Till

SPATIALLY VARIABLE, COMPLEX, AND DENSE

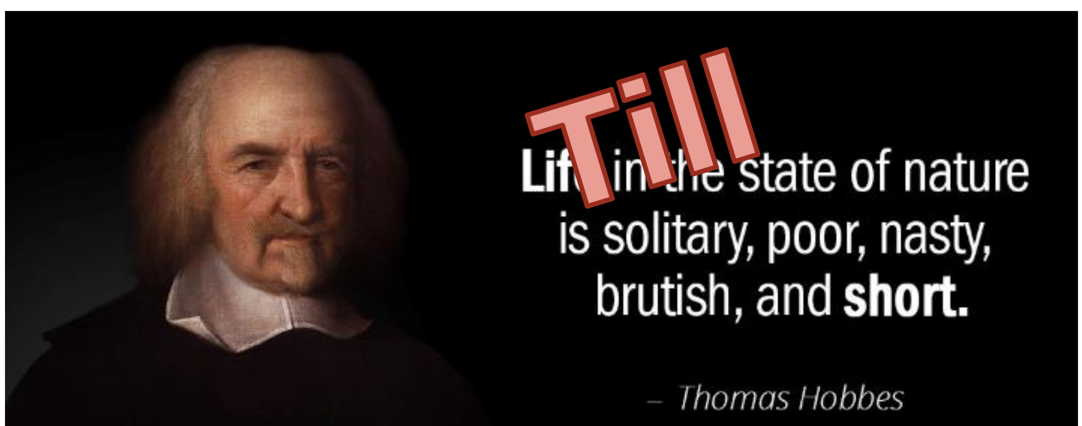
Carrie Jennings

University of Minnesota

and

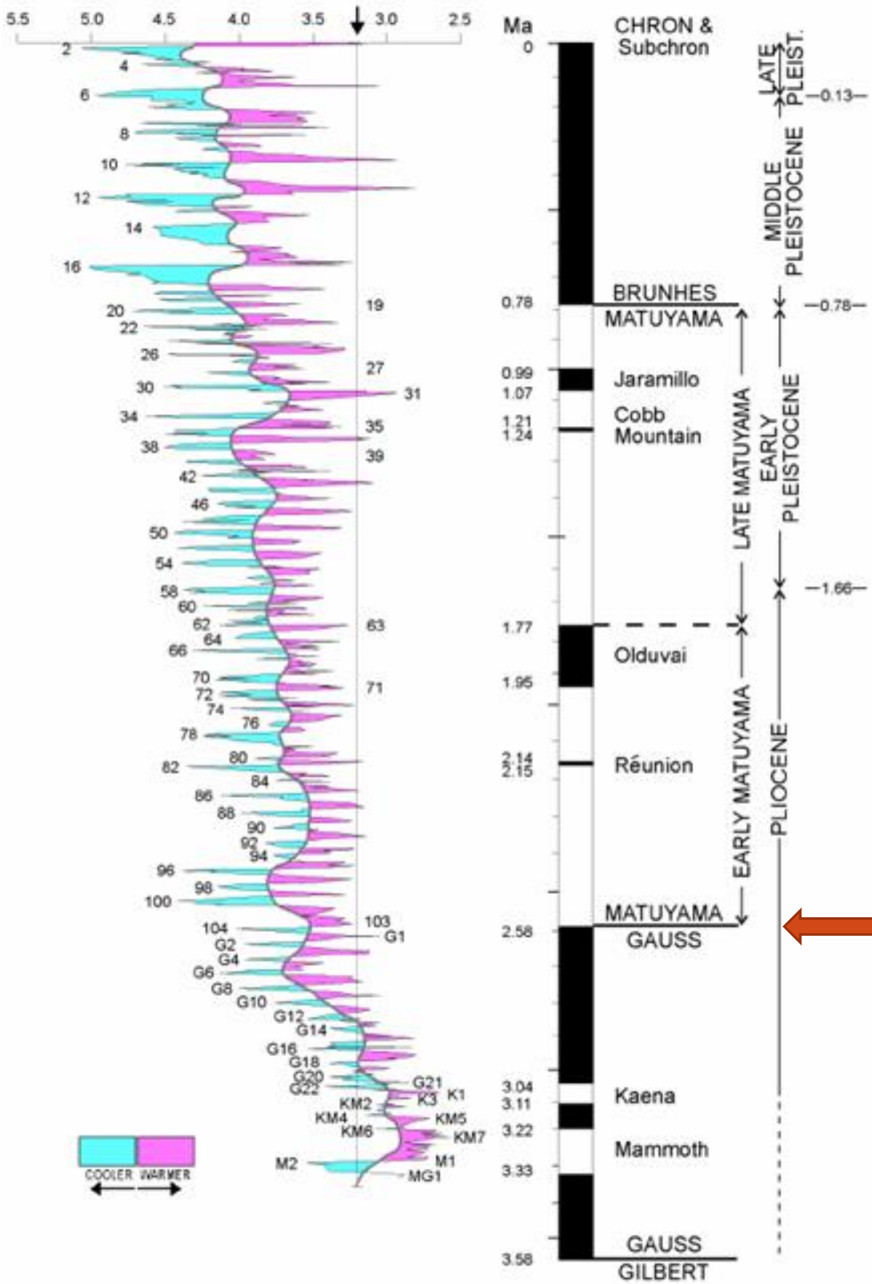
Freshwater

with apologies to Thomas Hobbes



THICK TILL STACK TO UNDERSTAND

LOTS OF GLACIAL PERIODS



Lisiecki and Raymo, 2005

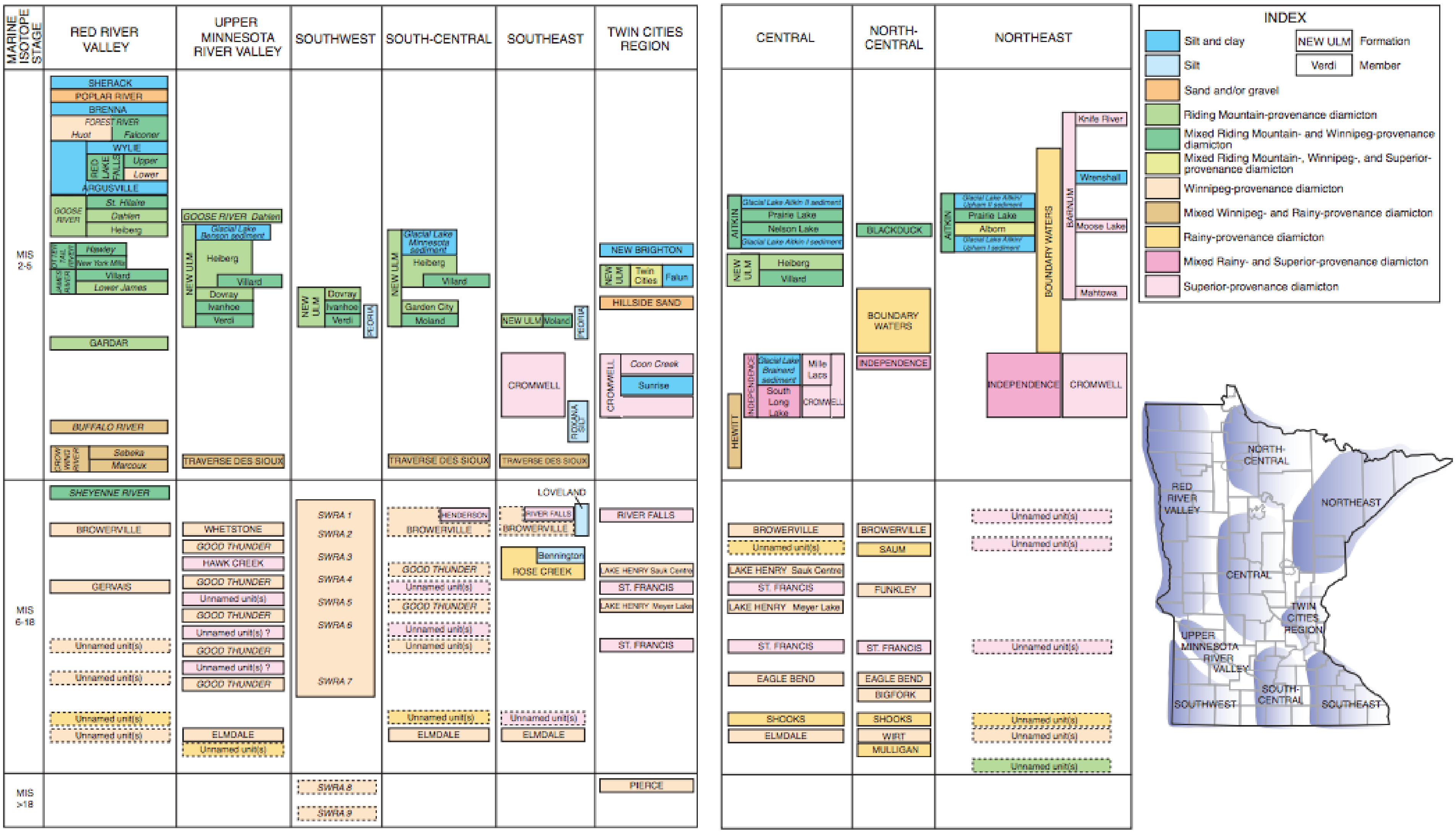


Figure 11. Stratigraphic columns and correlation for the Quaternary lithostratigraphic units of Minnesota. Each column represents the stratigraphy for the region shown on the map (inset). The vertical scale is relative time, although all units are broadly correlated to the marine isotope stages (MIS; left column). The Brunhes-Matuyama magnetic-reversal boundary occurred prior to MIS 18, and sediments with known reversed polarity are therefore considered to be older than MIS 18. However, many units have not been analyzed for their paleomagnetism, and it is likely that some older units shown on this chart may be older than MIS 18. Correlation of individual units from region to region is tenuous. The correlation section within each chapter of this report explains the correlations shown here, and the degree of uncertainty associated with the correlations. Units with dashed boundaries are either undefined or have an uncertain stratigraphic position. Italicized names (for example, *GOOD THUNDER* or *Dahlen*) are not yet formally defined.

GLACIAL PROCESSES AND DEPOSITS

- Glaciology—physics of ice movement
- Glacial Geology—sedimentary record of glaciation

TILL

- Product of the glacial erosion, transportation and deposition
- Inherent variability makes it difficult to sample, test and classify them
- In Minnesota, tills in the subsurface may also have been subjected to several glacial cycles, soil development and periglacial processes

FOR FULL CLASSIFICATION:

- Lithology and texture of components
- Stratigraphic position and age
- Mode of deposition—link facies characteristics to processes
- Hydraulic and engineering behavior

DIAMICTON IS NOT A DIRTY WORD

- Non-genetic

  di = two

  mict = mixture

- Bi-modal distribution

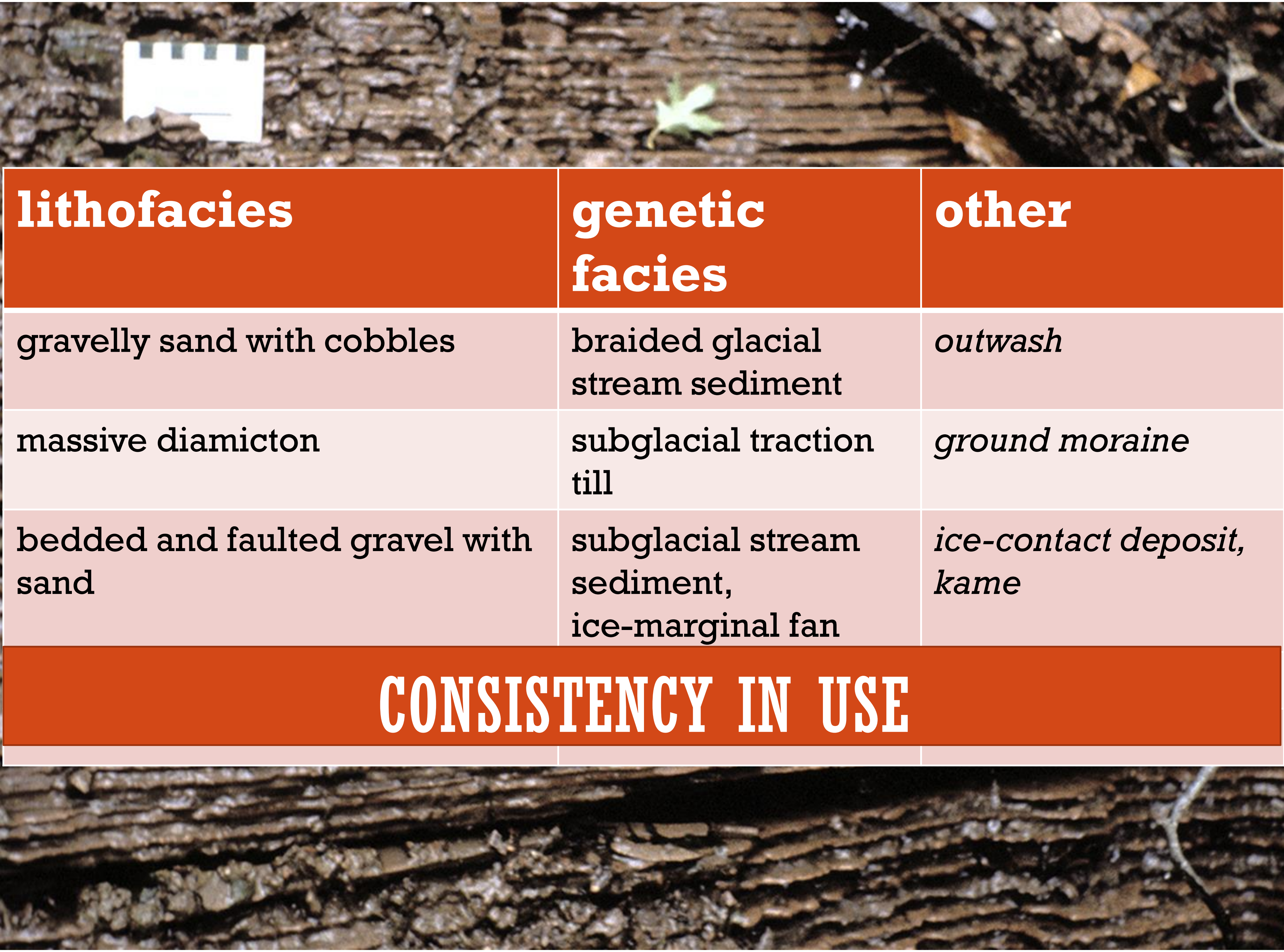
  matrix

  clasts

- Rock fragments suspended in a matrix
- Diamicton (sediment), diamictite (rock), diamict (rock or sediment)

Classification Approaches

- Lithologic or non-genetic
  - Has a tendency to be overly complex and repetitive
- Genetic
  - Emphasizes links between facies characteristics, processes and depositional environments
- I prefer a combination of both with descriptions of distinguishing features like:
  - Grain size distribution
  - Particle morphology
  - Fabric
  - Internal structures
  - Facies dimensions and geometry of unit
  - Nature of the contacts



lithofacies	genetic facies	other
gravelly sand with cobbles	braided glacial stream sediment	*outwash*
massive diamicton	subglacial traction till	*ground moraine*
bedded and faulted gravel with sand	subglacial stream sediment, ice-marginal fan	*ice-contact deposit, kame*

CONSISTENCY IN USE

3 PRINCIPAL SUBSTRATES

- Frozen bed
- Unfrozen rock bed
- Unfrozen, unlithified sedime

Margin of an Icelandic Glacier, Photo by Mark Johnson

gknight.com/photos/g21.jpg

UNFROZEN ROCK BEDS = YOUR GLACIAL CLASS?

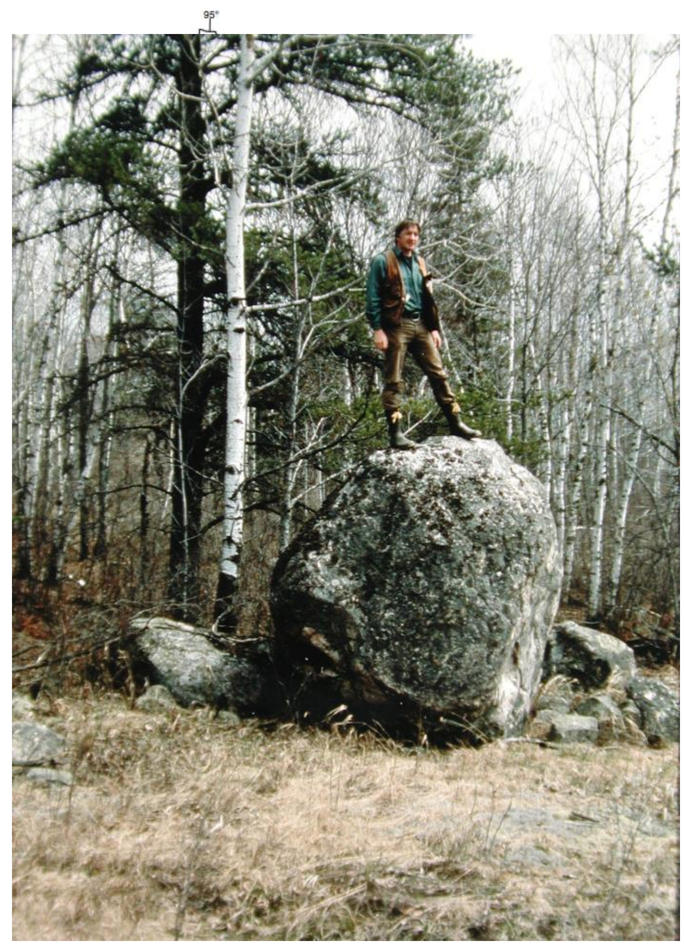
- Erosion by plucking and abrasion
  - Smoothed, striated, rock landforms
- Debris—(silt) produced by crushing
- Incorporated into ice and transported as glacier slides
- Debris-rich basal ice layer produces till

Margin of a Scandinavian bedrock valley glacier,

Photo provided by Andy Breckenridge

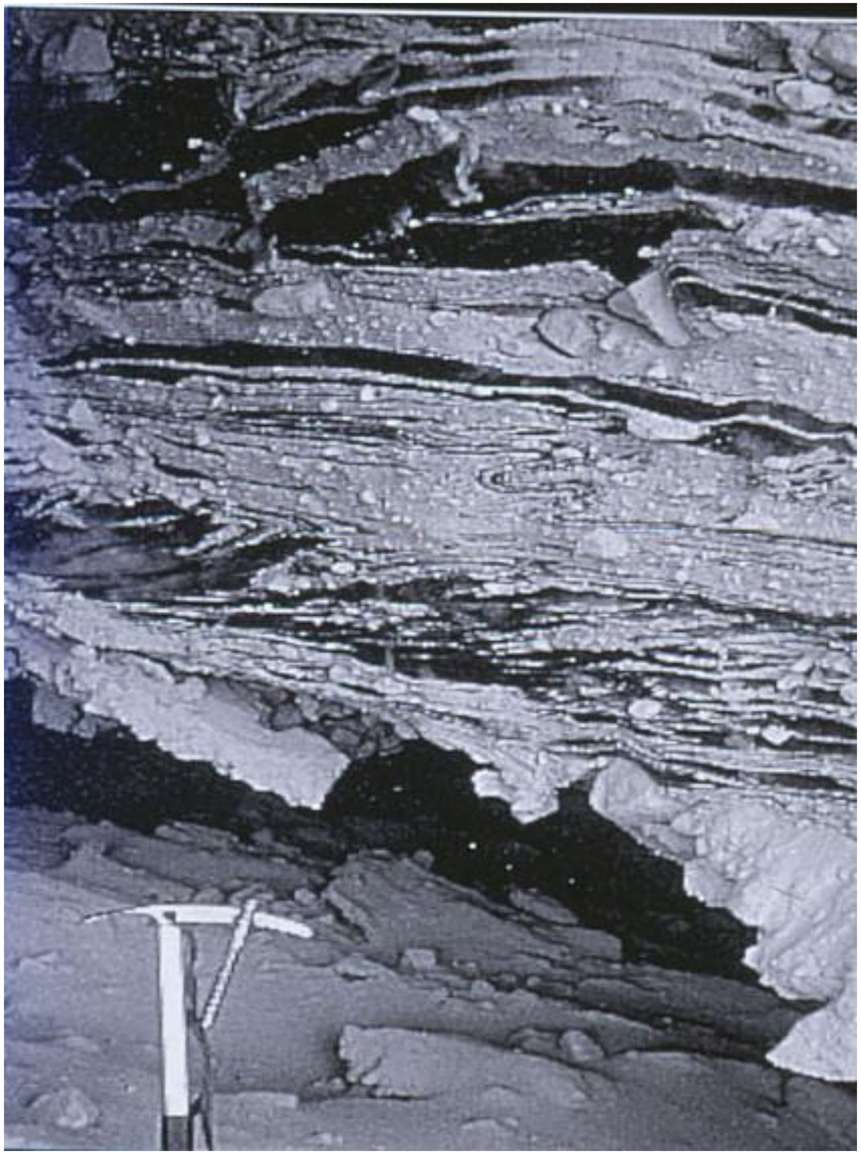
MAY BE RELEVANT IN NE MINNESOTA

- And even there, the inferred former presence of a thick saprolite may have created a soft bed for the ice.



BASAL-ICE MAY PRODUCE:

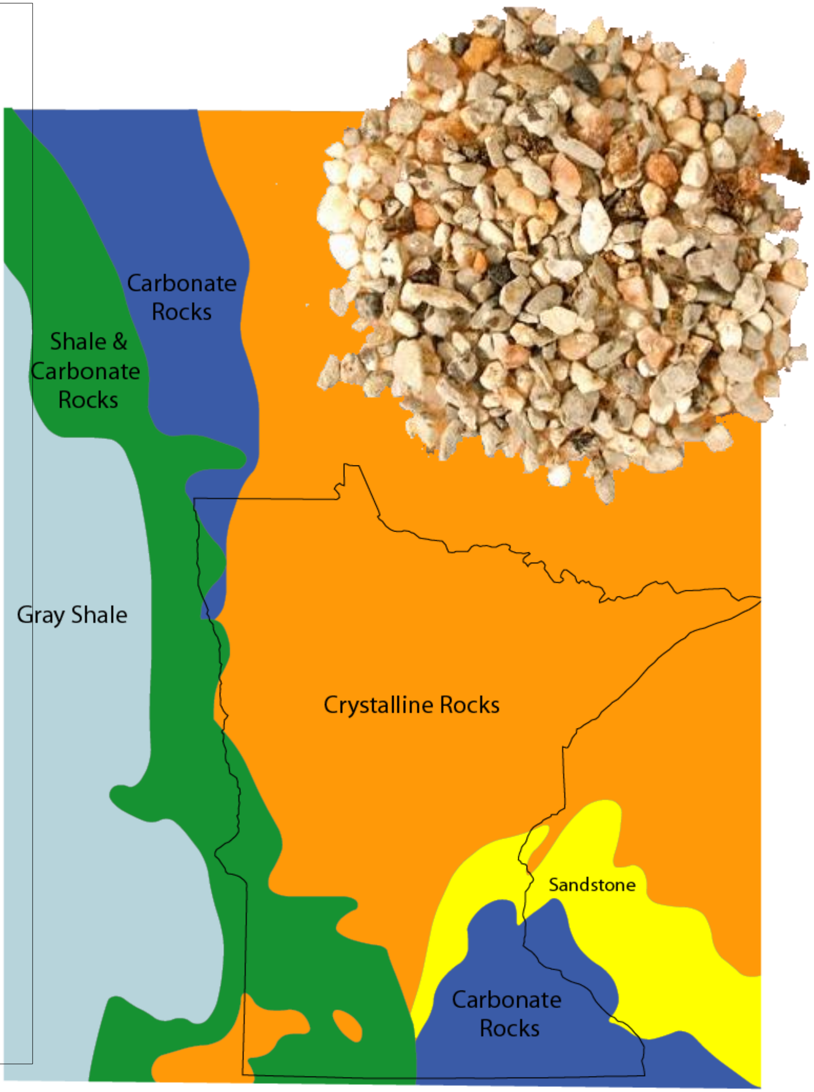
MELT-OUT TILL
LODGEMENT TILL



MELTOUT TILL

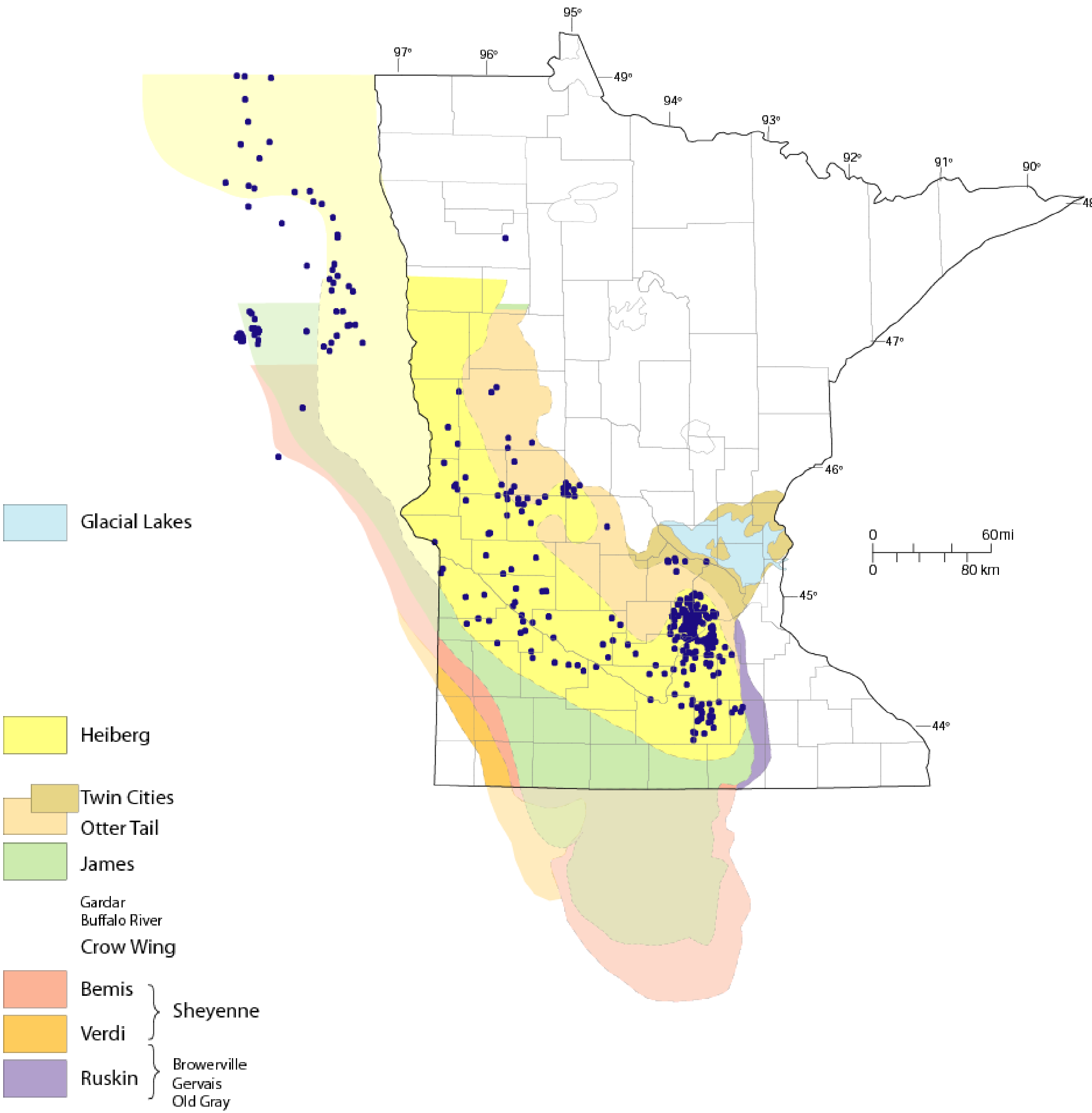
- stagnant or slow-moving ice
- poorly consolidated
  - not subjected to high pressures or shear
- variable texture
- relatively low density

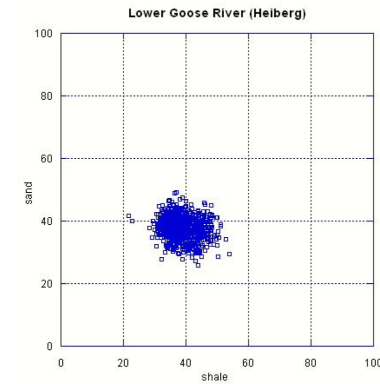
NOT THE WAY OUR ICE LOBES WORKED

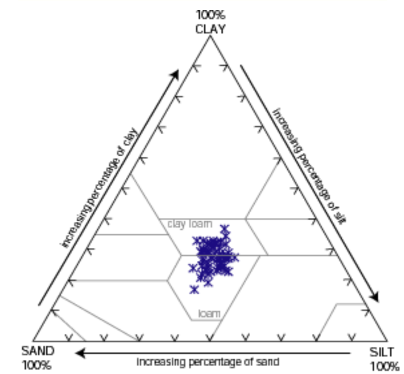


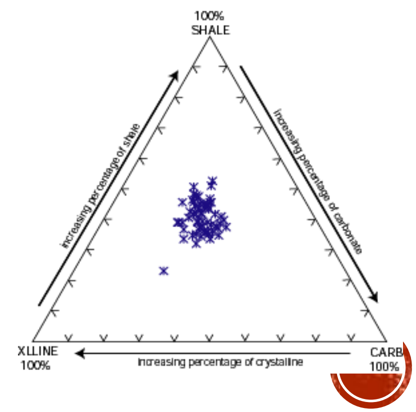
TYPICAL DES MOINES LOBE

COARSE SAND (1-2 MM) FRACTION


95°
97°
96°
49°
94°
93°
92°
91°
90°
48°
47°
46°
45°
44°
0 60mi
0 80 km
Glacial Lakes
Heiberg
Twin Cities
Otter Tail
James
Gardar
Buffalo River
Crow Wing
Bemis
Verdi
Sheyenne
Ruskin
Browerville
Gervais
Old Gray


Lower Goose River (Heiberg)
sand
shale
0
20
40
60
80
100

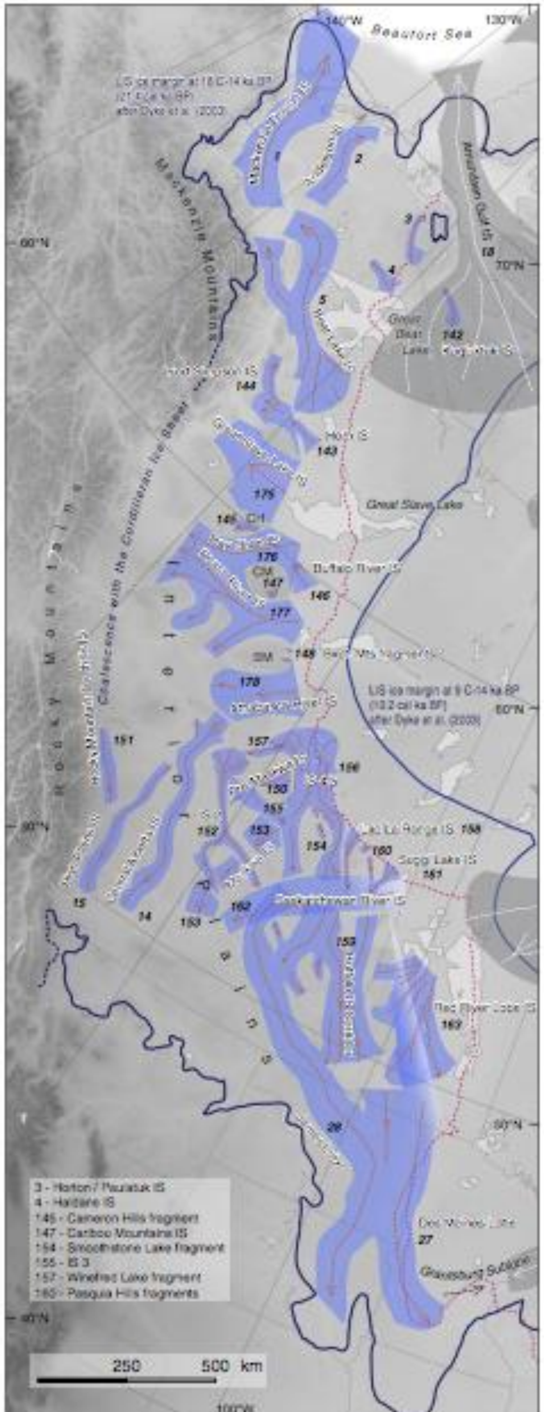

100%
CLAY
increasing percentage of clay
increasing percentage of silt
clay loam
loam
SAND
100%
SILT
100%
increasing percentage of sand

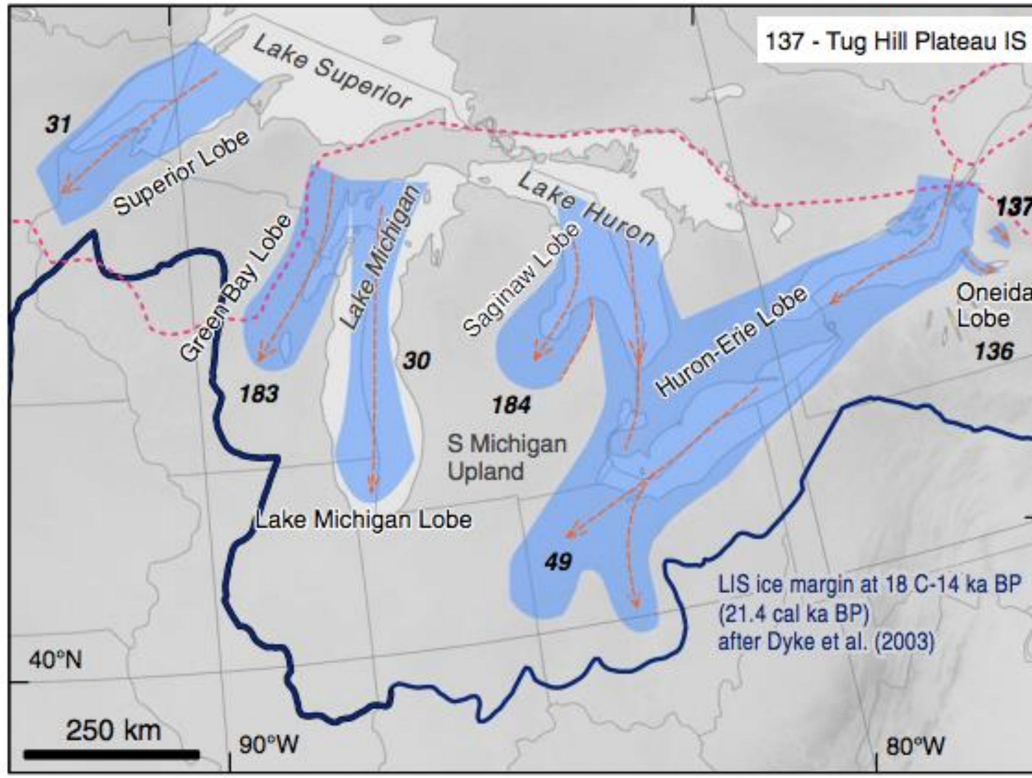

100%
SHALE
increasing percentage of shale
increasing percentage of carbonate
XLLINE
100%
CARB
100%
increasing percentage of crystalline

Ice streams in the Laurentide Ice Sheet: Identification, characteristics and comparison to modern ice sheets

Martin Margold [a,*], Chris R. Stokes [a], Chris D. Clark [b]

[a] Durham University, Department of Geography, Lower Mountjoy, South Road, Durham DH1 3LE, UK
[b] University of Sheffield, Department of Geography, Western Bank, Sheffield S10 2TN, UK





ns in the region of the Great Lakes (see Fig. 2 for location). Ice flow pattern of this ice sheet sector is described in Section 4.3 and more information abo
ilable in Supplementary data. Boundary of the Canadian Shield is marked by a pink stippled line (medium grey if viewing a black and white version of the

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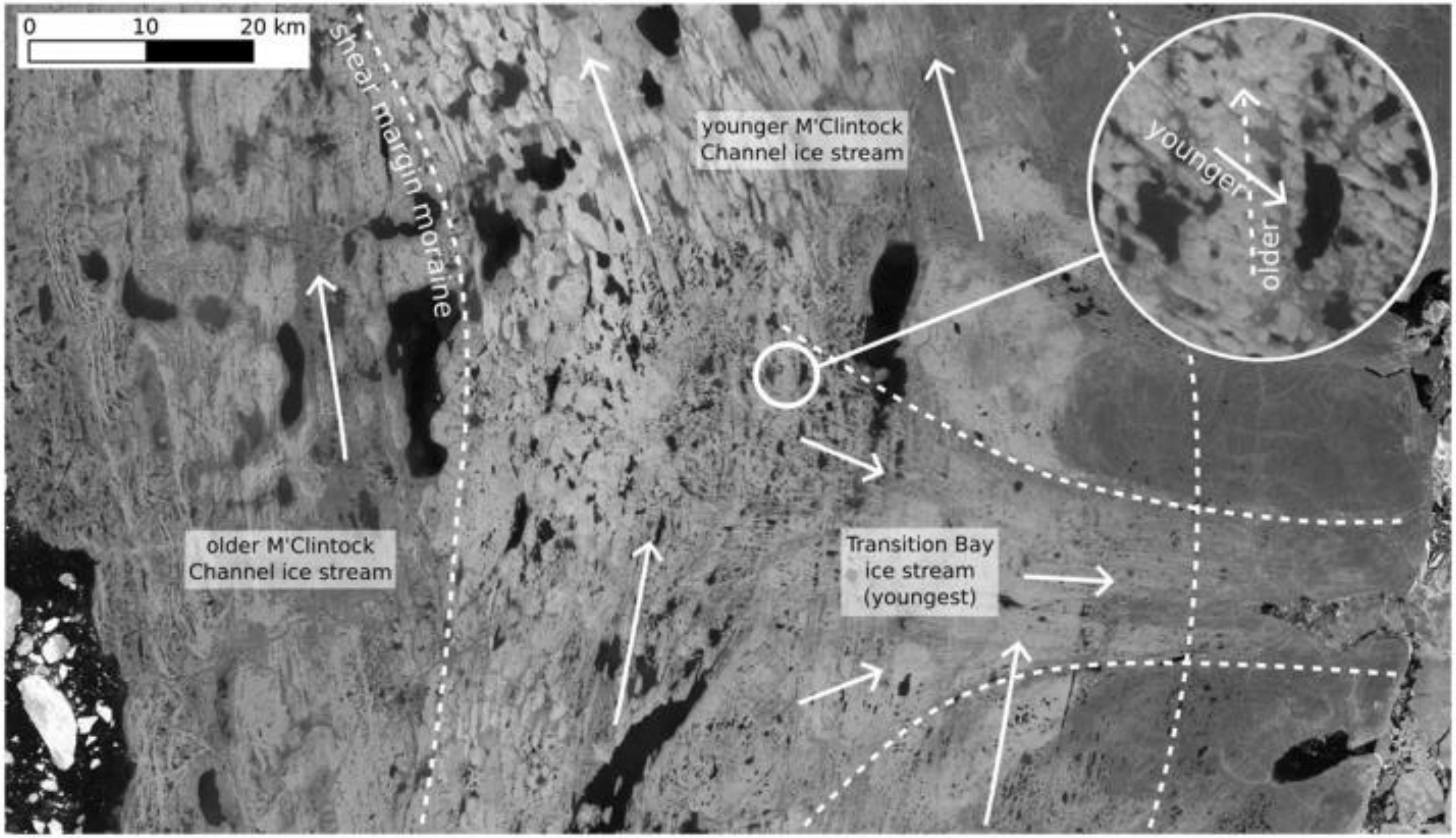

Fig. 4. Panchromatic Landsat image of southern Prince of Wales Island (reprinted with permission from De Angelis, 2007). Elongated bedforms depict changing ice flow directions. Boundaries of fast ice flow are indicated by a shear margin moraine (see Dyke and Morris, 1988; Stokes and Clark, 2002) running S–N across the centre of the image and by the outline of a sediment dispersal train in the case of the Transition Bay Ice Stream that flowed in easterly direction in the lower right part of the image.

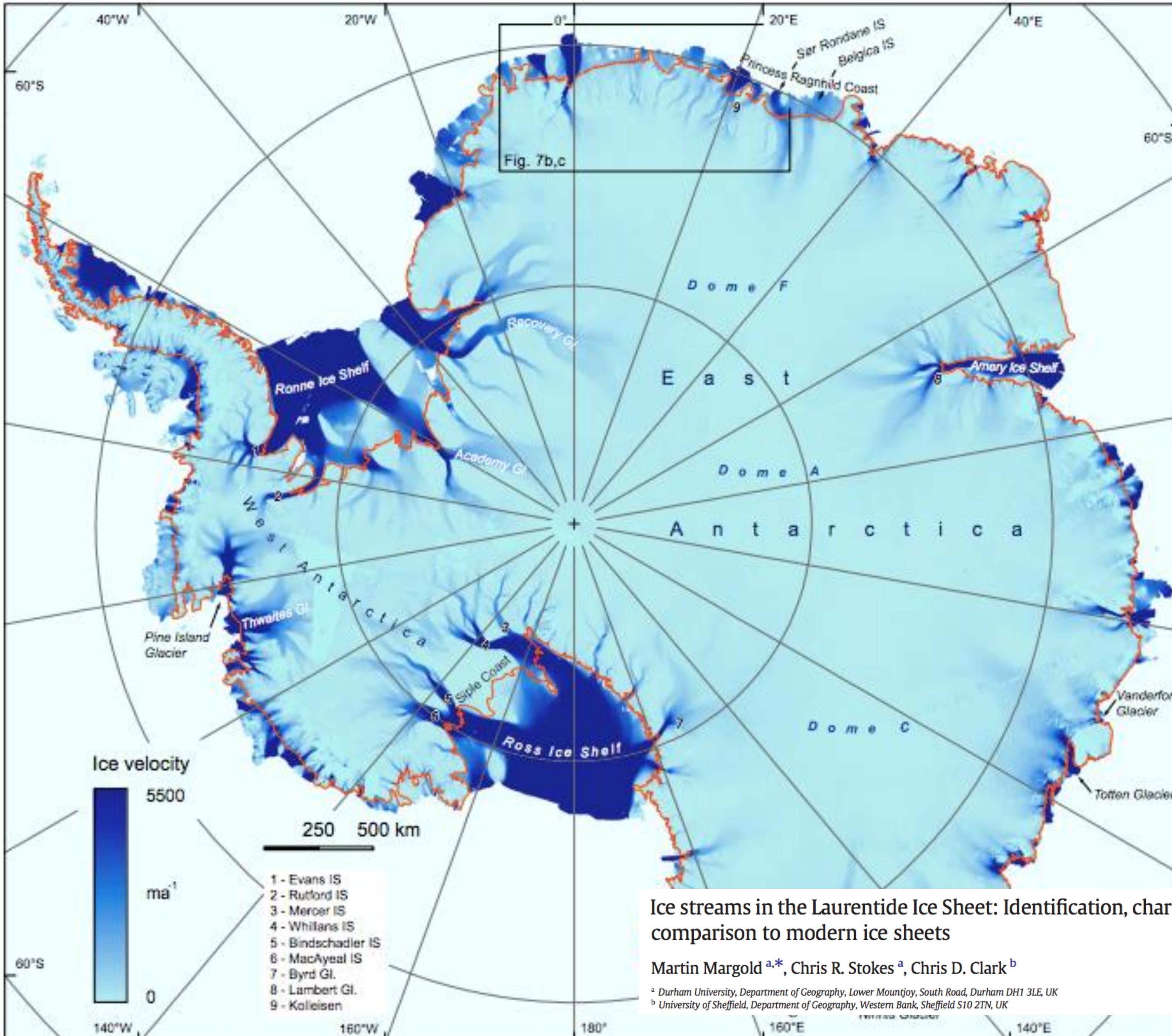

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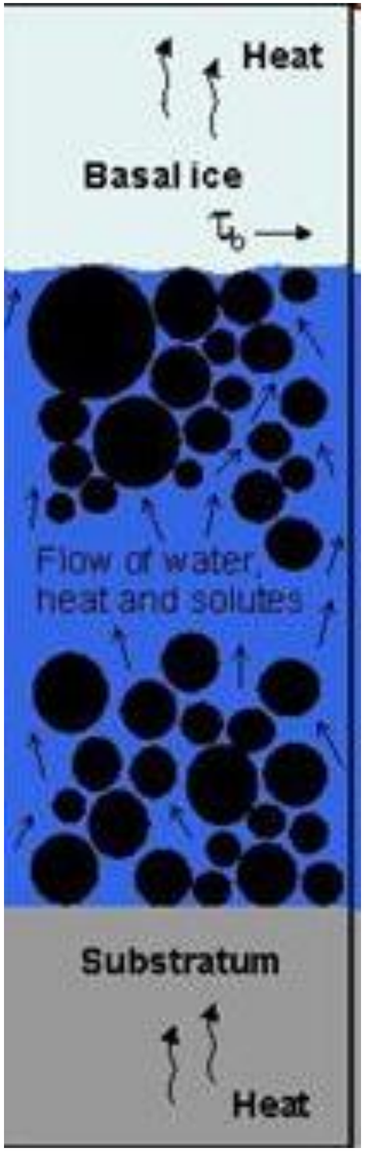
Fig. 1. Ice flow of the Antarctic ice sheets from Rignot et al. (2011c). Ice sheet grounding line (from Rignot et al., 2011a) is shown in orange (medium grey if viewing a black and white version of the manuscript). Ice streams mentioned in the text are marked, as well as the location of Fig. 7b and c. This figure is drawn to the same scale as Fig. 2.

UNFROZEN, UNLITHIFIED SEDIMENT BED

- Active area of research
  - Dr. Neal Iverson, Iowa
- How is till made and deposited from these processes?



SUBGLACIAL TRACTION IS KEY ISSUE

- For glaciology because it controls:
  - Strength of coupling of ice and bed
  - Response of glacier to driving forces
- For glacial geology because it controls:
  - Spatial and temporal patterns of erosion and deposition

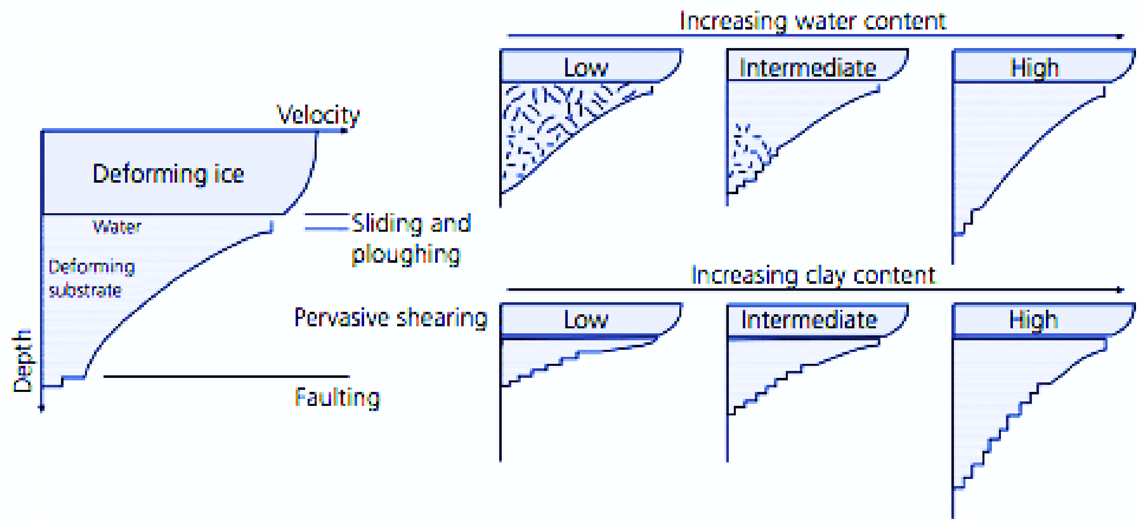


Figure 3. The effect of water content and clay content on the deformation of the substrate (after Alley (1989), Menzies (1989) and van de Meer *et al.* (2003)). An increase in water or clay content increases the depth of deformation and a possible switch from a brittle to a ductile behaviour

OBSERVATIONS

- deforming horizon is thin—
  - typically less than .5 m
- common to find shear and drag fold structures in glacial sediment
- deformation at greater depths has been interpreted as stacked shear "packages"

VARIABILITY IN GLACIAL SEDIMENT SEQUENCE

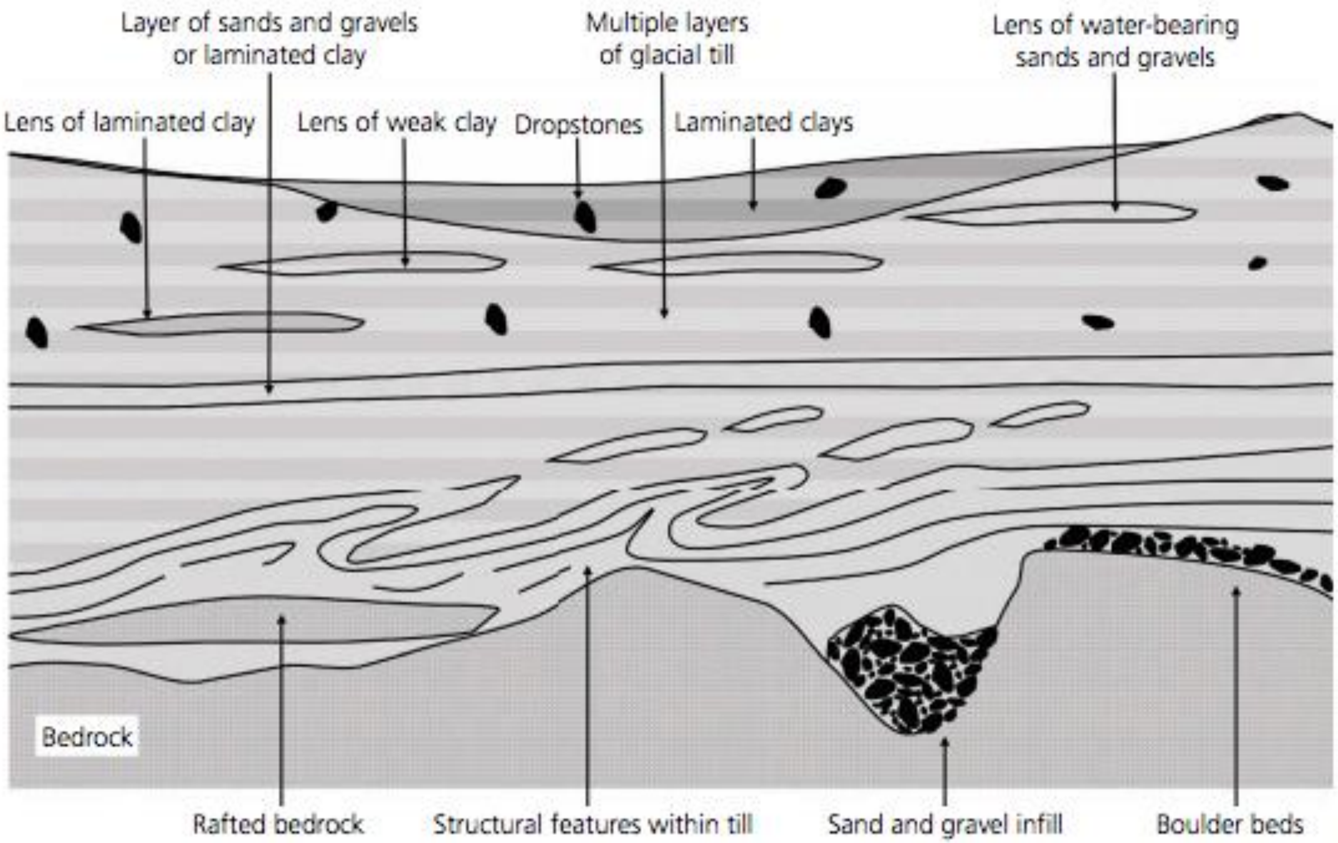
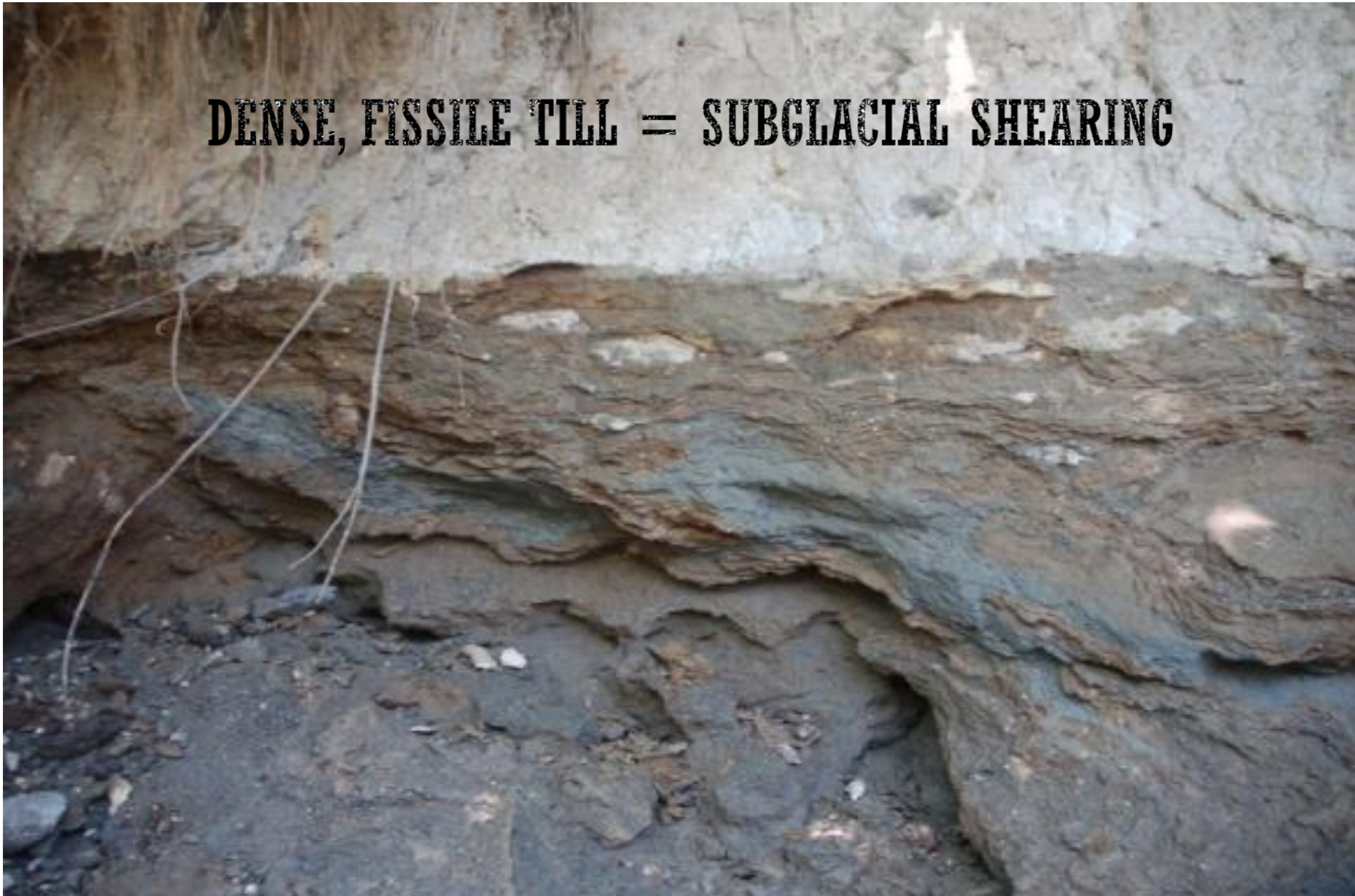


Figure 1. Features of subglacial tills highlighting the challenge of creating a three-dimensional image of glacial tills because of structural features associated with deformation and the difficulty of identifying bedrock due to rafted rock and boulder beds, lens and layers of weaker clays/water-bearing sands and gravels and dropstones (after Clarke (2017))

PERVASIVE BED DEFORMATION

- likely with high pore-water pressures
  - texture dependent
- sediment is weaker than ice or contact
- motion destroys incipient drainage
  - keeps pore water pressure high

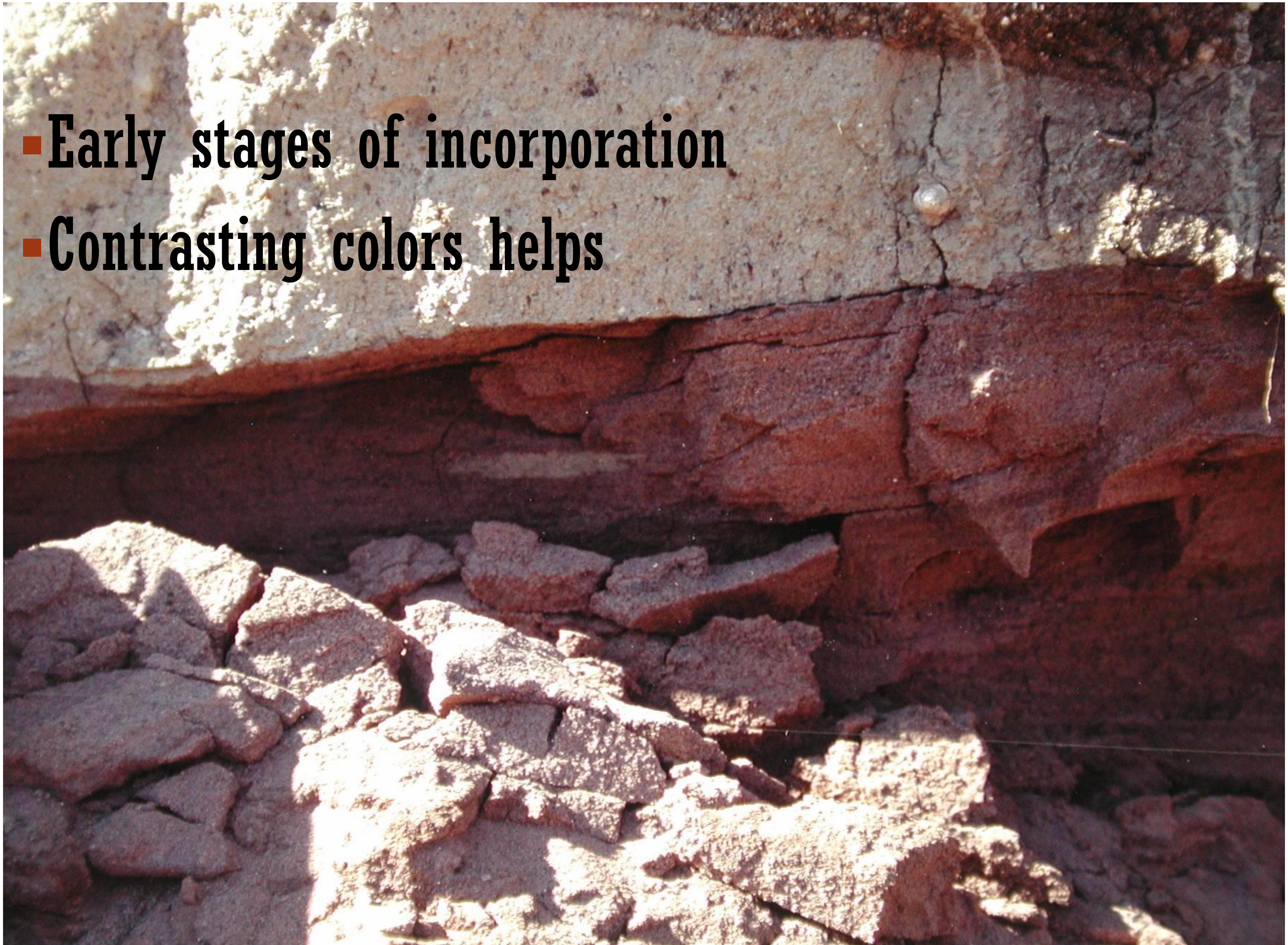
SEDIMENT SIGNATURES OF PERVASIVE DEFORMATION



HIGH TOTAL STRAIN PRODUCES A WELL-MIXED, MASSIVE TILL

TWIN CITIES FORMATION

- Early stages of incorporation
- Contrasting colors helps



TILL FABRICS

- Deformation causes preferred orientations of particles
  - weak fabrics parallel to shearing direction
  - transverse fabrics—rolling
  - variable strength depends on porosity, water, layer thickness
  - with sufficient strain, strong flow-parallel fabrics

DRUMLINS OF DONEGAL BAY

CAMBRIDGE AIR PHOTOS

Submerged drumlins. Donegal, Donegal, Ireland

MACRO FABRIC

FABRIC, SHEAR PACKAGES AND STRIAE

MICROMORPHOLOGY

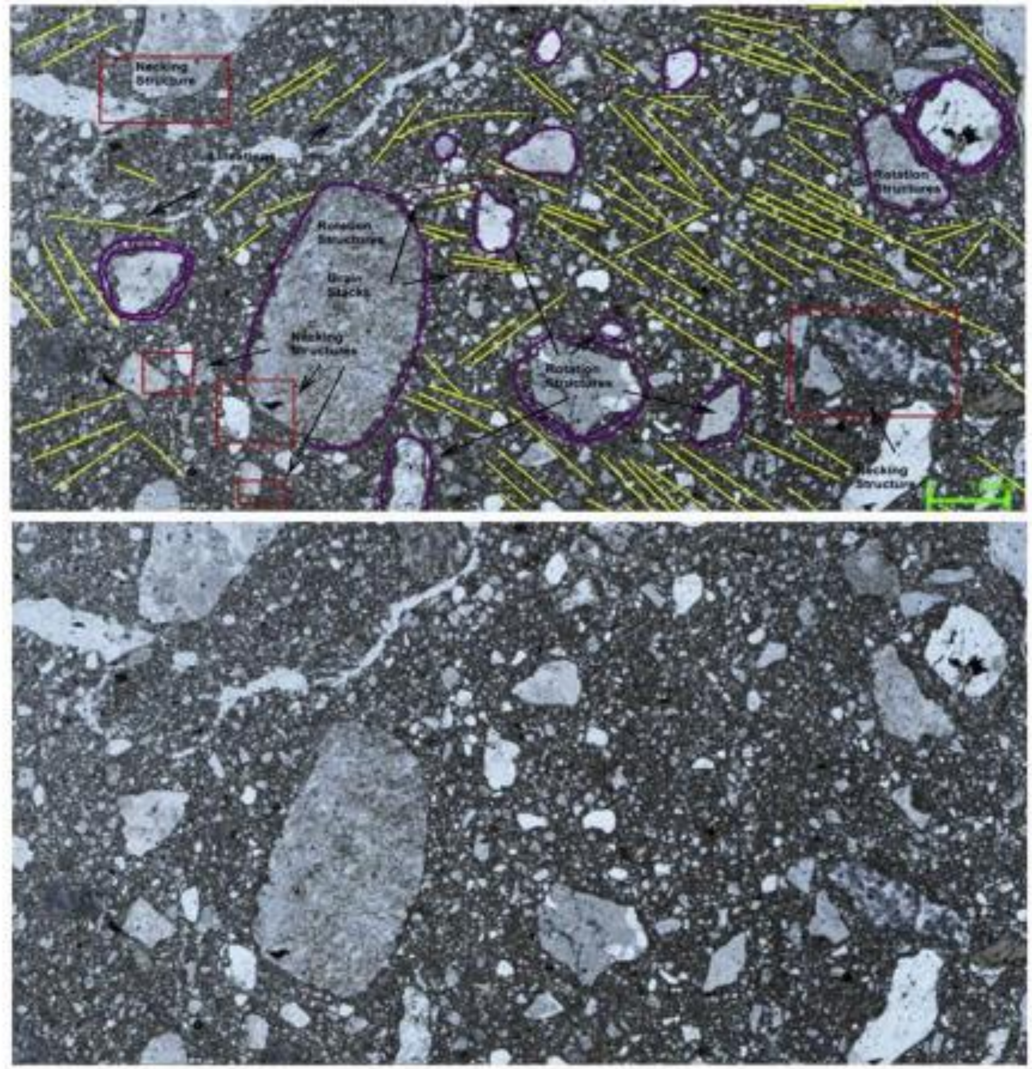


FIGURE 21.8

Subglacial till from Pine Point Mine, NWT, Canada (O-28-0022), exhibiting (in plane light) a large number of near-parallel microshears (yellow), rotation structures (purple), necking structures (inside the red boxes) and a large number of grain stacks.

CHAPTER 21

MICROMORPHOLOGY AND MICROSEDIMENTOLOGY OF GLACIAL SEDIMENTS

John Menzies[1,*] and Jaap J.M. Meer[2,*]

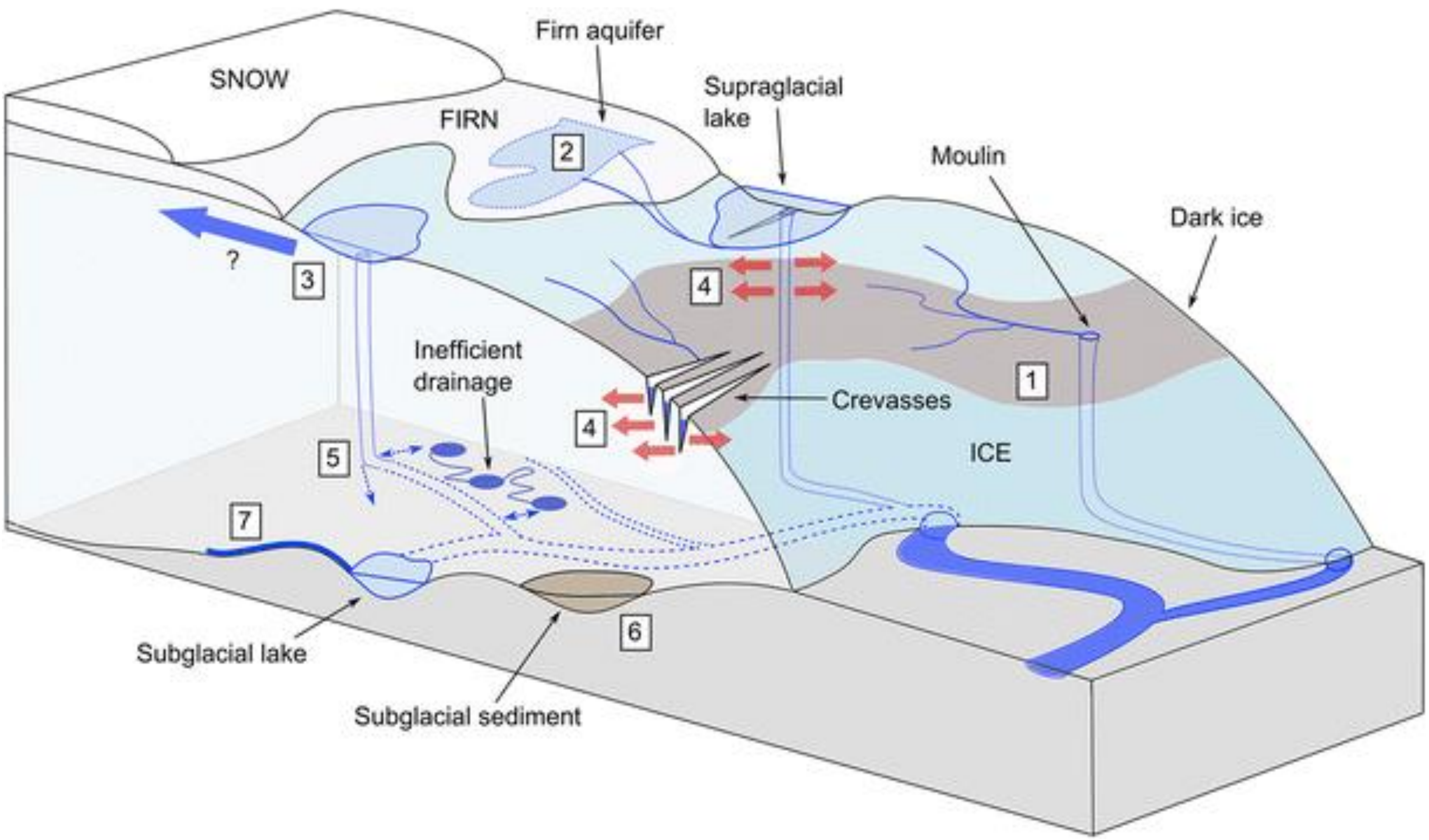
[1]Brock University, St. Catharines, ON, Canada, [2]Queen Mary, University of London, London, United Kingdom

GLACIAL TILL IS A RESULT OF

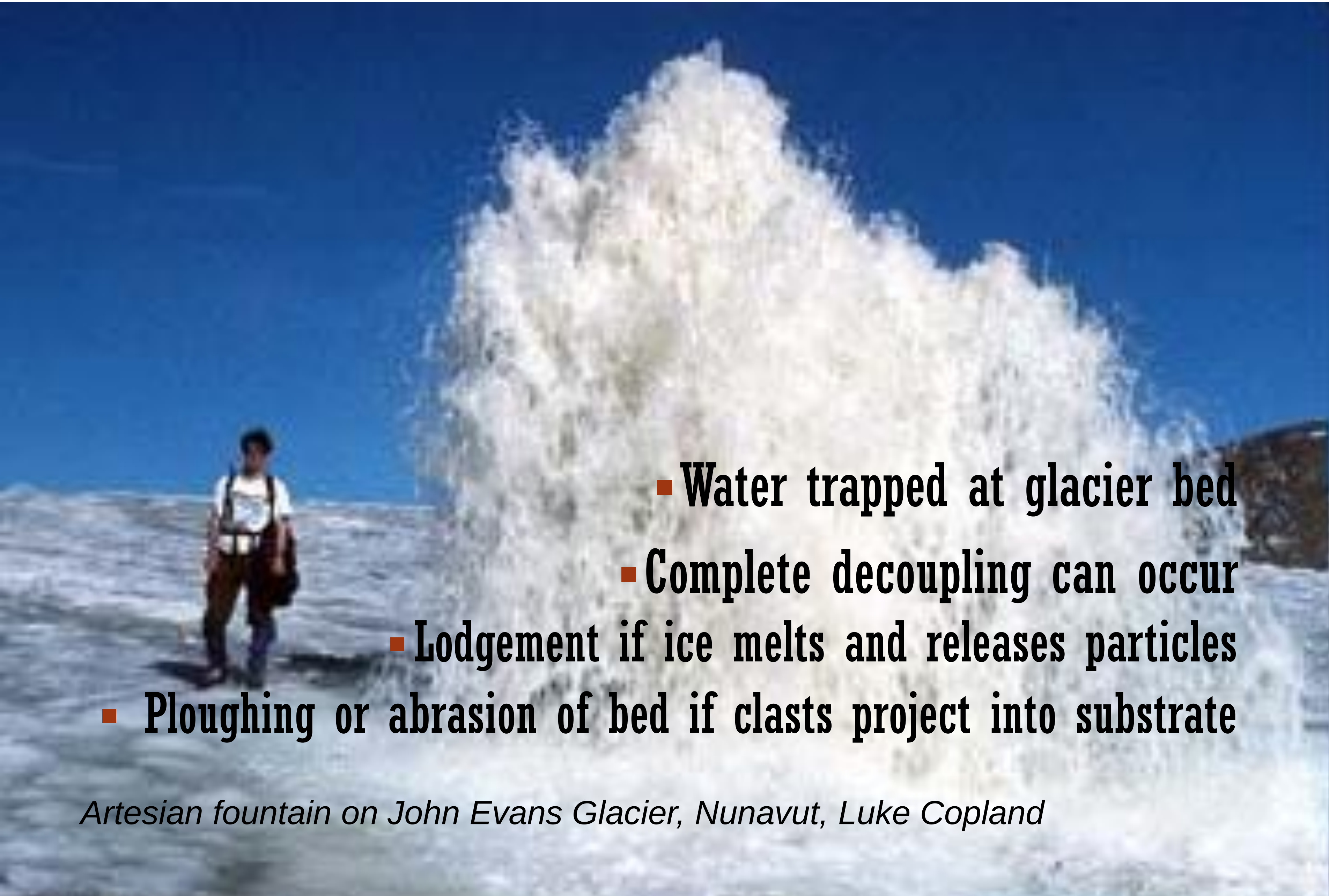
- Deposition alone (melt-out till)
- Deformation
- Combination of deposition and deformation (subglacial traction till)
- tills subject to shear and gravitational forces are denser

IT'S BOILS DOWN TO EFFECTIVE PRESSURE

Downward force of the ice

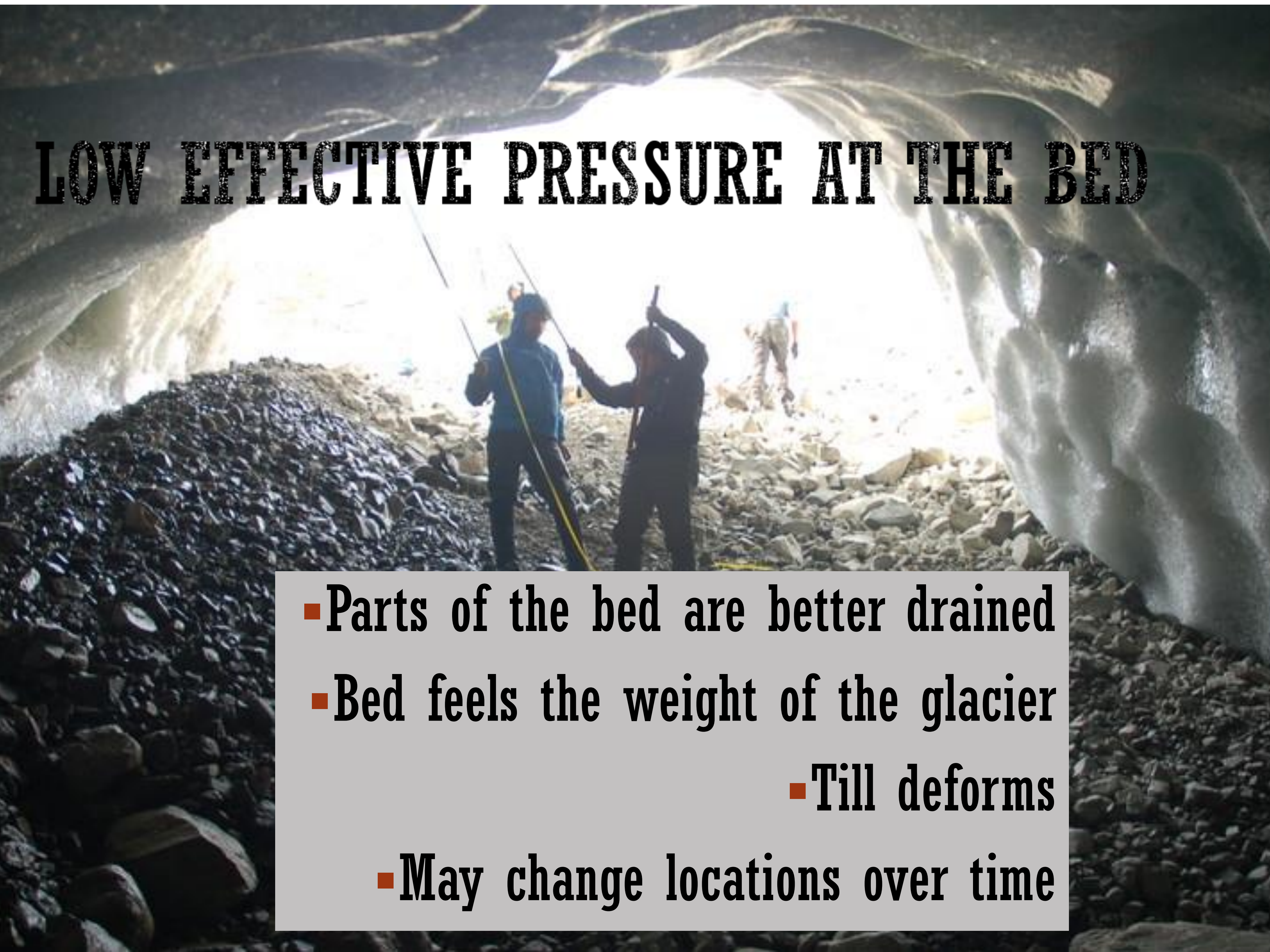


HIGH EFFECTIVE PRESSURE AT THE BED



- Water trapped at glacier bed
- Complete decoupling can occur
- Lodgement if ice melts and releases particles
- Ploughing or abrasion of bed if clasts project into substrate

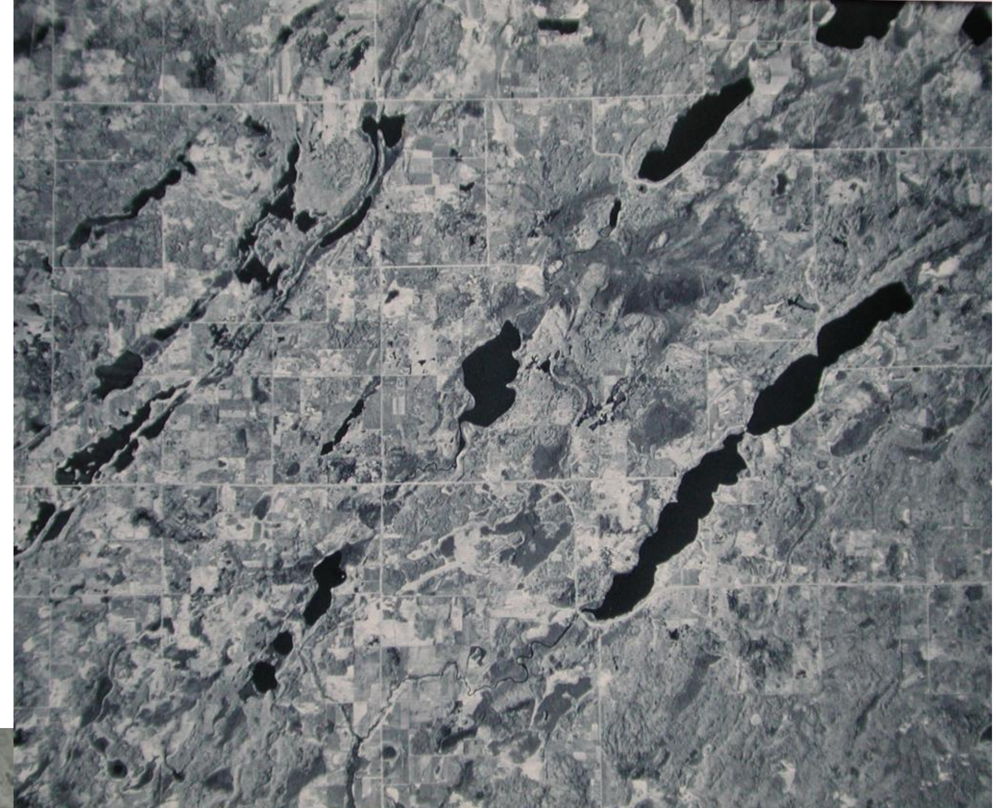
Artesian fountain on John Evans Glacier, Nunavut, Luke Copland



LOW EFFECTIVE PRESSURE AT THE BED

- Parts of the bed are better drained
- Bed feels the weight of the glacier
- Till deforms
- May change locations over time

DRAINAGES VARY FROM CANALS TO TUNNELS



DENSITY

- Theoretical maximum density 1.92 to 2.30 Mg/m3 (water content of 30–10%) assuming a particle density of 2.65 (Clarke, 2017)
- In situ densities of subglacial traction tills are similar to the theoretical densities

HYDRAULIC CONDUCTIVITY

- in situ permeability = intrinsic + secondary conductivity
  - function of the fabric
- total permeability is likely to exceed the intrinsic permeability
  - matrix-dominated tills have discontinuities and joints
  - close at about 12 m depth
- permeability of clast-dominated, supraglacial or melt-out tills is highly variable
  - lenses of more permeable materials

CONDUCTIVITY AND TILL TEXTURES

Till ≠ Clay

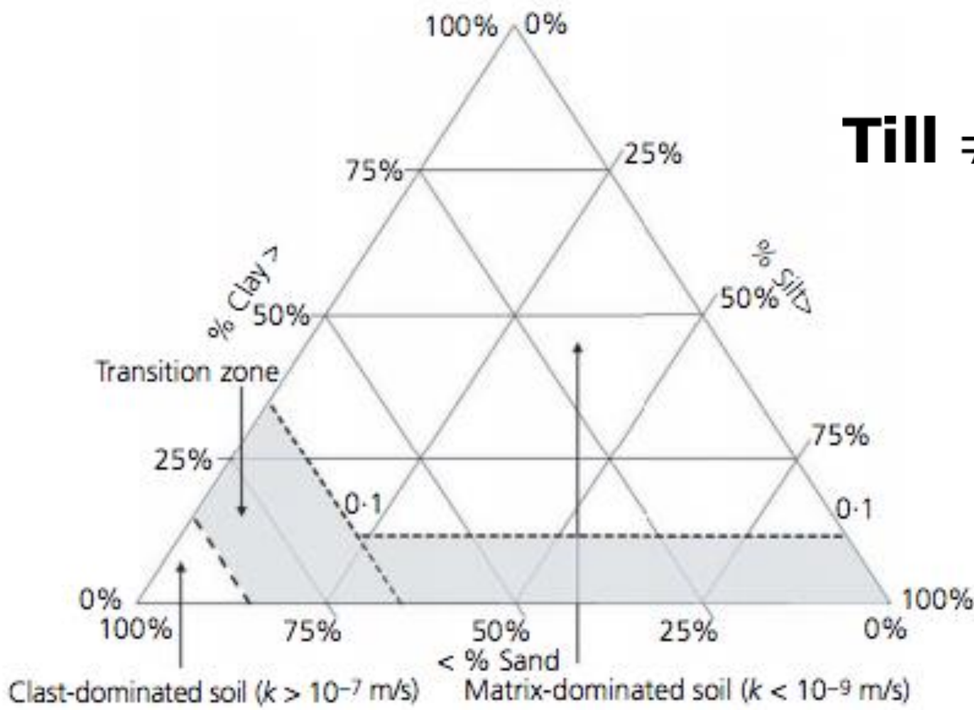
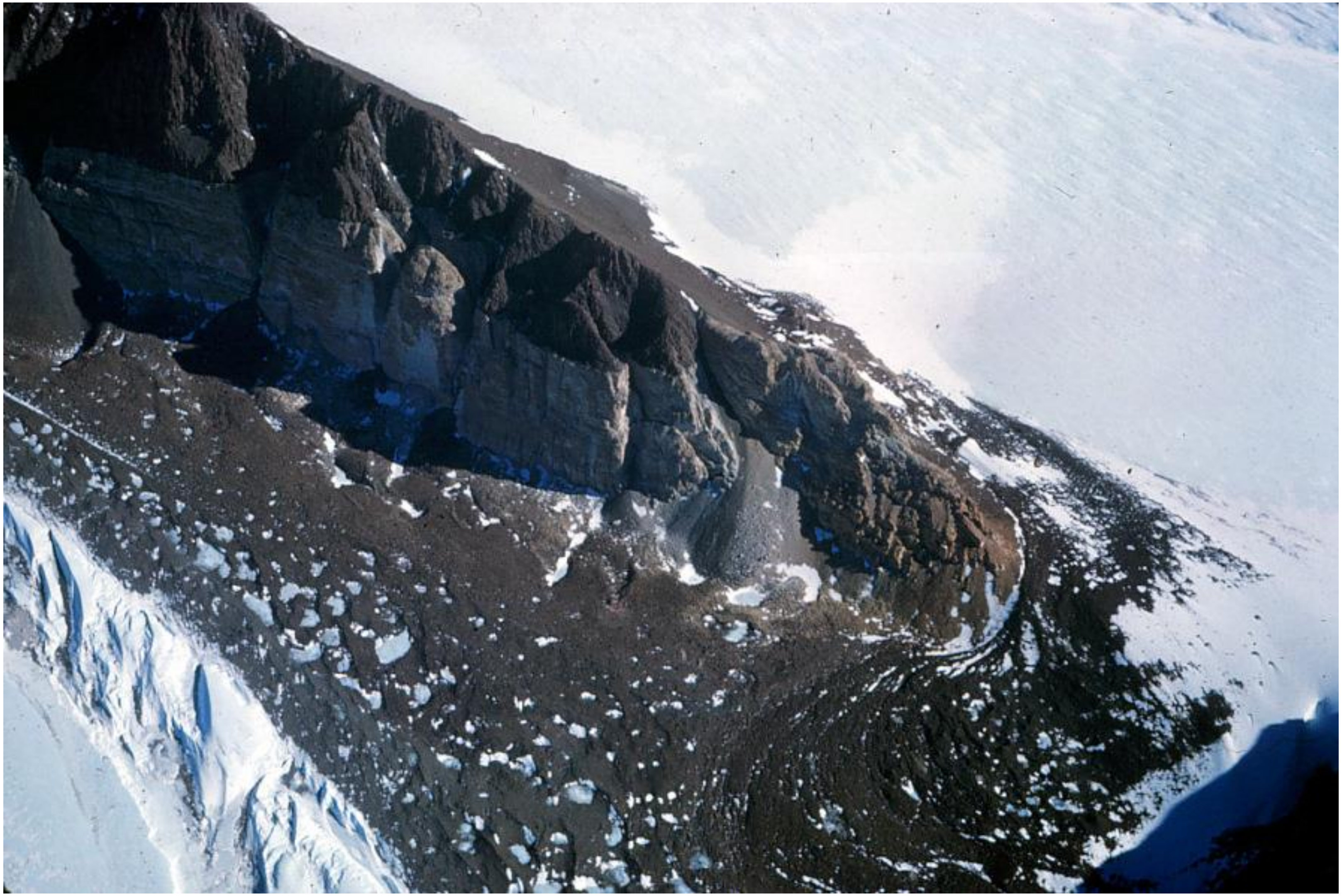


Figure 11. A relationship between the composition of composite soils and the coefficient of hydraulic conductivity showing that there are four distinct zones: matrix-dominated soils, clast-dominated soils, the transition between matrix- and clast-dominated soils and soils that are predominantly formed of silt (after Al-Moadhen *et al.* (2018))

STAGNANT ICE, ANTARCTICA, IN 1956, H.E. WRIGHT, JR.



ICE-WALLED LAKE PLAIN

Photo by H. Hobbs


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Image © 2008 DigitalGlobe
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Google

Ice-walled-lake plains: Implications for the origin of hummocky glacial topography in middle North America

Lee Clayton [a,*], John W. Attig [a], Nelson R. Ham [b], Mark D. Johnson [c], Carrie E. Jennings [d], Kent M. Syverson [e]

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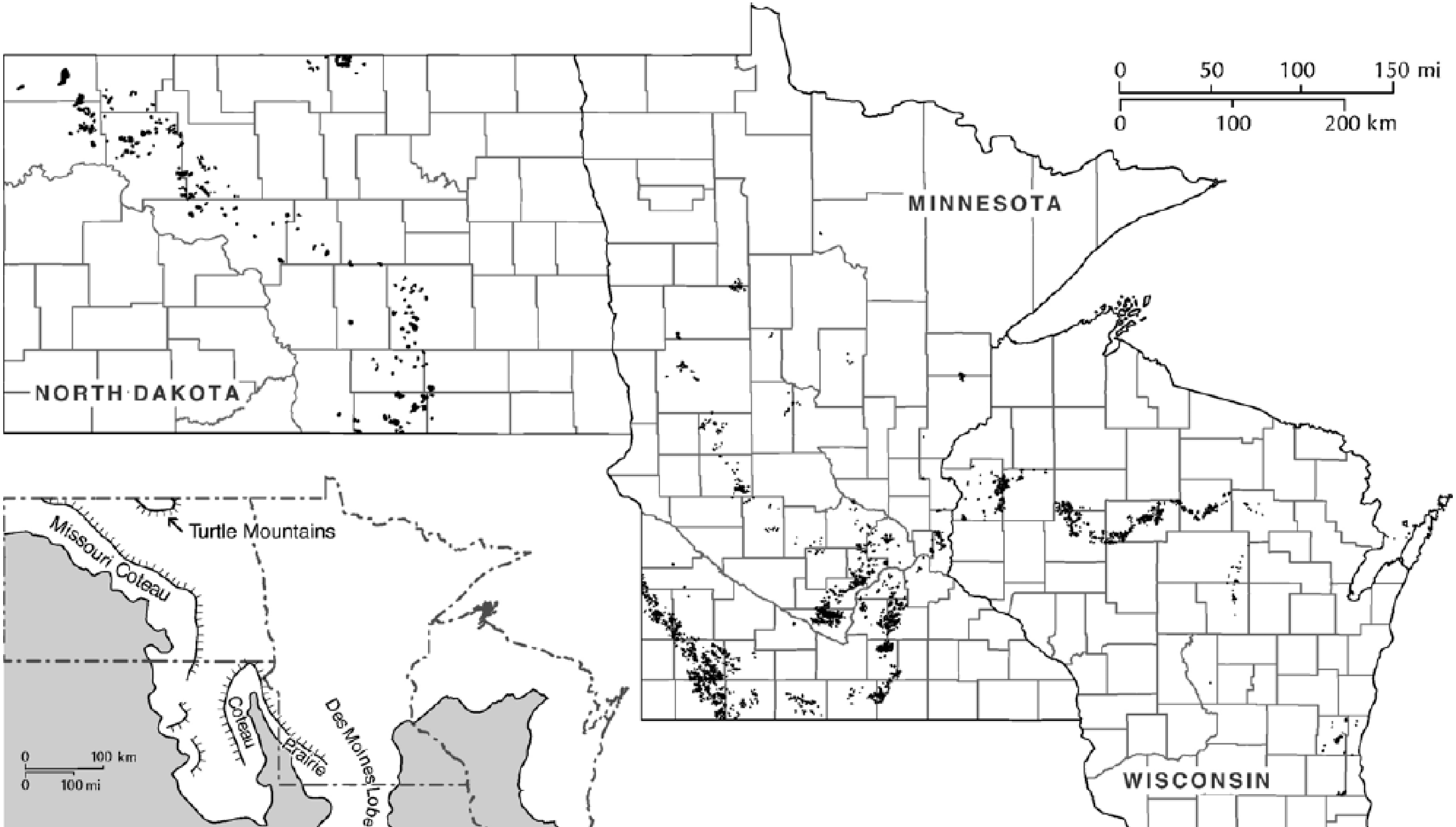
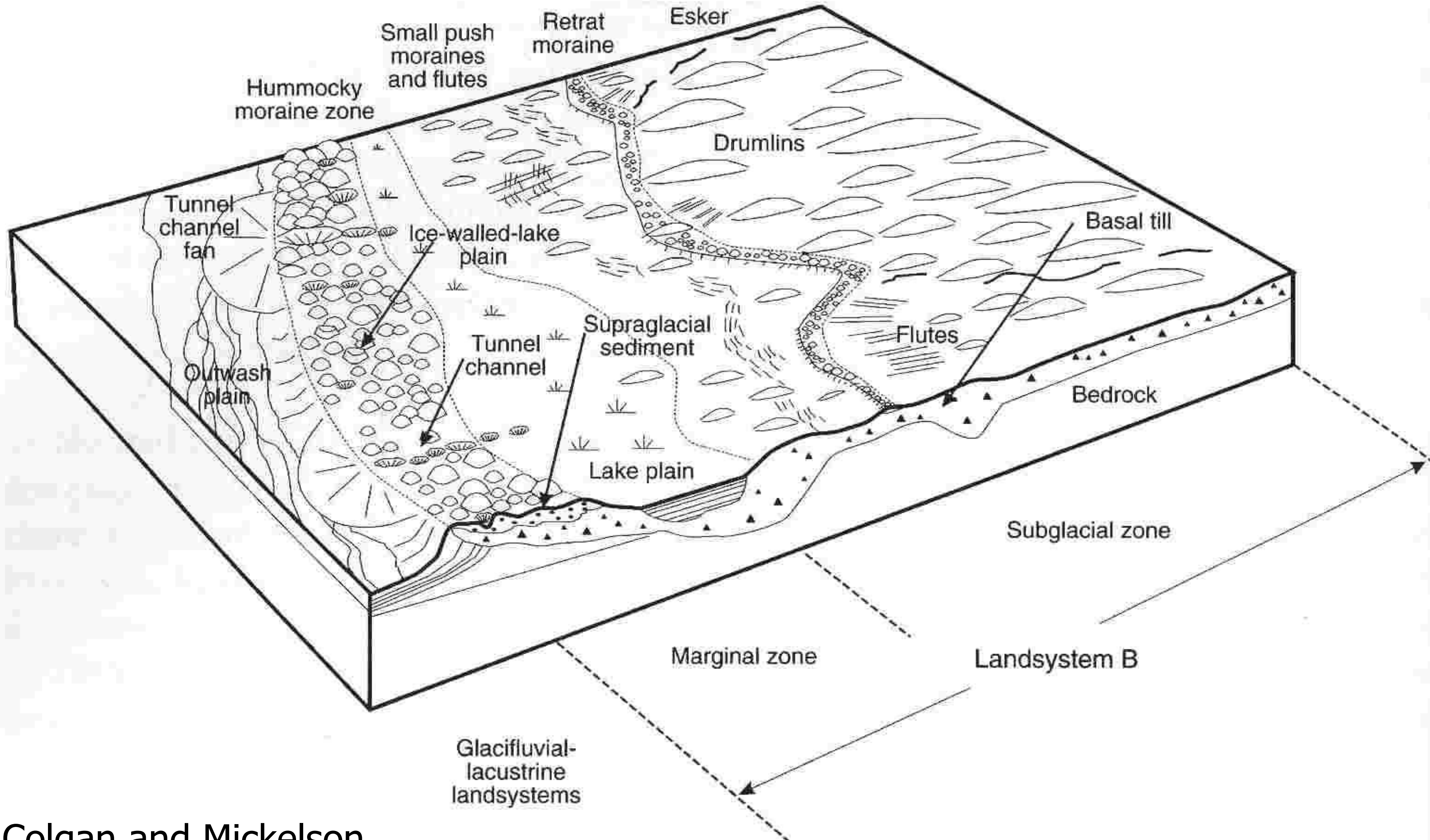
[b] *Geology Department, St. Norbert College, 100 Grant Street, DePere, Wisconsin 54115, USA*
[c] *Department of Geology, Earth Science Centre, Box 460, SE-405 30 Göteborg, Sweden*
[d] *Minnesota Geological Survey, 2642 University Avenue, St. Paul, Minnesota 55114, USA*
[e] *Geology Department, University of Wisconsin, Eau Claire, Wisconsin, 54702, USA*





Colgan and Mickelson

STAGNANT BURIED ICE

SUMMARY

Its all very complex

H.E. Wright, Jr.