UNIVERSITY OF TORONTO AT SCARBOROUGH

EESC31

GLACIAL SEDIMENTOLOGY AND STRATIGRAPHY

Fall 2022

Professor:
Nick Eyles

Teaching Assistant:
Syed Bukhari (Ph.D. Candidate)

Glacial geology: the study of the deposits and landscapes left by former ice sheets

Glaciology: a branch of geophysics focused on the study of snow and ice in general, and how glaciers and ice sheets form and flow

This course satisfies the glacial geology requirement for the Association of Professional Geoscientists of Ontario.

Please acknowledge that you have read and understood this course outline, the means of assessment, and deadlines for evaluations (worth 3 marks)

Q: Why do I need to know about glaciers and their deposits?

A: Canada is truly a 'glacial' country and, in past ice ages was almost completely covered by continental ice sheets as much as 3 km thick. Their growth and decay have 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 deal with the issue of permafrost that is now degrading in warmer climates. Huge volumes of groundwater are stored in glacial sediments and landforms and Canada's many thousands of lakes, large and small, are the product of glacial erosion. Much of Southern Ontario is a fossil glacial landscape no different from that found at the margins of modern ice sheets in Iceland.

Ice sheets 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 and removal of any older earlier glacial sediment records. The Toronto area is very unusual because it preserves of at least two glaciations (the penultimate glaciation the Illinoian and the last glaciation the Wisconsin, separated by a warm interglacial. The last Wisconsin ice sheet began to grow about 80,000 years ago in the sub-arctic and expanded into Southern Ontario after 23,000 years ago to cover the region until at least 12,000 years ago. During deglaciation when the ice sheet thinned and retreated, the Great Lakes were much larger and deeper as a result of the retreating ice margin blocking the outlet of the lakes along the St. Lawrence Valley, and the release of large volumes of meltwater from the melting ice sheet. It was a time of rapid environmental change as trees and animals migrated back into the area; the earliest human occupation was about 12,000 years ago when ice still here and herds of caribou migrated through Southern Ontario.

The final melt of the ice sheet at about 10,000 years ago ushered in the postglacial which is referred to as the Holocene epoch which means 'wholly recent.' We live in an interglacial and there is much debate as to whether anthropogenic climate change will delay the next ice age. The Holocene contains a series of climatic oscillations from warm (e.g. the Hypsithermal) to cold (e.g., the Little Ice Age) which have affected human civilizations.

Re-examination of the geomorphological record left by former ice sheets in Canada (using new satellite and other imagery such as LiDAR) is revealing new data about the structure and flow (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.

A good understanding of glacial geology is fundamental to conducting hydrogeological investigations and environmental site remediation of contaminated lands underlain by glacial sediments. Knowledge of glacial geology is also used in mineral exploration across the Canadian Shield.

Course Structure and Means of Evaluation

1) A series of 10 lectures.
2) Reading of weekly 'key papers' to accompany each lecture.
3) Completion of seven *weekly* online modules and short quizzes (each worth 3%: total 21%).
4) Completion of two week in-class laboratory exercise (beginning 20th October, and write-up due 3rd November) on mapping glacial landforms using digital imagery (20%)
5) An *individual* written mid-term paper due 12th November (20%) on the glacial geology of Southern Ontario, or any of the topics listed at the end of this course outline.
6) A *group* written paper and fifteen-minute in-class presentation due November 24th (30%) on a virtual field trip to a glacier or any glaciated area in Canada explaining why the area is significant.
7) Acknowledgement of course outline (3%)
8) Participation, and contribution to class (6%)

Note: There is no mid-term or final exam*. *Late submissions will be subject to a penalty of 20% marks per day

Field Trip

If demand warrants, I shall organize a one-day field trip to examine the glacial record of Southern Ontario

Office Hours

I will organize weekly office hours shortly and make an announcement on Quercus. This is a good opportunity to network and get to know everyone and I am asking everyone to join in and be part of the discussion.

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 12 weeks, you will understand:

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 geological 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 detailed reports, and making an in-class presentation

Lecture Topics *(Subject to change)*

Week 1: **8th September: no class**

Week 2: **15th September**
Lecture: Overview

- Paleoclimatology and ice ages: Why have glaciations occurred in the last 2.5 million years? What controls their timing?
- 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.

Week 3: **22nd September**
Lecture: How glaciers work: an introduction to glaciology and the science of glaciers

- Mass-balance and flow by internal deformation and sliding.
- Warm, wet-based vs. cold, dry-based ice masses and fast flowing ice streams.

Week 4: **29th September**
Lecture: Glacial *s*ediments and landforms

- Glacial processes and deposits: subglacial, englacial, supraglacial and proglacial environments.

Week 5: **6th October**
Guest Lecture: Dr. Shane Sookhan
Under the ice: Drumlins, megascale glacial lineations and other subglacial landforms

Week 6: **13th October: No lecture (Reading week)**

Week 6: 20th October

In class laboratory exercise with Shane Sookhan and Syed Bukhari: Using GIS imagery analysis to map glacial landforms (2 weeks)

Mid-term written report due (20 marks)

Week 7: 27th October

Continuation of laboratory exercise and class discussions

Week 8: 3rd November

Glacial history of Canada and Ontario

Subglacial laboratory exercise write-up due (15 marks)

Week 10: 10th November

Cold-climate, non-glacial processes and sediments in Canada's far North *(periglacial processes and permafrost*) and impact of climate warming

Term paper due Monday 12th November (30 marks)

Week 11 17th November

Invited lecture: Dr. Roger Paulen Geological Survey of Canada Mineral exploration in glaciated terrains e.g.., Canadian Shield and geophysical exploration methods

Note: Last date to drop course is November 21st

Weeks 12/13: 24th November- 1st December in-class presentations

<u>Module topics</u>

1) Origin of the Ice Ages
2) The Glacier System
3) Structure of the Laurentide Ice Sheet
4) Subglacial landforms
5) Origin of the Great Lakes
6) The Holocene
7) Great Lake water levels

Each module involves answering several questions on the content of that particular module and should take you no more than 2 hours. You will have two weeks to complete it.

The release of each module on Quercus will be timed to coincide with the lecture on the same topic.

Required readings (available online)

Sookhan, S., Eyles, N. and Putkinen, N. 2018. LiDAR-based mapping of paleo-ice streams in the eastern Great Lakes sector of the Laurentide Ice Sheet and a model for the evolution of drumlins and MSGLs. Journal of the Geological Society of Sweden 140, 202-228.

Eyles, N., Putkinen, N, Sookhan, S., Arbelaez-Moreno, L. 2016. Erosional origin of drumlins and megaridges. Sedimentary Geology 338, 2-23.

Doughty, M., Eyles, N. and Eyles, C.H. 2013. Seismic reflection profiling of neotectonic faults in glacial and postglacial sediment in Lake Timiskaming, Timiskaming Graben, Ontario/Quebec, Canada. Sedimentology 60, 683-706.

Stokes, C.R., 2017. Deglaciation of the Laurentide Ice Sheet from the Last Glacial Maximum. Cuad. Investig. Geogr. 43, 377-428.

Sookhan, S., Eyles, N. and Arbelaez-Moreno, L. 2018. Converging ice streams: a new paradigm for understanding the Laurentide Ice sheet in southern Ontario and deposition of the Oak Ridges Moraine. Canadian Journal of Earth Sciences 55, 373-396

Eyles, N., Mulligan, R., Paulen, R and Sookhan, S. 2018. Subglacial Bedforms in Southern Ontario: from Flood Paths to Flow sets. Geological Survey of Canada Open File Report 8481, 66 pp.

Hambrey, M.J. and Glasser, N. F., 2005. Glaciers.

Eyles, C.H. and Eyles, N. 2010. Glacial Facies. In: N.P. James and G. Dalrymple (Eds.) *Facies Models* Geological Association of Canada, *73-104.*

Margold, M., Stokes, C.R., Clark, C.D., 2018. Reconciling records of ice streaming and ice margin retreat to produce a paleogeographic reconstruction of the deglaciation of the Laurentide Ice Sheet. Quat. Sci. Rev. 189, 1-30.

McClenaghan, M.B., Paulen, R.C., 2017. Mineral Exploration in Glaciated Terrain. In: Menzies, J., Van Der Meer, J.J-M. (Eds.), Past Glacial Environments Second Edition, Elsevier, Amsterdam pp. 689–751.

Additional resources

There is a good summary chapter (9) on glaciation in Canada in Eyles, N. and Miall, A.D., 'Canada Rocks' (Fitzhenry and Whiteside, 2018).

Benn, D. and Evans, S. 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)

A series of virtual reality field trips (VRFTs) are available (**planetrocks.utsc.utoronto.ca/trips**) through Ontario and the Great Lakes designed to demonstrate real-world applicability of classroom concepts.

<u>Mid-term topics</u> (feel free to suggest others but *must have my approval 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
35. Ice streams in the Laurentide (or any modern) ice sheet
36. LiDAR mapping
37. The glaciology of the Greenland *or* Antarctic ice sheets
38. Holocene climate changes and civilization

Plagiarism in any form (written work, presentations) will not be tolerated and it is a severe academic offence reportable to the Dean for sanctions. "Normally, students will be required to submit their course essays to Turnitin.com for a review of textual similarity and detection of possible plagiarism. In doing so, students will allow their essays to be included as source documents in the Turnitin.com reference database, where they will be used solely for the purpose of detecting plagiarism. The terms that apply to the University's use of the Turnitin.com service are described on the Turnitin.com web site".

AccessAbility Services:
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, please feel free to approach the AccessAbility Services Office as soon as possible. They will work with you to ensure you can achieve your learning goals in this course. All enquiries are confidential. The UTSC AccessAbility Services staff members are available by appointment to assess specific needs, provide referrals and arrange appropriate accommodations (416-287-7560) or ability@utsc.utoronto.ca.

Nick Eyles
nicholas.eyles@utoronto.ca

Syed Bukhari
sajidb.bukhari@mail.utoronto.ca