Natural analogs for sustainable reclamation landscape design at Syncrude

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Abstract

Syncrude Canada Ltd is committed to providing a biologically self-sustaining, geotechnically stable, and maintenance free lease-abandonment landscape that has a productive capability at or above the predisturbance level, and erodes in harmony with the regional landscape. A philosophy being used in the design is that of creating a robust, mature landscape, that is, one which closely mimics geomorphologically mature features of the regional landscape. Such a landscape will have slow, relatively controlled erosion, and an inherent landform stability. The most significant aspect to long-term stability is control of the fluvial geomorphology of the reclaimed landscape.

In providing designs to be stable for hundreds or thousands of years, new approaches are required. For instance, designs must incorporate information from the study of local and regional landforms and landscape features using natural analogs and assessment of natural erosion rates. As well, long-term riprap durability becomes a greater issue, the effects of wildlife (and in particular beaver dams) and climatic change on the landscape must be considered, and an integrated hydrological, geotechnical, geomorphological, and biological approach must be used.

Introduction

Syncrude Canada Ltd. operates a large integrated Oil Sands surface mine and oil production facility at Mildred Lake, Alberta, approximately 40 km north of Fort McMurray (Figure 1). Syncrude's agreement for developing its Oil Sands Leases 17 and 22 includes commitment to provide a productive, self-sustaining, lease-closure landscape that is geotechnically stable and which evolves through geologic time in harmony with the regional landscape.[1]

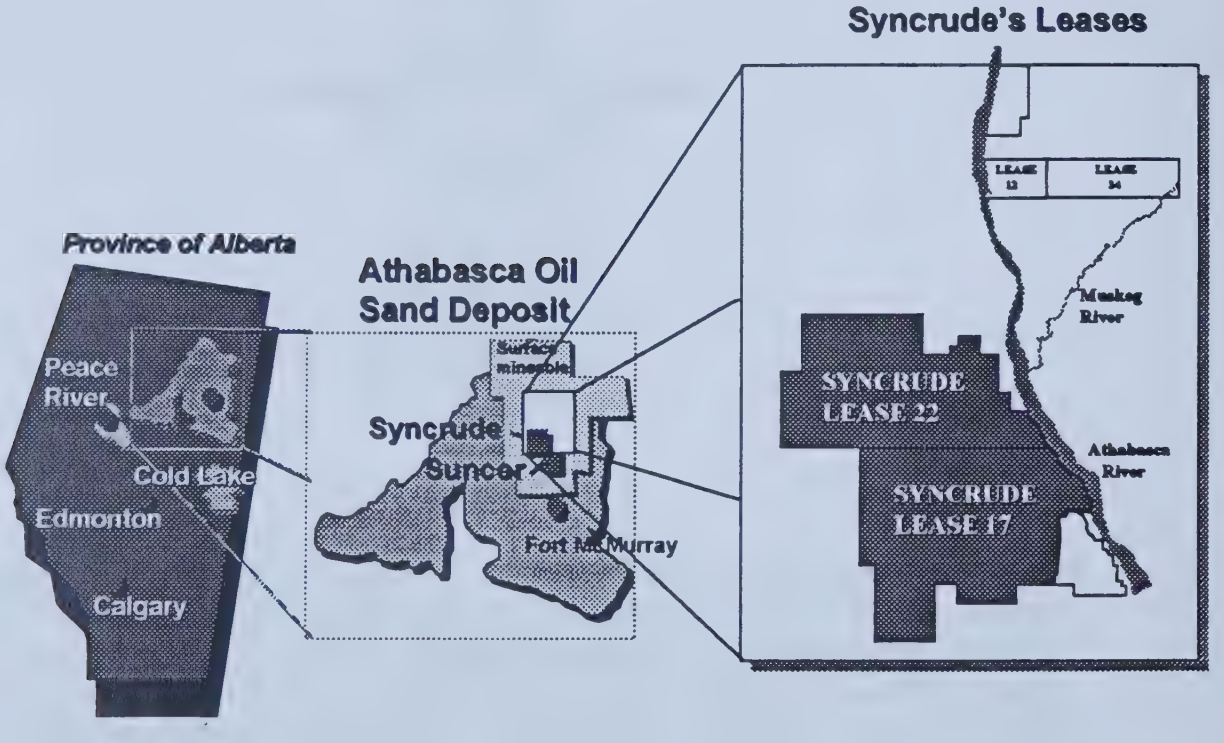

Figure 1
Location Plan

Traditionally, most mine designs have been largely dominated by production economics and geotechnical issues. Lease-closure issues have been relegated to the final years of production. More recently, greater attention has been placed on environmental issues related to lease-closure and incorporation of these issues in lease design before and during lease operation. Closure designs should include "preservation and protection of appropriate cultural, recreational, scenic, historic, and ecological values; control of erosion, slides, flooding and

pollution of water;... prevention of hazards to public health and safety; achieving harmony with the surrounding landscape; determining the best long-term use of the land so that restoration can be designed toward an appropriate end use."[2]

Some design criteria, by regulating agencies, may not be appropriate to create a sustainable lease-closure reclamation landscape. Instead, the landscape should be designed to mimic the natural one. Several philosophies have recently been developed to guide reclamation design including:

- creating a geomorphologically mature reclamation landscape
- creating a robust landscape — one which improves in stability with time
- creating a landscape which mimics natural systems in the area
- using best available demonstrated control technology (BADCT)[3] to insure best landscape design and construction to reduce long-term liabilities
- invoking a design-for-closure philosophy in which mine and tailings designers and planners work together with reclamation specialists to develop a sustainable final landscape

Adoption of a suitable design-for-closure plan is needed to ensure that the reclamation landscape will be maintenance free. The reclamation area of 18,000 ha is very large. It will contain erodible tailing sand deposits, lakes of fine tails (clay/fines water emulsion - 30% solids by weight) capped with water, 40 km of first order constructed streams, 200 km of second and third order streams, vertical relief of 200 m, and some slopes steeper than typically found in upland areas of the natural landscape. To ensure that these elements can work together in a sustainable landscape, careful planning and construction are required. In some cases, mine designs must be altered to fit the final landscape plans. This approach, presently being applied at Syncrude, requires considerable involvement from specialists in a variety of fields.

Regional setting

Syncrude Leases 17 and 22 are in the mid-boreal mixed wood ecoregion dominated by aspen and black spruce, with frequent white spruce stands and bogs. The area is flat to gently rolling with broad gentle uplands and deeply incised meandering rivers. Much of the upland area is heavily populated by beavers which generally have a moderating influence on creek-flows, natural

erosion, and sediment yields. In muskeg areas, very little overland flow has been observed as it has been found that most of the flow occurs as seepage through the muskeg. The large storage capacity of the muskeg results in attenuation of peak flows except when partially frozen.

The climate is temperate continental with long, cold winters and short, warm summers. During the winter, there is about 150 mm (water equivalent) of snowfall and rivers and creeks are covered with ice from about November until May. The mean annual precipitation at the Syncrude site is about 460 mm with about 75% of this precipitation returned by evapotranspiration, the remaining as runoff. Analysis of recent climatic and streamflow data shows that peak flows from all but the largest watersheds are controlled by intense summer rainstorms rather than by snowmelt events.

The bedrock geology of the Athabasca Oil Sands area has been described by many including Mossop[4]. Devonian limestone outcrops are found along both the MacKay and Athabasca rivers. The limestone is overlain by Cretaceous McMurray Formation (Athabasca Oil Sand) which is in turn overlain by Cretaceous Clearwater Formation marine clays and silts. Occasional 80-500 mm thick indurated "siltstone" layers are present in these Clearwater clays. The formations are generally flat-lying and continuous except where locally eroded by glacial or fluvial processes.

The surficial geology west of the Athabasca River, more specifically, at the Syncrude site, consists of thin Quaternary sediments such as glacial till, overlain by glaciofluvial sands, gravels, glaciolacustrine silts and clays as presented by Bayrock[5]. Much thicker Quaternary sequences cover uplands to the east and west[6]. The difference between these thicknesses is partially due to the Laurentide ice sheet retreating northward approximately ten thousand five hundred years before present (10.5 ka BP) depositing on-lap glaciolacustrine deposits and a paleoflood, 9.9 ka BP, scouring the low lying area around the Syncrude site. Locally there are Holocene alluvial and lake deposits and landslide colluvium. As mentioned above, extensive muskeg, up to 5 m thick, typifies much of the area.

The area east of the Athabasca River has markedly different surficial geology. The surficial soil is sand with occasional boulders and contains virtually no fines. This extensive sandy deposit is thought to be lodgment till or glacially overridden outwash deposits. Paleowind patterns have created sheet and dune deposits by reworking the sand. The resulting vegetation is much different in that jackpine is much more common, the forests are generally more open, spruce still fills most of the bogs, and large muskeg and organic areas are less common. Thus the character of the landscape is greatly affected by the surficial geology.

Syncrude Leases 17 and 22 include three significant watersheds including the MacKay River, Beaver River and Poplar Creek, and numerous small tributary creeks. To facilitate mining, the Beaver River was diverted in the mid 1970's into Poplar creek, and creeks that once flowed into the Beaver River are now intercepted and rerouted around the mine area (Figure 2). All other waters that either originate as runoff from disturbed areas, or are imported for use in the plant, are contained on site and recycled.

Figure 2- Beaver River Diversion around Syncrude's mine site.

Long-term design issues

In 1992, Syncrude began working on major drainage system alternatives for lease-closure based on the premise that the closure landscape would be maintenance-free. Some areas of risk were recognized and, as a result, studies were initiated, mostly in the areas of natural stream hydraulics and geomorphology, and regional hydrology. These studies are discussed in more detail later.

A geotechnical hazard assessment was conducted on various landscape alternatives and proved to be enlightening. One of the resulting philosophies being discussed is to adopt the "Best Available Design Control Technology" (BADCT)[7] in which designs are advanced to the best possible state with existing technology. Under this philosophy, each of the identified risk areas are investigated to a reasonable and practical level and the residual risks to the landscape are described as necessary. New risks may occur with time that were not foreseen in design and it must be assumed that natural replication will mitigate or reduce these risks. Such an example was recently observed on one of Syncrude's tailings structures. Pingo-like ice mounds where formed on a reclamation bench due to freezing of artesian seeps from the active structure[8].

For large reclaimed landscapes designed to be self-sustaining for hundreds to thousands of years, systems must be included that are adaptable to major rainstorms, fires, droughts, wind-storms, wildlife and human interference, climate change, and unfavorable combinations of these events. It is well known that steep unarmored slopes will flatten, planar slopes will gully, straight rivers will start to meander, immature convex-up reaches will become concave-up, lakes will infill and forest soils will undergo succession. Unplanned, rapid changes in the reclaimed landscape are not desirable. Such rapid changes could result in unacceptably high sediment loading of streams, gully scarring, and landslides. Instead, it is preferable to create a mature landscape, upon mine closure, so that the expected rate of change will be comparable to that of the reclaimed landscape in geologic time. Previous criteria for reclamation involving design recurrence intervals seem less appropriate than the design philosophy to build a robust and mature landscape by documenting and learning from natural analogs.

Streams and Rivers

Important natural analogs being studied are the natural streams and rivers of the area. Surface runoff, leading to major streams and rivers are the root of many hazards associated with the long term sustainability of the reclaimed landscape. It is imperative that the reclaimed, man-made streams flow into natural ones without jeopardizing the geotechnical stability of the lease-closure landscape. To provide continuity, these man-made streams must mimic the natural, more mature ones in the area. Otherwise these streams will be subject to excessive erosion in order to attain stability. Previous regulations that have required erosion protection and water conveyance structures to be designed for probable maximum floods (PMF), or a flood of a specific recurrence interval, may not be appropriate for designing a maintenance-free landscape. Designing based on natural analogs does not necessarily involve recurrence interval but rather mimics natural systems which may erode slowly during extreme events. The magnitude of 100-year and 1000-year events would be still considered in the design but only as guides to predicting long-term erosion rates.

Natural analogs have been documented by fluvial geomorphologists who have studied rivers worldwide and developed relationships between stream-flow rates, sinuosity, bed material, depth-to-width ratios, and slope. A reclamation design team has the ability to change most of these variables and can use published results to estimate stable regimes for all of these variables. Natural systems in the area allow verification of the applicability of the published regime relationships to the boreal forest area of Northeastern Alberta. Locally, two studies have been undertaken to determine properties of streams and rivers affecting Leases 17 and 22.

The first study involved examination of erosion rates and fluvial processes of existing natural streams on the Syncrude leases. Longitudinal stream profiles were created and results were documented. Most of these studies were based on existing contoured orthophotographs and knowledge of other Alberta rivers and creeks. It was found that most existing creeks and rivers are stable and unlikely to change significantly. Any stream which encounters the Athabasca River valley wall is subject to very slow degradation. The MacKay River, for example, is widening its valley at rates of about 2 m per century and downcutting about 0.2 m per century[9] (Figure 3). The lower reaches of this river may be considered to be geomorphologically immature as shown by the immature convex-up reaches of MacKay River (Figure 4).

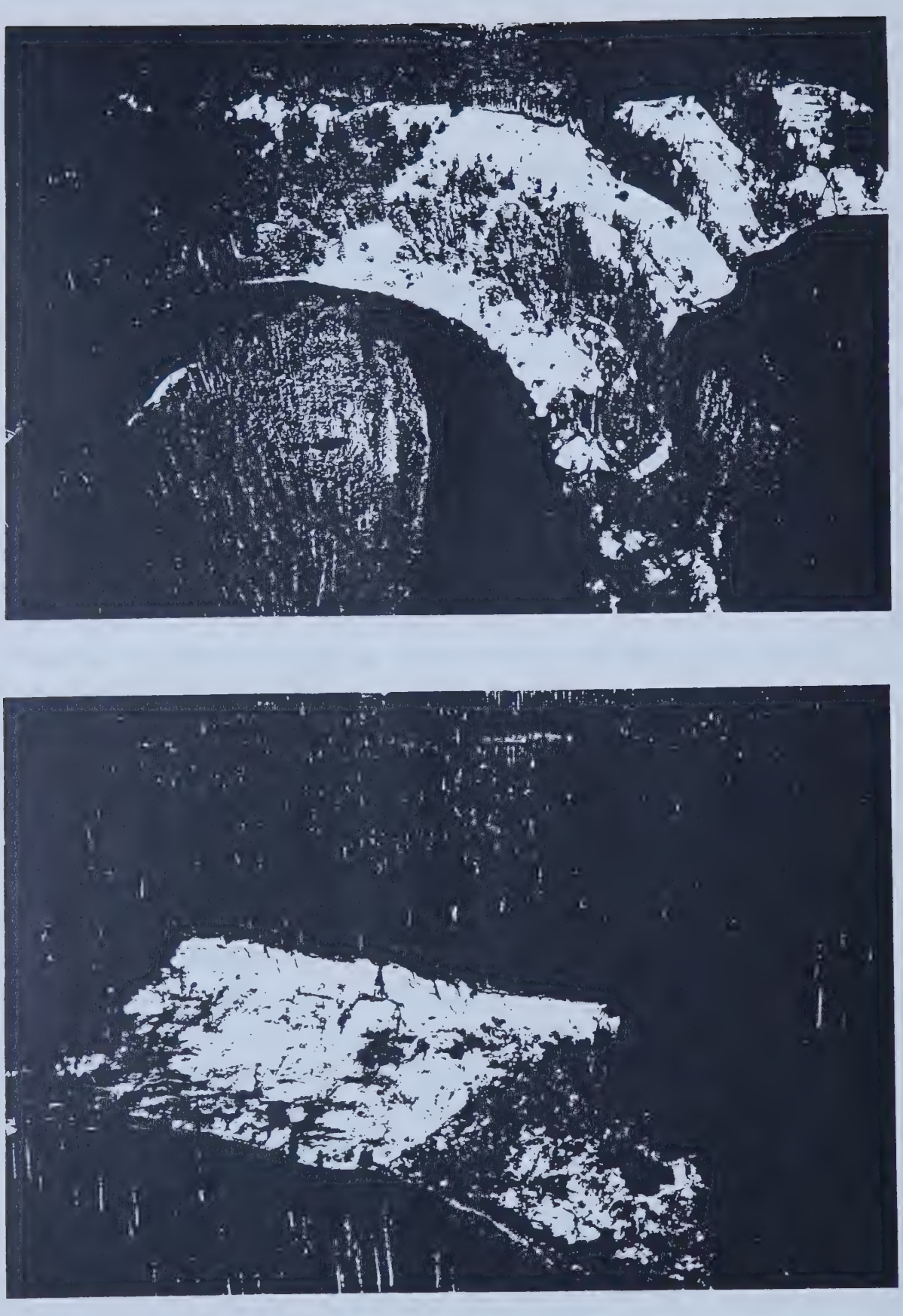

Figure 3 - MacKay River

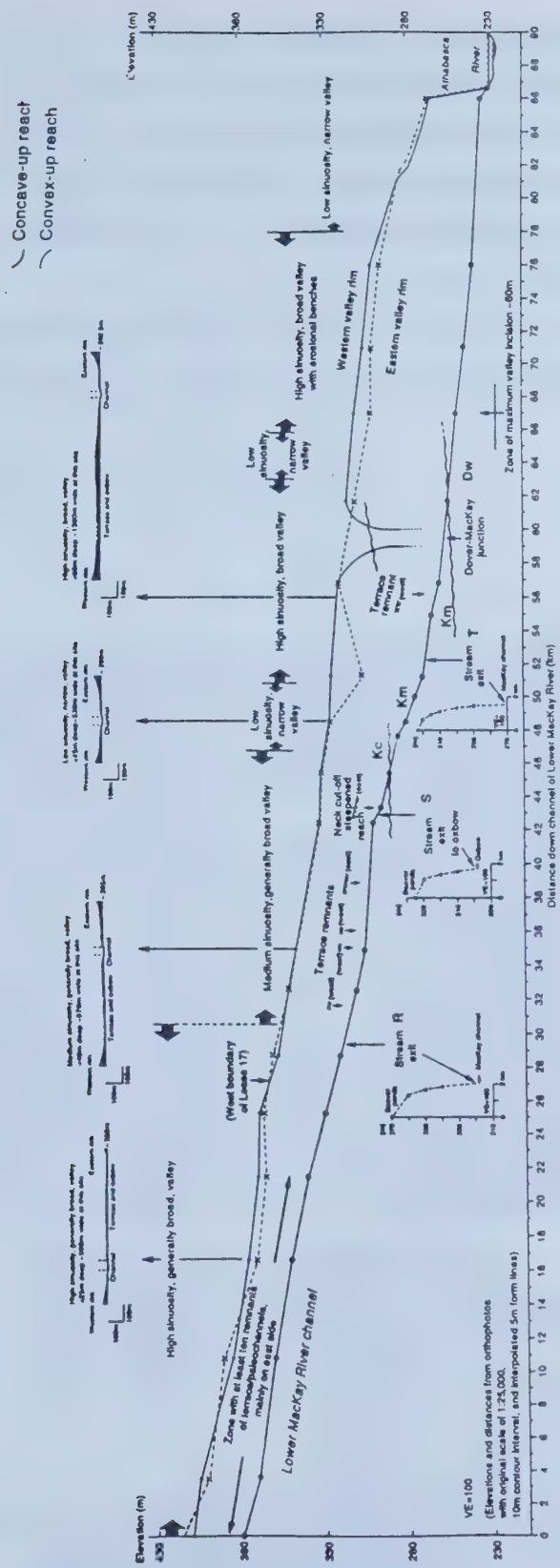

Figure 4 - Longitudinal profile of the MacKay River

A second study was initiated to document typical streams and rivers in the vicinity of the Syncrude site. This study included investigation of 40 different sites, some of which were located on different reaches of the same river or stream. Bedding material, typical cross-sections bedding slopes and meandering patterns where recorded and documented[10] (Figure 5). This information will be used to help in the re-establishment of areas to pre-disturbance conditions.

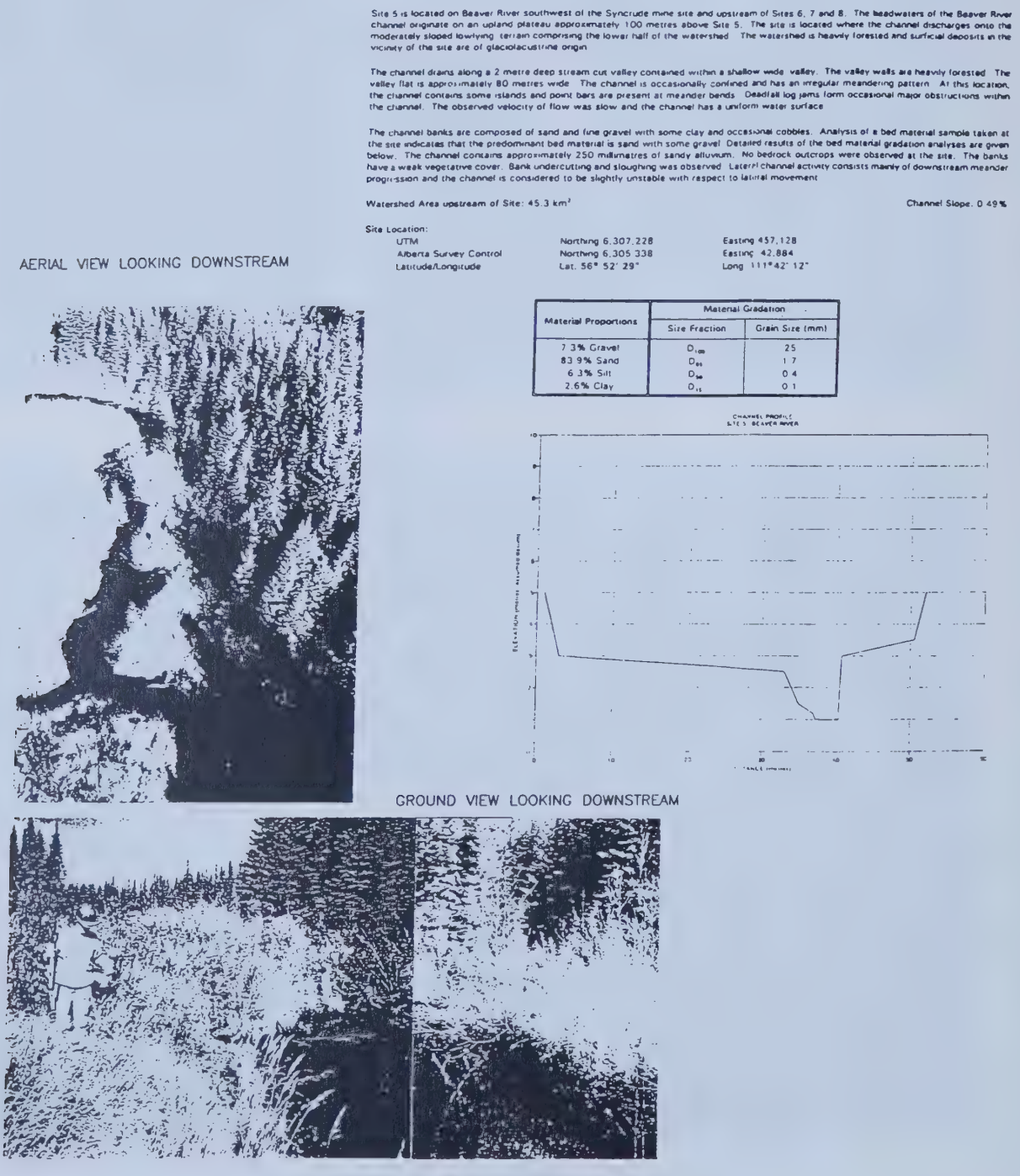

Figure 5 - Stream investigation summary sheet

The performance of reclaimed surfaces will affect the performance of the man-made streams. Relationships between pre-disturbance streams and reclaimed, man-made ones will be influenced by the difference in the characteristics of the basins they drain. Syncrude is monitoring runoff of some reclaimed surfaces and smaller undisturbed catchments by measuring streamflow (Figure 6). Syncrude plans to continue this activity for many years in order to collect a representative database. Syncrude also plans to test reclaimed streams made predominantly of clay and rock (know locally as bouldery ground) by monitoring erosion in response to a range of representative streamflows. This will establish relationships between natural and reclaimed streams and rivers.

Figure 6 - Streamflow monitoring station at Syncrude

The activities that involve undisturbed surfaces, such as documentation of natural streams and rivers and monitoring of runoff by measuring streamflow, should ideally precede development. This has occurred to a limited extent at the existing developed leases but is being implemented fully on the new Oil Sands leases. Climatic stations have also been installed on existing and new

leases. Monitoring includes precipitation, evaporation and snowfall in order to accurately measure localized precipitation events that would affect runoff and streamflow within regional watersheds.

Lake Design

Syncrude currently plans to construct two deep water-capped lakes and several shallow wetlands as part of the lease closure landscape (Figure 7). One of these deep lakes, intended as a demonstration lake, is currently being built and is scheduled to be fully operational by 2010.

Lakes are complex features involving beaches, littoral zones, thermo- and chemoclines, wave action, detrital layers, and islands. Although Syncrude's deep lakes will be different than regional lakes, some common features will exist. Examination of the biological aspects of regional lakes has been conducted and most recently the examination of topographic maps and aerial photographs, as well as flyovers of 29 lakes (with landings on 7) in the area have yielded valuable information about shoreline stability that could influence the design of the demonstration lake.

The development of littoral zones influences biological productivity, habitat and erosion control. Many lakes observed in Northeastern Alberta are less than 2 m deep, densely vegetated (100% littoral), and show little shoreline erosion. The wave forces are insufficient to dislodge the vegetation. The deeper lakes have a different mechanism of erosion protection. They have gravel and cobble shores and show capability of self armoring by exposure of the gravel, cobbles and boulders in the lakeshore soils (Figure 8).

Shoreline stability could be threatened by ice. Preliminary observations show that on the shallow lakes, the emerging vegetation is sometimes torn from the shoreline and pushed up on to the bank to create ice berms. This may become an issue, especially if breakwater islands are employed. Ice effects is an area not yet fully investigated.

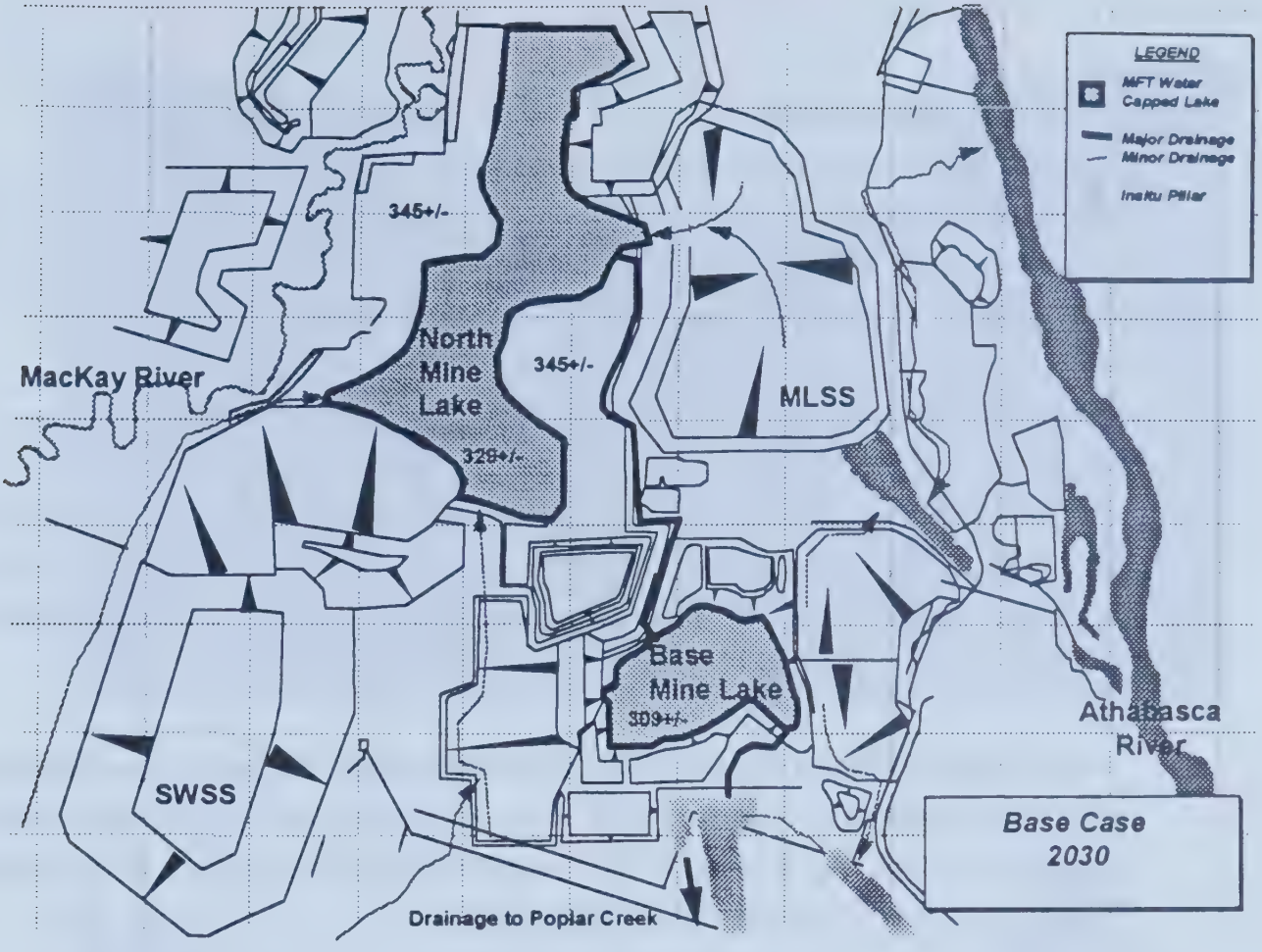

Figure 7 - A final drainage plan

Figure 8 - Shoreline protection of a deep lake near Syncrude

Beaver Dams

It is unrealistic to expect that all surface water flows will be fully contained. Beaver dams have the capability to divert streams to adjacent watersheds. This was documented at three locations along the MacKay river where beaver dams caused landslides due to increased elevation of water tables (Figure 9).

Most other erosion mechanisms are somewhat quantifiable but the beaver dam concentration will vary with a multitude of factors including available food source and population of beavers. Dams on creeks are common at the Syncrude leases. Approximately, 1000 beaver dams presently exist at the leases and will continue to do so after closure. Therefore Syncrude retained Alberta Environmental Center to help examine natural impacts from beaver dams on lakes, rivers and streams.

It was found that beaver dams have the potential to raise water levels by damming the outlets of lakes a short distance downstream of the outlet. Despite the fact that the forest cover and soils at the outlets of most natural lakes are not conducive to beaver dams, four of 29 large lakes within 80 km of Syncrude, are controlled by beaver dams.

Steep chute channels will be part of the lease-closure landscape and therefore beaver dams in gullies were also investigated. Beaver dams were found to reach heights of 3m (Figure 10) and where cascading failures occurred, there was evidence of bank erosion.

Nevertheless, the net influence of beaver dams is a significant reduction in erosion by trapping sediment and attenuating flows. On the basis of these preliminary results, lease-closure streams and lakes will be designed to accommodate beaver dams[11].

Figure 9 - Landslide along the MacKay River caused by beaver dams

Figure 10 - Series of 3 m high beaver dams around Ft-McMurray

Geotechnical stability

Fluvial geomorphology of creeks, streams and rivers was highlighted as the most important natural analog, as is precipitates erosion. However, the effect of erosion on geotechnical stability is also a significant concern. As mentioned earlier, a geotechnical risk assessment was performed on various landscape alternatives representative of different tailings disposal techniques. Certain "safety mechanisms" were recommended based on existing knowledge of gullying and bank failures. However investigation of related natural analogs is ongoing and will help validate and assess potential existing and future erosion development.

Erosion may be manifested as gullies, and as such, represents a failure mechanism potentially causing breaching of water and tailings filled lakes. Gullies in natural areas are the focus of an ongoing study to map their geological and fluvial nature and measure their rates of erosion. These will be compared with gullies forming on existing reclaimed areas.

Landslides are another form of instability observed frequently in Northeastern Alberta. In the Syncrude lease areas, approximately 100 active landslides were observed and documented on the MacKay River. Other major river valley slopes show evidence of past occurrences of landslides as well. The processes of landsliding and gullying are a natural part of the erosion process. They should be acceptable in the reclaimed landscape so long as breaching of tailings containment is avoided. Consequently, offsets from the MacKay River will be revised to provide more in-situ material between the river and any tailings containment (Figure 11). Barrier fills of 500 m to 1000 m wide with sufficient freeboard to permit settlements and erosion will be employed to insure geotechnical stability of water and tailings containment. A vegetated and armored low point in the lake barrier fills would serve to reduce all risk of lake overtopping, and would allow for a controlled relocation of the drainage path. This "emergency spillway" would reduce the risk of a catastrophic breach. Further, existing gullies could be strengthened using riprap and bouldery ground to slow initiation and development of future gullies.

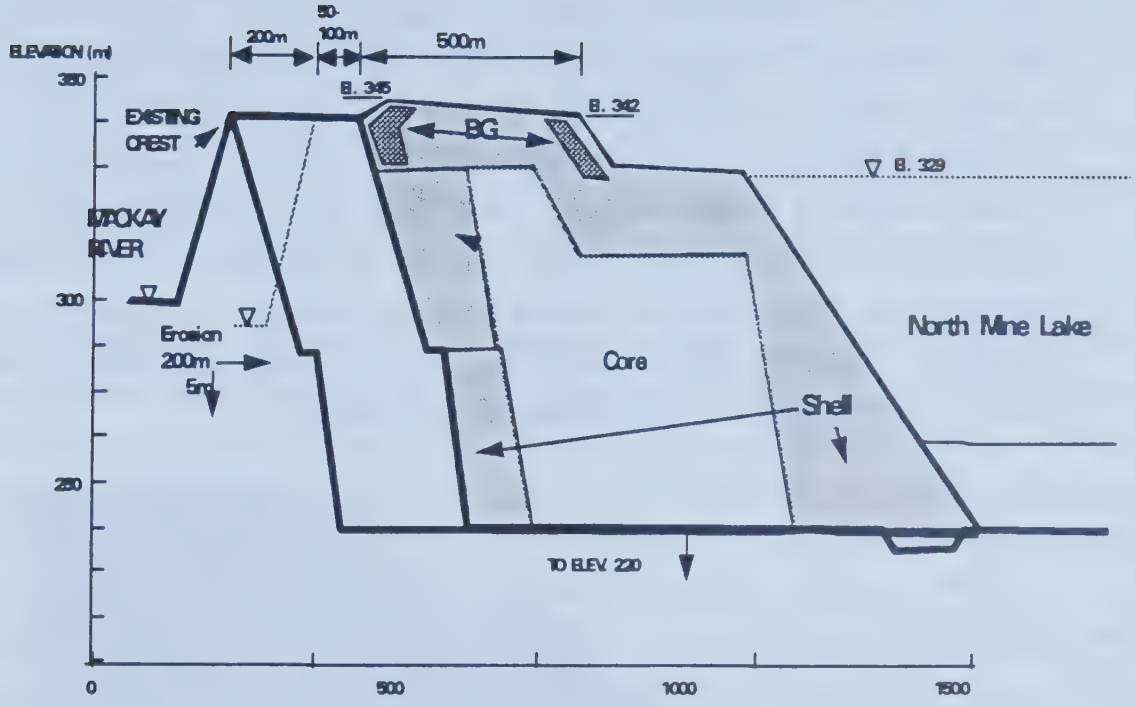

Figure 11 - Cross-section through the North Mine showing revised offset from the MacKay River

Bouldery ground has been mentioned for use in establishing the robustness of streams and rivers, lake shoreline and gullies. A robust landscape design is one which is inherently stable despite inevitable evolution over geological time frames. Tailings which consolidate and increase in strength with time are robust. Overburden dumps which have decreasing pore-water pressures are also robust. Finally streams, lake shoreline and gullies that contain this bouldery ground within the bank and bed materials will self-armor and become more stable as erosion occurs. The main components of bouldery ground would be clay and rock. Studies have commenced on the rock types that could be used. The tills are mostly composed of weathered Oil Sand and shale and are characteristically fine grained and have low rock content. Deposits of gravel are relatively rare and already exploited for operation. There are however, within the Oil Sand and more importantly in the Clearwater Formation overburden, numerous siltstone layers which may be used as the rock

component of the bouldery ground. Freeze-thaw weathering of these siltstones is under investigation.

Aeolian erosion

Over 50 km² of landscape will include tailing sand structures. They will rise to 60 m over the natural, undisturbed topography making them susceptible to wind and water erosion. These areas are being capped with soil and planted. There is a concern for aeolian erosion creating gullies in the tailings sand and that further windblown deposits may affect vegetation in other areas leading to more-widespread aeolian erosion. Areas east of the Athabasca River consist of stable vegetated dunes and sandsheets (Figure 12) with the exception of two areas to the northeast which have active dunes. Studies of these areas are underway, particularly to investigate the role of emergent vegetation and it's stabilizing effects on sand structures. There is evidence of vegetation stabilizing gullies and lessening further erosion

Figure 12 - Vegetated Sand Dunes

Post-closure monitoring

Syncrude recognizes that the reclaimed landscape will be subjected to unrestricted access for road building, logging, hunting, fishing, recreation and future development. A maintenance agreement with the government or third parties would be subject to changes in these organizations as most governments and other organizations historically have short lifespans. Therefore, apart from a planned post-closure monitoring period, on-going maintenance is not part of the Syncrude design. If however, maintenance was to become an option, even over a fixed period, small fix-ups and changes at key times could minimize the effects of erosion and geotechnical instability.

One might not expect all aspects of the reclaimed landscape to accomplish the design objectives upon commissioning. Therefore two timely elements are in place. First, as mining continues, areas are reclaimed and monitored providing an opportunity to study the effects of nature on the landscape and to allow for repairs during operation. Second, the post-closure monitoring period will allow minor changes to the landscape based on years or decades of further monitoring prior to final signoff. By lease-closure, in approximately 2035, Syncrude will have 50 years of performance data for some reclaimed areas. This data would include, for example, tree growth, erosion, release-water quality and streamflow. Syncrude is presently developing, with regulatory consultation, lease sign-off criteria for this post-closure monitoring period.

Economics

Ultimately, any design must take into account economics of the resource development including capital and operating costs, cash flow, and material availability. If the design of the reclamation landscape were left until the declining years of a project, the costs would be excessive and the final landscape sub-optimal.

Findings to date suggest that the improvements required to assure long-term stability are often a question of working smarter versus working harder. This could be accomplished by diverting specified overburden, necessary for long-term landscape development, to certain locations for little additional cost over transport to waste piles. In addition, there may be enhanced mining or tailings practices which could provide better reclamation designs. For example, in-situ pillars

could be left to reduce the risk of a lake breach, slopes could be designed at an angle that is attractive for reclamation, and out-of-pit dumps could be strategically located for optimal lease drainage patterns. Natural analogs would be one of many necessary tools to influence design. There are inherent trade-offs — how should money and effort be divided between various reclamation activities? From a societal perspective, how much effort should be put into reclamation, and how should it be balanced to protect against short-term versus long-term risks? The hazard assessment identified difficulties involved in assessing low probability with high consequence events (such as a breach of a tailing or water retaining structure) or low annual probability extended over millenniums. It is difficult to evaluate the acceptability of catastrophic events even in the far future. It was therefore found that the best concept in evaluating various development plans is to list the economic issues from inception to closure and the qualitative ratings of the hazards associated with each plan.

Summary

Designing for closure is now mandatory in all jurisdictions in Canada. Conventional criteria for reclamation are less appropriate for large reclaimed landscapes which need to be designed to be self-sustaining for hundreds to thousands of years. Instead, the design philosophy of building a robust and mature landscape based on natural analogs is a more reasoned approach.

The design of the mining and tailings systems must be conducted in close collaboration with reclamation planning to minimize short and long term risks while remaining economically attractive. The reclamation plan must be dynamic so that it can adapt to new information available from the natural environment, experience at reclaimed areas, changes in mine plans, introduction of new technologies and acceptance by stakeholders and regulators. It is important, throughout these processes to maintain careful documentation, open information sharing and involvement of various specialists, stakeholders and regulators in the decision making processes.

Investigations into natural analogs, including streams, rivers, lakes, hillslopes, dunes and landslides is continuing on all Syncrude leases. The information gained from these investigations will be critical in the ongoing development and optimization of the Syncrude lease-closure plan.

Acknowledgments

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