FROM EXPLORATION TO POST-CLOSURE—THE BENEFITS OF USING TERRAIN STABILITY ASSESSMENTS IN MINE LIFE PLANNING

Victoria Stevens, B.Sc., P.Ag., P.Geo.
Natalie Tashe, M.Sc., P.Ag.

Stantec Consulting Ltd.
2042 Mills Road Unit 11
Sidney, BC V8L 5X4

ABSTRACT

Terrain stability assessments are an important a planning tool that is used from the routing trails for mineral exploration through construction, to post-closure changes in stability from mining activities. Quantifying landscape stability conditions can influence mine design and reclamation plans, while site-specific terrain stability assessments for construction of exploration trails and drill pads will help prevent localized instability. Mechanisms of alterations to terrain stability will change through the life of a project, and may include such forces as landscape-level groundwater fluctuations associated with pit dewatering; slope loading resulting from waste rock dumps; subsidence resulting from underground mines, or alterations to hydrologic networks due to infrastructure construction that directs drainage onto downslope terrain. All of these mechanisms can affect reclamation planning and end-land use objectives. The benefits of applying diligent terrain stability assessment protocols are two-fold: economic and environmental. Economic benefits can be derived from lowered project costs for access road maintenance, proactive versus reactive planning, and reduced mitigation and monitoring measures associated with post-closure activities. Environmental benefits include reduced impacts from landslides negatively affecting sensitive receptors such as fisheries habitat or wetland environments, and by preserving soil resources.

Key words: hazards, mapping, subsidence, groundwater, instability, reclamation

1.0 INTRODUCTION

Terrain stability is a vital component of analysis for any mine project. Commonly regarded as a concern only associated with steep mountainous slopes, terrain stability can actually be affected by mine project activities on all landscapes via several mechanisms. These mechanisms can include ground disturbance from clearing activities, alteration of surface water flow through redirection of stream flow by roads or mine features, changes to near-surface groundwater flow through pit dewatering, or subsidence from subsurface mining.

Terrain stability in British Columbia is commonly rated on a three- or five-class system, depending on mapping scale and the intensity of field surveys. Small scale or reconnaissance level mapping may use the three-class rating system of Unstable (U), Potentially Unstable (P) or Stable (S). Detailed or larger-scale mapping will utilize a more refined five-class system based on the hazard of instability resulting from ground disturbance, typically timber removal, ranging from Class I, II or III denoting no to minimal stability concerns, Class IV denoting potential instability resulting from site disturbance to Class V terrain which denotes active instability or a high hazard of instability resulting from site disturbance.

Landscape attribute studies (Rollerson, 2002) demonstrate that identifying and describing terrain features, such as gullies or convergent slopes, can indicate the susceptibility of that slope to failure. Hazard assessments require consideration of terrain features, geomorphic processes and terrain stability classification to identify potential hazards to the project, the environment and workers on site.

Each project will develop its own terrain stability rating framework depending on the characteristics of local terrain. This framework is developed by understanding how the terrain in the study area is influenced by the local bedrock, climate, geomorphic processes and historic stability as evidenced in the airphoto record. For example, landslide susceptibility and rates under similar climatic events can be strongly influenced by underlying bedrock type (Guthrie, 2005). This framework is refined through fieldwork and site observations, and should be considered a living document through the life of a project. Reclamation planning should also consider factors such the characteristics of local parent material salvaged for capping and how it is affected by climatic events, upslope geomorphic processes such as avalanches, processes such permafrost or alpine freeze-thaw cycles. This is of particular importance to sensitive downslope receptors of sediment such as fish-bearing streams should instability develop on reclaimed slopes.

Terrain instability can result in significant impacts to the environment, the economic success of a project, and the safety of a project. Landslides can significantly impact or destroy habitat such as fish-bearing streams or valuable riparian habitat. Unvegetated and unstable slide headscarps and slide paths can introduce a chronic source of sediment to the landscape. Stabilization of slide features can be time-consuming and expensive. Infrastructure directly impacted by landslides or impacted by chronic sedimentation, such as downslope ditch and culvert networks require repair and expensive maintenance. Proactive hazard identification and analysis can pay off in the long-term avoidance of costly maintenance and mitigation activities and assist in the success of reclamation objectives.

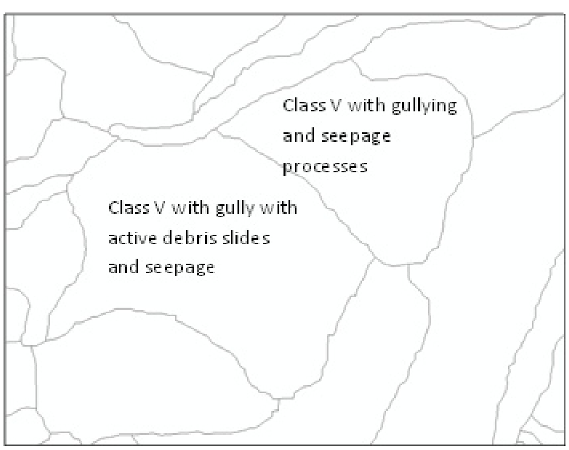
2.0 TERRAIN STABILITY AT ALL PHASES OF A PROJECT

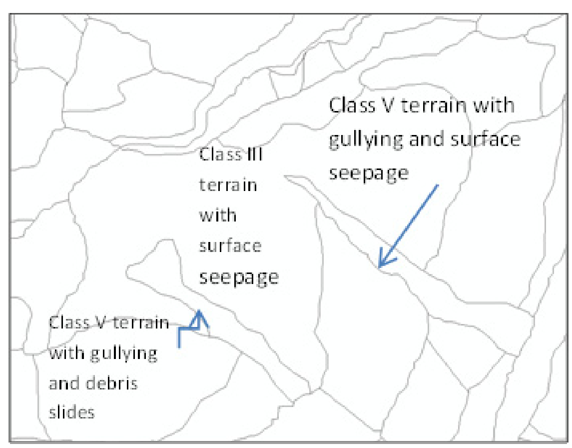
One of the first steps when considering the stability of a project is to understand how terrain stability is affected by the different phases of a mine project—construction, operations and post-closure. During construction, vegetation clearing can result in direct slope loading and lowering of the slope reinforcement strength provided by tree roots. Exploration trail and road construction commonly results in redirection of stream flow, and when this drainage is directed onto potentially unstable downslope terrain, it can result in saturation and debris slides. Placement of road spoil material on steep downslope terrain can also result in slides. During operations, seepage from sediment ponds located near potentially unstable or unstable slopes can result in the development of slides from seepage erosion and/or ground saturation. Shoreline erosion of tailings ponds can undermine the toes of slopes and result in retrogressive slides or slope raveling, depending on slope conditions. A commonly-observed analogy to this process, while not associated with mining, is the erosion of the banks of Williston Reservoir, where terrain not naturally exposed or attenuated to shoreline erosion has resulted in extensive cutbank slumping, shoreline ravelling and sedimentation to the reservoir.

3.0 TERRAIN STABILITY MAPPING AT ALL SCALES

A common challenge in all stages of project development is the alteration to drill programs, mine footprint, study areas and location of mine features as additional data is collected and mine planning is refined. Exploration is restricted on Class V terrain, and is often included as restrictions in Notice of Work documents, therefore obtaining exploration maps at an appropriate scale to minimize hazard while maximizing access options is key. The issue with map scale and terrain stability is that an area or polygon may be assigned a Class V stability rating due to the inclusion of an unstable feature that is not necessarily indicative of the stability of the entire area or polygon. For example a polygon that is delineating a moderately steep slope with a small but geomorphically active gully at 1:10,000 scale mapping will have a Class V stability rating, since the gully is too small to map as its own polygon; however, at 1:2000 scale mapping, it may be possible to isolate the Class V gully from the moderately steep Class III on either side of the gully, opening up more areas of stable terrain for exploration programs.

This scenario arose on a project that had been mapped at 1:10,000 scale for terrestrial ecosystem mapping (TEM) purposes and the client wished to run further exploration programs in an area of interest within the local study area. The area of interest included polygons with Class V stability ratings, but the client noted that some of the area in those polygons could potentially be reviewed at a larger scale to delineate areas of Class V terrain from the more stable adjacent areas. Fortunately, the database for this mapping included stability ratings (not necessarily included in all TEM products), and had been extensively field checked in the area of interest. The Notice of Work stated that no exploration was to occur on Class V terrain. The client inquired if there was an opportunity to use high-resolution digital imagery to refine the stability ratings in a small area of interest comprising of approximately 20 polygons. We were able to review the 1:10,000 mapping in PurView TM, a 3D digital mapping program, review field data and observations, and revise the mapping accordingly. By working at a larger scale, we were able to further delineate Class V terrain from adjacent stable terrain, as illustrated in Figures 1 and 2.





Figures 1 and 2. Figure 1 (left) with larger Class V polygons at 1:10,000 scale. Figure 2 (right) at 1:5,000 illustrates how Class V terrain has been delineated at a larger scale and adjacent Class IV terrain has been joined into one polygon.

The requirement of a dataset must be understood before undertaking this type of re-mapping exercise—the keys to being able to successfully complete this task was good field data in the area of interest, access to high resolution digital imagery, a project-specific terrain stability framework derived by qualified geoscience professionals, staff who had been on the ground in the area, and an understanding of how drill programs impact slope stability processes.

As a project progresses, landscape-scale mapping will transition into site or feature-specific mapping, such as performing road hazard assessment on access roads, locating safe set-backs from unstable slopes, or identifying high-water marks on debris-flow prone streams. Baseline information on stability may be collected or established at the start of construction for long-term monitoring programs. Refined terrain stability mapping may be performed on an as-needed basis for continued exploration programs, and professional staff may be required to develop mitigation recommendations should instability develop on a project.

4.0 TERRAIN STABILITY IN ALL CLIMATES

Terrain stability regimes are strongly influenced by climatic effects, and significant slide events are strongly correlated to intense rainfall (Guthrie, 2005), or timing of climatic events such as rain-on-snow phenomenon, whereby rainfall on snowpack can result in catastrophic release of water onto vulnerable terrain. When considering the effects of mining activities on terrain, practitioners must understand what environmental factors will come into play over the life of the project and at all scales, from the effects of discontinuous permafrost on pipeline integrity (Weston et al. 2010) to seasonal freeze-thaw effects on maintenance of road cutslopes. These effects and the unpredictable timing of these events can also affect reclamation success, through erosion of soil capping and rilling or gullying of waste dumps.

Coupled with terrain stability ratings is the identification of geomorphic processes, such as rock slides, debris slides, surface water seepage, avalanches or permafrost activity. The mechanism of disturbance, the vulnerability of the landscape to different processes, and the seasonal and annual variation of the processes needs to be considered when performing effects analysis and reclamation planning. How these processes interact with the terrain characteristics needs to be considered as well; for example, considering how surface seepage will affect different types of parent material, for example cohesive morainal till versus sandy glaciofluvial deposits.

A project located in the Selwyn Mountains in the Yukon, located in the discontinuous permafrost zone, considered the option of using an 80km long concentrate pipeline from the mine site to a rail load-out area. Permafrost and associated processes such as ground heaving, frost shattering and solifluction was observed throughout the Project area, but was not ubiquitous in all areas of the corridor. Permafost presents engineering design and construction challenges, such as ground heaving or subsidence, but when climate change is factored into the long-term integrity of the pipeline, a hazard framework needed to be developed as presently stable slopes could become destabilized as a result of potential future changes to the permafrost regime. The goal was to develop a matrix whereby existing terrain stability was combined with the probability of permafrost occurring in a polygon to develop a geohazard rating that captured the long-term stability rating of the terrain under a changing climate. This was completed by identifying terrain and vegetation attributes associated with permafrost features, such as imperfect or poor drainage, north-facing slopes, bulging or lobate slope shape, and black spruce forest stands. Combined with field observations, terrain mapping, and terrain stability classification, geohazard ratings were applied to each polygon to provide screening-level quantification of long-term terrain stability.

5.0 SLOPE LOADING

Spatially analyzing the intersection of waste rock dumps with unstable and/or geomorphically active terrain is another key step in assessing long-term effects on both the stability of the landscape and the mine features. Locating the dumps away from adjacent potentially unstable or unstable terrain is also key to long-term mine feature stability. For example in Figure 3, waste rock dumps at the decommissioned Bullmoose Coal Mine are set back from downslope unstable rock bluffs, ensuring long term stability of the dumps.

Figure 3. Waste rock dumps are set back from a failure in bedrock, ensuring long-term stability of the site.

Factors to take into consideration with waste rock dumps are active geomorphic processes both within and adjacent to the feature. Slope seepage can be strongly influenced by slope loading and could result in slope instability should seepage increase or waste material becomes saturated by the seepage and becomes unstable. Mitigation measures may need to be identified, such as rock drains or toe drains to ensure adequate drainage of the waste material. Processes in adjacent terrain, as noted above, can affect long-term stability. Waste dumps located near dynamic fluvial environments could be affected by shifting river channels and result in erosion of the toe of the dumps. The historic flow patterns can be identified and mapped from aerial imagery based on both terrain and vegetation features, and can inform waste rock dump placement with adequate channel set-backs, toe slope reinforcement recommendations and/or monitoring recommendations.

6.0 INTERACTIONS OF NEAR-GROUNDWATER SURFACE CHANGES ON TERRAIN STABILITY

Excavation of mine pits, dewatering of the pit, and loading of slopes with waste rock can result in alterations to the near-surface groundwater flow regimes within slopes, and can result in wetting or drying of terrain. Where these wetting or drying scenarios occur, instability or other terrain effects can occur. If a wetting scenario is coincident with potentially unstable or unstable terrain, the increase in pore water pressure and/or development of seepage erosion can result in instability or increased rates of existing instability. Where a drying scenario may develop in sandy soils on potentially unstable or unstable terrain, the loss of cohesion within the soil could result in instability, often in the form of slope raveling or debris slides. In areas of terrain already experiencing surface seepage processes, an increase in near-surface groundwater flow could result in increased surface seepage volumes and pressures, potentially resulting in surface erosion. Wetland areas can also be impacted by wetting or drying scenarios, resulting in flooding or subsidence.

To predict where near-surface groundwater changes could affect stability or terrain conditions, groundwater models that include groundwater surface elevations and predicted elevational changes at different stages of mine life, typically during Operations and at Post-Closure, are obtained and spatially analyzed. Where the groundwater surface elevations approach or retreat from the topographic surface, those areas are identified as areas of potential wetting or drying scenarios. When overlain with spatial terrain attributes such as terrain stability class, geomorphic processes, or wetland areas, effects can be predicted where the wetting or drying scenarios intersect areas of potential or existing instability, active geomorphic processes affected by groundwater (seepage, debris slides) or vulnerable terrain features. Once the areas potentially affected by changes in near-surface groundwater are identified, the effects can be predicted on terrain, infrastructure and site safety. Appropriate monitoring programs, mitigation techniques or site avoidance can be recommended to ensure long-term review and monitoring of potential alterations to the landscape.

These potential effects become important to other scientific disciplines included in the Environmental Assessment (EA) process as near-surface groundwater changes can result in potential changes to soil conditions typically defined by drainage, such as gleysols or organic soils, wetland function parameters for ecosystem classification and habitat quality, or geotechnical considerations of infrastructure placement and long-term monitoring.

7.0 SUBSIDENCE FROM UNDERGROUND MINING

There are several issues to be cognizant of on projects involving underground mineral mining, such as long wall mining. Subsidence can occur as a result of removal of subsurface mineral-hosting seams that undermine the overlying bedrock, resulting in sinking, cracking or tilting of the overlying terrain. The effects of subsidence are more pronounced on sloping terrain than flat terrain (Elsworth and Liu, 1995). Subsidence resulting from underground mining can destabilize vulnerable terrain directly above or adjacent to the underground mine features. It can also affect groundwater regimes through several mechanisms including changes to hydraulic conductivity through changes in bedrock fracture spacing (Elsworth and Liu, 1995) and disruption of flow directions. As described above in reference to pit dewatering, these near-surface groundwater changes can result in wetting or drying scenarios and have similar effects on stability. As well, subsidence can result in redirection or total disruption of surface water flow where channels are re-directed through changes to surface topography or flow into the subsurface as a result of surface cracking or sinking. If it remains subsurface, it can affect the near-surface groundwater regime again as described above, or it can emerge in a new location and could destabilize new areas depending on the terrain the new channel develops on and if that area is attenuated to creek flow. Several factors should be considered when determining the potential effects on terrain stability, such as the timing and magnitude of the subsidence, what form will the subsidence take, and how will hydrologic and hydrogeologic regimes be affected (Bell et al, 2000).

Subsidence analysis is performed by obtaining geotechnical and hydrogeological models of predicted project effects and comparing predicted impacted areas with existing terrain mapping. By considering how potential subsidence will affect terrain stability in those areas, monitoring and mitigation plans can be developed. Monitoring terrain stability is key for areas that may be susceptible to subsidence as the timing of subsidence can be unpredictable and can occur slowly or rapidly, and may result in topographic and groundwater changes over a very long timescales (Bell et al., 2000).

8.0 TERRAIN STABILITY CONSIDERATIONS AT RECLAMATION

The success of a reclamation plan can be affected by terrain stability. Landslides occurring on slopes or from road networks can result in site loss, the deposition of unsuitable growth medium (rocky slide deposits for example), and erosion of reclaimed sites. Road deactivation will reduce the hazard of slides originating from the road networks either through failure of the fill slope, or cut slope and through the re-establishment of stream networks. Slides commonly develop on resource roads where a sediment-plugged culvert results in water flowing across or down a road, and saturating downslope fill materials. Therefore removal of drainage structures, even on gentle terrain, is essential during site decommissioning. Mimicking natural terrain features, such as swales or undulations will assist in reestablishment of natural drainage network patterns and lower sediment erosion potential.

9.0 CONCLUSION

Terrain stability affects and is affected by all phases of a mine project. Understanding the local stability conditions and predicting how terrain stability will be affected by the project will inform mine planning and assist in reclamation success. Alteration of near-surface groundwater regimes through pit excavation and dewatering, changes to surface topography through subsidence and alterations to hydrologic networks through road construction can affect the long-term stability of a project. However, through hazard mapping and project effects analysis, these changes can largely be mitigated. The benefits of applying diligent terrain stability assessment protocols are two-fold: economic and environmental. Economic benefits can be derived from lowered maintenance costs associated with well-designed and well-functioning road networks, fewer logistical delays that can be caused by washed-out roads or unstable drill pads, lower and more predictable mitigation costs, the benefits of proactive versus reactive planning, and reduced reclamation costs associated with post-closure activities. Environmental benefits include preservation of sensitive ecosystems and vulnerable receptors, preservation of soil resources, and reduced site loss.

10.0 REFERENCES

Bell, F.G., Stacey, T.R., Genske, D.D. 2000. Mining subsidence and its effect on the environment: some differing examples. Environmental Geology 40, 135-152.

Elsworth, D. and J. Liu. 1995. Topographic influence of longwall mining on ground-water supplies. Ground Water 33, 786-793.

Guthrie, R.H. 2005. Geomorphology of Vancouver Island [electronic resource]: mass wasting potential. B.C. Ministry of Environment. Victoria, BC. Research Report No.RR01.

Rollerson, T., T. Millard and B. Thomson. 2002. Using terrain attributes to predict post-logging landslide likelihood on southwestern Vancouver Island. Res. Sec., Van. For. Reg., B.C. Min. For., Nanaimo, B.C. Tec. Rep. TR-015/2002.

Weston, S., V. Stevens, and G. Butt. 2010. Quantifying Remote Northern Terrain Geohazards in a Changing Climate, Southeastern Yukon. Proceedings, Geohazards V. Kelowna, B.C.