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Thirty years of revegetation experience at the Key Lake uranium mine in northern Saskatchewan

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Abstract

The Key Lake Mine is located within the Athabasca Basin in northern Saskatchewan and has been active as a mining and/or milling operation since the early 1980s. The mine site will undergo significant reclamation activities over the next one to two decades. Surficial soil in the area is dominated by erodible, well-drained, outwash sand with low nutrient levels. The climate is cold and dry, meaning plants must be cold-hardy and drought-tolerant. Vegetation is also the primary means of erosion control. Re-establishing vegetation on reclaimed areas is challenging, but is also critical to the long term success of reclamation. Early efforts at revegetation focussed on replanting the climax vegetation (typically jack pine) directly to recreate the forest. The methodology evolved over time to combine seeding of grasses with tree planting; this was more successful, but was still not achieving the goal of regenerating the forest.

Observations of the initial stages of natural succession on waste rock piles have suggested that revegetation should begin with pioneer species such as mosses, lichens and shrubs. Creating suitable micro-topography for the introduction and establishment of key pioneer species, and taking advantage of available sources of nutrients and soil amendments can propel the revegetation process onto a trajectory of ecological succession and natural reforestation. Recently, Cameco has adopted a multi-disciplinary approach to revegetation efforts. This paper provides a brief description of our efforts to take advantage of the available resources (local plants, soil amendments) to facilitate the revegetation process.

1 Introduction

Uranium mining in northern Saskatchewan has provided a significant contribution to the economy of the province for more than 40 years. Additionally, the Athabasca Basin will continue to be a major source of uranium for the global nuclear industry for decades to come. As of the start of 2011, there were 65 reactors under construction globally, and it is estimated that there will be an additional 104 reactors coming online by 2020 (Cameco, 2011), creating a need for development of future uranium mines. To ensure that the uranium mining industry remains viable and sustainable, it will be necessary to progressively reclaim existing and future mines, adhering to provincial and federal regulations regarding reclamation. Revegetation is a major part of the reclamation process. Revegetation of disturbed areas can be challenging at these northern sites. Given that the natural soils are derived from a sandy parent material, they are typically coarse textured (sand and gravel) with limited moisture storage capacity and low levels of soil nutrients, primarily as a result of low organic matter content.

1.1 Site description

The Key Lake Mine site is located at the southeastern margin of the Athabasca Basin in northern Saskatchewan, as shown on Figure 1. The climate of the area is characterised by short, cool summers and extremely cold and dry winters. Average temperatures are typically below freezing from November through April. Environment Canada data collected from 1971 to 2001 (Environment Canada, 2010) show average annual precipitation of 481 mm, with 73% of this falling in the summer months of May to October. Lake evaporation at Key Lake has been estimated at between 365 and 460 mm, by pan evaporation and empirical methods respectively (CanNorth, 2010).

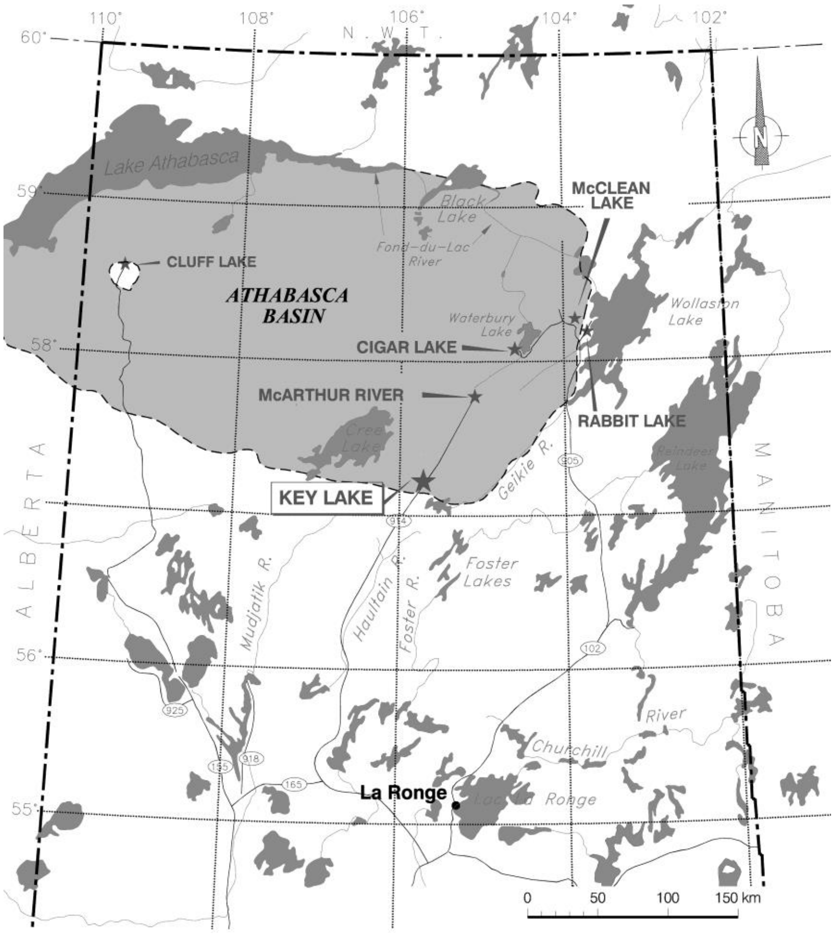

Figure 1 Key Lake location map

The surficial sediments consist of glacial deposits derived from the underlying sandstone and thus are dominated by sandy tills that contain trace to some fines (silts and clays) and relatively uniform outwash sands (Bayrock, 1977). The bedrock is composed of sandstone from the Athabasca Group, which unconformably overlies granitic and metamorphic basement rock. The majority of uranium deposits found in the Athabasca Basin occur at this unconformity between the sandstone and basement rocks. Therefore, most waste rock piles from mining operations in the Basin contain a mixture of outwash sand, till, sandstone and basement rock, usually in reverse order of deposition as a result of the mining sequence (i.e. basement rock and sandstone overlying outwash and till).

The Key Lake site was home to two ore bodies; the Gaertner and the Deilmann. Mining of the Gaertner ore body began in 1982 and was completed in 1987. The Deilmann ore body was mined from 1984 to 1997. A total of five waste stockpiles were generated from the mining process, as illustrated on Figure 2. The Gaertner waste pile consists of non-mineralised sand, sandy till, sandstone and basement rock. The Deilmann South waste rock pile (DSWRP) consists of sand, sandy till and sandstone material, while the Deilmann North waste rock pile (DNWRP) pile contains all of these materials plus basement rock. The Gaertner and Deilmann Special Waste piles consist of low grade mineralised sandstone and basement rock; these piles will be processed through the mill prior to final closure. All of these disturbed areas will require reclamation and need to be revegetated.

There is no longer active mining occurring at Key Lake; however, the mill continues to operate, processing uranium ore from the nearby McArthur River Mine. Cameco anticipates that ongoing reclamation of disturbed areas will continue during operations with a focus on reclaiming waste rock piles over the next two decades.

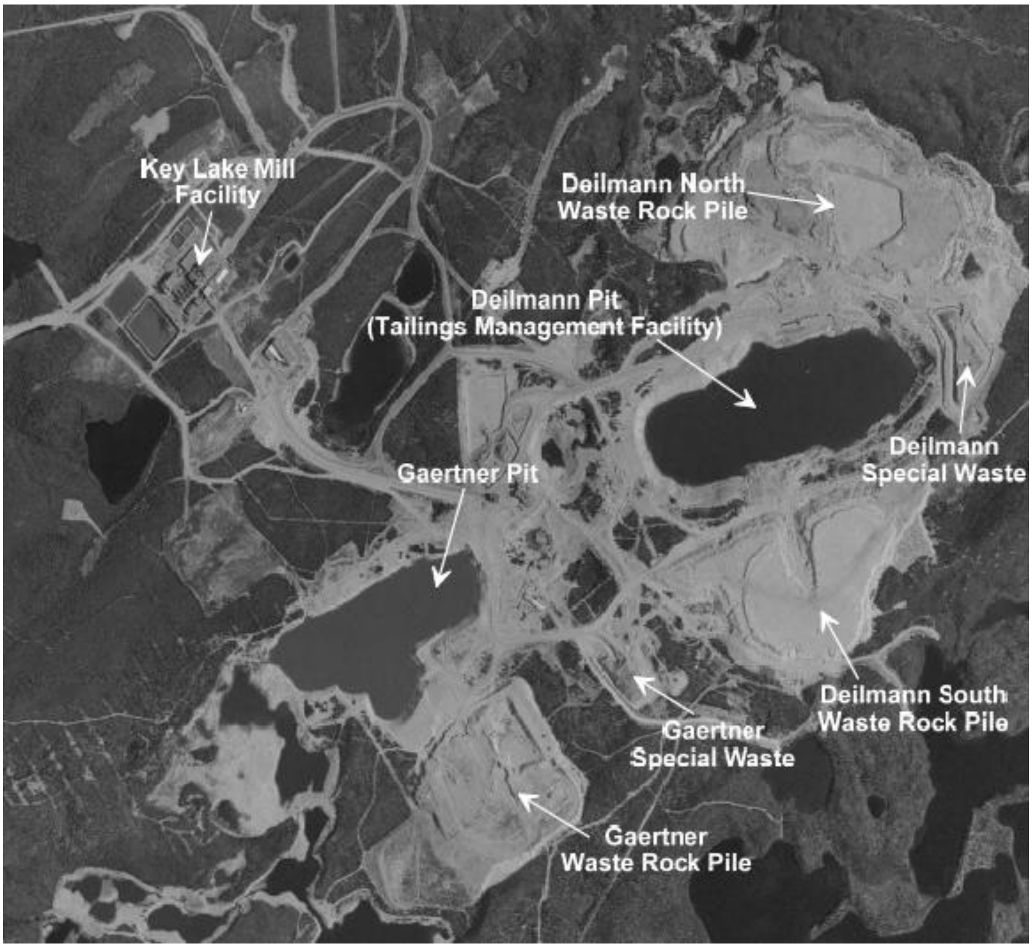

Figure 2 Key Lake site plan

1.2 Natural vegetation

Characteristic natural overstory vegetation found in the Key Lake area is comprised primarily of jack pine (*Pinus banksiana*), with small stands of black spruce (*Picea mariana*) being present in lower slope and depression areas. Trembling aspen (*Populus tremuloides*) is also present, but is sparse and is usually intermixed within the dominating jack pine stands. The characteristic natural understory vegetation consists mainly of blueberry (*Vaccinium myrtilloides*), bearberry (*Arctostaphylos uva-ursi*), mosses and lichen. Soils consist of a sand substrate overlain by a shallow duff layer consisting of woody debris and needle litter. This organic horizon (also known as LFH (litter-fibric-humic)) found in undisturbed sites in the region is less than 5 cm, and commonly 1–2 cm in thickness. The *Field Guide to the Ecosites of Saskatchewan's Provincial Forests* developed by Forest Service of the Saskatchewan Ministry of Environment describes the Key Lake area as a BS3 Ecosite (McLaughlan et al., 2010). This type of ecosite is common within the boreal shield ecozone. This natural disturbance dependant ecosite type relies on forest fire to assist with the propagation of overstory and understory vegetation. Without the influence of forest fire, the serrotinous jack pine cone would have difficulty opening allowing for the dispersal of viable seed. The typical fire cycle in this ecozone is 50 to 150 years.

1.3 History of revegetation work at Key Lake

The first experimental or test work on revegetation at the Key Lake site began in 1978. Since then, there have been many programmes aimed at improving revegetation success. The early objective of revegetation work was to “restore vegetation to areas where it has been removed” (Cameco, 1989). This consisted of sowing grass or planting jack pine seedlings. The test work was well-intended; however, the majority of the testing was empirical-based and results were not always repeatable.

After limited success, a more rigorous attempt was made to improve revegetation efforts. From 1993 to 1998, an experimental tree planting and grass plug trial programme was implemented (Haji, 1999). The progress of the planted trees and grass plugs were monitored over several years using a more scientific method. The monitoring programme included:

- Assessment of growth vigour. The height and width of the seedlings and grass plugs were measured for statistical analysis and a subjective assessment of seedling vitality was made.
- Gauging the effect of slope aspect on the success of tree planting.
- Assessment of seed viability. Greenhouse trials were conducted to evaluate the germination and emergence of the seeds prior to field trials.
- Assessment of direct seeding of jack pine and native grass seed.
- Evaluation of methods for revegetating sloped areas with a combination of hydro mulch, grass plugs, jack pine, willows, balsam poplar and birch.

The overall success of the re-greening programme at Key Lake was monitored over the following years. Assessments were conducted in 1999 (Golder and PPS, 1999) and in 2002 (Golder, 2002). Golder and PPS (1999) gave a detailed assessment of the progress of the vegetation trials. The important observations from this assessment were:

- The creation of micro-environments (e.g. ridges, cleat furrows) was beneficial for seed germination.
- Nutrient deficiency was the most severe plant growth limiting factor.
- Plants grown from seed native to the Key Lake region, performed better than plants grown from standard commercial seed mixtures.
- Jack pine seedlings exhibited better growth under conditions where they are protected from the wind and physical disturbance (e.g. windblown sand).
- Grasses flourish initially, but begin to recede after about three years or when the supplied nutrients begin to run out. The grass provides a protective cover to prevent sand drifting with consequent damage to jack pines in the first few seasons.

The Golder (2002) assessment included only a general site inspection of the same set of plots and included the following broad observations:

- There was a noticeable increase in moss and lichen cover over the three year period since the 1999 assessment.
- There was an apparent positive relationship between the health of the moss cover and health of the planted jack pine seedlings.
- Extensive ground covering by graminoids (grasses) appeared to impair jack pine seedling growth and reduce over all species diversity especially endemic species such as moss, lichen and blueberry.
- Blueberry plants appeared to be an efficient early coloniser on a variety of disturbed sites.
- Willow was frequently naturally colonising.
- Die-back and signs of stress on jack pines, to varying degrees, were noted throughout the sites inspected.

It was noticed during these assessments that the natural mosses provided erosion control, created a matt that would act as a sort of sponge or store-and-release cover for water storage, and increased organic content.

Where there was continuous moss cover, or at least an occurrence of healthy moss, jack pine seedlings were generally doing well. Conversely, where moss was absent and graminoids tended to be more abundant, jack pine seedlings often appeared stressed or showed sign of die-back. They speculated that there may be a symbiotic relationship between moss and jack pine trees, and the presence of moss enhances tree survival and growth. However, it was cautioned that the absence of moss cover and poor health of jack pine trees in a specific area may be related to other factors that simply impair the growth of both species. It was hypothesised that the graminoids had a competitive advantage over the jack pine trees for growth resources (e.g. water and macronutrients).

Nutrient deficiency was related to the low organic levels in the soil, as well as the poor moisture holding capacity of the sands. Therefore, nutritional amendment during the first three years was deemed critical for successful, sustainable revegetation.

Despite the observation that mosses and lichens appeared to enhance jack pine growth, there was no recommendation made to investigate the mosses and lichens. However, there were recommendations to cut back on fertiliser to limit grass vigour and use grass plugs on steeper slopes where grass seed did not seem to take hold.

Starting in 2006, a series of revegetation trials on the Gaertner waste rock pile were initiated. The focus of these studies was to determine the influence that surface texture has on the development of vegetation on reclaimed soils. Three plots were selected on the basis of material variety and surface conditions encountered on the pile. The three plots included:

1. An area consisting of hummocky terrain created by dumping of basement rock material. Surface material consisted of fine and coarse soil materials, as well as intact rock. This area is on the west perimeter of the waste rock pile.
2. An area known as “dimpled sand”, which consisted of low relief hummocky terrain characterised as a shifting sands environment where coarse sand material continually moves when exposed to winds.
3. An area of flat basement rock that was relatively level with poor drainage. For the trial programme, a bulldozer was used to create a hummocky landscape on the flat basement rock area. The result was an exposed heterogeneous mixture of fine and coarse soil, as well as intact rock.

The plant species used in the trial included awned wheatgrass (*Agropyron subsecundum*), slender wheatgrass (*Agropyron trachycaulum*), rough hair-grass (*Agrostis scabra*), redtop (*Agrostis stolonifera*), American vetch (*Vicia americana*), tufted hair-grass (*Deschampsia caespitosa*) and jack pine. Planting methods included direct planting of grass and tree plugs and hydroseeding techniques. Plots received pre-weighed seed and fertiliser application prior to being raked into the surface. Finally, the plot surfaces were covered with a mulch treatment (wood fibre) with a modified hydromulch process.

Initial findings from these plots (PPS, 2007) included:

- Site vegetation growth was limited by nutrition and elevated heavy metal soil content for vegetation growing directly on the basement rock.
- Fertilisation was required to ensure good plant establishment.
- The hummocky surface in the flat basement rock areas created micro-environments that allowed development of vegetation by providing protection from wind erosion.
- The dimpled sand area was limited by both water holding capacity and nutrient supply.
- The hummocky areas were able to support vegetation with careful management including provision of nutrients and introduction of species.

In 2007, two of the sideslopes of the Gaertner waste rock pile were flattened to slopes of 3H:1V and diagonal rips or break lines were constructed on the slopes using a ripper tooth on a large bulldozer. The slopes were then hydroseeded with a grass mixture similar to that described above. The purpose of the diagonal rips was to create micro-environments that were previously seen to have benefits for vegetation growth and preventing water erosion. The ripper-tooth technique was found to be simple and inexpensive. Initial findings from these diagonal slashes indicated that the method was effective in creating the desired micro-environments.

2 Recent observations and experience

Field observations over the last three to four years have led to a shift in thinking regarding the establishment of vegetation at Key Lake. It has been observed that on barren waste rock surfaces, several species of vascular plants are able to establish a toehold, including grasses, shrubs and tree seedlings; however, they are widely scattered and frequently fail to thrive or die-out after a few years. Mosses, on the other hand, are slow to establish initially; at first only small patches form. In the early stages, it can be very difficult to see the moss at all, as most of the plant is below ground and it will appear to be dead during dry periods. However, through natural dispersal of the moss spores, these clumps progress into larger mats that are able to colonise large areas. Figure 3 shows a large expanse of moss which has self-established on the surface of the Gaertner waste rock pile. Note that this is not the typical environment we associate with moss, this is an elevated, flat, dry area with no shade that is highly susceptible to wind erosion.

Figure 3 Moss cover on the Gaertner waste rock pile

One species of moss that appears to be particularly well-suited to colonising these barren expanses of sandy waste rock is *polytrichum piliferum*; however, other species, including *polytrichum juniperinum* and *bryum,* have also been observed.

Grasses seeded in advance of, or concurrently with tree planting, thrive quite well as long as fertiliser additions are made regularly; however, they usually die out within a two to three years after active fertilisation has been discontinued. Mosses have been observed to replace the grasses in these cases.

Erosion of the sandy Key Lake soil by wind or water is an issue for maintenance of roads and ditches, but it also affects the ability of vascular plants to colonise areas being revegetated. Once established, the moss is able to maintain a stable "cover". In fact, even under the extreme conditions of blowing sands, the moss is able to minimise saltation of sand from an area, while appearing to withstand some degree of burial by sand blown from elsewhere. Figure 4 shows the rhizoid system of a typical moss found at Key Lake. These root-like structures perform some of the same functions (water and mineral transport and anchoring of the plant). The moss forms a sod-like mat on the soil surface that holds together so well that it can be cut-out and picked up much like grass sod. The resistance to physical disturbance is illustrated in Figure 5. In this photo, two lines in the sand were drawn with a finger using the same force/pressure, the line on the left shows the loose erodible nature of bare soil. The line on the right shows the change in soil resistance in the presence of only a sparse moss cover.

Following the colonisation of an area by moss, it appears to be much easier for other species to become established as well. Figure 6 shows a constructed embankment slope that was finished in 1982. Initially, jack pine trees were planted over the entire slope. The jack pine survived for varying periods of time; however, it can be said that reforestation was not successful in this case. Today, as shown in the figure, this small portion of the slope is covered with mosses, lichens, shrubs (blueberry and willow) and a few jack pine seedlings. It appears that once the conditions are right, the trees will establish themselves. A jack pine forest is much more than just the jack pine trees, it requires the presence of forest understory plants in order to become established.

Figure 4 Rhizoid system of polytricum moss

Figure 5 Resistance to physical disturbance with (left) and without (right) a (sparse) moss cover

Figure 6 Embankment slope with natural colonisation processes underway

Given the observed benefits and importance of moss in the succession process, the ability to propagate mosses is essential. An internet search revealed that moss can be propagated very simply by breaking it into small pieces and spreading it onto the soil surface, with only surficial incorporation in the soil to prevent it being blown away. An informal bench scale trial (not described here) showed the simplicity and success of this method.

All of the above, more recent observations are consistent with the speculations made about the benefits of moss in the Golder (2002) report.

3 Developing a revegetation strategy

The 'lessons learned' from revegetation experience at Key Lake can be summarised as follows:

- A jack pine forest is a community of plants and other organisms that are symbiotic. These interdependent relationships can improve the moisture retention of the soil, create shade, improve nutrient availability (nitrogen fixing), instigate nutrient cycling, and provide erosion control.
- It is preferable to create the right conditions to establish the forest ecosystem and work with the natural succession process, rather than trying to apply standard agricultural techniques.
- A multi-disciplinary approach to revegetation is required. This should involve, at minimum, plant ecologists, micro-biologists, soil scientists, hydrologists and geotechnical engineers.

Provincial legislation in Saskatchewan (Saskatchewan Ministry of Environment, 2008) requires northern mine operators to restore mine sites to a condition that is similar to the conditions that existed prior to disturbance by mining operations.

To develop a revegetation strategy that will satisfy this objective and incorporate the 'lessons learned', a more holistic approach was required. Accordingly, a multi-disciplinary approach has been adopted by Cameco for development of reclamation and revegetation strategies, particularly in regard to waste rock pile reclamation. This approach requires coordinated efforts among the various scientific disciplines to ensure that all aspects of the soil-plant community are addressed. An understanding of the biological and micro-biological processes, soil physics and chemistry, hydrological water balance, and physical stability of the reclaimed landscape is essential to creating an ecosystem that will be on a trajectory toward a sustainable forest community.

In 2010, Cameco constructed an instrumented watershed on the DNWRP, for the purpose of monitoring the performance of a test cover. Two field trial covers were constructed on basement rock on the surface of the DNWRP. The cover trials were designed using an enhanced moisture store-and-release approach. They consist of 1.0 m (nominal) of local till material placed on the compacted waste rock surface. Additionally, a natural site in a nearby undisturbed area was instrumented to collect baseline information for comparison and assessment of the cover trials. The natural monitoring site (NMS) consists of a jack pine forest with a lichen/moss and blueberry understory, typical of the region. The cover trials and the NMS were instrumented to collect meteorological data and soil profile data (volumetric water content, matric suction and temperature). On the surface of the test covers, a revegetation study plot was constructed.

The overall objective of these cover and vegetation trials was to enhance available soil nutrients and soil moisture of the cover soils placed on the waste rock that will facilitate revegetation. To meet this objective: the vegetation trials will specifically be used to: evaluate the potential benefit of using various soil amendments for revegetation; evaluate two methods for transplanting a native moss species (*Polytrichum piliferum*) onto reclaimed soil materials; and, evaluate the transplant success of jack pine, bearberry, blueberry, birch, alder, aspen and willow onto these till materials. Details of the construction and current status of this revegetation study are outlined by Leskiw et al. (2011). Initial observations, however, indicate that the use of both naturally available and commercially sourced soil amendments have the potential to improve soil moisture storage and provide sufficient nutrients that will allow vegetation to thrive on the till material.

Cameco plans to use the experience gained through vegetation testing since 1978, as well as the results of ongoing experimentation to develop a guidance document for re-establishing vegetation on sites affected by mining operations in the Athabasca Basin of northern Saskatchewan.

4 Summary

Re-establishing sustainable vegetation at the Key Lake Mine site is challenging due to low nutrient levels and poor moisture storage capability of the native soils. Over thirty years of revegetation experiments and testing has been reviewed to develop new strategies and testing for revegetation of reclaimed soils at Key Lake. The objective of revegetation is to return the mine sites to a condition similar to pre-mine conditions.

Recent observations of waste rock piles at Key Lake influenced a change in thinking with respect to revegetation practises at the site. Specifically, the natural colonisation of native mosses on barren waste rock surfaces was observed to control soil erosion and allow other native plant species to recolonise disturbed areas.

A multi-disciplinary approach has been implemented to enhance our understanding of the symbiotic relationships that exist in the Boreal forest eco-sites in the Key Lake region. An instrumented watershed cover trial that incorporates a vegetation trial has been constructed on the DNWRP. These test plots will be monitored over time. Information gathered from these test plots in addition to the experience previously gained will be used to develop site specific guidelines for revegetation and reclamation of areas disturbed by mining operations.

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