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*Mines Branch Program
on Environmental Improvement*

**FIELD OBSERVATIONS CONCERNING
DRAINAGE FROM TAILINGS DISPOSAL AREAS**

by

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MINERAL SCIENCES DIVISION

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Mines Branch Investigation Report IR 74-52
FIELD OBSERVATIONS CONCERNING DRAINAGE
FROM TAILINGS DISPOSAL AREAS

by
A. Jongejan*

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SUMMARY

Field work in connection with the study of the processes involved in the weathering of tailings disposal areas was done in a part of N.E. Ontario and N.W. Quebec.

This work covered a) experiments concerning the collection of samples of drainage water and samples of tailings from various types of locations, b) the collection and storage of samples of the microbiological population of the waters, c) the chemical analysis of the water samples, and d) the preliminary determination of the extent of water pollution due to the seepage of acid water from tailings in the relevant area, and the determination of the feasibility of a detailed study of one particular area.

The experiments in connection with the collection and analyses of various types of samples were generally successful. Only a few points for improvement were indicated.

The feasibility of either surveying the extent of water pollution due to acid drainage or of studying one tailings area in greater detail was demonstrated.

The most important factual results of the study were the following: a) The effect of the addition of lime on the pH of the water decreases rapidly. This observation confirms the same result obtained experimentally in the laboratory. b) The phenomenon that the acidity of the drainage water increases up to a certain distance after it has seeped out from the tailings area may be more widespread than is realized. This phenomenon may originate in the particle size distribution of the tailings minerals. c) Although a few tailings areas produced acid water, the extent of the pollution seemed limited due to the low amount of solutes in the water.

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Direction des Mines
Rapport d'investigation IR 74-52

OBSERVATIONS D'UNE ENQUETE SUR LE DRAINAGE DE REGIONS
CONTENANT DES DEPOTS DE RESIDUS

par

A. Jongejan*

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RESUME

Une enquête sur le terrain a été menée afin d'étudier les processus d'altérations sur des dépôts de résidus de certaines régions du nord-ouest québécois et du nord-est ontarien.

Ce travail comprenait a) des expériences sur la cueillette d'échantillons d'eau de drainage et sur des échantillons de résidus de différents types d'emplacements, b) la cueillette et le remisage d'échantillons de la population microbologique des eaux, c) l'analyse chimique des échantillons des eaux, et d) une détermination préliminaire de l'étendue de la pollution causée par la fuite de l'eau acide des résidus de la région désignée, et la possibilité d'entreprendre une étude détaillée d'un site particulier.

Les expériences faites en rapport avec la cueillette et les analyses des différents types d'échantillons se sont avérées, en général, un succès. Quelques points seulement étaient susceptibles d'améliorations.

Il a été démontré que c'était possible d'examiner l'étendue de la pollution de l'eau causée par l'acidité ou d'étudier un dépôt de résidus plus en détail.

Les résultats réels les plus importants de l'étude ont été les suivants: a) une rapide diminution de l'effect produit sur le pH par l'addition de chaux; cette observation confirme les mêmes résultats obtenus en laboratoire; b) le phénomène de l'augmentation de l'acidité dans l'eau de drainage après qu'elle ait été

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filtrée des résidus semble plus répandu qu'on^{ne} le réalise.
L'origine de ce phénomène est la granulométrie des minéraux
résiduels; et c) même si quelques dépôts de résidus produisent
de l'eau acide, l'étendue de la pollution semble limitée à
cause de la petite quantité de minéraux solubles dans l'eau.

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INTRODUCTION

A reciprocal relationship exists between the experimental study on the weathering of mill tailings done in the laboratory, and field observations made in tailings disposal areas. The latter serve to obtain impressions about processes that may take place. These possibilities can then be supported by evidence established by experiments, which, in turn, can detect the role of factors that have been overlooked in the field. Observations made in various tailings disposal areas during the summers of 1971 and 1973, were limited due to the lack of equipment required for detailed field studies.

In this field-work a search was made, particularly, for a small tailings pond in N.E. Ontario and N.W. Quebec that might be suitable for a detailed field study. The requirements of a tailings pond suitable for field study, at this stage of the project, are:

- a) The tailings composition should contain sulphides and carbonates.
- b) The tailings should produce acid drainage.
- c) The size of the pond should not be much larger than one square mile.
- d) The drainage should flow off into a nearby river.
- e) The tailings pond should not be in active operation.
- f) The sedimentation area of the tailings preferably should not be controlled by embankments or other management methods.

The area between Towns No. 0 and 2* had appeared promising in this respect. It contained at least two ponds that could fulfil these requirements as well as another pond that produced drainage water having a pH = 5.6 as compared with pH = 3.0 of the former. The particular nature of the microbial population in the drainage water sample having a pH = 5.6 suggested that the acidity might originate in the action of the micro-organisms rather than primarily in the particular mineral composition of the relevant tailings.

*Particular locations are indicated by a number because of the confidential nature of the observations detailed in this report, and because they are not relevant to the results of the observations.

Because of information that one of the two aforementioned tailings ponds, having a pH = 3, would be reactivated by resumed mining operations, it was considered unsuitable for study. The results of experiments done in the laboratory had suggested that any mechanical disturbance of the tailings after sedimentation would alter the composition of the drainage water. This suggestion was supported by the evidence that the composition of the drainage water from the tailings pond of the mine that would be reactivated had changed significantly after the drainage ditch had been cleaned out. The effect is shown in Table 1. The increase in the amount of solutes was produced by fresh mineral grain surface areas that had become exposed.

TABLE 1
The Effect of Mechanical Disturbance of a
Tailings Deposit on the Composition of the Drainage Water*

Drainage	Composition in ppm							
	Na	K	Ca	Mg	Fe	Si	Cu	Zn
Before	46	3.3	172	64	39	18	0.5	32
After Mechanical Disturbance	120	10	323	78	80	25	1.2	38

Because the tailings areas between Towns No. 1 and 2 had not been visited to the same extent as those around Timmins, Kirkland Lake and Rouyn, the objectives of the field work during the summer of 1974, were the following:

- a) Experiments should be done concerning the collection of four types of samples: 1) samples of drainage water, 2) samples of tailings at various depths of the pond, 3) samples of drainage water at various depths within the tailings pond, and 4) samples of the microbial population.

*The chemical analyses were done by Mrs. V.H.E. Rolko, chemist, Mineral Sciences Division, using atomic absorption spectrophotometric techniques.

- b) The use of methods and equipment for the chemical analyses of drainage water in the field, as well as the methods for storage of microbial samples that had appeared promising in the laboratory, had to be checked in practice. The analyses of tailings as well as the determination of microbial species could only be done in the laboratory, although it is feasible to start work on the latter in the field with improved field equipment
- c) The results of the chemical analyses of the drainage water samples in the field should be used to establish the extent of water pollution due to seepage from tailings ponds in the relevant area.
- d) An attempt should be made to obtain information about the structure and composition of the tailings pond that produced drainage water having a pH = 5.6 and contained dissolved sulphides.
- e) The search for a tailings pond meeting the requirements for a detailed study should be extended.

METHODS AND RESULTS OF RELEVANT EXPERIMENTS

General procedure

All water samples were analyzed in the field within 6 hours after collection, except where indicated otherwise.

The pH and conductivity of a water sample were measured using, respectively, a Sargent Welch, Model PBX, pH meter, and a Delta, Model 1114, conductivity meter. Subsequently, the microbial population was collected from a part of the sample by filtration. This resultant sterile filtrate was then used for the chemical analyses.

Chemical analyses

Delta's field titration outfit No. 412, Hach's DR/2 spectrophotometer and Hach's methods for the determination of calcium, magnesium, total iron, ferrous iron, copper, zinc, sulphate and sulphide⁽¹⁾ were used. Although chemicals for the determination

of phosphate, nitrate and silicate were available and had been experimented with in the laboratory, they were not used due to lack of time.

Most of the samples that contained a very high concentration of iron took a long time to analyze because of the need for the removal of iron by filtration, and it was clear that the method for filtration should be improved.

Collection of microbiological samples

Field methods for the collection of micro-organisms were applied using Millipore's filtration apparatus, membrane filters and pads. Six different types of nutrient broths had been prepared in the laboratory. Two ml of each was used for the collection of a particular part of the microbial population. The 2-ml portions had been stored in sealed ampules. This number of nutrients was considered capable of collecting most species of micro-organisms. However, because this number of nutrients could be expected to be impractical for future use, two other types were used in order to obtain information on the possibility of reducing this number in future field work.

The six standardized types of nutrients included the '9K' broth for the collection of "iron bacteria", pH = 2.5 (F1)⁽²⁾, a nutrient to collect "sulphur bacteria", pH = 4.0 (F2)⁽³⁾, the standard "Total Count" nutrient (F3)⁽⁴⁾, a modified "Triple Sugar" broth (containing no thiosulphate or ferrous ions) (F4)⁽⁵⁾, a nutrient for the collection of yeasts (F5)⁽⁶⁾ and a nutrient for the collection of molds (F6)⁽⁷⁾. The references indicate the types of nutrients that were used and not the exact compositions. These nutrients were prepared from standard solutions that had been developed in laboratory experiments. This subject will be dealt with in a future report describing the results of the microbiological work.

Culture tubes containing 4 ml dilute (1:100) 14 broth and 0.25 g finely ground (1 μ) pyrite were used experimentally as a substitute for the combination of F1 and F2 nutrients. Because

the resultant composition is essentially that of F1, containing a high concentration of iron, it has been indicated as Fp. It appears that more work will have to be done concerning the most suitable composition of a substitute for F1 and F2 nutrients.

A commercially available "Yeast and Mold" broth (Millipore)⁽⁸⁾ was used experimentally as a substitute for the F5 and F6 nutrients. The disadvantage in this combination is the often heavy growth of molds that obscures the presence of yeasts. The information on the presence of both types of micro-organisms is important because of the available evidence⁽⁹⁾ that certain species of yeasts may promote the action of Thiobacilli, while certain species of molds may impede their action.

The number of nutrients to be used in field work should preferably be reduced to a maximum of three types for practical purposes.

The filters carrying the micro-organisms were transferred in the laboratory to culture tubes containing 4 ml of the same nutrient broth as was used in the field. One part of each broth was plated in dilutions, 5×10^{-2} , $(5 \times 10^{-2})^2$, $(5 \times 10^{-2})^3$ and $(5 \times 10^{-2})^4$. Another part was freeze-dried for possible further study.

The micro-organisms stored in the F1 and F2 nutrients were transferred to Erlenmeyer flasks containing 10 ml fresh F1 and F2 nutrient. The presence of "iron and sulphur bacteria", respectively, was established by determining the reduction of ferrous iron (F1) and thiosulphate (F2) by titration.

The terms "iron and sulphur bacteria" have been used for convenience. They do not restrict the meaning to particular microbial species, but rather to their particular metabolic activities involving the relevant compounds. Various species can be expected to be present; if not in each, then certainly in different samples. The principal problem is to collect as many species of micro-organisms as possible with one nutrient. The experimental nutrient (Fp) that contained pyrite and that had developed a pH of approximately 3 to 4 due to dissolution of pyrite, apparently collected no micro-organisms that oxidized

thiosulphate, while it seemed to collect more micro-organisms that oxidized ferrous iron than the F1 nutrient. It is possible that thiosulphate is not oxidized in the presence of dissolved sulphides; and it has been established that the oxidation of ferrous iron is preferred over that of thiosulphate. Many of the iron bacteria collected in the Fp pyrite type of nutrient could not be subcultured in F1 broth* so that the nature of these micro-organisms is problematic. "Molds" had developed to a great extent, as was observed microscopically. The number of bacteria that were present was apparently small. A very similar combination was observed in the drainage water from Mine No. 8 (see pg 28).

The presence (+) or absence (-) of micro-organisms that oxidize ferrous iron and/or thiosulphate in, respectively, F1 and F2 broths added to the F1, F2 and pyrite-type collector nutrients is shown in the relevant tables in this report under columns indicated as F1, (F1 nutrient added to micro-organisms collected in the F1 nutrient), F1p (F1 nutrient added to micro-organisms collected in the field using the pyrite type of nutrient), and, similarly, F2 and F2p.

The presence of Enterobacters was established by inoculating lauryl-tryptose (LT) broth with the relevant F3 cultures and, subsequently, plating the LT cultures on Levine's E.M.B. agar. Colonies, developed on this agar, were examined microscopically, for further confirmation, and were used in conjunction with Enterotubes (Hoffman-laRoche).

Although a procedure for the determination of micro-organisms in core samples has been developed in the laboratory, no work was done in this respect because the study was not intended to produce detailed results. Identification of all collected species is a major undertaking and not essential in the objectives outlined on pp 2 and 3. Particularly, the separation and identification of various species of iron and sulphur bacteria is tedious and time consuming.

*These cases have been indicated by (+) in the Tables.

The collection of tailings samples

Core samples of tailings were collected using an Oakfield soil sampler which proved to be very effective. Unfortunately, the depth of the tailings that could be sampled was restricted to 3 ft. An unduly long delivery time had prevented the acquisition of accessories for the collection of samples from greater depths. However, a collection of samples from greater depths can be expected to be successful using this sampler as long as the layers of the tailings do not contain a great deal of water so that the tailings begins to flow.

The collection of water samples

During previous field work, difficulties were experienced in obtaining water samples from several locations. Shallow pools could not be approached because of the muddy consistency of the tailings. Similar difficulties were experienced in locations where the drainage creeks had developed into fair streams. The banks were often too soft to stand on.

Consequently, an apparatus to overcome these difficulties to a certain extent, was developed by the Technical Services Division* from a sketch indicating the basic principles of its operation.

It consists essentially of 4 pieces of 3 ft long, 1 inch diameter, aluminum conduit tubing which can be connected to each other using a bayonet fitting attached to stainless steel inserts. These inserts serve not only as connectors for the aluminum tubes, but they also carry a 1/4 inch diameter stainless steel tube. This tube acts as a suction line between a plastic hand-pump fastened to the aluminum tube near the handle of the apparatus, and a replaceable one-liter plastic sample bottle snugly held in a stainless-steel basket on the collecting end of the apparatus. When suction is applied, water flows into the bottle through a stainless-steel syphon fastened to the bottle

*C. Jermy, Engineering Technologist, Technical Services Division, Mines Branch, Department of Energy, Mines and Resources.

using a teflon plug and special cap. The syphon extends slightly below a mudplate attached to the bottom of the basket. A valve arrangement serves to indicate when the bottle is filled in deep water and it prevents contamination of the suction line. After collecting a sample, the bottle containing the sample is stored and for each sample a separate bottle is used.

Using this apparatus it was possible to collect water samples from locations up to a distance of approximately 10 ft either from pools having a minimum of 1/4 inch of water or from river beds approximately 10 ft deep.

The apparatus worked very satisfactorily; approximately 80% of the samples could not have been collected without its use.

Several syphon tubes were available for the purpose of sterilizing the intake. An alcohol burner was used for this purpose. However, this aspect did not appear to be practical in the field because of the extremely windy conditions on the ponds. Another method of sterilizing the tubes will have to be developed.

The collection of water samples from various levels of the tailings ponds

An arrangement to collect water samples from different soil levels was used. Since it was originally designed⁽¹⁰⁾ for the collection of water samples in soils in areas of intermittent rainfall, its use was restricted to levels that had not become waterlogged.

It consists essentially of a one-liter plastic bottle having a funnel-shaped top which contains a breather tube. The inside diameter of the latter is sufficiently large to allow the insertion of a tube having a smaller outside diameter through which the sample can be pumped up. The bottle is placed in a hole drilled with an auger to a depth from which the sample has to be collected. The material removed by the auger is treated as a core sample which is repositioned after placing the bottle at the bottom of the hole. The apparatus performed satisfactorily in the tailings pond of the Mine No. 7.

The depth of the hole from which a sample can be collected is restricted by the solidity of the tailings. A similar restriction was involved in the use of the tailings sampler described on pg 7. A layer approximately 2 in. thick at a depth of approximately 2 1/2 ft in the tailings pond of the Mine No. 7 flowed too slowly to fill the hole and prevent deeper penetration. However, at a depth of 6 ft, a layer was cut that flowed to the extent that the collection of samples from lower levels was prevented.

In order to obtain water samples under these conditions from deeper levels, another type of sampler is being developed. Several stages of experimentation were involved in the construction of the water sampler; difficulties were encountered at each stage and had to be solved. The development of this new sampler to a satisfactory level of performance will require much time as it will involve the simulation of tailings pond conditions.

RESULTS OF FIELD OBSERVATIONS

Description of the drainage relations of various tailings areas

The major belt containing the ore deposits between Towns No. 1 and 2 lies in an E.W. direction and covers a distance of approximately 20 miles. The tailings areas from the mines drain into creeks that flow roughly in the same direction. These creeks eventually flow into River No. 1 that flows in the N.S. direction. The general situation of the area is shown on Figure No. 1.

Water draining from tailings areas of various mines, as well as water from various locations in the drainage basin that would be indicative for the extent of possible pollution, were sampled and analyzed. The particular locations of the samples are indicated in Figure 1 by their sample numbers, which are also used in the following description:

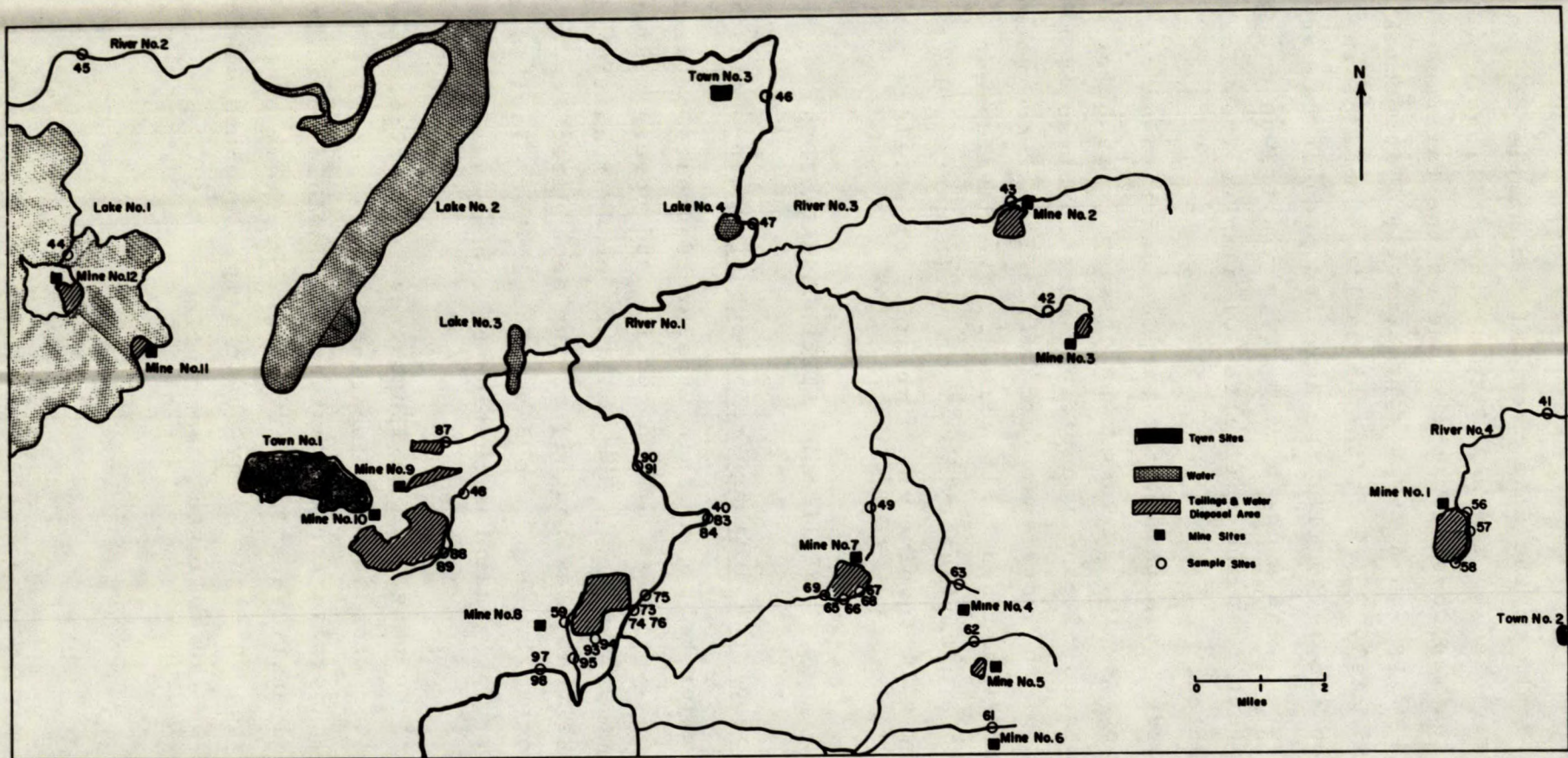


Figure 1. Area Covered by Field Observations.
 Numbers refer to those used in the text.

a) Drainage water from the abandoned gold Mine No. 1 flows into the small river No. 4. The water sample collected at site No. 41 had a pH 6.7 and a conductivity of 52 micromhos. Since the pH had increased significantly from 5.6 near the site of Mine No. 1 to near neutrality, the conclusion was made that the extent of the pollution was limited (see under sub-heading 'The tailings area from Mine No. 1', pg 14). No attempts were made to follow the creek (river) because of the swampy condition of the terrain as well as from the point of view that this aspect of pollution had lower priority than that originating in acidity produced by the weathering of sulphides.

b) The tailings area of the abandoned gold Mine No. 2 drains into a side-arm of the small river No. 3. Drainage water in the low part of this area was collected from a gully at site No. 43 that flowed into the river at approximately 75 ft distance from this site. It appeared to have a pH = 6.6 and a conductivity of 51 micromhos.

The erosion patterns on this pond were impressive and suggested the process involved in the encroachment of natural vegetation on the pond. Shallow erosion gullies widen and deepen with the formation of small terraces similar to the geomorphology of actual rivers. Vegetation begins to encroach on the comparatively high and dry ridges between the erosion gullies (air-water balance).

A sample of water that drained from the nearby smaller tailings pond of Mine No. 3, collected at site No. 42, had a pH = 6.5 and a conductivity of 80 micromhos. Consequently, no pollution due to acid drainage from these tailings areas could be expected.

c) The tailings areas of the inactive gold Mines No. 11 and 12 border on lake No. 1. They are partly submerged. A water sample from the lake collected at site No. 44 near the causeway to the island on which Mine No. 12 is located, had a pH = 7.8 and a conductivity of 63 micromhos.

d) Water samples were collected from creeks in which drainage flows from tailings and other waste disposal areas of the following small abandoned mines:

The sample collected at site No. 61 represented drainage from gold mining operations No. 6. It had a pH = 6.9 and a conductivity of 34 micromhos.

The sample collected at site No. 62 represented drainage from gold mining operations No. 5. It had a pH = 7.1 and a conductivity of 40 micromhos.

The sample collected at site No. 63 represented drainage from copper mining operations No. 4. It had a pH = 6.5 and a conductivity of 355 micromhos. Its insignificant acidity and comparatively higher conductivity were attributed primarily to bog conditions around the sample site.

Consequently, no significant acid drainage from these small areas appeared to have developed.

e) Because the drainage waters from the larger tailings disposal areas of Mines No. 7, 8, 9, and 10 drain into river No. 1, water samples of this river were collected at several sites and analyzed. The results of the determinations are listed in Table 1.

Water of river No. 1 flows apparently via lake No. 2 where a sample was collected at site No. 45. The sample from site No. 40 was taken in a period of heavy rainfall, while samples No. 83, 84, 90, and 91 were collected in a comparatively drier period. Samples No. 83 and 90 were collected from the surface water and samples No. 84 and 91 from the water near the bottom of the river.

Since the acidity of the sample collected at site No. 46 could be attributed to bog conditions, it seems evident that the acidity of the river (samples No. 90-91) is neutralized in a comparatively short distance from the area into which acid waters from the tailings disposal sites of the Mines No. 7 and 8 drain. The conditions in that area are also affected by the presence of a forest-products plant just north of the location of the mines.

TABLE 1

Results of Determinations of Water Quality of Samples Collected from Various Locations
Along River No. 1 as Indicated in Figure 1

Sample Number	pH	Micro- mos	Composition in ppm						Actions of micro-organisms**				
			Ca	Mg	Fe	Cu*	Zn	SO ₄	F1	F1p	F2	F2p	
45	6.8	63				-							
46	5.3	86	10		0.1	-		50		-	-	-	
47	6.3	81	8		0.1	-		43		-	+	-	
90	7.3	32	5	4	0.5	0.01?	0.2	23		-	-		
91	6.85	28	3	3	0.6	-	0.1	22		-	-		
40	6.5	105	8		0.9	-	0.12	40		-		+	
83	5.7	65	4	4	3.5	-	0.18	55		-	-		
84	4.8	29	4	5	0.8	0.04	0.13	27		-	-		
75	4.8	29	4	2	0.61	0.06	0.09	22		-	-		
73	5.6	34	3		0.63	0.06	0.08	23		-		+	
97	4.15	44	8	4	2.5	0.01?	0.2	37		-	-		
98	4.5	30	3	2	0.9	-	0.2	21		-	-		

* - Sample contains less than 0.01 ppm Cu.

** See text pg 6.

The most unexpected observation was the acidity in the river upstream well beyond the part that receives drainage from the tailings.

The zinc contents of the water may appear to be high; this may be partly due to the field method used in the zinc determination, which will not be accurate for low concentrations.

Observations on individual tailings areas

The tailings area from mine No. 1

The tailings area from the abandoned Mine No. 1 is located approximately 2 miles west of settlement No. 2. A water sample (No. 32) collected in the summer of 1973 from the drainage ditch north of the pond had a pH = 5.6. The water appeared to have a microbial population that consisted primarily of various species of the Enterobacter family. Because of the presence of dissolved sulphide in the water (0.4 ppm), and the sulphur metabolism and fermentative action of some of the Enterobacter species, it was conceivable that a microbial population of this type could develop and possibly be maintained partly due to the sulphide content of the water that might seep as near-neutral water from the tailings.

Although the pathogenic nature of the species is questionable and the species that were determined (Klebsiella and Citrobacter) are known to survive in soils(11), their relation to pathogenic bacteria made it important to study this tailings pond in greater detail.

Water samples and tailings samples were obtained from the locations shown in Figure 2 in which the same sample numbers have been used as those listed in Table 2. This table shows the results of the determinations done on the collected samples.

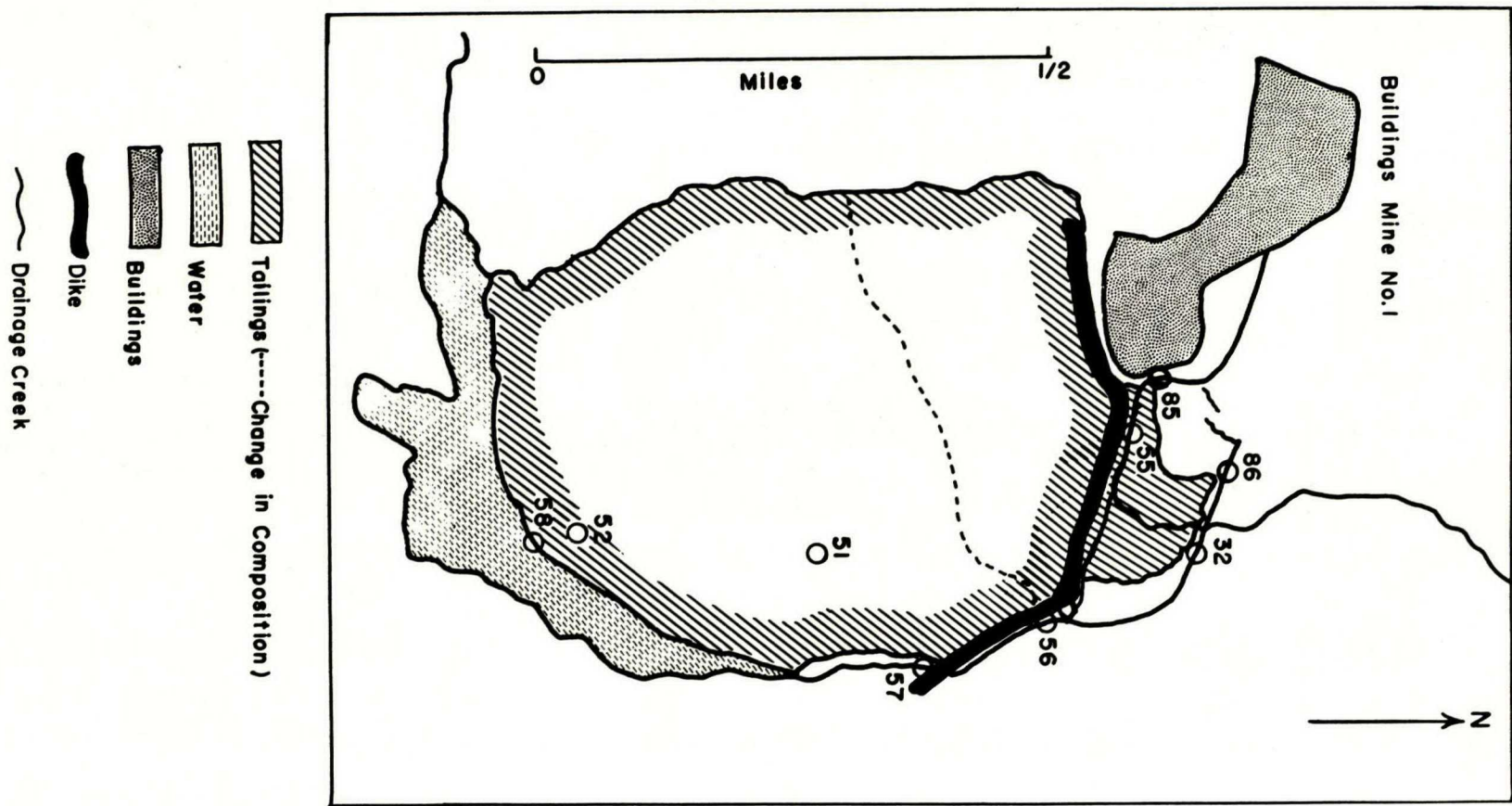


Figure 2. The Tailings Disposal Area of Mine No. 1. Numbers refer to those used in the text.

TABLE 2

Results of Determinations on Samples Collected in the Tailings Pond of Mine No. 1

Sample Number	pH	Micro-mhos	Composition in ppm					Actions of micro-organisms			
			Ca	Mg	Fe	Zn	SO ₄	S**	F1	F2	Enterobacters
58	8.65	100	10				140			-	-
57	6.90	68	16				27			+	-
56	6.85	73	14				30			-	+
55	6.4	205	30				100			-	+
85	6.7	230	46	18	12	0.08	90		-	-	
86	6.2	350									
32*	5.6	265	34	6	3.8	0.86		0.4			+

*The chemical analyses were done by Mrs. V.H.E. Rolko, chemist, Mineral Sciences Division, using atomic absorption spectrophotometric techniques.

**Sulphur present as sulphide.

TABLE 3

Results of Chemical Analyses of Tailings Samples Collected from the Tailings Pond of Mine No. 1

Sample Number	Composition in wt %						
	Fe(total)	Fe ²⁺	S(Total)	SO ₄ ²⁻	Ca	Mg	CO ₂
53	7.08	5.58	0.96	0.19	4.13	2.18	3.77
51	5.34	3.83	0.63	0.16	4.04	2.00	3.76
52	3.97	2.80	0.42	0.10	3.20	1.64	4.23

The water drains for the greatest part towards the south end of the pond. It forms there a pool which flows northwards in a creek on the east side of the pond. It is evident from the results of the determinations that the drainage water from the tailings is alkaline and that it becomes progressively acid when it flows northwards. The connection that apparently once existed between the direction of the waterflow through the building sites and this creek was very shallow and almost dry in a period of heavy precipitation during which the samples were collected. However, this connection was apparently deeper in the past.

The results of the chemical analyses of core samples are listed in Table 3.

The results indicate that a gradual leaching of the elements towards the south takes place in the top 3-ft layer of the pond. The compositions in general suggest that the carbonate to sulphide ratio is approximately 8.5 to 1.7 (by weight) so that the alkalinity of the drainage would agree with results of experiments done in the laboratory⁽¹³⁾. Since no complete analysis is available, it is not known to what extent the Ca, Mg and ferrous iron surplus over that required for the presence of pyrite and carbonates can be accounted for by silicates. However, the leaching of the minerals towards the low end of the pond was apparently accompanied by an increase in CO₂ content. This phenomenon is probably related to a retention of CO₂ suggested by observations on another pond described elsewhere⁽¹³⁾.

The acidity of the drainage that developed after the water had left the pond could not be detected at site No. 41 (see Figure 1) so that the extent of pollution is limited. The results suggest that gradients exist in the processes that produce acidity. They can be expected to be similar to other geochemical phenomena.

It remains possible that the acidity of the water near the buildings site is due to the action of micro-organisms in view of the mild acidity that can be produced by Enterobacters as compared with that produced by relevant Thiobacilli. It is

feasible that the Enterobacters survived because of the particular coincidental combination of circumstances, e.g., the composition of the drainage water.

However, the following points should be considered in this respect:

- a) The presence of a tailings pond is not a prerequisite for the survival of certain species of Enterobacters in the wild(11).
- b) The presence of Enterobacters has not been detected in originally-alkaline drainage water from tailings areas of other abandoned mines, where there was no obvious reason that sewage contamination would be less likely. Detailed studies, however, may prove differently.
- c) In the field observations made over the past few years on approximately two dozen different tailings-disposal areas, none produced drainage water having a similar mild acidity. Nor was it produced in percolator experiments on tailings samples from another 15 mining companies. The particular acidity was produced, however, in preliminary experiments involving particular grain size distributions in mixtures of pyrite and calcite. The particular conditions in these experiments approached those of stagnant conditions, while the conditions in the field were the opposite.
- d) If the source of the nutrients for the Enterobacters originated solely in sewage from the buildings site, Enterobacters could be expected to be present downstream and not upstream. However, if the drainage from the pond develops a particular gradient in the water composition favourable for the survival of Enterobacters, then their presence upstream becomes feasible.
- e) The role of the sulphur bacteria at site No. 57 is problematic. If the acidity originated in the action of these micro-organisms in the drainage creek, they could be expected to be present farther down along the creek producing a lower pH. However, it is quite possible (and

consistent with synecological phenomena in vegetation) that zones develop due to the water flow and the changing composition of the water. Thiobacilli apparently developed downstream near New Brunswick mining operations after the drainage had left the tailings area. Far more evidence in this respect has to be obtained by detailed studies before the presence of these phenomena can be considered as established. The matter is complicated by the fact that the flowrate of the water varies, which may or may not favour the development of zones of typical microbial populations.

The observations on this pond were also worthwhile because of the observations that the layered structure of a pond can be porous. Air pockets (probably small lenses) were cut by the tube during the collection of the core samples, so that air bubbled up through the top layers which had become muddy due to the heavy rainstorms. Although all field observations during 1971 and 1973 had confirmed the layered structure of tailings areas, the possible presence of porous lens-type structures had not been realized.

The tailings area of mine No. 7

The operating gold-zinc mine No. 7 is located approximately 3 miles east of river No. 1. Its tailings pile drains westward via a 3-4 mile long creek into this river in the same area as the drainage from the tailings pile of mine No. 8. The mine water of the mine No. 7 of which a sample was collected at site No. 49 (see Fig. 1), flows presently northwards into a side arm of the small river No. 3.

A discussion with the manager and the mill superintendent indicated that only a small part of the area where the tailings had flown from the pile could be considered to be inactive for the near future and to be a possible location for study. However, since structurally the phenomena in the long drainage creek appeared most important, attempts were made to obtain

samples along this creek. Unfortunately, the area surrounding the tailings pile is flooded with tailings which in turn are bordered by drainage waters. Freshly cast tailings covered a large part of the area towards the creek. It appeared, therefore, impossible to reach sample sites down the creek in the time available.

The fresh tailings effluent, collected at site No. 69, is alkaline. This alkalinity is due to the addition of lime in the mill. The water becomes acid after casting the tailings, as was determined from samples collected from water south of the tailings area (sites No. 65 and 67). Whether or not the increase in acidity is gradual or in which way gradients follow the structure of the area are problems for detailed studies of tailings ponds.

The comparatively rapid decrease of the effect of lime as compared with that of limestone (CaCO_3) has also been shown in laboratory experiments described in a previous report⁽¹²⁾.

The sampling of seepage water near the pile did not appear to be promising because of the variations in the composition of the ore that is mined and in the subsequent composition of the tailings that is produced. According to information given by the manager, the tailings contained, originally, approximately 10% sulphides. This content has increased to approximately 20-25% in recent tailings because of the aforementioned variation in the composition of the ore as well as due to the custom milling of a copper bearing ore.

Samples of drainage water and related tailings samples were collected at two locations in the water pools on the south side of the tailings pile (No. 65 and 67). Using a water collector described under the heading on pg 8, water was also collected at a depth of 6 ft at a site (No. 72) half-way between the tailings pile and the most western sample site.

The results of the determinations on these samples are listed in Table 4.

TABLE 4

Results of Determinations on Samples Collected in the Tailings Area of Mine No. 7

Water Sample Number	pH	Micro- mhos	Composition in ppm							Actions of micro-organisms*			
			Ca	Mg	Fe	Fe ²⁺	Cu	Zn	SO ₄	F1	F1p	F2	F2p
69	8.15	2000	740				0.65		2500				
72	7.2	2800	540	340	13		0.05	0.42	2900				
65	3.4	390	30		180		0.09	0.04	305	-	+	+	-
67	3.55	420	32		205		0.45	0.03	270	-	(+)	+	-
49	2.65	3500	120		1700	10	1.5	0.65	9000	+	+	+	-

Tailings Sample Number	Composition in wt %							SO ₄	Total S	CO ₂
	Ca	Mg	Fe	Fe ²⁺	Cu	Zn				
69	0.63	1.73	12.22	3.54			0.67	1.16	10.90	0.65
70	0.55	1.59	7.74	1.66			0.16	0.16	7.45	0.24
71	0.58	1.78	5.75	1.96			0.095	0.32	4.35	1.17
66	0.40	2.77	5.45	2.62			0.092	0.23	3.03	0.96
68	0.44	2.44	4.84	2.78			0.088	0.30	2.14	0.77

*See pg 6.

The water sample collected at site No. 69 represents that of the effluent. The results of the determinations indicate that the acidity increases with the distance from the casting site. With the increase in acidity the iron content increases, while the calcium and sulphate contents decreased. The nature of the mine water (No. 49) is different; a large amount of undetermined cations (alkalies?) should be present to balance the high sulphate content of that water.

The composition of the fresh tailings separated from the fresh effluent (collected at site No. 69) suggests that approximately 7.5% pyrite is present according to the ferrous iron content. It is not known, however, in which forms the large surplus of sulphur over that required for pyrite as well as the significant amount of ferric iron are present. The sulphur content would indicate that at least approximately 17% sulphides may be present.

In view of a pyrite to carbonate ratio of approximately 7.5 to 1.5 (by weight) the drainage from this tailings is close to being potentially acid. The high calcium content of the water collected at site No. 72 as well as the alkalinity of the effluent can be expected to originate in the addition of lime in the mill.

The compositions of the tailings samples collected from 4 ft and 6 ft depths (respectively samples No. 70 and 71) contain essentially the same proportion between sulphides and carbonates as well as the large surplus of sulphur over that required for the presence of pyrite, in spite of the leaching effect shown by the decrease in the content of sulphides.

Although the acidity of the water has been used as a criterion for pollution, it is questionable to what extent this is valid. It might be preferable to take also the conductivity into consideration.

The impression obtained during the fieldwork was that acidity of the water did not prevent plant growth when the conductivity of the water was comparatively low. However, when the conductivity increased, plant growth decreased.

Observations made during the drilling of the hole for the water collector indicated that water flows along particular layers. These layers alternate with series of layers that did not seem to contain an appreciable amount of water. In the 6-ft hole, only two layers that contained water, were present at approximately 1 1/2 ft and 2 1/2 ft depth. The layer at 1 1/2 ft depth was very thin (approximately 1/4 inch) and merely showed excessive moisture. The layer at 2 1/2 ft depth was approximately 2 inch thick and consisted of a muddy paste. The layer at 6 ft depth, which may be the bottom layer according to the information given by the manager, was considerably thicker and consisted of watery mud. Water sample No. 72 was collected at that level. It may represent nearly stagnant water of the tailings after it is cast. This composition follows the trend of the increase in acidity after the water seeps from the pile.

The tailings area from mine No. 8

The mine No. 8 has not been operated since 1967. Its buildings are presently being dismantled. The tailings pile of this operation, originally a zinc-gold producing mine, is located on the west side of, and very near river No. 1. The locations of the samples that were collected are shown in Figure 3. The results of the determinations done on these samples are listed in Table 5.

Although a certain amount of water drains eastwards into the river and also a small part of the tailings has flowed out of the pile on that side, the creek on the west side probably drains most of the water. It is connected with drainage flowing out of the south side. The water drainage pattern on the south side is complex. The presence of "F1" type bacteria was indicated in samples collected from sites No. 59 and 95. No sulphur bacteria (Fe type) could be detected in these samples. However, samples collected from sites No. 93 and 94 contained "F2" type, but no "F1" type micro-organisms.

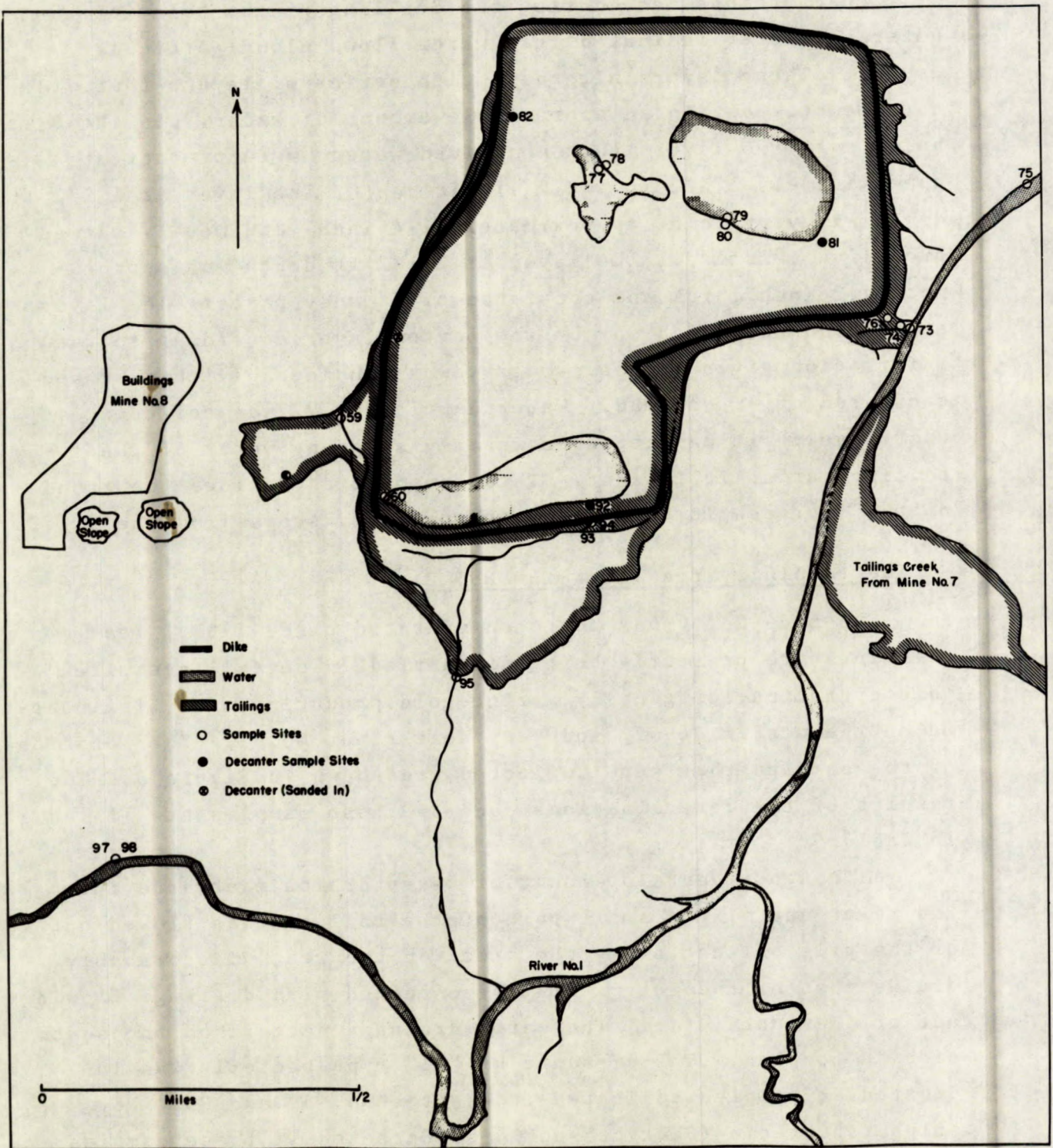


Figure 3. The Tailings Disposal Area of Mine No. 8
Numbers refer to those used in the text.

TABLE 5

Results of the Determinations on Samples Collected in the Tailings Area of Mine No. 8

Water Sample Number	pH	Micro- mos	Ca	Mg	Composition in ppm					Actions of micro-organisms*					
					Fe	Fe ²⁺	Cu	Zn	S	SO ₄	F1	F1p	F2	F2p	
82	3.8	4100	440		2100	155	1.9				770	-	-	+	-
77	3.35	1400	160		10		1.7	0.42			970	-	+	-	-
79	3.2	1200	120		15		1.4	0.28			720	-	(+)	+	-
81	6.45	900	160		5.5		0.18	0.12	0.05		440	-	-	+	-
76	2.4	4000	52		1600	140	5.3				1200	-	(+)	-	-
73	5.6	34	3		0.63		0.06	0.08			23	-		+	
75	4.8	29	4	2	0.61		0.06	0.09			22	-		-	
60	3.15	440	36		22		0.70	0.23			295	-	(+)	-	-
92	4.25	560	42	32	89	13	0.17	0.7	0.04		500	-		-	
93	3.45	810	50	35	840	12	0.17				780	-	(+)	+	-
94	3.0	4600			4300	100	13.8				8500	-	-	+	-
95	2.5	4800			1100	45	16.0				9000	+	-	-	-
59	3.0	680	44		60		0.40	0.15			500	+	+	-	-

Tailings Sample Number	Composition in wt %						
	Ca	Mg	Fe	Fe ²⁺	Zn	Total S	SO ₄ CO ₂
78	1.37	1.75	10.34	5.63	0.11	4.25	0.25 0.08
80	1.24	2.29	8.91	6.98	0.10	1.51	0.52 0.09
74	1.23	2.36	10.13	7.69	0.18	2.78	0.75 0.23

*See pg 6.

The pile contains three pools of water. The water levels in these pools were considerably higher than the levels in the decanters that had not sanded-in. For example, the water level in the decanter from which the sample at site No. 81 was collected is 12 ft below the surface of the pond, in spite of its location at approximately 15 ft distance from the edge of the pool. The decanter No. 92 is even closer to the pool and it has a similar difference in level.

The results of the determinations of samples No. 81, 82, and 92 collected in the decanters indicate that the water in the nearby pools, collected at sites No. 79, 77, and 60, respectively, is more acid. The iron content of the water in decanter No. 82 was considerably higher than that in the nearby pool (No. 77). The sulphate content of both waters, however, was similar.

The composition of the water in the decanter (No. 81) and that of the nearby pool on the northeast side of the pile (No. 79) are also significantly different. The core sample collected at site No. 80 indicated that the water in the northeast pool is probably separated from that in the decanter by an impervious layer of tailings. The sample collected at site No. 78 did not clearly indicate the presence of such a layer. However, since the depth of the sampling was 3 ft, no definite conclusion can be made that no impervious layer is present between 3 and 12 ft depths. Because of the difference in the composition of the water samples, No. 77 and 82, it seems likely that such a layer may be present at a level different from that in the northeast pool. However, it is also possible that the whole top layer of site No. 78 represents an impervious layer because of the similarity between the compositions of samples No. 78 and 80. It seems very probable that the compositions of the water in the decanters represent that of water seeping in from deeper levels of the tailings pile.

The depths of the tailings piles are considerably greater than those of tailings ponds so that, in particular, a sampling apparatus that can cope with muddy conditions has to be developed for a detailed study of tailings areas, as has been mentioned under the heading on pg 8.

The water sample collected near the foot of the pile (No. 76) at the east centre-corner seems to represent drainage from a layer other than that present in the decanter No. 81. Acidity appeared to increase slightly downstream as was indicated by samples collected at sites No. 73 and 75. The "F2" type micro-organisms, however, were apparently not present at site No. 75.

The samples collected in the south part of the area (No. 60, 92, 93, 94, and 95) indicated that the water in the decanter (No. 92) is less acid than that of the pool (No. 60) and that the acidity increases in the creek with the distance from the tailings pile. Sample No. 93 represents the composition of fresh drainage water. In sample No. 94 the effect of settling has to be taken into consideration as it was collected from the pool formed by water collected at site No. 93. The composition of sample No. 95 might represent that of drainage water from the west and the south sides combined. It is possible that the amount of drainage from the south side is small as compared with that along the west side, as indicated by the aforementioned distribution of iron and sulphur bacteria; notwithstanding, the water samples No. 59 and 94 had the same pH. The observation concerning the increase of acidity away from the tailings pile is thus similar to those in tailings areas from mines No. 1 and 7.

The results of the analyses of the tailings samples indicate that the sulphide content varies significantly. However, even if approximately 2 to 3% of sulphides is present as in sample No. 80, the carbonate content is very low, approximately 0.2%. This sample, however, represents that of the impervious layer that may separate the water in the pool from that seeping in the decanter (No. 81).

The acidity in the pool from which the sample No. 77 was collected represents the action of the tailings composition No. 78.

Phenomena connected with the presence of impervious layers can only be detected in a more detailed study than could be done in the limited time that was available. Recent experiments in the laboratory suggest also that factors such as the particle size distribution apart from that of the total surface area affected the ratio between pyrite and calcite that is critical in the resulting pH of the water.

The acid drainage water in this area did not prevent plant growth. Bulrushes, horsetails and sedges grew abundantly and were actually indicative of the course of the major drainage channels. A slimy growth could be observed in the water on the south side close to the pile. This growth consisted apparently for the greatest part of actinomycetes and to a lesser extent of rod-shaped bacteria when examined under the microscope in the laboratory. Iron (hydr)oxides had deposited along the mycelium-like threads, while the bacteria were not encrusted as could be expected from Ferrobacilli. This observation is one example of the many subjects to be dealt with in detailed investigations.

The collection of samples down the drainage basin farther than site No. 95 appeared too time consuming due to the swampy conditions in that area.

The tailings area from mine No. 9

The compositions of water samples collected from sites No. 46 and 47 had indicated that the effect of drainage from the tailings piles of mine No. 9 had become negligible according to the result of the determinations of samples No. 46 and 47 (see Table 1). However, evidence obtained from the samples collected in the tailings areas of mines No. 7 and 8, had also shown that the acidity of the drainage water from these mines had changed in a comparatively short distance. Consequently, information about the composition of the drainage water from the tailings areas of the gold mines No. 9 and 10 might complete the reconnaissance of the area.

With the kind cooperation of the general superintendent and the project engineer, a sample from the drainage at site No. 87, which flows into a creek connected eventually with river No. 1, was obtained (see Fig. 1, p. 11).

The results of the determinations done on this sample were as follows: pH = 7.2, conductivity = 950 micromhos, Ca 160 ppm, Mg 40 ppm, Fe 7 ppm, SO_4 650 ppm

The composition of the tailings has varied little over the years so that the extent and effect of layering, as is present in other tailings areas, is negligible according to the information given by the project engineer. A part of the drainage water is recycled and the part that drains eventually into the creek is treated to let the ultrafines settle before the water enters the drain wells. The steep banks of the tailings piles are downgraded to facilitate a revegetation program that is in progress.

The tailings area from mine No. 10

Water from the tailings area of mine No. 10 drains into a creek of which a sample was collected at site No. 48 (see Fig. 1). This creek is connected with that containing the drainage from mine No. 9 before it flows into lake No. 3. Its water had a pH = 7.5 and conductivity of 350 micromhos.

With the kind cooperation of the mill superintendent, samples were collected a few yards from the spillway at site No. 89 and at the location (No. 88) where this water flows into the creek. The results of the determinations done on these samples were:

Water at site No. 89 -

pH = 8.9, conductivity 950 micromhos, Ca 200 ppm, Mg 5 ppm, Fe 0.3 ppm and SO_4 580 ppm.

Water at site No. 88 -

pH = 7.25, conductivity 105 micromhos, Ca 21 ppm, Mg 10 ppm, Fe 3.5 ppm and SO_4 38 ppm.

The results indicate that not only the alkalinity but also the conductivity of the water decreased rapidly.

The composition of the tailings has varied little over the years so that the nature of the tailings areas of mines No. 9 and 10 are apparently comparable, except that the pyrite content in the tailings from mine No. 9 is probably higher than that from mine No. 10. However, the effect of the drainage on water pollution does not seem to be significant according to the results of the pH and conductivity determinations.

DISCUSSION

The objectives concerning the experimentation with methods of collecting various types of samples and concerning the analysis of water samples in the field were reached for the greater part.

The methods used for the chemical analyses were satisfactory. Only when the water contains much iron, the determination of other elements becomes time consuming because pressure or suction filtration methods, used in order to speed up the procedure, did not perform well.

The use of the water sampler was very satisfactory, while the same can be expected of the tailings sampler when it has the required accessories. The water collector also performed satisfactorily. An apparatus that can collect water and/or tailings from different levels in muddy tailings layers is being developed and will be used when a detailed study of the structure of a tailings area, and a tailings pile in particular, is required. The requirement of portability of the sampling apparatus is emphasized.

The methods used for the collection of microbiological samples can be improved by reducing the number of nutrients. A part of the work on this aspect, presently being done in the laboratory, should be done in the field, when a detailed study is considered.

The results of the field work show not only the nature of a reconnaissance of a particular area in connection with determining the extent of water pollution caused by (acid) drainage from tailings disposal areas, but also the nature of a detailed field study of one particular tailings area.

The factual results of the work indicate:

a) Tailings disposal areas can contain specific layers that contain water alternating with impervious layers. The composition of the water in the layers need not necessarily be the same so that they affect the composition of the drainage water in different ways.

b) Alkaline effluents from tailings can become acid at some distance from the location where the tailings are cast. The same is valid for alkaline drainage. This phenomenon may be more widespread than is realized or may be obscured when the criteria have been confined to the reactions of bulk tailings compositions in water⁽¹³⁾. Although the increase in acidity of the water along the creek in the area of mine No. 1 was attributed to possible fermentative action of Enterobacters, it is also possible that the particular gradient in the acidity and in the composition of the drainage water was favourable for their development.

The acidity increased not only in the water from the tailings areas of mines No. 1 and 7, but also along the acid drainage creek of the tailings area of mine No. 8. The water in the pools on top of the pile of that mine differed in composition as well as in pH from the water contained in the nearby decanters at lower levels. The water in the decanters probably represent seepage from layers well below the top. Definite conclusions, however, can be made only on results of a more detailed study.

An increase in acidity in tailings disposal areas in New Brunswick was attributed to traces of thiosulphate which drained from the tailings and which formed a nutrient source for Thiobacilli downstream. It is quite possible that the action of micro-organisms in the water has its effects on the composition

of water. However, because of the waterflow, a wider distribution of these organisms than determined in this fieldwork could be expected except where they represent evidence for the existence of biogeochemical zones.

Acidity can be attributed for a great part to the fine fraction of the tailings composition. The grains of this fraction are suspended longer in the water than the comparatively coarse or heavier particles. The ultrafines particularly produce acidity in the water as has been experienced in laboratory experiments whereby the effective action of the total surface areas of the relevant minerals becomes complicated. The action of micro-organisms in this respect is not known. It is probable that this action is connected with the rate of dissolution rather than with final equilibrium conditions.

The effect of the ultrafines can be expected to be the greatest in active mining operations where the supply of freshly cast tailings is continuous. The increase in acidity away from the tailings area of inactive mining operations suggests the development of geochemical gradients. These gradients can develop due to the effect of the horizontal flow of the water on sedimentation segregation as experienced in the laboratory, or possibly to the same effect on time differences involved in various rates of reactions in the chemical processes. The difference between the effects of suspended and settled particles in this respect is still problematic.

When the effect of differences in particle sizes between pyrite and calcite is considered, comparatively fine-grained pyrite will settle with coarser calcite. The fine-grained calcite can be expected to be carried farther downstream than the pyrite having the same particle size. The combination of fine-grained pyrite and coarse-grained calcite produces acid water because of their surface area properties. Consequently, an acid zone in the drainage stream can develop even if the original combination of minerals may favour alkaline conditions.

Although, logically, an alkaline zone should be formed by the fine-grained calcite that is carried farthest downstream, it is more likely that the calcite is dispersed so far downstream that its effect becomes negligible because of its dilution. During the progression of time after the mining operations have become inactive, the acidity in creeks and rivers that carried the suspended particles can be expected to recede gradually to the tailings area because the finest particles will gradually become completely dissolved. It is unfortunate that these phenomena cannot be studied in all their consequences in the drainage from mine No. 8 because of the interference of the effluent of the active operations from mine No. 7.

The effects of the horizontal and vertical sedimentation-segregation as well as the effect of time (recession towards the deposits) can be expected to be among the major factors to be considered when studying the drainage water compositions of a tailings area in the field. The results of laboratory experiments on samples from Mining Companies No. 17 and 18⁽¹³⁾ can be reviewed in the light of the foregoing. The effects of compositions of samples collected from tailings areas of these mines in the field on water in percolators could not be compared directly with those of fresh tailings. This difference between the effect of the compositions of weathered and fresh tailings samples on water is possibly due to a combination of the age and the resultant particle size of the tailings.

The beneficial effect of the presence of some carbonates (limestone, calcite, etc.) produced by the counteraction on acidity is, thus, unfavourably affected by the phenomenon of horizontal segregation-sedimentation which can be expected to have its beginning during the milling process. Also, the phenomenon of a possible temporary CO₂ retention that was mentioned elsewhere⁽¹³⁾ has to be considered in this respect. It is possible that the increase in acidity after the water seeps from the tailings area is caused by a decreased effect of a possible temporary CO₂ retention.

A factor which has not been studied experimentally is that of the diffusion of oxygen on the oxidation of the sulphides. Water flowing in creeks and rivers can be expected not only to have a higher oxygen content than stagnant water, but also to increase the action of diffusion. For example, the creek along the tailings pond of mine No. 1 was particularly turbulent due to heavy rainstorms when the samples were collected, while the samples in the tailings areas from mine No. 8 were collected in near stagnant conditions.

The origin of the acidity of the water samples collected above the location where the drainage from the tailings areas of mines No. 7 and 8 enters river No. 1 is problematic. Tailings can be observed along the river banks downstream for a long distance. Upstream, however, no such observations were made. Possible effects of bog acids or a yet unexploited mineralization should not be ruled out.

The observations that plant life did not seem to be affected greatly even in the tailings areas, do not imply a similar effect on other forms of life in the river No. 1. The field method for determining very small traces of copper, which may affect these forms of life is limited.

It should be emphasized that all the foregoing 'conclusions' are based solely on the results of the determinations that were done. More detailed studies, including also the large areas that were not covered, may indicate differently. Definite conclusions cannot, therefore, be made. This report describes particularly the possibilities for field studies that can be done, and it outlines particular subjects that appear of importance for further investigation.

Generally however, it can be expected that the pollution in the area covered may be locally concentrated in view of the low conductivities of the collected water samples, hence the low amounts of solutes in the waters. Significant concentrations may be confined to swamps that can act as natural settling basins. In view of the number of tailings areas that drain

into river No. 1, the impression was obtained that the pollutant effects of these areas do not seem to be highly significant.

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