UNIVERSITY OF TORONTO AT SCARBOROUGH

EESC31

GLACIAL SEDIMENTOLOGY AND STRATIGRAPHY

FALL 2016

Lectures: Thursday
7-10 pm Room MV120

Professor:
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Teaching Assistant:
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Q: Why do we need to know about glaciers and their deposits?

A: Canada is truly a ‘glacial’ country and glaciation has profoundly affected our landscapes, dictated much of our recent geological history and controlled the initial peopling of North America. Glaciers still survive in the Rockies (supplying rapidly-dwindling water to the Prairies) and in the High Arctic. Much of the far north is ‘permafrozen’ i.e., underlain by frozen ground much of which was inherited from the last ice age. Geo-engineering and construction activity, forestry, agriculture, mineral exploration in the far north, environmental geoscience investigations, soil science, and hydrogeological work all require a firm knowledge of glacial deposits and their distribution and stratigraphy. Mining, oil exploration and infrastructure development in Canada’s far north all have to deal with the issue of permanently frozen ground (‘permafrost’) that is now degrading in warmer climates.

Ice sheets as much as 3 km thick have covered Canada many times in the past 2.5 million years during what is termed the Pleistocene epoch. As many as 50 different glaciations are recorded in the deep ocean record but far fewer are recorded on land because of erosion. The latest ice sheet (the 'Laurentide ice sheet') which was the culmination of the last (Wisconsin) glaciation, left southern Ontario as recently as 12,000 years ago when Paleo-Indians migrated into Ontario from the west. Canada's landscapes and surface sediments have been profoundly modified by glaciation; much of Southern Ontario is a fossil glacial landscape no different from that found at the margins of modern ice sheets in Iceland.

Re-examination of the geomorphological record left by ice sheets in Canada (using new satellite and other imagery such as LiDAR) is revealing new data about the glaciology of the ice sheets, especially the presence of fast flowing arteries called 'ice streams' such as occur in the Greenland and Antarctic ice sheets today. Geologists are now using a so-called 'landsystem approach' to mapping the sediments and landforms left by paleo- ice streams in Canada. The 'subglacial landsystem' refers to a wide range of sediments and landforms created at the base of the ice. The most common sediment type is 'till' which is manufactured by deformation and mixing of pre -existing sediment that was overrun by the ice sheet. Existing drainage systems are dammed by ice so much material is deposited in lakes and by meltwaters. Glacial sediments are usually very complex and vary spatially and with depth and thus are a challenge to geo-engineering and hydrogeology projects etc., especially in urban areas where pre-existing glacial geological ground conditions have been much modified by human activity. Much groundwater in Canada is stored in these sediments. Glacial sediments are the major source of aggregates (sand and gravel) needed for construction and there is a massive shortage in southern Ontario.

The peak warmth of the last interglacial warm period (which is called the 'Sangamon interglaciation') occurred just after 110,000 years ago and the Laurentide Ice Sheet began to grow shortly thereafter at the beginning of the Wisconsin glaciation. Its growth was not continuous and it took some 60,000 years to fully expand during the Late Glacial Maximum ('LGM') some 20,000 years ago. One of the best records of its early growth anywhere in North America is found right here in Southern Ontario in sediments preserved along Scarborough Bluffs and in the Don Valley Brickyard. The Great Lake basins are the direct result of large-scale glacial erosion. Huge changes have taken place in flora and fauna as a consequence of glaciation. If natural climate cycles driven by 'Milankovitch' astronomical variables have not been disturbed too much by human activity Canada will find itself once again, under ice.

Ice had disappeared by 6,000 years ago (remnants survive as the Penny Ice Cap on Baffin Island) and the period from about 7 to 4,000 years ago was warm and accompanied by low Great Lake water levels (an event referred to as the 'Hypsithermal'). Climate cooling after 4,000 years ago is called the Neoglacial and saw the regrowth of glaciers in western Canada and a rise in the level of the Great Lakes. A phase of cooling between 1300 and 1900 AD is referred to as the Little Ice Age (LIA). The end of the LIA has seen a warming trend (except for short lived phases such as in the 1970's) and glaciers are now shrinking world-wide. Much debate surrounds isolating the effects of warming due to natural causes, from man-made influences.

Ancient pre-Pleistocene glaciations occurred several times in Earth history at about 2.9 Ga (Pongola glaciation), 2.4 Ga (Huronian glaciation), between 750 and 545 Ma (Neoproterozoic), at 440 Ma (Late Ordovician) and between 350 and 250 Ma (Late Paleozoic). The origins and extent of several of these are controversial e.g., the Neoproterozoic 'Snowball Earth' which has been viewed as a global glaciation and linked by some to the 'Cambrian explosion' of complex metazoan organisms some 550 million years ago.

Course structure

This course consists of: 1) weekly lectures and in-class discussions based on previously assigned readings, 2) weekly quizzes based on the previous week's lecture and assigned readings, 3) a substantial group project and in-class presentation at end of the course, 4) a field trip in late October at a date to be announced and; 5) a final written exam.

The course will review the cause of glaciations and their geological and geomorphological effects paying especial regard to the lengthy record of past glacial and interglacial climates preserved in southern Ontario. By the end of this course you will be able to recognize the principal glacial sediments and landforms across Canada and know how these have been classified and mapped using a variety of methods for environmental geoscience investigations.

There is no formal course text book only assigned readings on which weekly quizzes and the final exam will be based.

Teaching methods

The course is based on a weekly three-hour class except for Reading Week (October 10-14th). Each week will commence with a short (20 minute) in-class test (simple definitions etc.,) based on the previous week's lecture material and assigned readings, which will be marked and returned to you in class. These quizzes are designed to keep you on top of material and determine *whether you will need to drop the course by November 17th* (see below). I will then lecture for approximately 2.5 hours during which time questions and discussions are invited *at any time*. During the lecture I will ask questions to promote discussion and assess your overall participation which is worth 5% of your total marks.

Note: Lectures are also available as a Web-Option.

We will circulate prior to every week's lecture pdfs of key papers. Please read these, make notes on what you do not understand and try to critically assess their significance in understanding glaciers and the glacial geology of Canada. You must come prepared to discuss this material in class.

Fieldwork
There will be a *voluntary* field trip in late October to Peterborough for a show and tell on glacial sediments and landforms. I will circulate a sign up list and itinerary later. There will be a small charge for transportation and you will be responsible for shared costs of one night's accommodation. We will use *Planetrocks.utsc.utoronto.ca* for the field trip.

By the end of the course you will know:

1) How glaciers and ice sheets form and flow.
2) How sediments are produced and deposited in various glacial environments on land (terrestrial environments) and in the sea (glaciomarine environments).
3) The glacial geologic history of Canada and Ontario over the past 2 million years.
4) Cold climate but non-glacial environments (e.g., periglacial processes and deposits).
5) The timing and causes of glaciations in the remote past.
6) How glacial sediments are investigated and mapped for applied investigations (e.g., geophysics, groundwater, terrain mapping, waste disposal, mineral exploration etc) are conducted in glaciated areas.

Why this course is important
This course satisfies the glacial geology requirement for the Association of Professional Geoscientists of Ontario. Climate change is an important topic in our society and it is vital to understand how climates have varied in the recent and remote pasts. Glacial geology is also key to hydrogeology and environmental site remediation of contaminated lands underlain by glacial sediments. Knowledge of glacial geology is also used in mineral exploration.

COURSE OUTLINE AND TOPICS (subject to change)

Week 1: **8th September**
Overview of course themes Part I: Basic terminology and concepts
Glaciology: the science of glaciers (their mass-balance and flow, deformation, sliding). Wet-based *vs.* dry-based ice masses, and ice streams
The history of the *Laurentide Ice Sheet* in Canada
Paleoclimatology and paleo-climate change: Why and when do glaciations occur? What controls their timing in Earth history? The use of *oxygen isotopes* in deep marine sediments and the *Milankovitch astronomical variables.*

Week 2: **15th September**
Overview of course themes Part II.
Subglacial, englacial, supraglacial and proglacial environments
Glacial sedimentology: Glacial processes and deposits: a landsystem approach
Quiz 1 *(based on Readings and Week 1 lecture material)*

Week 3: **22nd September**
Mapping glacial sediments in Canada
The landsystem approach. Introduction to the *subglacial landsystem* on 'hard', 'soft' and 'mixed' substrates and the *supraglacial landsystem*
Quiz 2 *(based on Week 2)*

Week 4: **29th September**
Glacial sediments and landforms deposited by meltwaters on land (*glaciofluvial environments*), in ice-contact lakes (*glaciolacustrine environments*) and seas (*glaciomarine environments*)
Quiz 3 *(based on Week 3)*

Week 5: **6th October Glacial geology of Ontario: field trip overview**
Quiz 4 *(based on Week 4)*

Week 6: **13th October** No class: Reading Week

Week 7: **20th October**
Invited lecture: **Shane Sookhan** (Ph.D candidate) **The origin of drumlins and other subglacial landforms: results of new GIS imagery analysis methods**

Week 8: **27th October**
Cold-climate, non-glacial processes and sediments *(periglacial processes*) in areas of permanently-frozen ground *(permafrost*) in Canada's far North
Quiz 5 *(based on Week 7)*

Week 9: **3rd November**
Applied aspects of glacial sediments Part I
Geophysical exploration methods and environmental geoscientific investigations e.g., waste management, hydrogeology and hydro-stratigraphic assessments
Quiz 6 *(based on Week 8)*

Week 10: **10th November**
Mineral exploration in glaciated terrains

Week 11: **17th November**
Ancient glaciations of the last 2800 million years
Invited lecture: Kirsten Kennedy (Ph.D candidate): Late Precambrian (Neoproterozoic) glacial sedimentology and tectonics: the 'Snowball Earth; controversy
Quiz 7 *(based on weeks 9 and 10)*

Last day to drop F courses without penalty

Week 12: **24th November**
In-class group presentations commence

Week 13: **1st December**
In-class group presentations end and revision session for Final Exam

Essential reading for course:
I do not recommend any particular textbook but Benn and Evans (2010) 'Glaciers and Glaciation' (Hodder Education) is the classic text but is rather long; 802pp. W.S.B Paterson's 'Physics of Glaciers' (Pergamon Press: 2nd Edition, 1981) is still good, as is Glacial Geology: Ice Sheets and Landforms' by M.R. Bennett and N.F. Glasser (Wiley, 1996) and Eyles, N. 'Glacial Geology for Engineers and other Earth Scientists' (1983; Pergamon Press) is also worth a look. There is a good overview chapter on glaciation in Canada in Eyles, N. and Miall, A.D., 'Canada Rocks' (Fitzhenry and Whiteside, 2010). All these are accessible in the library.

The overall summary by Eyles and Eyles (2010) '*Glacial facies models*' is recommended and that by Hambrey and Glasser (2011) which I will supply in pdf. I would also ask you to use the web site *Planetrocks.utsc.utoronto* jointly-developed with Richard Gao and Shane Sookhan which contains much information on glacial landforms and deposits across Ontario and which will be used for the field trip.

Readings will be circulated one week prior to relevant class.

Marking schedule and assignments

1) Seven multiple-choice, in-class quizzes (5 marks each) **35 marks**

2) Participation in in-class discussions **5 marks**

3) Group (3 people *max*) 10 minute in-class PowerPoint presentation *either* on the glacial geology and history of any area of Canada *or* on any topic from the list below. **Note**: Each group must register and get approval for their topic with NE first. You are required to submit a *one-page abstract* to NE one week prior to your presentation **25 marks**

4) Final exam: **35 marks**

Note: There will be NO re-writes for missed tests: weekly tests cannot be retaken. If you miss a test supply a Doctor's note and appropriate UTSC documentation and you will be assigned an average mark based on your performance in the preceding quizzes. No medical documentation = a mark of zero.

Accessibility Students with diverse learning styles and needs are welcome in this course. In particular, if you have a disability/health consideration that may require accommodations especially on the field trip, please approach me and/or the AccessAbility Services Office *as soon as possible*. I will work with you and AccessAbility Services to ensure you can achieve your learning goals in this course. Enquiries are confidential. The UTSC AccessAbility Services staff (located in S302) are available by appointment to assess specific needs, provide referrals and arrange appropriate accommodations (416) 287-7560 or ability@utsc.utoronto.ca.

Plagiarism Cheating of any kind is not tolerated and will be reported to the Chair and Dean immediately.

Possible presentation topics (you are free to suggest others)

1. Origin and global climatic significance of Heinrich events
2. Causes of the medieval warm period
3. The origins and effects of the Little Ice Age
4. Mineral exploration in glaciated terrains
5. Origin of fiords
6. Postglacial lake levels in the Great Lakes
7. Postglacial changes in global sea level
8. Human migration into North America
9. Himalayan Uplift hypothesis for Pleistocene glaciations
10. Human evolution and climate in East Africa
11. Submarine permafrost
12. Permafrost thawing under modern day climate warming
13. Glaciation on Mars
14. Snowball Earth
15. Glaciotectonic processes and structures
16. The Laurentide Ice Sheet: formation and decay
17. Origin of the overdeepened Great lake bedrock basins
18. Preglacial drainage in the Great Lakes region
19. Glacial landsystems as a means of classifying glaciated terrains
20. Karst
21. The sedimentary and biological record of the last interglacial at Toronto
22. Eskers; types and depositional processes

23. Sedimentation in glacial lakes and typical facies
24. Glaciomarine environments
25. Glaciers of Alberta (or British Columbia, Yukon, Alaska etc.)
26. Periglacial processes and structures
27. Geology and wine in the Niagara Peninsula
28. NAMOC
29. Drumlin fields of Ontario; where are they and how did they form?
30. How does till form and how is it deposited?
31. Mid Pleistocene Transition:
32. Human migration into North America:
33. Drumlins
34. Permafrost
36. Ice streams in the Laurentide (or any modern) ice sheet
37. Till-forming processes

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Office Hours: 6-7 pm Thursdays outside MV120 immediately before the lecture or in my office (EV308) *by appointment*.