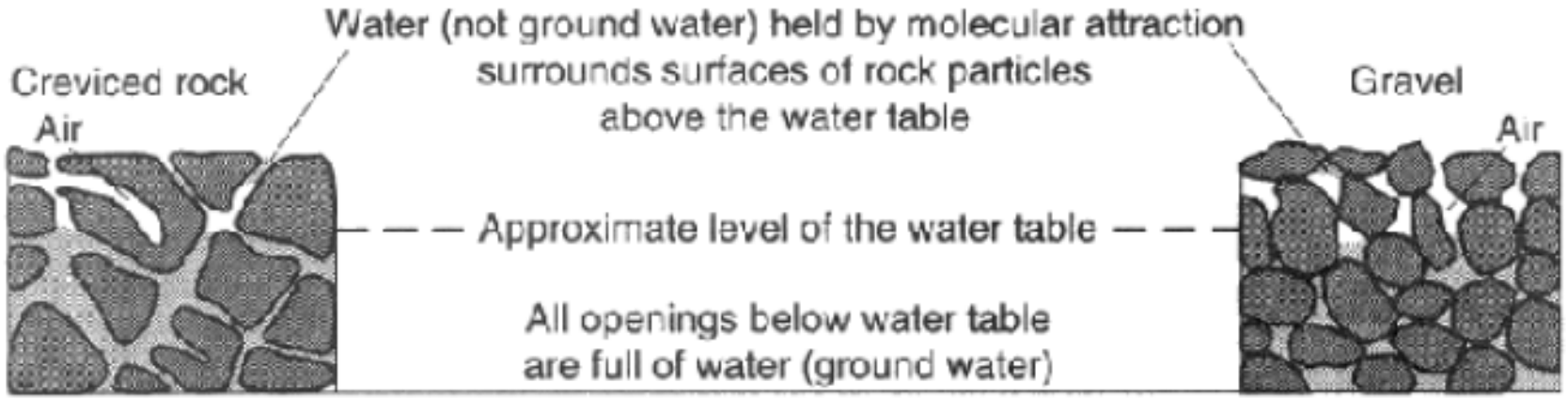



Loch an Eilein Chubhraidh
Loch an Eirbaill
Loch BeagSgaireich an Fheadha Mhoir
Loch nan Tri Tom
Loch an Druinga
Loch a' Bhroma
Loch nam Faoileag
Loch Airigh na Ceargaich


EXPLANATION
UNSATURATED SAND AND GRAVEL
SATURATED SAND AND GRAVEL
FRACTURES
WATER TABLE
Land surface
Bedrock
NOT TO SCALE


Water (not ground water) held by molecular attraction
surrounds surfaces of rock particles
above the water table
Creviced rock
Air
Gravel
Air
Approximate level of the water table
All openings below water table
are full of water (ground water)


TOP of [Bed]ROCK Surface: ***TOR***
EXPLANATION
UNSATURATED SAND AND GRAVEL
SATURATED SAND AND GRAVEL
FRACTURES
WATER TABLE
Land surface
Bedrock
NOT TO SCALE


Water (not ground water) held by molecular attraction surrounds surfaces of rock particles above the water table
Creviced rock
Air
Gravel
Air
Approximate level of the water table
All openings below water table are full of water (ground water)

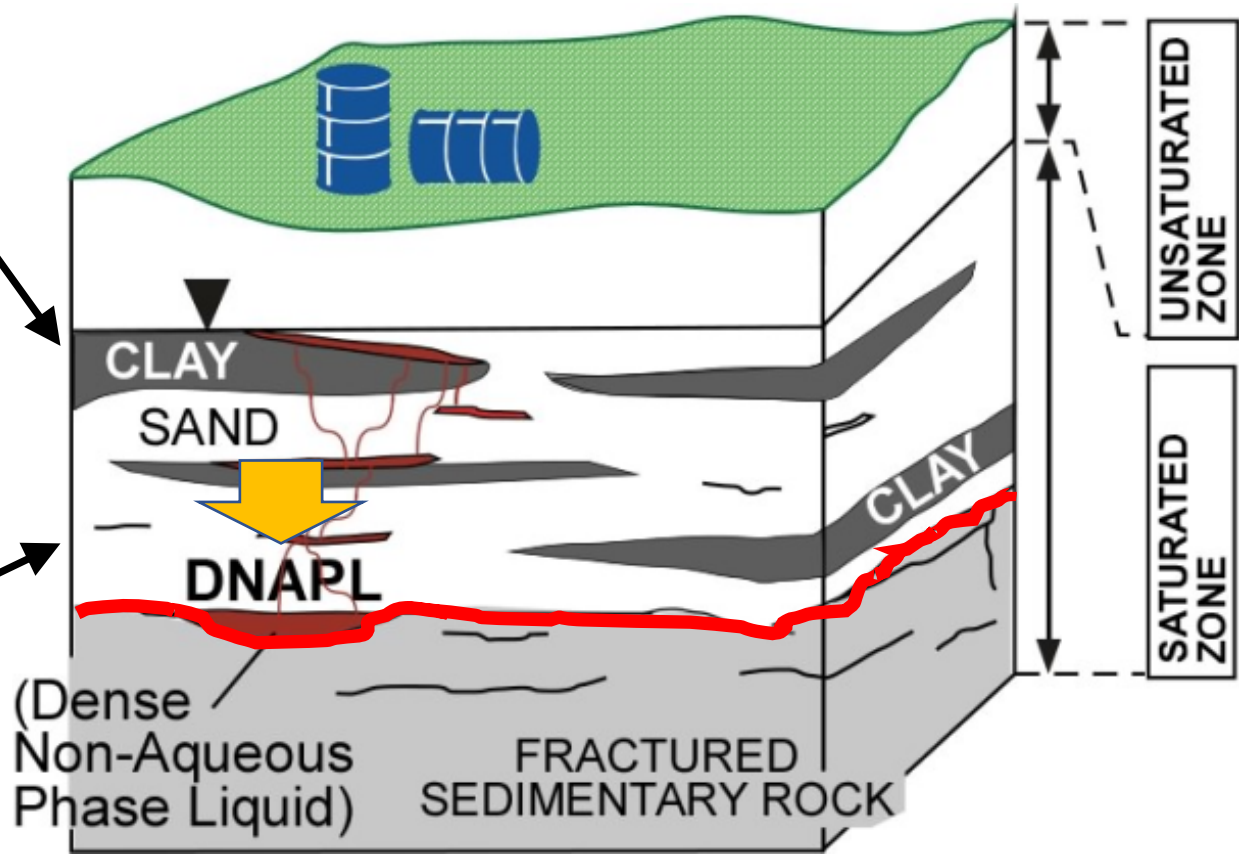
Dual Porosity in Unconsolidated Media

Immobile Porosity

Relatively low permeability bypassed by advective flow and dominated by diffusive flux

Mobile Porosity

Relatively high permeability and dominated by advective flow



Source: Chuck Newell and Tom Sale

Selected Data Objectives for Remedial Investigations in Bedrock Terrains

- **Morphology (Shape) of TOR surface**
- Identification mapping of contaminant storage reservoirs and contaminant migration pathways
- Identification of significant fracture zones
- Mapping of Spatial position of interconnected fracture pathways in bedrock
- Hydraulic characteristics of unfractured or lightly fractured matrix and more highly fractured regions within rock mass
- Characterization of mineralogical or other factors such as chemical weathering which may affect fate and transport of contaminants..
- (*More on this at NARPM)*

Bedrock Investigation Tools and Methods

- Linear Trace Analysis
- Geologic Mapping
- Surface Geophysical Surveys
- Drilling and Coring into Bedrock
- Borehole Geophysics
- Borehole testing
- Hydraulic
- Chemical
- Interconnectivity Testing
- *Much More on this at NARPM*

A few Words on Conceptual Site Models in Bedrock Environments

Similar to CSM development in unconsolidated deposits…

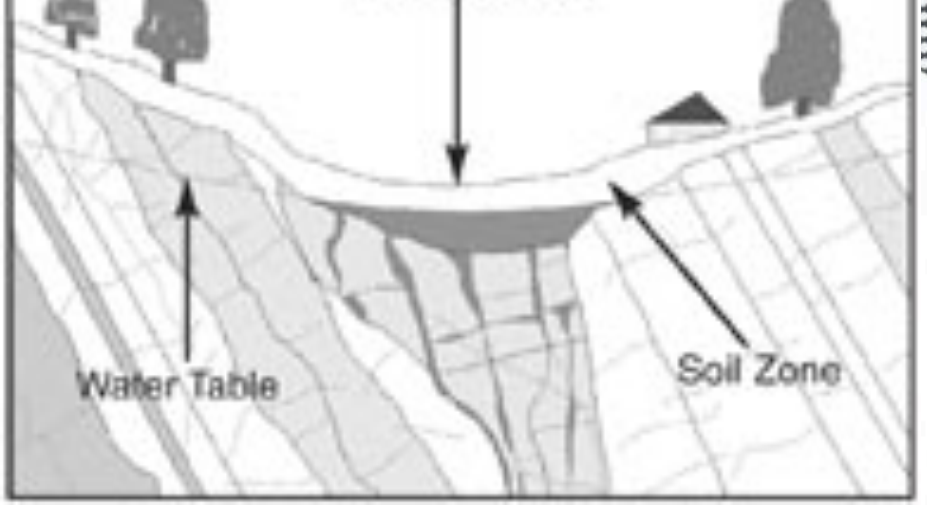
- Sources
- Migration Pathways
- Receptors

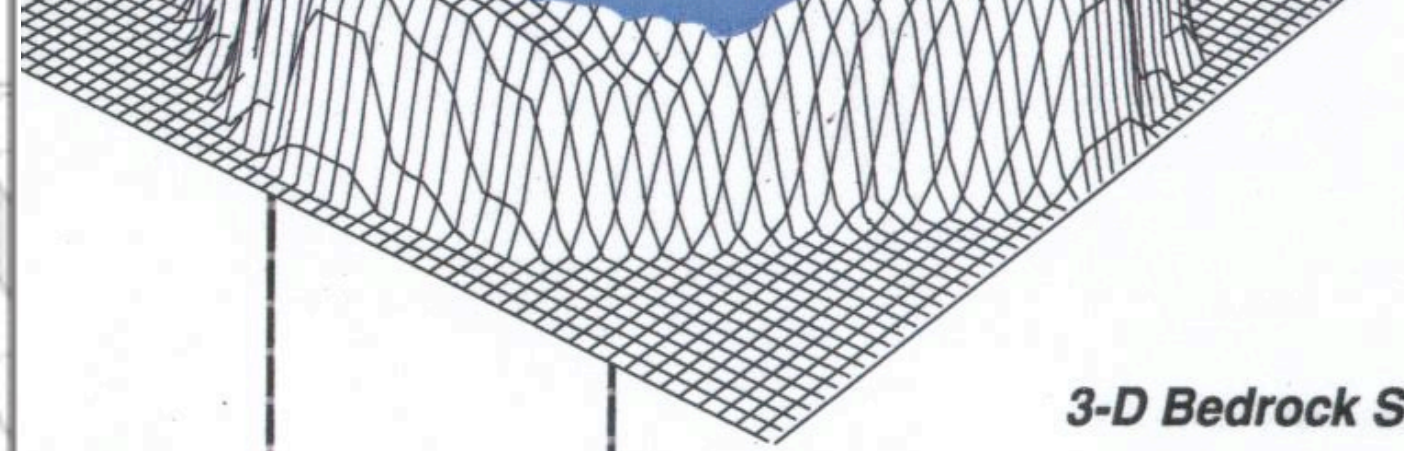
But More difficult and expensive due to greater depths of investigation and other factors..

More unforgiving due to inherent complexity of fractured rock

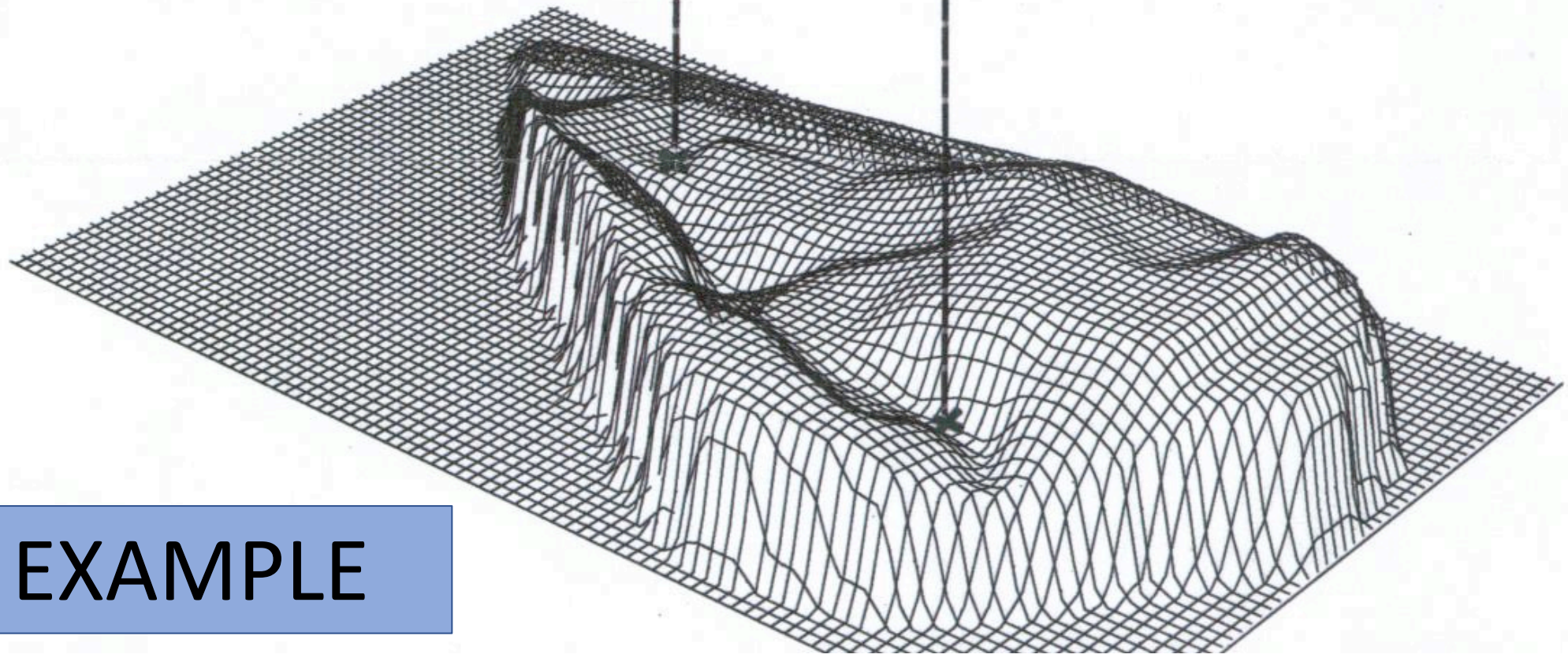
Punishing to the geologically ignorant

Much More on this at NARPM ..





3-D Bedrock Surface



CSM EXAMPLE

Does your CSM need a 3D Geologic Makeover?

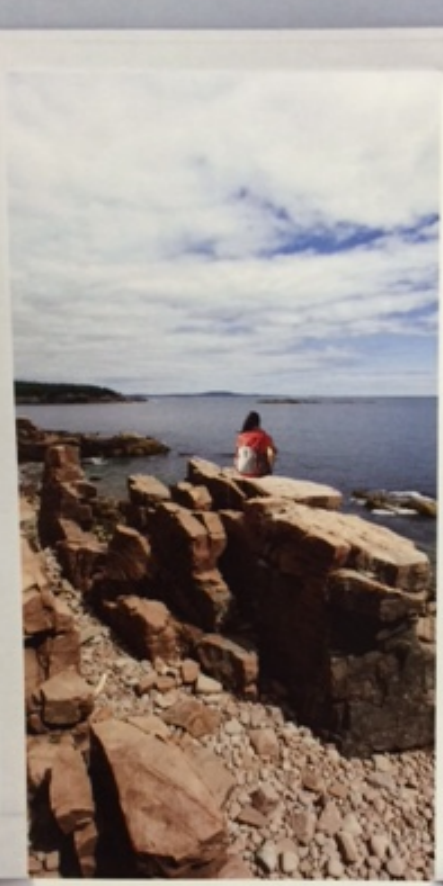
- Robust Geological Model Informs CSM and Determines Characterization Approach and Remedial Strategy
- Essential for early-phase site characterization
- Retrospective Application to Existing Sites
- –Optimize Existing Remedies
- –Adjust Monitoring Networks

- When all else fails…ignore above and punt with “Equivalent Porous Media” approach and/or use modeling approaches to overcompensate for poor geologic understanding

SCRAP HEAP OF FAILED NON-GEOLOGIC CSM's

If only my team had paid attention in those "Rocks For Jocks" classes

Scientific Integrity



gets you there...

EPA

robust science
clean environment
healthy communities

http://www.epa.gov/scientificintegrity