R.M.HARDY & ASSOCIATES LTD.

REPORT

ON

REQUIREMENTS FOR DEVELOPMENT OF A REHABILITATION PLAN

CLINTON CREEK MINE
CASSIAR ASBESTOS CORPORATION
(1977)

Prepared for:

Yukon Territory Water Board

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
OBSERVATIONS AND DISCUSSION	4
1) Tailings Disposal Area	5
2) Clinton Creek Waste Embankment	9
3) Porcupine Dump	14
AVAILABILITY OF DATA	14
TABLE 1. Summary of Monitoring Records	16
TABLE 2. Record of Movement - Monitor 24	17
TABLE 3. Record of Movement - Monitor 25	18
TABLE 4. Record of Movement - Monitor 26	19
TABLE 5. Record of Movement - Monitor 29	20
ESSENTIAL REQUIREMENTS FOR REHABILIATION PLAN	22
1) Geotechnical	25
2) Environmental	26
RECOMMENDATIONS	27
REFERENCES	35

APPENDICES

APPENDIX A - Photo Documentation

APPENDIX B - Results of Laboratory Testing

- Procedures and Results of Laboratory Strength and Classification Tests
- Substrate and Tissue Analysis

INTRODUCTION

R.M. Hardy & Associates Ltd. were requested to undertake an analysis of the overall stability conditions at the Cassiar Asbestos Corporation mine site at Clinton Creek, Yukon Territory and to provide recommendations for the requirements to develop a site rehabilitation and abandonment plan. The specific terms of reference were: "prepare for the Yukon Territory Water Board a suitable stability analysis proposal for the Cassiar Asbestos Corporation mine site at Clinton Creek, such that if followed the results would allow development of a site rehabilitation and abandonment plan, to the satisfaction of the Regional Manager, Water Resources".

The study comprised a site visit September 19th, 1977, a meeting with Mr. Gerry Vincent, mine manager for Cassiar Asbestos Corporation, a review of available air photos taken in 1970 and in 1976, and a review of documentation consisting of three reports prepared by Golder Brawner and Associates Ltd. and one report by Environmental Protection Services, Fisheries and Environment.

The field inspection was relatively short. Approximately five hours were spent at the site with emphasis placed on inspecting the overburden waste disposal area and the tailings waste disposal area. The overall site was also inspected and photographed from a light aircraft. Samples of the waste materials were secured for a limited laboratory testing program and chemical analyses. In addition, samples of the vegetation in the immediate vicinity of the tailings disposal area and from areas well removed from the influence of the mining operation were secured for analyses.

The field inspection was directed to the geotechnical aspects as well as environmental and reclamation requirements. The geotechnical assessment was carried out by J. I. Clark, Ph.D., P.Eng. and the rehabilitation requirements relative to a revegetation program were assessed by W. E. Younkin, Ph.D. Since rehabilitation and revegetation is dependent upon the stabilization of the slopes, the recommendations in this regard are presented within the context of various alternatives for stabilization of the slopes and stream courses.

Insuffcent data are available at present to allow a detailed stability analysis of the various slopes involved with the waste disposal. It is apparent, however, that virtually all areas of the waste overburden materials (predominantly argillite) and of the tailings disposal area (predominantly serpentine and asbestos fibres) are currently moving. It is also evident that it is impractical to arrest the movement except in localized areas. The thrust of our recommendations is therefore directed towards providing a stabilization and rehabilitation plan which will accommodate the moving mass and still maintain a proper drainage of the affected water sheds without resulting in unacceptable environmental damage.

Authorization for this investigation was issued by the Regional Director, Northern Affairs Program, Department of Indian and Northern Development, Whitehorse, Yukon Territory by means of contract number Y7WA-17.

OBSERVATIONS AND DISCUSSION

Virtually all of the waste embankments inspected showed signs of instability, including that portion of the tailings disposal area which failed originally in 1974. Moreover, both Wolverine Creek and Clinton Creek showed signs of very active bank erosion and down cutting.

The problems associated with rehabilitation of the tailings disposal piles are considered most serious since the material contains an appreciable amount of asbestos fibre which could contaminate Wolverine Creek and perhaps even ultimately Forty Mile Creek and the Yukon River. We have been unable to determine the level of asbestos fibre content which would be considered hazardous. It is apparent from observing the effects of the breakthrough of the dammed up water after the failure in 1974, that a large amount of asbestos fibre was left deposited in Wolverine Creek flood-plain up to the level of the high water mark. The problems of water pollution associated with the waste dump at Clinton Creek are less serious. A more significant problem at this location is the provision of a stable drainage course from Hudgeon Lake. Porcupine Creek has also been dammed off with wastes but we were unable to make a detailed examination of this area. Our observations from the aircraft and a review of the reports cited at the end of this report, indicate that because of the relatively small flow and the coarser waste material at the bottom of the valley, Porcupine dump is not as severe a problem area as Clinton dump. Our specific observations follow:

1) Tailings Disposal Area

The overall site conditions as they existed in 1976 are shown in the aerial photograph in Appendix A.

Photograph 1 shows the failed portion of the tailings pile. The failure occurred in 1974. It is clear from the cracks on the pile that movement is still occurring in this area. There also seems to be a substantial amount of spreading at the bottom. We are unable to assess to what extent the spreading was carried out with mechanical equipment at the time that the channel was bulldozed through. Photograph 2 shows a view of the channel that was evidently bulldozed in 1974. The very fresh face of the right bank indicates it is moving and experiencing continual erosion. It is obvious the channel has squeezed shut to a large degree since it was bulldozed open. Photograph 1 also shows a lobate form north of the failed area which was reported to have been moving at a rate of 3 inches (76 mm) per day in January 1976. Observations of movement had been taken only over a relatively short period. This photograph, as well as the aerial photograph, indicates that the direction of movement of the southern portion of this slope is towards the mass that failed in 1974. A substantial amount of bulging at the bottom indicates the failed mass is supporting the south side of this slope. In our opinion it is quite possible that a failure similar to that experienced in 1974 could occur at this location. The movement appears to be a combination of flow within the tailings mass as well as a failure of the foundation soils.

The surface characteristics of the unstable tailings pile suggest that the failure mode in this area could be the result of failure within the active layer. The slope mantle apparently includes poorly consolidated materials (likely colluvium), partly or fully saturated during the warm season. When surcharged, this subgrade may experience a flow movement, behaving as a viscous mass over a surface of frozen material. The freeze-back should elevate the active layer into the tailings materials, however, a similar process could seasonally recur within the tailings embankment.

Another cause of the failure could be the result of a thickening of the active layer at the edges of the embankment, due to a reduction of the insulating effect of the organic layer as it is compressed. If the natural soils are not stable in the thawed condition, sloughing will occur at the edges of the embankments and will migrate upslope. This type of failure is time-dependent (governed by the rate of thawing). If applicable for this area, this type of instability could affect the remaining segments of the tailings embankments in the future.

To our knowledge there is no information available on the active layer at this location. It was reported by the mine manager to be of the order of 12 to 18 inches (305 to 457 mm) but this is inconsistent with the vegetation which occurs on the slope.

Photograph 3 shows the area where tailings were being dumped at the time of our field inspection. The angle of repose of the frontal part of the tailings pile is judged to be at about 38° to 39° as previously reported by Golder Brawner and Associates. The natural slope of the ground in this area is flatter than the slope to the south and that towards the bottom of the valley. Localized failures will very likely be experienced at this location but it is unlikely that they would encroach on Wolverine Creek.

The texture of most of the exposed tailings is coarser than the material below the surface as most of the fines have been removed by wind or surface run-off. However, as a result of continued movement, fresh material is continually being exposed. Unless the pile is stabilized, it cannot be assumed that the coarser material at the surface will prevent fibre and dust being raised from the surface.

Photograph 4 shows the area downstream and the material deposited in the stream bed when the water broke through after the failure in 1974.

Direct shear tests carried out on samples of the tailings show a peak friction angle of about 46° and a residual angle of 30°. The difference between peak and residual indicates that a fabric develops on a shearing surface as the shearing progresses. This may be due to a large amount of asbestos fibre present in the tailings sample tested. The test specimens were all taken from one sample of tailings and may not be representative of the entire area.

It is expected that the tailings and waste dump heaps for the most part will be left in place. If these materials are not suitable for plant growth there are few ways in which they can be modified. From the samples collected on our visit to the site in September it appears that the tailings heap will be unsuitable for plant growth because of high magnesium, sulphate and nickel levels (see Appendix B). This does not appear to be the case for the waste rock which in addition appears to weather quite rapidly. In this case waste rock may be used as a cap on the tailings pile to ameliorate the adverse chemical effects and provide a fine grained substrate capable of holding moisture and nutrients.

The establishment of species trials will be necessary to demonstrate that the medium is capable of supporting plant growth and to select those species most suitable for the site conditions provided. Commercially available species proven successful in studies conducted in similar latitudes would provide the basis for the establishment of such trials (Younkin 1976, Mitchell and McKendrick 1974 and 1975). In addition cuttings and transplants of locally available native species should be tested to determine their suitability for growth on the mine spoils.

2) Clinton Creek Waste Embankment

A large amount of movement is evident in this dump. From an examination of the aerial photographs taken in 1970, it is clear that failure was occurring at that time. The failure assumed two modes: flow within the mass and foundation failure as evidenced by scarps which appear on the aerial photographs.

It is apparent that the steep hillside (sloping some 30°) did not provide any significant support to wastes dumped from the crest. The weak deposits forming the alluvial floodplain of Clinton Creek were unable to resist shear stresses from a 600 foot (183 m) high embankment resulting in the foundation failure. (Bulging of the pile toe and adjacent floodplain is noticeable on 1970 air photos.) It is conceivable that additional material dumped over the sliding mass progressively advanced the failure across the entire valley bottom. Moreover, if the floodplain material was of low permeability, the loading of the embankment could have created excess pore water pressure in the foundation material which, in turn, could itself precipitate failure extending through the foundation. Temporary recession of the permafrost table in the valley bottom would be a contributing factor.

Water impounded upstream of failed waste mass could further degrade the permafrost conditions in the valley bottom and impair the stability of the toe of the waste dump. The extent of this thawing and whether or not equilibrium will be reached is dependent on the heat source effect of the pond and the energy exchanges to the atmosphere and into the permafrost.

Photograph 5 shows the west end of the dam and the stream channel on the north side. The cracks throughout the dump are evident in this photo as well as in the aerial photo. It is clear it would not be practical to stabilize this mobile mass. Photograph 6 shows a closer view of the cracks within the mass and one of the graben features.

The north-eastward movement towards Clinton Creek at the toe of this slope, as reported in January 1977, was comparatively minor. It can be seen from photograph 7 that there is continual erosion and fresh slumping at the toe.

Bottom heave has also been reported from the previous observations at the site. Photograph 8 shows the left banks of natural soil downstream from the culverts. We understand that the maximum flow for 1977 occurred in May and was equal to approximately 1000 cfs (28 m^3/sec). A large amount of fines was eroded from the toe of the slope as shown in photographs 9 and 10, leaving a boulder paved bank. Accurate records of peak flow are not available but we understand that they will be obtained in the future beginning in 1978. It is clear that extensive erosion can be experienced during peak flow periods depending upon the duration. Further erosion will initiate accelerated movement of the slopes of both the left and right banks.

We understand from discussions with the mine manager that it is intended to put velocity barriers consisting of large boulders in this channel to reduce the erosion potential of the stream. In our view this step by itself would not serve any useful purpose as to barriers would be outflanked and erosion could be accelerated in either bank. Previous recommendations for this channel included bank protection as well as velocity barriers.

As pointed out in previous reports the waste overburden material is predominantly argillite and it breaks down very rapidly after it is excavated and exposed to weathering. A sample of the materials secured was subjected to direct shear tests and showed a residual friction angle of 23°. A peak friction angle for this material could not be defined because of the nature of the sample. When the material is deposited in the piles it consists of large chunks which behave essentially as a coarse angular granular material. The angle of repose of this material is in the range of 35° to 40°. As it breaks down the mass assumes the properties of the constituent material and as movement occurs, the shearing resistance would approach that represented by the residual strength parameters. Pore water pressure within the mass could result in even flatter slopes being unstable.

It is clear that the waste material is very unstable and that there will be a continued encroachment on Clinton Creek. Thus, the stability of the creek can only be assured by designing to accommodate the mobile mass or by a substantial modification to the dam. In 1974 the maximum depth of water behind the dam was reported to be 50 feet (15.2 m). In 1976 it was reported to be of the order of 120 feet (36.6 m). Clearly, this is a substantial dam and the existing gradient is much steeper than the original gradient through the displaced reach of Clinton Creek. For long term stability the dam, outlet works and channel must conform to proper engineering design principles.

3) Porcupine Dump

The spoil piles in this area are also experiencing movement as illustrated in Photograph 12. A small reservoir has developed as a result of the blocking of Porcupine Creek but the water appears to be percolating through the spoil. It is reported that the majority of the rock at the bottom of the slope is large diameter serpentine boulders and this would account for the flow of water through the mass. Since the coarse material at the bottom of the valley is relatively permeable and since the flow appears to be quite small, it is unlikely that a much greater reservoir will develop. The argillite and Serpentine boulders do not appear to be contributing sediment to the small outflow. We do not consider this area to present a potential hazard with respect to pollution of the stream. Rehabilitation requirements in this area would be predominantly concerned with meeting the stability requirements for surface reclamation.

AVAILABILITY OF DATA

At our meeting with Mr. Gerry Vincent, mine manager, we discussed what data are available to serve as a framework for analysis in the development of a rehabilitation plan. During this discussion the following points were made:

i) No information is available on the engineering properties of the tailings of the waste rock.

ii) No testing of the natural soils has been carried out.

iii) There is no information available on the permafrost table. The active layer was reported to be 12 to 18 inches (305 mm to 458 mm) thick but this appears to be inconsistent with the vegetation in the area. It was reported that natural cuts in the permafrost revealed very little ground ice.

iv) There is not information available on the behaviour of the permafrost underneath the waste pile or tailings. This is considered to be a very significant point in developing any plan to recontour the waste piles.

Reference was made to some hydro seeding trails which were initiated in 1977. It was also reported that trials had been carried out at Cassiar, B.C. over a three-year period and that successful revegetation techniques had been developed. The surface movement monitoring program that is currently carried out was described. Monitoring of the Porcupine pit is being carried out daily and this is the main focus of attention. It was intended to monitor the waste piles on a monthly basis but it is now mostly carried out when time is available.

Mr. Vincent indicated that he would be able to provide to the Regional Office:

i) monitoring records of tailings and waste piles,

ii) results of revegetation trails at Cassiar,

iii) chemical analyses of waters and tailings.

Monitoring records were received for monitors 24, 25, 26 and 29 on November 30, 1977. Monitors 24 and 25 are located on the portion of tailings which failed in 1974 on section line 113500 N. Monitor 24 is near the top and monitor 25 near the bottom. Monitor 26 is near the top of pile towards the North end near the area of current disposal and monitor 26 is near the bottom of the pile. Both are on section line 114500 N.

The length of the monitoring period ranges from 139 to 309 days. The rate of movement ranges from small to exceptionally high. All monitors showed a rate of movement which could be considered failure. A summary of the result is presented in Table 1.

TABLE 1. Summary of Monitoring Records

	Δ ft.	Δ Elev. ft.	Monitoring Period
24	1.28	0.52	309 days
25	7.60	2.53	309 days
26	57.55	60.27	264 days
29	58.94	25.79	139 days

TABLE 2 - RECORD OF MOVEMENT
MONITOR 24 - DECEMBER 23, 1976 to OCTOBER 27, 1977

Date	Elapsed Time	Δ Northing ft. (m)	Δ Easting ft. (m)	Δ ft. (m)	Δ Elevation ft. (m)	Horizontal Movement Rate ft./day (m/day)
Dec. 23/ Jan. 20	28 days	0.01 (0.003)	0.10 (0.03)	0.10 (0.03)	-0.04 (-0.01)	0.003 (0.001)
Jan. 20/ Feb. 22	33 days	0.01 (0.003)	0.03 (0.01)	0.03 (0.01)	-0.18 (-0.05)	0.009 (0.003)
Feb. 22/ March 25	31 days	0.01 (0.003)	0.09 (0.03)	0.09 (0.03)	-0.08 (-0.02)	0.003 (0.001)
March 25/ April 5	11 days	0.13 (0.04)	0.06 (0.02)	0.14 (0.04)	+0.06 (+0.02)	0.013 (0.004)
April 5/ April 26	22 days	0.05 (0.02)	0.02 (0.01)	0.05 (0.02)	-0.12 (-0.04)	0.002 (0.001)
April 26/ May 19	23 days	0.03 (0.01)	0.05 (0.02)	0.06 (0.02)	-0.60 (-0.18)	0.003 (0.001)
May 19/ June 10	22 days	0.18 (0.05)	0.33 (0.10)	0.38 (0.12)	+0.36 (+0.11)	0.017 (0.005)
June 10/ July 13	33 days	0.01 (0.003)	0.15 (0.05)	0.15 (0.05)	+0.26 (+0.08)	0.005 (0.002)
July 13/ Sept. 13	62 days	0.04 (0.01)	0 (0)	0.04 (0.01)	-0.11 (-0.03)	0.001 (0.003)
Sept. 13/ Oct. 27	44 days	0.01 (0.003)	0.24 (0.07)	0.24 (0.07)	-0.07 (-0.02)	0.005 (0.002)

average rate of horizontal movement = 0.004 ft./day
(0.001 m/day)

TABLE 3 - RECORD OF MOVEMENT
MONITOR 25 - DECEMBER 23, 1976 to OCTOBER 27, 1977

Date	Elapsed Time	Δ Northing ft. (m)	Δ Easting ft. (m)	Δ ft. (m)	Δ Elevation ft. (m)	Horizontal Movement Rate ft./day (m/day)
Dec. 23/ Jan. 20	28 days	0.18 (0.05)	0.79 (0.24)	0.81 (0.25)	-0.09 (-0.03)	0.028 (0.008)
Jan. 20/ Feb. 22	33 days	0.18 (0.05)	0.70 (0.21)	0.72 (0.22)	-0.23 (-0.07)	0.022 (0.007)
Feb. 22/ March 25	31 days	0.15 (0.05)	0.47 (0.14)	0.49 (0.15)	-0.28 (-0.09)	0.016 (0.005)
March 25/ April 5	11 days	0.03 (0.01)	0.37 (0.11)	0.37 (0.11)	-0.05 (-0.02)	0.033 (0.010)
April 5/ April 26	22 days	0.03 (0.01)	0.03 (0.01)	0.04 (0.01)	-0.18 (-0.05)	0.002 (0.001)
April 26/ May 19	23 days	0.1 (0.03)	0.69 (0.21)	0.70 (0.21)	-0.18 (-0.05)	0.030 (0.009)
May 19/ June 10	22 days	0.12 (0.04)	0.86 (0.26)	0.87 (0.27)	-0.14 (-0.04)	0.039 (0.012)
June 10/ July 13	33 days	0.27 (0.08)	0.77 (0.23)	0.81 (0.25)	-0.18 (-0.05)	0.025 (0.008)
July 13/ Sept. 13	62 days	0.30 (0.09)	1.49 (0.45)	1.52 (0.46)	-0.68 (-0.21)	0.024 (0.007)
Sept. 13/ Oct. 27	44 days	0.30 (0.09)	1.23 (0.37)	1.27 (0.39)	-0.52 (-0.16)	0.028 (0.008)
TOTALS	309 days			7.60 (2.31)	-2.53 (-0.77)	

average rate of horizontal movement = 0.025 ft./day
(0.007 m/day)

TABLE 4 - RECORD OF MOVEMENT
MONITOR 26 - DECEMBER 23, 1976 to OCTOBER 27, 1977

Date	Elapsed Time	Δ Northing ft. (m)	Δ Easting ft. (m)	Δ ft. (m)	Δ Elevation ft. (m)	Horizontal Movement Rate ft./day (m/day)
Dec. 23/ Jan 18	26 days	3.05 (0.93)	5.83 (1.78)	6.58 (2.01)	-10.26 (- 3.13)	0.253 (0.077)
Jan. 18/ Feb. 10	23 days	3.53 (1.07)	5.76 (1.76)	6.75 (2.06)	- 9.85 (- 3.00)	0.294 (0.090)
Feb. 10/ Feb. 23	13 days	1.58 (0.48)	2.82 (0.86)	3.23 (0.98)	- 4.59 (- 1.40)	0.249 (0.076)
Feb. 23/ Mar. 11	16 days	1.13 (0.34)	3.04 (0.93)	3.24 (0.99)	- 3.03 (- 0.92)	0.202 (0.062)
Mar. 11/ Mar. 25	14 days	1.45 (0.44)	3.0 (0.91)	3.33 (1.01)	- 4.20 (- 1.28)	0.238 (0.073)
Mar. 25/ April 5	11 days	0.74 (0.23)	0.81 (0.25)	1.09 (0.33)	- 2.23 (- 0.68)	0.099 (0.030)
April 5/ April 15	10 days	0.84 (0.26)	2.90 (0.88)	3.02 (0.92)	- 1.78 (- 0.54)	0.302 (0.092)
April 15/ April 26	11 days	0.59 (0.18)	1.41 (0.43)	1.53 (0.47)	- 2.33 (- 0.71)	0.139 (0.042)
April 26/ May 19	23 days	1.87 (0.57)	3.93 (1.20)	4.35 (1.33)	- 4.39 (- 1.34)	0.189 (0.058)
May 19/ June 10	22 days	2.39 (0.73)	4.36 (1.33)	4.97 (1.51)	- 3.68 (- 1.12)	0.266 (0.081)
June 10/ July 13	33 days	3.24 (0.99)	5.78 (1.76)	6.63 (2.02)	- 5.33 (- 1.62)	0.201 (0.061)
July 13/ Sept. 13	62 days	6.96 (2.12)	10.78 (3.29)	12.83 (3.91)	- 8.60 (- 2.62)	0.207 (0.063)

average rate of horizontal movement = 0.218 ft./day
(0.066 m/day)

TABLE 5 - RECORD OF MOVEMENT
MONITOR 29 - JUNE 10, 1976 to OCTOBER 27, 1977

Date	Elapsed Time	Δ Northing ft. (m)	Δ Easting ft. (m)	Δ ft. (m)	Δ Elevation ft. (m)	Horizontal Movement Rate ft./day (m/day)
June 10/ July 13	33 days	0.45 (0.14)	13.22 (4.03)	13.23 (4.03)	-5.63 (-1.72)	0.401 (0.122)
July 13/ Sept. 13	62 days	1.18 (0.36)	25.18 (7.67)	25.20 (7.68)	-11.52 (-3.51)	0.406 (0.124)
Sept. 13/ Oct. 27	44 days	1.00 (0.30)	20.49 (6.25)	20.51 (6.25)	-8.64 (-2.63)	0.466 (0.142)
TOTALS	139 days			58.94 (17.96)	-25.79 (- 7.86)	

average horizontal movement rate = 0.424 ft./day (0.129 m/day)

The vector sum of the movement of the monitored hub along a horizontal plane is represented by Δ. The total change in elevation is shown by Δ Elev. It can be seen that monitor 25 at the bottom of the slope of the failed portion is moving at about 5 times the rate as monitor 24 at the top of the slope. Monitor 29 at the bottom of the slope which has not yet broken out is moving at about twice the rate as monitor 26 at the top of the slope. The change in location for monitors 24, 25 and 29 are about 2.2 to 2.5 times the change in elevation whereas the change in elevation is slightly greater than the change in location for monitor 26. This indicates that it is likely experiencing rotational failure as well as settlement. The other monitors (24, 25, 29) are experiencing some settlement but mostly reflect the change in surface elevation of the original ground.

Tables 2, 3, 4 and 5 show the monitoring records for each of the individual monitors. The important point indicated by these records is that there is no significant change of rate with time. All records show some variation for the periods analyzed. Two show a greater rate at the end of the monitoring period, one is the same and one is slightly less. The only conclusion that can be drawn is that there is not a trend towards a decrease in the rate of movement with time.

Mr. Vincent indicated that they would be initiating work on the tailings disposal pile shortly after our visit. It was his intention to unload the top of the pile and move the materials to the north and redeposit them on flatter slopes in that area. The objective of this recontouring is to reduce the rate of downslope movement of the pile. When asked about the plan for recontouring he indicated that it was on a cut and try procedure. He had no predetermined slopes or contours established. The unloading will no doubt help reduce the movement but in our view it should be carried out in accordance with a well defined recontouring plan which would lead to eventual stabilization.

No data were received on results of revegetation trials or on chemical analyses of waters and tailings.

ESSENTIAL REQUIREMENTS FOR REHABILITATION PLAN

The site rehabilitation and abandonment plan is normally prepared prior to or in the early stages of mining and is aimed at leaving the mined area in a stable condition, consistent with the natural surrounding landforms and vegetation or having the potential to achieve a vegetative cover consistent with the end land use. The end land use is normally determined by the governmental agency responsible for the administration of the land and is highly dependent upon the land use prior to mining. In the case of the Clinton Creek mine a reasonable end land use would be to return the land to a wildlife habitat suitable to that area. Normally information is gathered on the vegetation and soils, bedrock and surficial geology, hydrology, and the chemical and physical characteristics of the tailings and overburden. From this a materials handling plan is developed aimed at producing stable slopes and placing materials on the surface which provide a suitable plant growth medium.

From our review of existing information, a visit to the mine site and discussions with the mine manager, it appears that little of the above has been done. Observations reveal that in almost all areas the waste and tailings embankments are unstable and are gradually moving. In addition it is suspected that the tailings heaps and to a lesser degree the waste overburden is toxic to inhospitable to plant growth. If left in this condition widespread slope failure and surface erosion will impede plant establishment and result in continued blockage and pollution of the streams feeding out of the area.

At this point it is too late to produce a normal rehabilitation plan as decisions have been made and implemented which are economically irreversible. In general what needs to be done now is to collect sufficient information to allow design of a rehabilitation and reclamation scheme which will be compatible with existing conditions and the desired end land use but at the same time be within reasonable economic limits.

The objectives of the rehabilitation plan are to:

1) reduce or prevent erosion
2) protect watersheds from siltation or chemical contamination
3) reduce the impact on the aesthetics of the area
4) return the area to an appropriate land use.

The first two objectives are probably the most important for they are the key to the success of the others. However to meet these objectives requires that:

1) the surface is sufficiently stable for plants to establish and grow
2) the surface material is suitable both chemically and physically for plant growth
3) seed of species adapted for growth in that area is available in adequate quantities.

To date we have no information on the status of a rehabilitation plan. Therefore we must proceed under the assumption that there is no plan or that it is in an early stage of development. In the absence of guidelines, we have assessed the requirements within the framework of our past experience and from governmental guidelines for rehabilitation planning in Alberta.

The essential baseline data required to develop a rehabilitation plan can be categorized into two components: geotechnical and revegetation. We view the following data as essential to development of a rehabilitation plan:

1) Geotechnical

a. Permafrost regime - The behaviour of the permafrost under the tailings and waste disposal areas must be determined. If the permafrost table is moving up into the tailings, the recontouring plan adopted will be very different from that which will be required if it is degrading under the piles. The permafrost conditions can be determined by drilling a few test holes (about 4 to 8 at each location) and by relatively simple geophysical techniques.

b. Properties of natural soils - The soil profile and properties in conjunction with the geothermal regime must be known to assess long term stability. This can be accomplished by test borings, field tests and laboratory analysis.

c. Properties of waste and tailings materials - Sufficient sampling and testing of the waste and tailings material should be carried out to establish the range of engineering properties which must be taken into account in the stability analysis and design of rehabilitation measures. Classification and strength tests are required.

Once the thermal and soil conditons are established, the interrelationship of individual embankments (and effects of impounded water) and permafrost foundation may be analyzed to predict future thermal changes. This will permit evaluation of possible long term thermal equilibrium and its influence on the stability of existing dumps. Subsequently, the stability of the embankments may be assessed on a rational basis.

d. Flood-frequency curves for Clinton Creek and Wolverine Creek - The design of stable channels for the creeks requires the establishment of flood frequency curves and the selection of an appropriate design return period.

e. Orthophoto mosaic - An orthophoto mosaic should be developed for the entire mine area. The scale should be 1":500' (1:6000) with contour intervals of 25 feet (7.6 m). The existing surfical drainage patterns should be analyzed and illustrated on an overlay. This would serve as a base for stability analysis, and the development of recontouring and revegetation plans.

2) Environmental

a. Develop a detailed overlay of the lease area showing aerial extent and ages of waste and tailings piles. This will be used in the establishment of a sampling program to determine the chemical and physical properties of the various materials to be revegetated.

b. Sample and analyze waste and tailings piles to provide information on the following: lithology, rate of weathering, texture, cation exchange capacity, pH, sodium adsorption ratio, electrical conductivity, available nutrients (N, P, K, Ca, Mg, S), trace and potentially toxic elements (Fe, Mn, Bo, Cu, Zn, Cl, Cd, Ni, Na, SO_4).

c. Establish species, fertilizer and surface manipulation trials on materials identified from the above program to be suitable as a plant growth medium. This will be necessary to validate the revegetation specifications which should form a part of the mine abandonment plan. Because wildlife habitat is the projected end land use, test plantings should also be made of various tree and shrub seedlings and selected native species. Recolonization by native species should be encouraged as a part of the surface stabilization program.

RECOMMENDATIONS

Assuming that the essential data outlined in the previous section is obtained we recommend the following stabilization alternatives be investigated.

A. Clinton Creek

Stabilization of all waste embankments is not economically feasible. It is essential, however, that the dam be stable and that the reach of Clinton Creek affected by the waste pile be stabilized. This will be a difficult design assignment as it must be developed in a manner which will accommodate the moving mass. We recommend that consideration be given to a channel training works comprising a series of velocity barriers and bank and bed armouring. The outlet from Hudgeon Lake must be designed to accommodate the peak flow or modified to provide storage capacity and a regulated flow.

Some improvement in stability can probably be effected by recontouring portions of the waste pile but a considerable amount of investigation is required before a design can be developed. This design approach would necessitate periodic maintenance for several years.

We recommend that consideration be given to an alternative design which would extend the dam and raise the elevation so that the outlet and channel can be positioned at a higher elevation in natural soils. The channel should be designed to accommodate the peak flow determined from the flood frequency curve for the selected design return frequency. This alternative would require a thorough investigation to ensure that the relocated channel could accommodate the increased gradient. Concrete lining and energy dissipators may be required for the entire reach of Clinton Creek affected by the waste pile.

This design approach would allow a substantial buildup of waste materials at the toe of the embankments. The overall stability of the waste pile would be enhanced by the increased toe load (the top of the slopes could be unloaded in the process) and would provide a more suitable contouring for revegetation.

B. Wolverine Creek

We recommend that the channel of Wolverine Creek be designed to eliminate the possibility of contact with the tailings. This will require a substantial amount of recontouring of the tailings and either a culvert or open channel at a higher elevation. The design must be based on a thorough investigation as outlined in a previous section. Consideration should be given to construction of a small diversionary dyke upstream of the reach which could be affected by the tailings. The dyke would divert the drainage to a culvert or open channel above the present elevation of the stream bed. This would again allow increased toe loading as an aid to stabilization of the failed section.

We consider it likely that more failures will occur in the tailings before a rehabilitation plan can be finalized. Data gatherings from about 3 additional monitors, placed between 25 and 24 should be started immediately. Monitors should also be placed along a line north of the 1974 failure (approximately section 114,000 N). We also recommend that test borings and geophysical observations be made to investigate the permafrost conditions beneath and within the tailings pile in order to develop a recontouring plant before next spring.

C. Porcupine Creek

In our opinion this channel will not require extensive rehabilitation but this should be verified as a part of the detailed study. We recommend that consideration be given to building up the toe of the slopes along this reach by flattening the slopes at the top and recontouring to provide a suitable surface for revegetation.

D. Revegetation

The revegetation program could require several years of trials after the essential data have been collected. The results of current on-site revegetation trials may provide much of the necessary data required to develop a program. The information from these trials should be made available as soon as possible in order that it can be assessed relative to the development of a final revegetation scheme.

We recommend that the rehabilitation plan with respect to revegetation include the following:

1) A brief description and illustration of how re-contouring will be carried out to reconstruct and place the best material for revegetation on the surface to include:

- burial or blending of toxic or sterile material
- final slope angles of high walls, dumps and backfilled areas including rationale for slopes selected
- length of time between recontouring and seeding and/or planting
- representative cross-sections and longitudinal sections through the mining area showing the

distribution and composition of overburden following mining as well as the original, after mining and final land configuration. The final land use statement must be considered in selection of acceptable landscape features.

2) A surface drainage contour map or overlay showing the final anticipated contours and surface drainage pattern at a scale not smaller than 1 inch equals 500 feet (1:6000). Contour interval should not be greater than 25 feet (7.6 m).

3) A revegetation suitability overlay or map and accompanying descriptive summary based on:
   - anticipated chemical properties of the mine soil (reconstructed soil) - pH, exchangeable sodium, sodium adsorption ratio, electrical conductivity (EC), toxicity, fertility status
   - anticipated topographic factors - slope, aspect, elevation, micro-climate
   - anticipated physical properties of the mine soil (reconstructed soil) - texture, structure, bulk density, stoniness, colour, weathering rate.

   The revegetation suitability overlay or map should be used as the basis for developing and preplanning the revegetation program. Individual recontoured sites which have dissimilar characteristics (site limiting factor for revegetation - above items) will require specific revegetation prescriptions. A typical revegetation prescription should be developed, based on existing reclamation research and technology as indicated below.

4) A description of the revegetation prescription should include:

- combination of plant species to be seeded
- seedbed preparation methods including creation of micro sites to encourage seedling establishment
- seeding methods and time-tables
- combination of tree and shrub species to be planted
- location of tree and shrub plantings for various uses
- planting methods, spacing and number of woody plants to be used
- description of the method and time frame required to manage and maintain the initial vegetative cover to obtain soil stabilization and a self-sustaining plant community which will develop into a forest environment for wildlife habitat, and/or other use of at least equal productivity to that prior to mining.

5) A brief description and illustration of the planned progress of reclamation for all disturbed areas (roads, settling ponds, campsites, dumps, pits, diversion ditches, berms, etc.) following abandonment by:

-a series of diagrams by yearly intervals

- a time and sequence schedule bar graph.

All technical data for the rehabilitation plan should be included in appendices for reference. The body of the reclamation plan should consist of a written report interpreting the technical data accompanied by a series of overlays, maps, diagrams and mosaics.

Respectfully submitted,

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T2P 2W5

December 30, 1977

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"Second Report to Cassiar Asbestos Corporation Ltd. on Stabilization Measures for Mine Closure." (Final submission April 1977)

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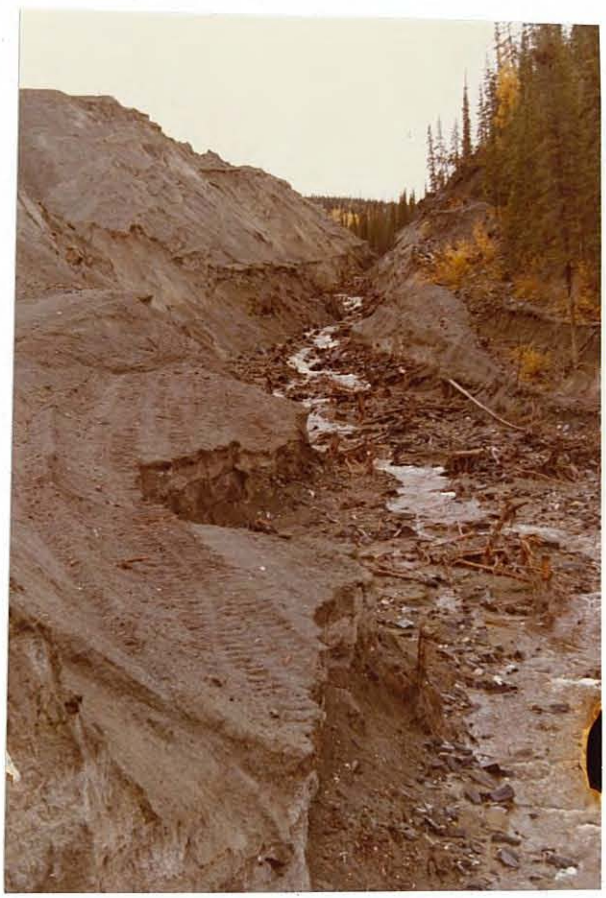
APPENDIX A

PHOTO DOCUMENTATION


№ 23 A 37389

#1 Failed portion of tailings embankment. Failure occurred in 1974. Cracks throughout the failed mass indicate current movement.



#2 Wolverine Creek Channel looking upstream. Eroded banks are fresh. Note recent slumping.

#3 Current tailings disposal at northwest end of embankment. Angle of repose is about 38°.

#4 Floodplain of Wolverine Creek downstream from tailings pile. Tailings were deposited after the embankment failure in 1974.

#5 West end of dam forming Hudgeon Lake.

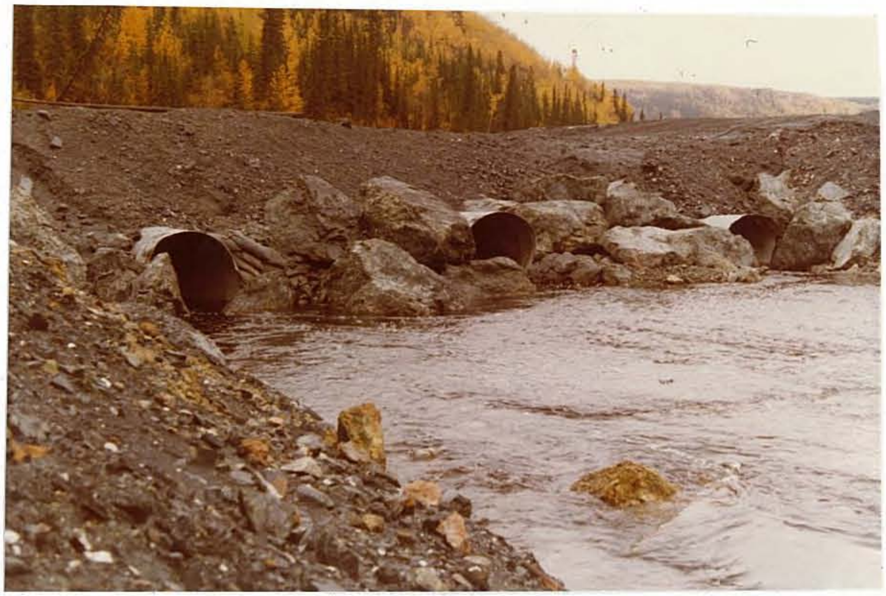
#6 Closeup view of surface cracks in waste embankment.

#7 Eroding bank at toe of waste-embankment along Clinton Creek.

#8 Eroding bank of natural slope immediately downstream from culverts.

#9 Clinton Creek looking upstream. Fines have been eroded from the toe of slope.

#10 Erosion from toe of slope during period of peak flow.



#11 Inlet of culverts draining Hudgeon Lake.

#12 Waste embankment on Porcupine Creek.

APPENDIX B

RESULTS OF LABORATORY TESTING

RESULTS OF STRENGTH AND CLASSIFICATION TESTS
TAILINGS AND OVERBURDEN WASTE

INTRODUCTION

Laboratory testing was undertaken to provide a general evaluation of the mechanical properties of representative samples of tailings and overburden materials obtained from the Clinton Creek Mine in the Yukon. The test results have been used to evaluate, on a preliminary basis, characteristics of waste and subgrade materials, environmental and other geotechnical aspects of the project.

Tests, conducted in the R. M. Hardy and Associates Ltd. laboratory in Calgary, included moisture content, Atterberg Limits, grain size distribution and direct shear strength determinations. All tests were run in accordance with the American Society for Testing and Materials (A.S.T.M.) specifications. These are listed in Table 1.

TABLE 1

Testing Specifications

Test	Specification Used		
Moisture Content	A.S.T.M.[1]	D2216-63T	(1963)
Atterberg Limits (plastic)	A.S.T.M.[2]	D424-59	(1971)
(liquid)	A.S.T.M.[3]	D423-66	(1972)
Sieve	A.S.T.M.[4]	D422-63	(1972)
Hydrometer	A.S.T.M.[4]	D422-63	(1972)
Direct Shear Strength	A.S.T.M.[5]	D3080-72	(modified)

[1] Laboratory Determination of Moisture Content of Soil

[2] Test for Plastic Limit and Plasticity Index of Soils

[3] Test for Liquid Limit of Soils

[4] Particle Size Analysis of Soils

[5] Direct Shear Test of Soils Under Consolidated Drained Conditions

TEST PROCEDURES AND RESULTS

Moisture content, Atterberg Limits and grain size distribution test results are shown on Plates 1 and 2. Moisture content is the ratio of the weight of water contained in a sample to the over-dry sample weight. The moisture content for both material samples is 9.0%.

The plasticity index of a material is the liquid limit minus the plastic limit. The liquid limit of a material is expressed as the water content at which two halves of a soil cake will flow together for a distance of 0.5 in. (12.7 mm) along the bottom of the groove separating the two halves under specified mechanically induced vibrations.

The plastic limit of a material is the lowest moisture content at which the material can be rolled into threads 0.125 in. (3.175 mm) in diameter without the threads breaking into pieces.

The plasticity index for the overburden material is 8.6. The liquid limit and plastic limit is 27.3 and 18.7 respectively. According to the Modified Unified Classification System for Soils the remolded material exhibits characteristics of a low plastic inorganic sandy clay.

Grain size distribution is calculated from two methods as described below. The distribution of particle sizes larger than 0.375 in. (9.525 mm) is determined by standard sieving while the distribution of particle sizes smaller than 0.375 in. (9.525 mm) is determined by a sedimentation process, using a hydrometer. The resulting grain size curves show that the overburden sample is composed of particles corresponding to 52.5% sand size, 31.5% silt size and 16% clay size. This material breaks down rapidly by slaking. These results cannot be considered representative of the mass but only of the sample tested for strength properties. The tailings material contains 59% sand sized particles, 34% gravel sizes and 7% fine sizes. This material (predominately serpentine) is the most stable of the overburden wastes and is therefore more representative of the mass of tailings.

Direct shear strength tests were conducted on both remolded samples. The results including visual descriptions and shear stress versus horizontal displacement and shear stress versus normal stress curves are shown on Plates 3 and 4. The tests were oriented towards determining the residual shear characteristics of the materials and thus peak shear properties are only approximate.

Preparation for direct shear testing involved trimming the specimen to tightly fit a 2.36 in. (60.0 mm) square box. The shear apparatus was then mounted in the shear testing machine, submerged, and the specimen consolidated under a normal load.

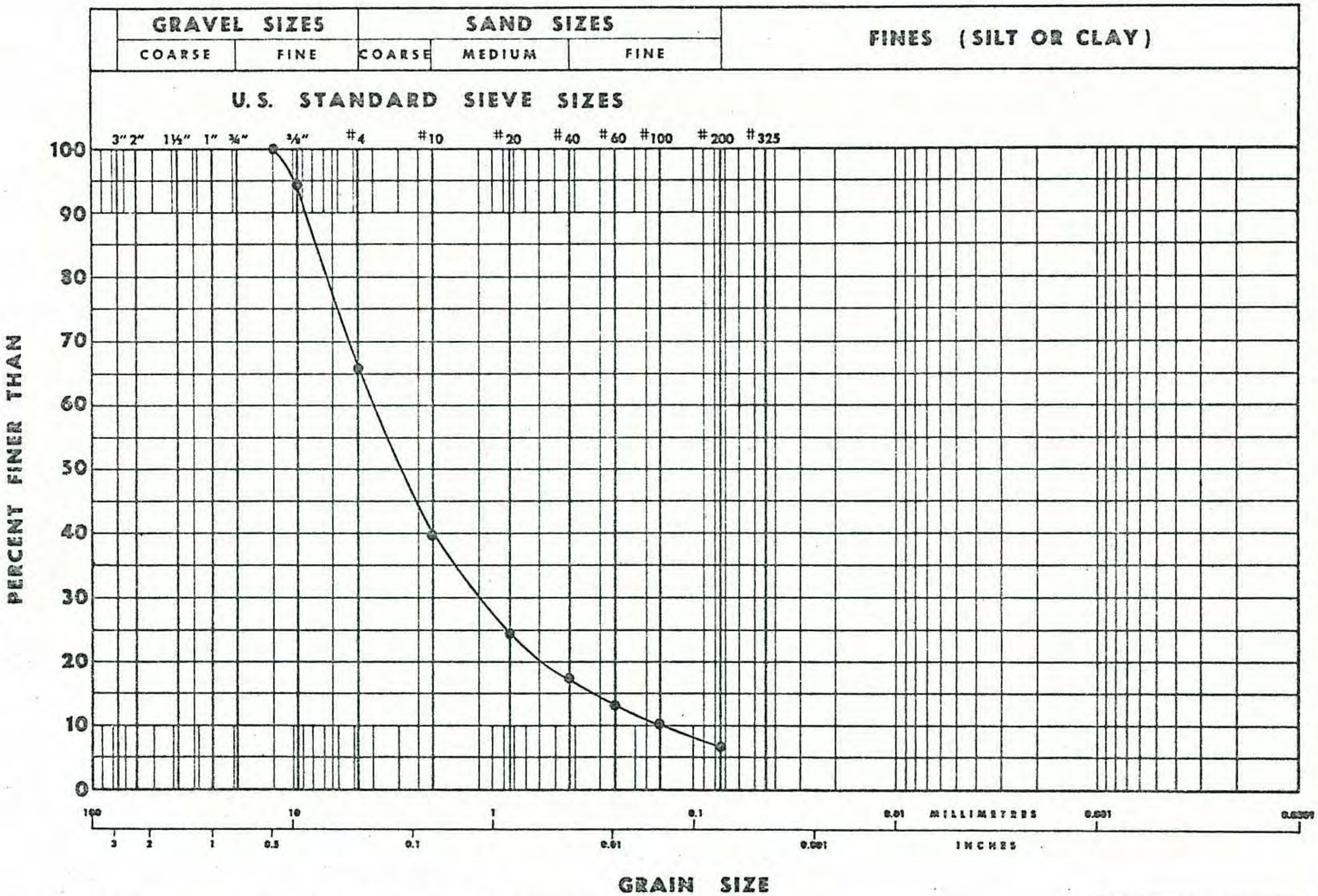
The testing procedure is detailed below. The specimen was initially sheared forward until 0.3 in. (7.6 mm) horizontal displacement occurred. The shear motion was then reversed and the specimen was sheared backwards until the horizontal displacement was -0.3 in. (-7.6 mm). Finally, the specimen was sheared forward at a reduced rate until it passed the starting point. The resulting shear stress at zero horizontal displacement indicates the residual shear strength at that normal load.

The tailings material was tested at two normal loads (σ_n = 69 KPa (10 psi) and 207 KPa (30 psi) and the overburden sample at three normal loads {σ_n = 138, 276 and 414 KPa (20, 40 and 60 psi)}. Generally, only one specimen was necessary for all normal loads, however, in one case lifting problems required the preparation of two specimens.

Results indicate the residual angle of shear resistance (ϕ_L) is 30 and 23 degrees for the tailings and overburden materials respectively.

Residual cohesion values are close to zero for both materials. (Cohesion in terms of effective residual strength for these materials is expected to be zero.) Cases where greater than zero cohesion has been obtained may indicate that the pore pressures have not fully dissipated during testing.

The rate of shear varied depending upon the degree of perviousness of the samples, however, it was expected to be slow enough to allow the natural dissipation of increase in pore pressures.



REMARKS:

Gravel Size 34%

Sand Size 59%

Fines 7%

Moisture Content 9.0%

D_{10} =	MM.
D_{30} =	MM.
D_{60} =	MM.
C_U	
C_C	

NOTE: UNIFIED SOIL CLASSIFICATION SYSTEM

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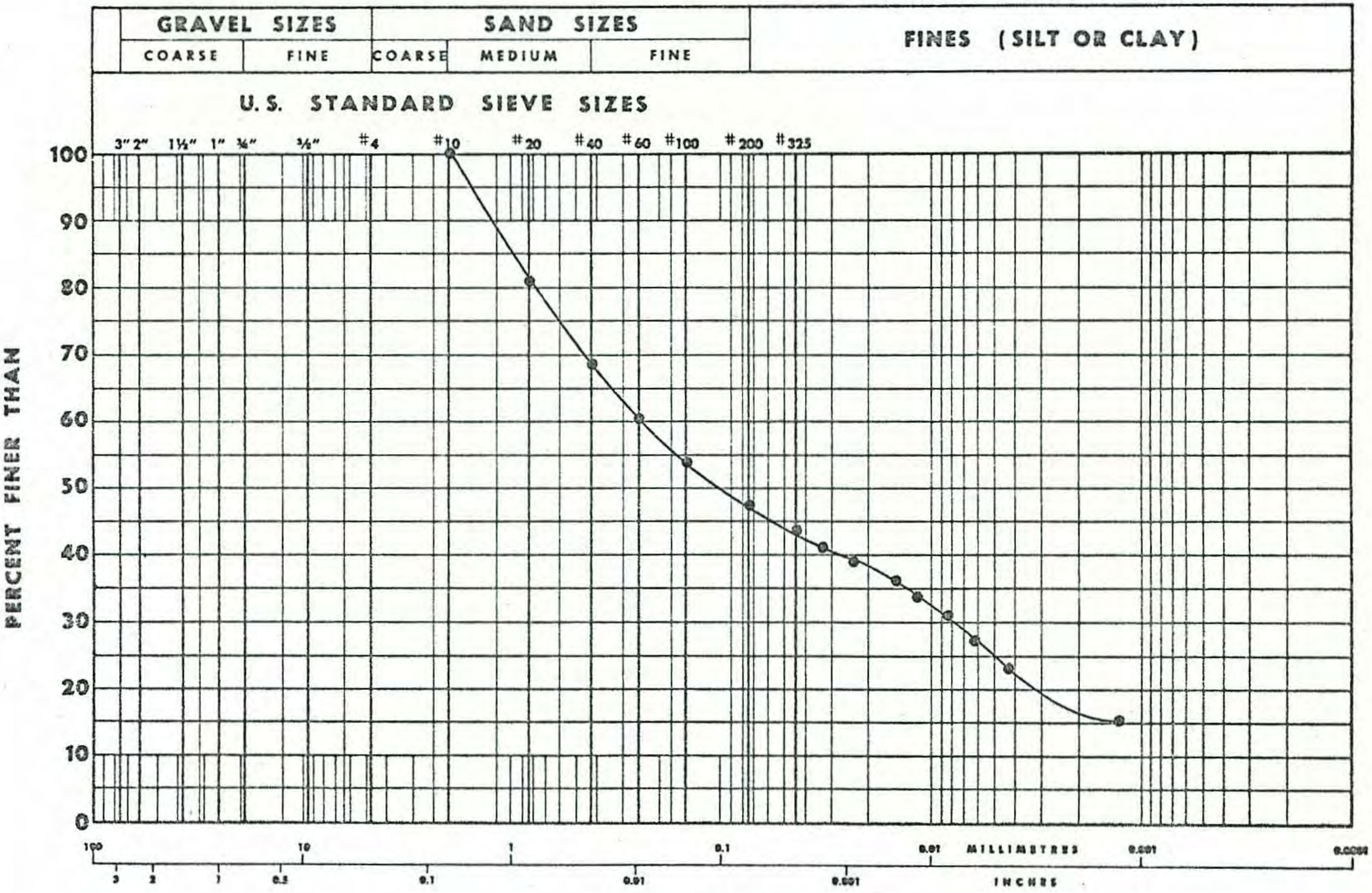
CONSULTING ENGINEERING & TESTING

GRAIN SIZE CURVE

LAB ORDER NO. K 3986
CLIENT Clinton Creek Mine
SAMPLE #1
SOURCE Tailings
TECHNICIAN M.L.
DATE TESTED 10/12/77

PLATE 1



REMARKS: Liquid Limit 27.3 Sand size 52.5%

Plastic Limit 18.7 Silt size 31.5%

Index of Plasticity 8.6 Clay size 16%

Moisture Content 9.0%

NOTE: UNIFIED SOIL CLASSIFICATION SYSTEM

D_{10} =	MM.
D_{30} =	MM.
D_{60} =	MM.
C_U	
C_C	

R.M. HARDY & ASSOCIATES LTD.
CONSULTING ENGINEERING & TESTING

GRAIN SIZE CURVE

LAB ORDER NO. K 3986
CLIENT Clinton Creek Mine
SAMPLE #2
SOURCE Overburden
TECHNICIAN M.L. DATE TESTED 10/12/77

PLATE 2

SUBSTRATE AND TISSUE ANALYSIS

Samples of both tailings and waste dump materials and tissue samples from plants growing adjacent to the tailings heap and near the townsite of Clinton Creek were taken while on site in September and shipped to our Edmonton Analytical Chemistry Laboratory for analysis. Because of the general lack of research in the area of plant toxicities, differences in analytical technique and the wide range of tolerances that various species exhibit, it is difficult to say with certainty the levels of various elements that will retard plant growth or actually cause plant damage or death. The following comments on specific aspects of the analysis are based on an interpretation of the available literature.

TAILINGS

The results of the chemical analysis of the mine tailings were typical for a serpentine rich material, showing high concentrations of nickel and magnesium and low levels of the major fertilizer elements N, P and K. In addition sulphates were found in what appear to be extremely toxic levels (Table 1).

The few studies reported on nickel toxicity (Chapman) 1966 suggest that concentrations of exchangeable nickel anywhere from 3 to 70 ppm are excessive and may be toxic. The analysis of the mine tailings shows a concentration of 39 ppm which suggests that it is potentially toxic. The tailings sulphate levels of 17,000 ppm are believed to be highly toxic. Although there are no reported studies of the effects of this high a concentration, levels of 5000 to 7000 ppm have been shown to reduce plant growth by 40 to 50% (Chapman 1966).

The excessive magnesium levels in the tailings are not so much a toxicity problem as one of nutrient imbalance. Studies have shown that wherever magnesium occupies over 90% of the sites on the exchange complex there are severe reductions in plant growth. This is believed to be related to extreme calcium deficiency (Walker 1955). There is limited information which suggests that this and nickel toxicity may be corrected by liming (Hunter and Verganano 1952); however much more work is needed in this area before this could be applied as a general principle.

The major fertilizer elements N, P and K are at levels too low to sustain plant growth. If an adequate cation exchange capacity can be developed (see next section) this problem can be overcome by the application of N, P and K at 90, 90 and 170 kg/ha respectively.

OVERBURDEN

The overburden material does not appear to pose any toxicity problems. Like the tailings material it exhibits low levels of the major fertilizer elements N, P and K. These deficiencies can be overcome by fertilizing if an adequate cation exchange capacity can be developed. The cation exchange capacity is an index of the amount of colloidal material in a soil capable of holding nutrients and moisture. Without this colloidal material, water and any applied nutrients move quickly through the system and are unavailable for plant use. The cation exchange capacity will be reduced proportional to the amount of material larger than 2 mm in a given sample. However the results do suggest that fines are present from which a cation exchange capacity can be developed and that the materials as deposited appear to weather rapidly.

TISSUE ANALYSIS

While on site in September obvious differences in the health of species adjacent to the tailings heaps and near the townsite were noted and tissue samples collected for analysis. Because of the known serpentine origin of the ore body it was suspected that plant health might suffer due to a Ca/Mg imbalance and potential nickel, chromium or zinc toxicity. In addition it was felt that excessive salts could pose a problem and sodium and chlorides were added to the list of elements for analysis. At that time it was not suspected that sulphates were a potential problem and they were not included in the analysis.

As suggested by the soil analysis neither sodium nor chlorides appear to pose a problem (Table 2). The uptake and concentration in plant tissues of sodium at 50 to 90 ppm and chlorides at 110 to 8600 ppm is below that generally reported in the literature as resulting in reduced plant growth (Chapman 1966).

The calcium levels in the plant tissues appear to be generally in the intermediate ranges found for plants of this type. The magnesium levels however are consistently much higher than normal on the tailings site though the literature is too scanty to determine if these levels are actually toxic. As in soils, the Ca/Mg ratio is more diagnostic than absolute tissue levels of either element. In general, plants having adequate levels of calcium have a Ca/Mg ratio of greater than one. As this ratio falls below one, Ca deficiency and/or Mg toxicity begin to occur (Wallace et al. 1968, Walker 1954). The point at which damage begins

Table 1. Chemical analysis of tailings and waste rock overburden (primarily argillite) from Cassiar's Clinton Creek Mine.

Analysis	Units	Tailing		Overburden	
		Value	Comments	Value	Comments
pH (aqueous)		8.39	moderately alkaline	7.48	slightly alkaline
Conductivity	mS/cm	0.95	no problem	1.75	no problem
Sodium Absorption Ratio		0.19	no problem	0.58	no problem
Exchangeable Cations:					
Sodium	me/100 g	0.02	no problem	0.06	no problem
Potassium	"	0.01	deficient	0.12	deficient
Calcium	"	0.9	deficient	38	no problem
Magnesium	"	42	excessive	2.8	no problem
Chromium	µg/g	<0.1	no problem	<0.1	no problem
Nickel	"	39	potentially toxic	0.65	no problem
Zinc	"	<0.2	no problem	0.65	no problem
Cation Exchange Capacity	me/100 g	42.5	moderate	41.6	moderate
Exchangeable Sodium %		0.05	no problem	0.15	no problem
Chloride	µg/g	42.5	high but non-toxic	42.5	high but non-toxic
Sulphate	"	17,000	excessive - likely toxic	200	low to moderate
Nitrate - N	"	3.5	deficient	2.5	deficient
Available Phosphorus	"	<1.5	deficient	<1.5	deficient
Boron (hot water soluble)	"	4.8	potentially toxic	0.8	no problem

Table 2. Chemical analysis of tissue samples of several plant species grown in the vicinity of the townsite of Clinton Creek and adjacent to the mine tailings heap.

		Ledum sp.		*Vaccinium* sp.		*Populus* sp.		*Carex* sp.
Sample	Units	Tailing	Townsite	Tailing	Townsite	Tailing	Townsite	Tailings
Sodium	µg/g	61	90	50	83	54	65	75
Calcium	"	3830	3480	3360	16300	6890	3440	2580
Magnesium	"	5960	3140	16200	6120	8780	2510	7370
Chromium	"	11.5	3.7	36	3.7	15	6.2	30
Zinc	"	31	32	24	386	218	23	73
Nickel	"	24	4.3	80	4.6	41	6.7	70
Chloride	"	960	1030	110	8600	1010	500	220

to take place has not been established for most plants. It is known that a ratio of below .2 results in serious calcium deficiencies in lettuce and tomatoes (Walker 1954). On the tailings site all of the tissues analyzed had a Ca/Mg ratio below 1, however only *Vaccinium* sp. and *Carex* sp. at .20 and .35, respectively, had levels which approached those reported as growth limiting for tomatoes and lettuce.

The levels of zinc within the tissues varied between sites, generally being below 40 ppm but reaching levels of 200 to 400 ppm for two species. The literature is sparse concerning this element but does suggest that tissue levels of from 30 to 200 ppm are intermediate with levels above 400 potentially toxic (Chapman 1966).

Similar to vegetation grown on serpentine soils (Walker 1954) tissue levels of chromium and nickel were consistently higher in the vegetation adjacent to the tailings site averaging 23.1 and 53.7 ppm, respectively, versus 4.3 and 5.2 ppm for vegetation near the townsite. The tissue levels in plants adjacent to the tailings heap are in the high range for both of these elements and in some cases may be at toxic levels.

As can be seen from the foregoing, the available literature is too incomplete to determine from tissue analysis alone the causes of the observed plant toxicity symptoms on the Cassiar Mine site. These analyses do show that adjacent to the tailings certain elements are being accumulated in tissues at levels that would be toxic for some plants. It should also be kept in mind that the plants exhibiting these toxicity symptoms are not growing on the tailing heap itself, a material which analysis has shown to be definitely toxic, but on undisturbed native soils adjacent to the tailings. This strongly suggests that the increased tissue accumulations have occurred due to movement of tailings material by wind or water onto the adjacent soils. The maximum distance of this impact from the tailings heap and the amount and rate of accumulation of various potentially toxic elements in plant tissue leading to injury are unknown at this time.

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