RECLAMATION OF WASTE ROCK DUMP SLOPES AT THE KITSAULT MINESITE

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INTRODUCTION

The Kitsault molybdenum mine is located near the head of Alice Arm, approximately 140 km northeast of Prince Rupert. Open pit mining is carried out in a truck and shovel operation. Due to the steepness of the terrain, waste rock is stored in terraced dumps. The technique for building the terraces is for a bulldozer to push piles of blasted waste rock up to and over the advancing terrace face. This results in a gravimetric separation of the rock, with stones and boulders bouncing onto and down the slope, while fines are retained in crevices at or near the top. In the final terrace, the bench surfaces contained approximately 15 to 25% soil-sized particles (< 2 mm in diameter), while the slopes are covered with stones and boulders. This foundation of boulders is important for dump stability.

The post-mining land use proposed for the site is a wilderness forest with protected watershed values. To create this, a vegetative cover will be established on areas affected by the mining operation. The largest area to be covered will be the waste rock dumps. In field trials, an erosion controlling, self-sustained plant cover, which accelerates natural plant succession, has been established on dump benches (Price and Thirgood, 1983).

REGRADING DUMPS TO A SHALLOWER ANGLE

In the provincial reclamation guidelines, the suggested method of reclaiming terraced dump slopes is to regrade slopes to a shallower angle of repose. To meet this requirement, the Kitsault dumps have been designed so that two slopes and one bench can be regraded into one long slope. The advantages of regrading are that: 1) it reduces the likelihood of mass wasting; and 2) by moving finer particles from the bench onto the slopes, one creates a better media to support plant growth. The disadvantages of this procedure are the difficulty and inherent costs of moving large amounts of material.

RECLAIMING DUMPS AT THE ROCKS NATURAL ANGLE OF REPOSE

The alternative to regrading the slopes is to leave them at their present angle of repose. However, this creates a problem with regard to reclamation. The layer of boulders, so important for dump stability, in its present form contains no fines and thus will not support plant growth. Therefore the first step towards successfully revegetating natural angle of repose slopes will be to cover the surface with a layer of material containing soil-sized particles. The research results, shown in Table 1, indicate that 15 to *25%* soil-sized particles in the cover is adequate for vigorous, substained plant growth.

Using Natural Soils As A Capping Material

An obvious source of soil-sized materials, are the soils*[1] that covered the minesite before the mine was built. The present mine operators are conserving all of this resource encountered during mine expansion.

To test the use of stockpiled soil as an amendment for reclaiming the slopes, a field trial was established in 1981. The trial site chosen was a recently built dump, whose slope was 30 m long and stood at 36 , the natural angle of repose. Three rates 0.6, 1.2 and 2.4 x 10^3 m^3 ha-1, of peat-like material were dropped onto the plots by a front end loader. Although it contained many logs and roots, the peat was relatively stone-free compared to the other stockpiled soil. For all 3 treatments, the peat slid approximately the same distance down the slope, never covering more than the upper half of the slope's length.

Soon after the peat had been applied, fertilizer and seed were hand broadcast onto the plots. By the end of the first growing season a good cover of agronomic species was established on the peat-covered portions of the fertilized plots. Growth was slower on the unfertilized plots, but has since increased.

To date the growth of herbaceous species remains strong (the 1984, mean aerial biomass was 383 g m^{-2}). As in other trials, the legume birdsfoot trefoil is beginning to dominate the swards. None of the plots show any sign that the peat has moved.

Using soil to cover dump slopes has several drawbacks. A major problem is the small quantity available. Although the present mine operators are committed to saving any soil encountered during mine expansion, the previous owners, who operated the mine from 1965 to 1972, did not. Soils from the earlier developed areas have been buried. Another restriction on the quantity of soil available is that the soils themselves are thin.

*[1]Soil is defined as the fines-containing, unconsolidated layer above the bedrock, including both the layer in which plants root and any material below it.

TABLE 1

The percentage of waste rock particles less than 2 mm in the surface 0 to 10 cm and resulting plant growth in several trials, September 1984.

Date Trial Est'd	Waste Rock % < 2mm #	$\bar{x}$	S_D	Plant Growth #	$\bar{x}$	S_D	Type of Vegetation
1970	8	17	± 6	4	389	± 263 gm^{-2}	grass & legume
1982	12	24	± 9	8	308	± 106 gm^{-2}	grass & legume
1977	8	20	± 4	18	16	± 12 cm	alder

Note: grass and legume growth is air-dried above ground biomass, alder growth is height

#: number of samples

TABLE 2

The proportion of fines in the overburden used in research trials.

OVERBURDEN	% <2mm #	$\bar{X}$	S_D
SPY HILL PEAT	4	28.1	± 11.5
SPY HILL MINERAL	10	15.4	± 4.0
594 BENCH	10	30.1	± 7.1

#: number of samples

the area onto which the mine has recently expanded was previously covered by a thin organic layer over bedrock (Folisol). The rugged microrelief coupled with the shallow depth of these soils has hampered, and will hamper, their recovery. Jn waterlogged depressions, deeper organic soils are found, but these are not very extensive.

Another problem with using soil as an amendment is its quality. A large proportion of the material stockpiled is in fact composed of stones and rocks (Table 2). Of the soils sources listed in Table 2, Spy Hill Mineral is typical of most of the stockpiled material. Comparing the percent fines data for soil with that for different waste rock types (Tables 1 and 5), one can see that these so-called soils are not much better than the waste rock as a source of fine material. The poor quality of this soils has been reflected in field-trials (Table 3). The growth of agronomic species in a number of trials has been as good or better on the waste rock.

It is concluded that the soil resources of the minesite are limited and much of what is available is poor quality. Therefore other sources of fine material should be considered. Bringing "soils" from other areas is undesirable as it would be both prohibitively expensive and it would itself increase the area of disturbed land.

Using Waste Rock As A Capping Material

An alternative to using natural soil as capping material is to use the waste rock, as has already been suggested. For the most part the waste rock is too rocky to be suitable. That was the original problem. However, like most Cu-Mo porphyry deposits, the Lime Creek intrusives contain a variety of different rock types. For example, on the terrace built for the 1981 soil-slope trial, it was observed that some of the waste rock quickly crumbled into smaller particles. Following up on this observation, in 1982 plans were made to test the incompetent*[2] waste rock in *a* field trial. The area of the pit containing this rock type was identified and a dump slope was set aside for the trial. The trial site is the longest dump slope on the site. Over 120 m long at the north end, it stands at the rock's natural angle of repose of 36°. When reclaimed the slope will be broken up into shorter lengths. For experimental purposes it poses a rigorous test. Two plots, each over 20 m wide, were marked out on the crest and berms were built along the bottom for sediment control. In the usual truck and shovel operation the incompetent waste rock was brought to the site and then a bulldozer pushed it over the crest, where it was spread by gravity. In all, 15,000 tonnes of rock were applied, completely covering the original surface.

*[2]As the appropriate geological terms given to this rock type are complex and emphasize the rock's mode of formation rather than its present characteristics, I have chosen to use the term "incompetent" when referring to rocks that are distinquished by their rapid disintegration.

TABLE 3

Above-ground air dried biomass data collected from the research trials at the Kitsault minesite, September 1984.

Trial	Growth Medium	Air-dried above ground Biomass g m^{-2} #	x	± S_D
KM-70.1	Waste rock	4	389	262
	Spy Hill Peat - 10 cm deep	4	374	64
KM-82.1	Waste Rock	8	308	106
	Spy Hill Mineral - 30 cm deep	8	98	49
	594 Bench - 30 cm deep	8	211	19

TABLE 4

The % <2 mm surface of the incompetent waste rock cap. Data is from two of the transects sampled in June 1984. Both are from the longer of the two plots in this field trial.

	DISTANCE FROM CREST (m) 20	40	60	80	100	120
	% < 2 mm					
A:	44	27	39	43	13	0
B:	32	33	38	28	31	37

A week after dumping, some excess seed and fertilizer was hand broadcast onto the upper half of both plots. The amendments failed to stick to the fine grained, smooth surfaces and collected in gullies, on ledges, and amongst stones. The resulting vegetative cover is sparse. A more complete cover would have resulted if a tackifier had been used to hold the seed in place.

In the first year about 25 percent of the resulting surface contained soil-size material. Over the first winter, slumping covered more of the lower sections with fines and subsequent rock breakdown and surface erosion has continued this process. Results from some of the transects sampled in June 1984 are shown in Table 4. Sampling showed that 70 to 100 percent of the slope surface contained sufficient fines to support plant growth. In comparison on the surrounding slopes, fines are limited to the upper 5 m.

Future plans for the trial include establishing a more complete vegetation cover to determine whether the present surface is compatible with the proposed land use.

CHARACTERISING ROCK TYPES AS SOURCES OF FINES

At the same time as the field trial testing incompetent waste rock was established, samples of various rock types were collected from the pit and the rock dumps for a complementary laboratory study. The two questions addressed in this study were:

1. What other properties does the "incompetent" waste rock have?
2. How does it differ from other rock types present in the waste material?

As many of the rocks' properties result from their mode of formation, an understanding of the site's geology is important for answering both questions. Around 54 million years ago, the site was covered with interbedded sedimentary rocks, primarily fine grained argil lite and greywacke. Subsequently, the sedimentary rock was intruded into by a series of igneous stocks. A broad zone of hornfels developed in the surrounding sedimentary rock as a result of this intrusive activity. The zone of highest molybdenite grades roughly corresponds to the contact zone of the central intrusive stock. Varying from granodiorite to quartz monzonite in composition, the central stock shows pronounced hydrothermal alteration.

Characterizing all the variation in rock types present in the waste is beyond the scope of this inquiry. So it was decided to concentrate on three types, the hornfels, the potassically-altered intrusive and the so-called incompetent intrusive rock. The hornfels and the potassically-altered intrusive are the two most common rocks in the waste. By comparison the incompetent rock is relatively rare. However it appears that, if necessary, enough exists to cap all the dump faces.

All three rock types were formed under high temperatures and pressures and in the absence of air and water. Exposed to ambient conditions at the

TABLE 5

The proportion of particles of different size in samples collected from the surface of waste rock dumps.

WASTE ROCK TYPE	% < 2 mm		% Sand		% Silt	% Clay	
	$\bar{X}$	S_D	$\bar{X}$	S_D	$\bar{X}$	$\bar{X}$	S_D
10 years after exposure							
Hornfels (bench)	12	±4	52	±1	37	11	±5
Igneous potassic (bench)	22	±8	70	±0.2	17	13	±7
Recently dumped							
Igneous potassic (bench)	24	±9	66	±2	25	9	±1
Igneous incompetent (slope)	35	±10	65	±6	27	8	±2

TABLE 6

Mineral composition of different rock types.

Rock Type	Most Common Minerals (> 5%) - in decending order
Hornfels	
- Spy Hill	quartz, plagioclase, biotite
- H101	quartz, plagioclase, biotite, chlorite
- SEL	quartz, biotite, muscovite, plagioclase
Potassic intrusive	
- G201	quartz, K feldspar, muscovite
- G203	quartz, K feldspar, muscovite
- G204	quartz, K feldspar, muscovite, calcite
- 82.1	quartz, K feldspar, muscovite, calcite (biotite)
Incompetent intrusive	
- D203	quartz, K feldspar, biotite
- D204	quartz, muscovite, calcite
- D206	muscovite, calcite
- 82.4	quartz, K feldspar, muscovite, calcite

Note: Samples SEL, 82.1, and 82.4 were collected from the waste rock dumps, the other samples are from the pit.

earth's surface, the rock particles eventually alter into products that are more in equilibrium with the newly imposed physico-chemical conditions (Oilier, 1969). This process is called weathering. The rate of change and the products formed will depend on the characteristics of both the rock and the weathering environment. Important characteristics of the rock include the size and arrangement of crystals, the rock's fabric and its mineral composition.

As the data in Table 5 shows, the proportion of fines produced by blasting and subsequent weathering of the hornfels waste rock is significantly less than that from the cohesive potassic intrusive. The proportion of fines from the incompetent waste rock is the highest. Notably, the data for the incompetent waste rock is from 10 m down the previously described slope trial, while that of the other two rock types was from samples collected from a bench surface. Slopes of hornfels and potassic rock contain little or no fines.

The ability of the hornfels to resist degradation is due to the cohesive interlocking of small grains (Figure 1) and the large amount of quartz (Table 6). Various researchers have observed that fine-grained rocks weather more slowly than rocks which are of a coarser grain size (Birkeland, 1974; Carrol, 1970), such as the intrusives. One possible reason for this is that the intergranular surface area increases with a decrease in grain size; hence more energy is required to disaggregate the finer rock (Birkeland, 1974). The cohesive interlocking structure is a barrier to water and other weathering agents. This restricts mineral breakdown to exposed grains on the rock's surface. Further weathering is prevented by the high quantity of quartz, which is quite resistant to weathering. Pétrographie studies show that plagioclase and biotite crystals in the hornfels are surrounded by quartz. Should one of these more easily weathered minerals be removed, the resulting cavity will likely be lined with resistant quartz, preventing further penetration. As the grains are small, the loss of a few from the surface will not significantly reduce the overall rock strength.

In contrast to the equigranular hornfels, the potassic and incompetent rock are porphyries, that is they contain large crystals, or phenocrysts, in a fine grained matrix (Figure 2). In both rocks, the phenocrysts consist of quartz and K feldspar. Calcite and moscovite, along with quartz and K feldspar, are in the groundmass (Table 6). The most significant difference between the cohesive potassic and the rapidly degrading incompetent rock, is that the incompetent rock contains high quantities of calcite and moscovite and more groundmass (Table 7).

Soluble in rainwater, calcite can be expected to dissolve quite quickly in a high precipitation environment like Kitsault. As calcite dissolves, pores are created which weaken the support around phenocrysts and allow weathering agents to penetrate further into the rocks (Figure 3).

The muscovite in the groundmass is sericite, a fine grained muscovite formed by hydrothermal alteration. According to mineral stability schemes (i.e. Goldrich, 1938) muscovite should be relatively resistant to weathering. However, crystals formed by hydrothermal alteration may contain more flaws

TABLE 7

The proportion of calcite and mica in different rock samples collected from the pit.

Rock Type	Sample No.	% $CaCO_3$	% Mica	Dominant Mica
Hornfels	H101	0.83	10	biotite
	7PM	0.92	20	biotite
Potassic Intrusive	G101	4.67	2	muscovite
	G201	4.17	5	muscovite
	G203	3.67	5	muscovite
	G204	5.17	5	muscovite
Incompetent Intrusive	D201	6.92	10	muscovite
	D203	2.50	30	biotite
	D204	6.83	5	muscovite
	D206	31.08	60	muscovite
	D207	26.92	60	muscovite

Note: % $CaCO_3$ was calculated from % carbon, with the assumption that all the carbon is from calcite. Percent carbon was determined with a Leco C analyser.

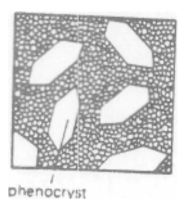
% Mica was estimated from the relative intensity of the 10Å peak in XRD scans of powder mounts and from total chemical composition.

FIGURE 1

A schematic diagram of hornfels rock
showing its fine grained granular fabric

FIGURE 2

An example of porphyritic texture. Most of the
Intrusive rock in the waste is prophyritic



Porphyritic texture

FIGURE 3

A schematic diagram of an incompetent rock particle. The displacement and/or solution of the groundmass is likely responsible for the rock breakdown.

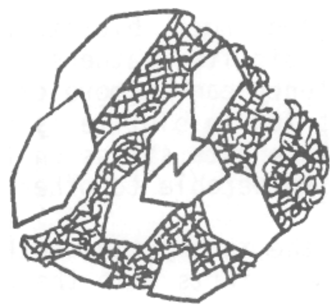
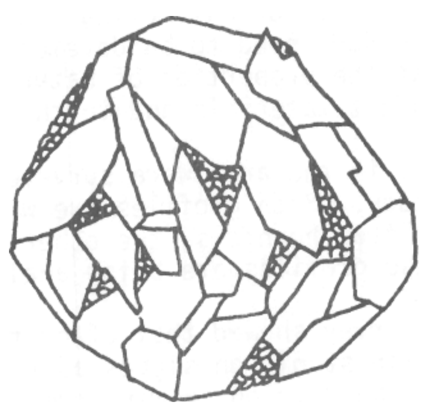


FIGURE 4

A schematic diagram of a potassic rock particle prior to weathering.



or other areas of weakness than the crystals studied by Goldrich (1938). In which case weathering may be faster than predicted.

While weathering may be occurring, probably the most important property of muscovite with regard to rock disintegration is that there is little cohesion among separate muscovite crystals and with other minerals. As a result any stress will create fractures and cause disintegration.

In several samples of incompetent rock, biotite rather than muscovite, is the dominant mica (Table 6). Biotite weathers less quickly than calcite but its effect on rock competency can be more dramatic. In contact with oxygenated water, the ferrous ion in biotite is oxidised to the larger ferric ion. The volume increase puts stress on the entire rock, creating fractures and making it more vulnerable to other weathering conditions.

Similar to the weathering of the incompetent rock previously described, weathering of the potassic rock starts with the groundmass, which quickly falls apart. However, in the potassic rock the amount of groundmass exposed is relatively small (Figure 4). After this is lost, the surface is entirely resistant, these crystals resist further degradation in much the same manner as the hornfels.

PERFORMANCE OF WASTE RUCK AS A SOIL

Up to this point, the data presented has focused on the weathering that occurs in the first few years after the waste rock is exposed to the atmosphere. Breaking down rapidly is an important quality for a capping material, if vegetation is to be quickly established. Equally important are properties which affect its long term performance as a cover. For example, it should be resistant to mass wasting and surface erosion.

With soil development and plant growth, factors promoting weathering will be intensified. Most studies evaluating mine waste, in order to predict their future properties, use traditional soil analysis techniques. However, these methods are poorly suited for estimating the future performance of mined materials. Other methods need to be developed. One method used in this project is to look at the properties of natural soils that have developed from similar parent materials and in the same environment.

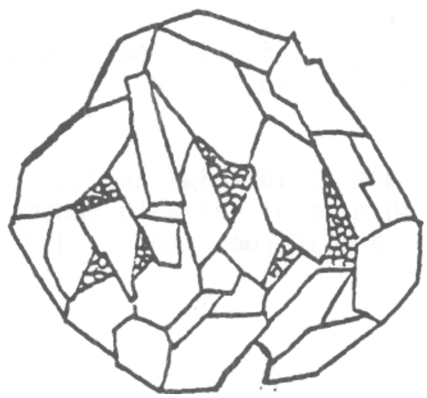
In order to do this, soils in the area were surveyed and two profiles were selected for intensive study. Both profiles are within the proposed pit limits; one has developed from hornfels, the other from intrusive rock, At present, samples from these profiles are being analysed.

Results from the initial survey showed that after thousands of years of weathering,, soils can remain stable on slopes as steep as 36°. This supports the hypothesis that soils can develop on mine dumps which are at the natural angle of repose.

As the extent of incompetent rock in the area is limited to the area already

FIGURE 5

A schematic diagram of a potassic rock particle after the loss of exposed groundmass.



mined, it is not possible to find examples which show how it alters in a natural soil. Thus artificial weathering techniques will have to be used to predict its future performance. Methods which duplicate the type of weathering observed in soils in this area have been successfully used in other studies carried out in the pedology laboratory at the University of British Columbia (Singleton, 1978). To ensure that the appropriate method is chosen, it will first be tested on the parent material of one of the natural soils presently being studied. Successfully duplicating the changes observed in the natural soil will be considered proof that the technique is valid, and can be used to predict the future properties of the incompetent waste rock.

The combined results from the field trial and this laboratory study should show whether or not capping dump slopes with incompetent waste rock will support the development of a wilderness forest and protect water quality.

CONCLUSION

In conclusion, research done in advance of dump completion is looking at the possibility of reclaiming slopes at their natural angle of repose. Results to date show that the waste rock is an attractive alternative to prestripped soil as a growth medium. The focus of present research is to determine whether a cover of incompetent waste rock will be compatible with the long term end land use for the site.

Mile the data collected and the environmental effects considered are those of the Kitsault minesite, the waste rock soil properties, geology, and dump construction are similar to those of many hard rock mines in B.C. Many mines lack sufficient reserves of "soil", either because much of the mine had been developed before the necessity of soil conservation was realized or because the quality and quantity of "soil" is low in steep glaciated mountain landscapes. Thus, although the conclusions reached vis a vis identifying and using different waste rock types specifically refers to the Kitsault mine, the methodology is generally applicable and the potential benefits of optimally placing different rock types are great.

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