

The Role of ViroSoil Technology in Supporting Sustainable Coastal Development and Enhancing Environmental Remediation

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ABSTRACT

The risks associated with coastal development in locations where Potential Acid Sulfate Soils (PASS) and Actual Acid Sulfate Soils (AASS) are present have long been recognised and the potential to cause oxidation of pyrite resulting in the formation of sulfuric acid leachate that will degrade the immediate and receiving environment is well documented.

Risk based management of development associated with PASS and AASS has been developed and a range of remediation options have been recommended including neutralisation of acidity and management of associated metal and metalloid contaminants. The role of ViroSoil Technology in addressing issues associated with the disturbance of PASS and AASS has yet to be fully realised throughout Australia in a variety of contexts.

ViroSoil Technology has been successfully applied to permanently neutralise the actual and potential acid generating capacity of sulfidic marine clays, dredge spoils, and other acid sulfate soils. ViroSoil Technology will halt the generation of acidic, metal-laden leachate, bind into non-bioavailable forms any metal contamination present in the soil, facilitate revegetation of affected areas, and has proved successful in improving the yield of commercial aquaculture and agriculture operations impacted by Acid Sulfate Soils (ASS).

Results from various commercial projects are presented and the applicability of ViroSoil Technology to promote sustainable coastal development is explored in conjunction with the possible role of ViroSoil Technology in large-scale environmental remediation projects where exposure of ASS is causing significant environmental harm.

Introduction

Complete oxidation of iron sulfides produces acid at a rate of 4 moles of H⁺ per mole of pyrite that is oxidised to sulfate and iron oxyhydroxides and, in Actual Acid Sulfate Soils (AASS), this process commonly produces pore water and soil leachate pH values of less than 3.0. In the soil, low pH values can enhance the mobility of ecologically hazardous trace metals (Forstner & Wittman, 1981; Salomons & Forstner, 1984; Bernhard et al., 1986), adversely affect plant growth, and result in damage to engineering structures.

Where rapid rises in the water table (associated with floods, for example) allow the low pH, potentially trace-metal enriched, water to be flushed into nearby waterways, larger scale ecological, geochemical, and engineering impacts are likely (Fitzpatrick, et al, 1996). Because the transformation of Potential Acid Sulfate Soils (PASS) to AASS can have significant environmental impacts there is a need to manage land use and development in affected areas so as to minimise or eliminate possible adverse impacts (Graham & Larsen, 2000; Naylor, et al, 1995). Acid Sulfate Soils are closely related to the more problematic monosulfidic black oozes (MBOs) commonly found throughout Australia (Sullivan & Bush, 2002), and have been shown to have a significant impact on coastal developments, property development and industry (Appleyard, et al, 2002; Smith, et al, 1999).

PASS management has involved a variety of approaches including the following: a) preventing particular types of development; b) control of drain design and location; c) backflushing drains with seawater; d) physical separation of the sulfide minerals from the soil and removal for safe disposal;

e) accelerating oxidation of the soil and treating the affected water on site; f) removal of affected soil for disposal below the water table, adding lime to neutralise the acid; or g) which is typical, doing nothing and hoping the consequences will not be too serious.

Of the soil treatment options, the most popular involves blending lime with the soil to neutralise any acid that may be produced during sulfide oxidation, but although this method is reasonably economical, the use of large quantities of lime can have undesirable side effects on soil texture and composition and its use may not result in the trapping of trace metals released during sulfide oxidation.

An alternative approach involves mixing ViroBind reagent, an environmentally safe chemical additive used in ViroSoil Technology, with PASS; this approach has the additional appeal of using a reagent which is partly derived from a waste material (in this case, alumina refinery residue) to solve an environmental problem.

Mineralogically, ViroBind reagent consists of, among other compounds, hematite, quartz, boehmite, gibbsite, calcite, sodalite and whewellite, with minor hydrotalcite, hydrocalumite, halite, lepidocrocite, brucite, ferrihydrite and cancrinite, which together have a very high surface area to volume ratio and a high charge to mass ratio. In combination, the texture and mineralogy of ViroBind give it a high trace element trapping and binding capacity (>1000 meq/kg dry reagent at pH values >5.0) and the ability to strip trace elements from water in contact with it, initially rapid adsorption is followed by further adsorption over several days, and subsequently with precipitation and co-precipitation reaction over several weeks and months.

If metals binding tests are repeated using 0.2 mM/L concentrations of each ion, all metal ions are almost 100% adsorbed within five hours and at ion concentrations of 0.5 mM/L >90% of all metal ions, except Ni, are adsorbed within 50 hours. Clearly, even at these unnaturally high concentrations, most environmentally significant trace elements can be trapped by ViroBind reagent, and tests on ViroBind reagent mixed with sediments, ASS and other hazardous solids that have aged for up to six or seven years show that metals remain trapped, with an increase of metals binding capacity at a rate of approximately 40% increase every six months.

ViroBind also has a high acid neutralisation capacity, due to an abundance of mineral phases that form weak bases. Tests indicate that greater than 3.5 moles of acid can be neutralised by one kilogram of dry ViroBind reagent. Acid neutralisation is initially rapid and then continues to increase slowly over several days. Despite its high acid neutralisation capacity, when dry ViroBind reagent is mixed with analytical grade water at a ratio of five parts water to 1 part ViroBind reagent, the mixture has a pH of approximately 8.0.

Average concentrations for major components in the ViroBind reagent (expressed as weight percent of the oxide) are: SiO₂ (16%), Al₂O₃ (23%), Fe₂O₃ (30%), Na₂O (7%), K₂O (0.13%), MgO (0.7%), CaO (3.17%), MnO (0.04%), TiO₂ (6.6%), P₂O₅ (0.17%), CO₂ (2.79%), and SO₂ (0.19%); the loss on ignition is high in ViroBind reagent. Average total trace element concentrations are: As (<20 mg/kg), Ba (9 mg/kg), Cd (<1 mg/kg), Co (8 mg/kg), Cu (18 mg/kg), Ga (42 mg/kg), Ni (33 mg/kg), Pb (52 mg/kg), Sc (100 mg/kg), Sr (38 mg/kg), and Zn (7 mg/kg).

Selective extraction data show that only a small proportion (<2 % for most elements) of the trace elements in ViroBind reagent can be removed by compulsive exchange reagents and hence, it is very unlikely that future leaching could lead to environmental contamination. A higher proportion of the trace metals (including iron and aluminium) can be released by treatment with nitric acid, but given the high acid neutralising capacity of ViroBind reagent, there is little chance that acid leaching would increase environmental metal loads, and none has been observed in the field.

Following extensive TCLP testing over ten years, ViroBind reagent has been classified by most environment protection authorities in Australia and abroad as a non-hazardous, inert solid, and very few restrictions beyond basic handling and safety procedures apply to its use in environmental applications. Some trace elements are adsorbed to ViroBind reagent, and others form low solubility

precipitates by direct reaction with minerals in the reagent. When the trace metal concentrations in solutions in contact with the reagent are very high, metals compete for the available sites and competitive adsorption data indicate the sequence of binding strength to be Cr>Fe>Cu>As>Pb>Mn>Zn>Cd>Ni>Co.

Other research has shown that ViroBind reagent has a very high capacity to trap phosphate and to hold it in a form that is plant available but is not leachable by rain or normal ground water hydraulics; phosphate removal is rapid, and over 95% of phosphate in 1.0 L of 2.0 mM phosphate solution can be removed in two hours. This observation has significant relevance in ASS treatment, as one of the main problems associated with revegetating acid scalds and other ASS affected areas is lack of nutrients in the soil.

These properties suggest that ViroBind reagent has a high potential to neutralise acid released during the formation of AASS and the potential to trap and hold any trace metals that may be released. The potential value of ViroBind reagent in ASS management has been confirmed by laboratory studies of ViroBind reagent and PASS mixtures that are artificially oxidised, as well as in a variety of extensive field trials and large-scale commercial applications throughout Australia. ViroBind reagent can not be easily leached out of the soil matrix once it is mixed with PASS, and when it reacts with any acid it does not appear to produce any undesirable reaction products.

Acid sulphate soils (ASS) exist in coastal lowlands in many parts of the world (e.g. Dost & van Breemen, 1982, Dent, 1986, Dent & van Mensvoort, 1993), particularly in tropical and subtropical regions (e.g. White et al., 1997) where they have been linked to the degradation of subaerial and aquatic ecosystems. Potential acid sulphate soils have a high sulphide mineral content (dominantly, but not exclusively, pyrite) and are stable while they remain beneath the water table, but if the water table falls during a drought, or as a result of human activity (e.g., drain construction or excavation work), sulphides can oxidise releasing acid and dissolved metal ions, and forming AASS.

Environmental problems associated with acid released during the transformation of PASS to AASS include scalding of vegetation, fish kills and degradation of aquatic ecosystems (e.g. Callinan et al., 1993, Sammut et al., 1995); the acid can also damage building foundations and underground infrastructure such as cable networks and pipe lines (e.g. Dent, 1986).

One way of avoiding environmental problems associated with acid sulphate soils (ASS) is not to disturb them in any way that may increase exposure to atmospheric oxygen or increase the leaching of acidic, and potentially trace metal enriched, water. However, this strategy is not always possible given the increasing agricultural, residential and other commercial developmental pressures on the coastal lowlands where ASS are common, and it will not reduce the natural discharge of acidic water that may periodically emanate from undisturbed ASS.

Furthermore, it is not possible to completely reverse the effects of past disturbance of ASS by modifying the engineering work that caused the disturbance (e.g. removing flood mitigation gates or filling in drains) because much of the acid that was produced during the earlier formation of actual ASS is temporarily stored in near-surface soils and can be leached during any water movement through re-saturated soil (Lin et al., 1998). Consequently, active intervention strategies are often required where previously disturbed ASS requires remediation and where the benefit of developing a particular area of land justifies the cost of treating the ASS.

ASS Treatment Strategies

One possible active intervention strategy would involve physically removing all ASS material and placing it in sealed and capped disposal dumps or depositing it where it will remain permanently below the water table. Ideally, it should be deposited under seawater, because seawater has sufficient natural buffering capacity to neutralise any stored acidity that may be present, but in most places there are stringent restrictions on dumping such materials in marine environments.

Furthermore, this strategy is very costly to implement and consequently, it can only be considered where modest volumes of ASS material are involved and where the benefits of developing the site are large enough to justify the cost. Physical relocation of ASS material has been used at some coastal resort development sites, but it is not practical for remediation of ASS on agricultural land.

The most commonly used active intervention strategy involves the addition of lime to the ASS material to neutralise any stored acidity and any acid that may be produced when sulfidic material in the soil oxidises some time in the future. This strategy is often incorporated in ASS management plans that also involve minimising any fall in the water table and may involve physical removal of some ASS material for safe disposal elsewhere. There is no doubt that if it is applied correctly and in the appropriate amounts, lime can successfully prevent acid release from ASS material. However, there are some disadvantages associated with the use of lime that need to be considered; these are:

- a) Lime is expensive because it needs to be mined, crushed, sieved and transported to the site; for some forms of lime, additional treatments are also necessary.
- b) Lime is slightly soluble in natural rainwater, and most ground waters and consequently (particularly if a series of wet seasons precede a drought), much of the lime which has been applied to the ASS may have been leached from the soil before the acid that it was supposed to neutralise was in fact neutralised.
- c) In some coastal settings, particularly near mangroves, adding too much lime may pose a greater environmental risk than not adding enough and hence, application rates need to be determined very carefully; this may be a problem if there is any chance that lime may be leached from the soil.
- d) There is new evidence that bicarbonate ions, formed when some of the lime dissolves, may accelerate the decomposition of pyrite (Evangalou, 1999).
- e) The formation of gypsum, when calcium in the lime reacts with sulphate produced during the oxidation of sulphide minerals, may adversely affect the hydraulic properties (e.g. drainage) of the soil. The specific gravity of gypsum is about 2.3 compared to about 2.7 for calcite and 2.9 for aragonite and because one mole of gypsum can form from each mole of calcite or aragonite, the gypsum will take up more space and the permeability of the soil may be reduced.
- f) If coarse lime is used to form reactive subsurface barriers or to line drains, its effectiveness decreases as the grains of lime become coated with iron- and aluminium-oxyhydroxides that precipitate when the pH of the water is raised by the lime and the gypsum that forms (as in point 5) tends to block the pore spaces between the particles of lime.

Therefore, as noted above, a good alternative to the use of lime involves the use of ViroBind reagent, which is suitable for use in the management and remediation of ASS. ViroBind reagent provides a cost-effective alternative to lime for the management and rehabilitation of ASS, and it has the advantages that; a) it cannot be leached from the soil by rainwater or groundwater before acid that needs to be neutralised has formed, b) a waste product is being used instead of material that has to be mined and processed, c) it enhances the nutrient retention capacity of the soil and promotes plant growth, d) it has little effect on the concentration of bicarbonate ions that may accelerate pyrite decomposition, and e) it can be used to line drains and form reactive subsurface barriers that maintain their permeability and reactivity over time.

The main disadvantage of using the ViroBind reagent is that more ViroBind reagent than lime may be required to neutralise a given amount of acid. However, this requirement may not be a major handicap, because it has been shown that some of the primary ingredients of ViroBind reagent can enhance pasture growth and improve nutrient retention in the soil, thus making it economical in other ways (Ward & Summers, 1993; McPharlin et al., 1994; Summers et al., 1996; Summers & Pech, 1997).

Other alternatives to the use of lime include the use of crushed ultrabasic rock, some fly ash and bottom ash materials and precipitates, such as magnesium hydroxide, that can be produced from hypersaline brines. Most ultra-basic rock contains substantial quantities of olivine, which weathers readily releasing reactive hydroxide ions that can neutralise acid (e.g. Krauskopf & Bird, 1995); many minerals in other rocks also release hydroxide during weathering but weathering rates are usually too slow to provide much benefit in the management of ASS.

Although crushed rock material can be successfully used to minimise acid release from ASS, whenever this option is considered it is important to ensure that the selected rock material does not contain unacceptably high concentrations of potentially environmentally hazardous trace elements that could be released during rock weathering. Most fly ash and bottom ash also have acid neutralising capacities and can provide a useful source of essential micronutrients in some soils (e.g. Schuiling, 1998) but, as with the use of crushed rock, it will be important to ensure that the concentrations of potentially environmentally hazardous trace elements in the fly ash are low.

A further, rather more costly, alternative involves the use of small quantities of magnesium hydroxide that can be prepared by carefully controlling the evaporative concentration of hypersaline salt lake and groundwater brines that are themselves an environmental problem in many arid zones. All these alternative strategies have their advantages and disadvantages in relation to particular soil types, particular land uses, and the availability of the required raw material, and the same types of advantages and limitations apply to the use of lime. The important point is that the use of lime in ASS management and remediation is not the only option, and more consideration should be given to some of the alternatives both by researchers and by practitioners of ASS management and remediation.

Use of ViroSoil Technology to treat ASS

Environmental problems associated with ASS involve both the direct effects of surficial soil acidification and the leaching of acid into drains and rivers. Near-surface soil acidification can be treated by physically mixing ViroBind reagent with the soil at a mixing ratio determined by both the actual soil acidity (or AASS) and the sulfide mineral content of the potential ASS or (PASS).

In the most simple approach using ViroSoil Technology, ViroBind reagent is thoroughly mixed with the top 20 cms of affected soil, but in some areas treatment to greater depths has been required; the treated area can be successfully replanted immediately after treatment. This treatment is particularly useful in areas where prolonged or excessive release of acid has caused acid scalds and completely prevented plant growth. Remarkably good plant growth (including both grass and a variety of tree species) on previously barren ground was achieved within four weeks; the addition of some mulch may be required to increase the organic carbon content of the soil; the addition of fertiliser may further improve plant growth rates.

ViroSoil Technology can also be used to form reactive subsurface barriers to prevent acidic water entering drains or natural watercourses. These barriers are not intended to impede groundwater seepage into the drains, but to neutralise the pH of water before it enters the drain. The reactive barriers are placed near (and parallel to) drains and water courses by digging a trench to below the water table and backfilling it with a predetermined mixture of ViroBind reagent and excavated soil; the trenches should be deep enough to intercept all acid groundwater leachates and additional reactive barriers can be placed elsewhere on the contaminated site as required.

If the barriers are designed to protect a water body from acid generated from a large area of ASS, the effective life expectancy of the barriers will be limited and the time over which they will remain effective depends on groundwater flow rates and acidity levels. Because groundwater flow rates and acidity may vary seasonally and from one year to the next, it is impossible to make accurate predictions of how long a particular barrier will remain effective at a particular site. To overcome this potential problem, piezometers have been installed between installed barriers and the water body being protected such that they can be monitored regularly.

When the pH of water in the piezometers falls below about 6.0, it is likely that much of the acid neutralising capacity of ViroBind reagent has been used up, and either the barrier needs to be replaced or a new barrier needs to be installed parallel to the original barrier. Barriers can easily be formed using machinery that is common on many farms or development sites; barriers have been constructed by contractors at a modest cost, and water in the piezometers can be readily monitored by farmers or developers without the need to employ specialists.

Applications of ViroSoil Technology

Example No. 1: ASS in Golf Course Application

Club Pelican Golf is Australia's first golf course designed by world-renowned Australian golfer, Greg Norman. Constructed at a cost of \$50 million and opened in 2000, this spectacular 18-hole golf course is located near Golden Beach on Queensland's Sunshine Coast. Surrounded by national parks on two sides and Bell's Creek on another, the course blends perfectly with its coastal environment, cleverly incorporating the natural landscape to enhance the unspoilt beauty of the area. Club Pelican Golf also boasts one of the finest clubhouse and practice facilities in Australia. The golf course covers an area of 45 hectares, and is composed of 6,359 metres of championship tees, utilising dwarf Bermuda greens, Riley's Super Sport Couch on fairways and Santa Anna Couch on the tees.

Club Pelican Golf used ViroSoil Technology to treat ASS scalding part of their golf course. It was found that in constructing the course in 1999-2000, the property developer had dredged a canal and used a substantial quantity of potentially acid generating sand and clay to create a fairway. After construction, it was observed that large areas of the fairway would undergo acid scalding and would not support grass growth, as characterised by large bald patches of grey, waterlogged soil.

Despite several attempts using lime to correct the acid scalding caused by oxidation of the ASS used in the centre of the fairway, the scalds had either not been corrected at all or had returned after rain events. As they were in a highly visible part of this world-class golf course, it was deemed vital that the unsightly scalds be effectively treated with something more than a short-term, neutralising "fix". The acid scalds were not only unfavourable from a golfing point of view, but were visibly unattractive, with little or no grass being supported.

Lime had been used on a regular basis to treat the scalds since the course was constructed, but it had rapidly washed away or leached from the soil profile during rainfall events. Consequently, the treatments had not provided a permanent or even semi-permanent solution for the scalds or for the treatment of the underlying potential of ASS. Therefore a more sustainable solution was sought, which would not require repeated maintenance and would result in improved fairway appearance.

Conditions on the fairway at Club Pelican Golf had many of the hallmarks of a classic ASS environment. These include water-logging, soft, fine clays, silts and estuarine sands, a grey hue to the soil, soil scalds, and yellow jarosite mottles or red iron oxide mottles can be seen in excavated soil.

It was found that the percentage of sulphur in the clay component of the fairway was 0.063%, with anything over 0.05% representing the presence of ASS in clay, whereas the sand component was just 0.009, with anything over 0.02% representing the presence of ASS in sand. Soil pH was on average 5.1 prior to treatment; a soil pH of 5.5 is generally considered to be the minimum acceptable value for grass growth. The total potential acidity (TPA) of the clay component was equivalent to 2.3 kg of lime per m³ of clay, but the total actual acidity (TAA) of the clay was 0.0; the TPA of the sand component was equivalent to 0.4 kg of lime per m³ of sand, but the TAA of the sand was 0.0.

The fact that most of the acidity was potential acidity accounted for why the pH values were not substantially lower than those measured. This finding indicated that acid was being actively produced and that the scalds were formed when surface evaporation concentrated the acid in just mildly acidic

groundwater that was driven upwards in the capillary fringe zone of the soil. The fact that the appearance and severity of scalds was apparently linked to rainfall events further confirmed this theory.

To rectify the problem, it was decided that the turf on the fairway would be stripped off, so that ViroBind reagent could be applied to the affected soil profile at a blending ratio to be determined by Virotec's computerised ASS treatment model, and the turf would be replaced together with fresh top soil over the project area. The treatment areas would be monitored but largely left to weather for six to eight months and then re-sampled to assess the AASS characteristics of the soil.

Three treatment areas were identified, with the first being an area of substantial acid scalding to which the ViroBind reagent was applied as a layer at a depth of about 100mm and mixed lightly by rotary hoe. The second treatment area was a similar size area where ViroBind reagent was thoroughly mixed with the clay and sand components to a depth of approximately 200mm. The third treatment area was a control area that was simply stripped and re-turfed with no addition of ViroBind reagent.

After eight months, it was clear that the ViroBind reagent treatment had effectively remedied the acid scalds and the Riley's Super Sport Couch fairway grass had fully re-grown, with no acid scalds reappearing during this time. This observation was confirmed by laboratory analysis of soil samples taken after eight months, which indicated that the oxidisable sulfur content of the soil and the total potential acidity of both the lightly mixed and fully mixed treatment areas had been significantly reduced. Acid scalding continued to occur in surrounding areas of the fairway that had not been treated.

In the first treatment area, sulfur had been reduced to 0.003% at 100mm and 0.014% at 300mm and TPA was equivalent to just 0.1 and 0.7 kg of lime/m³ respectively. In the second treatment area sulfur had been reduced to 0.006% at a depth of 200mm and TPA was equivalent to just 0.3 kg of lime/m³. The fact that there was a greater percentage of sulfur and higher TPA value at 300mm than at 100mm in treatment area one, tends to confirm the proposition that even the ASS at depth was improved by the addition of ViroBind reagent, and that potential acidity was greater at depth than on the surface of the fairway. It was also concluded that the treatment layer in both treatment areas would have created a favourable condition on the surface of the fairway, because any groundwater coming to the surface would have to pass through the ViroBind reagent and thus be neutralised before concentrating at the surface, thereby eliminating the tendency to kill fairway grass.

After the application, the head groundsman reported: "Repeated attempts to solve our acid sulfate soils problem had failed so we turned to ViroSoil Technology. We had tried liming the fairway several times with little or no long-term effect, and we were desperate to come up with a more permanent solution because these acid scalds were in a highly visible part of the fairway, and many golfers complained about both the look and the poor golfing performance of this area.

"After applying ViroBind reagent to the main ASS hot spots, we re-turfed the area and waited to see what would happen. To be honest, in either a positive or negative direction, nothing much happened for quite some time. We thought this was probably due to the drought and not much groundwater rising from below the fairway to activate the ASS. We waited for quite some time. While the scalds didn't return, the control plot looked pretty much the same as the treated areas. So while we were happy to not have the scalds, it appeared that by just lifting the turf and exposing the soil for a period of time we got the same result as applying the reagent.

"However, after about the ninth month, it became obvious that grass on the control plot was beginning to die off while the treated areas looked as healthy as the best part of our course. We can recommend that this approach seems viable to treat ASS, particularly if it were applied to dredge spoils before there are used in golf course construction or property development."

Conclusion

This paper has explored the mechanisms present in acidic soil, sediments, tailings and dredge spoils which cause the production of what are collectively called Acid Sulphate Soils, and has included a discussion of the relationship between potential and actual acidity and their relevance for environmental remediation.

The paper has also examined the strengths and weaknesses of the various alternatives to treating Acid Sulphate Soils, and has introduced the application of ViroSoil Technology to effectively neutralise potential and actual acidity in soils as well as the permanent sequestering of heavy metals within the soil matrix. Such an approach is now considered best practice in the treatment of Acid Sulphate Soils, and is currently the most sustainable method for dealing with this pervasive problem in Australia.

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