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AN EXPERIMENTAL STUDY OF THE WEATHERING OF MILL TAILINGS IN CONNECTION WITH WATER POLLUTION: PHYSICAL ASPECTS OF THE WEATHERING OF TAILINGS PONDS

by

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MINERAL SCIENCES DIVISION

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PHYSICAL ASPECTS OF THE WEATHERING OF TAILINGS PONDS

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A. Jongejan* and A. L. Wilkins**

SUMMARY

A few factors affecting the water flow-rates through tailings samples have been studied. In view of the close connection between the mineral surface-area of tailings exposed to water and the chemical composition of the water seeping through the tailings, it appeared practicable to calculate the specific grain-surface areas of tailings from water flow-rate measurements. Because the specific surface area is an intrinsic property of a tailings sample and can be correlated with other properties, such as volume and density of the mineral grains and with the calcium that dissolved out of the minerals, it was considered one of the principal factors connecting the physical and chemical aspects of the weathering process.

The results of the flow-rate measurements indicated that drying and sedimentation segregation affect the mineral surface-area that is exposed to water. The effect of these factors increased with the sulphide content of the tailings. Drying promotes the cementing action of iron hydroxides and calcium sulphate and, subsequently, the formation of impervious aggregates. Sedimentation segregation, during the pouring of the tailings, produces layering. The finest and lightest particles that settle last, form a dense top on each layer which controls the water flow-rate.

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CONTENTS

1. INTRODUCTION

The diversity of subjects involved in the study of the effects of seepage from tailings ponds on water pollution has been covered in other reports(1 to5). Apart from external factors, such as topography and climate, the chemical, physical, and microbiological aspects could be distinguished.

This report gives a description of the experiments comprising the first of two parts of the study relating to some of the physical aspects of the weathering process.

The physical aspects are primarily those related to the particle-size distribution and to the surface areas of the tailings minerals. These two factors are included in those which typify the chemical properties of a particular tailings sample(2, 4).

In addition, attempts have been made to obtain information on the physical aspects alone, particularly in connection with the flow of water through a tailings pond in the field. Consequently, the effects of particle-size distribution and of grain-surface area on the behavior of water have been studied in the laboratory experiments on the rate of flow of water through tailings samples.

The importance of the hydrological properties of tailings ponds is evident in the field, where the drainage pattern forms the basis for the resulting pollution. A tailings pond can be considered to be a recent sediment, and problems connected with it are limited to depths shallower than those of deep-seated, ground-water sources.

Attempts to reduce air pollution, due to fine particles being blown about by the wind, are concerned with the establishment of a vegetative cover. They constitute an agronomic problem in which the hydrological properties are important. The methods used to study the flow of water through a tailings pond in the field could preferably be those used in agricultural hydrology, extended to include those of sedimentary petrology, and adapted to the problems presented by the weathering of a tailings pond.

Several of the relevant instruments and methods have previously been studied by the first author of this report in connection with the movement of elements through soils. Although some of them may be applicable to a field study of tailings ponds, because of the same principles being involved, preference was given, in the current investigation, to obtaining basic information by using apparatus as simple as possible, in order to facilitate the estimation of values for the many factors involved.

Initially, the laboratory experiments were focussed on problems dealing with factors controlling the geometrical flow of water through tailings ponds in the field. The first stage of the study, described in this report, deals with the rates of water flowing in one direction (one-dimensional). The results of these experiments have already been described in an MSD Internal Report (MS 72-26), but are included here for completeness.

After the effect of the water flow on the chemical reactions and equilibria became apparent, the focus of the experiments changed to the investigation of the possibility of simplifying the measurements, and to expressing the results of these measurements in a form that could be considered in relation with the results of the experiments on the chemical aspects of the weathering process.

The rate of water flow is related to the particle-size distribution and to the grain-surface area in particular; the experiments deal with the possibility of measuring the surface area by means of measurements of the rate of water flow. Consequently, the problem considered the extent to which the results of measurements of the surface area of tailings could be used to predict water flow rates.

Since the grain-surface area exposed to water is an intrinsic property of a tailings sample, it could possibly be related to other properties, such as pH, conductivity, and/or the metal ion content(s) of the water flowing through the tailings. The interaction between these aspects will be studied in the second stage of the study of the chemical aspects. After field observations have been made, a second part of the study on the physical aspects may deal with a water flow through a tailings pond in two directions (two-dimensional), and its possible effect on chemical reactions.

2. EXPERIMENTAL METHODS

2.1. Flow-Rate Measurements

The experiments involved the measurement of the time needed for a certain amount of water to flow through a small column of tailings sample, contained in a vertically-positioned glass tube.

The glass tube had a 25-mm inside diameter (or approximately 5 cm^2 cross-section) and was approximately 3-4 ft long. It was plugged at the bottom with a rubber stopper, having a 0.75-in. hole. A coarse screen in the hole of the stopper consisted of a grid of non-corrodable pins, which retained a 0.75-in.-thick layer of 3-mm glass beads, upon which a 0.25-in.-thick layer of glass wool was pressed. This arrangement prevented any retardation in the water flow and retained the tailings column.

A sample of tailings from the Heath Steele Mine in New Brunswick was used in the experiments to be described.

Too much time appeared to be required for experiments using unit layers of tailings having a 10-cm thickness, as was originally planned. Layers of 1-cm thickness proved to be more suitable.

The rates of water flow were measured through columns of various lengths, consisting of one single layer. They were compared with the rates of flow through columns of the same length, but consisting of a succession of approximately 1.5-cm-thick layers. In addition, the difference was measured between the time required for a certain amount of water to seep through a column of tailings under a decreasing head, and that required for a certain amount of water to seep under a constant head through the same height and cross-section of tailings.

Before discussing the results of these runs, various difficulties experienced in the course of the experiments will be described.

At the start of the experiments, the plan was to mix a large amount of sample, as received, into a slurry with water, to pour this slurry into the tube, to allow the tailings to settle and then to adjust the thickness of each layer of sediment to a series of centimetre marks on the tube. This procedure appeared inconvenient, because of the fine tailings clouding the water and of the long settling time needed.

Consequently, moulds were cut from a ceramic tube having the same inside diameter as the glass tube used for the flow-rate experiments. By cutting lengths of 1, 2, and 3 cm, and filling them with a thick slurry it was hoped that the desired layer-thickness would settle out after mixing the contents of the moulds with 100 ml water and pouring this mixture into the tube.

Because the samples obtained in that way did not produce a consistent thickness of layer, the tailings were allowed to damp-dry in the moulds, using filter paper at the bottom. They were levelled off when almost dry and then mixed with 100 ml water; this mixture was then poured into the tube. Although the consistency of the layer-thickness was improved by this procedure, the thickness itself had increased, e.g., the 1-cm mould produced a 1.5-cm-thick layer and the 2-cm mould produced a 2.5-cm-thick layer. However, this method was adopted for interim use.

The arrangement at the bottom of the glass tube was closed off with a stopper while the slurry solids were settling. Because some water had collected in the glass wool and in the beads at the bottom of the tube, the flow-rate measurement was commenced after the first 15 minutes. Even with these precautions, the first part of the volume vs. time curve was more erratic than the sections produced after approximately one hour.

For the experiments in which a constant head of water was used, an attachment to the top of the tube was made. It consisted of a plastic tube, having approximately the same diameter as the glass tube and attached to it with a stopper. This plastic tube was provided with a water inlet and

and an outlet. The inlet was connected to a water feed, regulated by a needle valve to a flow slightly greater than that through the tailings sample. This attachment worked satisfactorily. However, the start of the flow-rate curve again appeared to be erratic, notwithstanding that the samples used in the constant-head experiments had already been used in the decreasing-head experiments.

2.2. Measurement of Grain-Surface Area Exposed to Water

The same apparatus was used for the measurement of the specific grain-surface area exposed to water as for the measurement of the rates of water flow (see Section 2.1). The only difference in the actual measurement was that a few properties had to be determined that had not been required for the flow-rate measurements.

The method described by Dodd et al.(6) has been used for the measurement of grain surface. Refinements of this method to account for tortuosity and grain-shape factors have been ignored to keep the method simple, and also because these factors would vary between different tailings compositions.

The surface area exposed to water was calculated using the general formula:

$$S_o = \sqrt{1/k' \cdot \frac{A}{\mu K} \cdot \frac{\epsilon^3}{(1-\epsilon)^2} \cdot \frac{g}{L}}$$

in which

S_o = grain-surface area exposed to water in cm^2/cm^3;
A = cross-sectional area of the tube;
μ = viscosity of the liquid in poises;
ϵ = porosity of the tailings column, being the total volume of voids per volume of the column;
L = height of the tailings column;

g = gravitation constant; and
k' = Kozeny's constant, assumed to be 5.0(7).

The porosity factor, ε, was calculated from the relation $\varepsilon = 1 - \frac{W}{A.L.\rho}$, where W is the weight and ρ the density of the tailings sample. The porosity factor was calculated for each column length. The constant, K, was determined by plotting, on log-normal paper, the rate at which the water head above the tailings column in the tube diminished, calculating the slope, B, of the linear relationship $\log h_o - \log h_1 = B.t$ (in cgs units, which were applied throughout the measurements) and introducing this slope, B, in the relation $B = \frac{K.\rho'}{2.303\ A}$, where

h_o = height of the water column at time 0(t_o)
h_1 = height of the water column at time 1 (t_1)
t = $t_1 - t_o$
ρ' = density of the liquid

The values of the specific surface areas have been expressed in cm^2/cm^3 units. The volume of the solid particles is thereby considered, rather than the bulk volume, which includes that of the pores. The preference of using a volumetric over a gravimetric specification originates in the connotation of this factor with the water flow in the field — viz., a waterflow through a certain volume of tailings. Additionally, the chemical properties appear to be more closely related to the volumetric than to the gravimetric properties of a tailings composition(4).

The constant, K, was also calculated by means of a computer. The differences in the results obtained by the two methods did not appear to be significant*.

The accuracy of the determinations was sufficient for comparative purposes. Attempts are being made to improve the accuracy by using smaller-bore glass tubes and, finally, by standardizing the procedure.

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*Recently, a FORTRAN program for the Mines Branch Computer has been developed by W.S. Bowman, Technical Officer, Physical Chemistry Group, Mineral Sciences Division, for the entire calculation of the specific surface area, according to the relevant formulae.

For some tailings, however, the values obtained for various column lengths differed substantially. The reason for the variability in the rate of water-flow might lie in a particular sensitivity of a tailings sample to packing, as well as to chemical reactions that started in the water flowing through tailings containing much sulphides. Iron hydroxide precipitates, and small bubbles that developed sometimes, made the volumetric measurements subject to significant variations. This difficulty was also experienced in the measurement of the specific gravity, for which a Russell volumeter was used. No improvement in the last mentioned measurements was obtained when dioxane was used instead of water.

The cross-section of each tube was calculated from the results of measured lengths of the water columns and the corresponding water-volume weights. The value used in the calculations of the surface areas was an average of ten measurements.

The weighed sample was mixed with water to form a slurry which was then poured into the glass tube. The sample was allowed to settle. The measurement was started after the water had been flowing for about two hours.

In the experiments involving the factor of drying, the surface area of the fresh tailings was measured first. The water was then allowed to drip out of the tube overnight, after which it was heated at approximately 40°C for 5 days by a heating tape wrapped around the total length of the glass tube.

3. EXPERIMENTAL RESULTS

3.1. Measurements of the Rate of Flow

The relationships indicated by the results of the experiments are most suitably depicted in graphs in which time is plotted against the volume of water that had seeped through a certain layer of tailings.

Figure 1 shows the relation between time and the amount of water that had seeped through layers of various thicknesses. Layers, from 2 to 20 cm thick, were made by means of the 2-cm-thick mould. Each sample was mixed with 100 ml water. This mixture was poured into the tube and allowed to settle for 45 minutes. The zero time for the determination of the flow-rate was taken as being after 15 minutes of free flow. The tube was cleaned out between samples. The time of each run was either 28 hours total, or the time that was needed for 200 ml water to flow through the sample after adjusting the head to a height of 55 cm at the beginning of the experiment, whichever was the lesser. The actual thickness of the layers is indicated in Figure 1.

Figure 2 shows the relation between time and the amount of water to seep through various columns of tailings, consisting initially of damp-dry layers, about 1 cm thick. The actual thickness of the layers during the measurement was approximately 1.5 cm. Each sample from the mould was mixed with 100 ml water and this mixture was poured on to the column already present in the tube, until a thickness of 20 cm was obtained. The water-head was adjusted to 55 cm at the beginning of each experiment. The time of each run was 32 hours or the time that was needed for 200 ml water to flow through the sample, whichever was the lesser. If it was expected that the finish of the run could not be timed (i. e., during nights or week-ends), the run was stopped by plugging the bottom with a stopper, in the same way as was done during the settling time. Only slight effects on the curves could be noticed at these points of stoppage.

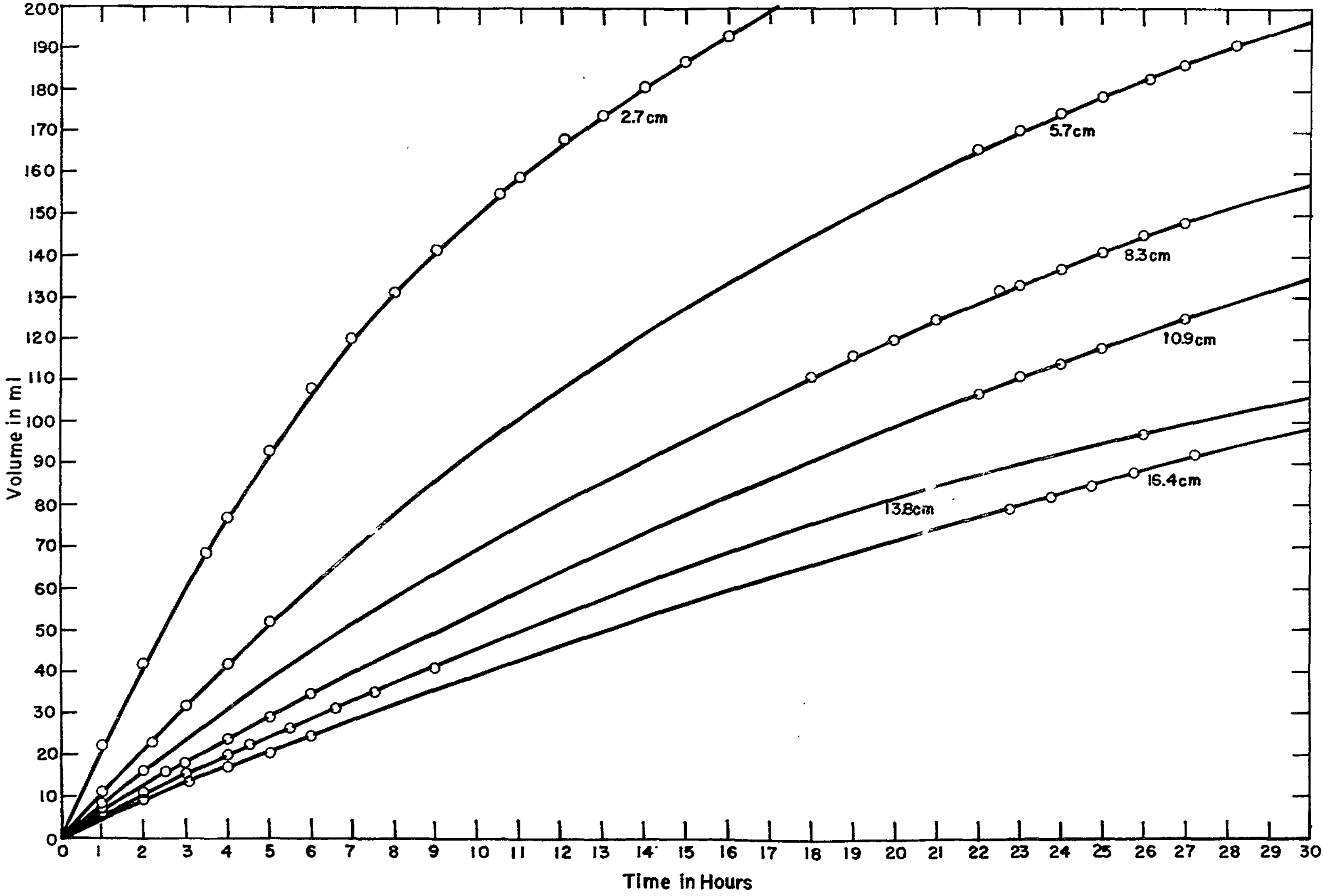

Figure 1. The relation between time and the volume of water that seeped through layers of Heath Steele tailings (thicknesses indicated).

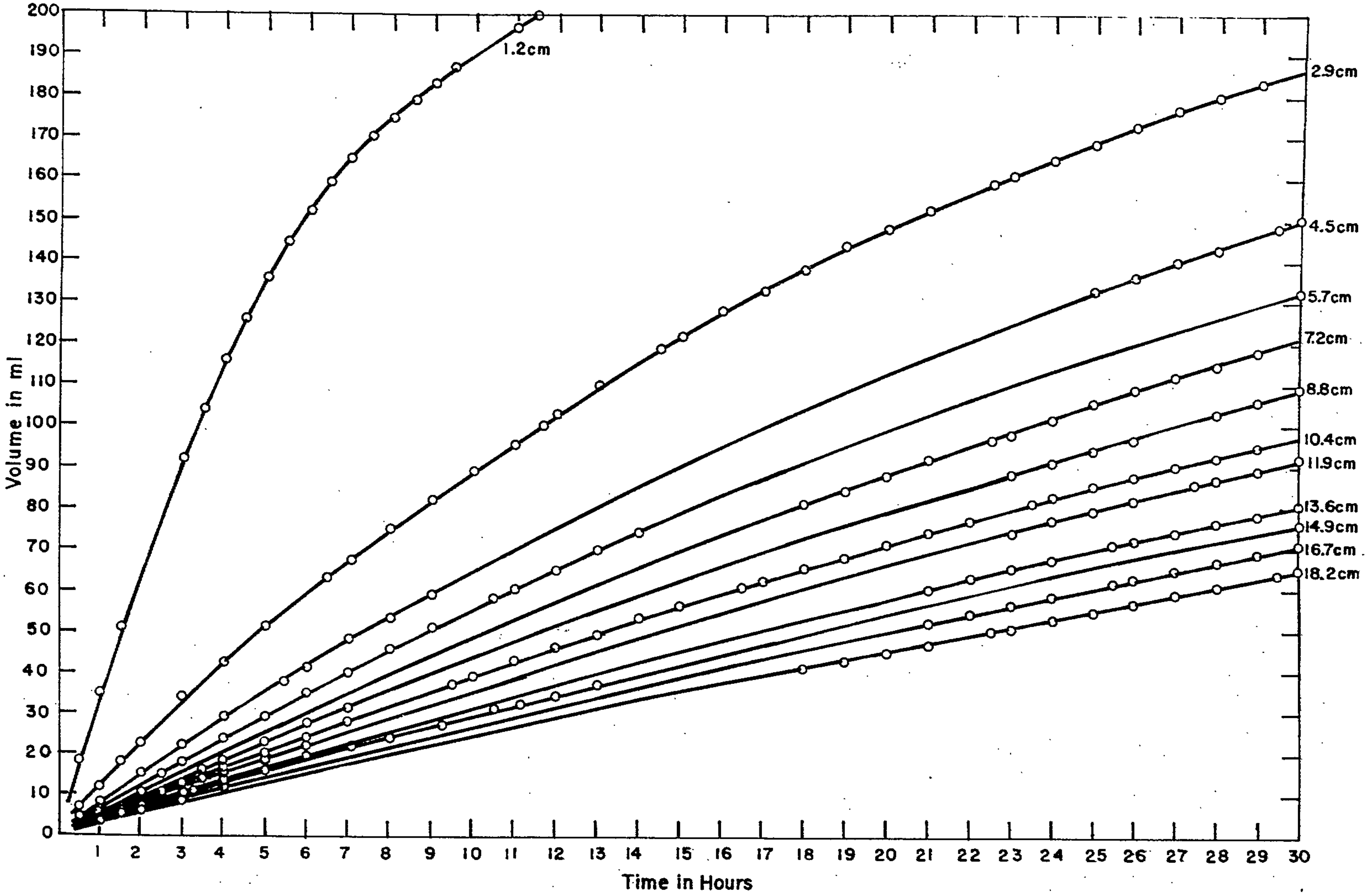

Figure 2. The relation between time and the volume of water that seeped through columns of Heath Steele tailings, made up 1.5-cm-thick layers. The total height of the column is indicated at the end of the curves.

Figure 3 shows the relation between the time and the amount of water that seeped, under constant head, through various thicknesses of tailings.

The samples, used in the experiments that produced Figure 1, were later used for the constant-head experiments by fixing the attachment for producing a constant water-head to the top of the tube after measuring the flow-rate under a decreasing head.

The time of each run was 28 hours or the time needed for 200 ml to flow through, whichever was the lesser. The measurements were started only a few minutes after the constant head had been established.

The constant-head experiments produced linear curves, indicating flow-rates slightly higher than those observed at the start of the corresponding decreasing-head experiments. This was due to the constant-head column being higher than the 55-cm head used at the start of the decreasing-head experiments.

In order to make the foregoing information more applicable to the flow of water through a real tailings pond, the amount of water should be preferably considered to be constant. Certain amounts of rainfall alternate with periods of dryness and evaporation; therefore, the most useful information would refer to the depth to which a certain amount of water would penetrate in a certain time. Although the penetration of the water front cannot be shown, the relationships in the foregoing figures have been converted for that purpose and are redrawn in Figures 4, 5, and 6.

Experiments involving the flow of water through a layered column under a constant head have not yet been conducted.

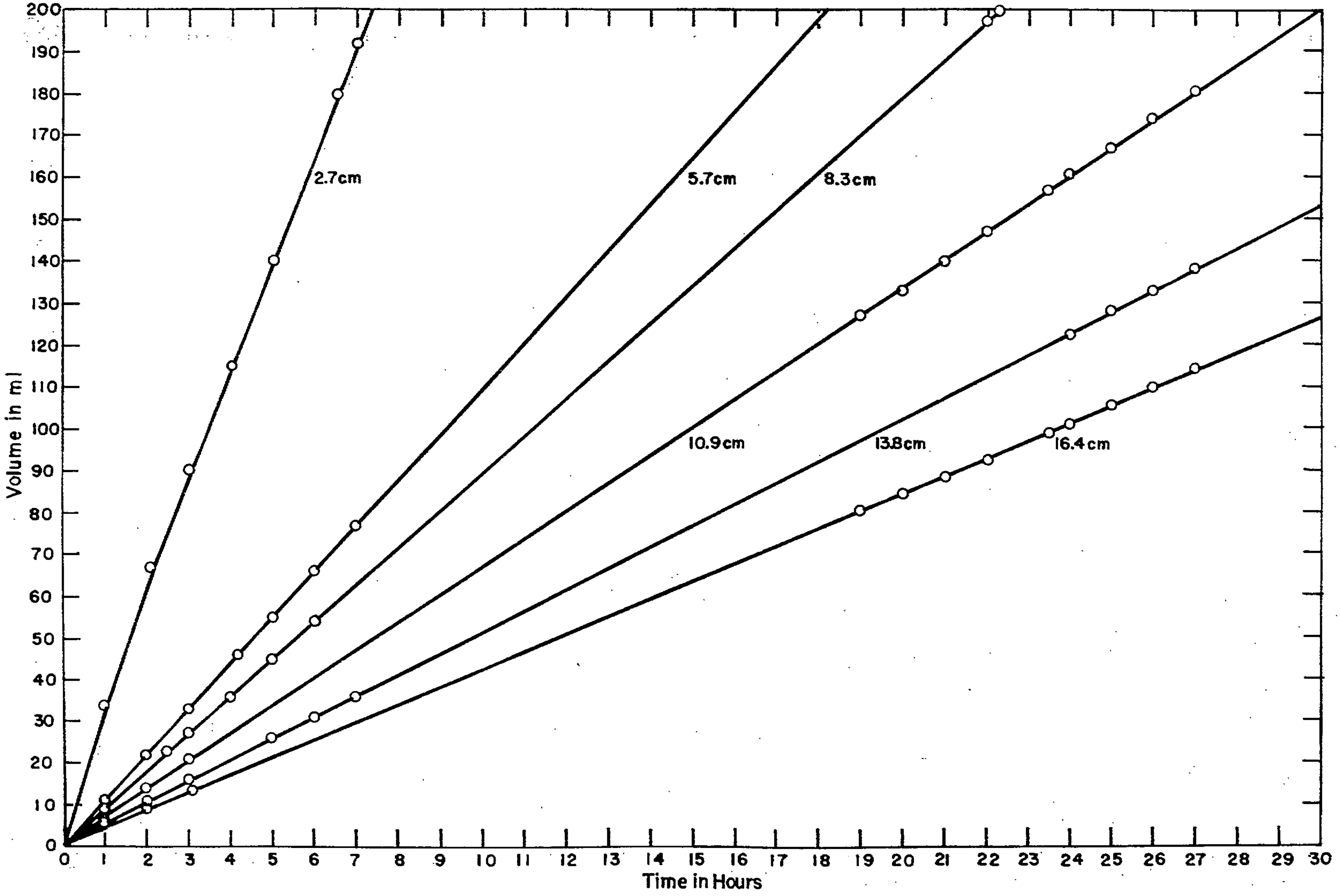

Figure 3. The relation between time and the volume of water that is produced by a constant-head water supply and seeps through layers of tailings, of which the total thickness is indicated on the curve.

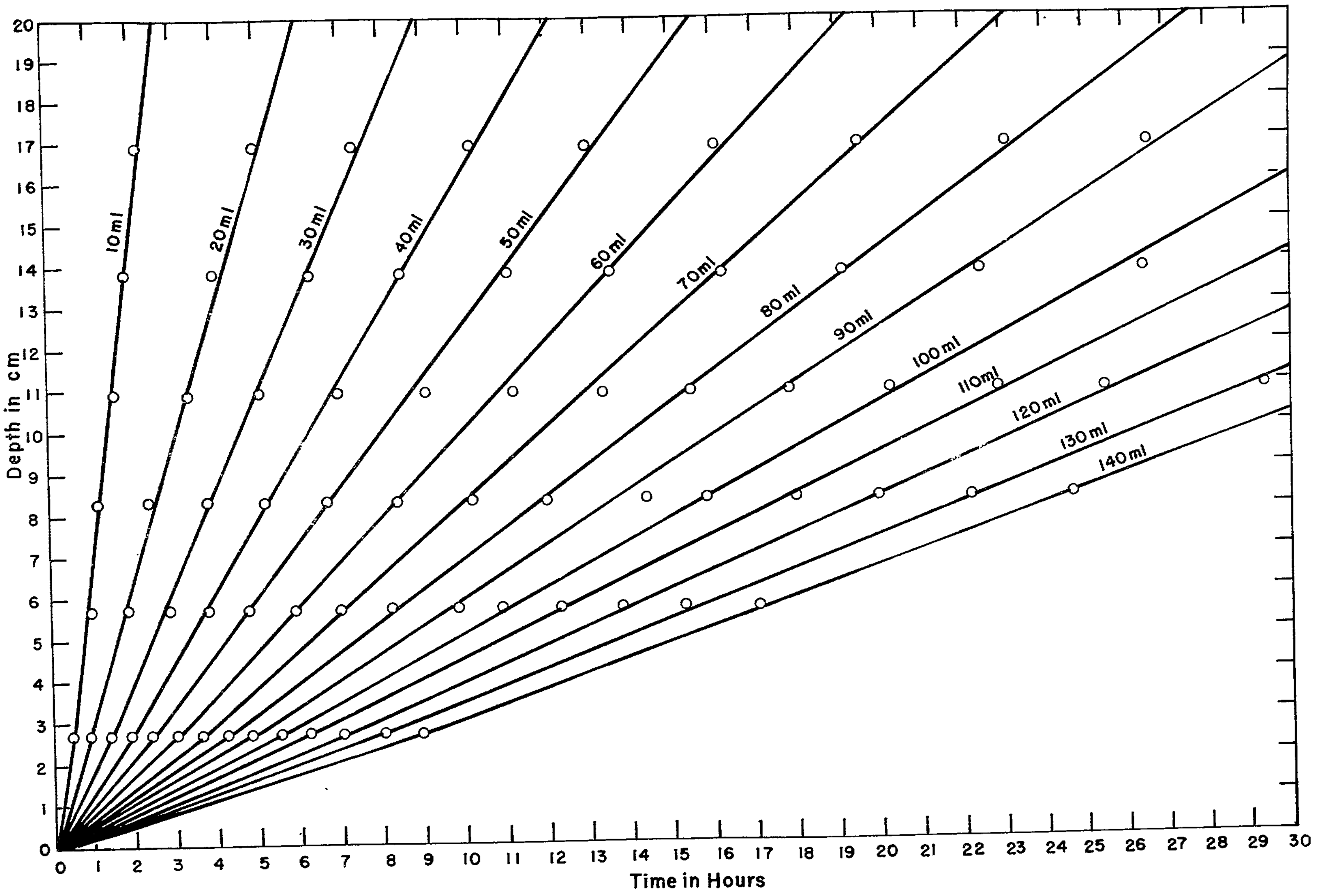

Figure 4. Graphs showing the depths of uniform columns of Heath Steele tailings penetrated by various volumes of water in a given time. This figure is a conversion of the results shown in Figure 1.

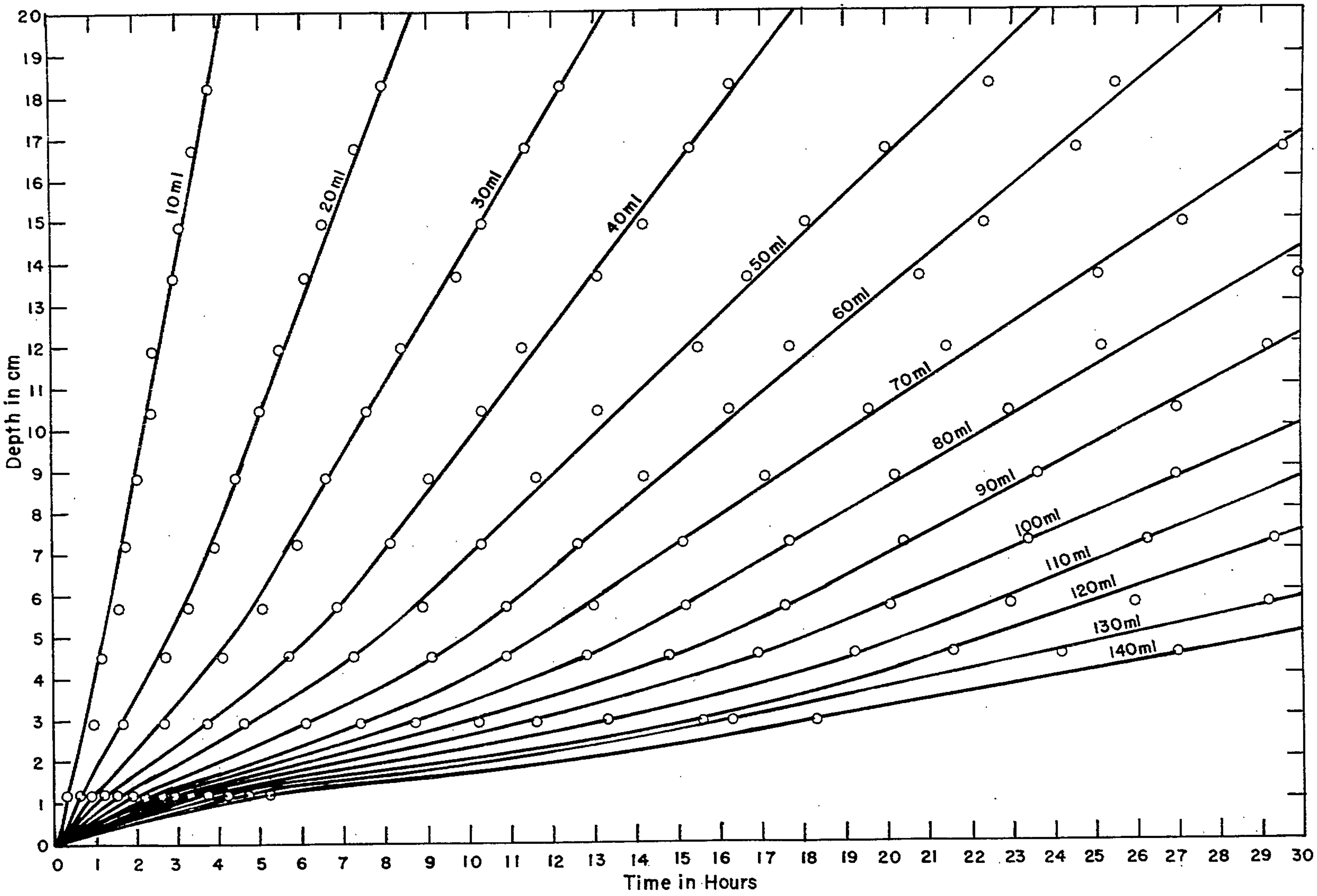

Figure 5. Graphs showing the depths of columns of Heath Steele tailings, consisting of 1.5-to 2-cm-thick layers, penetrated by various volumes of water in a given time. This figure is a conversion of the results shown in Figure 2.

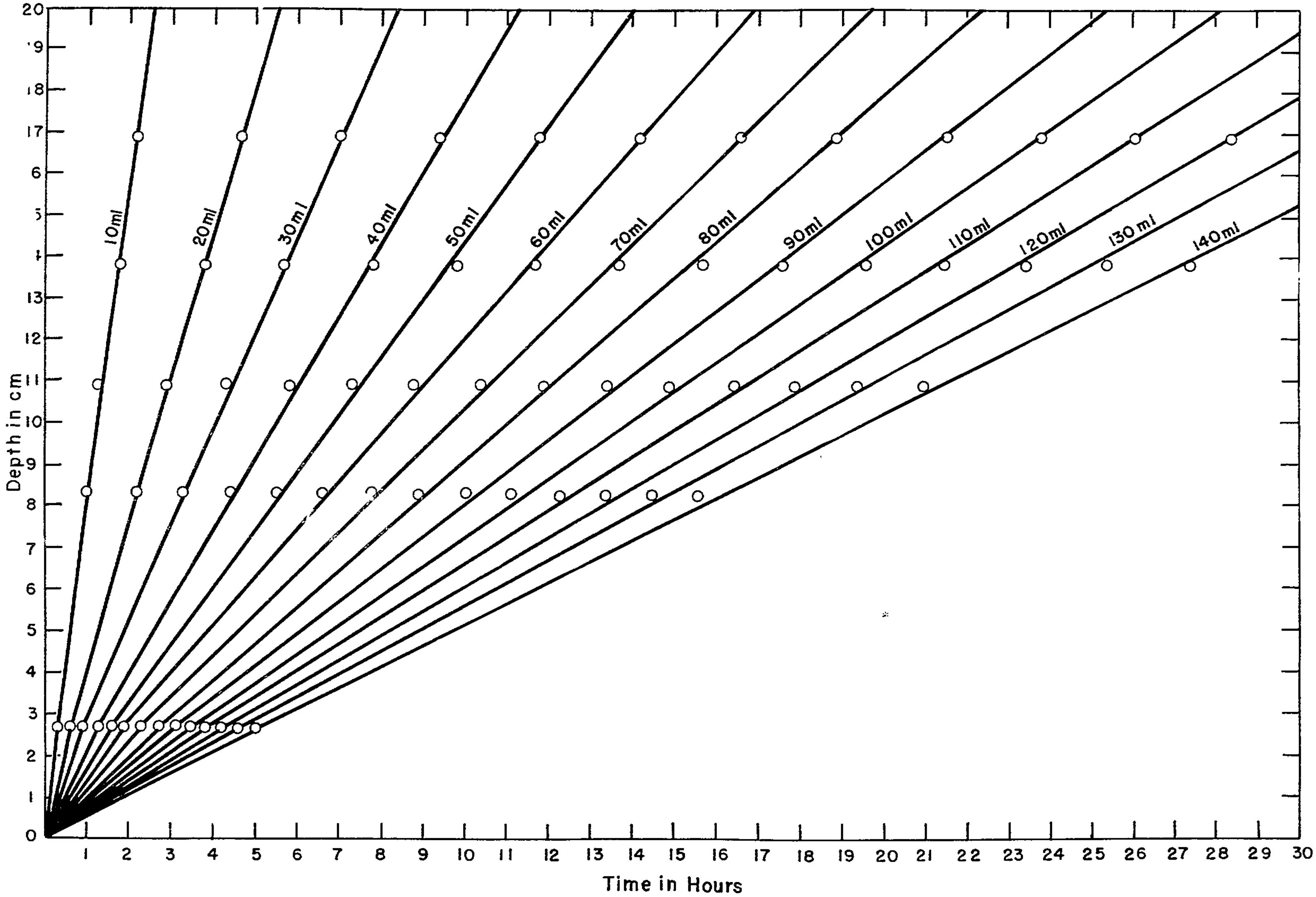

Figure 6. The depths of columns of uniform Heath Steele tailings, penetrated by columns of water supplied by a constant-head source, in a given time. This figure is a conversion of the results shown in Figure 3.

3.2. Measurements of a Few Factors Affecting the Grain-Surface Area of Tailings Exposed to Water

The results of the measurement of the specific grain-surface area of each tailings sample, supplied by various mining companies*, have been listed in a previous report(3). These results were used to calculate the specific surface-areas of columns that consisted of several tailings samples.

The values of the surface areas of particular tailings samples would, theoretically, not be affected by alternating them to form layered structures. Each layer would be representative of the sample concerned. Experimentally, however, the effect of layering had been demonstrated in the experiment on the rate of flow of water, and was described in Section 3.1. This effect originates in the packing of the column. When a tailings sample is placed in the glass tube, a certain amount of sedimentation segregation takes place; the light and fine particles settle on top of the heavy and coarse particles. The same result was observed in several tailings ponds in the field, where the intermittent pouring of tailings produced layered structures. Variations in the mineral compositions will also contribute to layering, but this effect can be expected to be far smaller than that of sedimentation segregation. Obviously, the results of the interactions of these and other local factors can only be observed in the field, where it may affect the localization of natural plant growth. In a certain tailings pond, the observation was made that, at places where the greatest amount of sulphides had leached out to a depth of about 6 inches, grass (e.g., Agrostis alba) had started to grow. There was no vegetation where layers of fine-grained sulphides were still present closer to the surface.

The purpose of the laboratory experiments is, therefore, to demonstrate the complexity of the effects of a few physical factors on the grain surface-area exposed to water (abbreviated to surface area in the

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*The numbers **referring** to the relevant mining companies are those used in other reports(3, 4).

following). These factors concern the effect of layering and mixing of different tailings, and that of drying. In these initial stages of the study, the principal goal is to obtain qualitative information from experiments which can later be developed and improved further, according to the value of the information in relation to the over-all weathering process.

The effect of drying was demonstrated drastically with high-sulphide tailings. The tailings sample from Company No. 15 was selected for this experiment. There were indications that it had a particular sensitivity to the amount of sample used in the specific surface-area measurements. Whereas the difference in the results of the measurements of surface areas of other tailings, using either a 50-or a 100-g sample, had been comparatively small (e. g., 95 and 103, 133 and 136, 100 and 104, 104 and 107, 84 and 85, 175 and 184, etc., cm^2/cm^3)*, the value of the surface area of this sample (183) was taken as the average of three values (163, 181, and 204) for 50-g, 75-g, and 100-g samples, respectively. The average surface area of two other samples was 247 (255, 239). The average surface area of these two samples, after drying, was reduced to 68 (80, 56). Notwithstanding the erratic results obtained in the measurement of the surface area of this particular tailings sample, the effect of drying appeared obvious. If no particular precautions are taken to protect the sample from atmospheric humidity, reactions take place in the tailings sample on standing, and large impervious aggregates can be expected to be formed.

However, since the samples had been dried at 60°C for approximately two days in these first drying experiments and these conditions could be considered to be significantly different from those in the field, the experiment was repeated at a lower temperature (40°C) for a longer period (5 days).

The sample that had been used in the drying experiment at 60°C, however, was depleted. Another sample was available, that had become

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*From here on, the designation cm^2/cm^3 will be omitted for sake of brevity.

so hard on standing that an attempt had to be made to crush and grind the sample to a certain extent to break up the aggregates. After this attempt, the surface area appeared to be 137 (130, 140, 144, and 135). In order to avoid decreasing the original grain sizes by too-vigorous tamping and grinding, it is very probable that the aggregates had not been completely broken up. However, notwithstanding that the surface area had been reduced by long standing and by subsequent treatment, it decreased further to 58 (56, 61) after drying at 40°C. This sample was also used in the following experiments.

The effect of sedimentation segregation on the grain surface-areas of tailings columns, could be compared with that of packing various grain sizes in arrangements consisting either of layers of different tailings or of mixtures of these layers.

Drying could be expected to vary with the composition of each layer. No drying experiments were done on the columns containing mixtures, because the effect could be expected to be homogenously distributed through the column.

The results of the measurements of the various experimental arrangements are listed in Table 1. The "calculated" values in this table were derived from the measurements of the volume of each layer and that of the total column (cm^3), combined with the results of the specific surface-area measurements on each tailings sample concerned (cm^2/cm^3)(3).

The surface area of the mixed tailings samples appeared to be smaller than that of the layered arrangement. This difference is due to packing of the range of grain sizes.

The effect of drying was not as pronounced as in the experiment on the tailings sample from Company No. 15. Unfortunately, the effect of drying was not measured in Arrangements Nos. 1, 2, and 7, which contained the tailings sample from Company No. 15. The results, however, indicated that the surface areas remained the same or increased slightly after drying. It is possible that tailings compositions, containing a comparatively small amount of sulphides, do not form aggregates by chemical reactions and subsequent evaporation of the water. This phenomenon can be expected to be connected, in acid tailings, with the formation of iron (hydr)oxides which probably cement the mineral grains together.

A true increase in surface area, due to drying of tailings containing small amounts of sulphides, may be caused by the reduction of the adhesion between grain surfaces. However, this is very improbable, in view of general sedimentological experience. A more likely possibility is that the fine-grained tops of each layer pack more tightly, so that they become less pervious to water, thereby decreasing the water-flow; one agglomerate can be considered to have formed, that blocks the entrance and stops the water-flow. The increase in surface area, in that case, is apparent only and not a true increase.

Generally, the principal effect of drying is in the increased packing of mineral grains. The dissolving action of the water on the bulk tailings composition is then retarded by the formation of impervious aggregates.

The measured surface areas were greater than those calculated, except in Arrangement No. 4. This result originates in the sedimentation segregation. The discrepancy in Arrangement No. 4 is probably due to a decrease in surface area of the tailings from Company No. 12, which contained a large amount of sulphides. Reactions may have taken place and impervious aggregates may have formed on standing. The originally-determined value of the surface area was used in the calculation, whereas the experiment was done much later and the measurement of the surface area of the sample after standing was not repeated.

The results of the measurements of the surface areas in Arrangement No. 7, generally, follow the pattern that could be expected. The surface area of tailings from Company No. 15 decreased after the column was extended with a layer consisting of the coarser tailings from Company No. 1. It increased again after a third layer of fine-grained tailings had been placed on top of the previous two. However, the sedimentation segregation in both the double-and triple-layered arrangements increased

TABLE 1

Specific Surface-Areas of Columns Consisting of Various Arrangements of Tailings Samples

No.	Arrangement in the Glass Tube	Particle-Size Code*	Specific Surface-Area Exposed to Water (cm^2/cm^3)				
			Tailings	Layered Column		Dried Column	Mixed Column
				Calculated	Measured		
1	25 g tailings no. 15	0. 3. 7.	137	85	101		87
	25 g seasand	9. 1. 0.	3. 60				
	25 g tailings no. 15	0. 3. 7.	137				
2	50 g tailings no. 15	0. 3. 7.	137	108	164		124
	50 g tailings no. 1	3. 3. 4.	68				
	50 g tailings no. 15	0. 3. 7.	136				
3	30 g tailings no. 13	1. 5. 4.	137	173	210	218	127
	30 g tailings no. 4	0. 3. 7.	327				
	30 g tailings no. 13	1. 5. 4.	137				
4	30 g tailings no. 10	1. 4. 5.	85	147	139	161	107
	30 g tailings no. 12	1. 2. 7.	216				
	30 g tailings no. 10	1. 4. 5.	85				
5	35 g tailings no. 11	1. 4. 5.	105	73	75	78	69
	25 g seasand	9. 1. 0.	3. 60				
	25 g tailings no. 11	1. 4. 5.	105				
6	25 g tailings no. 3	2. 3. 5.	135	126	133	141	97
	25 g tailings no. 11	1. 4. 5.	105				
	25 g tailings no. 3	2. 3. 5.	135				
7	50 g tailings no. 15	0. 3. 7.	137	137	135		
	50 g tailings no. 1	3. 3. 4.	68	99	118		
	50 g tailings no. 15	0. 3. 7.	137	112	142		

*The particle-size code "a. b. c." stands for +100 mesh 10a%, -100 +325 mesh 10b%, and -325 mesh 10c%, as has been explained more extensively in another report(3).

the surface areas significantly, above the expected surface areas, as the calculated values in Table 1 indicate.

4. DISCUSSION

The transition from the flow-rate experiments, that were done in the initial stages of this study, to measurements of specific surface-areas of mineral grains in tailings exposed to water, is based on the very close relation that appeared to exist between the surface areas and the chemical reactions that take place in the weathering process. Although chemical and physical aspects of the process could be distinguished from each other, it appeared that certain relationships could be not be separated experimentally(4).

The following observations were made concerning the results of the flow-rate experiments:

a) The flow rate was decreasingly affected by an increase in column thickness, so that the flow rates through more than 2 to 3 ft of tailings might be considered to be steady from a practical point of view;

b) layering of the columns decreased the flow rates; this phenomenon is due to the lightest and finest particles settling down last, forming a layer that reduces the flow rate more than would a homogeneously-packed column; only one of these layers of fine particles is present in a column consisting of one layer, whereas more of these layers are present in columns consisting of more than one layer: this effect of sedimentation segregation is, therefore, multiplied by the number of layers; the curves of the 5.7-cm-thick layered column in Figure 2 coincide, therefore, almost with the 10.9-cm-thick column in Figure 1, which consists of one layer only;

c) results of experiments, referring to comparatively thin layers, were more inconsistent than those involving thick columns, because the top layer of fine particles has more blocking effect than the rest of the column;

although the total weight of fine particles is proportional to the total weight of the sample, the reducing effect on the flow-rate appears to be particularly affected by the settling of the last and finest particles;

d) the curved nature of the graphs in the Figures 1 and 2 is obviously due to the decreasing hydrostatic pressure of the water-head. This relation is log-normal; when the head of water remains constant, linear relationships are produced, as is shown in Figure 3.

The flow-rate experiments were made, using one particular arbitrary set of conditions. Although they would be eliminated in comparisons between flow-rates through various tailings compositions, surface-area calculations based on flow-rate measurements appeared preferable, in view of the connection with the chemical aspects of the weathering process.

The results of the specific surface-area measurements of tailings from various mining companies indicated that the surface areas varied with the tailings compositions(3).

The results of the flow-rate experiments indicated that sedimentation segregation, and the subsequent production of layers, affect the flow-rate and, therefore, also the surface areas exposed to water.

Drying appeared to affect the surface areas additionally, according to the composition of the tailings. It is probable that the surface area of high-sulphide tailings decreases more by drying than that of low-sulphide tailings. The formation of agglomerates can be expected to be due to evaporation of the water, to crystallization of the dissolved solids, and to subsequent cementing action, particularly by iron (hydr)oxides.

Since the specific surface-area exposed to water is different from the theoretical surface area, a comparatively coarse-grained tailings sample can have a larger surface area exposed to water than a fine-grained tailings sample, because of the difference in packing and because of the formation of impervious aggregates.

The effects of sedimentation segregation and that of drying can be observed in the field. The first produces the formation of lenses and layers. Upon the pouring of a certain amount of tailings, the sulphides in the bottom part of a newly-poured layer start to leach out, leaving the fine-grained top layer, that still contains sulphides, progressively less subject to the dissolving action of the water. The effect of drying is the probable origin of channeling which, after erosion, produces gullies. Obviously, the geomorphological nature of the tailings pond is another decisive factor in this process.

The weathering process, in general, can be expected to proceed from the surface of the tailings downwards. Local conditions will govern the direction of water-flow, the formation of a water level, the increase in thickness of the tailings pond (pile), etc. Although layers will be affected by such local conditions, the general effect will be a retardation in the amount of material that dissolves, because of a decrease in grain surface-area exposed to water. This retardation of dissolution may have little effect on the resulting pH if the proportion of the types of minerals in all size-fractions is similar. However, if carbonates are predominantly present in the coarse fractions, and sulphides in the fine fractions, a gradual decrease in pH can be expected.

A conclusion that the foregoing results would indicate a preference towards keeping a tailings homogenous by any of the agricultural methods, will also have to solve the question as to what would happen in the environment when an increased amount of solutes drains off in a comparatively short period.

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6. REFERENCES

1. A. Jongejan, An Experimental Study of the Weathering of Mill Tailings in Connection with Water Pollution. Part 1: Development and Examples of Study Methods. Mines Branch Investigation Report IR 72-4, 8 March 1972.
2. do Part 2: Preliminary Experiments. Mines Branch Investigation Report IR 73-55, 18 September 1973.
3. do Part 3: Mineralogical Analyses of Tailings Samples from Various Mining Companies in Canada. Mines Branch Investigation Report IR 73-14, 4 May 1973.
4. do Part 4: The Effect of Tailings Samples from Various Canadian Mining Companies on the Composition of Water. Mines Branch Investigation Report IR 73-55, 18 September 1973.
5. A. Jongejan, Progress Report on Project No. E-PC 71-02, The Effects of Slag Heaps and Tailings on the Pollution of Water. A Summary of the Progress in the Study of the Microbiological Aspects of the Project. Mineral Sciences Internal Report MS 73-25, 18 September 1973.
6. C.G. Dodd, J.M. Davis and F.D. Pidgeon, Measurements of Specific Surface Areas of Non-Porous Powders by a Pressure-Decline Liquid-Permeability Method. J. Phys. Colloid Chem., 55, 684-900 (1951).
7. (i) P.C. Carman, Fluid Flow Through Granular Beds, Trans. Inst. Chem. Engrs. (London), 15, 150 (1937).
   (ii) M.R. Wyllie and A.R. Gregory, Fluid Flow Through Unconsolidated Porous Aggregates. The Effect of Porosity and Particle Shape on Kozeny-Carman Constants. Ind. and Eng. Chem., 47, 1379 (1955).