ESS 431 Principles of Glaciology
ESS 505 The Cryosphere
FINAL EXAM STUDY GUIDE 2018

1. Terminology

Give short definitions of the following 10 terms.
[There may be different terms on the actual test.]

- GISP2
- Glacial polish
- Grounding line
- Milankovich
- Pancake ice
- Brine channel
- Pingo
- Pancake ice
- SMOW
- Stokes force

2. Glacier erosion

(a) ***Local scale*****:** describe 3 ways in which a glacier can erode its bed.
Be sure to address:

- the role of water
- the role of debris-rich ice
- the role of bedrock chemical composition
- which mechanism(s) tend to make the bed smoother, and which make(s) it rougher.

(b) ***Global scale***: Explain how topography of the Earth controls glacierization (existence of glaciers in a region), and conversely, how glaciers may also exert some control on the regional topography, particularly in areas of tectonic uplift.

3. Periglacial processes

(a) Please plot a typical temperature profile for the upper 20 m of permafrost in the middle of the summer.

- Label your depth (m) and temperature (deg C) axes carefully.
- Label the active layer, which is the near-surface layer that thaws seasonally.
- Describe the salient features in your diagram.
- Why does the temperature gradient change at the base of the active layer?

(b) Consider a 1-meter-thick saturated soil layer, as it freezes. Assume that pore space makes up 30% of the soil by volume, and that the pores are full of water (saturated soil).

(i) Estimate the frost-induced heave of the ground surface, if the soil neither loses nor gains water as it freezes.

(ii) How is your answer to (i) likely to compare with observations of frost heave in sandy soils, in silty soils, and in clays, in cold regions where soil moisture is abundant? Explain why you see these differences.

4. Geochemistry of ice cores and ocean cores

(a) Define $\delta^{18}O$, explaining the meaning of all terms and factors.
(b) What climatic variables affect $\delta^{18}O$ of H_2O in ice cores, and why?
(c) What environmental changes affect $\delta^{18}O$ in foraminifera in ocean sediments, and why?
(d) Sharp increases in $\delta^{15}N$ in the air extracted from bubbles in an ice core can reveal the presence of abrupt climate warming at the ice-core site in the past.

- Explain the connection in words, i.e. how and why does this work?

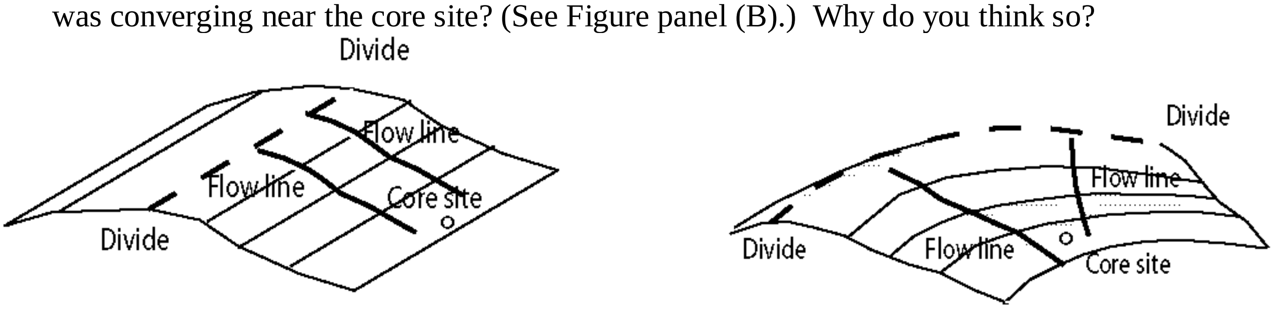
5. Ice sheets of the solar system

(a) *Ice-core site selection*

A few years ago, UW glaciologists ran a field project to select the site for the deep ice core recently drilled in West Antarctica. As part of the planning process prior to going into the field, they needed to estimate the (horizontal) ice-flow velocity at the surface at one potential ice-core site. That site is ~29 km downstream from the flow divide, and the ice there is ~3350 m thick. The accumulation rate in this portion of the ice sheet is approximately 0.33 m a^{-1}.

(i) Assuming that this part of the ice sheet is in steady state (i.e. not thinning or thickening), estimate the velocity at the potential core site in panel (A) of the figure. ***Explain in prose the steps that you are taking and the assumptions that you are making.***

(ii) Would your answer be the same if the divide were curved, i.e. the ice flow from the divide was converging near the core site? (See Figure panel (B).) Why do you think so?



(A) (B)

(b) Martian Ice Caps

Geomorphological features near the polar ice caps on Mars are suggestive of past water flow. An obvious question is whether that water may have originated beneath an ice cap, due to subglacial melting. Based on current estimates for relevant physical parameters, assess the likelihood that basal melting is taking place beneath the current north polar ice cap.

The central portion of the north polar ice cap on Mars is ~3000 m thick, similar to the central parts of the Greenland and Antarctic ice sheets. The surface temperature is much lower, ~130°C below zero, as are accumulation rates, at $\sim 5 \times 10^{-4}$ m a^{-1}. Because the Martian ice is much colder, the thermal properties also differ from those for ice sheets on Earth. For water ice at -100°C,

k (thermal conductivity) ~ 3.5 W m^{-1} K^{-1}
A(T) softness parameter = 3.06×10^{-22} Pa^{-3} s^{-1} (Glen flow law for ice)
C_p (specific heat capacity) ~ 1390 J kg^{-1} K^{-1}
R (universal gas constant) = 8.314 J K^{-1} mol^{-1}

Areothermal flux (the Martian analog of geothermal flux on Earth) is estimated as ~0.030 W m^{-2}.

(i) Does vertical heat transfer within the ice cap occur predominantly through advection or diffusion? Support your answer quantitatively using a Péclet number.

(ii) Based on your answer to (i), estimate the basal temperature for the ice cap. Is melting likely at present, assuming that the pressure melting point is approx. –1°C at the base of 3 km of ice, in Martian gravity?

6. Brine in sea ice

Sea ice is distinguished from freshwater ice by its inclusions of liquid brine. The salinity of the liquid in an individual brine pocket (S_b) varies between 35 parts per thousand (‰) and about 250 ‰. The salinity of a bulk sample of natural sea ice (S_i) typically varies between 0 ‰ and approximately 12 ‰, depending on ice thickness and age (multiyear v. first year).

(a) You have just sampled a core from young first-year ice, of thickness 0.5 m, in the middle of winter. The air temperature (T_a) is -25 C. You measure the temperature of the ice (T_i) at 5cm intervals along the core. Sketch a vertical profile of the approximate values of T_i you expect to record as a function of depth, between the ice surface and the ice-ocean interface. Also sketch the approximate profiles of S_i and S_b that you expect to measure over the length of the core. Indicate the approximate magnitudes of maximum and minimum temperatures and salinities.

(b) Indicate on your sketch where you would expect to find maximum and minimum values of brine volume (v_b). An approximation for brine volume from Frankenstein and Garner (1967) may be useful:

$$v_b = S_i\left(0.0532 - \frac{4.919}{T_i}\right),$$

where S_i is in ‰, T_i is in °C, and v_b is a percentage.

(c) What will likely happen to the profiles of T_i, S_i, and S_b once the summer sun begins to shine on the ice?

7. Recent changes in ice sheets

(a) Name and give a brief summary of three methods glaciologists use to measure ice-sheet mass balance.

(b) Why are ice shelves important to ice flow? What are two key factors that allow rapid (several weeks to a few months) ice-shelf disintegration?

(c) What is the primary process responsible for recent speedups and thinning of many major outlet glaciers that terminate in the ocean? How did climate change influence this process in the past and how might climate change influence this process in the future?

8. Ice sheet – climate interactions

Explain why:

(a) climate warming has different effects on an ice sheet, depending on the season in which the warming occurs (give 3 reasons)

(b) as a large ice sheet grows, accumulation changes tend to act as a negative feedback on further growth.
(c) the ablation on an ice sheet increases roughly as the third power of the summertime temperature (in ^{o}C) at the terminus.
(d) Using your answers above, why might you expect that the ice-volume curve during ice ages would look like saw-tooth cycles?

9. Ice albedo feedback

a) Qualitatively describe the ice-albedo feedback (IAF) mechanism.

b) Is it a positive or a negative feedback.

c) Would changes in ice thickness or ice extent be more likely to impact the IAF? Why?

d) One approach to quantifying the IAF is through a "gain ratio" defined by

$$R_T = (T_2 – T_1) / (T_3 – T_1),$$

where T represents surface temperatures predicted with a climate model. T_1 is the temperature resulting from a model run representing current climate conditions. T_2 is the temperature resulting from a model run with some external perturbation (like a +5 W/m^2 increase in surface longwave flux) where all feedbacks are operative. T_3 is the temperature resulting from a simulation where the climate is subject to the same external perturbation and the IAF mechanism is switched off by keeping the surface albedo fixed in the perturbed run to the same values used in the baseline simulation. The following table gives annual averaged surface temperatures (T) and ice thicknesses (h) for three such model runs.

Type of simulation	Temperature	Ice Thickness
baseline simulation	T_1 = -16.31 °C	h_1 = 3.18 m
+5 W/m^2 flux with IAF	T_2 = -15.76 °C	h_2 = 2.50 m
+5 W/m^2 flux with no IAF	T_3 = -15.90 °C	h_3 = 2.96 m

(1) Calculate the gain ratio R_T.
(2) A gain ratio R_h can also be defined for ice thickness (h) in an analogous manner. Evaluate R_h from the thickness data in the table.
(3) If the ice surface is typically melting during the summer, would you estimate R_T or R_h to be more sensitive to summer ice conditions? Why? Which gain ratio should be more sensitive to winter ice conditions? Why?