Incorporating Geotechnical Investigations to support reclamation on resource projects

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ABSTRACT
Integration of geotechnical drill logs and drill data into terrain and soils mapping provides a powerful tool in reclamation planning for industrial development. For large resource projects such as pipelines and mines, reclamation planning commonly includes baseline soil and terrain mapping to inform reclamation aspects such as soil salvage and terrain stability planning, and geotechnical drill logs provide detailed information on soil depths and assist refinement of terrain mapping in terms of depth to bedrock and surficial materials. Geotechnical drill logs are imported into geographic information systems (GIS) and cross-referenced to terrain maps. Surficial material depths are modelled across the project development area and soil salvage volumes are calculated using drill log depths. Quantifying permafrost and accurate hazard mapping in areas of permafrost can rely heavily on both fieldwork and geotechnical drill logs to identify areas of potential permafrost geohazards and their potential impact on resource infrastructure and reclamation. Examples of project work that uses geotechnical logs for data and model verification are presented for areas of complex geohazards, permafrost hazards and deep organic soils.

RÉSUMÉ
L'intégration de données de forage géotechniques à la cartographie des dépôts de surface et des sols constitue un outil efficace dans la planification de la réhabilitation de site de projets d'exploitation de ressources naturelles. La planification de la réhabilitation d'anciens sites miniers ou d'oléoducs, nécessite généralement la cartographie des dépôts de surface et des sols. Ce type de cartes fourni de l'information en lien avec certains aspects de la démarche de réhabilitation, tels que la planification de la récupération et de la stabilité des sols. Pour leur part, les données de forage géotechniques fournissent de l'information détaillée sur l'épaisseur des sols, et permettent de raffiner la cartographie des unités de terrain quant à la profondeur du socle rocheux et la nature des dépôts de surface. Les rapports de forage géotechniques sont importés dans un système d'information géographique (SIG) et les données sont y sont croisées avec la cartographie des unités de terrain. La profondeur des différents matériaux de surface est modélisée à partir des données de forage, permettant ainsi le calcul des volumes de récupération des sols. La quantification du pergélisol et la cartographie des risques dans les zones de pergélisol peuvent être appuyées à la fois par des données de terrain et des données de forage géotechniques afin d'identifier les zones potentielles de risques géologiques liés à la présence de pergélisol, ainsi que leurs impacts potentiels sur les infrastructures associés à l'exploitation des ressources et sur la réhabilitation de site. Des exemples de projets utilisant des données de forage géotechniques dans le processus de validation des données et des modèles sont présentés pour des secteurs comportant des risques géologiques complexes liés à la présence de pergélisol et de sols organiques profonds.

1 INTRODUCTION

The success of resource extraction projects is not only based on the financial success of the project, but also the successful reclamation and closure of the project. Reclamation planning starts at the initial design phases, by incorporating baseline environmental data, mine design, regulatory requirements and end land-use goals into a comprehensive closure plan. Reclamation planning utilizes data from all aspects of a project – terrain studies, geotechnical drilling programs, groundwater studies and final mine design to predict the final landscape conditions that require reclamation. Geotechnical studies play a key role in assisting reclamation programs by providing extensive data on the physical and chemical properties of the subsurface sediments.

The key to reclamation planning is accurate baseline information and mapping that combines data on surficial materials, soils, soil and rock geochemistry and vegetation with subsurface data from geotechnical investigations. This baseline mapping allows reclamation staff to determine the volume and quality of soil and surficial materials available for salvage, to identify stable areas of soils storage, supplies of organic materials as a source of soil amendments and to mitigate permafrost hazards and geohazards such as landslides and gully erosion. Accessing both surface and subsurface greatly enhances the baseline mapping and helps develop a robust reclamation plan.

2 RECLAMATION PLANNING

A major component in reclamation planning is the assessment of reclamation material which includes soil/ surficial materials and overburden material. Drill logs and soil samples taken during trench and drill programs will help determine the potential of the sampled materials to be used as soil cover material. In order to use the material, it has to meet root-zone suitability criteria and as well as provincial and national metal concentration standards (AAFRD 1987). This suitable material must be in sufficient quantities to fully reclaim all areas disturbed by project activities, including roads and ancillary facilities. Some minor modifications of sampling and data collection can be made to geotechnical drill and sampling programs to meet the needs of reclamation overburden characterization as well as engineering data requirements.

Drilling and trench programs that record surficial materials, textures and depth to bedrock and provide samples at key material depths become instrumental in reclamation material handling decisions. As well, geotechnical design for stability of the landscape at closure ensures a solid base for reclamation activities.

3 SURFICIAL MATERIAL MAPPING

For the purposes of reclamation planning, surficial material refers to the upper one to three metres of sediment on the landscape as interpreted by aerial photo interpretation and field work. Surficial material is part of terrain mapping that defines landforms Surficial material mapping is commonly completed as part of the initial studies in a resource extraction project to define overburden materials at the landscape scale. Landform interpretation is completed using three-dimensional aerial photography on hard-copy photos, or more commonly, digital mapping using orthorectified photos projected into three dimensions in a geographic information system (GIS) program such as ArcGIS-based PurView™. Terrain polygons are digitally delineated by landscape characteristics including interpreted surficial material, drainage, aspect, slope, vegetative indicators and geohazards. Polygons should be homogeneous but can include more complex areas of terrain such as headscarps and deposits of landslides. Terrain polygons are field-checked for accuracy and the mapping can be used for site design such as routing of access roads, location of tailings storage facilities, or pipeline crossing locations. As well, surficial material and terrain mapping can be used for reclamation planning by interpreting the depths of surficial materials and quality of the materials for soil salvage.

Terrain and surficial material field programs typically rely on hand dug soil pits that may reach a depth of up to two metres. While a great deal of information can be collected from these pits, the conditions at depth are interpreted through aerial photo interpretation and an understanding of glaciated and non-glaciated landscapes. Drill programs, both geotechnical and exploration, can be used to provide more information on subsurface conditions not collected during field programs. In some areas, such as the mountainous regions of British Columbia, the quantity of available good quality surficial material for salvage is limited due to shallow surficial materials typical of steep slopes, or thin soils on shallow bedrock. Determining accurate depths is key to accurately mapping these sediments. In cases where surficial materials are limited, lower quality surficial material is salvaged and amended with organic materials and fertility to improve soil productivity, so incorporating as much available data as possible is key to meeting soil volume requirements.

Through the initial exploration and geotechnical design phases, geotechnical drill logs and subsurface investigation information can been incorporated into the terrain mapping by importing the logs in GIS and cross-referencing the data with the interpreted terrain mapping. The goal of the cross-reference is to refine depth to bedrock interpretations, surficial material thicknesses and textures and coarse fragment content of the materials (Figure 1). As well, petrographic logs from oil and gas exploration can be used to map surficial material depths (Hicken et al. 2008).

Figure 1. Glaciofluvial deposit with sandy loam texture but high coarse fragments limits the reclamation suitability. Geotechnical drill logs can provide this type of information for the entire depth of the drill core.

2.1 Terrain Stability

Terrain stability assessments are an important 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.

Each project will develop its own terrain stability rating framework depending on the characteristics of local terrain (Rollerson et al. 2002). 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). The framework is further refined through fieldwork and site observations, and should be considered a living document through the life of a project.

During baseline mapping the level of detail of mapping may be such that areas of stable ground adjacent or between unstable areas may be “lumped” with areas of instability. This can restrict the options for routing for planners, especially in mountainous or rolling terrain. By incorporating geotechnical data into GIS mapping, the stable and unstable areas can be better refined (Figure 2).

Conversely, the terrain mapping can provide operational information on the accessibility and safety of further drilling programs, such as screening potential drill pads for unstable or steep terrain. In British Columbia, no roads can be constructed on unstable terrain (BC MEMPR 2009), so the terrain mapping can play an important role in planning drill programs.

Geotechnical data can also assist in characterization of the type of instability that could arise, such as a deep seated slump or a shallow bedrock failure. Geotechnical drill information can also help in the design of stable resource roads through a similar use of data – depth to bedrock, characteristics of the surficial materials at depth will assist in determining if a road will be constructed as a full bench rock-cut or wholly in sediment, or a combination of both. As roads require deactivation after mine closure, adequate design for stability of the road prism over the long-term is important. Managing the materials that result from road construction is also key for reclamation – salvaging good quality soil and including the road in salvage calculations will contribute to a successfully reclaimed landscape.

Figure 2. Geotechnical investigations assist in site planning, such as ensuring waste rock dumps are located on stable terrain away from unstable slopes.

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.

Geotechnical investigations can support terrain stability analyses on both naturally-occurring and man-made landscapes. Surficial material depths and characteristics, depth to bedrock and the inherent properties of the underlying bedrock, combined with surface information such as slope, drainage, and indicators of instability such as tension cracks, will assist in predicting if the landscape is prone to instability. Mine site design can incorporate this information for safe siting of ancillary facilities and soil stockpiles.

4 SOIL MAPPING

Soil maps at varying scales and complexity exist for much of agricultural areas of Canada. Many pipelines and resource roads in Western Canada are routed through agricultural areas due to favourable ground conditions – level to gently sloping open areas free of urban and commercial development. Infrastructure for mines including drainage pipelines and powerlines can be located on agricultural lands adjacent to mining leases. Protection of agricultural soils during pipeline and facility construction is largely based on surface investigations such as soil surveys and classification exercises, but geotechnical trench logs can play a role in soil mapping by providing subsurface information such as depth to bedrock that is not commonly attained through surface investigations.

Soil association mapping is commonly based on surficial materials, such as till (morainal material), glaciolacustrine, or glaciofluvial deposits and is further delineated by soil classification (CSSC 2014) and soil characteristics such as erosion potential, wind erosion potential and chemistry. Based on field data and soil mapping, reclamation suitability mapping is commonly developed, whereby soil horizons are assessed and assigned a reclamation suitability rating (for example, good / fair / poor). The depth of soil salvage is determined based on the reclamation suitability i.e. the thickness of the good quality soil horizons, and mapped across the areas of disturbance. Soil salvage plans are essential for reclamation planning as site reclamation and revegetation success is based on having a sufficient supply of good quality soil available, or a sufficient supply of amendments to add to fair or poor quality soils. Amendments include salvaged organic materials from wetlands (organic soils) or chemical fertilizers or geotextiles such as coconut mats. Trench and drill log data will help determine if the subsoils are suitable for amendment to produce a better quality reclamation material.

4.1 Organic Soils

During reclamation of resource projects, organic material is an important resource to conserve as it can be added to poorer quality sediments to improve the texture, fertility and organic matter content of the soil to improve reclamation success. Quantifying organic accumulations in wetlands or areas of seepage will allow planning for salvage and storage of large volumes of organics (Figure 3). The depth of organics can be difficult to determine from surface investigations that can only reach a depth of 1-2m by handheld auger. Combining surface and subsurface investigations, the volume and hydrologic nature of the wetland can be more accurately quantified and managed accordingly.

For pipeline construction, there is less emphasis on salvaging organic soils, since the majority of the backfill is imported to support the pipe. However, the wetland depths are used to refine the surficial material and soil mapping in order to increase the accuracy of the project mapping and alignment sheets.

Figure 3. Depths of organic materials in wetlands can be hard to determine through surface investigations alone.

5 OVERBURDEN MAPPING

In mining, overburden refers to deep deposits of sediments that overlie the mineral resource zone that are not blasted and are rather excavated (i.e. not bedrock), such as the material overlying buried coal seams. In pipeline or infrastructure development, overburden refers to the material excavated from the trench, also referred to as subsoil. With resource development, overburden is often assessed as part of the exploration and geotechnical drill programs (Figure 4) as it will be brought to the surface either through preparing for open pit mining operations or in pipeline construction where trench material brought to the surface. Overburden can provide a significant source of reclamation materials where there are insufficient soil salvage supplies, such as using overburden as a cover for large waste rock dumps.

Figure 4. The intensity of a drilling program plays a key role in accuracy of the overburden volume calculations for soil salvage

Geotechnical data helps screen for the suitability of the physical characteristics of the salvaged materials. As with surficial materials and soils, the information collected during geotechnical investigations, such as texture, coarse fragment content, and depth to bedrock, can be incorporated into the overburden management strategy and provide spatial confirmation of reclamation suitability for salvage. Geotechnical drills logs will provide depths of textural changes and material types which is invaluable to determining overburden salvage volumes (Figure 5). Drilling programs can provide information on the thickness and reclamation suitability of the overburden underlying wetlands and the depth to bedrock for soil salvage planning. However it is important for geotechnical staff and the terrain/soil staff to collaborate on what information is collected and how it is described so that it is useful to both parties, such as which textural and coarse fragment content descriptors or classes to use in drill logs.

Figure 5. Soil and surficial material samples collected from different depths to two metres. Note the difference in colour, structure and texture and how they change with depth. Each layer will have different characteristics that play into soil handling plans, especially on pipelines.

For a large mining project in mountainous British Columbia, soil association mapping completed using an existing terrain map comprised of polygons delineated on surficial material type and thickness, topography, drainage, slope and geohazards as a base map. Soil associations were correlated to the surficial material mapping and modelled across the landscape, taking elevation and biogeoclimatic zones into consideration. Reclamation planning for extensive waste rock dumps, tailings storage facilities and various infrastructure, such as the camps, determined the volume of soil salvage required to meet reclamation objectives at closure. As some areas of the project are located on steep terrain, the depth to bedrock varied from 0.5 metres to several tens of metres, and varied across the project footprint. In order to meet the required soil salvage volumes to fully reclaim very large waste rock dumps, both soil and overburden assessments were undertaken in order to identify as much suitable material as possible for salvage. The sheer volume of suitable material to be stored also required use of the terrain and terrain stability mapping to identify areas of stable terrain with no upslope geohazards where the stockpiles could be safely located.

5.1 Overburden geochemistry

While the physical characteristics of the overburden are important in determining reclamation suitability, the geochemical parameters of the material must be analysed as well. Overburden geochemistry refers to the chemical constituents found in sediments that can affect reclamation objectives, for example, naturally occurring metals that can negatively affect vegetative regrowth, and thereby interfere with reclamation success. The geochemistry of overburden can change with depth, as the geochemical signature will reflect for example, near surface soil chemical processes, and groundwater influences at depth and proximity to an ore body.

For areas of precious metal mining or coal mining, it is important to ascertain the concentration of these naturally occurring metals and elements that may exist in the soils and overburden as part of the reclamation suitability assessment. This is especially key for mining projects with naturally high background levels of metals such as aluminum, selenium, or lead, as there may be sufficient volumes of overburden with good physical characteristics to meet the reclamation objectives, but this material could exceed regulatory limits for metal concentrations for healthy vegetative regrowth and animal consumption (CCME 1999). The background levels of metals and other toxic parameters will vary across the project area and with depth to the ore body. For example, drill log samples can help determine the depths at which overburden is no longer suitable for salvage due to high levels of metals as metal concentrations are typically higher in the zones closest to the ore body.

Geochemical analyses will also assess for saline and calcareous soils that, while not as toxic as heavy metals, can still seriously inhibit vegetation growth. This geochemical data is often obtained through sampling of the geotechnical drill and trench samples is key to delineating areas suitable for soil salvage.

6 PERMAFROST MAPPING

Permafrost can present many challenges to resource extraction projects, through mechanisms such as subsidence, solifluction and stability management. Climate change presents further complexities to long-term design for pipelines and the associated infrastructure required by mines such as processing plants and construction camps. In particular, in areas of discontinuous permafrost, accurate permafrost mapping is a necessity for designing and building stable and safe pipelines and buildings. Geotechnical information such as drill logs, along with geophysical studies, will provide both spatial and subsurface information to determine how to manage for permafrost during all phases of a project lifetime.

A project located in the discontinuous permafrost zone in the Yukon, considered the option of using an 80km long concentrate pipeline from the mine site to a rail load-out area (Weston et al. 2010). Permafrost and associated processes such as ground heaving, thermokarst and solifluction was observed throughout the Project area, but was not ubiquitous in all sectionss of the corridor. Permafost presents engineering design and construction challenges, such as meltout or subsidence, but when climate change is factored into the long-term integrity management of the pipeline, predicting the long-term stability of the corridor becomes difficult. 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 subsurface geotechnical investigations can allow for accurate mapping to support engineering of a stable pipeline.

Another use of geotechnical drill information for characterizing permafrost is to assist in determining the drainage patterns of a project area. This information is key for site planning, construction and site drainage design and sediment and erosion control. The hydrology of permafrost can be complicated by shallow active layers that do not thaw uniformly during warmer months, and may result in a drainage surface that does not reflect interpreted surface drainage patterns (Woo and Steer 1983). This uneven melting can result in differential areas of surface drainage and seepage at depth. The depth of this active layer can be identified by both geophysical and geotechnical subsurface investigations and will help delineate areas of potential solifluction, melt-out and ponding for project design purposes.

Permafrost can also be used as a tool for reclamation involving waste management at sites where off-site disposal is financially and/or logistically prohibitive – by sealing waste in secured and engineered landfills, and burying those landfills in clean gravel or fill, the permafrost zone can be raised above the landfill, effectively freezing the waste and preventing issues with groundwater leaching. This method has been used during the reclamation of some Distant Early Warning (DEW) Line radar stations in Nunavut (Government of Canada 2013).

7 CONCLUSIONS

Incorporation of geotechnical data and subsurface investigations is an important step in successful reclamation planning for salvaging reclamation materials and handling overburden. Understanding the local stability conditions through accurate characterization of surface and subsurface materials and predicting how terrain stability will be affected by the project will inform site planning and assist in reclamation success.

Through terrain mapping, geohazard mapping, and soil mapping incorporating geotechnical data, effects to the environment can be mitigated and the reclamation planning will work to address known effects. The benefits of incorporating environmental and geotechnical data are two-fold: economic and environmental. Economic benefits can be derived from lowered reclamation costs associated with comprehensive and well-informed reclamation plans. Environmental benefits include meeting reclamation objectives and end-land use requirements and attaining successful project closure.

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