UNIVERSITY OF TORONTO AT SCARBOROUGH

EESC31

GLACIAL SEDIMENTOLOGY AND STRATIGRAPHY

FALL 2018

Lectures: Thursday
7-10 pm: Room MW140

Professor:
Nick Eyles

Teaching Assistant:
Shane Sookhan (Ph.D Candidate, DPES)

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 of the earlier sediment record. 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 which leave 'megascale glacial lineations' on their beds. Much of the GTA is built across the bed of an ice stream.

Geologists are now using a so-called 'landsystem approach' to map 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 25,000 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 retreated from Southern Ontario by 12,000 years ago and Paleo-Indians began to migrate into southern Ontario while much of the north was still ice covered. Ice disappeared from Canada by 7000 years ago (small remnants survive as the Penny Ice Cap on Baffin Island) and the period from about 7 to 4,000 years ago was warmer and drier than today 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.

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 the 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 STRUCTURE

This course consists of:

1) Weekly lectures,
2) 5 weekly quizzes based on the previous week's lecture material and assigned readings,
3) A laboratory exercise (weeks 5-7) on mapping glacial landforms using digital imagery,
4) A group written project and in-class presentation at end of the course,
5) A field trip in mid-October and;
6) A final written exam.

Note: There is no mid-term exam.

TECAHING METHODS

The course is based on a weekly three-hour class except for Reading Week (October 8-12th). 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 19th* without academic penalty (see below). I will then lecture for approximately 2.5 hours during which time questions and discussions are invited *at any time*.

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 one day field trip in late October (week 8) to the Peterborough and Scarborough areas for a show and tell on glacial sediments and landforms. We will circulate a sign up list and itinerary later. There will be a small charge for transportation.

LEARNING OUTCOMES

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 conversant with:

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) Current approaches to mapping glacial landforms using high resolution digital imagery such as LiDAR data.

7) 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.

8) Researching and writing a detailed report and making a public presentation.

LECTURE TOPICS

Week 1: 6th September

Overview of course

-Paleoclimatology and ice ages: Why and when do glaciations occur? What controls their timing in Earth history?
-Oxygen isotopes in deep marine sediments.
-Milankovitch astronomical variables and their control on glacial/interglacial cycles.
-The history of the Laurentide Ice Sheet in Canada over the last 2 million years.

Readings: Course outline
Chapter 9 in Eyles and Miall (2018)
Dyke et al. (2002)
Hambrey and Glasser (2005)

Week 2: 13th September

How glaciers work: an introduction to glaciology and the science of glaciers

-Mass-balance and flow by internal deformation and sliding.
-Wet-based vs. dry-based ice masses and fast flowing ice streams.

Readings: Chapter 9 in Eyles and Miall (2018)
Dyke et al. (2002)
Hambrey and Glasser (2005)

Week 3: 20th September

Glacial *s*ediments and landforms

Glacial processes and deposits: subglacial, englacial, supraglacial and proglacial environments. Deposition by glacial meltwaters (glaciofluvial environments), in ice-contact lakes (glaciolacustrine environments) and in seas (glaciomarine environments)

Reading: Eyles and Eyles (2010) '*Glacial facies models*'
Quiz 1 (based on lectures Weeks 1 and 2 and assigned readings)

Week 4: **27th September**
Invited lecture: The origin(s) of drumlins and other subglacial landforms under ice sheets
Shane Sookhan
Reading: Eyles et al. (2018a, b), Sookhan et al. (2018)

Week 5: **4th October**
Laboratory exercise: Using GIS imagery analysis methods to map subglacial landforms
Shane Sookhan
Quiz 2 (based on weeks 3 and 4)
Reading: Yu et al. (2015), Sookhan et al. (2016)

Week 6: **11th October** No class: Reading Week

Week 7: **18th October**
Invited lecture: Dr. Roger Paulen, Geological Survey of Canada: Mineral exploration in glaciated terrains
Reading: McClenaghan & Paulen (2018)

Week 8: **25th October**
Glacial history of Ontario: overview of field trip
Subglacial laboratory exercise due (15 marks)
Reading: Sookhan et al. (2018) and CANQUA Field Guide (Eyles et al., 2018)
Quiz 3 (based on week 7 only)

TBA **One day glacial field trip: Peterborough to Scarborough**

Week 9: **1st November**
Applied aspects of glacial sediments
-Geophysical exploration methods and environmental investigations including waste management, hydrogeology, geoengineering
Quiz 4 (based on week 8 and field trip)

Week 10: **8th November**
Cold-climate, non-glacial processes and sediments
(periglacial processes) in areas of permanently-frozen ground *(permafrost*) in Canada's far North

Week 11: **15th November**
Ancient glaciations of the last 2800 million years focussing on Late Precambrian (Neoproterozoic) glacial sedimentology and tectonics: 'Snowball Earth'
Quiz 5 (based on weeks 9 and 10)

19th November Last day to drop F courses without penalty

Week 12: **22nd November**
In-class group presentations commence

Week 13: **29th November**
In-class group presentations continue followed by revision session for Final Exam

Essential readings for course:
There is a good summary chapter (9) on glaciation in Canada in Eyles, N. and Miall, A.D., 'Canada Rocks' (Fitzhenry and Whiteside, 2018) available in the bookstore and library.

Benn and Evans (2010) 'Glaciers and Glaciation' (Hodder Education) is the classic comprehensive text and is in the library.

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). All these are accessible in the library.

Marking schedule and assignments

1) Five 'in-class' quizzes (4 marks each) **20 marks**

2) Laboratory exercise on digital mapping **15 marks**

3) Written, illustrated report and 15 minute in-class PowerPoint presentation by groups (maximum 3 students) *either* on the glacial geology and history of any area of Canada *or* on any topic from the list below. **30 marks**

Note: Each group must register and get approval for their topic with the Teaching Assistant Shane Sookhan first. *You are also required to submit a one-page abstract to Shane one week prior to your presentation*:

4) Final exam: **35 marks**

NOTE

There will be NO re-writes for missed weekly tests. In case of medical issues you will need 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.

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.

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 but must have approval of TA first)

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. Origin of the Oak Ridges Moraine
21. The sedimentary and biological record of the last interglacial at Toronto (Don Valley Brickyard)
22. Eskers; types and depositional processes
23. Sedimentation in glacial lakes and typical facies
24. Glaciomarine environments
25. Modern 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. Rogen Moraines
34. Permafrost
36. Ice streams in the Laurentide (or any modern) ice sheet

Nick Eyles
eyles@utsc.utoronto.ca.

Office Hours: 6.30-7 pm Thursdays outside MV140 immediately before the lecture or in my office (EV308) by appointment only