Slope Instability and Gas Hydrates

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I will talk today about two very different projects, linked only by my involvement in both: one on deep seated creep (which was done in association with Mark Nixon, and with some modelling work done by Alpha Laforio and Branko Ladanyi), the other is gas hydrates.

The questions that I see arising at this workshop are:
- *Why do we monitor?*
- *What do we monitor? And*
- *Where do we monitor?*

Slope Stability
Clearly, ground surface response is influenced by the elements that are being discussed today (active layers and ground temperatures). We can monitor active layer response to surface change by looking at active layer depth, soil consolidation versus depth, slope curvatures, and so on. As active layers thaw and water is liberated we can further ask:
- *Where does that water go?*
- *What is its state?*
- *How does it change the geotechnical properties of the ground?*

As Al Taylor and Vlad Romanovki showed us, climate change is reflected in deep ground temperatures. With changes in temperature come associated changes in soil strength, so that climate change introduces issues of slope instability even in continuous permafrost, such as on the Beaufort Sea coast.

Slope instability has a number of aspects: deep-seated creep, solifluction, active layer detachments, rotational landslides, retrogressive thaw flow slides, and so on. All of these slope processes can be linked back to the primary things that we are trying to monitor. As Fred Wright pointed out, we cannot be monitoring things so that we can detect change after the change has happened. Some surface processes respond very quickly, as Steven Wolfe pointed out with the deep active layers that developed in 1998. As monitoring proceeds, there will be useful possibilities to examine processes to get a clearer understanding of what we are monitoring, how we are modelling those processes.

In the area that I work (Mackenzie Delta, Tuktoyaktuk coastal plain, coastal slope of Yukon) there is a great deal of ice-cored topography. Typical topography that we are examining is ice-cored hills. There is a core of more or less pure ice, with a thin, variable cover of glacial till, and a base of sand. (slide) This is an example of a hill about 40 m high that shows abundant evidence of creep. About 1987, we established a GSC project to examine slope instability at this site, in particular deep-seated creep of the permafrost.

In an *ad hoc* way, there was enough money to launch a field investigation, following which we have been routinely collecting data at this site. There are five slope-indicator sites on Involuted Hill, two on Lousy point, and at Yaya Lake. The slope indicators are conventionally used in landslide studies in the geotechnical industry. Slotted casing are installed, down which a probe is inserted to measure changes in inclination. Repeated measurements make it possible to measure the nature and rate of movements within the ground. At the toe of the slope, where the creep rate is expected to be the greatest, the creep rate is so slow that we are close to the limits of detection with this instrumentation. Results over several years show modest but significant rates of movement, varying with depth according to the temperature, the geometry of the hill, and the dynamics.

Through monitoring work with Branko Ladanyi, we have linked this back to geotechnical engineering, since creep is also of interest for foundation engineering. Many northern structures are founded on permafrost, with pile foundations relying on the strength of adfreeze bonds with permafrost. Looking at the literature, we we able to monitor the behaviour of this site as a cold-based glacier, using theory developed in the 1960s very effectively.

These sites are accessible, and could be included in a monitoring network. In an ad hoc manner, we have tried to collect the kind of monitoring data that is being discussed at this workshop: reliable ground temperature data, near surface temperatures using dataloggers between infrequent visits to the site to piece together a long-term record. Our interest in collecting this data was to help us understand the creep processes that we were investigating.

The creep rate of this hill is very slow at the moment, as dictated by the strength conditions of cold permafrost. If the permafrost warms however, the creep rate will accelerate, which will lead to changes at the surface (cracking etc.), which will open up the possibility of more rapid change such as active layer detachments. The question that I would pose at this workshop is whether we should continue to monitor sites of this sort in the future?

Gas Hydrates

As permafrost temperatures change, there is a change in many parameters that control sources and sinks of greenhouse gases. The role of natural gas hydrates has been an interest of mine over the last 5 years or so. The potential of natural gas hydrates lies in the fact that they represent a very concentrated source of methane, which is a very effective greenhouse gas. On a worldwide basis, the total amount of methane tied up in hydrates may be about twice the amount of hydrocarbon locked up in conventional and unconventional oil and gas. Recent reports in *Nature* and elsewhere also indicate that methane may have been very important in climate change in the geological past. The concern that I have is that the interaction between climate change, permafrost warming, and release of methane into the atmosphere is that this is a potential positive-feedback to further global warming. We are not currently monitoring gas hydrate sources and sinks to any significant degree, as Steve Robinson's presentation illustrated.

The gas hydrate regime is not straightforward to understand. There are tremendous sources of the gases, and deep (greater than 600 m) permafrost occurrences throughout arctic basins. Al Taylor recently did some modelling for us that suggests that the permafrost at 800-2000 m depth may take on the order of 5000 years to respond. Gas hydrates are held throughout the permafrost profile, however. Gases are released even with thickening of the active layer. There are already conduits for gas hydrate release into lakes and other situations.

If we are monitoring to find out what may happen, we need to ask ourselves how much we know about what is already happening. In this case we do not know much. There are many places that we would want to measure what is going on, and we do not yet fully understand current processes. The challenge that I put is whether monitoring can incorporate this kind of unconventional research into potentially important processes?