The Rhodesian approach to the vegetating of slimes dams

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SYNOPSIS

To prevent environmental pollution from mine dumps, it is necessary to stabilize them either mechanically or biologically. In the long term biological stabilization is more attractive because of its permanent nature. Initially, the basis of stabilization is in the correct siting and construction of the dump.

The main toxic factors influencing plant growth on Rhodesian mine dumps are arsenic, antimony, copper, nickel, a high ratio of magnesium to calcium, excessive soluble salts, high pH, and low macronutrient content. Root-growth studies in culture solution and pot experiments are used to supplement information on the suitability of plant material obtained from replicated field trials on mine dumps.

In addition to the selection of plants for toxic tolerance, it is advisable to provide multiple-layer protection with trees, shrubs, and grasses. Further, a range of different plant species gives greater biological stability.

Protection must be provided for young plants against wind erosion and the abrasive effects of windblown sand. Planted wind breaks are preferred to mechanical forms; windrows of garden refuse make good wind breaks and at the same time introduce organic material to the dump and provide a good environment for seedling establishment.

The use of artificial fertilizers and sewage effluent is recommended to hasten the development of a complete and protective plant cover.

SAMEVATTING

Om omgewingsbesoedeling deur mynhope te voorkom moet hulle meganies of biologies gestabiliseer word. Biologiese stabilisering is op die lang duur aantrekliker omdat dit van 'n permanente aard is. Die aanvanklike grondslag vir die stabilisering is die korrekte plasing en konstruksie van die hoop.

Die vernaamste giffaktore wat plantegroei op Rhodesiese mynhope beïnvloed is arseen, antimoon, koper, nikkel, 'n hoë verhouding van magnesium tot kalsium, oormatige oplosbare soute, hoë pH en 'n lae makrovoedingstofinhoud. Wortelgroeistudies in kultuuroplossings en poteksperimente word gebruik om die inligting oor die geskiktheid van plantemateriaal deur replikaveldproewe op mynhope ingewin, aan te vul.

Dit is raadsaam om benewens die keuse van plante wat teen gifstowwe bestand is, voorsiening te maak vir meerlaagbeskerming met bome, struike en gras. Verder gee 'n reeks verskillende plantsoorte groter biologiese stabiliteit.

Die jong plante moet teen winderosie en die skuuruitwerking van waaisand beskerm word. Aangeplante windskuttings is beter as meganiese vorms; rye tuinafval maak goeie windskuttings en voeg terselfdertyd organiese materiaal by die hoop en verskaf 'n goeie omgewing vir die vestiging van saailinge.

Die gebruik van kunsmis en riooluitvloeisel word aanbeveel om die ontwikkeling van 'n volkome beskermende plantbedekking te bespoedig.

INTRODUCTION

In Rhodesia, mine dumps have created interest more for their offence to aesthetic values than for any practical reason, but the situation is rapidly changing as the country becomes more industrialized. Industrial progress is associated with a greater demand for minerals, and technical progress will make the mining of lower-grade ores economically more attractive. In consequence, more and bigger mines will be the future trend, the mine-dump problem will escalate, and with it the related practical problems of environmental pollution.

This pollution will be in two main forms—chemical and physical, each with its specific problems. To prevent pollution from mine dumps, it is necessary to stabilize them either mechanically or biologically. Naturally, the biological approach is more attractive because, in the long term, it is more permanent and less costly to maintain.

The problem can therefore be summarized as the establishment of any type of vegetation on the sterile and, in varying degree, toxic medium provided by the waste materials of the mining industry that are dumped on the land surface.

The need to stabilize mine dumps has been recognized for some time; the Rhodesian Chamber of Mines, in collaboration with the Natural Resources Board, first drew attention to the problem in their Mine Managers' Circular entitled 'The Promotion of Vegetative Covers on Mine Slimes Dams and Sands Dumps', in 1961[1]. Their stated intention was to eliminate the unsightliness and dust nuisance of mine dumps and to prevent the blockage of natural drainage channels by mine-dump erosion. It was also suggested that certain slimes dams in Rhodesia would be difficult to vegetate because of the presence of elements such as arsenic, antimony, copper, lead, and zinc in gold ore residues. Later in the same year, the Mineral Resources Committee of the Natural Resources Board set up a Technical Committee to investigate the stabilization of mine dumps[2]. At their inaugural meeting, held on the 18th September, 1961, this Committee agreed to undertake a country wide survey to

(a) establish the extent of the problem,
(b) draw up a list of problem dumps, and
(c) gain information about the growth of vegetation on dumps where this had occurred.

The ensuing survey conducted by the Department of Conservation and Extension, and presented to the second meeting of the Technical Committee in December, 1962, indicated that the erosion occurring both on and away from mine dumps was by no means wide spread or serious[3]. Further, the establishment of vegetation on mine dumps was generally greater than anticipated, and a high percentage of the dumps investigated had a plant cover of more than 40 per cent.

The Chairman of this second meeting indicated that the survey

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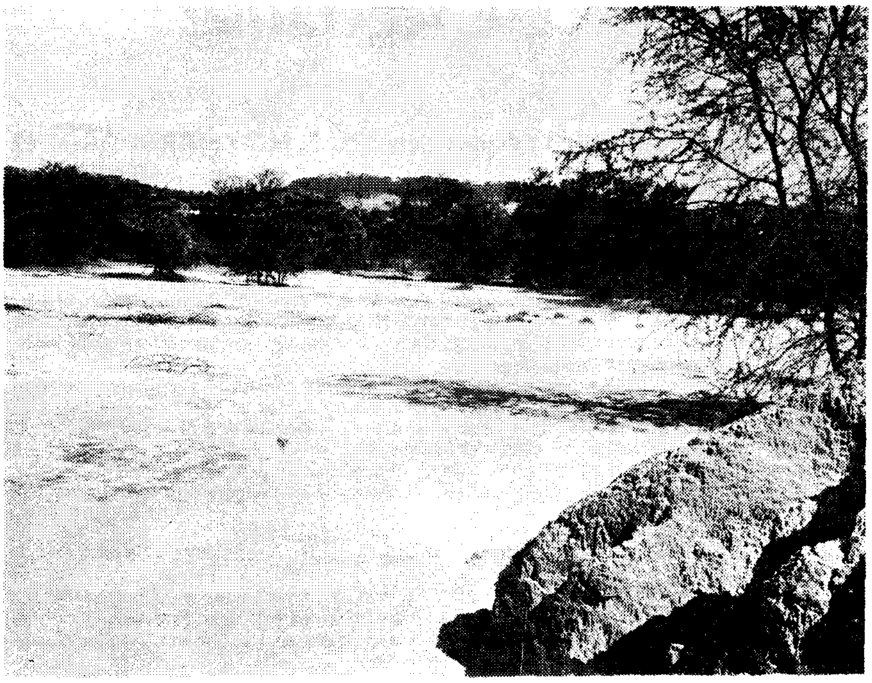

Plate I—Physical effect of mine dumps: the inundation of valuable township land by mine-dump erosion originating in the foreground.

had shown so many similarities to the position in South Africa that it was reasonable to work almost completely on South African experience. However, a limited series of trials was planned and initiated in February 1963. These trials lacked direction, and, as no results or conclusions were obtained, the trials can be classed as a failure.

This earlier failure to understand the problem is now producing its results, and recent records of the Natural Resources Board[4] indicate that a mine dump on the Camperdown Mine, near Selukwe, considered stable twenty years ago, was seriously eroding in 1962 and required urgent and essential action to prevent serious siltation of the Umtebekwe River. Because the Umtebekwe River supplies water to 250 ha of existing irrigation farming and has a further potential of over 1000 ha, a silt trap was constructed on the Camperdown Spruit at a cost of R.$10 810. The alternative to this would have been mechanical works on the dump itself, estimated to cost R.$100 000.

There are a number of other mine dumps in Rhodesia that can be predicted to result in similar environmental pollution in the near future[5].

The inherent problem of mine dumps is common to all forms of mining throughout the world—a number of workers are investigating the problem with the same objective in view but with different philosophies[6–12].

For a successful conclusion to the problem, it is necessary to classify the problem into its component parts as represented below. However, environmental reaction is complex, and factors contributing to cause, effect, and control of the problem are completely interrelated.

Cause		Effect		Control
Slimes dams		Physical		Biological
Concentrate dams	←→		←→	
Dumps		Chemical		Mechanical

Rhodesian mine dumps are often more or less devoid of vegetation. This is due to several factors, the most important of which are probably the presence of toxic components (Table I)[13], the deficiency of macronutrients, poor physical structure of the rooting environment, and the absence of humic/organic material and its associated soil microflora. Other factors of importance are dump construction, past erosion, slope, surface stability of dump material, wind, and climate[14].

Because mine dumps are devoid of cover, they are prone to erosion and likely to cause environmental pollution. To prevent pollution from mine dumps, it is necessary to 'find an economic and permanent method of stabilizing mine wastes . . . both to prevent pollution and to improve the visual appearance of mine workings'[6].

THE STABILIZATION OF MINE DUMPS

Effective stabilization and control of the mine-dump problem can be achieved by two methods or a combination of the two, namely mechanical and biological stabilization.

Mechanical control is more effective than biological control in the initial instance, but it could be more costly to implement and certainly requires maintenance and therefore does not solve the problem permanently. Biological control requires detailed research initially, but, once the information has been obtained, the solution is permanent and, in the long run, is considerably less costly than mechanical control[14].

Smith and Bradshaw[6] discuss two alternative methods of dealing with toxic mine wastes—removal or reclamation. Removal of the material for use as grit for roads or as a base for construction is considered a possibility in parts of Britain, where the amount of material is limited relative to the population density. In the more distant parts of the British countryside and in large-scale operations elsewhere in the world, these rather limited uses are unlikely to make much impression on the vast volume of mining wastes.

'Reclamation by covering with vegetation thus seems the only possible alternative, although stabilization by resin compounds and other physical means may be a temporary solution'[6].

BIOLOGICAL STABILIZATION

Biological stabilization is the most permanent solution and will ulti-

TABLE I

ANALYSES OF RHODESIAN MINE DUMPS [13]

No.	Mine	As p.p.m.	Sb p.p.m.	Cu p.p.m.	Ni p.p.m.	Pb p.p.m.	Zn p.p.m.	Mn p.p.m.	W p.p.m.	pH 1:5 H_2O	pH 1:5 $CaCl_2$	Soluble Salts %	% SO_2	% MgO	% CaO
1.	Gaika	2000	500	20	1200	20	100	2000	500	8,56	8,18	0,35	0,21	21,65	1,65
2.	Que Que Roasting Plant—old dump	4000	2000	1000	1000	1200	1500	1000	500	8,63	8,52	0,80	2,15	5,88	2,84
3.	Que Que Roasting Plant—new dump	3000	2000	900	400	800	1000	1000	500	7,50	7,35	0,02	3,19	1,65	1,44
4.	Globe & Phoenix—old sand dump	1200	1000	30	200	400	150	500	n.s.	8,77	7,94	3,08	0,03	3,43	1,09
5.	Globe & Phoenix—old slimes dump	1000	1500	30	300	400	150	1000	n.s.	8,38	8,08	0,98	0,56	9,63	2,09
6.	Bell Mine—top of dump	3000	1000	< 20	< 50	30	100	1000	n.s.	9,00	8,38	0,04	0,10	3,25	1,23
7.	Bell Mine—base of sands dump with couch	2000	150	< 20	< 50	50	100	1000	n.s.	8,98	8,07	0,02	0,06	4,25	0,86
8.	Bell Mine—side of dump	700	< 30	30	< 50	80	150	1000	n.s.	9,08	8,22	0,02	0,05	1,27	2,79
9.	Cam & Motor—red dump	10 000	50 000	50	100	50	300	2000	n.s.	8,88	8,54	0,65	0,78	3,50	1,97
10.	Cam & Motor—grey dump	approx. 5000	approx. 4000	100	300	200	400	2000	1000	8,85	8,80	2,94	5,66	6,57	2,88
11.	Cam & Motor—side of untreated dump opposite refinery	2000	500	30	250	30	50	2000	500	8,98	8,65[	2,50	1,13	6,67	3,34
12.	Fred Mine	5000	n.s.	< 20	150	50	50	1200	1500	8,70	8,33	0,27	0,66	1,59	
13.	Champion, Gwanda	10 000	20	30	30	20	250	1000	250	8,88	8,26	0,02	n.s.	0,56	
14.	Banshee, Gwanda	30 000	n.s.	250	50	30	700	1000	n.s.	8,20	7,99	0,53	1,51	0,36	
15.	Vubachikwa, Gwanda—new dump	approx. 1500	n.s.	< 20	30	< 20	250	5000	n.s.	8,53	8,15	0,11	0,85	1,50	
16.	Vubachikwe—old dump with good euphorbia	1000	n.s.	20	30	< 20	400	approx. 5000	n.s.	9,05	8,13	0,03	n.s.	1,34	
17.	Vubachikwe–old dump with poor euphorbia	5000	n.s.	50	30	< 20	1 000	approx. 5000	n.s.	7,10	6,84	0,49	5,82	1,82	
18.	Banket, Gwanda—new dump	20 000	n.s.	40	30	200	50	approx. 1500	n.s.	8,70	8,31	0,25	n.s.	1,14	
19.	Big Ben, Gwanda	approx. < 100	n.s.	50	200	70	< 50	2000	n.s.	8,78	8,54	0,59	1,56	1,27	
20.	Golden Valley	200	< 30	20	< 50	60	100	500	500	8,62	7,66	0,03	0,05	1,20	2,84
21.	Jumbo, Mazoe	250	n.s.	30	< 20	300	< 50	200	n.s.	2,75	2,70	1,81	4,36	0,28	
22.	Shamva Mine—sand dump	100	n.s.	20	< 20	< 40	< 50	< 100	n.s.	4,65	4,17	0,01	n.s.	0,53	
23.	Mangula Copper Mine—slimes dump	< 100	n.s.	250	< 20	< 20	< 50	< 100	n.s.	9,40	8,30	0,07	n.s.	1,10	3,60
24.	Alaska Copper Mine—slimes dump	< 100	n.s.	2500	20	< 20	< 50	500	n.s.	9,36	8,55	0,01	n.s.	2,36	
25.	Alaska Copper Mine—slimes dump, bottom	< 100	n.s.	4000	20	< 20	< 50	500	n.s.	9,00	8,20	0,01	n.s.	2,02	
26.	Falcon, Umvuma—old dump	200	n.s.	10 000	500	20	100	500	n.s.	6,88	6,60	0,18	n.s.	1,74	
27.	Gath Asbestos Mine, Mashaba	< 100	n.s.	< 20	3000	< 20	800	1500	n.s.	9,95	9,57	0,04	n.s.	18,00	
28.	Thornwood Asbestos	< 100	n.s.	< 20	3000	< 20	50	2500	n.s.	9,75	9,25	0,04	n.s.	15,90	
29.	Reliance, Umtali—old dump	> 5000	200	1200	1000	1000	900								
30.	Phoenix, Bindura—old dump	500	n.s.												

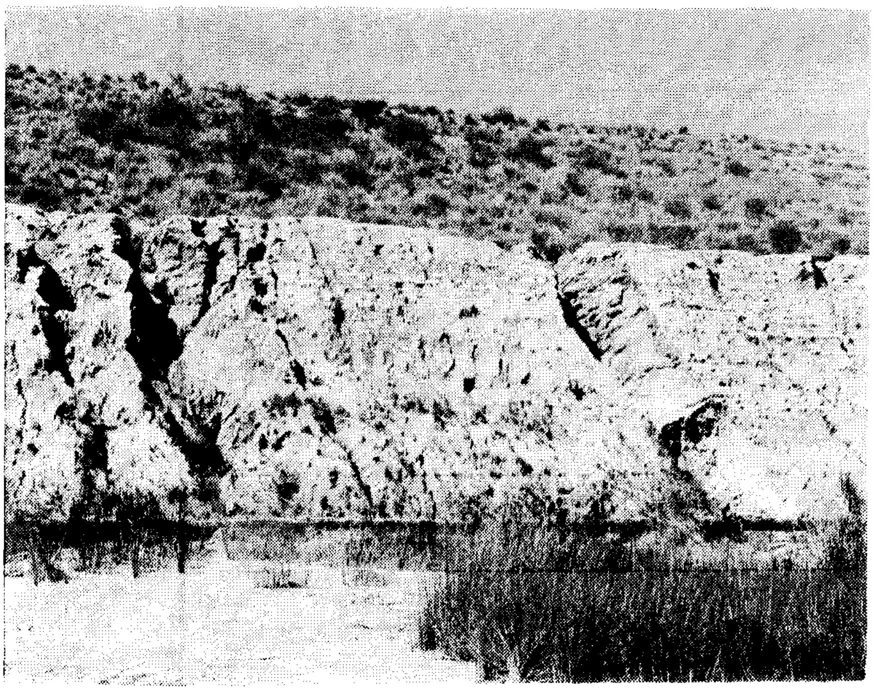

Plate II—Biological stabilization: the effect of planted grass in stabilizing the sides of a mine dump. The upper terrace is planted with *Cynodon dactylon*, the lower terrace is unprotected and is eroding rapidly.

mately prove to be the least expensive method of stabilizing mine dumps. Although ideal, biological stabilization is the more exacting method, having numerous associated problems that must be investigated and understood before stabilization can be effective.

The sooner biological control starts after dumping commences, the easier it is to stabilize the dump. While dumping is in progress, labour and capital resources are available for planting, fertilization, and maintenance until the vegetation is sufficiently established to persist. There is also the possibility of the use of sewage effluent and water for plant establishment, and, more important, responsibility for stabilization is definite. Once mines have been abandoned, the problem of stabilization is considerably increased as the situation deteriorates, further responsibility is difficult to allocate, and there is little or no supervision on site.

In general, the extraction processes used in modern-day mining reduce the majority of toxic substances to levels that do not seriously affect plant growth; because other factors are involved, however, this reduction does not necessarily mean that no problems remain in the biological stabilization of modern mine dumps.

Biological stabilization can be approached through the ecological process of plant succession, using pioneer plants that have very low nutrient requirements and are capable of existing under extremely harsh soil conditions. Through their root action and the deposition of organic material, these particular plants gradually improve the dump environment to a level at which more sensitive plants are able to establish themselves. On the other hand, the dump condition may be improved by incorporating organic waste with the mine-dump material before attempting to establish vegetation. Where the establishment of vegetation on mine dumps is contemplated, a combination of these two general approaches is usually adopted[11].

Considerable work has been done on the biological stabilization of mine dumps. Unfortunately, time and effort have been wasted by workers who have not always fully understood the subject.

TOLERANCE TO TOXICITY

The term *toxicity* is used in its broad sense to include all toxic situations. It includes chemicals, heavy metals, pH, and salt concentrations, both in the dump and in the water.

Plant life on a mine dump is closely related to the chemical conditions of the environment, and, until pioneer plants become established, the nutritive value of the dump material is dependent on its mineral composition. Under these circumstances, it is particularly important to have the constituent materials analysed. See Table I.

Certain plants can be found growing in situations that would normally be considered toxic to plant growth. In the initial instance, the plants must have become established in an inhospitable environment and modified it, and subsequently improved the situation to the point where other plants have been able to invade the area. The pioneer plants must have exhibited an ability to withstand the situation. These tolerances are genetically controlled and are specific to a situation, but the physiological mechanism involved is not clear[15]. Turner[16] concludes that copper and zinc tolerance in populations of *Agrostis tenuis* is due to complexing of the metal ions in the walls of the root cells, thereby rendering them immobile and innocuous. Accordingly, plants adapted to one toxic situation will not necessarily be successful in establishing themselves in other situations, and plants of the same species growing under normal environmental conditions will not necessarily exhibit the same tolerances to specific toxic materials as those growing in that toxic situation[17].

In commenting on the ability of plants to withstand higher than normal concentrations of toxic material, with specific reference to copper, Wild[18] states that there appear to be various methods by which this is accomplished. Some plant species are tolerant of a toxic situation through resistance to the uptake of toxic materials; these are commonly ruderal or adventive species, which are often well-known weeds. Their resistance to toxic materials is part of their general tolerance of a very wide range of habitats, which is one of the main factors making them successful weeds.

Other species are more specific in their tolerance to toxic concentrations, in that their tolerance follows from their ability to take up the toxic material to varying maximum levels without detrimental effect. These species can also occur out of the toxic situation, but often become more frequent under toxic conditions, possibly because of their ability to survive conditions that eliminate other plants and thereby reduce competition.

Other methods of biological stabilization have been used. These have frequently involved the blanketing of mine waste with a layer of non-toxic material such as soil, sewage sludge, or domestic refuse, into which seed is sown. A modification of this method is partial turfing in the hope that vegetation will colonize from the turf lines[6] or soil pocketing[19]. These methods are usually successful in the beginning, but the vegetation slowly dies back as the non-toxic material becomes contaminated with toxic components from the dump. Further, the plants tend to root only in the non-toxic material, thus forming a skin more or less unattached to the mine dump[6]. Once erosion starts in this layer, there is nothing to prevent it cutting deep into the dump. In any event, transport costs and the quantity of non-toxic material required make these methods prohibitively expensive.

SURFACE PROTECTION

The bare, unprotected surface of mine dumps is exposed to extreme temperature variations and to the abrasive action of wind-borne sand particles. These two factors affect the soil environment as well as the plants themselves, and have a significant influence on any vegetation programme.

Wind erosion must be countered with adequate windbreaks, either planted or mechanical. Although brushwood or wickerwork windbreaks can be used, tree windbreaks are to be preferred because their roots and leaves contribute organic material to the dump.

Where practical, mulching can be used in conjunction with windbreaks to control surface temperature and also to create a more favourable environment for plant establishment. Mulching will also stabilize surface conditions, thereby preventing severe erosion by wind or rain. Excessive erosion is often responsible for the destruction of many shallow-rooted seedlings; it is also responsible for the dispersal of planted seed. When vegetative mulch is used, it is necessary to stabilize the mulch with weights or with brushwood.

The use of garden refuse as a mulching material has a number of advantages in its favour. Firstly, it usually contains a wide range of successful ruderal or adventive weeds and, secondly, if collected near the mine dump, the weeds concerned will have developed some tolerance to toxic substances in the dump.

Alternatively, mulching materials such as plastic sheeting, bitumastic compounds, and paper pulp can be used[20], but the cost and the practicability of application of these materials must be taken into account.

HUMAN AND ANIMAL INTERFERENCE

An important factor in determining the successful establishment of vegetation on mine dumps is whether or not plantings have been interfered with, injured, and ultimately destroyed by animals or humans, particularly children.

Fencing is of value in preventing newly planted vegetation from being disturbed during the period of establishment. It also excludes animal and human movement, thereby allowing stabilization of surface conditions without the introduction of paths or tracks that will lead to erosion.

THE USE OF ARTIFICIAL FERTILIZERS

Ideally, it should be possible to select plants that will establish themselves on dump material without artificial assistance; this should be the long-term objective in any programme of biological stabilization. In practice, it is usually necessary to assist plants in their initial establishment in order to speed up the process and also to encourage initial root development. Even where plants have been selected for their tolerance to a toxic situation, or to low macronutrient levels, the addition of further plant nutrients in the form of fertilizer is still desirable.

EXPERIMENTAL PROCEDURE

Plant Material for Planting on Mine Dumps

The ability of plants to develop a tolerance to toxic substances has been established[6, 15-17, 21, 22]. Therefore, provided the toxic component is established in each toxic situation, somewhere a plant will be found that either exhibits a tolerance to this toxic situation, or can be selected for tolerance in a breeding programme. This forms the basis of the Rhodesian approach to the biological stabilization of mine dumps. Any artificial aids in ameliorating the dump environment are avoided if they are aimed at enabling plant survival. However, once suitable plants have been selected, the use of organic and inorganic ameliorants is encouraged, but the decision is left to the mining authority.

The approach presupposes the need for a careful analysis of each toxic situation. Notwithstanding the extreme variability of toxic components in Rhodesian mine dumps (Table I), the following are considered to comprise the main toxic factors influencing plant growth[13]:

- (i) Presence of toxic metals and soluble salts
  - (a) Arsenic and antimony
  - (b) Copper
  - (c) Nickel
  - (d) High ratio of magnesium to calcium
  - (e) High soluble-salt content.
- (ii) High pH values.
- (iii) Absence of or very low macronutrient content.

Once the main toxic components in mine wastes had been defined, selection of suitable plant material was based on

1. (1) the ability of plants to establish and colonize existing mine dumps known to contain the defined toxic components, and
2. (2) aggressive plants growing in natural situations known to have similar toxic components to Rhodesian mine dumps.

A considerable range of plant material has been collected from a

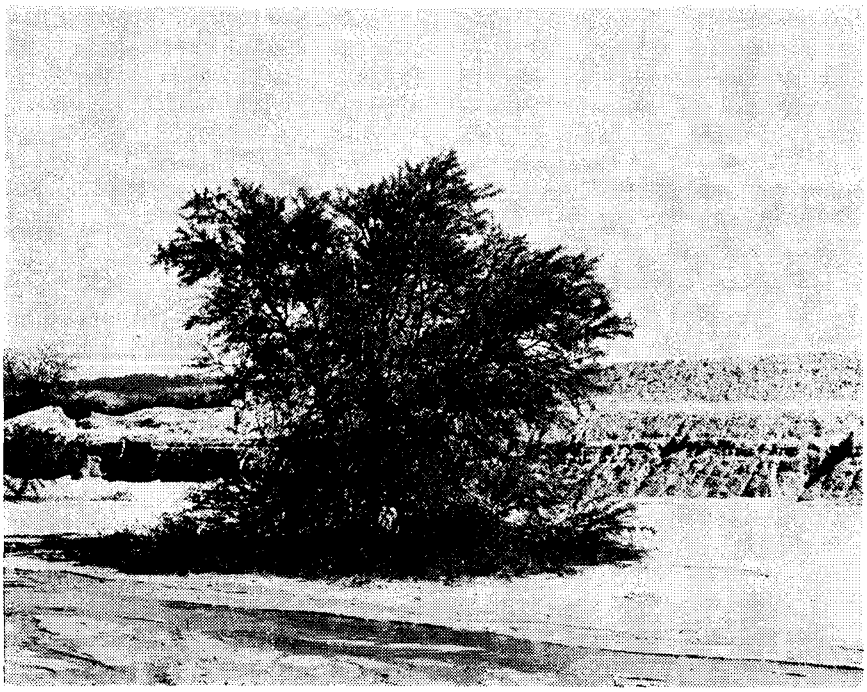

Plate III—Tolerance to toxicity: *Acacia karroo* adapted to growth in mine-dump material that has eliminated or excluded all other plant growth. Note the unusual development of the lower branches, probably through lack of competition from other plants.

number of mine dumps and natural salt pans in Rhodesia. A large number of tree and shrub species were obtained from the semi-arid areas of Western Australia and Israel; other species came from the Republic of South Africa (see Appendix). The more promising plant species have been bulked up and are available for distribution.

Laboratory Studies

Plants growing successfully in toxic situations produce normal root growth, whereas non-adapted plants fail to produce roots or they are malformed. Therefore, root studies of plants introduced into a toxic situation are likely to give a good indication of the plants' possible success in the biological stabilization of mine dumps containing that toxic situation.

Root-study techniques developed by Wilkins[21, 22], Jowett[23], and Bradshaw[16] have been modified to suit this research programme. The technique involves the measurement of root growth of single plants in a growth solution for 48 hours, compared with a similar period of growth in the same growth solution containing a known concentration of toxic substance.

This study of the reaction of selected plants to single toxic substances is still in progress and, when complete, will assist in the final selection of suitable plant material.

Pot trials are being conducted on mine-dump material from selected mines, under semi-controlled environmental conditions. The object of these trials is to determine the rooting ability of different plant species in dump material, and the effect of fertilizer in increasing the rooting ability.

Field Trials on Selected Mine Dumps

If undesirable dump erosion is to be prevented, the ideal type of vegetation to be established seems to be the following:

(i) a tree phase to serve as a wind break and for biological stabilization at depth through greater rooting ability,
(ii) a shrub phase to streamline wind movement over the tree windbreak, and to provide protection at an intermediate level, and
(iii) a stoloniferous-type grass phase for complete surface protection.

Replicated field trials of selected tree, shrub, and grass species have been undertaken on four mine dumps containing the main toxic factors encountered in Rhodesian mine dumps. Treatments are indicated in Table II.

In spite of the poor rainfall of the past summer, dump trials have made considerable growth, and certain species of tree, shrub, and grass are showing great promise. It is interesting to report that the growth response of a single plant species varies on the different dumps. This fact verifies the philosophy of the Rhodesian approach in that different plants differ in their response to toxic components, and that tolerant plants can be found for most toxic situations.

A full analysis of these dump trials has commenced and will include determinations of the mechanism whereby certain plants are able to make successful growth in toxic situations.

GENERAL

For practical purposes, it would appear that the line to be followed is already clear, but an adequate period of further work is necessary to confirm and guarantee these preliminary recommendations.

In the interim period and based on

TABLE II

REPLICATED FIELD TRIALS ON MINE DUMPS: FERTILIZER TREATMENTS

1. TREES AND SHRUBS		
TREATMENT	A	No fertilizer
	B	Compound 'D' fertilizer (8.15.10) 50 g per tree (8,82 kg/ha)
	C	Single superphosphate (20% P_2O_5) 0,5 kg per tree (882 kg/ha)
	D	Compound 'D' fertilizer + single superphosphate as above
		Annual nitrogen top dressing (50 g ammonium nitrate 34,5% N per tree) — applied to treatments 'B' and 'D' in December.
		Planting distances: 2,4 × 2,4 m (1764 trees/ha)
2. GRASSES		
TREATMENT	A	No fertilizer
	B	Compound 'D' fertilizer — 100 g/m² (1000 kg/ha)
	C	Grass mulch
	D	Compound 'D' fertilizer + mulch as above
		Annual nitrogen top dressing (37,5 g/m² ammonium nitrate 34,5% N) (375 kg/ha)—applied to treatments 'B' and 'D' in December.

the experimental results obtained to date, highly successful practical programmes of stabilization have been completed. Present knowledge and experience indicate that a successful dump-stabilization programme has sequentialized components. These are well illustrated in the programme being followed on slimes dams at Mangula Mine, and therefore slimes dams on this mine are discussed in more detail.

PROGRAMME AT MANGULA MINE

Mangula, the local African name for red metal, is situated 190 km north-west of Salisbury, at an altitude of 1200 m. The area experiences hot summers and mild, frost-free winters, with an average rainfall of 900 mm falling between November and March. There are strong, desiccating north-easterly winds in September and October.

The ore deposit lies within rocks of the Deweras System, which is composed of arkoses, arkosic schists, and chlorite-sericite schists, with occasional conglomerates and grits. The sulphide minerals are bornite and chalcocite, which occur in a finely disseminated form throughout the rocks. Chalcopyrite occurs marginally. The oxidation zone, with malachite, chrysocolla, pseudo-malachite, and occasional cornetite is mined in opencasts down to a depth of about 45 m.

The mine produces 110 000 tonnes of sulphide ore a month from underground by a method of sublevel stoping. Before hoisting, the ore passes through primary crushers, which reduce the rock size to approximately minus 200 mm. The surface grinding circuit consists of two identical Aerofall mills, 6700 mm in diameter by 1570 mm, plus two 2440 mm by 4570 mm long trunnion overflow ball mills, which reduce the ore to 65 per cent minus 200 mesh (the required size for copper extraction by flotation).

Slimes are pumped on to a 20 ha slimes dam via a 30 m diameter thickener, through a 200 mm steel pipe for a distance of 300 m. At the slimes dam, a peripheral system of discharge is employed. The slimes are 54 per cent solids by weight.

Siting of Slimes Dams

The construction and siting of slimes dams have a significant effect on the ease of stabilization. A dam situated on steep and sloping land has additional hazards caused by natural drainage from above the site. There is also the problem of flood-water disposal from the dam itself, as well as from the increased down-slope side. At Mangula these hazards are reduced by dumping on a slope of 2 per cent average. However, there is a further problem in that the area allocated for slimes dams is partially swamped. This has dictated an additional base-drainage system to supplement the toe drainage.

Angle of Slope

Where the slope is less than 45°, physical problems of stabilization seldom occur. The steeper the side, the more difficult it is to stabilize the dam. Slimes-dam walls on the Mangula Mine have a slope of approximately 20°.

Access

Irrespective of the type of stabilization programme, access to the top of the dam must be provided for vehicles. This greatly facilitates the transport of implements, plant material, fertilizer, and mulching materials.

Analysis

A detailed chemical analysis of the slimes dam is necessary to show the toxic components, as well as the degree to which plant nutrients are deficient. Table III is supplementary to analysis No. 23 in Table I.

Commencement of Stabilization Programme

The sooner stabilization follows the commencement of dumping, the more successful it is likely to be. In the long-term, biological stabilization is more attractive than mechanical stabilization, because of its permanent nature. There is an additional advantage in biological stabilization in that the dam can be made productive. Dickinson[7] reports increasing evidence of various forms of wild life establishing themselves on biologically stabilized slimes dams. At Mangula it has been necessary to protect experimental plots from over-utilization by antelope and hares.

Adams[19] has found that *Eucalyptus paniculata* planted on slimes dams at the Mazoe Mine have a more rapid growth rate than trees planted adjacent to the dam, and are providing a valuable source of mine timber. Elsewhere slimes dams have been used for recreational purposes[9, 11].

Plant Selection

It is essential that the selection of plant material is based on toxic tolerance, and there are a number of other important considerations.

Multiple-layer Protection. It is preferable to select trees, shrubs, and grasses to provide elevated protection and stabilization at depth.

Diversity of Species. A range of different plant species gives greater biological stability. The use of legumes and non-leguminous nitrogen-fixing plants should be en-

TABLE III
SUPPLEMENTARY ANALYSIS: SLIMES DAM NO. 3
MANGULA MINE

Total nitrogen %	Mineral nitrogen Ammonia + nitrate N p.p.m.		Available P resin extract P_2O_5 p.p.m.	Exchangeable K mg equivalents per 100 g
	Initial	After incubation		
0,000	3	9	6	0,18

SiO_2	62,90%	Specific conductivity: 110 micromho
FeO	9,3%	pH 9,5 reducing to 8,0 over a period of years
Al_2O_3	11,1%	
S	0,12%	

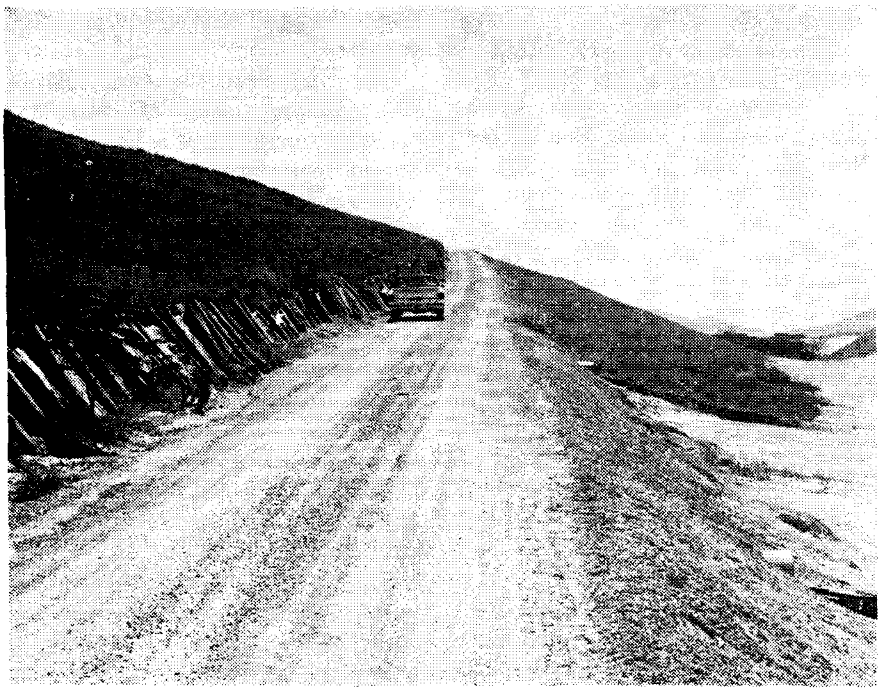

Plate IV—A well-prepared access road to the top of a mine dump. The 20° slope of the dam walls at Mangula Mine is illustrated.

TABLE IV

COST OF PLANT ESTABLISHMENT ON MINE DUMPS IN RHODESIA

	Trees	*Grass*
Preparation of hole and planting ($1,00 per 60 trees per day)	$29,40	$24,70
Fertilizer: 882 kg Single Superphosphate	44,10	
8,82 kg 'S' mixt (6:18:6)	0,48	
8,82 kg ammonium nitrate	0,54	
1000 kg 'D' (9:15:9)		55,40
Cost of plant material:		
1764 trees $10 per 1000	17,64	
Grass 6 bags at $1,00		6,00
TOTAL COST per hectare	$92,16	$86,10

couraged to improve the low nutrient status of the dam.

Plant Propagation. The use of plants easily established from seed is preferable for practical reasons. The majority of the more successful stoloniferous grass species are unfortunately poor seed producers and must be planted vegetatively. This did not exclude their use, and semi-mechanized methods have been developed to overcome this problem.

Low Nutrient Requirement. The plant must be able to survive in the low-nutrient situation experienced.

Surface Stability

Wind erosion was a serious problem on the Mangula slimes dam. It is calculated that 85 tonnes per day was removed in the form of dust during the five-year period prior to stabilization. This wind erosion must be countered with adequate wind breaks, either planted or mechanical. Windrows of garden refuse were used to provide an excellent mulch for the establishment of seedlings and surface protection. Garden refuse is also a valuable source of plant nutrients and often contains large quantities of viable plant material that establishes in the windrow and colonizes outwards onto dump material. Planted lines of Napier fodder (*Pennisetum purpureum*) and sugar cane (*Saccharum officinale*) were also used.

Fertilizer Ameliorants

The use of artificial fertilizer is recommended to hasten the develop-

TABLE V

COMPARISON OF COSTS OF MINE-DUMP STABILIZATION

Country	Method of stabilization	Effectiveness	Maintenance	Cost per hectare
U.S.A.	Physical: Straw harrowing	Fair	Moderate	U.S. $99-185
	Soil covering (10 cm)	Excellent	Minimal	617-1482
	Slag covering (22 cm)	Good	Moderate	2350-2600
	Chemical: Bituminous base	Good	Moderate	741-1852
	Lignosulphonate	Good	Moderate	617-1482
	Biological: 10 cm soil and vegetation	Excellent	Minimal	741-1605
	Hydroseeding	Excellent	Minimal	494-1111
	Chemical and vegetation	Excellent	Minimal	247-617
United Kingdom	Physical: Slag (22 cm)	Good	Moderate	£909-1818
	Biological: Refuse (5 cm) and vegetation	Excellent	Minimal	753
South Africa	Biological: Leaching and vegetation	Excellent	Minimal?	R400-700
Rhodesia	Biological: Toxic-tolerant vegetation	Excellent	Minimal	R$86-92 (309)

Plate V—Experimental plots at Mangula

ment of a complete protective layer of plants. From the detailed chemical analysis of the slimes dam it was seen that there was adequate potassium, but nitrogen and phosphorus were insufficient to support plant growth. As a result, an annual application of 70 g/m^2 single superphosphate (20 per cent P_2O_5) and monthly top-dressings of 20 g/m^2 ammonium nitrate (34,5 per cent N) are recommended during the summer period. Once full protection has been achieved, the application of further quantities of fertilizer will be determined by the use to which the dump is put.

Sewage effluent is a highly desirable source of plant nutrients, and its use on the Mangula slimes dam has provided a practical method of sewage disposal.

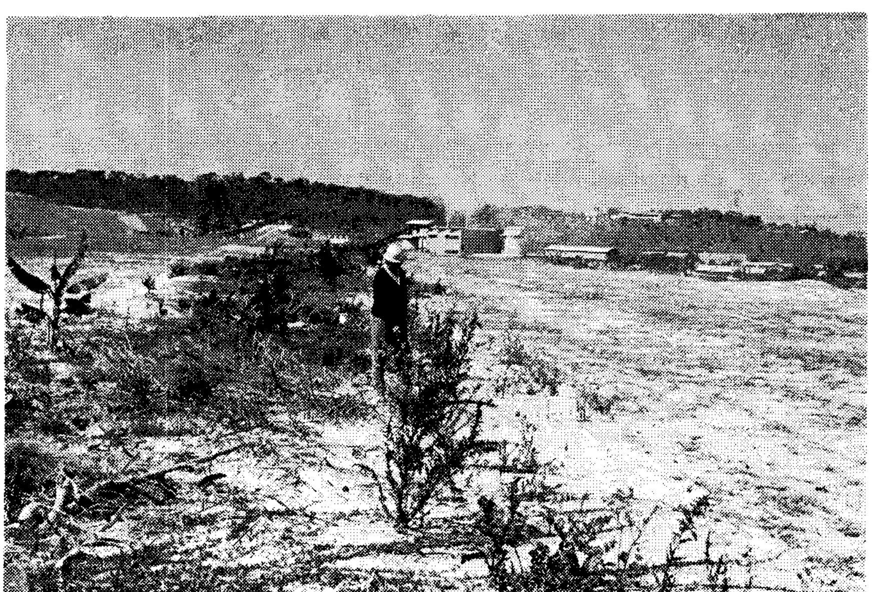

Plate VI—Windrows of garden refuse, showing the variety of plant growth resulting from viable plant material in the rubbish. Note the creeper (*Ipomoea sp.*) colonizing dump material in the foreground.

Human and Animal Disturbance

Some form of control of animal and human movement must be planned to prevent damage to young plants in their vulnerable establishment period. This often necessitates the use of fencing; the destruction of wild-life as an alternative is not recommended because in time wildlife should be encouraged onto the dump to assist in providing biological stability.

Utilization

Once plants have been established on a slimes dam, some form of utilization or harvesting should be encouraged to prevent them from becoming moribund.

Costs

An analysis of the cost of establishing vegetation on Rhodesian mine dumps is presented in Table IV. It should be noted that the amount of compounded fertilizer applied to grasses under experimental conditions was 1000 kg/ha in one application. Under practical conditions this has been reduced to 400 kg/ha applied annually for two or three years.

For comparative purposes, Table V is included.

ACKNOWLEDGEMENTS

The authors are grateful to Professor H. Wild of the Department of Botany, University of Rhodesia, for his helpful advice in the formulation of experimental procedures and in the selection of plant material; and to the Forestry Research Centre, Salisbury, for assistance in propagating seedling trees.

They would also like to thank the Rhodesian Ministry of Mines for their financial assistance in the provision of research fellowship funds; and the Management of the Messina (Transvaal) Development Company, Limited, for their encouragement and financial assistance in the presentation of this paper.

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APPENDIX I

PLANT MATERIAL: (COLLECTED—DISTRIBUTED—AVAILABILITY)

TREES AND SHRUBS:

Species	Original site	Form		Assumed toxic tolerance									Dumps being tested*				Availability for distribution
		Seed	Veg.	As	Sb	Cu	Ni	Cr	low pH	high pH	High sol. salts	Mg:Ca	C & M	M	T	C	
Acacia cyanophylla	N.S.W. Australia	x											80	120	128	64	
A. cyanophylla	Pretoria	x											20	10	10		
A. cyclops	Pretoria	x											32	32	32	32	x
A. karroo	Globe & Phoenix Mine	x		x	x					x	x	x					x
A. mearnsi	Inyanga	x															
Atriplex canescens	W. Australia	x														44	
A. glauca	W. Australia	x											8	8	32	8	
A. halimus	W. Australia	x											8	8	8	8	
A. lentiformis	W. Australia	x											48	40	32	24	
A. nummularia	W. Australia	x													8		
A. nuttallii	W. Australia	x													16		
A. phagodiodes	W. Australia (440)	x											8	8	8	8	
A. phagodiodes	W. Australia (421)	x											32	20	10		
A. polycarpa	W. Australia	x													8		
A. undulata	W. Australia	x											48	80	64	48	
Cassia absus	Trojan Mine	x					x	x			x						
Casurina equisetifolia	Pretoria	x											80	160	40		
C. glauca	N.S.W. Australia	x											48	40	32	32	
Crotaleria variegata	Jester Mine	x					x	x				x					
Eucalyptus camaldulensis	FRC. Rhodesia	x											20	40	20		
Eucalyptus gomphocephalla	Pretoria	x											80	120	40		
Eriosema psoraleoides	Trojan Mine	x					x	x			x				x		x
Flaveria trinervia	Cam & Motor Mine	x		x	x					x	x	x		x		x	
Glycine wightii	Mangula Mine	x				x				x							
G. wightii	Trojan Mine	x	x				x	x			x						
Indigofera setifolia	Jester Mine	x					x	x				x					
Kochia brevifolia	W. Australia	x												8	16		
Prosopis alba	Israel	x															
Rhus tenuinervis	Globe & Phoenix Mine	x		x	x					x	x	x					
Schinus molle	FRC. Rhodesia	x											10	20	10	8	
Sesbania microphylla	Jester Mine	x					x	x				x					
Tephrosia longipes	Feoch Mine	x					x	x				x					
Tamarix aphylla	Israel		x														
Tetraclinis articulata	Israel	x											10	16	8		
Vigna oblongifolia	Trojan Mine	x					x	x			x						

GRASSES:

Chloris virgata	Botswana	x								x	x						
Cynodon dactylon	Dett vlei, Wankie		x						x		x			x	x	x	x
C. dactylon	Cam & Motor Mine		x	x	x					x	x	x				x	x
C. dactylon	Connemara Mine		x				x	x	x	x	x					x	x
C. aethopicus	Mick Mine		x	x										x	x		x
Dactyloctenium australe	St. Carolina, P.E.A.		x								x			x	x	x	x
Digitaria pentzii	Botswana		x							x	x						
Eragrostis tenuifolia	Connemara Mine	x					x	x	x	x	x					x	
Heteropogon contortus	Jester Mine	x					x	x				x					
Imperata cylindrica	Dett vlei, Wankie		x						x		x						
I. cylindrica	Phoenix Prince Mine		x			x											
Loudetia simplex	Jester Mine	x					x	x				x					
Odyssea paucinervis	Botswana		x							x	x			x			x
Panicum coloratum	Jester Mine	x					x	x				x					
P. novemnerve	Jester Mine	x					x	x				x					
P. repens	Dett vlei, Wankie		x						x		x			x			x
Paspalum vaginatum	Natal, South Africa		x							x	x			x	x	x	x
Pennisetum setaceum	Phoenix Prince Mine	x	x			x								x	x	x	
Sporobolus sp.	St. Carolina, P.E.A.		x								x			x	x	x	x
S. spicatus	Botswana		x							x	x						
S. ioclados	Robins, Wankie		x								x						
S. virginicus	Sinamatella, Wankie		x								x			x		x	x
Cynodon dactylon	Mangula Mine		x			x				x							

*T = Trojan Mine. C & M = Cam and Motor Mine. C = Connemara Mine. M = Mangula Mine.

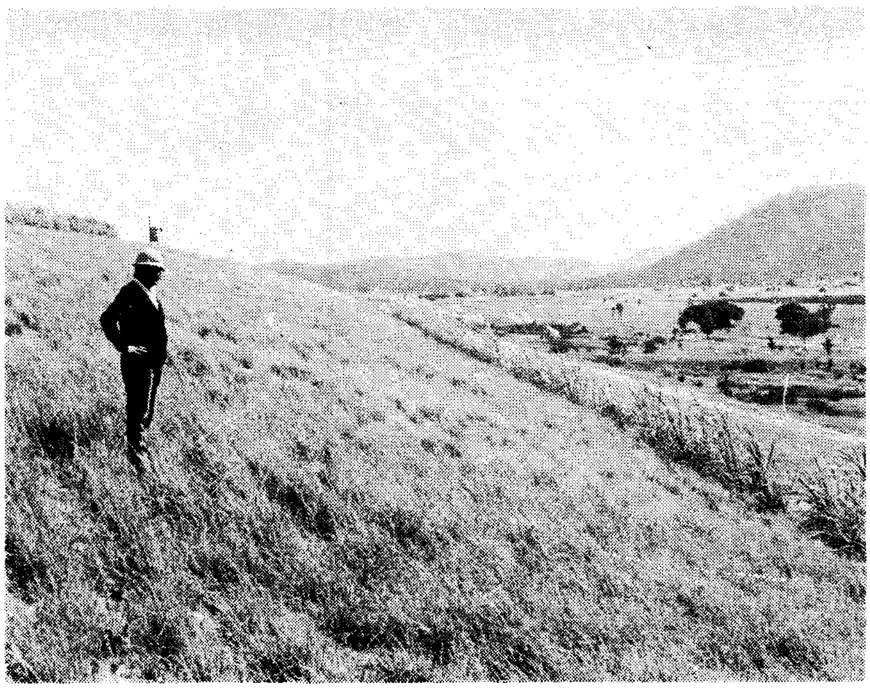

Plate VII—Biological stabilization on the side of a slimes dam to prevent windblown sand from affecting adjacent agricultural land: an excellent stand of planted grass (*Cynodon dactylon* and *C. aethopicus*) with windbreaks at Mangula Mine.

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Colloquium and general meeting

CONSTRUCTION OF SLIMES DAMS

A General Meeting and Colloiquum on the above topic was held on November 14th and 15th, 1973, at Kelvin House, Johannesburg.

Mr P. W. J. van Rensburg (President) was in the chair.

The Colloquium was attended by 135 delegates and was opened by the President at 9.10 a.m.

MEMBERSHIP

The President: I have much pleasure in announcing that the names of the undermentioned candidates, having been published in accordance with By-Law 5.2.2., Council has elected them to membership of the Institute in the following grades:

Fellow
K. O. R. Gebhard

Graduates
A. M. Childs, R. H. A. Plaistowe, L. Prinsloo, P. C. Pretorius, M. R. Storey, J. W. Wilson

Associate
P. A. G. Collett

Student
T. M. Ferreira

Transfers

From Graduate to Member
R. D. Beck, I. E. Francke, N. Kamp, C. G. Knobbs

From Student to Member
R. F. Hadfield, R. P. W. Henrard, R. A. Lindsay, B. N. B. Lund

From Student to Graduate
J. R. W. Lindsay, I. N. Sinclair.

I welcome the newly elected members to the Institute and congratulate those who have been transferred to a higher grade.

GENERAL

The President announced that the Cocktail Party, which the Chamber of Mines had kindly offered to hold for the delegates at the Colloquium, would be held at the Chamber of Mines Sports Club at 5.30 p.m.

The meeting ended at 9.20 a.m.