Landslide activity 9: **Landslides in Eastern Canada**

Description: A teaching lesson about the landslide potential of the sensitive marine clay (Leda Clay) of eastern Canada and a student activity. Students calculate the depth of potential failure along a river using real data. Using geological logs obtained from borehole coring, students evaluate landslide hazard along a fictional river valley, determining the most hazardous and the safest areas.

Materials: Overheads:

1. Champlain Sea
2. Sensitive Clay
3. Failure Sequence

Student worksheets 1 and 2 (Landslides in sensitive clay of Eastern Canada)

Teacher instructions and notes:

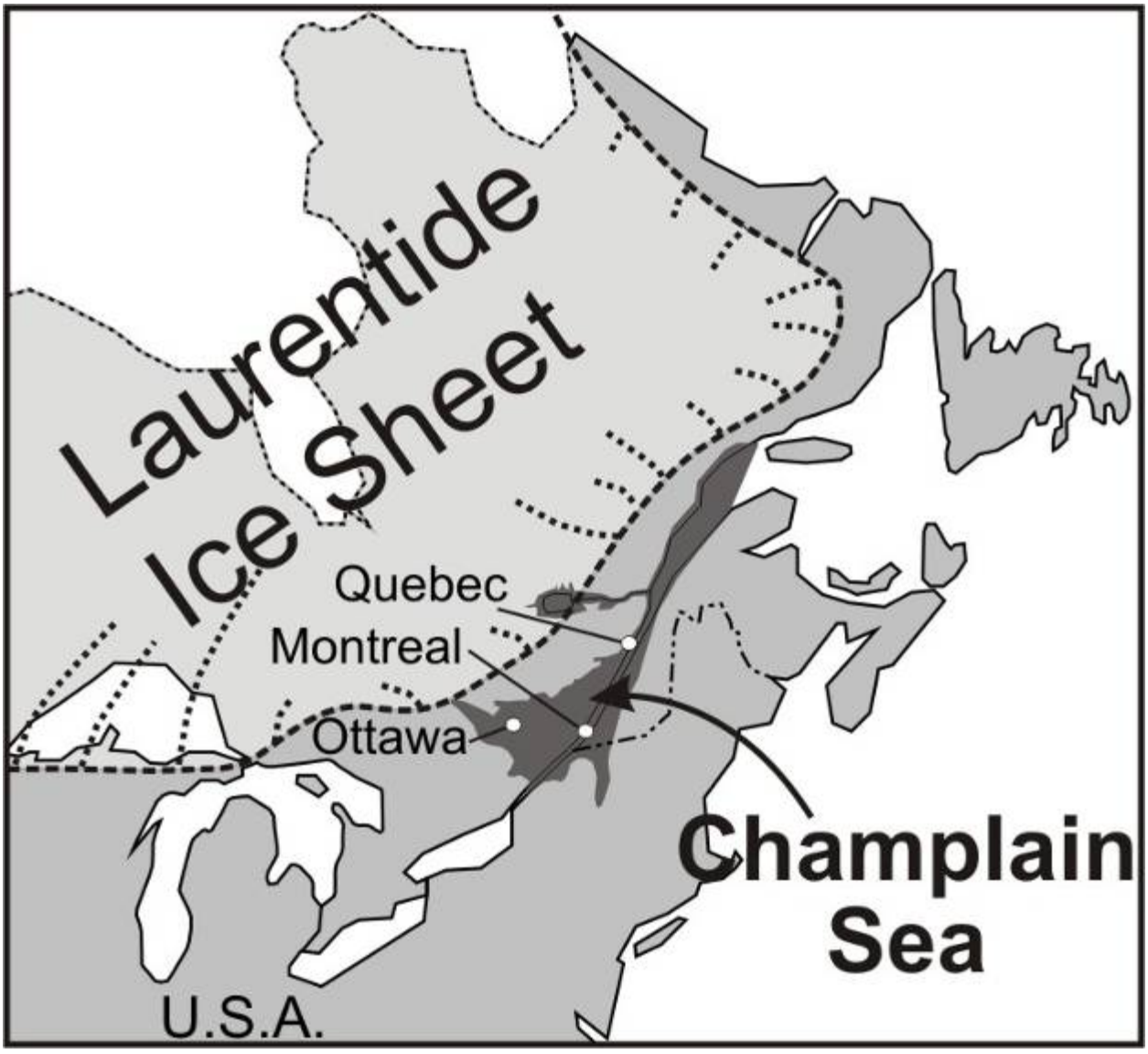
1. Explain the concept of sensitive clay.
    - **What is it?** Sensitive clay is a geotechnical term referring to fine grained glacial marine sediments that although seeming to be solid and stable, actually may suddenly loose their physical strength and liquefy (turn to liquid mud) if disturbed. It is known informally as Leda Clay.
    - **Where is it found?** Glaciomarine clay is found in areas once covered by the Champlain Sea, a temporary sea that covered the lower Ottawa, St Lawrence, and Saguenay valleys at the end of the last ice age. (See Champlain Sea figure) Note: Not all of this area is covered by clay and not all of the clay is sensitive.
    - **How is sensitivity determined?** Shear strength (ability of a sediment to resist forces that attempt to cause the internal structure of the sediment to permanently deform and slide against itself) is measured in both the undisturbed state (Cu) and after the sample has been remolded (Cr) by stirring. Sensitivity is the ratio of the undisturbed to remolded strength (Cu/Cr) and values exceeding 30 are considered to be sensitive. These tests can be done down the borehole in the field or on samples in the lab.
2. Explain why the clay is unstable, how these landslides move, and why large areas of flat land can be destroyed by these landslides.
    - Leda clay is composed of clay- and silt-sized particles of bedrock that were finely ground by glaciers and washed into the Champlain Sea. As the particles settled through the salty water, they were attracted to one another and formed loose clusters that fell to the seafloor. The resulting sediment had a loose but strong framework that was capable of retaining a large amount of water. Following the retreat of the sea, the salts that originally contributed to the bonding of the particles were slowly removed (leached) by fresh water filtering through the ground. If sufficiently disturbed, the leached Leda clay, a weak but water-rich sediment, may liquefy and become a 'quick clay'.
    - Trigger disturbances include river erosion, increases in pore-water pressure (especially during periods of high rainfall or rapid snowmelt), earthquakes, and human activities such as excavation and construction. After an initial failure removes the stiffer, weathered crust, the sensitive clay liquefies and collapses, flowing away from the scar (see Failure diagram). Failures continue in a domino-like fashion, rapidly eating back into the flat land lying behind the failed slope. The flowing mud may raft intact pieces of the stiffer surface material for great distances. This type of landslide is called an earthflow.
3. Distribute worksheet.
4. Using data from an actual borehole, students identify the critical depth at which the clay is sensitive and consider the ramifications of this clay occurring above, at, and below river level.

- (Critical depth is 23-27 m below ground surface. If this is at river level, the bank is vulnerable to landslides; if above river level it is still susceptible; if below river level, landsliding is less likely.)

5. By analyzing borehole data from holes drilled along a valley, students identify sections of the valley that are vulnerable to landslides. (answer: A, G, B, H)

Overhead 1

Champlain Sea



Overhead 2

Sensitive clay

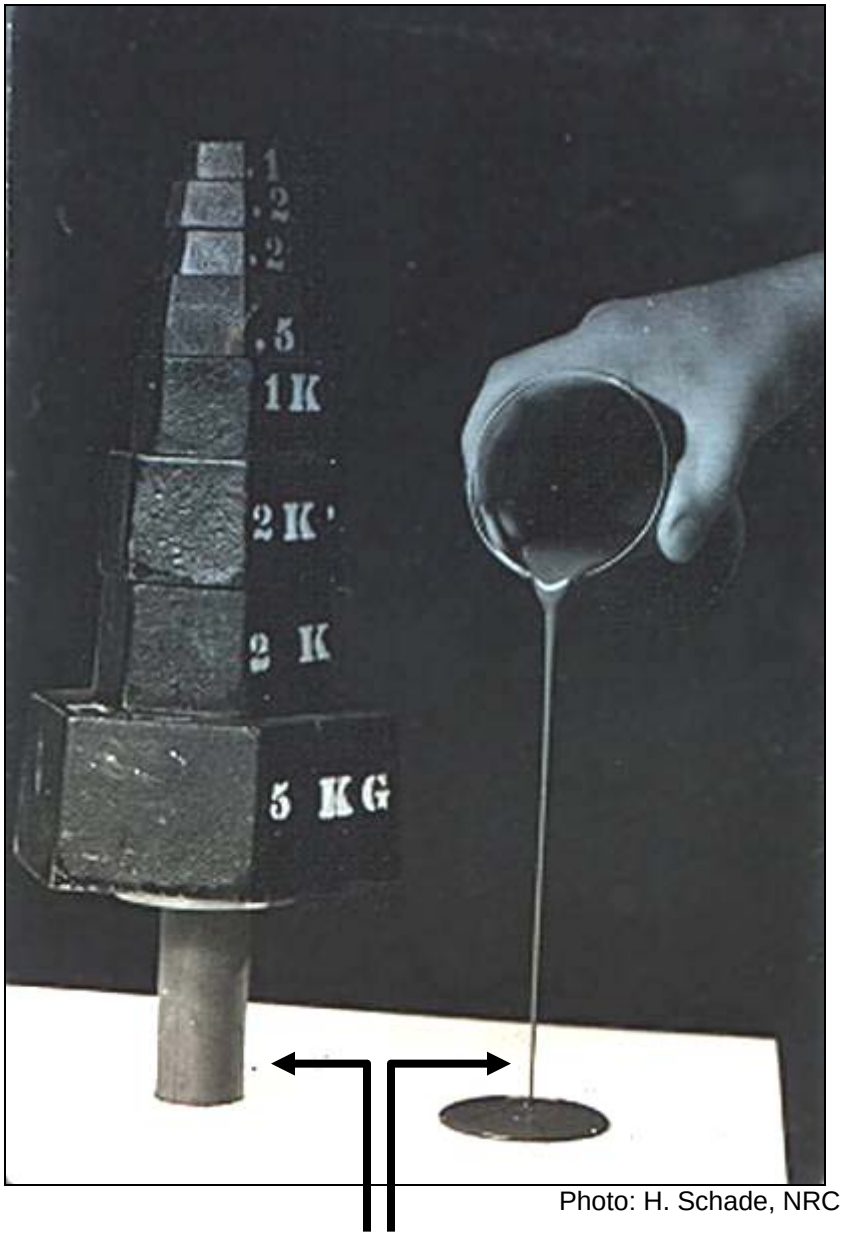


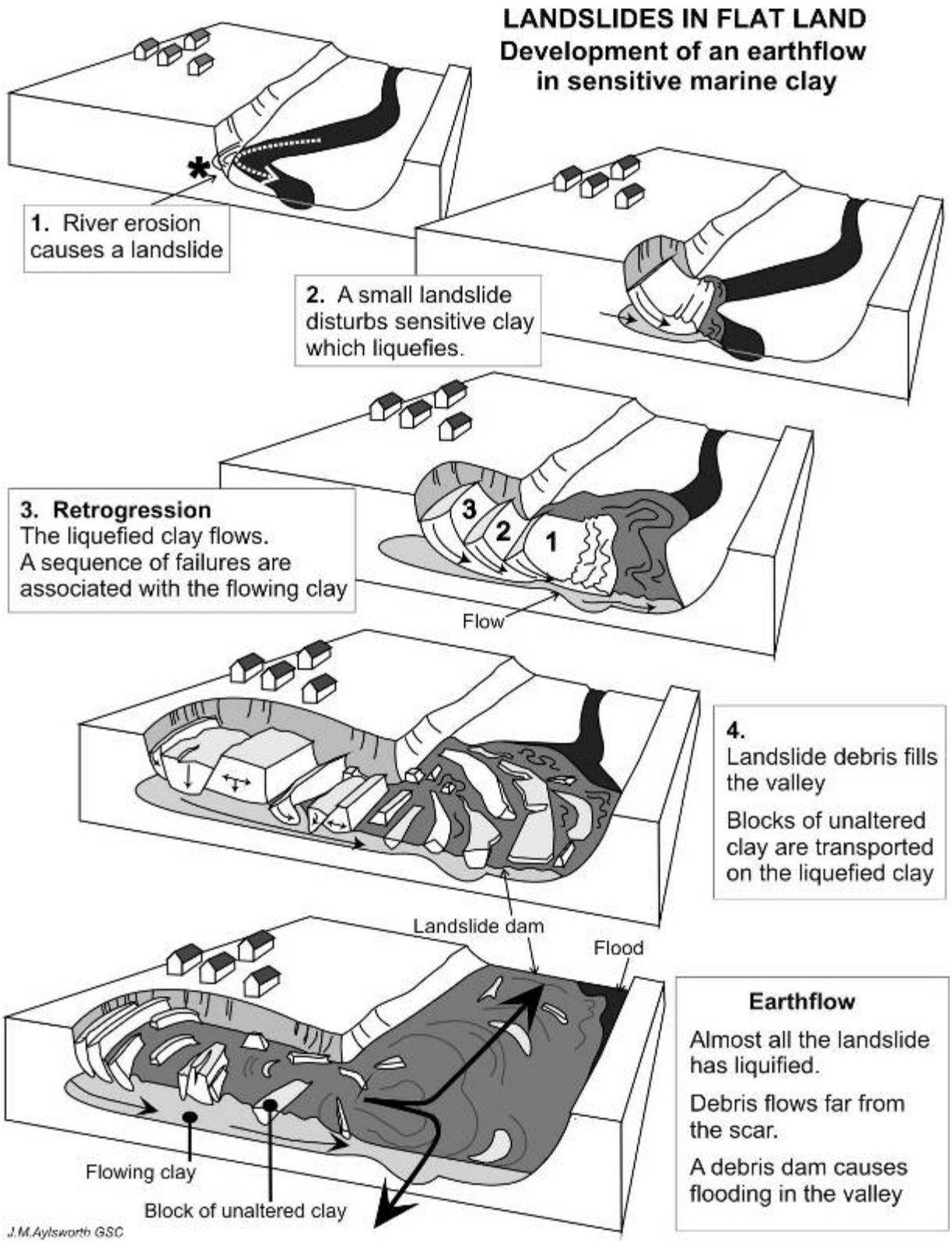
Photo: H. Schade, NRC

The same clay

If disturbed, sensitive clay may lose all physical strength and behave like a liquid.

Overhead 3

Failure sequence



 Name:_____

Landslides in sensitive clay of Eastern Canada

1. Identification of sensitive clay.

Geologists use measurements of the shear strength of sediment to identify clay that is geotechnically sensitive. Shear strength is the ability of a sediment to resist forces (stress) that attempt to cause the internal structure of the sediment to permanently deform and slide against itself and it is measured in both the undisturbed state (Cu) and after the sample has been remolded (Cr) by stirring. Sensitivity is the ratio of the undisturbed to remolded strength (Cu/Cr) and values exceeding 30 are considered to be sensitive. Using the following data collected from a borehole drilled above a steep slope, identify the critical depths at which the clay is sensitive and answer the following questions.

Depth below surface (m)	Geology	Undisturbed strength (t/m^2)	Remolded strength (t/m^2)	Sensitivity
5.0	sand	2.3	0.43	
10.0	sand	2.4	0.21	
12.5	silty clay	2.6	0.29	
15.0	silty clay	2.2	0.18	
17.5	clay	3.3	0.21	
20.0	clay	2.7	0.14	
22.5	clay	3.0	0.10	
25.0	clay	3.7	0.07	
27.5	clay	3.1	0.04	
30.0	clay	3.5	0.19	
32.0	till	4.0	0.43	
33.0	bedrock	5.0	0.58	

a.) The sensitive clay occurs at which depth or range of depths below surface? _____

b.) Why was the sediment not tested at 5, 10 and 32 m below surface? _____

_____

_____

_____

c.) Many sensitive clay landslides are triggered by river erosion at the base of the slope. Based on the critical depth of sensitive clay that you calculated, how vulnerable is the valley slope to landsliding if the depth of the valley to the river is the following? Explain your reasoning.

18 m: _____

_____

_____

_____

24 m: _____

_____

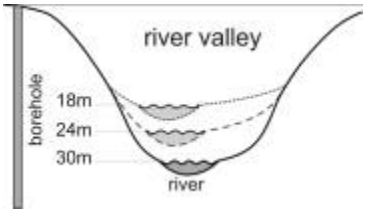
_____

_____

30 m: _____

_____

_____



2. The geology near the Blue River Valley is somewhat varied but generally consists of bedrock overlain by glacial till, which is overlain in turn by glaciomarine clay and deltaic sand. The Blue valley is entrenched about 25 m into a level plain and the valley walls are generally steep. Geologists suspect that at some unknown depth there is a layer of clay that is geotechnically sensitive – that is, although having the appearance of solid earth, it might loose its physical strength and liquefy – turn into a liquid mud. Sensitive sediments are prone to landslides. A borehole was drilled down into the ground and samples collected and tested. Given this data, identify which segments of the river are a landslide hazard.