Clean Patterns in Icy Dirt

Exploring spontaneous patterns in freezing soils

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Thanks!

Wonderful collaborators:

Field: Linc Washburn, Ron Sletten, Suzanne Anderson, and Ray Fletcher

Instrumentation: Carrington Gregory, Chris Stubbs

Modeling: Brad Werner, Mark Kessler, Brad Murray, and Mike Mellon

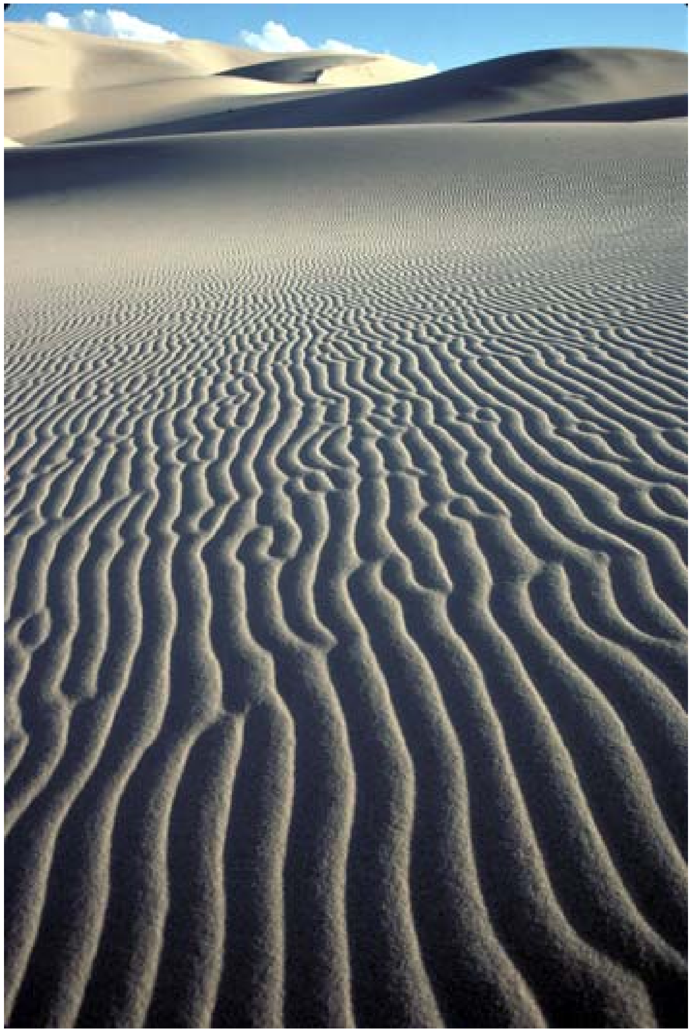
Dedication to Linc Washburn

He contributed immensely to the field of periglacial geomorphology through his research, his publications and his personal qualities. He inspired, encouraged and aided researchers and organizations world wide.

- *Seminal work on patterned ground*
- *Author: Geocryology*
- *Founder and Director of QRC*

Patterns in Nature

- Patterns in nature can be aesthetically striking
- They attract scientific attention (provide a focus)
- Excellent research targets: they manifest interesting interactions under conditions that may be particularly instructive (signal is large,little noise)
- Invite probing questions and search for deeper understanding



Ripples, Eureka Dunes

Striking order out of highly random processes

Outline

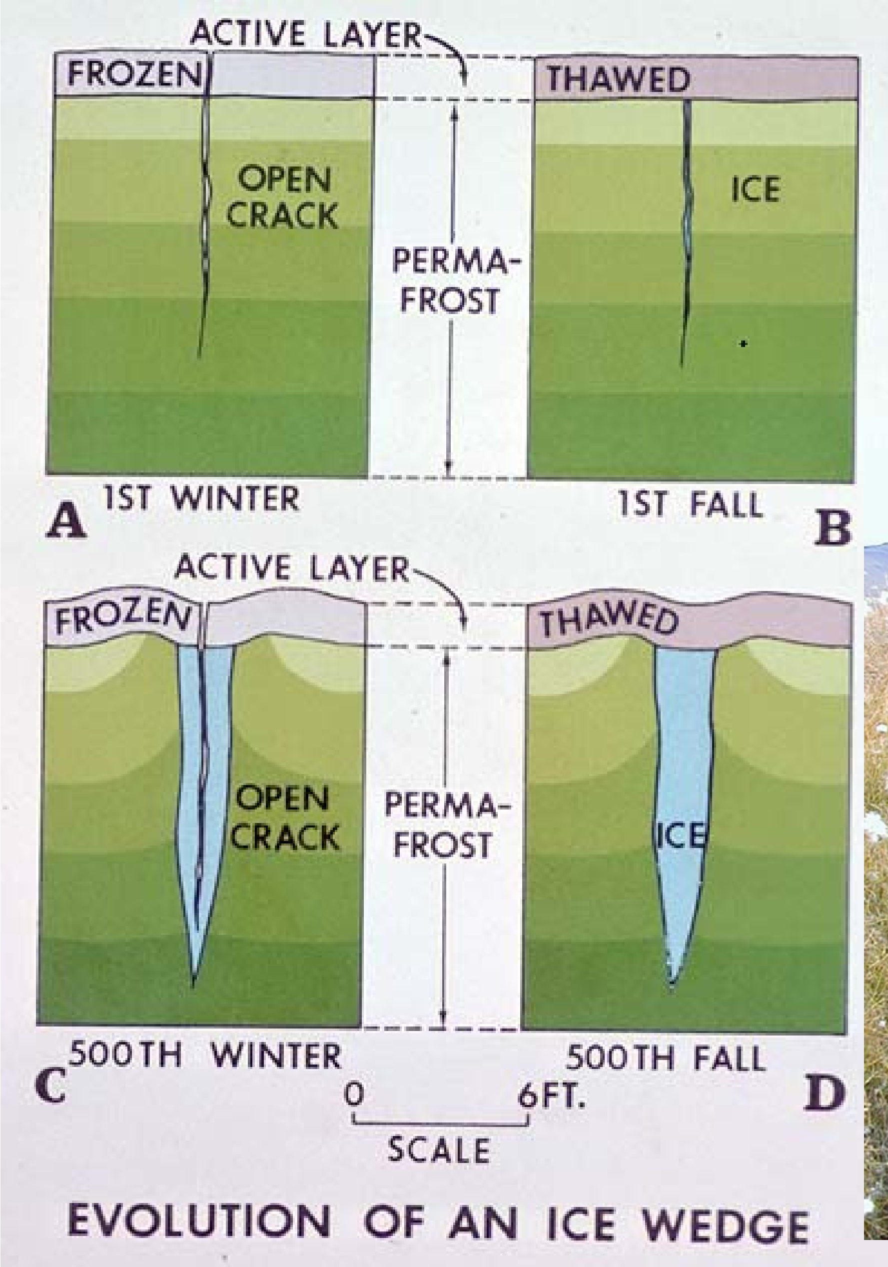
- Illustration of patterned ground types in cold region soils
  - Contraction cracking: 10-20 m
  - Ice induced: 2-4 m and 0.1 m

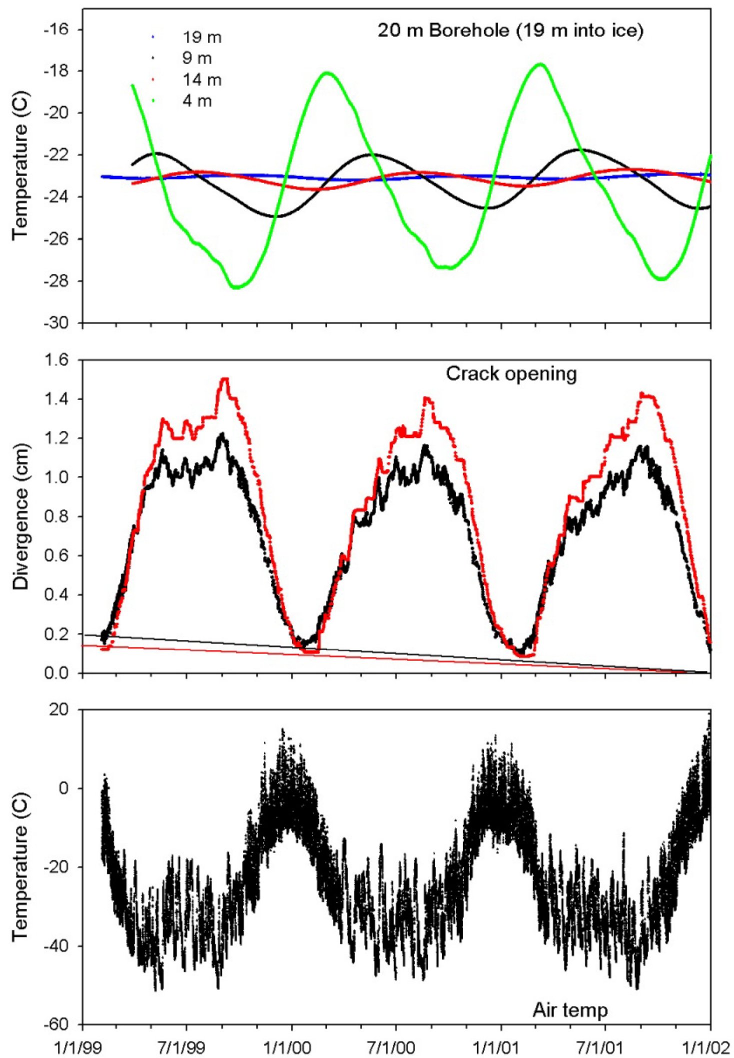
- Insights into processes and feedback that underlie the self organization

Polygons, Victoria Valley

Ice-Wedge Polygons

Spacing is a multiple of crack depth

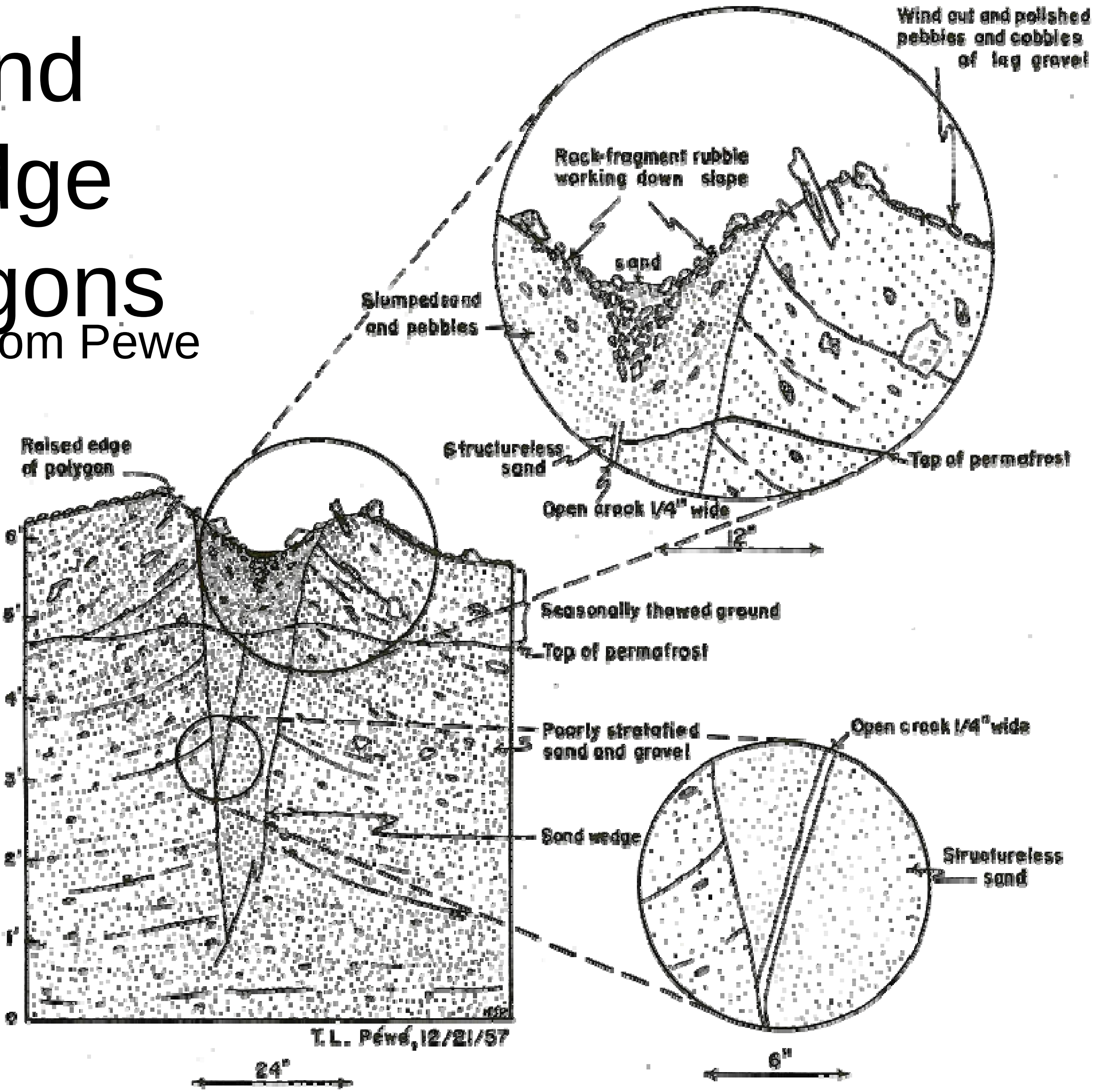




20 m Borehole (19 m into ice)
19 m
9 m
14 m
4 m
Temperature (C)
-16
-18
-20
-22
-24
-26
-28
-30
Crack opening
Divergence (cm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Temperature (C)
20
0
-20
-40
-60
Air temp
1/1/99
7/1/99
1/1/00
7/1/00
1/1/01
7/1/01
1/1/02

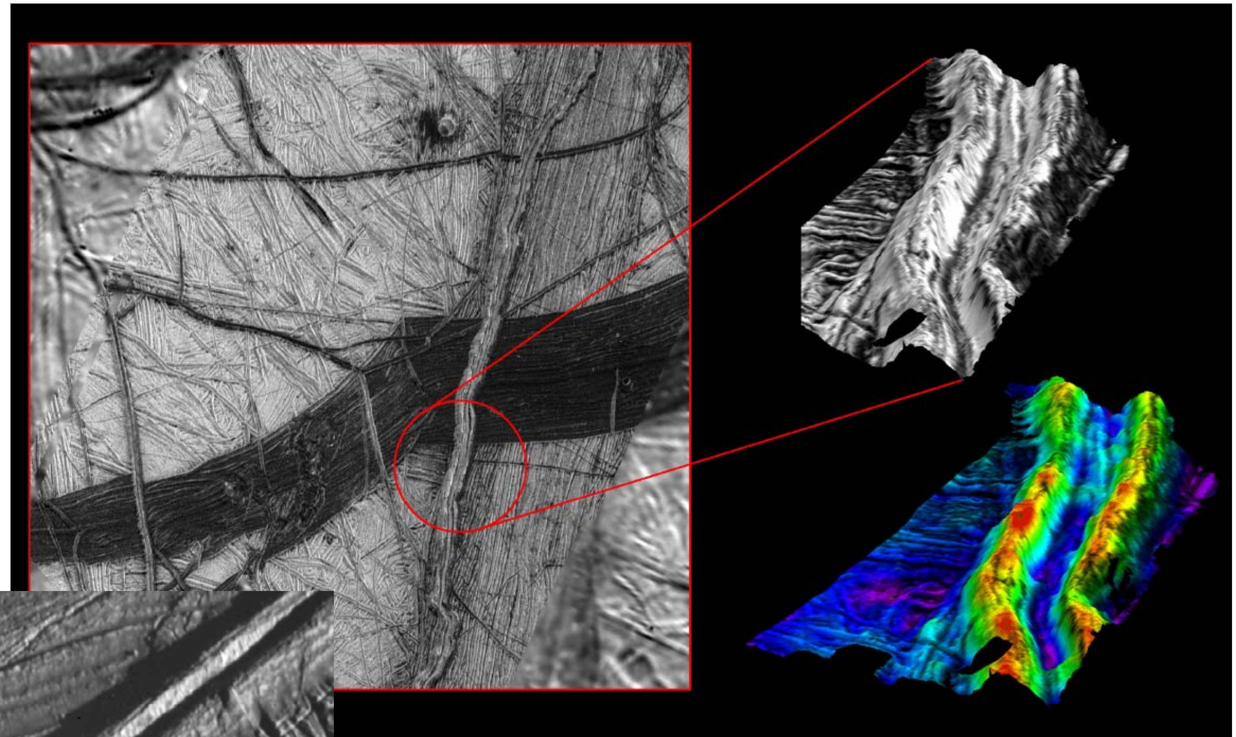
Sand wedge Polygons

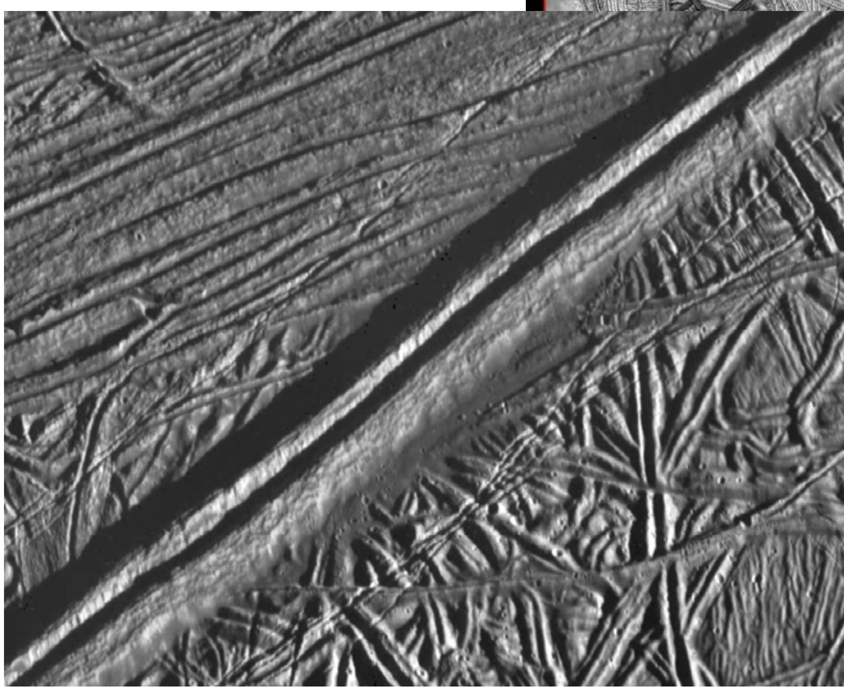
From Pewe

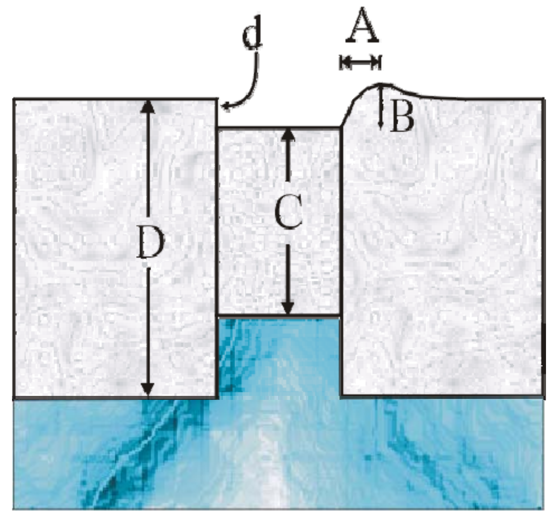


Note long troughs bordered by identical ridges

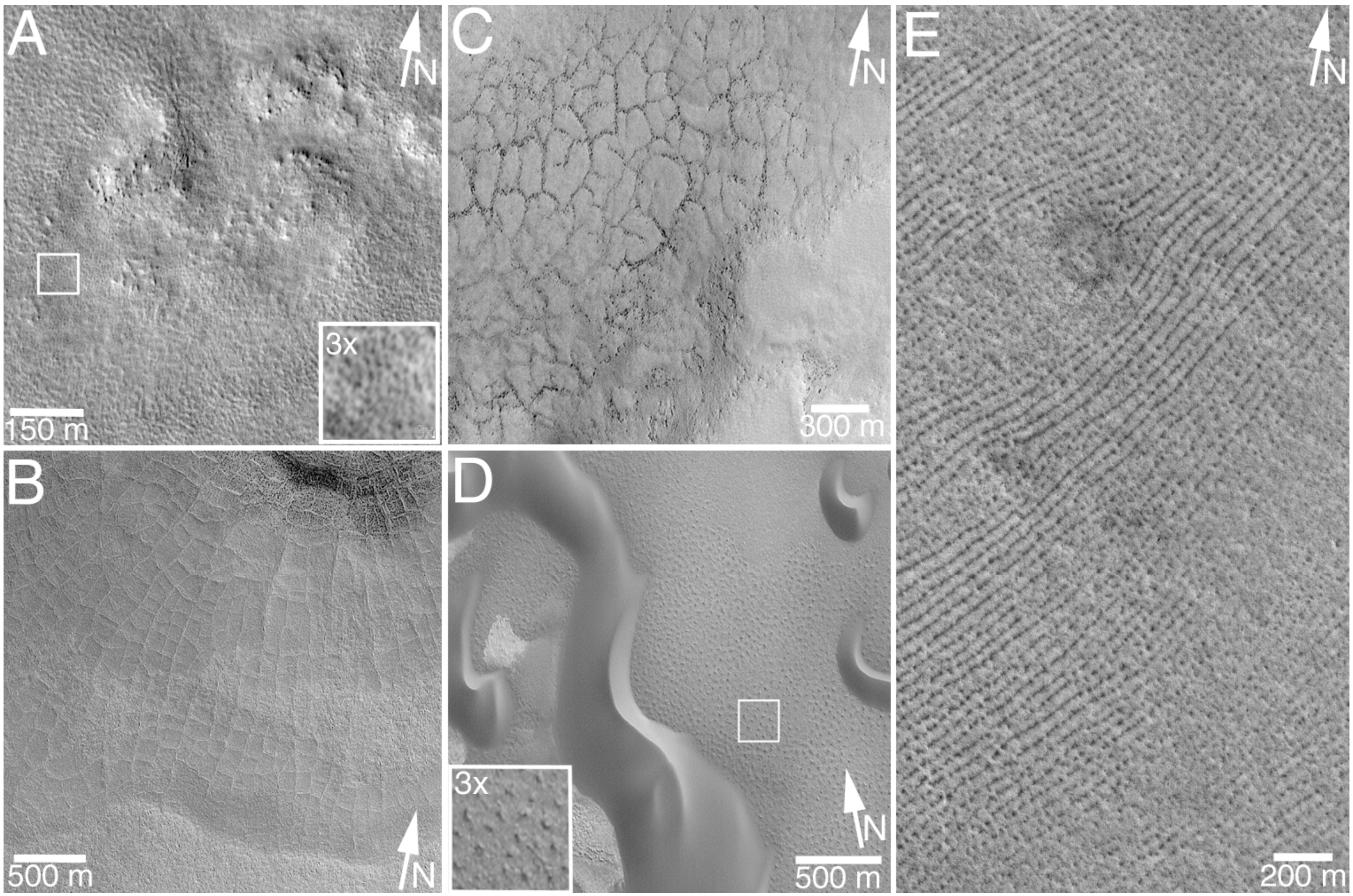
Europa Ice Thickness







Surface patterns contain rich information about the properties and processes active in the less accessible underlying material.



Raised Beaches, Spitsbergen

Isostatic Uplift due to reduced ice load

Stone Circles, Spitsbergen

Patterns beckon closer attention (from meter to atomic scales)

- Sorted circles
- Sorting, frost heaving and sorting details
- Active layer processes; spatial variation in temperature, thermal properties & moisture
- Ice lensing phenomena
- Freezing in porous media (soil & rocks)
- Premelting behavior; quasi-liquid films

Freezing Clay: Ice lenses (Tabor)

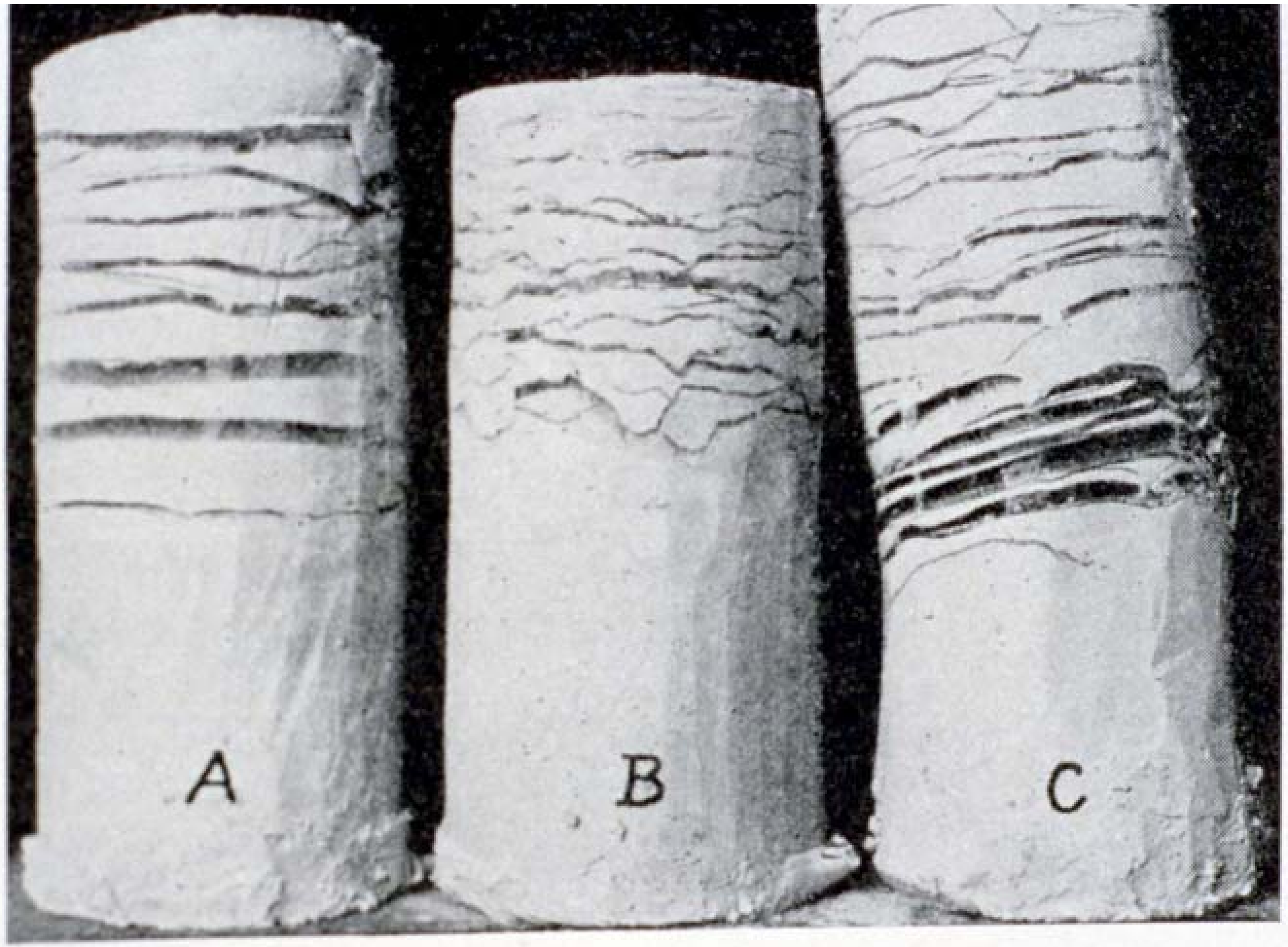


FIG. 11.—Clay cylinders frozen (*A*) under no surface load; (*B*) under iron weigh
sulated from clay by wooden disc; and (*C*) under iron weight in contact with clay.

QuickTime™ and a decompressor are needed to see this picture.

From Cold Regions Research & Engineering Laboratory: 4.5 day

Sorted circles, Spitsbergen, ~3m

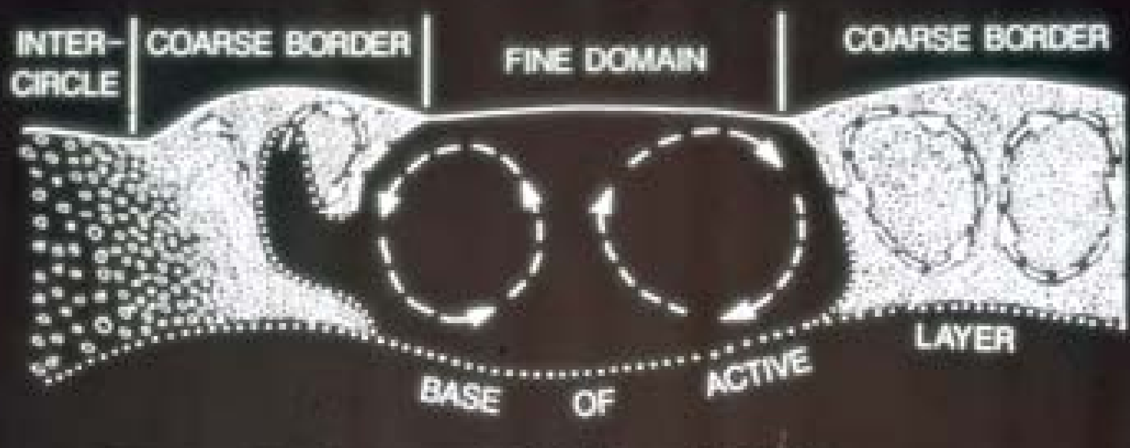


Fig. 5. Movements in sorted circles proposed by Hallet et al. (1988).

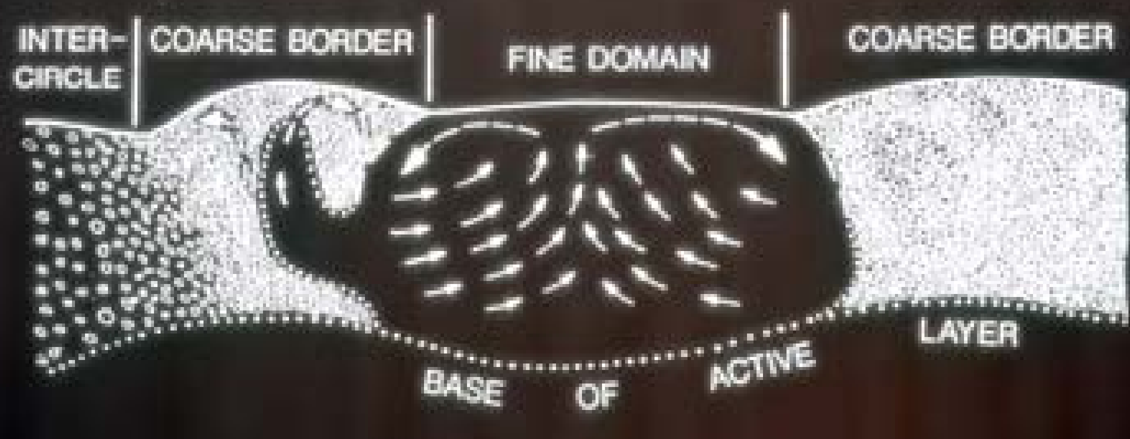
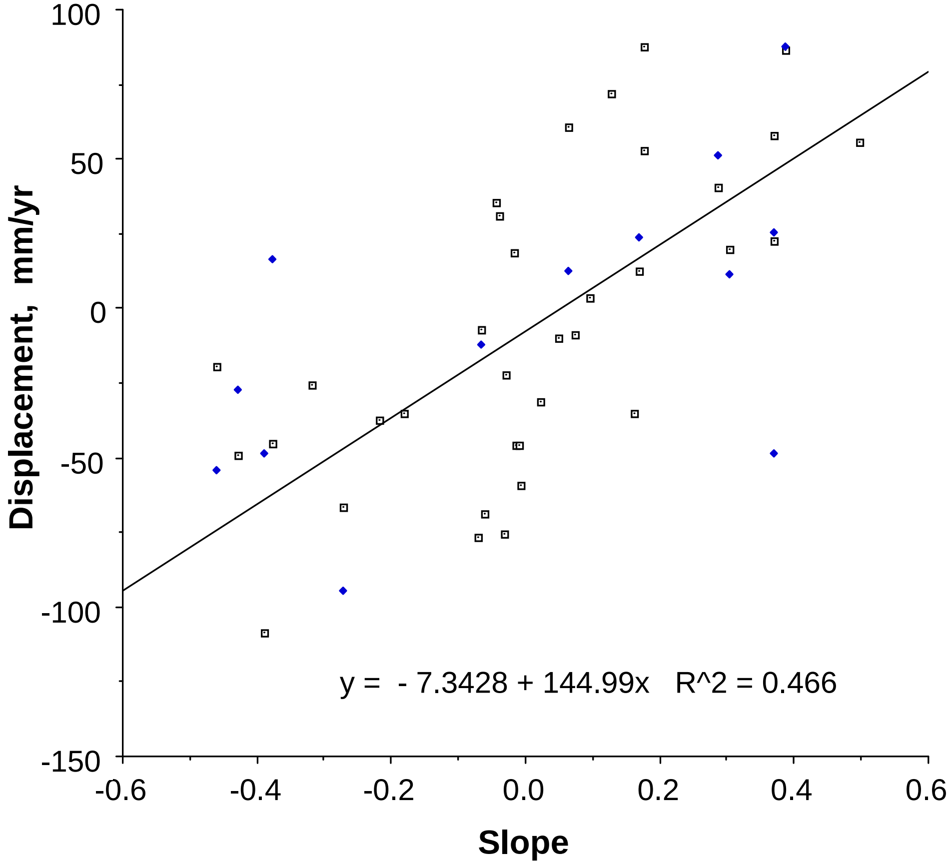


Fig. 6. Another possible explanation of the movements observed on the surface by Hallet et al. (1988).

Surface Displacements Scale with Slope

Note: vertical scale is not correct; numbers should be divided by 10.

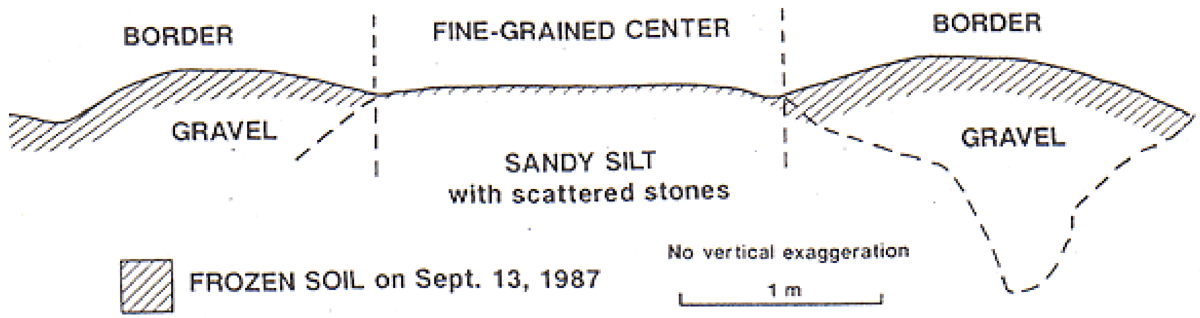


As down slope motion scales with topographic gradient it should modify the surface diffusively

Modern electronics enable continuous measurements through the seasons

Cross-Section Sorted Circle

Topography & subsurface



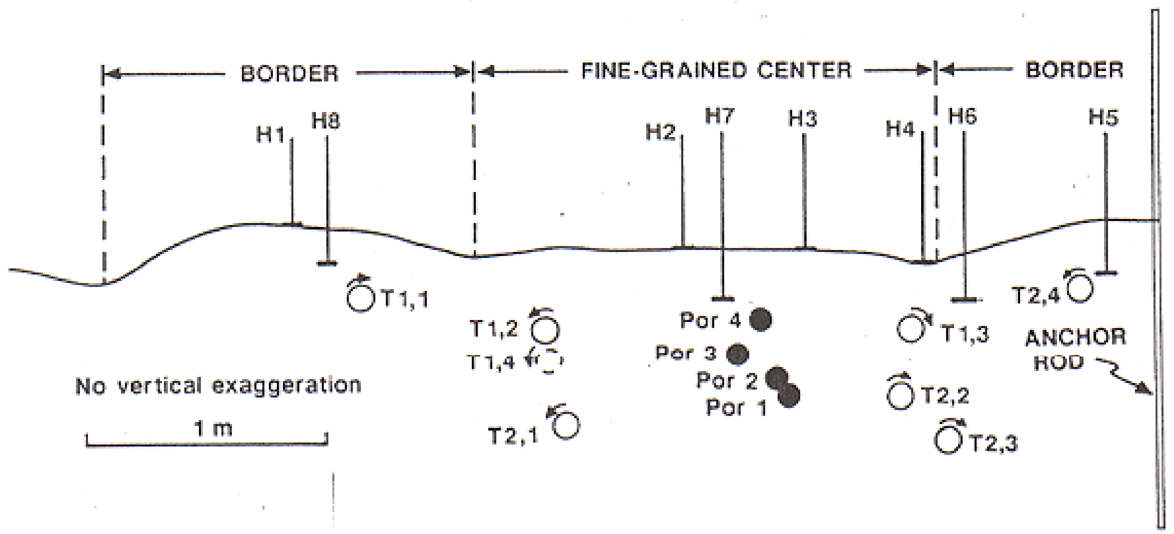
Instrumentation:

H: heave sensors

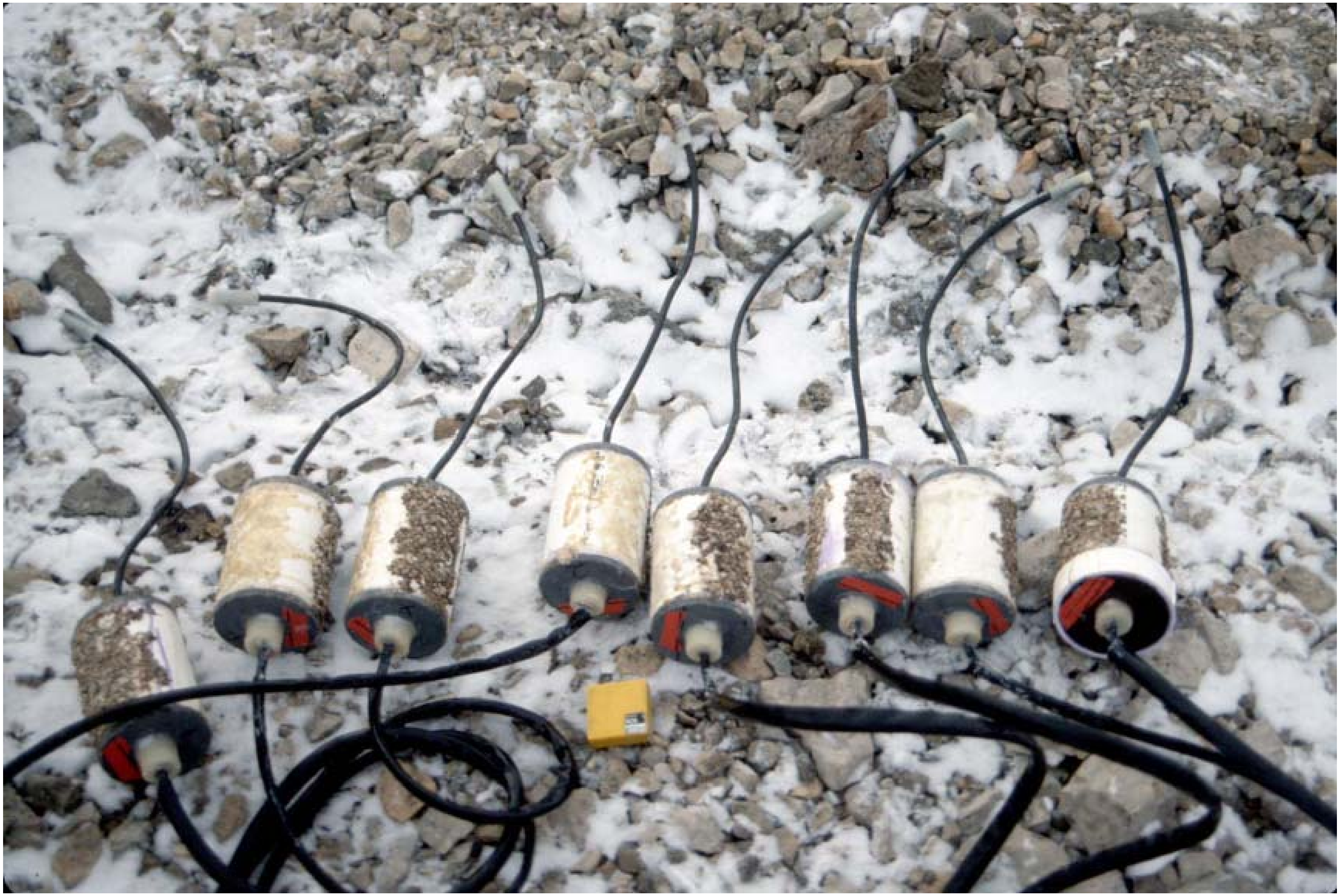
T: tilt sensors

Por: pore pressure transducers

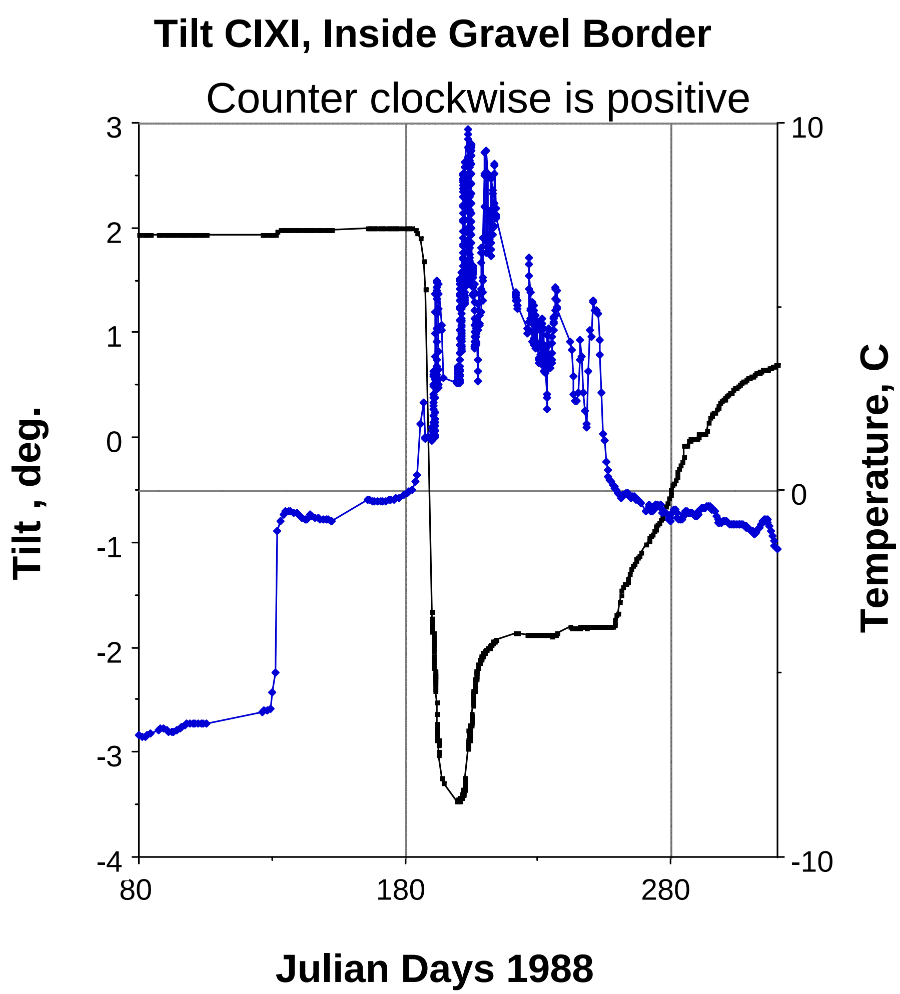
TRANSDUCER POSITION

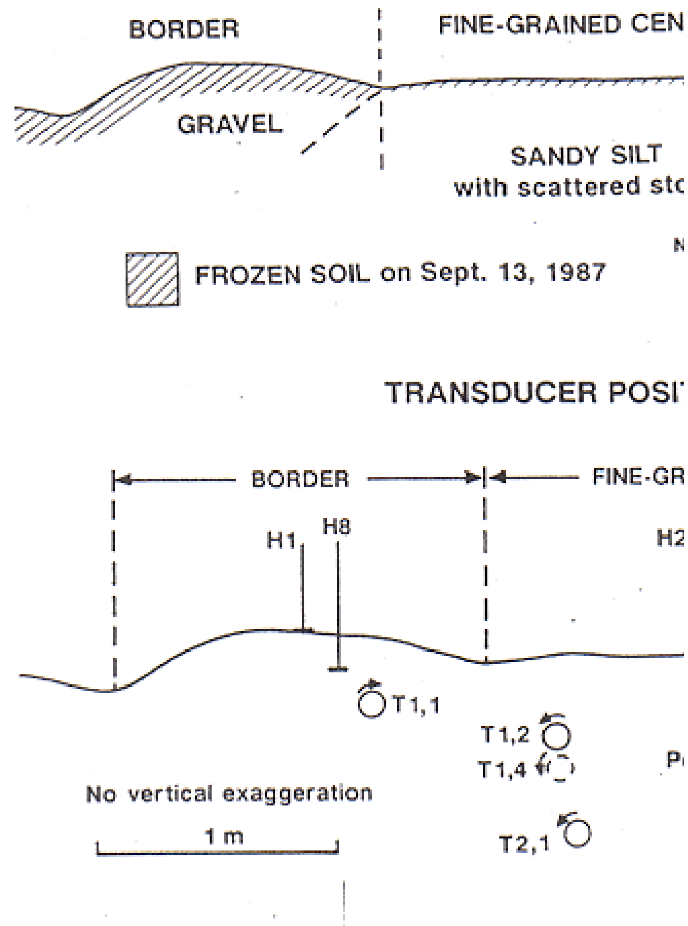


Tilt sensors



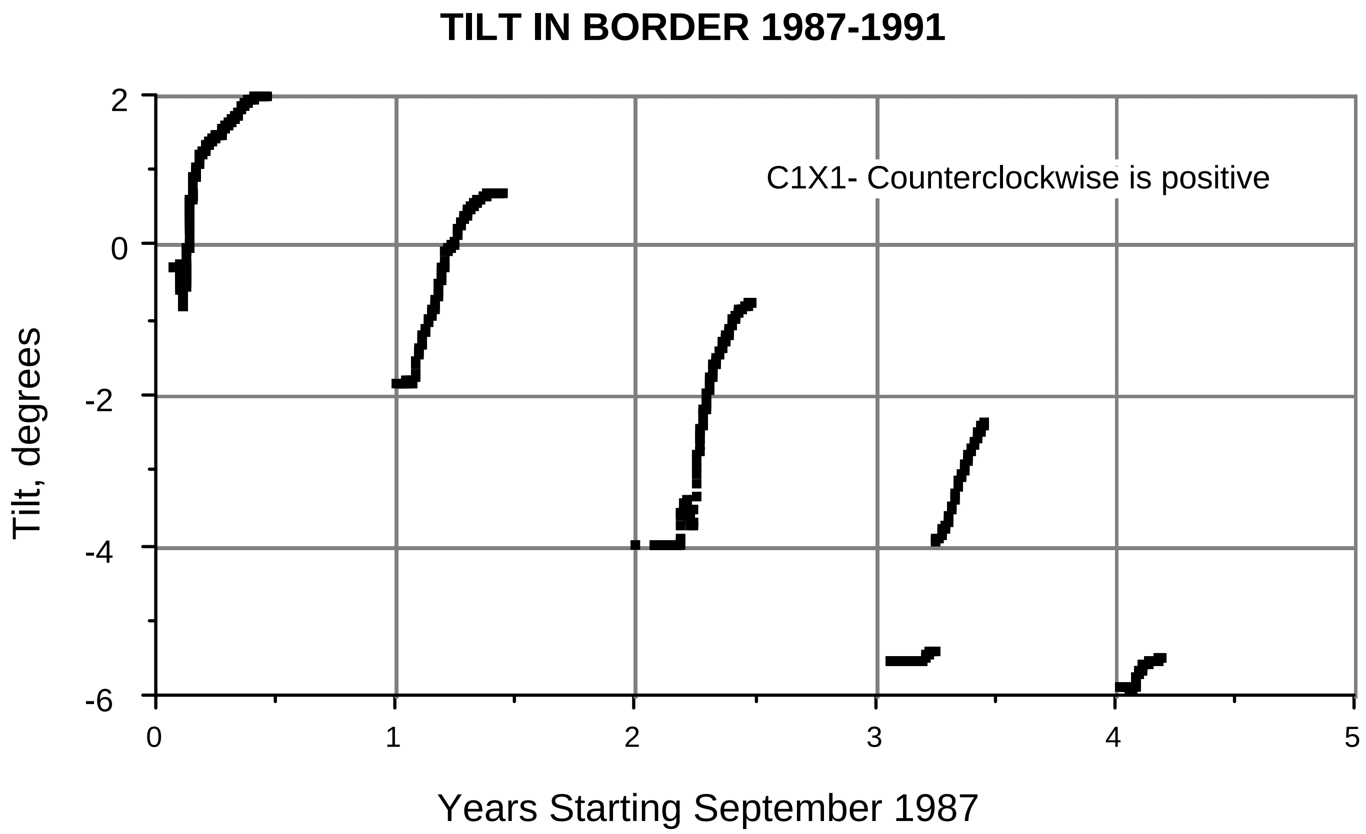
Tilt and Temperature, Spring through Fall



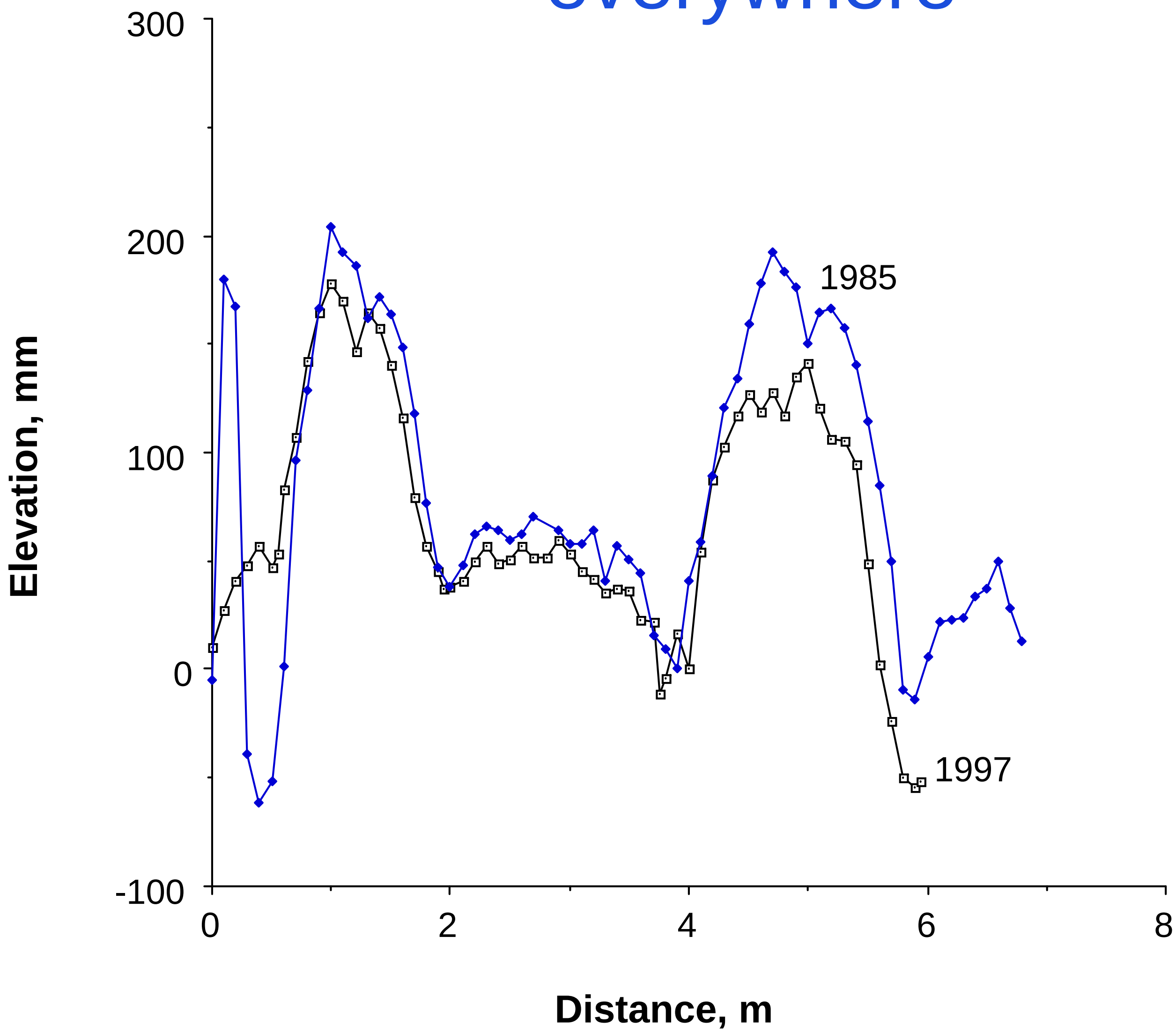


Residual Tilt (only fall periods shown)

Ratchet like, clockwise rotation (~1 deg/yr, full circle in centuries)



Distinct Topography is Sustained,
and yet surface material moves downhill everywhere



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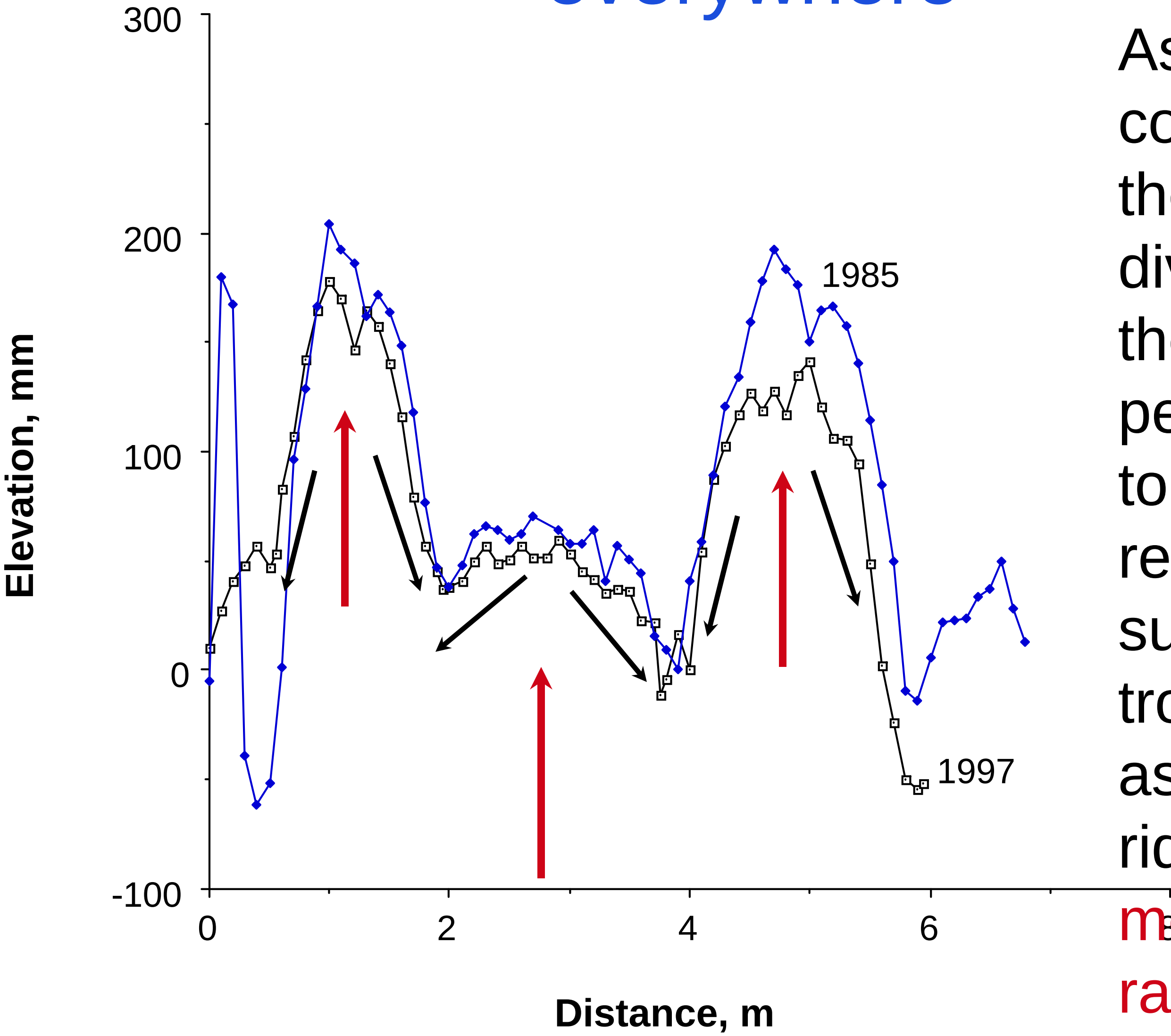
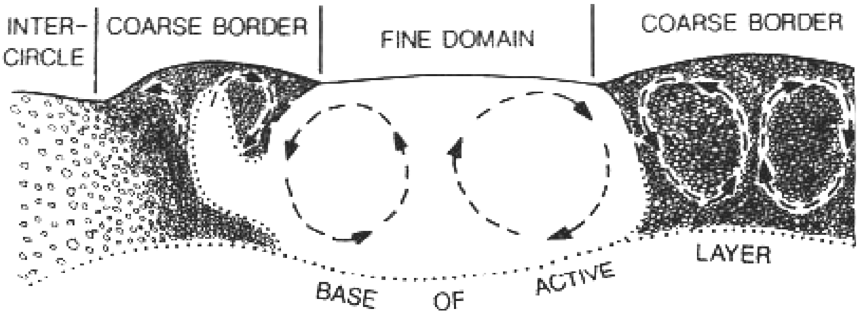


As material converges on the troughs, and diverges from the ridges, persistence of topography requires subsidence in troughs, and ascent under ridges (and mountain ranges)



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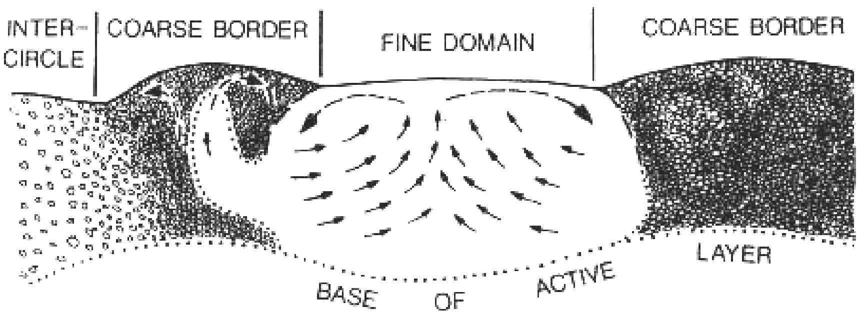


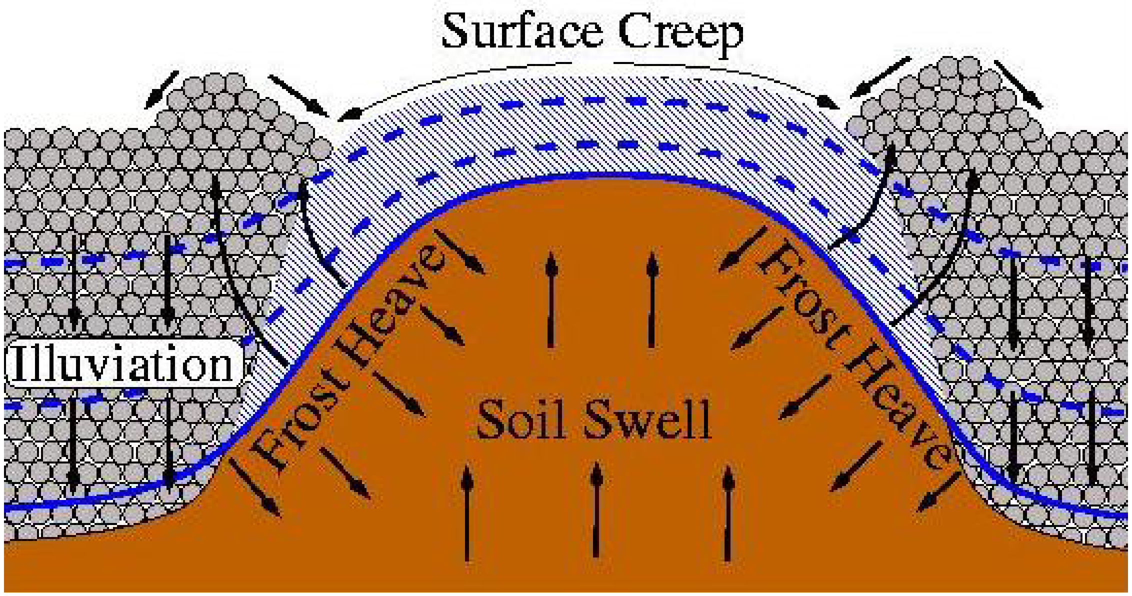
Fig. 6. Another possible explanation of the movements observed on the surface by Hallet et al. (1988).

Numerical model is consistent with conceptual model base on field observations

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Patterns: hallmark of complexity

Original state: layer of mixed material of nearly uniform thickness
Initial Phase: larger stones/pebbles move to the surface (upfreezing)
and then move laterally downslope

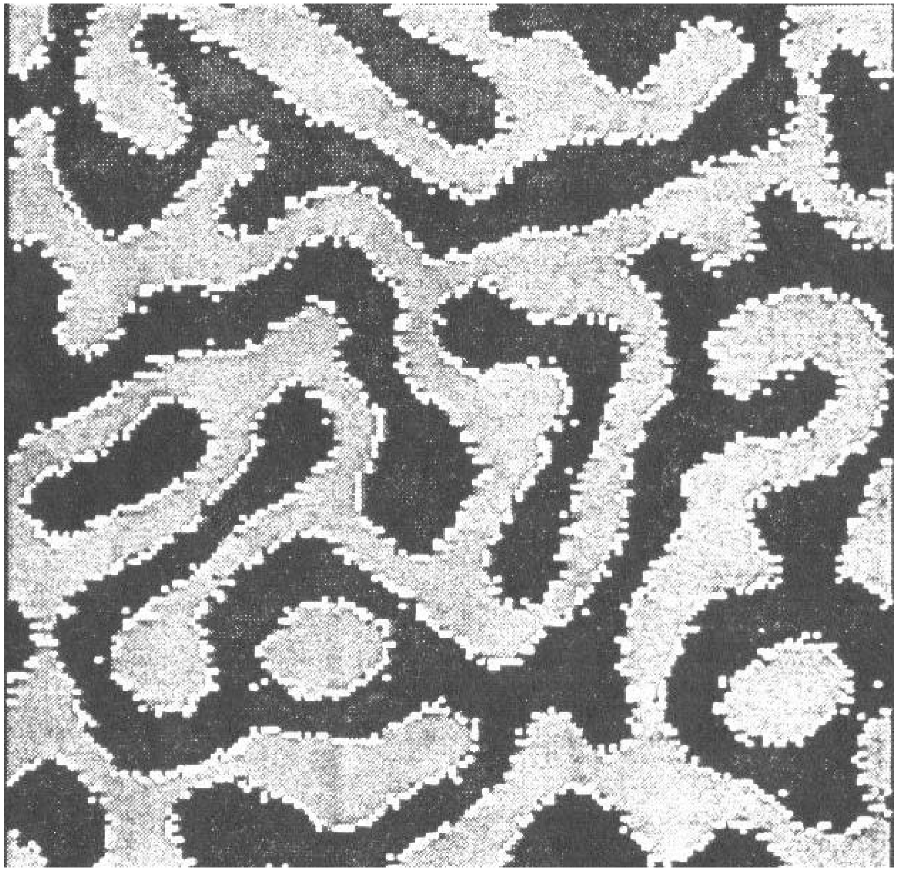


Courtesy of
Mark Kessler

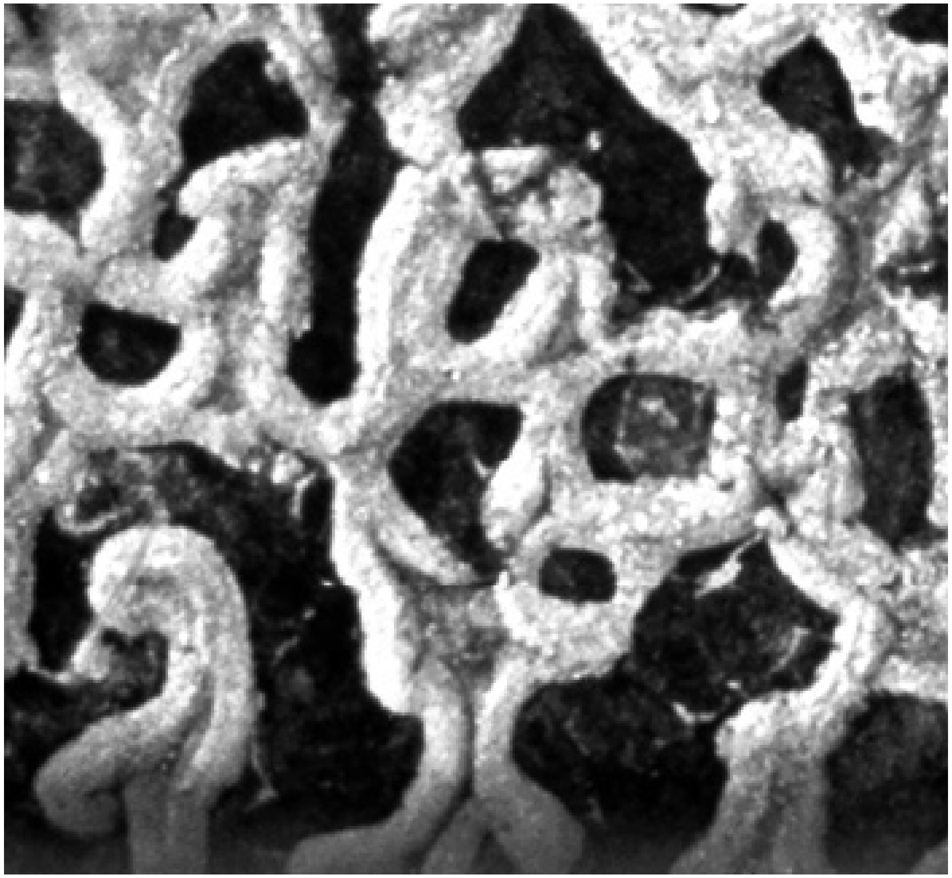
Mark Kessler's Model

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

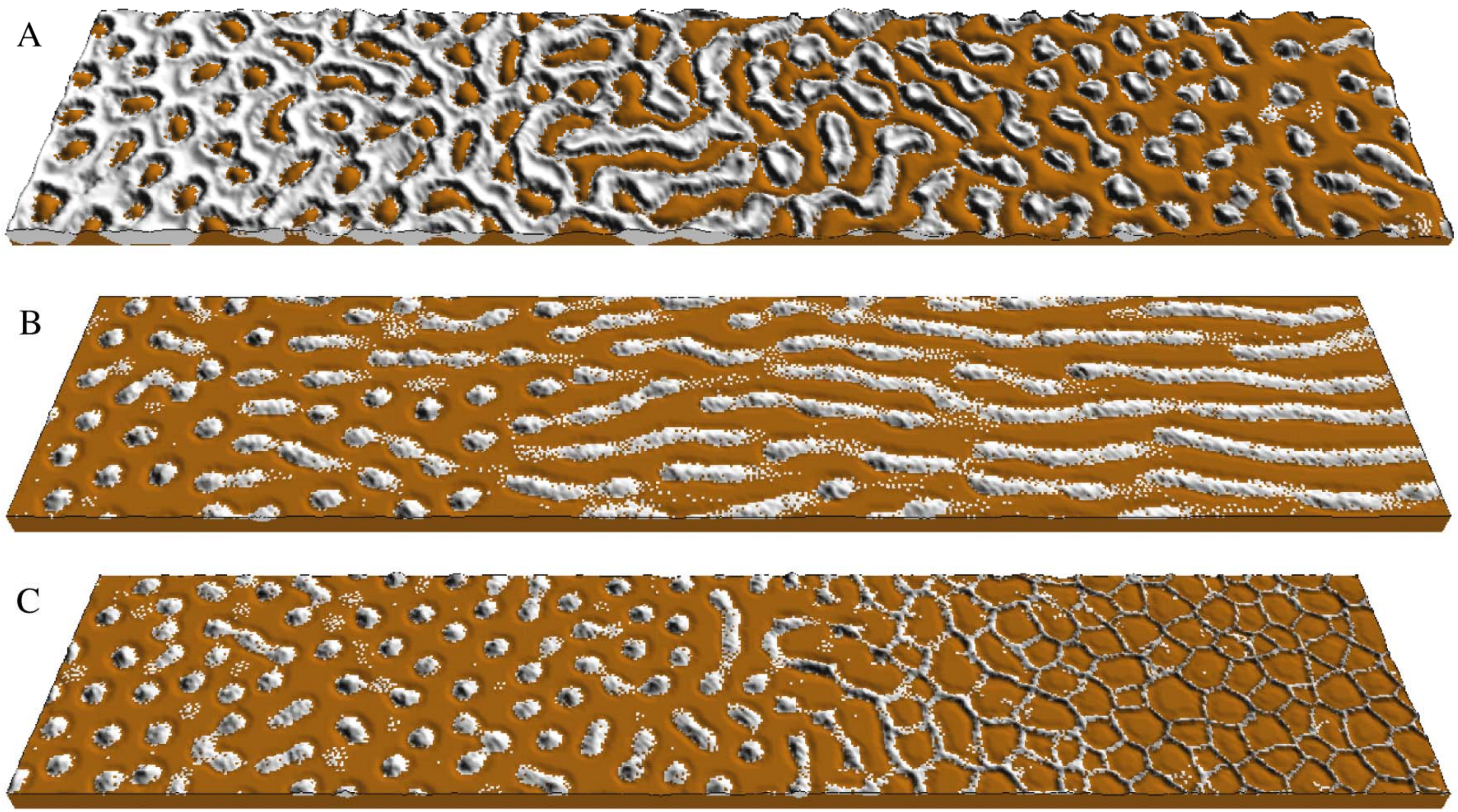
Sorting in 2-D



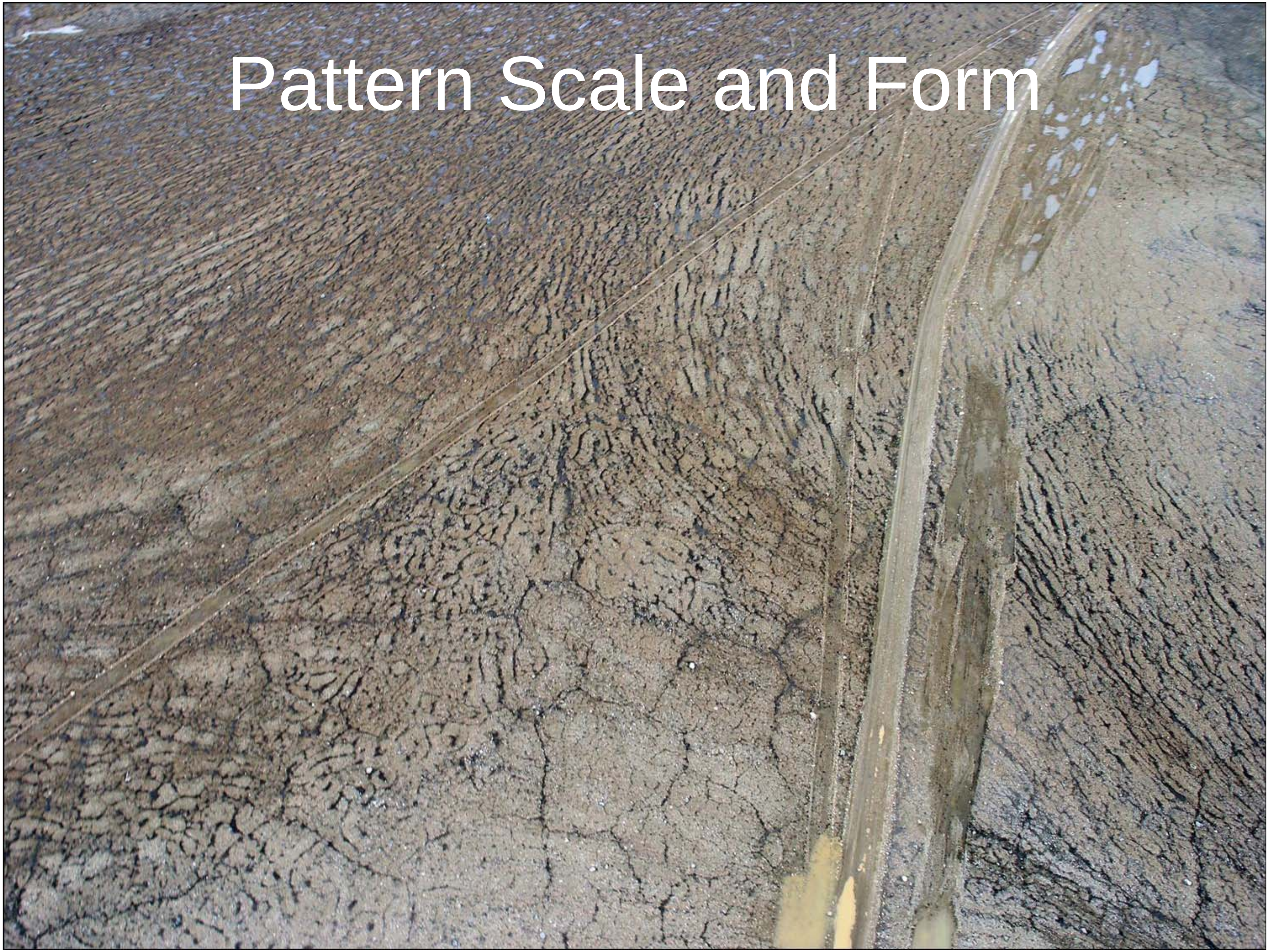
B. Werner, model



J. Sollid, photograph


A
B
C

Pattern Scale and Form

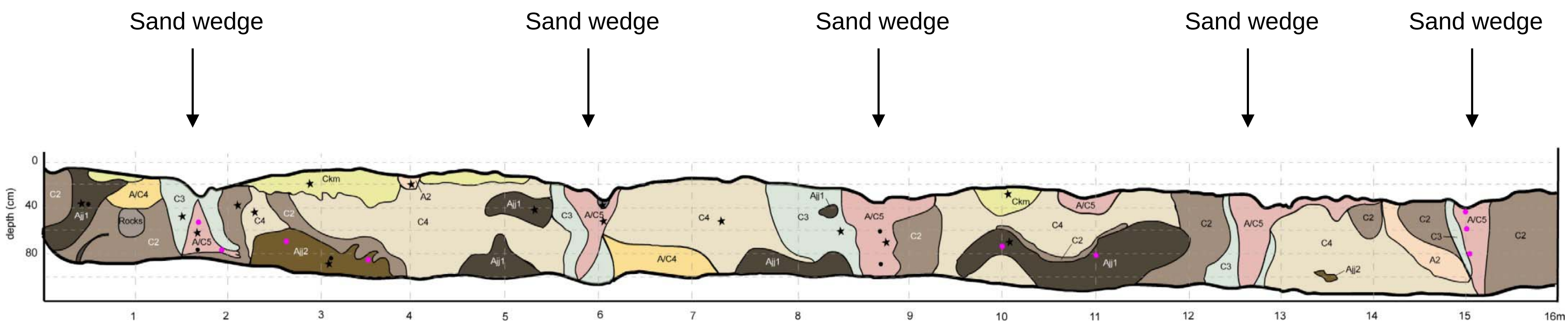


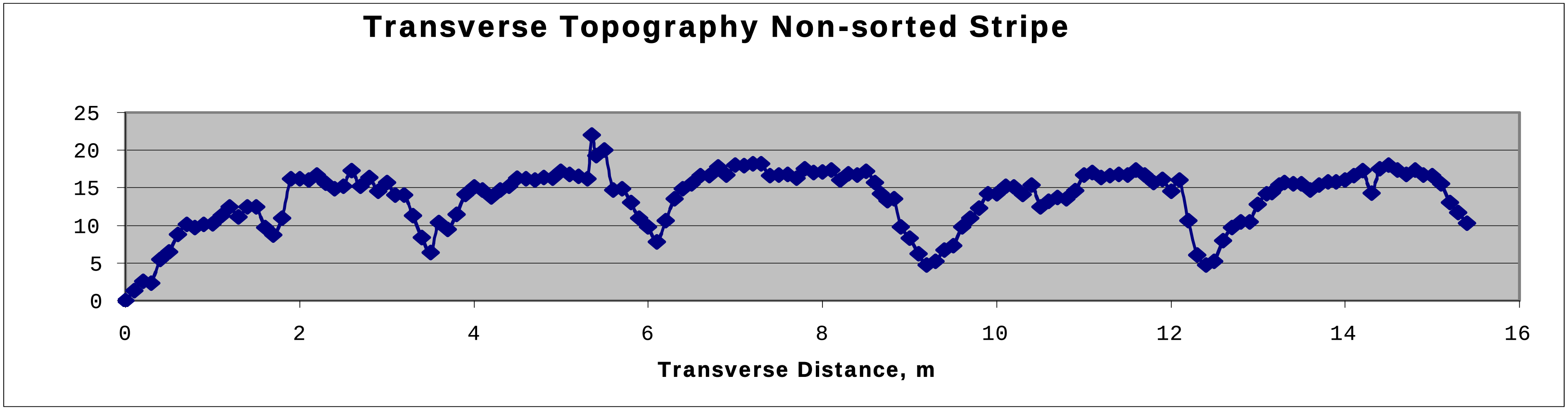
Stripes, NE Greenland

Trench excavated across non-sorted stripes

- 16 m in trench across none-sorted stripe
- 74 cm active layer 2004
- thawed to 130 cm in 2006

Trench Profile





- Form is very suggestive; diffusion tends to destroy the distinct troughs, hence they must be dynamically maintained by descent and ascent of material.
- Importantly this vertical motion also involves burial of organic carbon, an hence can affect how much carbon is stored in Arctic soils, and how much will be released to the atmosphere as the Arctic warms.
- Material must also move downhill O(1cm/yr).

Stone Stripes, M. Kea, ~0.15 m

Sorted Stripes, Canadian Rockies

The dominant process in these stripes appear to be the growth of needle ice, which displaces particles daily. Needle ice grows in the wet soil, lifting stones that topple to the side onto the stony domains.

by David Cavagnaro
This Living Earth

Needle Ice, Sierra Nevada

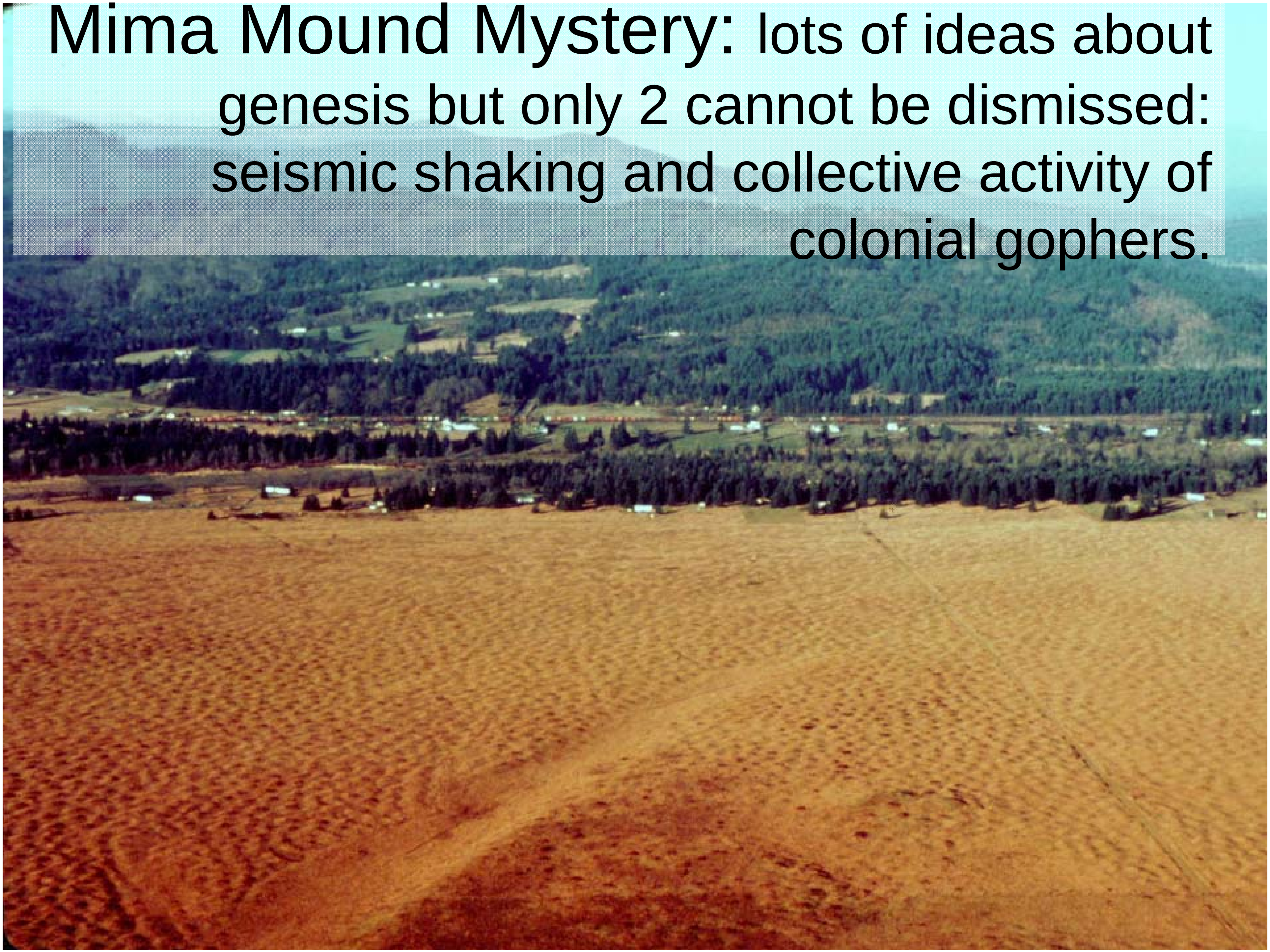
“The strange beauty of ice extruded from the earth on a cold morning contains hidden secrets of nature for those who look beneath their feet.”

by David Cavagnaro
This Living Earth

Needle Ice, Sierra Nevada

Concluding Remarks

- Illustration of patterned ground types in cold region soils
  - Contraction cracking: 10-20 m; penetration depth of seasonal cooling
  - Ice induced: 2-4 m and 0.1 m; frost heaving in active layer and needle ice growth (diurnal thermal boundary layer)
  - Heaving and sorting effect of ice is NOT related to 9% volumetric increase
- Insights into processes and feedback that underlie the self organization: texture, ice growth and heat flow.
- Cryoturbation is important not only for the resulting patterns but for the global budget of greenhouse gases.

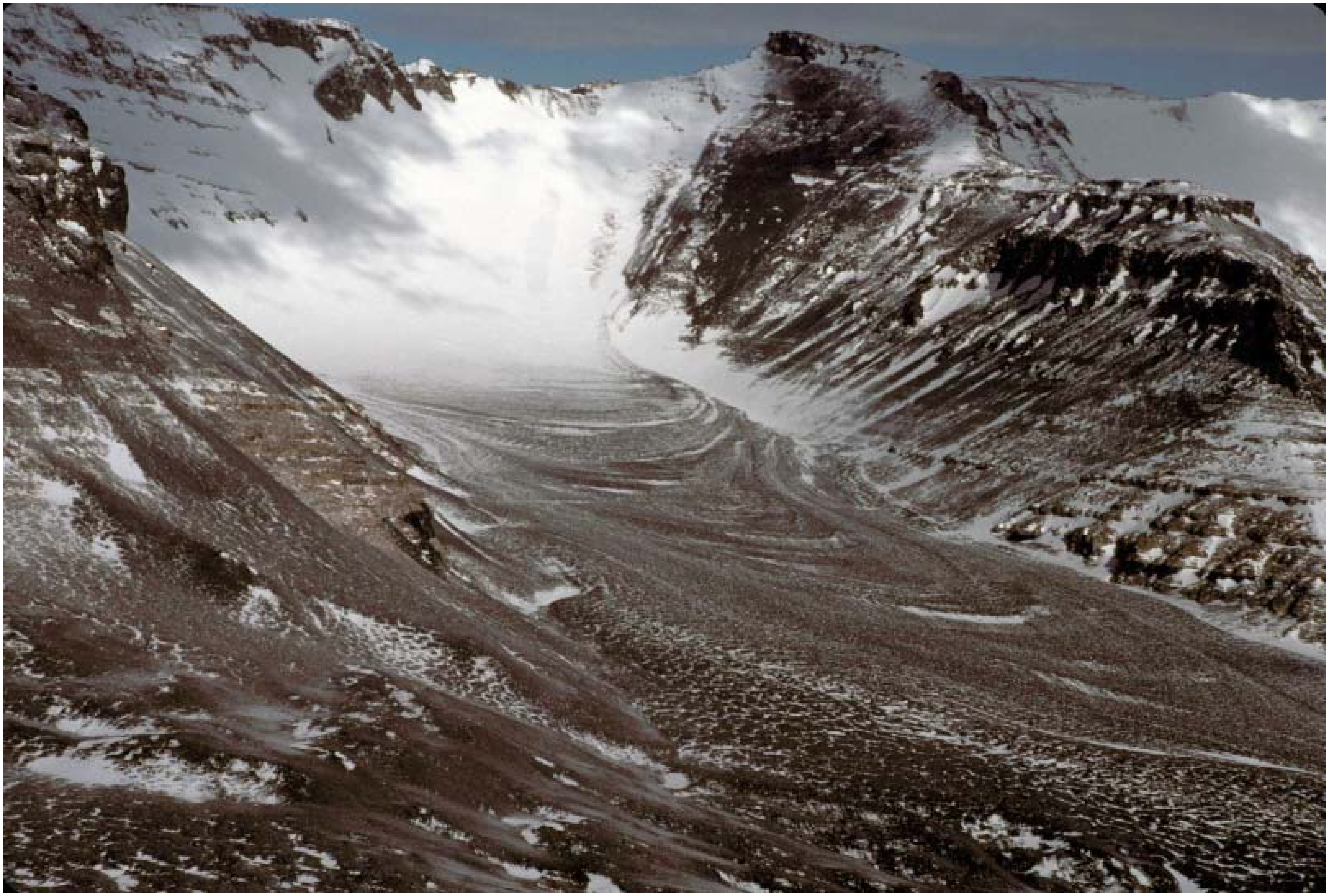

Mima Mound Mystery: lots of ideas about genesis but only 2 cannot be dismissed: seismic shaking and collective activity of colonial gophers.

Pingo (probably closed-system)

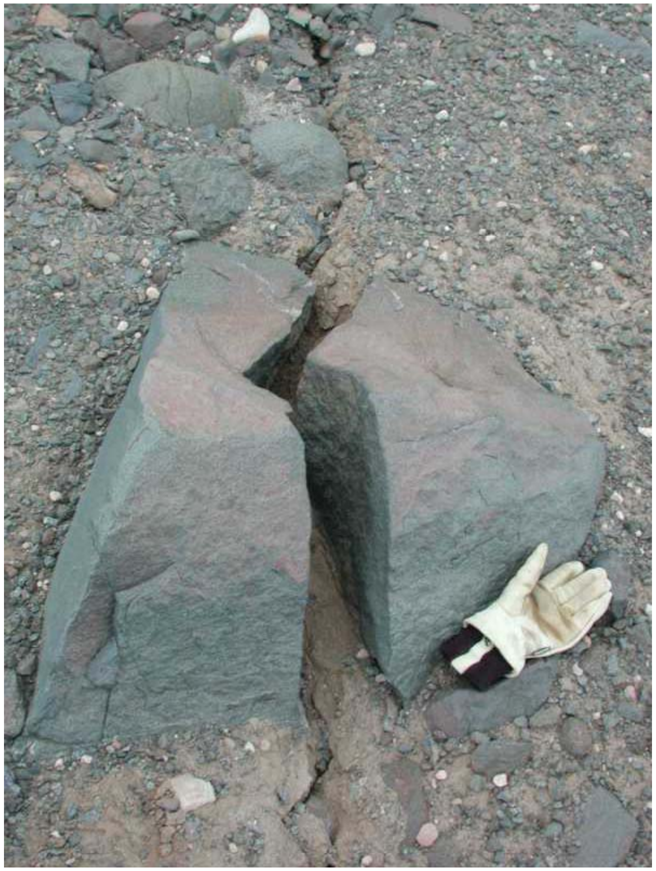
• leno@iconimaging.org

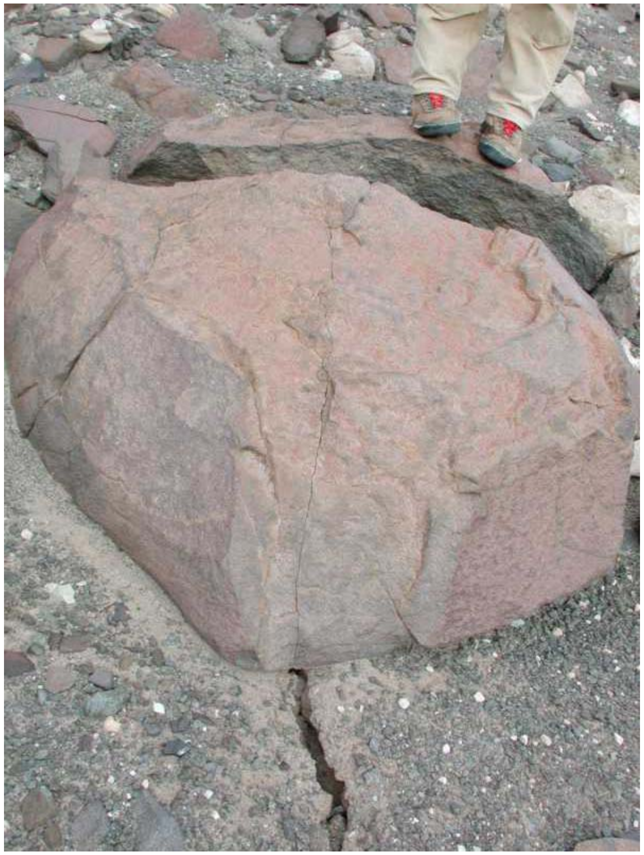
Characteristic Pattern	**Spacing**	**Dominant Processes**	**Governing length scale**
Sorted: - Circles on level ground - Stripes on sloping ground	Decimeters, where diurnal frost and needle ice growth dominates, to 2-4 m where seasonal freezing dominates	Size sorting associated with diurnal and seasonal freeze-thaw; gravity	Depth of diurnal/seasonal freeze-thaw
Non-sorted: Polygons	10-30 m	Thermal contraction cracks & infilling of cracks	Depth of contraction cracks

Mullins Rock Glacier, Antarctica



Cracked rocks






NSF - Continental Dynamics