ASSESSING SUBSTRATE GENESIS AND MECHANISMS OF FAST ICE FLOW ALONG THE SOUTHERN MARGIN OF THE CORDILLERAN ICE SHEET, BRITISH COLUMBIA, CANADA

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INTRODUCTION and OBJECTIVES

Extensive tracts of streamlined forms (drumlins, mega-lineations) are often used to infer rapid ice flow (including ice streaming) in former continental ice sheets. These inferences rely on two assumptions:

I) Rapid ice flow results mainly from the deformation of the water-saturated ice sheet substrate.

II) Substrate deformation creates streamlined forms.

Inferences of fast ice flow seldom include field evidence verifying these assumptions.

In southern British Columbia, a ~ 600 km long and ~80 km wide drumlin tract extends in a North-South direction and terminates near the Okanagan Valley. Such a tract hypothetically records the existence of a former ice stream.

We examine this possibility by i) assessing substrate and landform genesis along a portion of the tract, ii) proposing a conceptual model of substrate and landform genesis, and iii) evaluating the assumption of fast ice flow in light of the field observations.

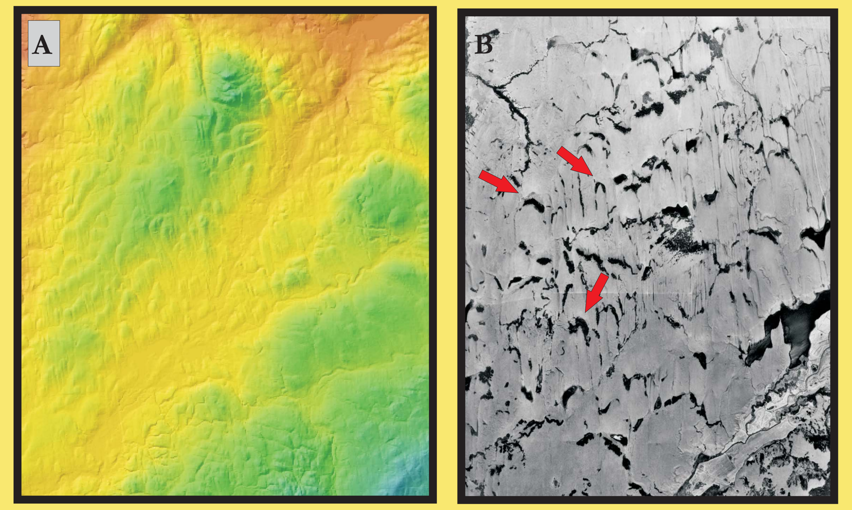


FIGURE 2: Drumlin morphology is more consistent with meltwater erosion than pervasive sediment deformation. A) Preferential drumlin development downflow of bedrock steps. B) Crescentic(hairpin) scours (occupied by lakes) around drumlin noses. Both elements result from flow separation around obstacles and erosion by vortices.

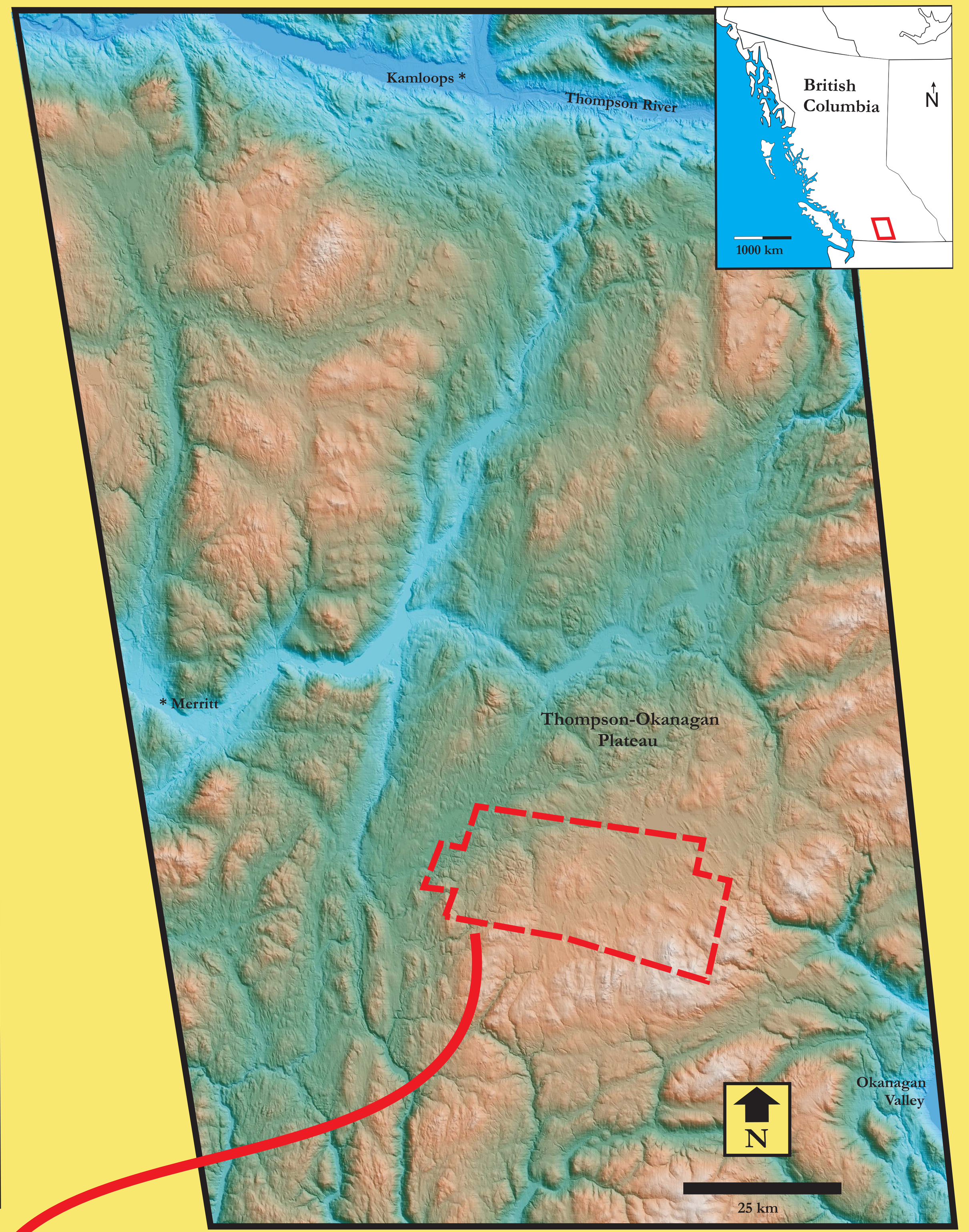


FIGURE 1: Portion of the ~600 km long and ~80 km wide drumlin swarm in southern British Columbia. Drumlins occur mainly on plateaus and in high elevation valleys aligned with the swarm. The swarm is continuous across prominent transverse valleys that are 1-3 km wide and 100s m deep. Fieldwork was concentrated in a portion of the drunlin swarm that bifurcates toward the Okanagan Valley (Figure 3) . Inset map shows location of drumlin swarm within western North America.

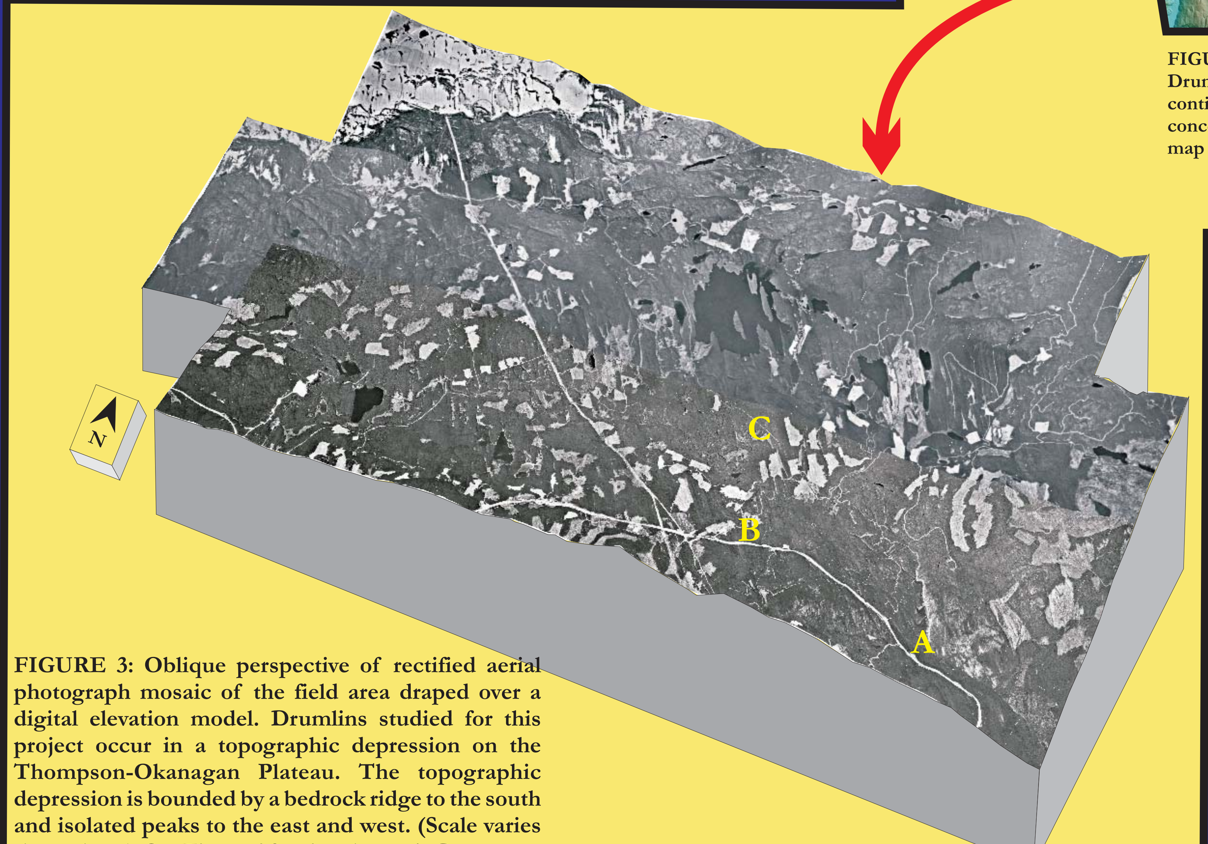


FIGURE 3: Oblique perspective of rectified aerial photograph mosaic of the field area draped over a digital elevation model. Drumlins studied for this project occur in a topographic depression on the Thompson-Okanagan Plateau. The topographic depression is bounded by a bedrock ridge to the south and isolated peaks to the east and west. (Scale varies throughout). See Figure 4 for site photos A-C.

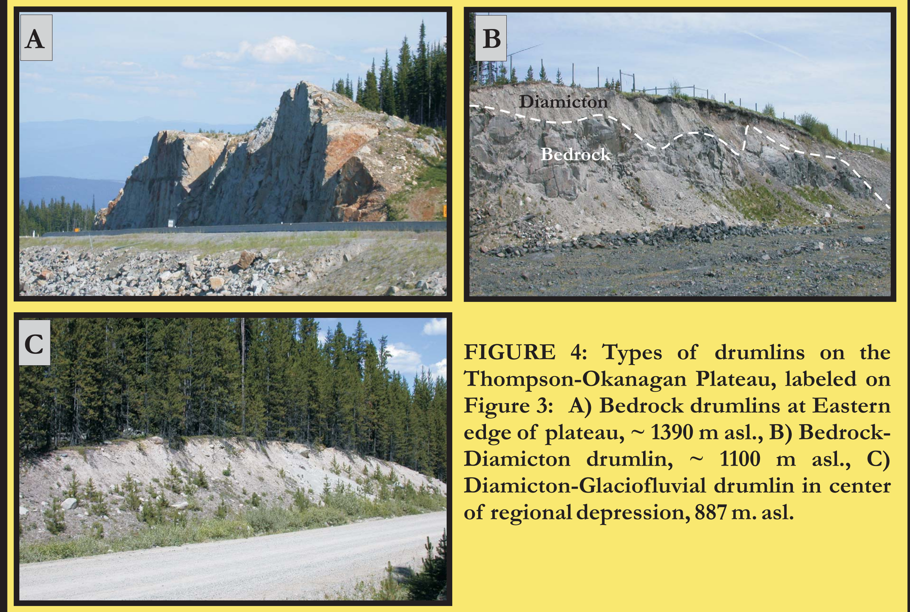


FIGURE 4: Types of drumlins on the Thompson-Okanagan Plateau, labeled on Figure 3: A) Bedrock drumlins at Eastern edge of plateau, ~ 1390 m asl., B) Bedrock-Diamicton drumlin, ~ 1100 m asl., C) Diamicton-Glaciofluvial drumlin in center of regional depression, 887 m. asl.

SEDIMENT CHARACTERISTICS OF THE PLATEAU LANDSYSTEM:

1) DIAMICTON:

Diamictons are very poorly consolidated and are composed of cobbles, pebbles and granules in coarse to medium sand matrix (65%/weight). They are massive to poorly stratified and are interbedded with cm-thick sandy grain-flow deposits.

Silt and clay are largely absent from the matrix, which accounts for the poor consolidation. When present, fines occur in laminations, in soft-sediment clasts, or as 'skins' around larger clasts. Ploughed cobbles and boulders also deform laminated fines.

Diamictons are found within drumlins and in the intervening areas where they are generally better stratified and sorted.

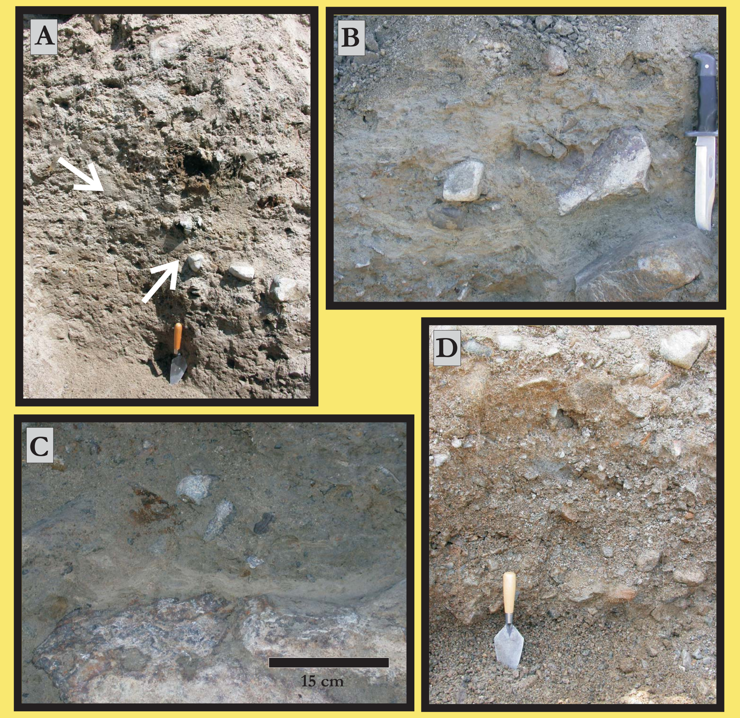
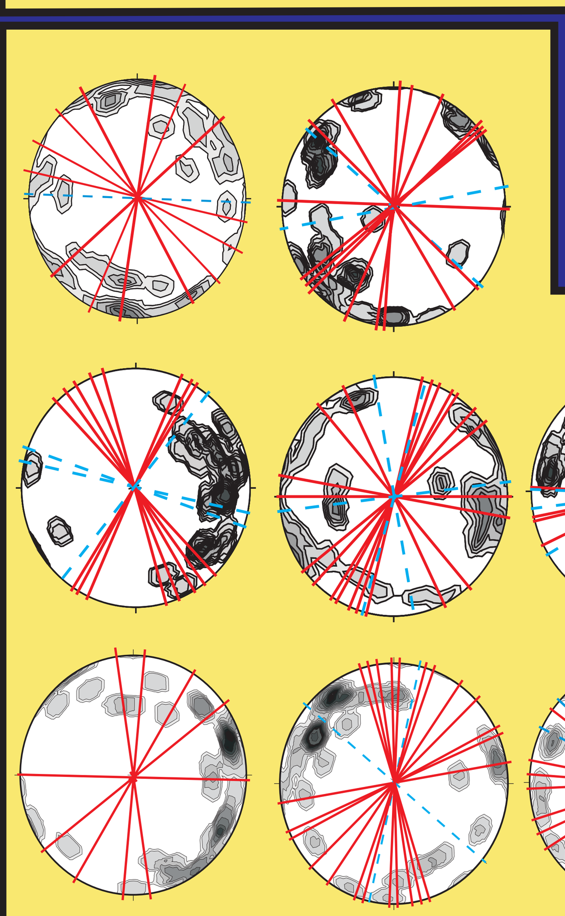


FIGURE 5: Texture and structures found in diamicton exposures within and between drumlins. A) Poorly stratified sand and gravel with soft-sediment clasts of clayey-silt (arrow), B) Localized deformation of laminated fines (silt, clay), C) Clayey-silt "skin" around cobble, D) Stratified and sorted angular gravel.



2) Clast fabric and clast morphological data analysis:

Clasts within diamictons are of two types:

A) Locally-derived angular, rod and blade-shaped clasts. These clasts lack striae and show no to few signs of glacial transport.

B) Exotic sub-angular clasts of varying lithologies. Multiple sets of striae are present and clasts contain abundant evidence of glacial transport (bullet-shape, kecls, plucked stoss and lee ends).

Clast fabrics are generally girdle-like with very few showing dominant clast orientations. Striae and clast morphological data are multi-modal and have widely distributed azimuths.

FIGURE 6: Schmidt equal area, lower hemisphere plots of clast a-axis data (n=30 for all plots). Orientation of the most recent striae (solid red lines) and keels (dashed blue line) are overlain on fabric data.

CONCLUSIONS REGARDING PLATEAU DIAMICTONS:

- Clast morphological characteristics show evidence of lodgement (shaped clasts, keels).
- Low consolidation and laminations within the diamicton and in soft-sediment clasts indicate melt-out of material.
- Girdle-like fabrics, low consolidation, curved striae and ploughed clasts all suggest deformation, albeit on a local scale (not pervasive).
- Gravel interbedded with grain flows are evidence for gravity flows.
- Therefore, plateau diamictons are polygenetic deposits

3) GLACIOFLUVIAL SEDIMENTS:

Glaciofluvial sediments consist of two types of deposits:

i) BOULDER GRAVEL WITHIN TUNNEL CHANNELS
These are poorly sorted deposits that are massive to poorly stratified. Clast imbrication is present where deposits are stratified. These deposits fill topographic lows and tunnel channels between drumlins. They generally have a hummocky upper surface and are overlain by eskers.

ii) BEDS AND LENSES WITHIN DRUMLINS AND DIAMICTONS
These are stratified pebble and sand deposits that are well stratified and sorted. These deposits occur within drumlins and grade laterally into diamictons.

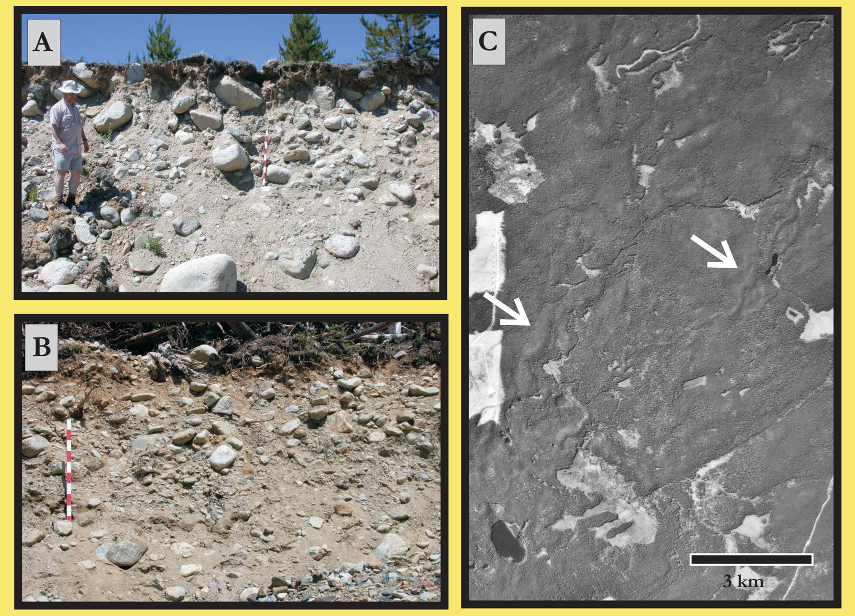
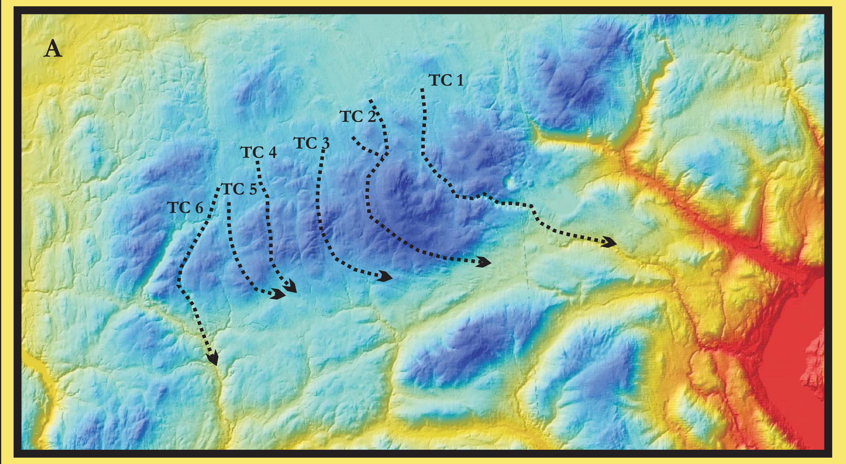


FIGURE 7: Boulder gravel deposits between drumlins. A) Poorly sorted, non-stratified boulder gravel, B) Better sorted, stratified and imbricate boulders and cobbles, C) Aerial photograph of eskers overlying hummocky topography of deposits such as A) and B) (Aerial Photograph 15BCB96056-247).

CONCLUSIONS REGARDING GLACIOFLUVIAL SEDIMENTS:

- Gravel and boulder deposits are emplaced by vigorous meltwater flows that alternatebetween hyperconcentrated and more fluidal flow conditions.
- The presence of eskers over these deposits indicates they have a subglacial origin. They fill tunnel channels cut through the drumlin swarm.

TUNNEL CHANNELS ON THE THOMPSON-OKANAGAN PLATEAU:



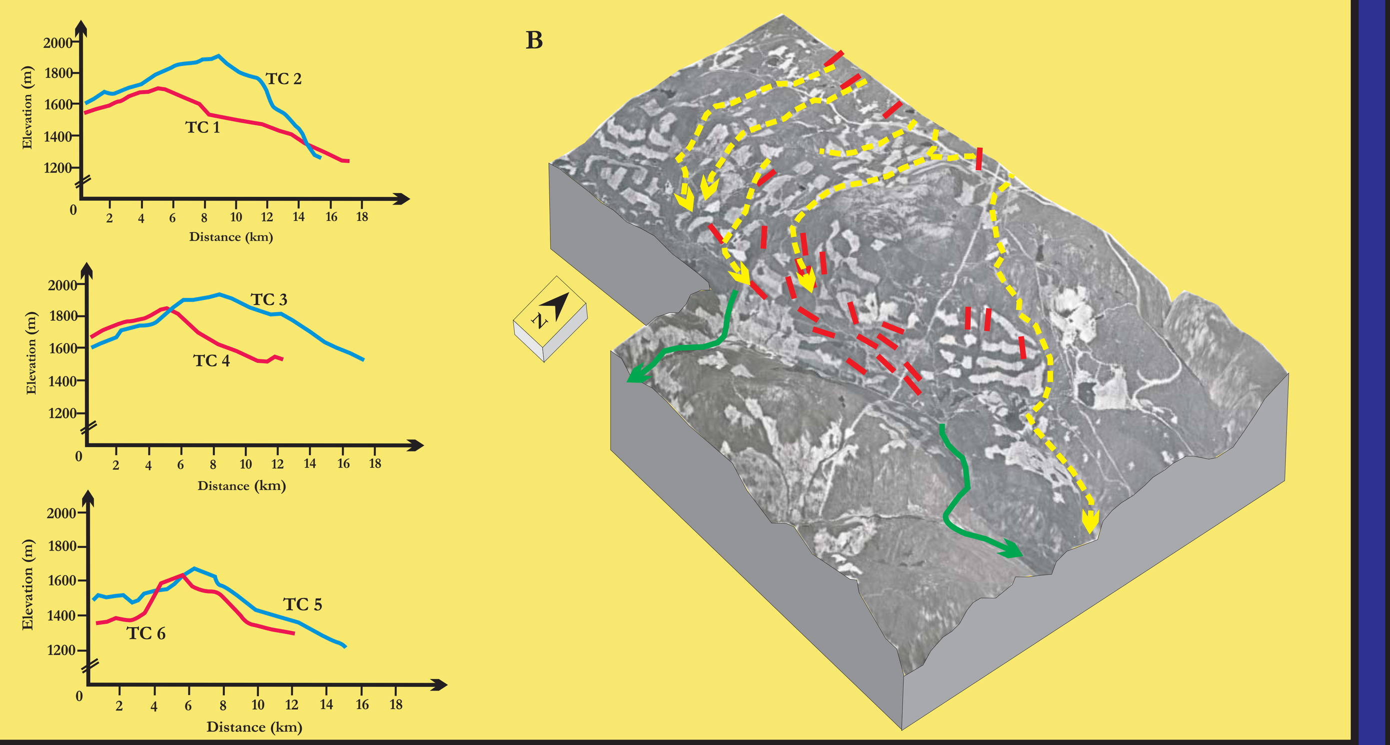
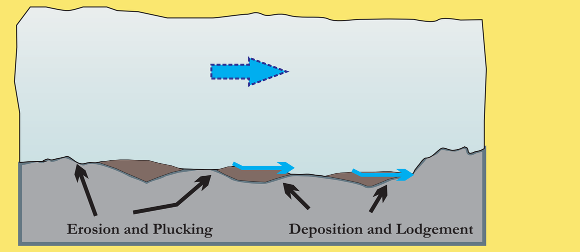
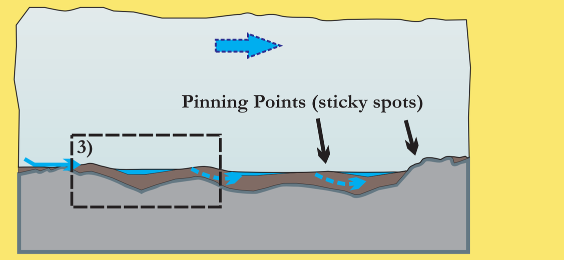


FIGURE 8: Tunnel channels on the Thompson-Okanagan Plateau. A) Tunnel channels cross a prominent bedrock divide at the southern end of the Thompson-Okanagan plateau. All channels have convex long profiles requiring a subglacial, pressurized system to drive water over the ridge. B) Drumlins curve around the lowest elevations of the bedrock ridge where they converge toward two single channels that cross through prominent bedrock obstacles. Subglacial meltwater broadflows changing to channelized flows are required to explain these observations.

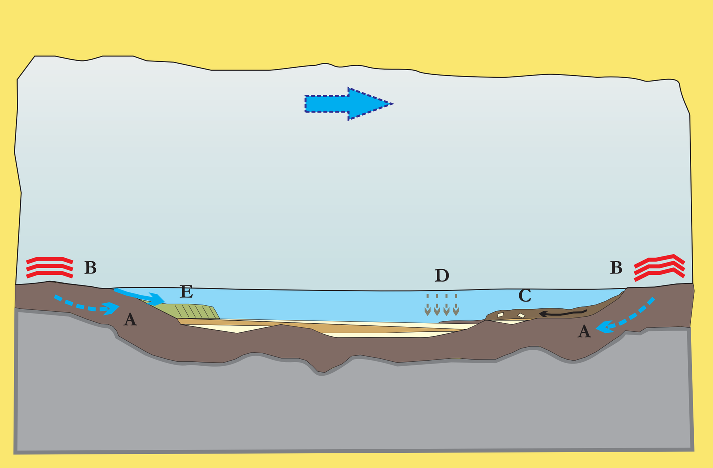
CONCEPTUAL MODEL OF LANDSYSTEM DEVELOPMENT:



1) Emplacement of basal till (lodgement) as a result of erosion and plucking, and deposition of the debris. Meltwater in thin films circulates at the ice-bed interface and aids sliding.

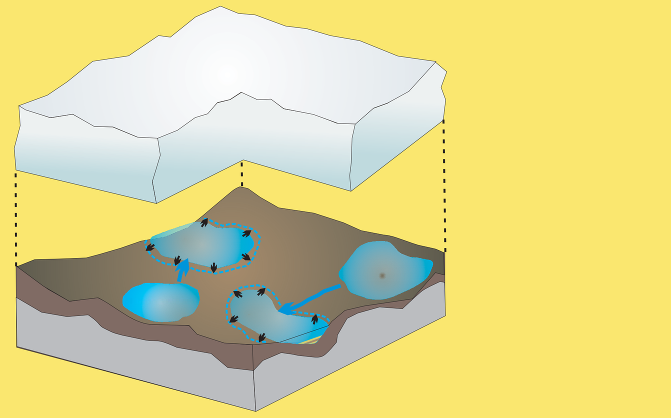


2) Basal till layer thickens as a result of prolonged erosion and deposition. Basal meltwater circulates at the bed and within the basal till sheet (ground water flow) increasing porewater pressure. Meltwater accumulates in depressions within the basal till. Fines begin to elutriate from the till due to water flow. The ice sheet is pinned on high points between cavities.



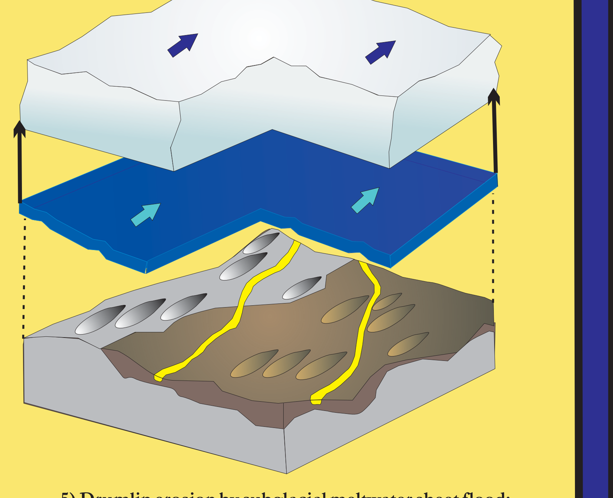
3) Sedimentation in subglacial cavities:

A) Water flow through substrate continues to elutriate fines. This creates poorly consolidated sandy diamicton. Fines are transported toward cavities. B) High shear stress at pinning points creates localized deformation of the weak material. C) Shear stress creates slope failures and mass flows into the cavity. D) Melt-out of englacial sediment over the cavity. E) Channelized flow between cavities deposits sorted and stratified sand and pebbles.



4) Cavity expansion and reorganization:

Advancing ice modifies cavity geometry and forces connection between cavities. Cavities expand at the expense of others. Former cavities are partly filled-in by squeezed and deformed sediment. Cavities are linked by channels which transfer water and sediment to expanding cavities. Channels may contain sorted sediments.



5) Drumlin erosion by subglacial meltwater sheet flood:

Subglacial sheetflood sweeps over Thompson-Okanagan Plateau and erodes drumlins into bedrock and the complex sediment assemblage deposited beneath the ice. This represents a regional unconformity that spans many plateaus of southern British Columbia. Tunnel channels are formed as sheet flow channelizes. Boulder gravel fill tunnel channels during waning stages. The passage of this meltwater sheet decouples the ice from its bed. Rapid ice flow can occur at this time as shear stress is nil and the glacier is floating.

CONCLUSIONS AND IMPLICATIONS FOR RAPID ICE FLOW:

1) The substrate of the Thompson-Okanagan plateau is polygenetic and records a multitude of subglacial processes. The substrate is not pervasively deformed, as many assume it to be in broad drumlin fields.

2) Drumlins are erosional landforms created by a subglacial meltwater sheetflood. Drumlins occur in association with tunnel channels formed during the same underburst event.

3) If the Thompson-Okanagan plateau landsystem records evidence of rapid ice flow, the mechanism of rapid ice flow is related to decoupling of the ice sheet from its bed during the subglacial underburst. Bed deformation accounts for very little of the possible motion.