

# **Ameliorative Techniques in Improving Revegetation Schemes**

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## **ABSTRACT**

Past mining activity in Cornwall produced wastes containing elevated concentrations of potentially toxic elements, such as copper, arsenic, nickel, manganese, cadmium and zinc, present mainly as sulphides. These wastes were dumped on land with little consideration to their environmental impact. Much of this waste has now been in place for over 100 years. Metalliferous waste is currently responsible for over 4770 hectares of derelict land in England; secondary contamination through the dispersal of toxic elements and acidity has yet to be accurately quantified. This dispersion occurs through the oxidation of the sulphides, leading to mobilisation under acid conditions as sulphates. Once in sulphate form the metals are readily available to vegetation. Uptake can induce detrimental effects, including retarded and complete failure of growth. The legacy of mine waste in Cornwall can be seen in the extensive areas of derelict land.

Establishment of vegetative cover is considered to be the most practical long term solution to the pollution, reducing oxidation of sulphides, increasing pH and limiting wind and water erosion. To allow vegetation to become re-established the acidic conditions, and release of harmful quantities of heavy metals, must be ameliorated. Compared with recent waste -produced by more efficient processing - old mine waste contains higher levels of heavy metals, and as a result requires major remedial measures to effect reclamation. It is shown that for old Cornish sites an in-situ method of treatment has the greatest potential for the control of acidity and levels of metals in solution.

Novel methods, involving the use of various industrial minerals, have been developed to control the conditions causing acid generation. The use of these materials as in-situ amendments is examined to evaluate the control of acidity and levels of toxic elements in solution.

Laboratory work shows that industrial minerals, used as in-situ amendments, have potential to control acid and metals in solution. These theoretical control characteristics are compared with results from field test sites. The direct effects of selected amendments on bacteria associated with acid production are also assessed. Monitoring of acid mobility and its effect on metal mobilisation has been conducted at various Cornish sites, and preliminary results are presented.

Acid mobility at numerous sites in Cornwall prior to vegetation, has been monitored and the effects of acid mobility on metal mobilisation are examined and reported.

## INTRODUCTION

Cornwall has produced significant quantities of tin, copper and arsenic for over two centuries. The early 19th century saw Cornwall producing two-thirds of the world's copper, and by 1870 half of the world's tin<sup>1</sup>. Sadly Cornwall's days as a leading producer are now over, and little if any, production can be expected in the coming years. There remains however the legacy of these years of mining activity - over 4000 hectares of derelict and contaminated land, covered by surface buildings, associated workings, and extensive dumps of tailings and waste rock. Although mainly exploited for tin, copper and arsenic, the wastes also contain elevated levels of cadmium, lead and zinc and other toxic elements. The problems of metalliferous mine waste have been reviewed elsewhere<sup>2</sup>. Processing in the past, using less efficient techniques, has led to the older wastes often having different chemical and physical characteristics from wastes produced today. This fact has often been ignored or misunderstood by local authorities responsible for returning the land to its pre-mining condition, leading to inappropriate reclamation schemes. Over the decades contamination of surrounding farmland has also occurred, the extent of which has yet to be quantified. Such soil contamination with heavy metals is usually permanent<sup>3</sup> and can introduce toxic elements to the food chain, with possible deleterious effects on human health. Apart from a few elements such as mercury, little is known about the chemical form of elements in man's diet, but it is known that the valency state of an element has a profound influence on its inherent toxicity<sup>4</sup>. Thus until research shows differently, it must be assumed that the increased intake of certain heavy metals, even at very low levels, is potentially harmful and certainly undesirable. In the light of this fact, the cessation of contamination of farmland in Cornwall is desirable. This of course means that the source of the contamination must be dealt with - remedial measures on farmland alone would be pointless.

In Cornwall the main method of dealing with derelict metalliferous mining land has been revegetation. The schemes adopted have sometimes been inappropriate, particularly where establishment of trees has been attempted, resulting in partial success or occasionally complete failure. Funds for land reclamation in Cornwall are limited, and if more money is not to be wasted then there is need for research into waste characteristics in Cornwall to increase the chances of successful revegetation schemes.

To this end a research group has been established at the Camborne School of Mines, using as a basis the results of related MSc projects conducted since 1980<sup>5,6</sup>.

## THE BENEFITS OF VEGETATIVE COVER

The establishment of a continuous vegetative cover is considered by many authorities to be the most effective and, in the long term, the cheapest method of controlling wind and water borne pollution from derelict sites. If land capability is not to be restricted then remedial measures must be effective on a permanent basis<sup>7</sup>, and revegetation partially fulfils this - it is a permanent solution but land capability can be somewhat restricted as explained below.

In Cornwall few alternatives to revegetation exist - sites are normally small (less than 1-hectares), with poor access and surrounded by areas of farmland. Previously some reworking of the wastes for tin and copper has occurred, which helped decontaminate the waste but did nothing to help revegetation. After the disastrous collapse of the tin price in 1985, such work ceased, and is unlikely to restart in the future. Productive forestry and agriculture can rarely

be considered because of the high levels of metals found in the wastes<sup>8</sup>, and farmland is now being taken out of production rather than being created. New housing developments have been established on a few areas of derelict land, but are preferably built in or around existing towns, where a good infrastructure is already present. Few major firms are willing to risk moving to factories in Cornwall due to its distance from the economic centres of the UK, and thus opportunities of developing the land in the form of industrial "parks" limited. Indeed several half full "parks" already exist.

Although revegetation has in some respects been "forced" upon local authorities as the only realistic option, it does have many benefits. Established vegetative cover can reduce pollution from mine waste, by inhibiting oxidation, reducing percolation and run-off water, and ameliorating acidic pH. The dispersal of toxic heavy metals into the environment is thus reduced. The presence of vegetation is known to improve the structural properties of soil by the formation and stabilisation of soil aggregates. Aggregate stability is one of the most significant factors influencing surface erosion<sup>9</sup>. In conjunction with this the extensive root system of grasses and shrubs presents a physical barrier to erosion and the release of organic materials further improves aggregation.

Once established, vegetation can become self-sustaining, and further remedial work becomes unnecessary, an important point when funding is poor and sporadic. This approach improves the visual impact of the sites, which is generally poor.

Having decided that revegetation is the best available option then the next question to be answered is what species should be introduced?

In the past little attention was paid to the range of species - if survival was thought likely then it was used, irrespective of the impact on localised site ecology. Often these tolerant species did not blend well with the local flora, a bone of contention with local people, who wanted these reclaimed areas to fit the surrounding countryside. Trees have been planted over quite extensive areas of derelict land in Cornwall, with very little success. Phytotoxicity of the waste (into which the trees are normally directly planted) is one of the causes of these failures. Recent work has shown that planting new forests on old farmland could trigger the release of toxic heavy metals accumulated over decades<sup>10</sup>. Soil in which trees are planted can become 10-20 times more acidic, causing a dramatic increase in the dissolution of heavy metals. Although derived from farmland that has undergone fertilisation with sewage sludge it is a useful comparison for the situation in mine waste. However there could be ways to overcome the problems - certain types of fungi protect trees from toxic concentrations of heavy metals by acting as filters around the roots<sup>11</sup>. But if trees are to be used at all great care must be taken in waste conditioning, selection of species, and timing of planting<sup>12</sup>.

Recent restoration work by Kerrier Groundwork Trust ensures that derelict areas are seeded with appropriate species, such as fescue, meadow grass, oxeye daisy, red campion, ribwort plantain, yellow rattle, poppy, bird's foot trefoil, corn chamomile, common vetch, heather, western gorse and broom<sup>13</sup>.

Using species that are not-tolerant of elevated levels of heavy metals introduces the need for waste treatment and amelioration, to alleviate toxicity and acidity, until vegetation becomes self-sustaining. Then the plants themselves may control the hostile conditions in the waste. This becomes clear when Cornwall is examined - after many decades, natural regeneration is usually very limited and the growth that does exist is characteristically patchy

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and varied with isolated areas becoming destabilised and the vegetation removed by wind and water action.

It has been the aim of the research group to determine the most effective method of controlling acidity and the release of toxic metals in Cornish waste, with a view to allowing the successful growth of non-tolerant plant species.

Prediction of pollutant movements through and away from the waste, by the establishment of toxic element dispersion mechanisms and patterns, was originally suggested as a way of improving reclamation strategies. Each case of contamination is unique and there is a need for a flexible predictive model. By determining the form of toxic elements and the routes of dispersal greater insight into their impact on planned revegetation strategies can be gained. Along with predictive modelling, novel methods of amelioration have been developed, the success of which will derive from the correct prediction of the variable conditions normally found within the boundaries of a derelict site.

These novel methods of reclamation must overcome the hostile chemical, physical and biological characteristics of the spoil. Acidic mine spoils are particularly hostile to vegetation due to direct damage inflicted on plant roots and uptake mechanisms by hydrogen ions<sup>8</sup> and also by the presence of plant-available heavy metals.

The use of various industrial minerals as *in-situ* amendments to the waste has been intensively investigated, and the initial results show that they have great promise in controlling acidity and release of metals into solution. Unfortunately previous research has indicated that the control of acidity can sometimes clash with control of metals in solution, and an example of this problem is also investigated here.

### DISPERSION OF TOXIC ELEMENTS FROM MINE SPOIL

A case study area at Tresavean mine (Cornwall) has been used to look at the problems of toxic element dispersion into surrounding farmland. A sampling program has been undertaken to determine element distribution patterns in the mine waste and surrounding pasture. Results and conclusions drawn so far are discussed.

#### Tresavean mine site

Tresavean Mine, the main study area of this research, is situated near the village of Lanner, in Cornwall, S.W. England, (figure 1). The mine is known to have been worked as early as 1745 and was an important copper producer<sup>14</sup>. It reached peak production in the mid 19<sup>th</sup> Century, producing both tin and copper<sup>15</sup>. The old mine site and dumps cover an area of approximately 15 hectares, situated on the side of the hill above the village of Lanner, and is surrounded by pastoral farmland.

#### (a) Reconnaissance survey

An initial reconnaissance survey was carried out at Tresavean to establish which elements are present and their approximate concentrations. In total 21 samples were taken

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from different types of waste around the site, screened at 1 cm, and the minus 1 cm fractions analysed by X-ray fluorescence (XRF) for total metal content.

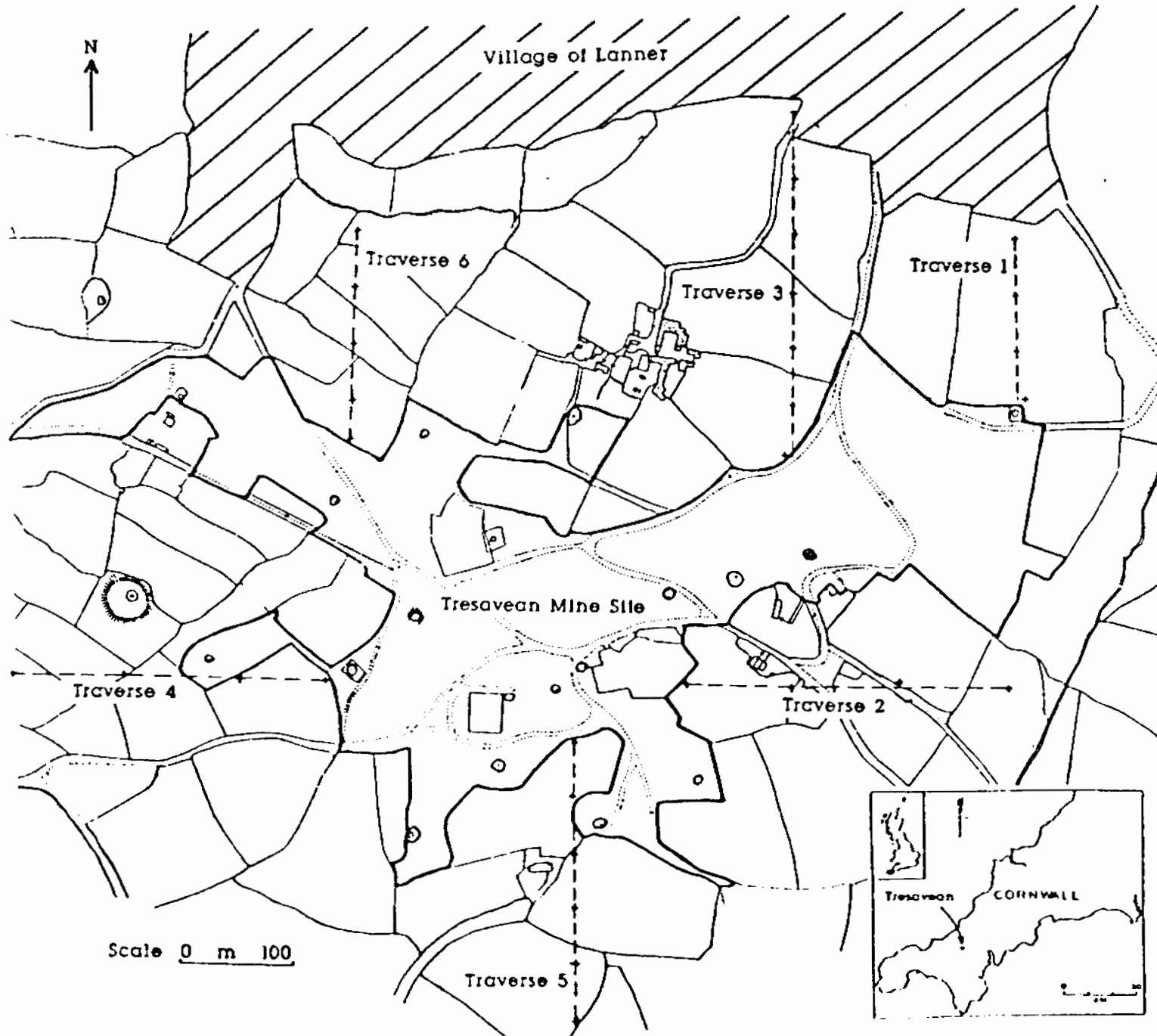


Figure 1: Location map of Tresavean with soil traverses

The qualitative XRF scan revealed the presence of As, Cu, Ni, Pb and Zn which, in terms of toxicity, are considered significant. Quantitative analysis results are summarised in Table 1. Each element had a wide range of concentrations in the samples tested - all the elements are considered to reach toxic levels, indicating that the site is contaminated by a range of elements, not just those of the exploitable ore minerals.



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Element	As	Cu	Ni	Pb	Zn
Minimum (ppm)	810	380	9	210	110
Maximum (ppm)	4600	26960	200	3350	13320

**Table 1:** Minimum and maximum concentrations of elements found at Tresavean mine site.

### (b) Preliminary results in spoil mineralogy

Examination of hand specimens from Tresavean has shown the presence of pyrite, chalcopyrite, arsenopyrite and cassiterite. Sphalerite has also been found<sup>15</sup>. Some hand specimens have a blue coating of hydrated copper sulphate on weathered surfaces.

### (c) Detailed spoil survey

A more detailed survey of Tresavean mine site has been completed. Samples were taken on a 50 m grid covering the whole site.

### (d) Tresavean soil survey

A soil survey of the surrounding farmland has been completed to establish the extent of contamination from the mine spoil and to determine if any patterns are discernable. Pasture-land surrounding Tresavean mine site was sampled on north/south traverses separated by 100 m, with sample interval 50m. Traverses extended 400m either side of the mine site (figure 1).

### (e) Sampling procedures

Surface vegetation or organic litter was removed, and a 2-3kg sample of mine waste taken with a spade.

Each sample was oven dried at 30°C for 48 hours, lightly ground using a pestle and mortar and sieved at 2 mm, the + 2 mm size fraction was discarded and the -2 mm fraction split into 2 sub-samples by riffing. One sub-sample was used for pH determination and the other for chemical analysis.

Soil samples were taken with a screw auger from the A horizon, after removal of the vegetation. Three samples were taken at each sampling point and combined. The -2 mm fraction was subsequently analysed for available metals.

### (f) Method of pH determination

A mixture of 1:2.5 w/v of spoil and deionised water was agitated, then left to stand for 10 minutes. The pH of the resulting solution was measured using a standard hydrogen electrode.

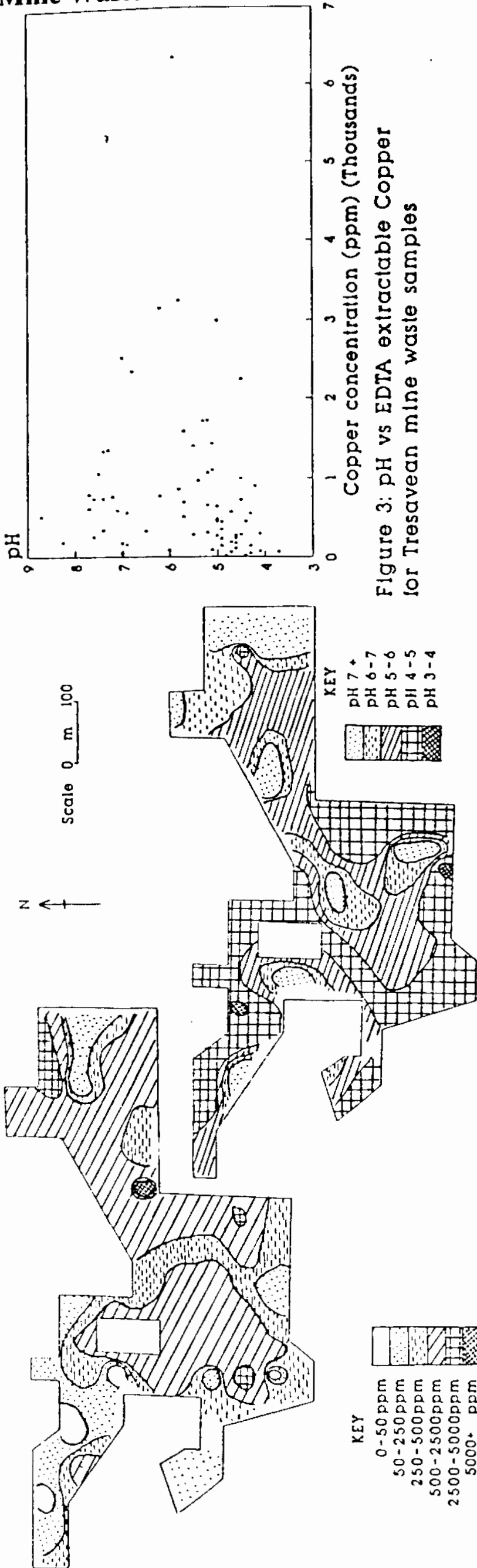


Figure 2a: EDTA extractable Cu distribution map

Figure 2b: pH of spoil at Tresavean

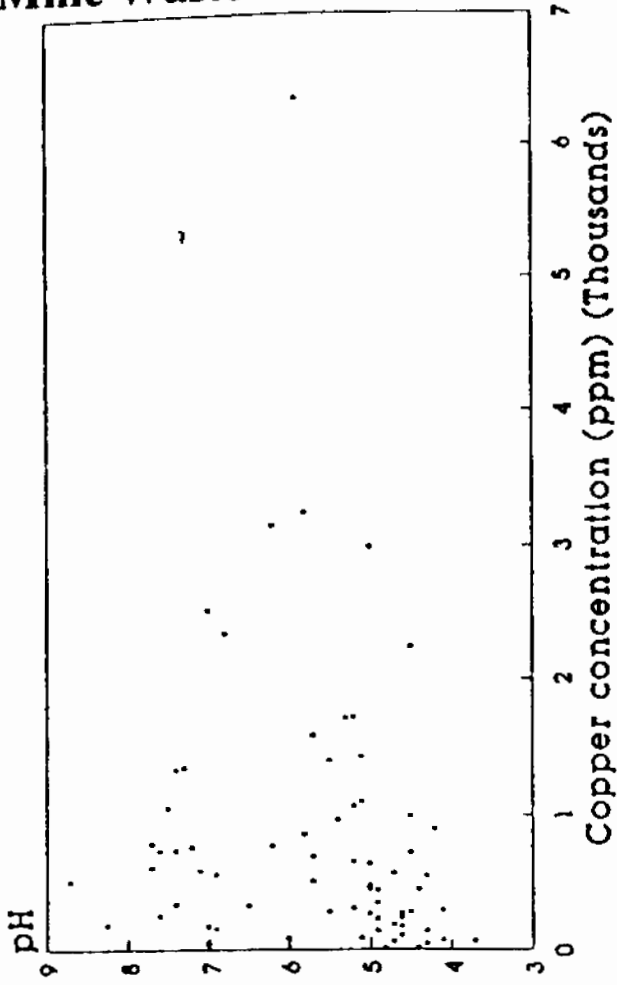


Figure 3: pH vs EDTA extractable Copper for Tresavean mine waste samples

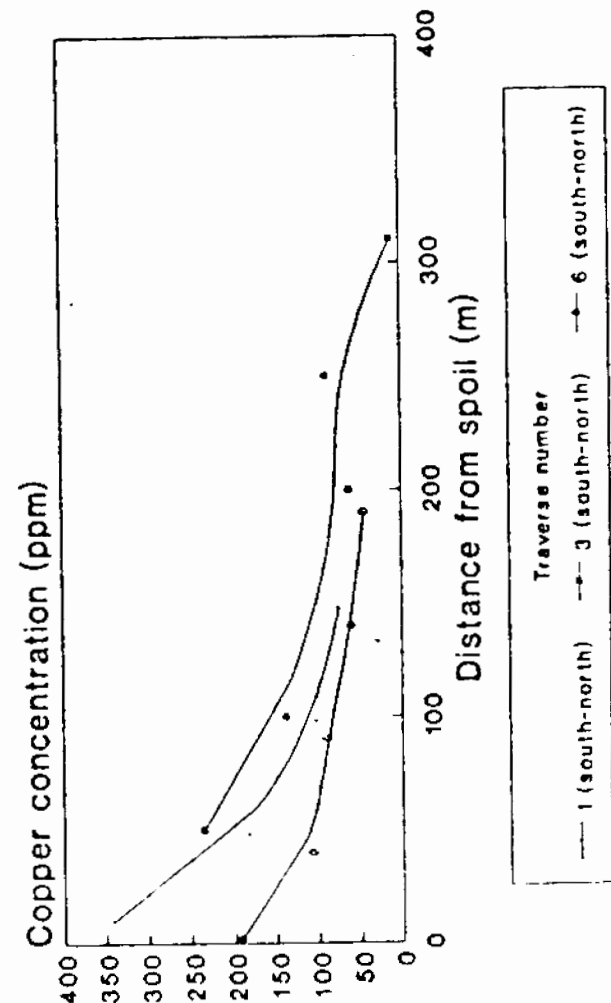


Figure 4: EDTA Extractable Copper from Tresavean soils

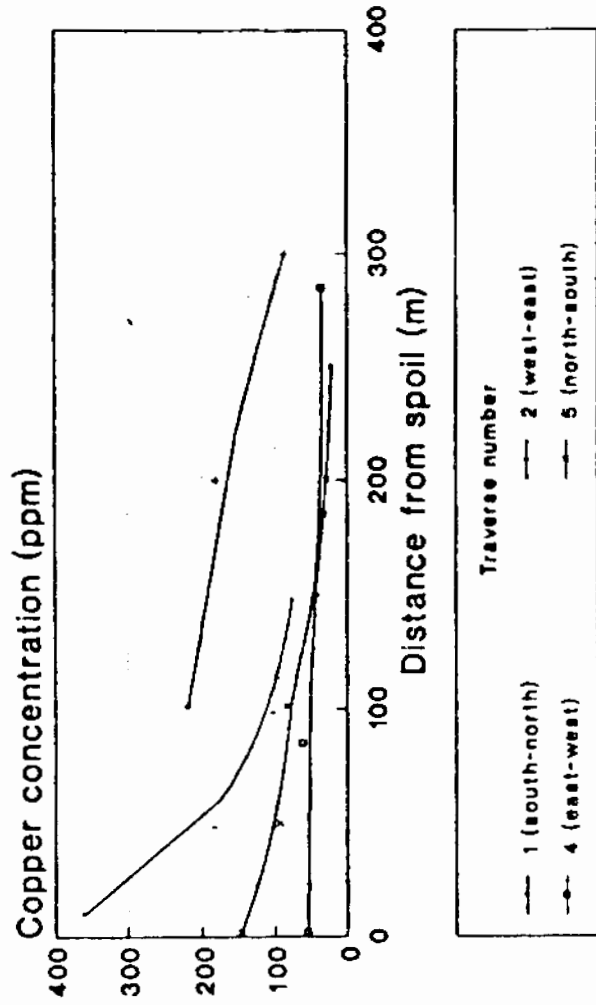


Figure 5: EDTA Extractable Copper from Tresavean soils

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### (g) Chemical analysis

Each sample was analysed by atomic absorption spectrophotometry (AAS) for "available" metal content - extraction of the available fraction was achieved by the agitation of 10 g of sample with 50 ml of 0.05M EDTA (di-sodium salt) for 2 hours<sup>16</sup>. On completion the liquid and solid phases were separated by filtration, and the resultant solution analysed by AAS.

### (h) Results and interpretation

Results from the pH determinations show that Tresavean spoil samples range in pH from 3.6 to pH 8.7, with an average of 5.6. Comparison of pH values and available copper can be made by examining figures 2 and 3 which show spoil pH and available copper distribution and pH versus available copper respectively.

There appears to be no correlation, between these two parameters. A possible explanation being the copper has been leached from the surface of the spoil. Also, sampling on a grid system results in some samples being of soil instead of mine waste. What can be seen from figure 3 is that most of the samples have a low pH indicating some acid production is continuing by way of pyrite oxidation and this low pH will keep any copper present in a mobile form.

South to north soil traverses away from the mine site show, as expected, copper concentrations decrease with distance away from the mine spoil (figure 4). The available-copper "trigger value" is exceeded for a distance of at least 1000m and up to 300m. The value above which toxicity may occur is 50ppm<sup>16</sup> It was expected that the south/north traverses would show the highest and most persistent contamination due to their aspect and morphology relative to Tresavean. These traverses run down slope from the mine site and are down wind of the southwesterly prevailing winds.

Figure 5 shows a comparison of available copper concentrations taken from 4 perpendicular traverses (traverses 1, 2, 4 and 5, figure 1). Results indicate that the west-east traverse has the highest levels of metals for the greatest distance from the mine spoil. This traverse appears to be more greatly affected by contamination from wind dispersion than the others, indicating the dominance of a westerly wind following the contours of the valley rather than the prevailing regional southwesterly wind. However, a more detailed examination may be needed to evaluate the effects on Traverse 2 from the area of mine spoil to the north.

These results reinforce the need for establishing a vegetative cover over the mine waste to reduce secondary contamination.

## ACID NEUTRALISATION VERSUS CONTROL OF METALS IN SOLUTION

Normally the solubility of problematical heavy metals is reduced as the pH becomes more alkaline, and above about 7 most metals are not considered phytotoxic. However sometimes the control of acidity can clash with the need to remove toxic elements from solution, and the two must be carefully balanced.



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Extensive work has already been completed on the use of industrial minerals, including natural zeolites, diatomaceous earth, vermiculite and Fuller's earth as in-situ amendments to control the generation of acidity and the release of metals into solution, and is detailed elsewhere<sup>17,18,19</sup>.

The question of whether less exotic materials that, such as MgO and Mg(OH)<sub>2</sub>, which are primarily pH adjusters can also successfully remove cations from solution permanently is an important one. MgO and Mg(OH)<sub>2</sub> have the advantage of relative cheapness when compared with some of the other industrial minerals already investigated. The potential of the other industrial minerals to control acidity has already been detailed elsewhere<sup>17</sup> and this potential exists in tandem with their ability to remove toxic cations from solution. MgO and Mg(OH)<sub>2</sub> have a far higher potential to control acidity. Work conducted at CSIRO<sup>20</sup> indicated that MgO could also remove cations from solution by precipitation in a high pH zone at the solid/solution interface. They have therefore been examined both for their amelioration of acidic conditions and removal of cations from solution. The major difference between them and the industrial minerals already examined is the method by which they control pH. Industrial minerals do so mainly by the removal of H<sup>+</sup> through adsorption or ion-exchange. The physical integrity of the amendment is not affected by the removal of hydrogen ions - other than through degradational effects of the acid. MgO [and Mg(OH)<sub>2</sub> and CaO/(OH)<sub>2</sub> - commonly used as pH adjusters] however work through dissolution to create OH ions which serve to raise the pH.

Tests were conducted on MgO and Mg(OH)<sub>2</sub> to determine the removal of cations from solution and control of acidity under the same test conditions already used for the other industrial minerals. The Mg(OH)<sub>2</sub> tested was supplied by Steetley Minerals as compacted spheres ("Magnaspheres") of three different size fractions, 0.5-2mm, 2-6mm and 6-12mm (hereafter referred to as MS 0.5-2, MS 2-6 and MS 6-12). The MgO tested in powder form ("Lycal 93/12F") was also supplied by Steetley Minerals.

An accurately known weight of sample (approximately 1g) was tumbled with 20.0ml of a mixed cation solution adjusted to pH 1.00, 2.00 or 4.00 using sulphuric acid, until equilibrium was reached. The cations present were As<sup>2+</sup> (60meq/100g), Cd<sup>2+</sup>, Cu<sup>2+</sup>, Fe<sup>2+</sup>, Mn<sup>2+</sup>, Ni<sup>2+</sup>, and Zn<sup>2+</sup>, each at (40 meq/100 g). At equilibrium the samples were centrifuged, and the pH and metal content of the supernatant solution determined. In the case of the MS the solid phase was subsequently separated from the solution - the solids present were in two forms, (i) the spheres of Mg(OH)<sub>2</sub> themselves coated with a coherent metal precipitate and (ii) a separate gelatinous metal precipitate. These two were separated from one another by careful washing through the appropriate size sieve to allow the precipitate to pass while retaining the spheres. Washing was carried out with a solution buffered to pH 10 with the appropriate Magnasphere, to avoid solubilising the metals bound to the surface of the spheres. The spheres were then dissolved in an excess of 4M sulphuric acid, and the metals present determined by AAS. The metals present as gelatinous precipitate were determined by the difference between the total metal added and that precipitated on the spheres surface.

In the case of Lycal 93/12F, the fineness of the sample precluded separation of the precipitated metals, and thus the split between surface deposited and free precipitate was not determined. Results are shown in Table 2. The selectivity sequences shown are based upon the cations removed at the solid/liquid interface.

Bold figures indicate total cations removed from solution as precipitate and surface bound (meq/100g) and light figures indicate surface bound cations (meq/100g). Final pH values

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are given for 1.00g of sample/20.0ml of cation solution.

Although total removal from solution is an important factor, selectivity can be more so. For all three size fractions As, Cu and Fe are preferentially removed, along with Zn for MS 0.5-2. However in the case of MS 6-12 and 2-6 usually less than 50 % of the total removed is precipitated on the surface, the rest being in the form of a separate gelatinous precipitate. For MS 0.5-2 the surface bound proportion of As, Cu, Fe and Zn ranged from 60 % to 95 %. The remaining elements were removed from solution to a lesser extent, particularly in the case of the two coarser sizes, where surface removal of Cd, Mn, Ni and Zn was less than 3meg/100g even at initial solution pH of 4.00, and total removal remained low. Surface removal of Cd, Mn and Ni by MS 0.5-2 was higher (although still less than 6meg/100g at initial pH 1.00 and 2.00), reaching a maximum for an initial pH of 4.00.

Initial pH	Final pH	Selectivity							Total Adsorption
<b>MS 6-12</b>									
1.00	4.75	As > Fe > Cu > Mn > Cd / Ni / Zn							
		36.1 22.7 13.1 4.8 2.3 1.7 3.4							84.1
		21.3 8.0 2.7 1.8 1.0 0.9 0.6							36.3
2.00	5.01	As > Fe > Cu > Mn > Cd / Zn / Ni							
		56.3 20.7 17.1 7.2 2.7 5.3 3.4							112.7
		19.0 10.2 4.5 1.7 0.8 0.7 0.6							37.5
4.00	6.10	As > Fe > Cu > Cd / Zn > Mn / Ni							
		43.0 31.3 28.2 10.2 4.1 6.1 2.6							94.2
		21.1 19.2 17.9 2.7 2.5 2.0 1.7							47.9
<b>MS 2-6mm</b>									
1.00	4.66	As > Fe / Cu > Mn / Cd / Zn > Ni							
		45.2 26.6 22.8 5.7 0.3 3.6 4.3							108.5
		15.3 9.7 9.5 1.6 1.3 1.2 0.9							39.5
2.00	5.10	Cu > As > Fe > Zn > Cd / Mn > Ni							
		35.7 58.8 23.7 9.3 3.9 7.3 6.0							144.7
		20.3 14.5 10.5 2.3 1.9 1.9 1.3							52.7
4.00	6.95	As > Cu > Fe > Zn / Cd > Mn > Ni							
		55.9 29.3 24.6 9.2 12.0 5.4 3.3							115.1
		16.9 13.8 9.9 2.4 2.2 1.8 0.9							38.0
<b>MS 0.5-2mm</b>									
1.00	6.10	Cu > As > Fe > Zn > Cd / Ni > Mn							
		>40.0 49.4 >40.0 34.9 9.6 37.2 7.8							218.9
		38.0 35.0 26.5 16.0 6.0 5.9 2.5							129.9
2.00	5.15	Cu / As > Fe > Zn > Cd / Ni > Mn							
		>40.0 >60.0 34.5 31.2 8.4 33.5 7.7							215.3
		36.5 35.9 25.8 13.6 5.0 4.8 2.9							124.5
4.00	8.18	As > Cu > Fe > Zn > Ni > Cd > Mn							
		>60.0 >40.0 >40.0 >40.0 39.6 24.5 27.7							231.8
		50.5 >40.0 37.2 32.7 15.7 14.4 11.1							164.4

**Table 2: Removal of cations from solution by Mg(OH)<sub>2</sub>**

The selectivity sequences are promising as both As and Cu are being effectively controlled, but it is unfortunate that Zn was not more selectively precipitated, as Zn is one of

the most mobile and problematical elements.

Lycal 93/12F raised the solution pH to between 9.74 (from an initial pH of 1.00) and 10.20 (from an initial pH of 4.00). However problems may arise when metals are precipitated from solution, as this may lead to cementation through crystal growth<sup>21</sup>, and possible impedance of plant roots and reduced growth.

In addition the small size of the particle does not confer great stability on those metals that are surface bound - although its total neutralisation capacity is higher than that of Magnaspheres weight for weight, every time a particle is totally dissolved the bound metals will be re-released. Larger particles have a longer lifetime, and therefore keep metals out of solution for longer. However, larger sizes have a smaller specific surface area and thus reduced contact with contaminated water originating in the spoil. Some compromise in size must therefore be reached. Total removal from solution increases as the particle specific surface area ( $m^2/g$ ) increases (i.e. as the particle size decreases), indicating that total removal is a function of surface area, or rather the rate of release of hydroxyl ions into solution. Final solution pH relative to initial pH also increases as particle size decreases-again indicating that the equilibrium level of OH is controlled by the available surface area. It must be noted however that although the total removals are high there is a wide disparity between total removal and surface bound cations, and it is here that the desire to control of acidity and levels of cations in solution comes into conflict.

Unfortunately there are problems with the use of  $Mg(OH)_2$  despite its suitable selectivity characteristics. Although MS and Lycal control acidity and cations in solution, there are two related problems. The first is the production of non-bound metal precipitate (in this case present as the gelatinous material). This is a consequence of MS's and Lycal's excellent acidity control - they are so effective at releasing OH that precipitation of some of the metals occurs in the bulk solution rather than at the solid/liquid interface. It is then possible for this precipitate to become physically distanced from the MS or Lycal. If the precipitate then moves into a low acidity area, the metals may be released in a concentrated surge, producing dieback for any vegetation whose roots tap into the vicinity. Secondly both will, if total acid exceeds the neutralisation capacity, dissolve and consequently re-release their load. In addition they implies that this interface is an area of instability, where the bound metals may "flake off" and become physically removed from the particle, leading to possible re-dissolution. Therefore the use of any material that neutralises acidity by dissolving and also controls cations in solution by precipitation can be seen as less than ideal.

These arguments presuppose that the laboratory test mimics response to exposure to cations at much lower levels over a far longer period of time than has been used here. Again only through the monitoring of field tests can these hypotheses be tested. Table 3 displays the total surface bound metal as a percentage of the total removed. MS 0.5-2mm has the highest % removal as a bound precipitate, this is expected as it also has the highest surface area to weight ratio. It would also be expected that the greatest removal would occur at the highest initial solution pH, and this is the case for MS 6-12mm and MS 0.5-2mm but not MS 2-6mm.

As both MS and Lycal buffer the pH to high levels the pH of the initial solution has less impact on the precipitation than in the case of the other industrial minerals tested, which produce lower final pH values. For both MS 6-12 and MS 2-6 total removal increases to a maximum at initial pH 2.00, but the % surface-bound does not increase accordingly as can be seen from Table 3.

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	Initial solution pH		
	1.00	2.00	4.00
	% metal bound at surface		
MS 6-12mm	43.2	33.2	50.8
MS 2- 6mm	36.4	36.4	33.0
MS 0.5-2mm	59.3	57.8	70.9

**Table 3:** Removal of cations at surface relative total removal from solution for  $Mg(OH)_2$ .

As already mentioned the presence of unbound metals may be a problem, obviously MS 6-12 and 2-6 would be unsuitable for use due to their low binding capacity (33.0% to 50.8 %). Even MS 0.5-2 produces a high proportion of unbound metals (binding only 57.8 % to 70.9 %). Even this bound material may with time become removed from the surface. Testwork so far completed has indicated that the other industrial minerals tested will retain their adsorbed metals against the continuing action of acid, and in this respect are far superior to both  $MgO$  and  $Mg(OH)_2$ .

In conclusion it seems that in the case of  $MgO$  and  $Mg(OH)_2$ , the excellent acidity control characteristics are negated by possible problems with precipitation of metals in an unstable form. This could result in future toxicity to vegetation that had become established. Only by ensuring that alkaline conditions prevail over the complete area to be treated would it be possible to use these products with any confidence. There is also of course the possibility of using  $Mg(OH)_2$  or  $MgO$  in conjunction with zeolites, but it must be remembered that zeolites will also degrade under highly alkaline conditions as well as acidic<sup>22</sup>.

### CONCLUSION

Available metal results from Tresavean spoil appear to have no direct correlation with pH at the site. This would indicate that a number of other factors are affecting available metal content, not least of all vegetation itself. This would suggest it may be necessary to assess each site to determine which available metal extraction method to use, rather than using one blanket method for each site. This conclusion reiterates a common theme in reclamation studies - that reclamation needs to be very much site specific.

### ACKNOWLEDGEMENTS

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