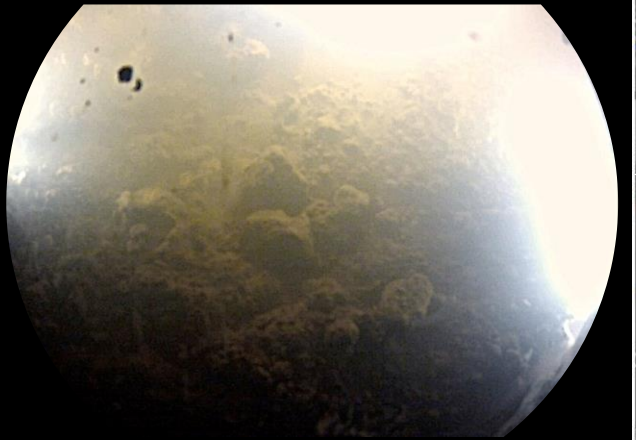
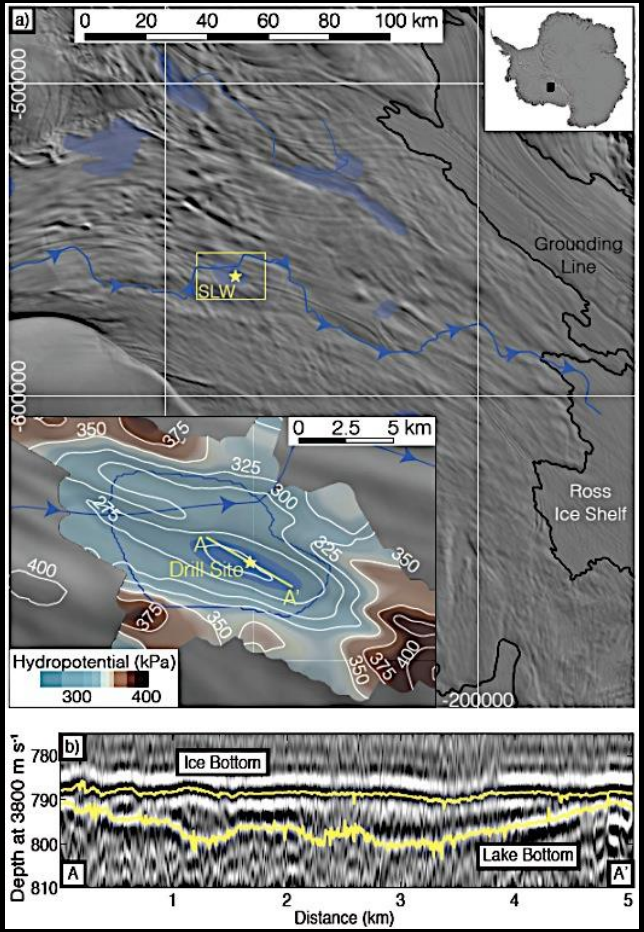
Environment and Processes of Subglacial Lake Whillans, West Antarctica





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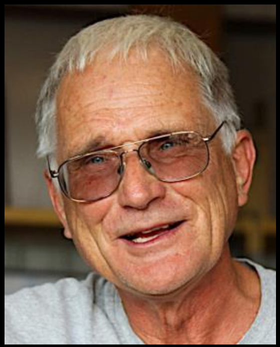
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Main Points

SLW sediment:

- comes from upstream and local marine sources
- shows evidence of various degrees of subglacial shear
- also evidence of recent dissolution (microbial mediation?)
- water saturated to compacted till - appears normally consolidated
- vertical clast fabric formed by decoupling during refilling
- last loading effect now over-printed

Lake discharge-recharge at low velocity

- ice recouples with lake bed at some lowstands
- till deformed into lake basin
- then ice re-floats and unloads
- no evidence of fluvial erosion or transport in subglacial flooding events
- flood velocities too low (<0.4 m/s) to entrain significant volumes of sediment
- water flow likely occurs in broad anastomosing sheets

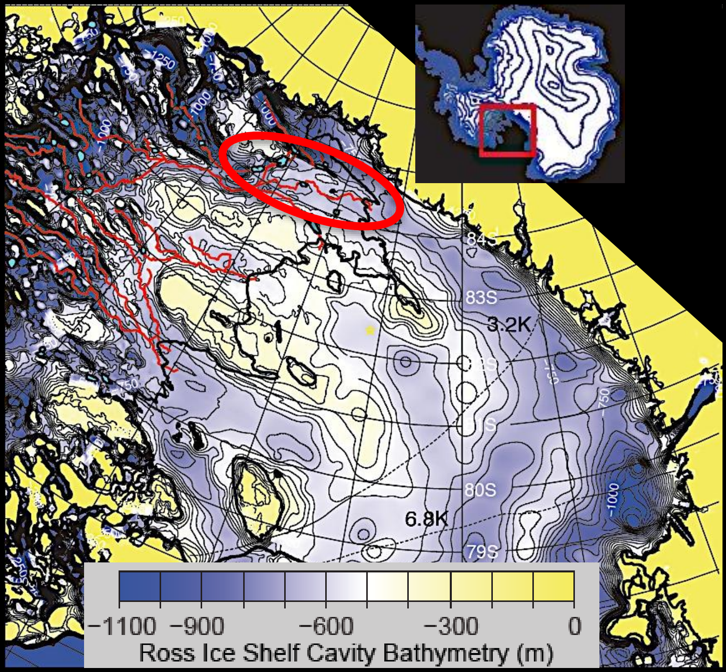
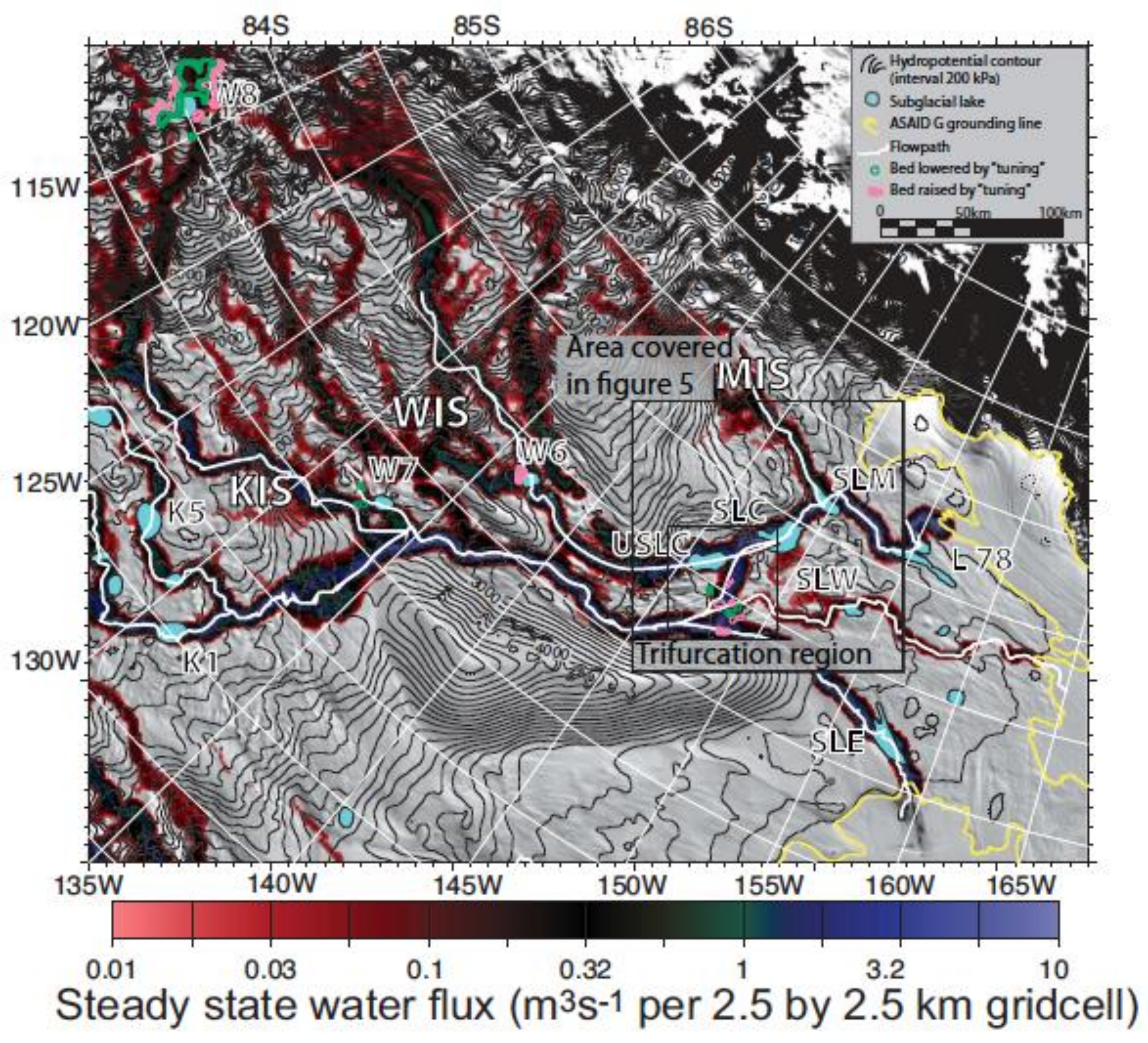


Image: Sasha Carter

A dynamic hydrological system

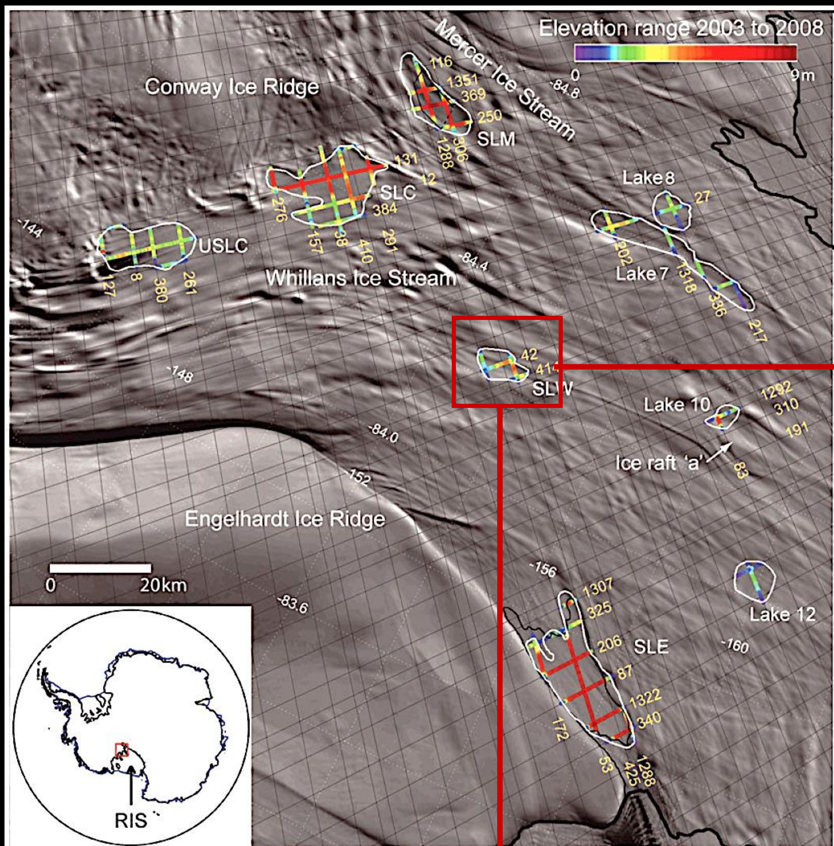
Lake is on a branch of a network of subglacial drainage

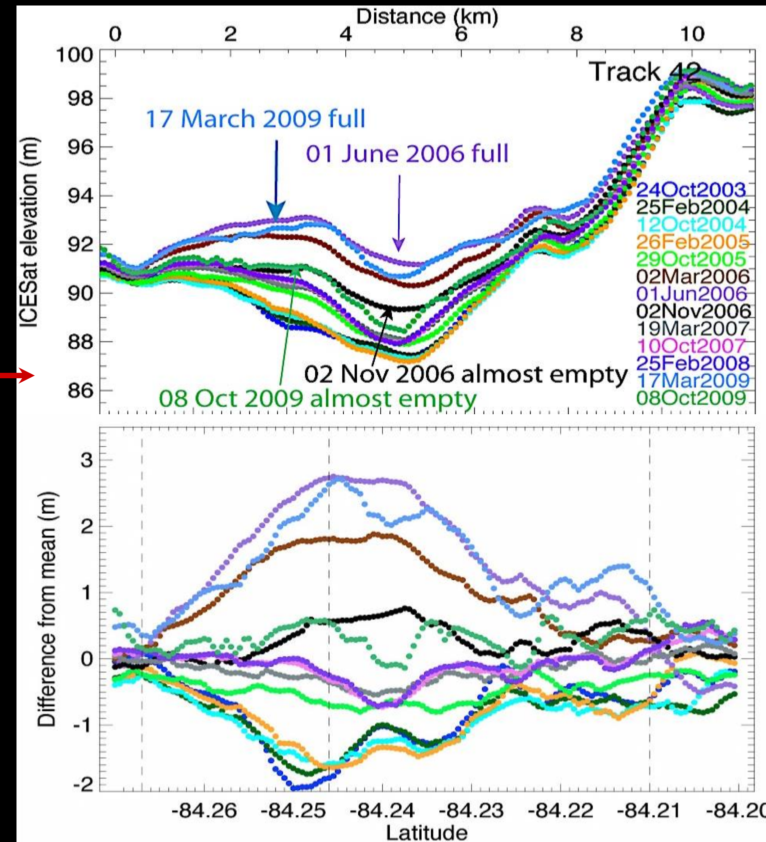


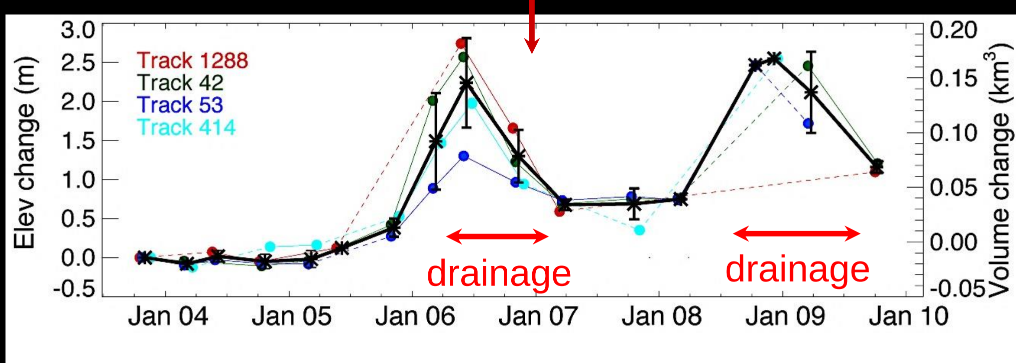
Carter et al., 2013

A dynamic hydrological system

Lake discharges and refills on a period of a few years







SLW has drained twice during the ICESat mission (2006 & 2009)

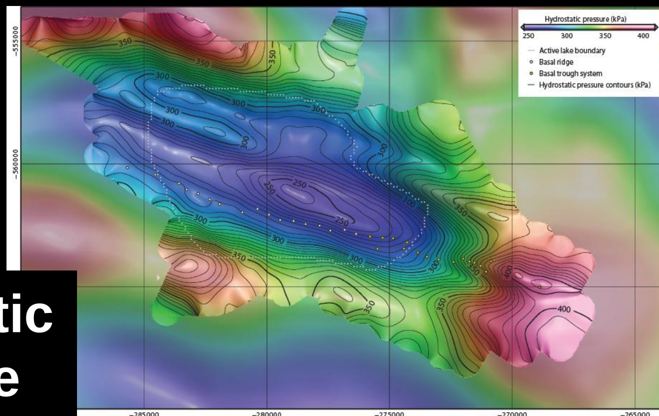
The 2009 discharge was captured during the last two ICESat campaigns

Now refilling

Fricker & Scambos 2009; Fricker et al. 2010

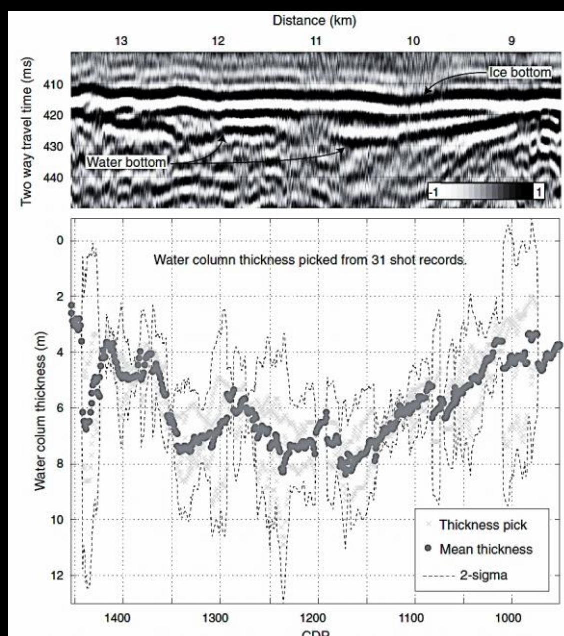
Geophysical team provided definition of the lake

and best site to access



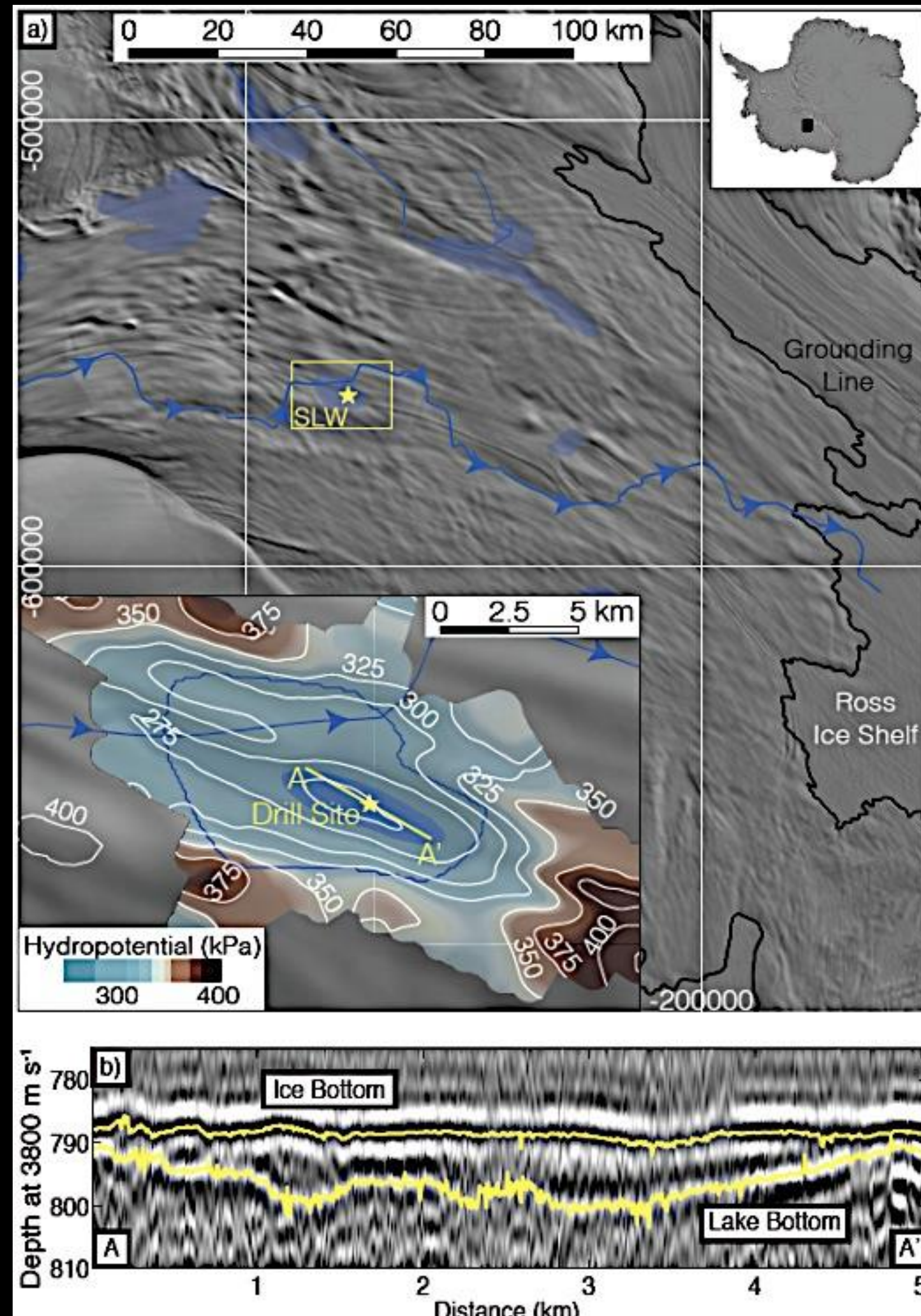
Hydrostatic pressure

Christianson et al. 2012



Seismic reflection

Horgan et al. 2012



Christner et al. 2014

Traversing from McMurdo

Camp set up by SLW

Lake bottom sediment rucked-up in front of camera

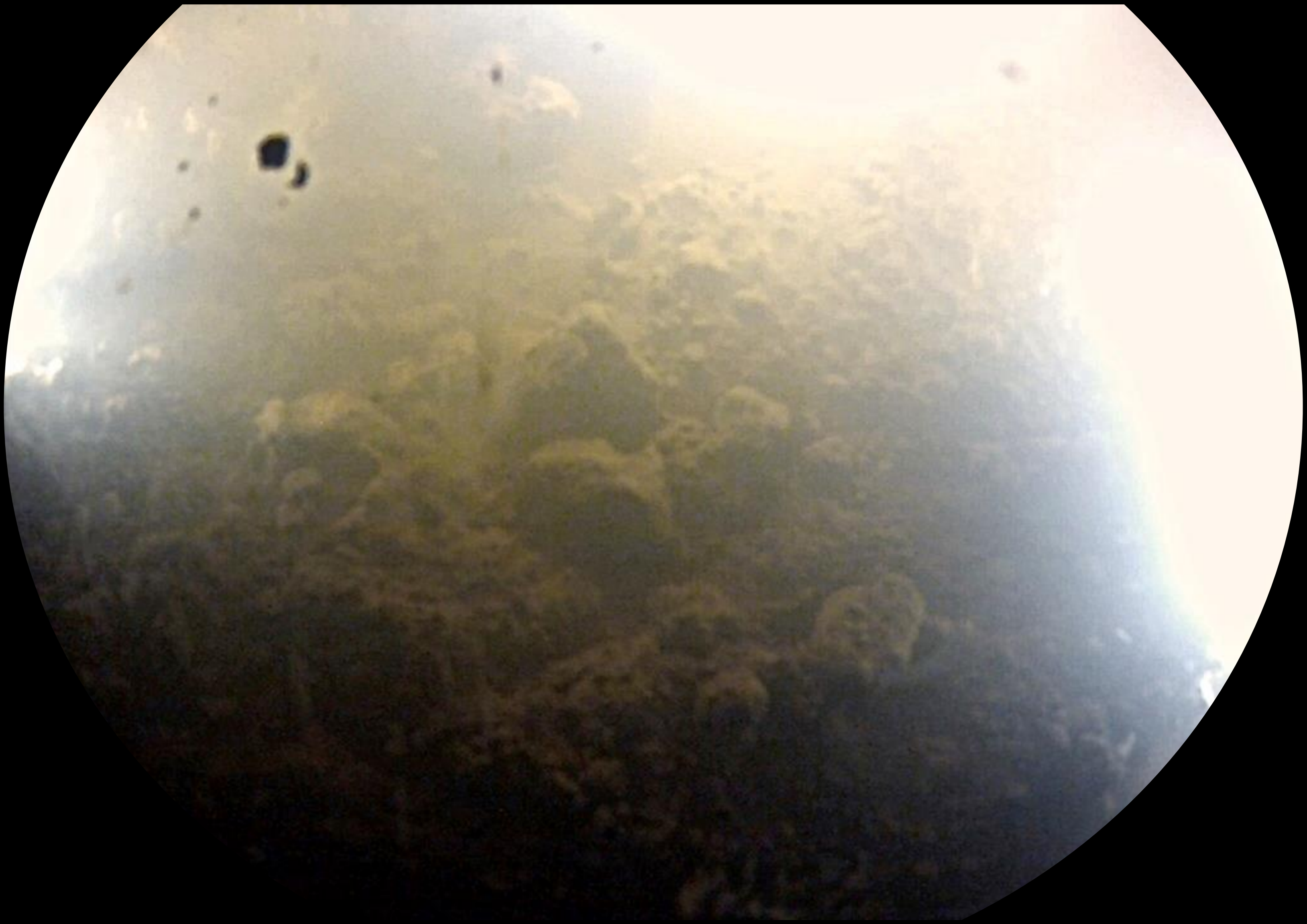
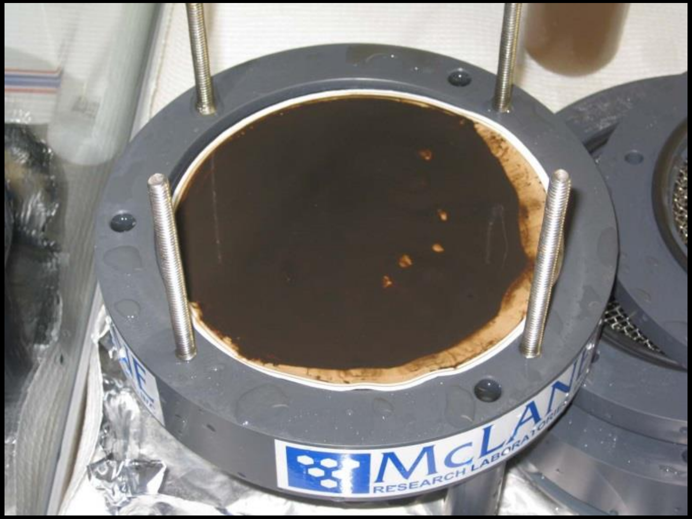


Image: Alberto Behar

Major WISSARD borehole science goals were achieved

Three ~0.4 liter water samples

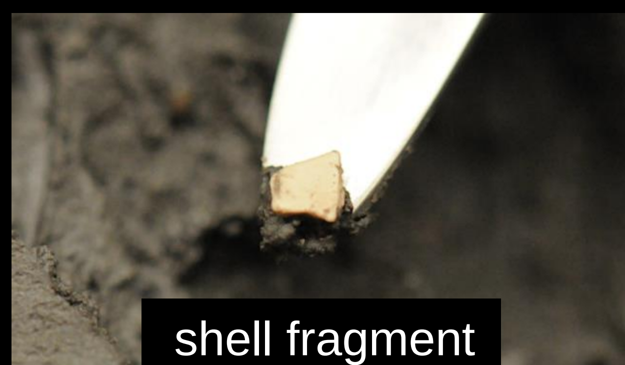


Suspended sediment filtered from lake water onto a 0.2 micron filter

Sediment from percussion, piston and multi-cores

Sediment core analyses

- ITRAX XRF scanner & XRF
- Geotek physical props scanner
- X-radiography
- Grain Mineralogy
- Clast lithology
- Biomarkers
- Particle size
- Clast fabric
- Paleomag NRM and AMS
- Grain & clast surface microtextures
- Thin section micromorphology
- Moisture content
- Strength tests



shell fragment

Core degassing

Sediment strength tests

General Description

Below ~1m of turbid water

Local basal melting + flow from upstream

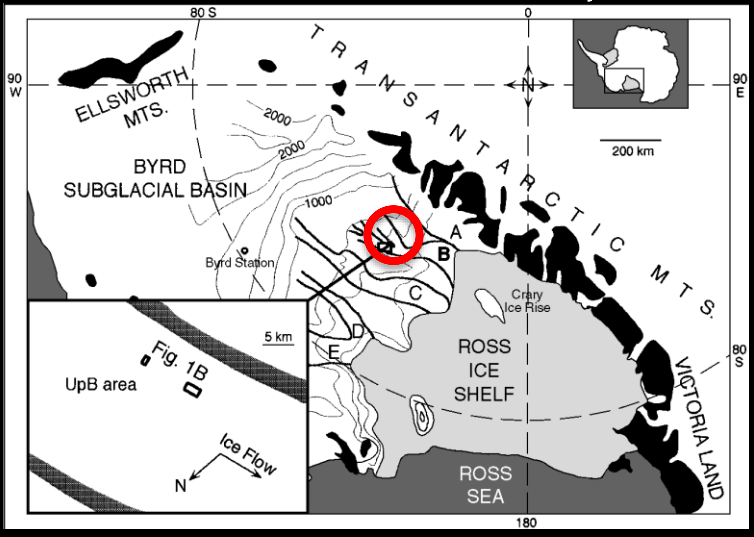
Structureless, clast-poor (<10%) muddy diamicton

Water saturated to compacted

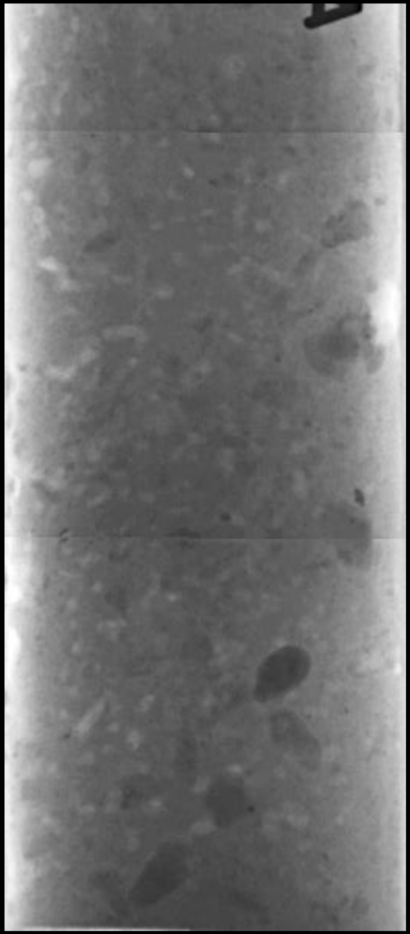
Appears very homogeneous

Compare with upstream (“UpB”)

Tulaczyk et al. 1999



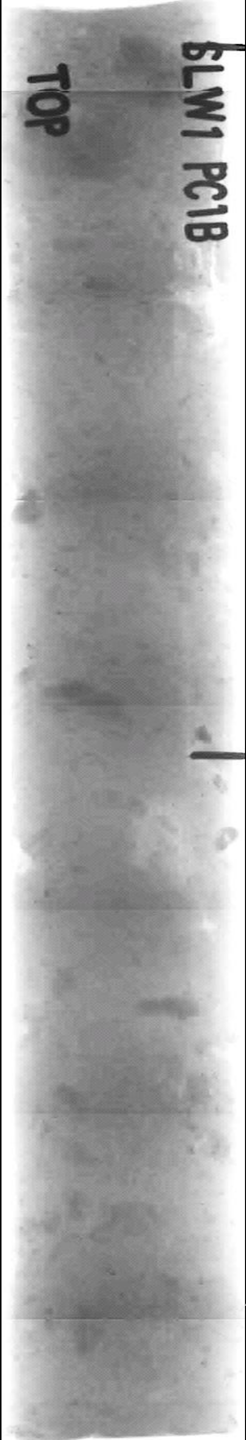
Core degassing



X-radiograph

Image through clear core liner

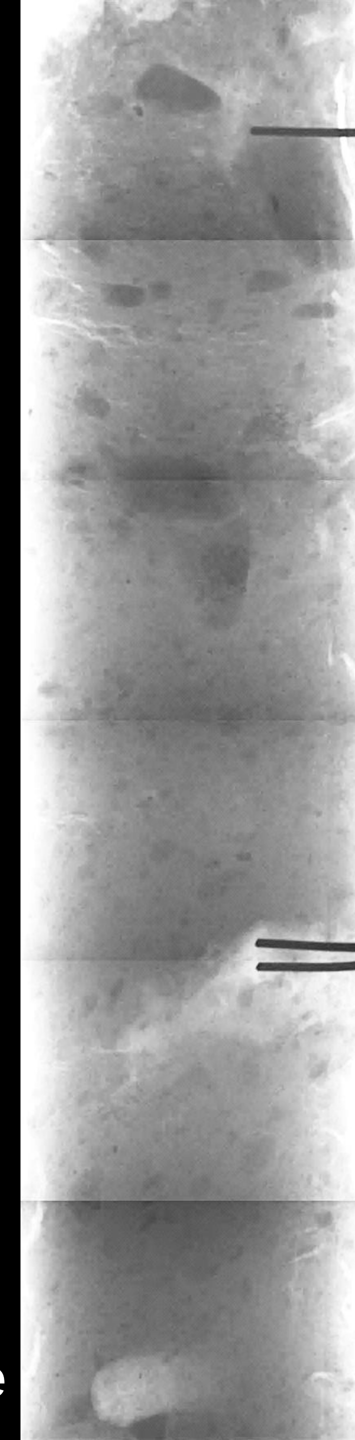
X-radiographs



- homogeneous - some weak layering?
- clast abundance - variable, < 10%
- clast orientation - locally preferred

artifacts

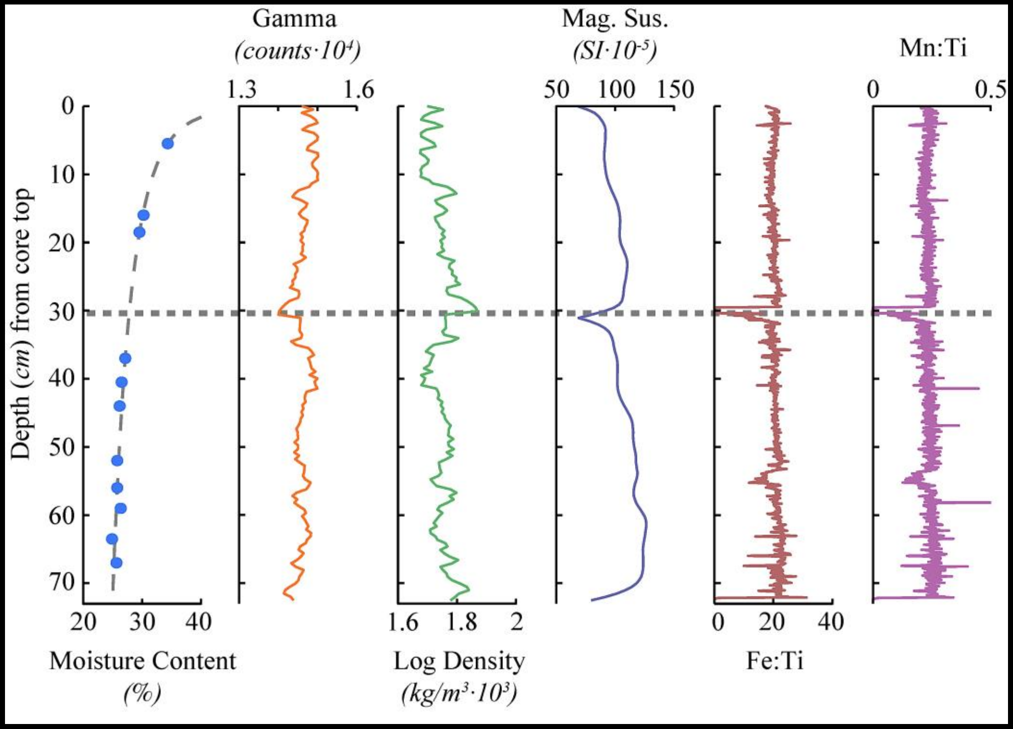
.84m-long core

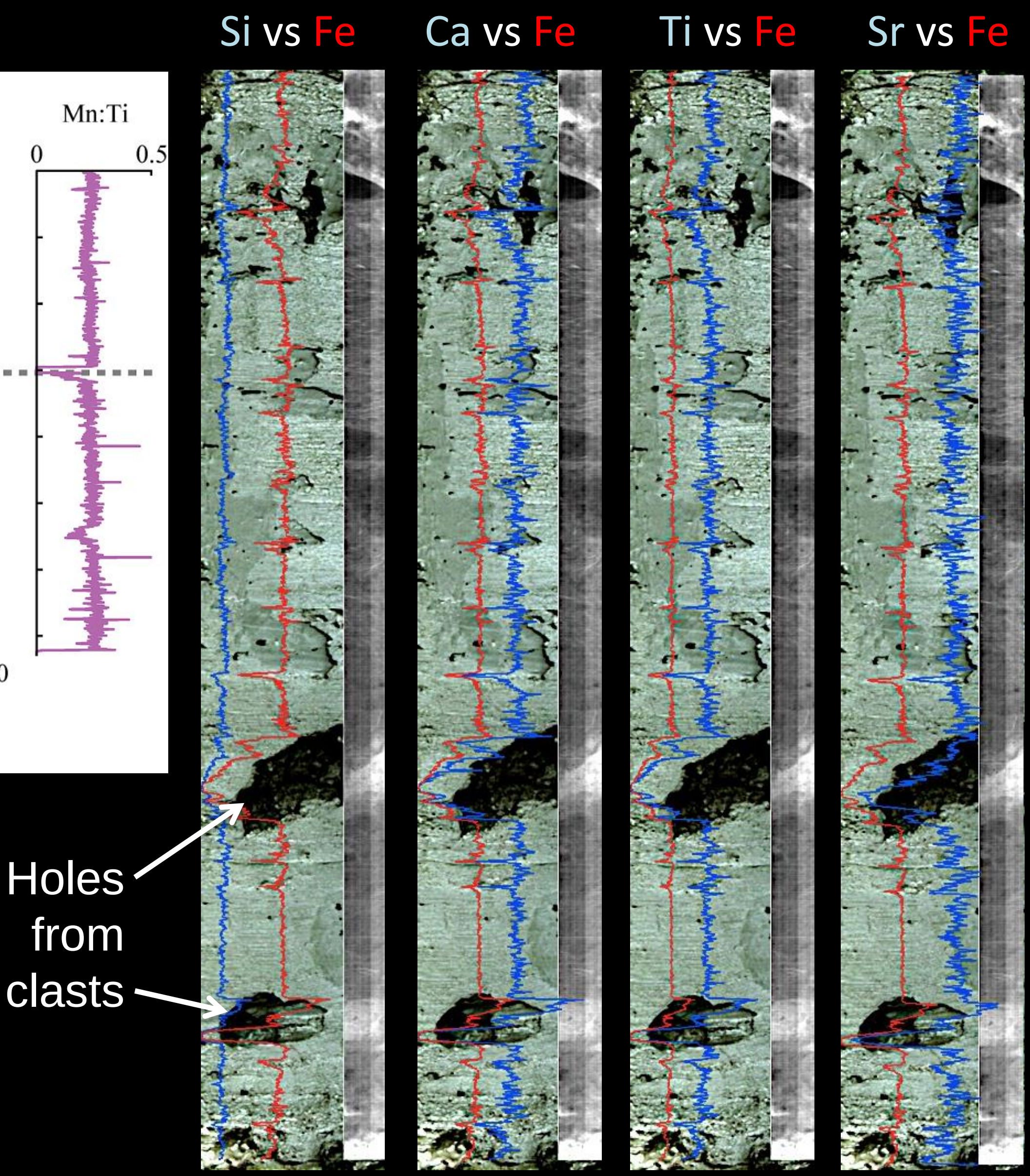


.41m-long core

Homogeneity shown by ITRAX XRF

(Percussion core)





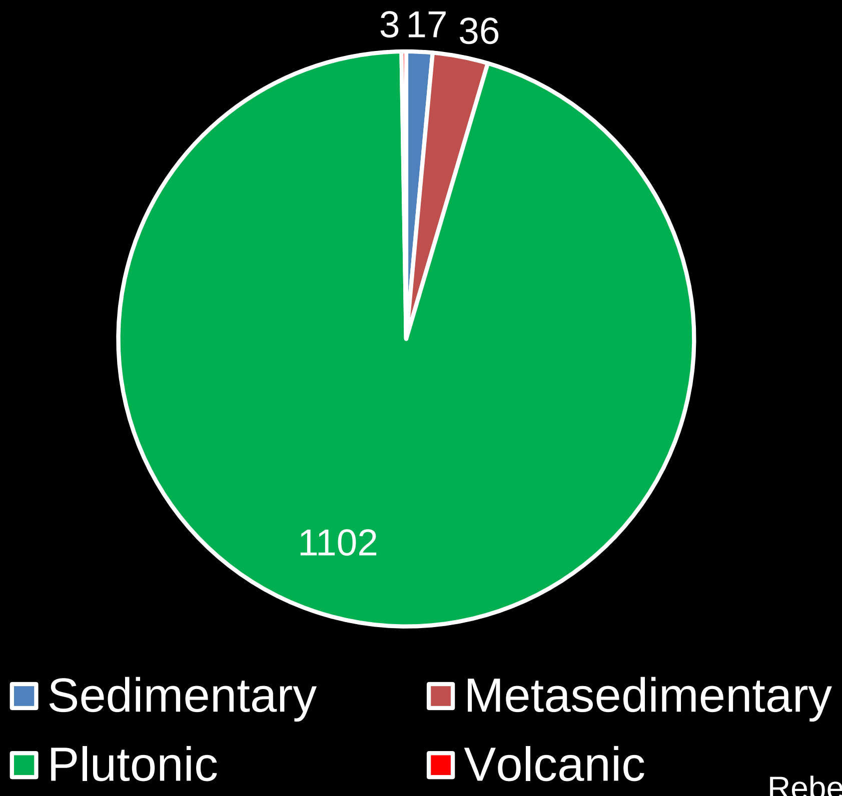
Provenance analysis

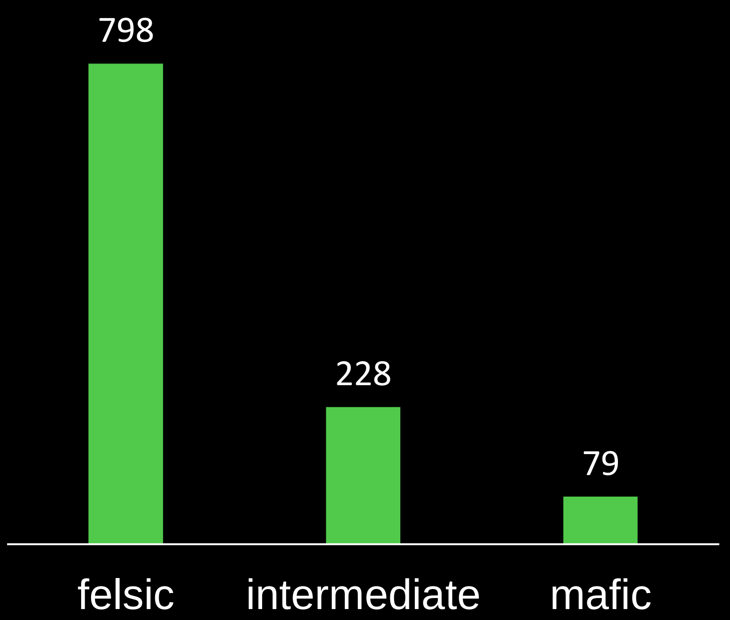
Methods

- Clast lithology
- Sand mineralogy
- Major/trace element chemistry
- Molecular biomarkers

Clast lithologies

1158 clasts - mostly from granules to fine pebbles



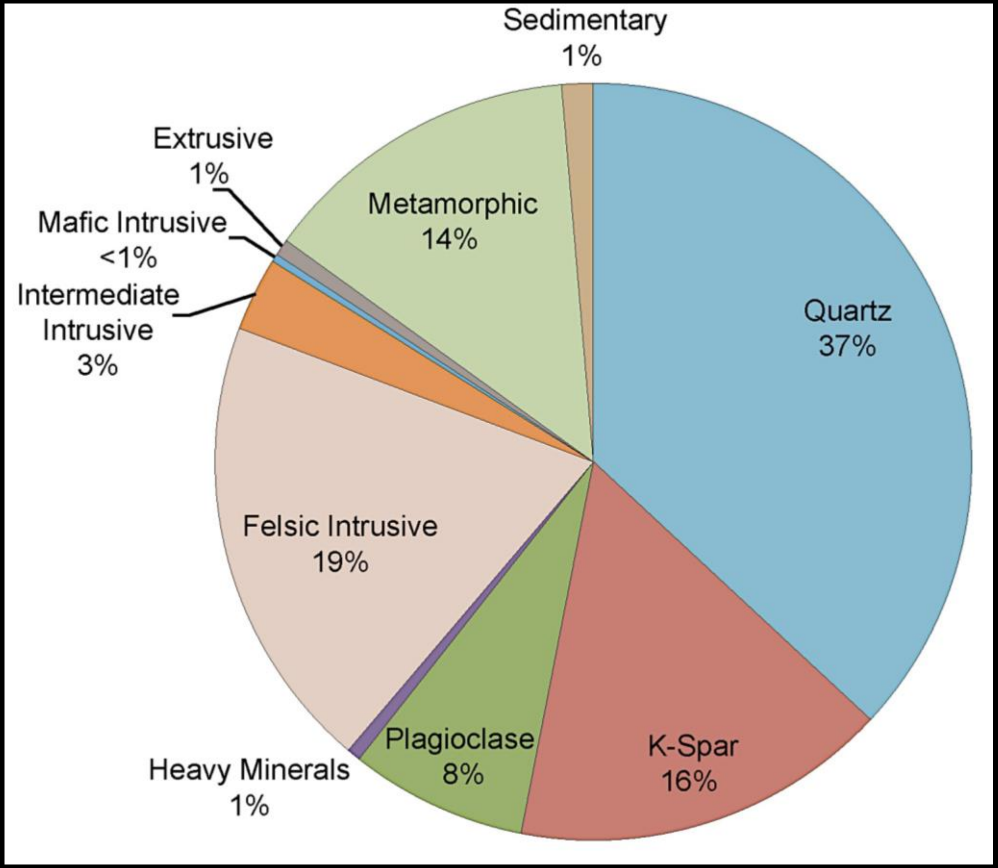


Composition of plutonic clasts

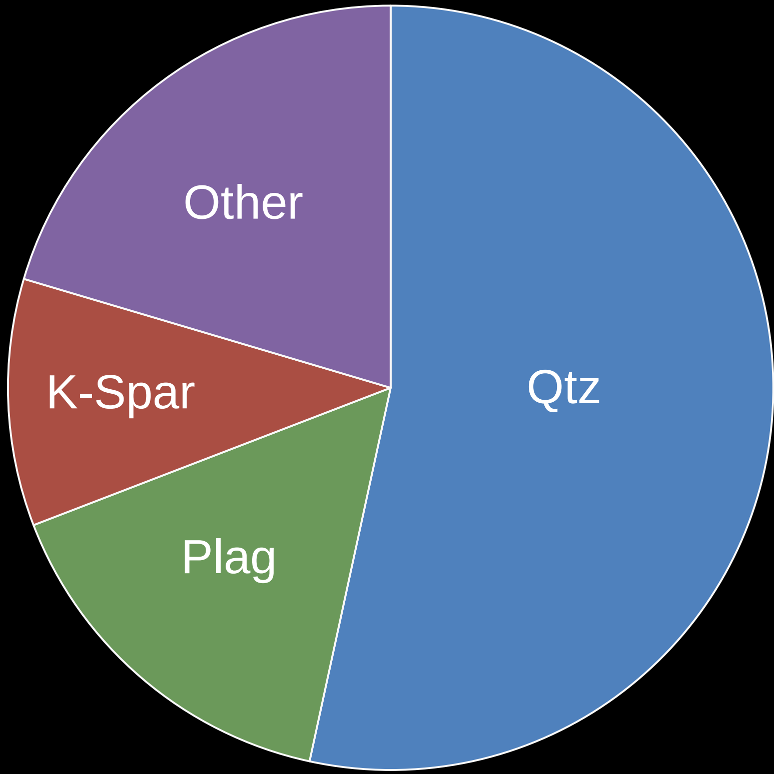
Rebecca Putkammen

0.5-2mm sand mineralogy

SLW



UpB



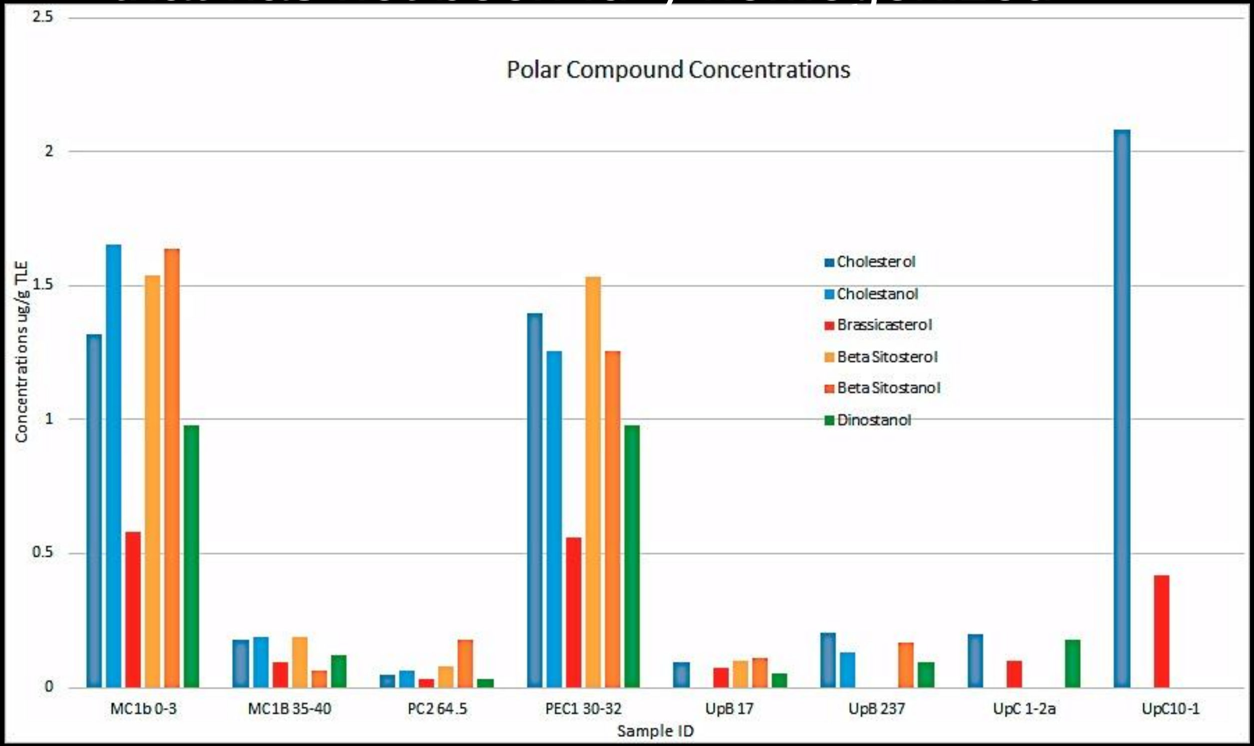
Tulaczyk et al. 1999

Clasts and sands indicate similar sources to UpB
But there are differences

Molecular Biomarkers

Appears to suggest

- Downstream increase in marine biomarkers
- Local source of related marine sediment that has not been fully homogenized



Jeremy Wei
Isla Castañeda's lab

Polar compounds found in sediments:

- Brassicasterol – specific to diatoms
- Dinostanol – thought to be specific to dinoflagellates

SLW water column geochemistry

- Consistency in chemical composition between three casts
- Nutrients N and P present in water column
- $\delta^{18}O$ indicates glacial meltwater as dominant water source
- Br/Cl indicate a diluted seawater signal

	pH	Na^+	K^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	Br^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	DIC (HCO_3^-)	$\delta^{18}O$
Cast 1	8.0	5118	175	473	1034	28	3657	5.1	1.4	1228	4.5	2095	-38.0
Cast 2	8.2	5285	177	477	1020	31	3827	5.8	0.7	1255	4.3	2130	-38.0
Cast 3	8.1	5389	178	486	1023	31	3904	6.6	0.4	1272	5.5	2109	-38.1

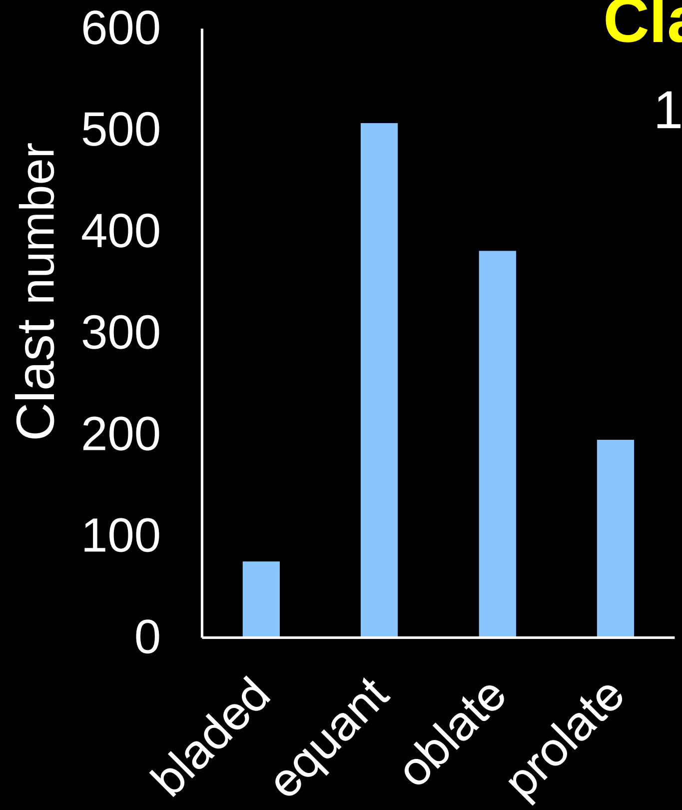
Units are ueq l^{-1} except for $\delta^{18}O$ and pH

Mark Skidmore

Br/Cl ratio of SLW is 0.00153, seawater is 0.00155 (Holland 1978)

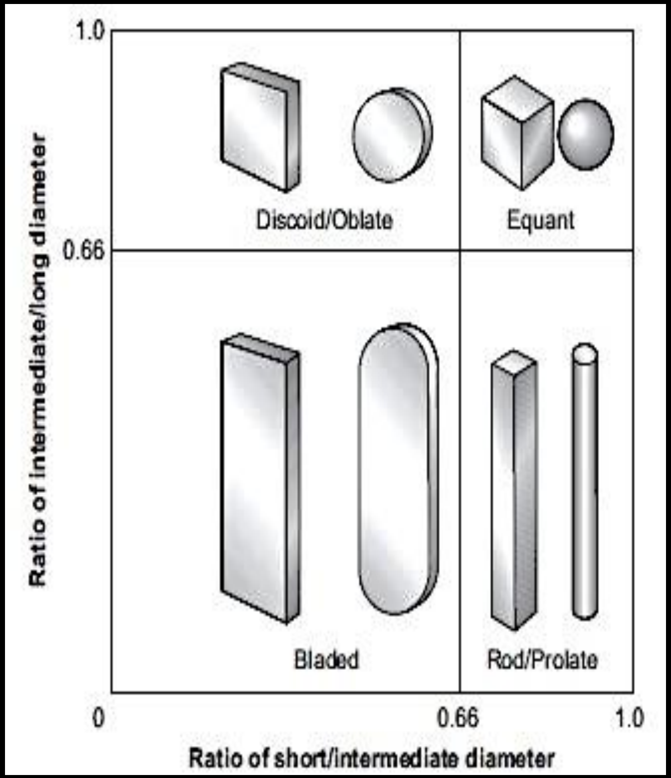
3.8 mM Cl = 1/144 strength seawater

Particle shapes and surface textures
to assess subglacial processes and dynamics



Clast Shape

1158 clasts

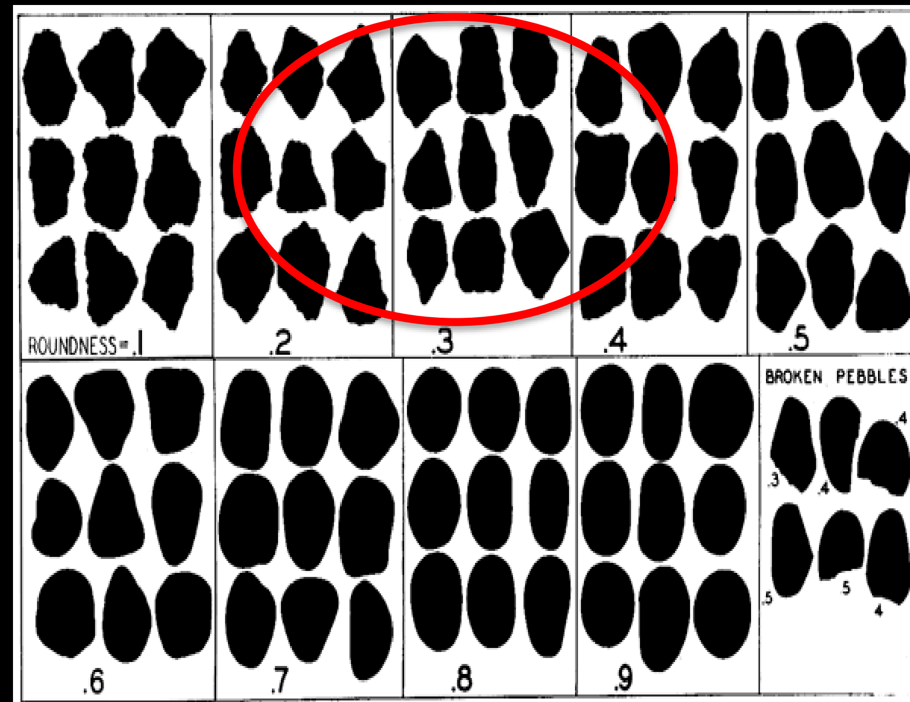


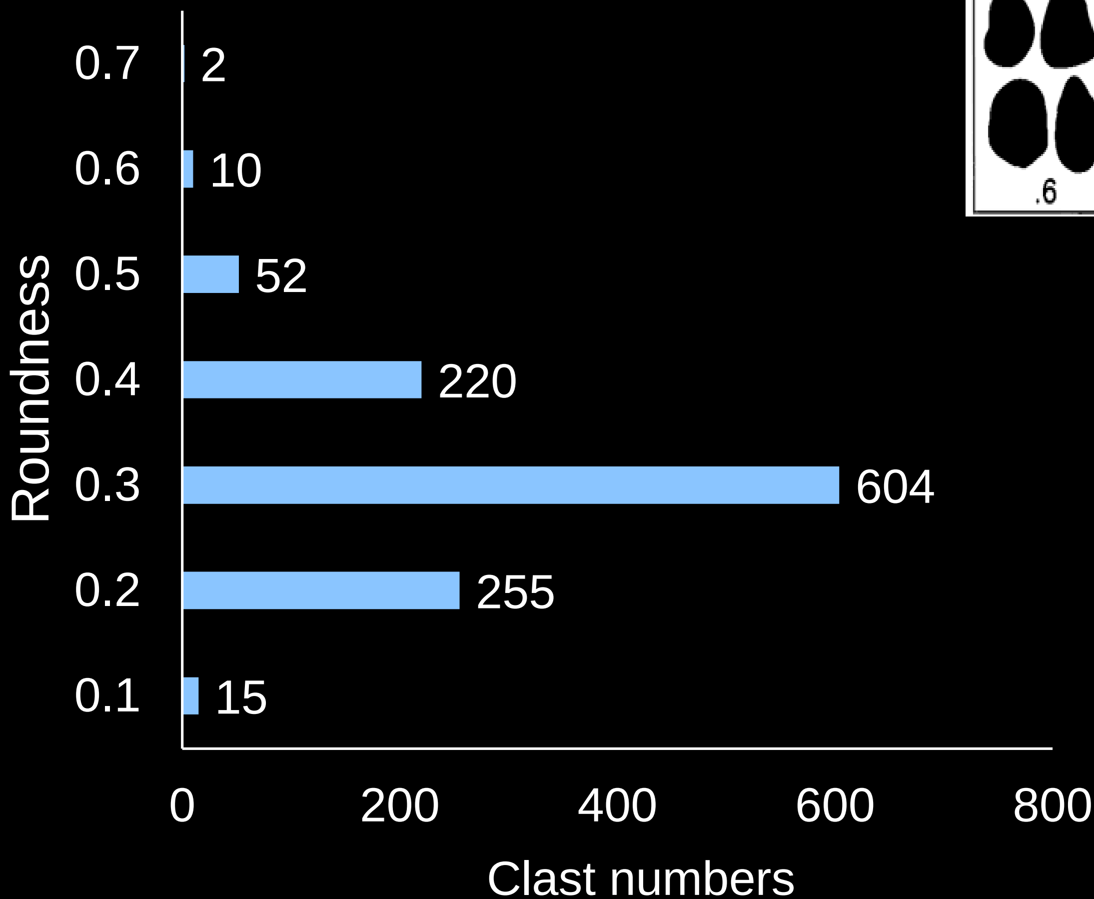
Dominant lithology – igneous & metasedimentary

Typical glacial shape for lithology

Clasts
angular, facetted and striated

Typical of subglacial till – not fluvial





Feature	Percentage of Samples
Faceted	10%
Striated	28%

Rebecca Putkammen

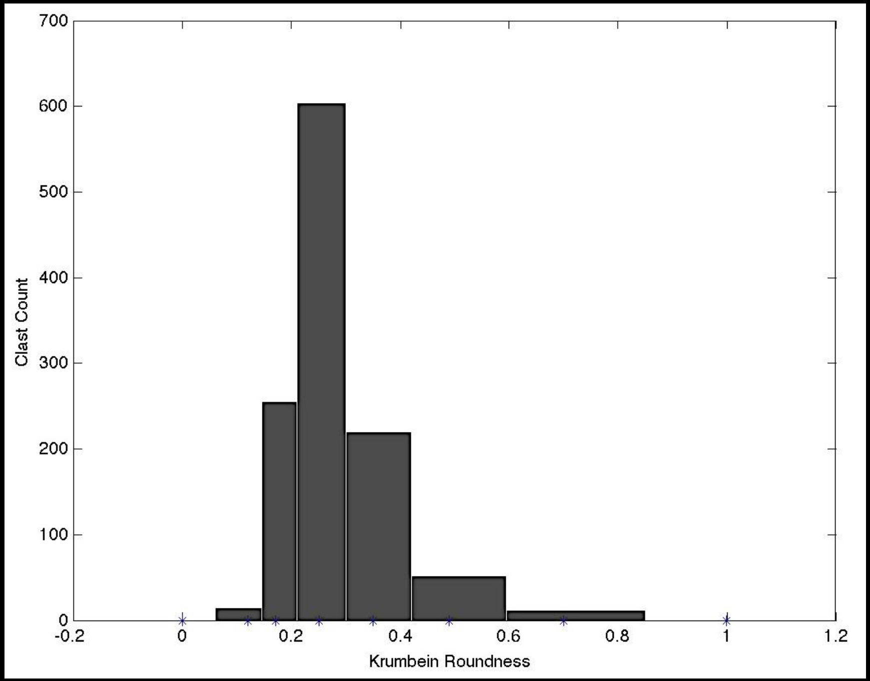
Clast features compared

UpB

- Striae: ~0.9% (?)
- Facets: 50%
- Roundness: subangular

SLW

- Striae: 28%
- Facets: 10%
- Roundness: subangular

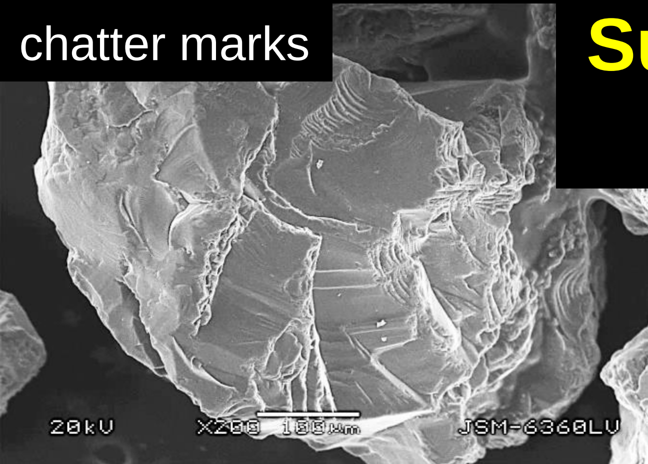


Tulaczyk et al. 1998

More striae but fewer facets downstream

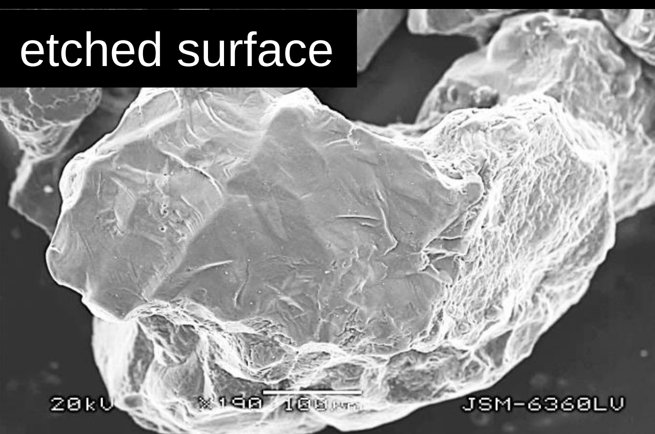
less bedrock interaction
more in-till contacts

Surface microtexture of quartz grains

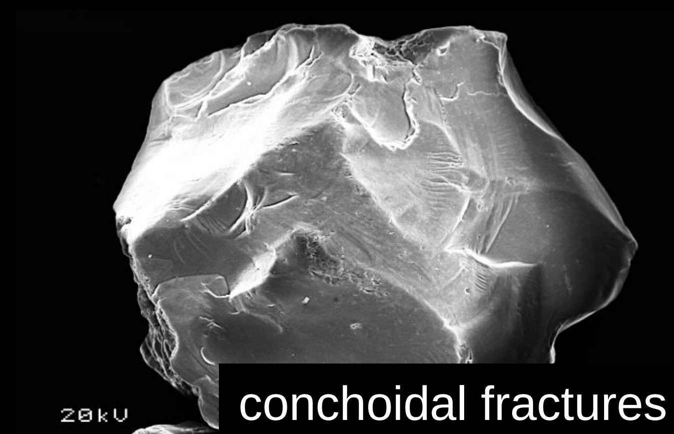


chatter marks

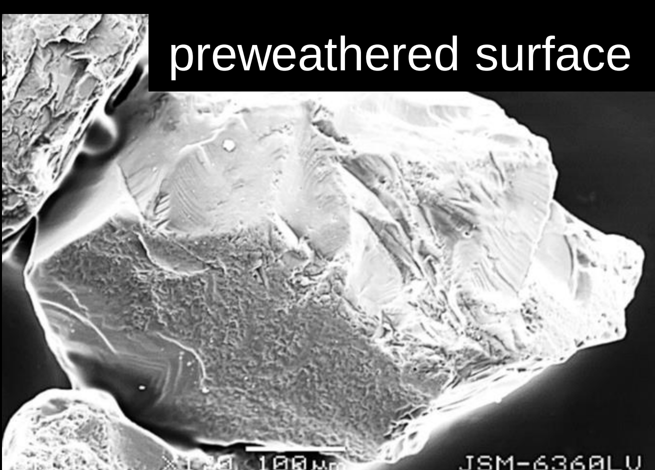
fresh surface



etched surface

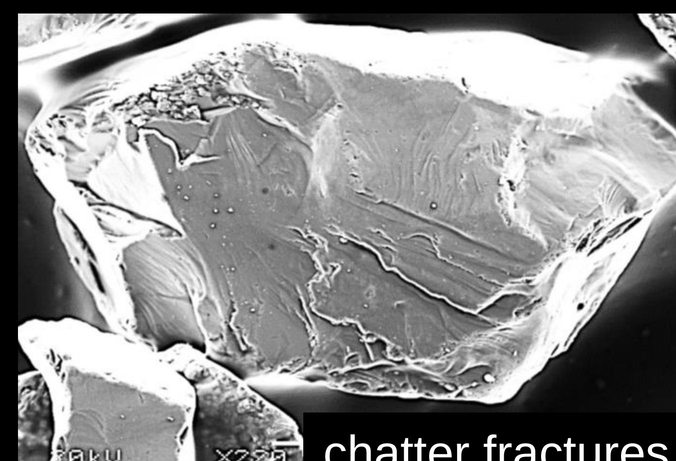


conchoidal fractures



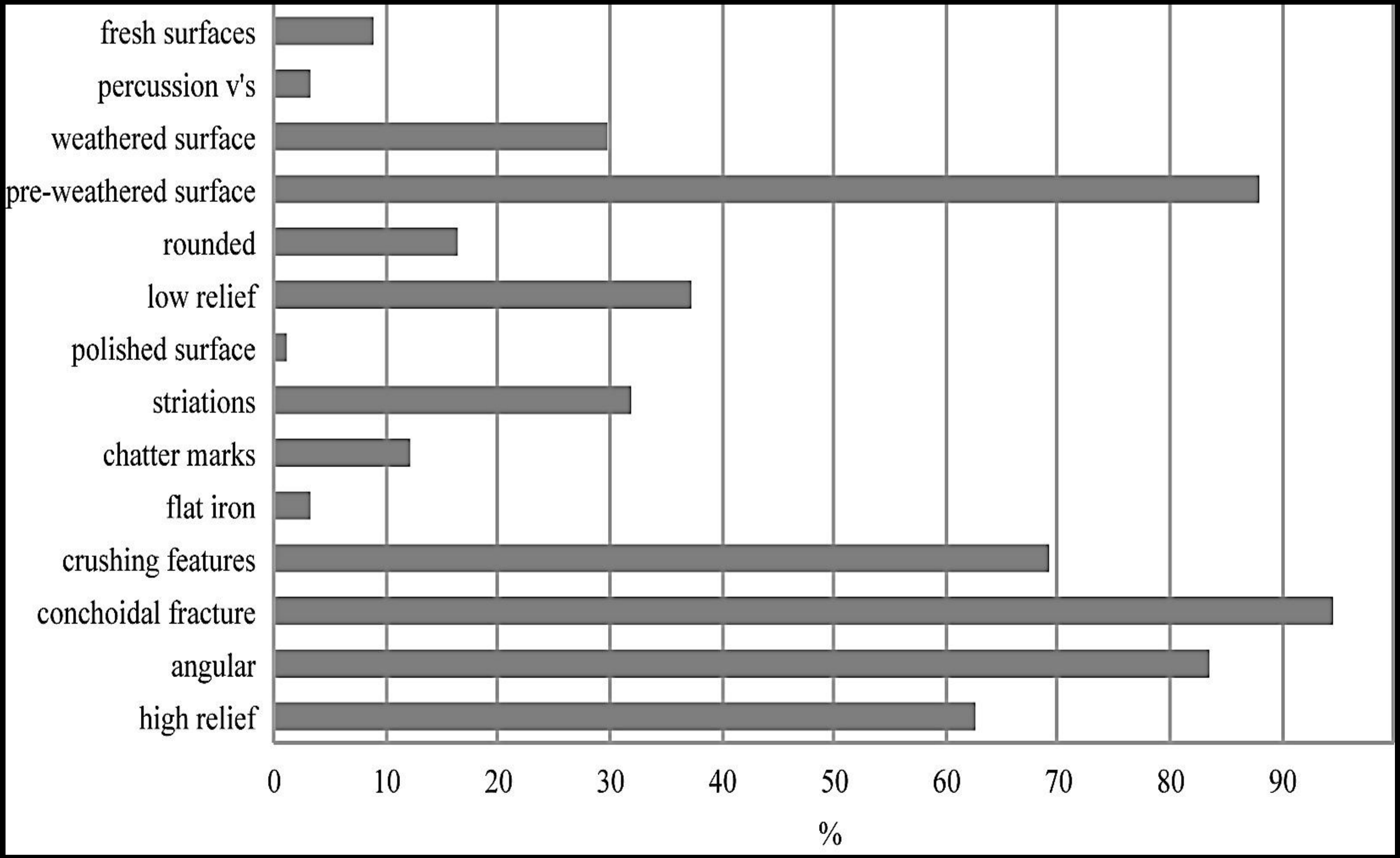
preweathered surface

by SEM on 120 grains
125-1000 µm in size


chatter fractures

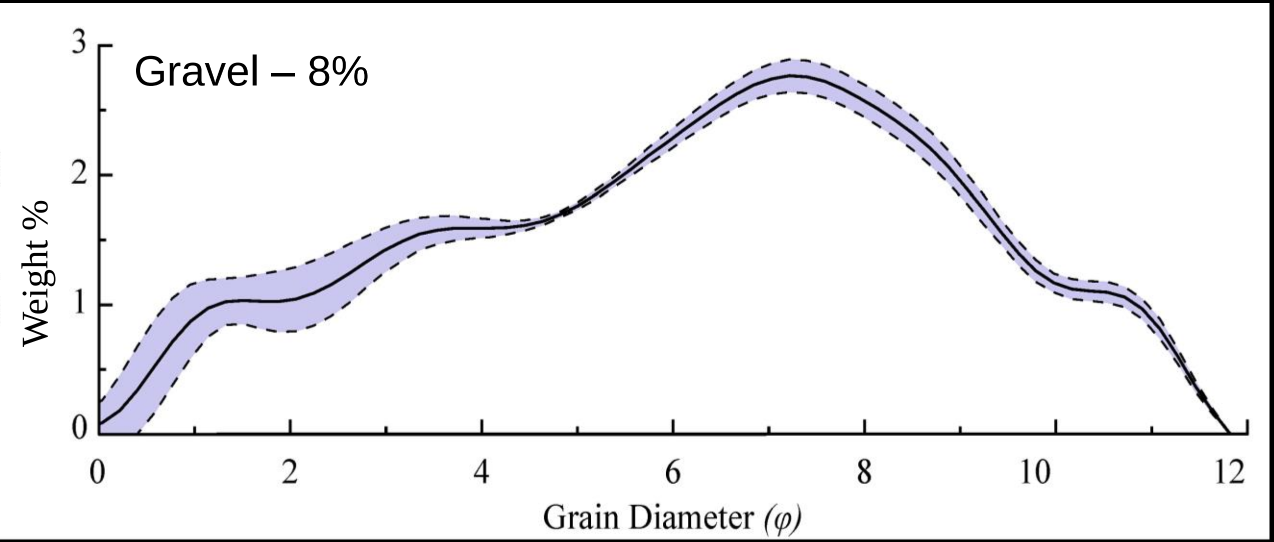
Rebecca Putkammen

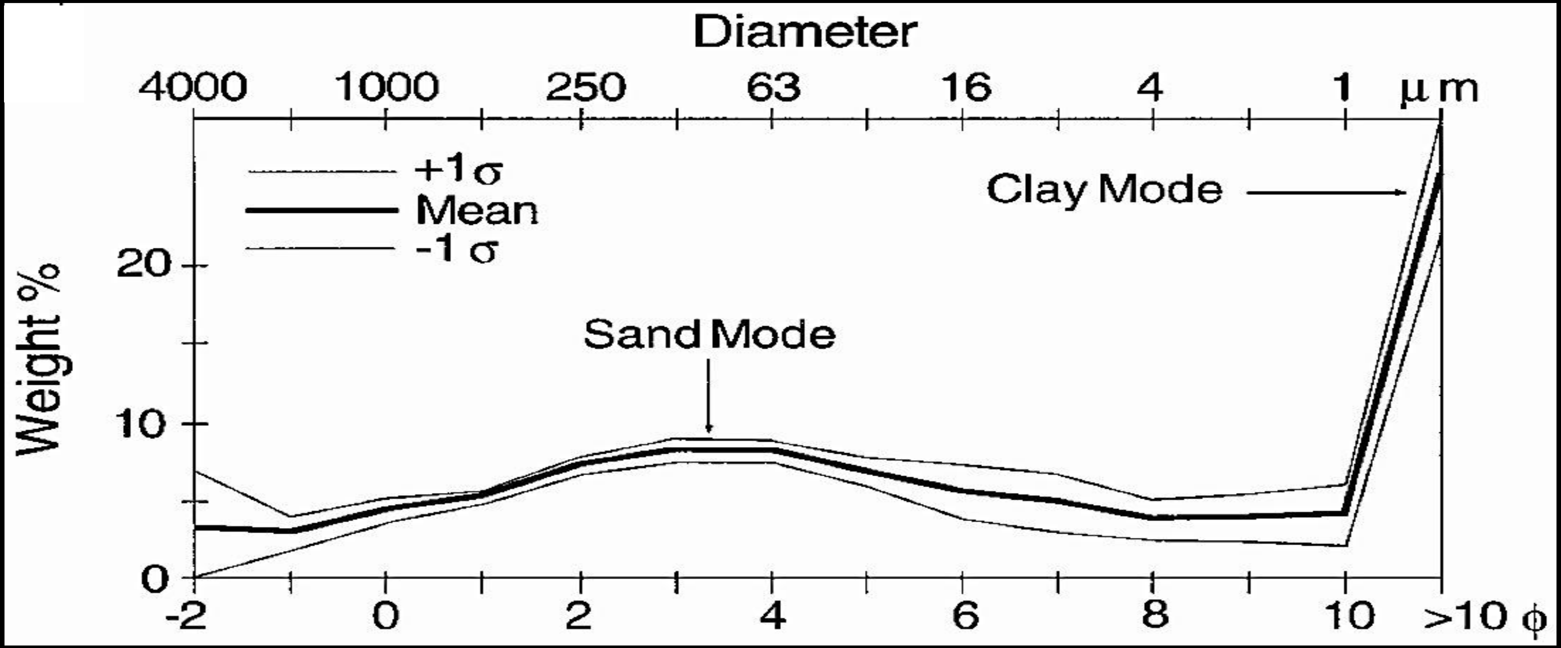
- Microtextures differ from UpB
- Infer a more complex history
  - weathering → crushing → fracture → abrasion → dissolution
  - → variable shear



SLW till particle size distribution

Finer (silt) mode to UpB

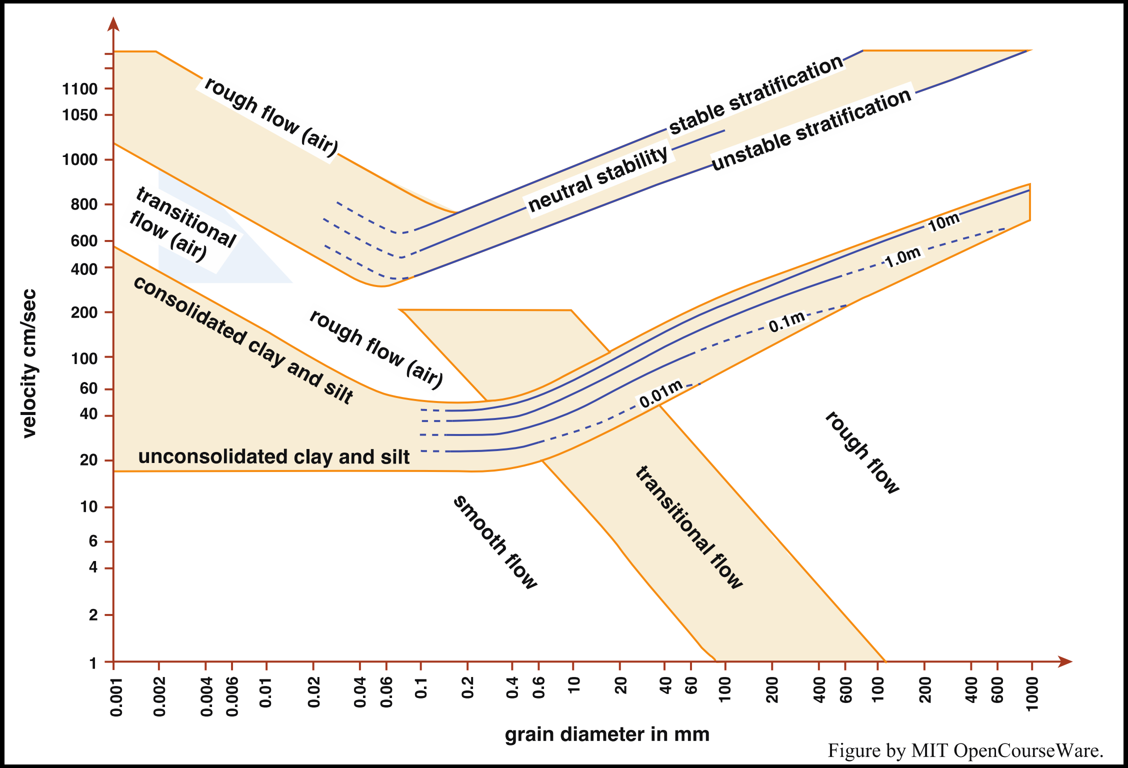




Tulaczyk et al., 1998

Texture of sediment infers

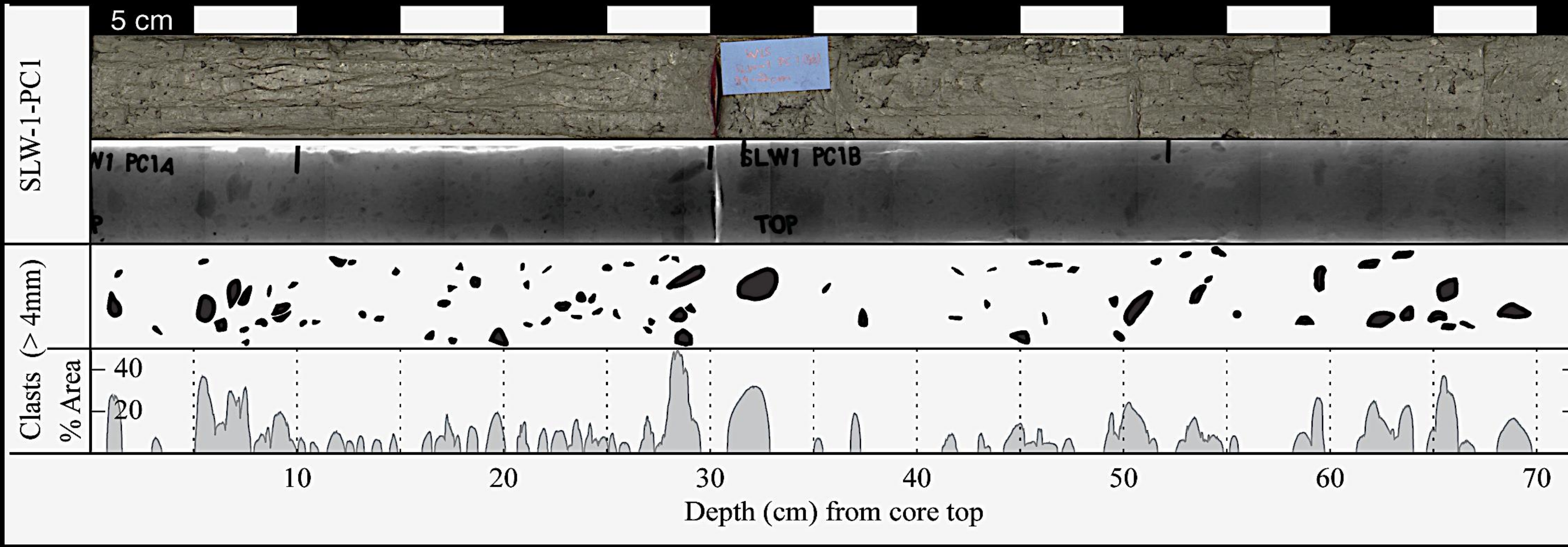
- no sorted sediments
- may be larger volumes of water moving around during discharge-recharge events
- but given gradients and inferred conduit size
- velocities likely to be low at <0.4ms^{-1} in 1m deep water column

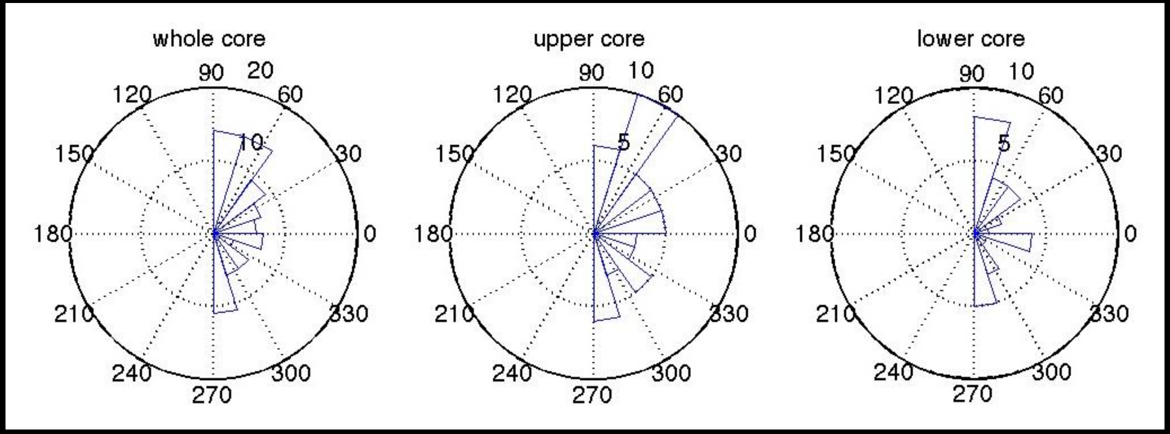


Hjustrom-Sundborg plot

Clast fabric

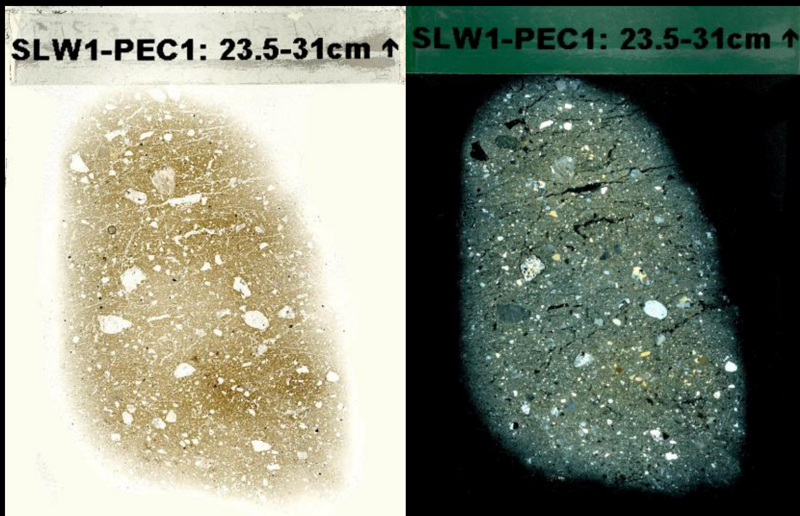
Core section shows >4mm diameter clasts
Measure apparent long-axis on 82 clasts



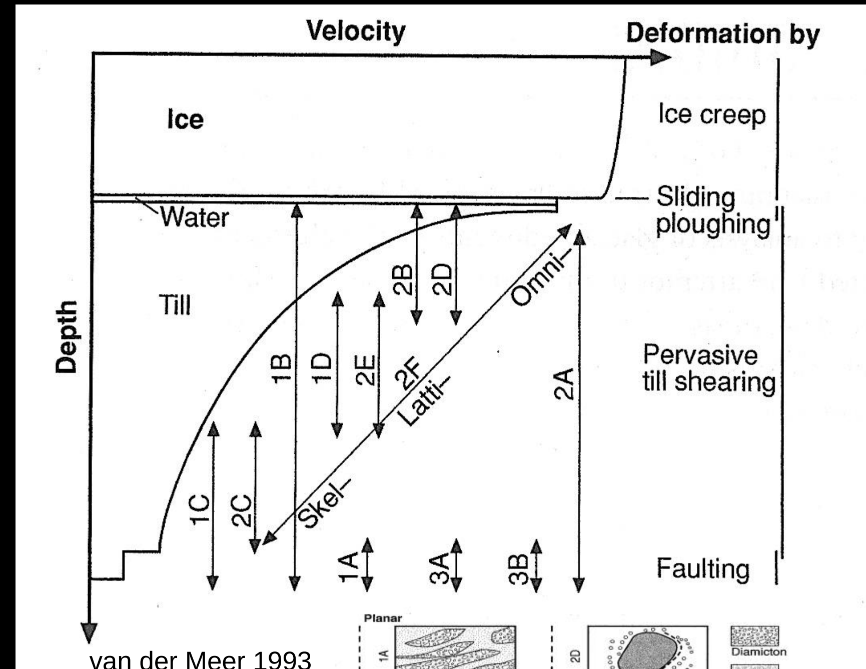


- weak vertical fabric
- not typical sheared till fabric
- formed with decoupling?

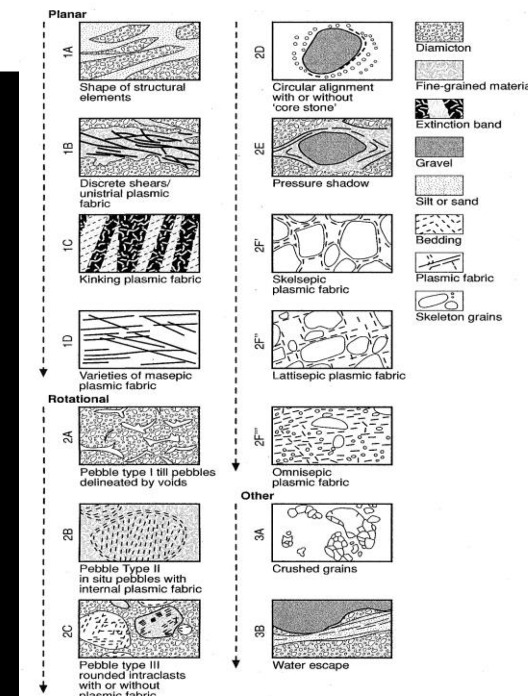
Till microfabric

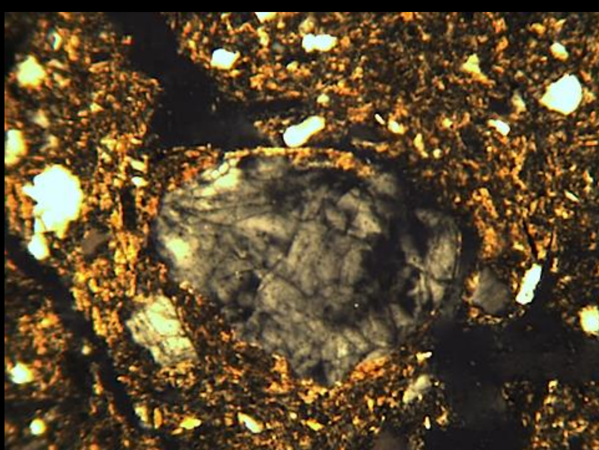


Fractures

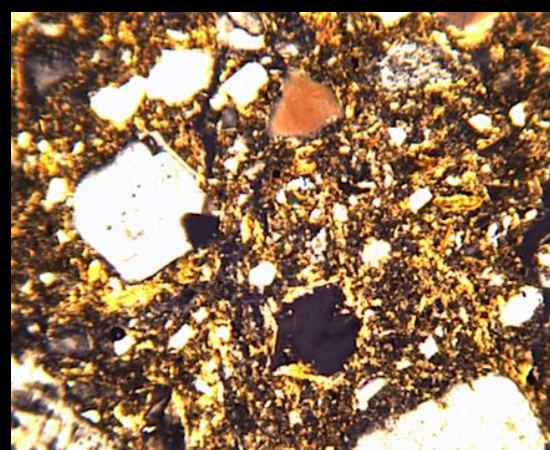


van der Meer 1993





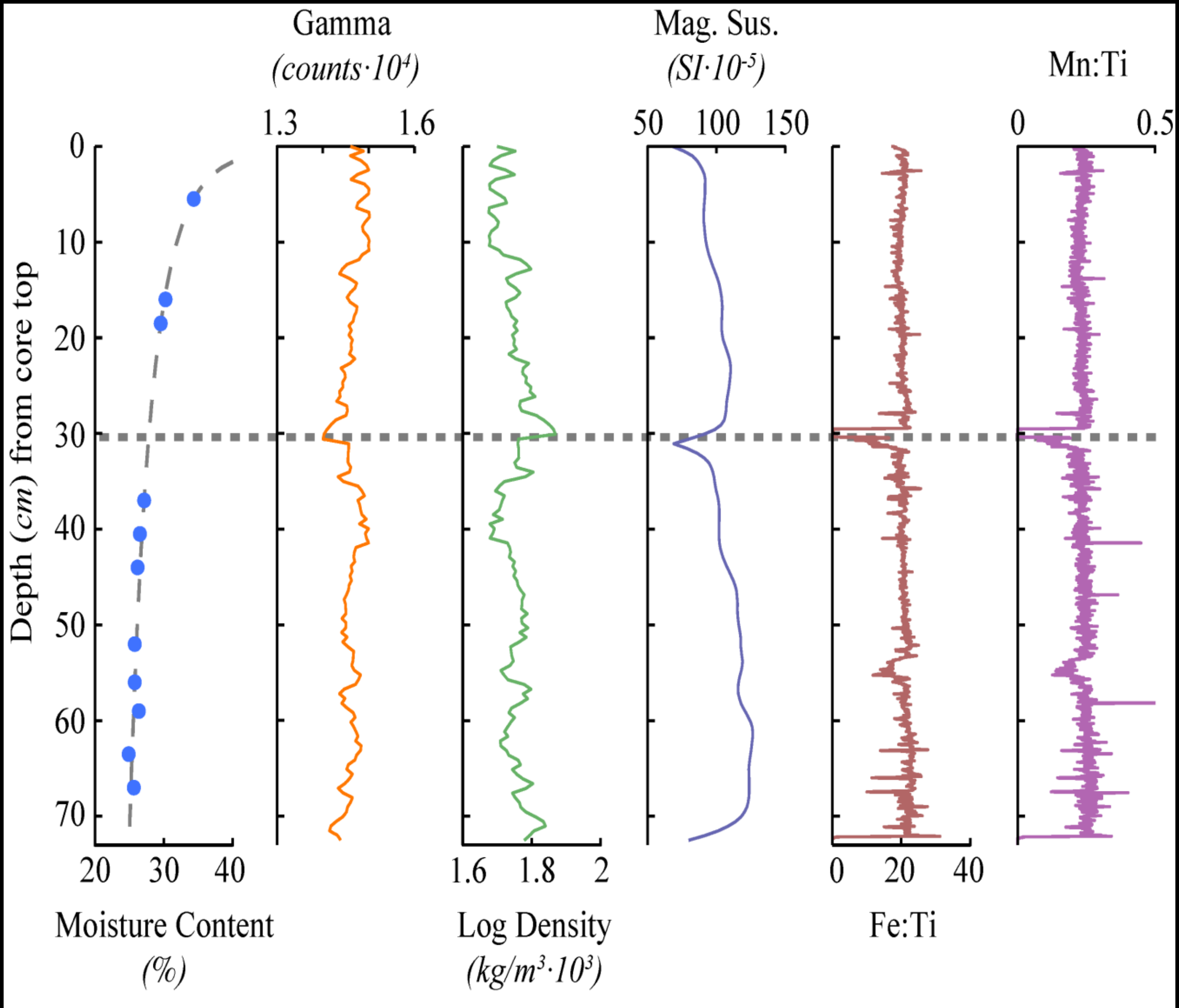
Skelsepic



Lattispeic

Physical properties

e.g.

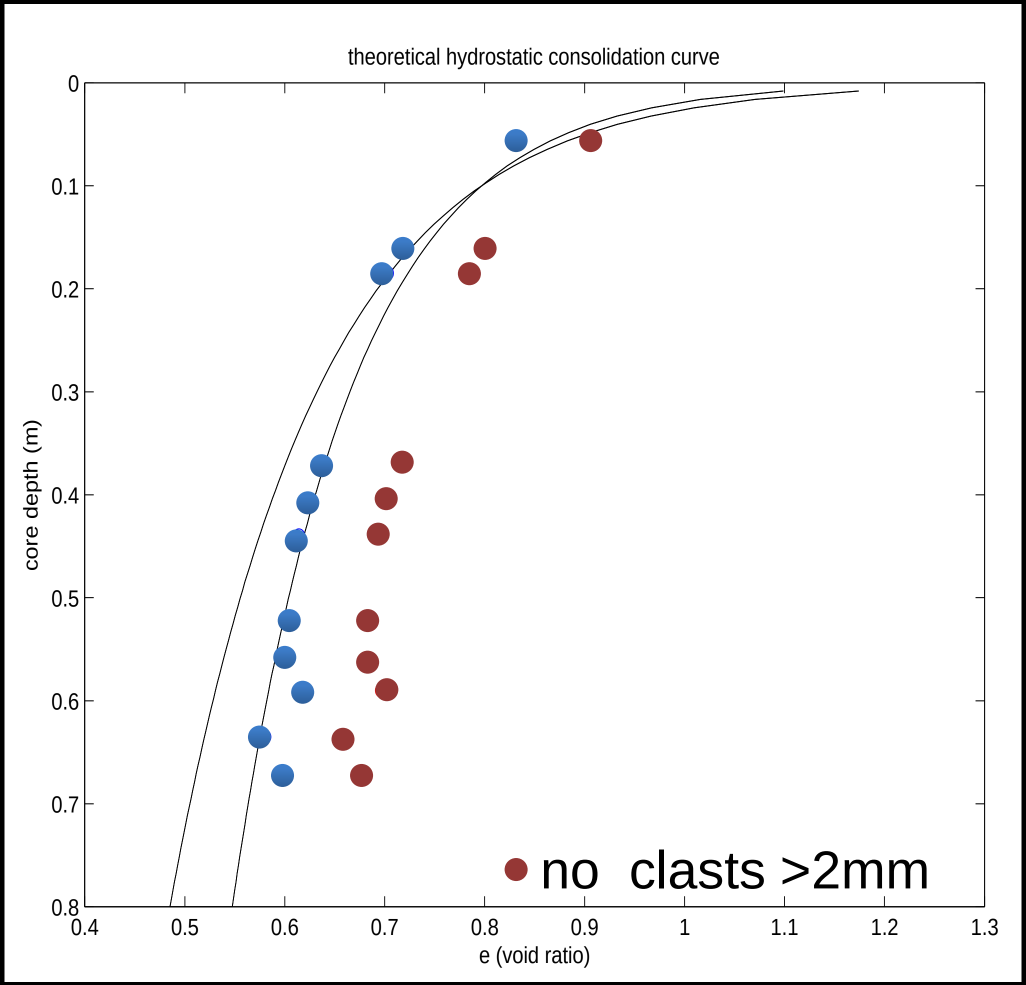


perhaps most interesting is water content and inferred consolidation

Consolidation vs depth

SLW till normally consolidated

appears any loading effect from last ice touch-down during lake drainage has been compensated



For hydrostatically consolidated sediment:

$$e = e_o - C_p log \frac{N_o}{N_{eo}}$$

e: void ratio

e_o: ref. void ratio

C: compressibility

N_o: effective normal pressure

N_{eo}: ref. effective normal pressure

$$N_o = N_{eb} + (\rho_t - \rho_w) g z$$

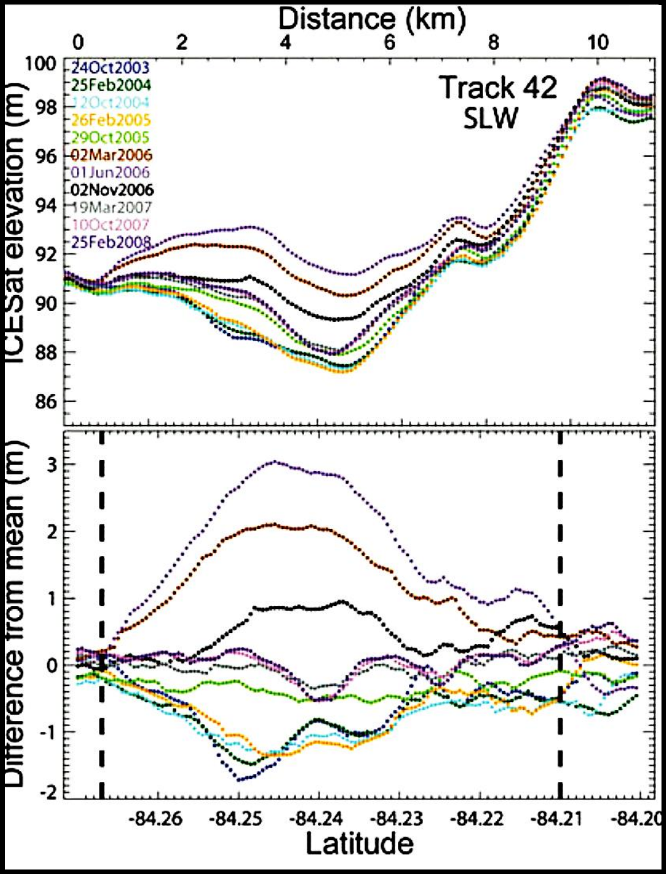
$$\frac{dN_e}{dz} = (\rho_t - \rho_w) g \approx 10 \text{ kPa m}^{-1}$$

converted water content to void ratio

Environmental Interpretation

No signs of sorting or lag surfaces
- quiescent conditions in the lake
- negligible deposition or erosion of lake sediment
- “floods” not typical floods – flow only at cm/s due to low surface gradients and wide conduits

But during ‘lowstands’ ice recouples with bed
- deforming new till into the lake
- mixes any older thin lake sediment into till



Fricker et al. 2010

Conclusions

SLW sediment
- homogeneous, structureless, clast poor, muddy till
- water saturated to compacted

Sediment sources
- minor differences with those of UpB
- at least a local marine component

Clasts, grains and microfabric
- a more complex transport history than UpB
- strong (but variable) glacial shear and recent dissolution

Lake discharge-recharge at low velocity ($<0.4 ms^{-1}$)
- floods move across WIP but no sign of fluvial erosion or transport
- flow unlikely via persistent conduits, most likely in braided sheets

At some lowstands ice recouples with lake bed (last 2004?)
- till deformed into lake basin
- then re-floats and unloads
- common for lakes on ice plains but unlikely in deeper interior lakes

Till appears normally consolidated
- loading effect from last lake drainage now compensated

Clasts have weak vertical fabric
- formed with decoupling during lake refilling