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STABILITY ENHANCEMENT OF COAL MEASURES STRATA WITH WATER-BASED CHEMICAL AGENTS

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ABSTRACT

This paper summarizes a contract report of work undertaken on behalf of the Department of Energy, Mines and Resources to ascertain the effectiveness of surface applied chemicals as a swelling retardant for use in underground coal mines. It addresses the mineralogical, chemical and mechanical aspects of the swelling clay problem. The experience of the use of swelling retarders in the oil well drilling industry is reviewed and the various types of stabilizing chemicals discussed. Finally, potential applications of the technology in coal mining are discussed with mention of the toxicity of the chemical agents and their relative costs.

INTRODUCTION

The strength and stability of underground coal measures strata is known to be affected by water from various sources, such as the mine atmosphere, dust suppressor sprays and connate water. One of the effects frequently associated with water absorption is the strength reduction and swelling of coal underclays, resulting in plastic flow of floor material into the opening. In some cases this can cause severe deformation of the roadways, necessitating costly and often repetitive repair.

Traditionally, the response to water softening of the strata has been either reinforcement by bolting or modification of the stress distribution. The recent development of roof sealant technologies and the growing experience of oil well mud specialists in the control of clay swelling prompted a review of these methods and their possible application in coal mines to alleviate some of the floor heave problems. The conditioning of water used in mines with chemicals that prevent clay swelling is an attractive alternative to traditional reinforcement/stress redistribution techniques. A contract to review the available information on behalf of the Department of Energy, Mines and Resources was let to Jacques, Whitford and Associates, Limited of Halifax, Nova Scotia. The final report (1) is summarized below.

SWELLING CLAYS

Both oil field engineering and civil engineering have to deal with problems which display some of the same swelling characteristics of clay materials, and much effort has been put into studies of cause, effect and remedies. It is worthwhile, therefore, to review some basic concepts which can provide insights into the behaviour of seat earth - a clay rich material frequently underlying coal seams.

The characteristic common to mining, civil and oil well experience is that there exists a class of materials which swell and soften when subjected to stress relief in the presence of water. They are almost universally referred to as shales, but this name presents some concern in that wide differences of opinion exist in regard to the classification and identification of shales.

Underwood (2) provides a valuable starting point in order to understand this class of materials. His classification of sedimentary rocks distinguishes between "soil-like or compacted" shale and "rock-like or cemented" shale. The soil-like shales include clay shale, silty shale, sandy shale and black shale. The clay shales have received much attention because they are notorious for creating difficulties in geotechnical engineering (3) and may also be the most important in the present context

Morgenstern and Eigenbrod (4) concentrated on the softening-upon-immersion in water aspect as an aid to classifying argillaceous soils and rocks. This approach was selected because it is the water deterioration characteristics which are important for many practical applications. Among these they include durability of tunnel walls, which returns us to the question of seat earths.

It seems a constructive hypothesis to suggest that coal measure shales can be included in the shale classifications cited above and that the potentially troublesome seat earths can be placed in the "compaction shale" category.

Furthermore, the troublesome materials exhibit the characteristics which in the literature fall under the collective heading "swelling clays". This hypothesis is presented in Figure 1.

Swelling Processes

Clay shales that swell, with associated softening and slaking, do so for reasons of both mechanics and mineralogy/chemistry. Swelling occurs only as a result of stress release in almost all practical cases - this is the mechanical aspect of swelling behaviour. However, some shales swell and others do not, because of differences in the mineralogy and chemistry of the clay particles and pore fluid - this is the chemical aspect. Non-clay minerals are also present in clay shales and clays, but they are essentially inert.

A similar view of the swelling process of clays and clay shales in situ is given by O'Brien and Chenevert (5): a) uptake of water due to differences between the electrolyte components of the shale pore water and the external fluid and b) uptake of water due to stress release. They note that the former process has a much greater swelling potential.

According to Peters and Stout (6) the clay particles are in flocculated equilibrium with their native fluids. Reduction of cation concentration by dilution with induced fluids such as mine water can occur and will result in dispersion. They postulate that a phenomenon similar to osmosis exists and the weaker solution forces its way into the clay lattice in an attempt to dilute the dense atmosphere of cations surrounding the clay plates. In this way the clay takes up the fresh water.

The chemical and mechanical aspects of the swelling of clays are reviewed briefly.

Chemical Aspects

Clay minerals are composed of sheets of molecules, with the sheets bound to each other by atomic bonds of varying strengths. The sheets are made up of units which contain silicon, aluminium, magnesium, etc. as positively charged atoms.

When the "right" atom is in place, the sheets or combinations of sheets ("layers") are electrically neutral. However, due to isomorphous substitution of these atoms by others of different electrical charge, the sheets or layers invariably have a net positive charge deficiency, which is balanced by adsorbed, exchangeable cations held on the outside of the sheets. The nature of the isomorphous substitution and the resultant charge deficiency explain most of the differences between the common clay minerals. The nature of the adsorbed cation explains much of the physical behaviour of the clay particles made up of bundles of these sheets and layers.

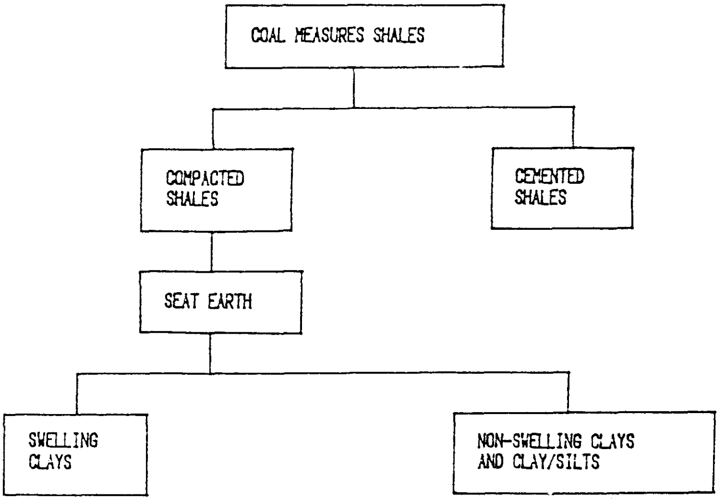

Figure 1 - A suggested classification of coal measures shales

The permanent net negative charge carried by the clay particle is measured by the cation exchange capacity,

$$\text{CEC} = \frac{\text{electrical charge deficiency}}{\text{unit mass}}$$

usually expressed as milliequivalents of electric charge per 100 grams of particle weight. The CEC is useful in assessing the potential for swelling, as well as plasticity and other characteristics.

The exchangeable cations are positively charged particles. In a clay suspension in water or in a saturated clay soil, the cations and water molecules are free to move in the fluid phase, but they take up positions adsorbed on the particle faces for the reasons given previously. Therefore, when a clay particle is dropped into water, both the mineral surfaces and attached exchangeable ions pick up dipolar water molecules, i.e. hydrate.

The ions with their shells of water move away from the mineral surface to positions of equilibrium to produce the "double layer". This behaviour is at the root of swelling characteristics since different ions result in different double layer thicknesses, which in turn change the properties of the mass of the particles. The controls on the rate and direction of the exchange reactions are valence, concentration of cations and pH.

Engineering experience and the study of clay mineralogy have identified certain clay minerals which are more susceptible to swelling than others, although the actual amount of swelling depends upon other factors such as the exchangeable cations and pH. Clay minerals can be arranged in descending order of swelling potential as follows:

sodium montmorillonite
calcium montmorillonite
illite (hydrous mica)
kaolinite

The most common cations occuring naturally are Na^+, Ca^{++}, Mg^{++}, and K^+. Of these, sodium has been found to have an important bearing on the structural status of a clay and is often described in terms of the exchangeable sodium percentage (ESP) where:

$$ESP = \frac{Na^+}{CEC} \times 100$$

A more comprehensive treatment of this topic can be found in standard reference texts (7,8,9).

Mechanical Aspects

In the compaction shales, the high density and the moderately high strength and stiffness which are associated with the unswelled state are attributed to the consolidating effect of many metres of overburden, which may have been thicker in the past than it is today, and also to the consolidating effect of dessication processes. In the first of these processes, the mineral grains have been squeezed together. In this squeezing process, the volume decreases by three mechanisms: i) sliding of grains past each other to produce a denser state of packing, ii) elastic deformation including bending of platey particles and iii) compression of the double layers at clay contact points. The high pore water tensions associated with dessication also force the particles close together. An additional effect of dessication is to drive off some of the water of hydration.

When these shales are subsequently unloaded, either by overburden removal or by the stress relief effects of a nearby excavation, borehole, tunnel and water is present, the above mechanisms tend to reverse and the volume increases.

A study of swelling due to unloading can provide insight into the potential magnitude of volume change and concurrent change in strength. In addition, an understanding of in situ behaviour requires a knowledge of the rate at which swelling occurs since swelling is a time-dependent process.

According to Terzaghi (10), the rate of swelling depends upon the permeability of the rock mass, which in turn has to be considered in terms of permeability of the intact shale and secondary permeability of the mass.

Taylor and Spears (11) point to structural features such as bedding plane laminations, joints, shear planes and rootholes in seat earth, which provide pathways for easier flow of water and hence are significant for the permeability and rate of swelling.

The magnitude of stress relief can be estimated from mathematical analyses which provide solutions for the stresses around openings of various shapes (12), and an estimate of the in situ stresses prior to mining.

Chemical - Mechanical Interaction

As noted above, stress release is a requirement before swelling occurs. Thus, the mechanical effect must occur before the chemical effect manifests itself. A link between these processes is described by Morgenstern and Balasubramonian (13). Two shales, the montmorilloritic Bearpaw shale and the predominantly illitic Morden shale, were allowed to swell both in their connate pore fluids and in distilled water after first establishing the swelling pressure for which the volume change was zero. The authors were able to demonstrate that the swelling in distilled water is predictable on the basis of double layer theory and that the double layer repulsion can be expressed as a component of the effective stress, i.e.

$$\sigma^1 = \sigma - u - (R - A)$$

σ^1 = effective stress
σ = total stress
u = pore water pressure
$(R - A)$ = component of effective stress associated with physico-chemical changes

SWELLING CLAYS IN ENGINEERING PRACTICE

In geotechnical engineering, swelling clays and clay shales are recognized for their tendency to cause heave of lightly loaded structures, with the heave of spillways constructed in clay shale cuts being a notable example (3). Softening due to stress relief and water uptake has also been widely experienced historically, leading to a variety of construction procedures.

Volume changes due to swelling are commonly measured by direct methods such as one-dimensional compression and swelling tests carried out on undisturbed samples. The swelling index, C, is obtained from these tests. The swelling potential is used for compacted soils; it is defined as the percentage volume change occurring for a sample compacted at optimum moisture content using standard procedures and allowed to swell under a surcharge of 7 kPa.

It is common in geotechnical engineering to seek empirical relationships between behavioural characteristics such as swelling and simple index tests such as Atterberg limits and grain size distribution.

The relationships between strength and the swelling process are part of a larger picture which relates consolidation stress history, weathering, stress changes during loading, pore water pressures during loading and other factors which are beyond the scope of this study. However, the essential features pertinent to this study is reliance upon direct measurement of strength after the clay has been permitted to swell rather than indirect correlations.

Another characteristic closely associated with swelling is disintegration when subjected to wetting and drying cycles. Slaking and dispersion are associated with the disintegration. Although this behaviour occurs in all clays, it is of greater interest to geotechnical engineers in the case of clay shales (3).

In oil well engineering, shale formations are recognized for their tendency to be unstable and to hydrate and to disperse in the presence of water. Brittle or sloughing shales are one class of instability problem which is due to mechanical and hydraulic fracturing; however, in the context of this paper it is the hydratable or swelling shales which are of interest. When drilling with fresh water or fresh water mud, these shales hydrate and become entrained in the mud, adding to the viscosity and creating problems of bit balling, mud rings, plugged flow lines, plugged shale shakers and high solids content. The ensuing enlargement of the wall bore promotes caving of the overlying formation.

Hydration is defined in the oil well context as the process of reabsorption of water which was expelled from the clay shale due to high stresses during the compaction period. This process takes place as a result of the stress relief adjacent to the borehole.

Once a shale has swelled by hydration the particles are less tightly bound. Those on the surface slake off, aided by hydraulic or mechanical erosion in some cases. This is known as dispersion. Amounts of swelling and dispersion are often, but not necessarily, proportional (5).

In coal mining, mudstones, shales and seat earths have been identified as subject to disintegration or weathering. Artler (14) describes a fireclay below the coal and a clay shale layer above it which weather - become soft and disintegrate - when exposed to moist air, especially in summer when the air is warm. Taylor and Spears (12) describe strata breakdown by uptake of water, aided by the laminations, bedding planes, shear planes and other structural features which permit ingress of water and permit swelling to be concentrated in mixed-layer clays. The oxidation of pyrite, accompanied by swelling, is also cited as being a contributing factor in breakdown.

A study of the Illinois Basin, by Rockaway (15), describes briefly the cyclothem and the environment in which "underclays" (seat earth, seat rock, ganister, fireclay) are deposited. It is hypothesized that the underclay was laid down in shallow fresh water, such as a delta. Typically it is composed of clay minerals, is slickensided, irregularly fractured and contains traces of plant roots (16). In addition, the clay mineralogy is quite varied. Thicknesses vary, usually being 1 to 2 m, but occasionally up to 10 m. The lower boundary is gradational with the underlaying shale, limestone or sandstone. They are described as lacking bedding, but do have a vertical zonation: the upper zone being carbonaceous and leached of calcium and iron, seldom more than 25 cm thick; the next being more highly plastic and free of carbonates; the lower being generally less plastic, enriched in iron compounds and carbonates, with limestone or iron carbonate nodules and pyrite often being found.

Fractures, fissures and slickensides are the main structural features. Rockaway (15), points out that these directly affect the bearing capacity of underclays below pillars by mechanicallly weakening the mass.

The studies reported by Rockaway (15) show that the characteristics of the underclay vary greatly both horizontally and vertically, and conclude that

"... it is evident that significant changes in thickness, lithology and induration take place over short distances ...". The significance of this observation is that data obtained in one specific location could be inadequate in other nearby areas of the same mine.

The moisture adsorption and swelling behaviours of a coal mine shale are described by Chugh et al. (17). A 75% illite/mixed layers, 25% kaolinite clay was tested in different conditions of humidity. Results demonstrated a substantial gain in moisture content of 4.1% and fourfold loss in strength as the ambient conditions change from the natural state to full immersion in water. The report also shows that moisture adsorption occurs over relatively short distances from the free surface but this is sufficient to cause real swelling problems because of moisture migration into the rock mass along fractures.

Effects of Swelling

The effects of swelling referred to above fall into three categories:

volume increase (squeezing of well bores and tunnel walls)
dispersion and sloughing
strength degradation

A corollary to swelling is swelling pressure, which develops where swelling is physically restrained but where chemically-induced swelling processes are acting.

Examples of volume increase have already been discussed in preceding sections.

Dispersion and sloughing are commonly cited in the literature, but specific examples have not been found in the present study.

Examples of loss of strength due to the adsorption of water for a selection of clay shales are given by Chenevert (18). In all cases, uptake of a few percent of water caused substantial strength reductions.

Swelling pressures in clays can be very large and Chenevert (18) shows an example where the pressure required to prevent swelling reached 35 MPa in an illite clay shale.

CHEMICAL STABILIZATION

In both oil well and civil engineering practice, soil and rock formations are treated in situ to improve their characteristics. Treatments are generally divided into two types: i) additives which produce a cement or gel in the voids (such as cement grout) and ii) additives which react with the soil particles to improve strength, reduce hydration and swelling and reduce dispersion of particles.

The treatment methods in the first category, which produce cements or gels in the voids, are not considered further in this report for the following reasons:

> Some of these agents are introduced by grouting methods. Penetration of pumped grouts is limited by the grout pressure that can be used and for underground applications pressure grouting seems entirely inappropriate.
>
> Other methods require intimate mixing of stabilizing agent with the soil by mechanical means. This is most common in highway and airfield construction. This again seems entirely inappropriate for mining purposes.

In the second category, the treatment methods all, in one way or another, rely upon the surface chemistry of the clay fraction of the soil. The use of chemicals to stabilize problems in oil well drilling and production is widely reported in the literature. A wide variety of materials are used, depending on local availability and other factors.

To a much lesser extent, chemical clay stabilization has been used in civil engineering. Clay soil stabilization with lime ($Ca(OH)_2$) has been described in connection with highway, rail and airport construction to improve roadbeds and bearing layers. The principle is the replacement of exchangeable cations (usually sodium) by calcium, resulting in flocculation and an increase in strength.

Wagener et al. (19) describe the use of gypsum ($CaSO_4 2H_2O$) to stabilize dispersive clay which occurs in the floor and embankment of a reservior in South Africa. The principle of the application was to replace the highly exchangeable sodium percentage which produces loose bonding between clay platelets with calcium, which will bond the platelets strongly and prevent dispersion. The gypsum was introduced both by direct application and as in a solution in the reservoir water.

Sydansk (20) reports the use of potassium hydroxide to stabilize clays. In laboratory tests, treatment effectiveness was found to depend on concentration, formation temperature and contact time. A 15% by weight aqueous solution of KOH and 16 hours contact time was found to "permanently alter the clay chemistry and render the clay insensitive to fresh water.

Hydraulic fracturing of impervious formations employing a combination of gels and other compounds, as well as potassium chloride (KCl) to stabilize the clays, is a well established technique (21, 22, 23, 24). KCl has also been used to stabilize shale intervals by cleaning drill holes using KCl concentrations of between 3 and 5% by weight in water (25).

Lauzon (26) notes that the best chemical treatment not only inhibits swelling of water-sensitive shales but must also adsorb quickly and prevent dispersion of fines. Chemicals that inhibit swelling most readily will show charge neutralization in dilute zeta potential experiments.

Thompson et al. (27) describe Cla-Ban, a proprietary polymer additive. Williams and Underdown (28) discuss new polymers for permanent clay stabilization. Laboratory studies of Polyamines (PA), polyquaternary amines (PQA) and polyacrylamides show the first two provide the best stabilization. As little as 2% PA or PQA is effective in maintaining permeability gained after acidation.

Roehle and Hackett (29) describe laboratory techniques for testing shale-swelling inhibitors. They report polyacrylamides had little effect on a smectite-kaolinite shale.

Minton (30) discusses drilling fluids used in drilling North Sea Tertiary shales. A sea water/KCl/polyacrylamide mixture is used for "hydratable" smectite and illite clays.

Hill (31) reports that cation exchange capacity of the clay is useful for predicting the concentrations of clay control additives. The CEC can be easily determined by adsorption of methylene blue and by sodium ion exchange with ammonium acetate.

Thomas and Crowe (32) refer to the use of fluoboric acid to reduce CEC and hence enhance stability.

Penkov and Levik (33) report successful clay stabilization with gypsum-potassium muds with pH 8.5 - 9.5, 1000 - 2000 mg Ca^{++} and 5000 - 15000 mg K^{+}/litre.

Drilling fluids consisting of oil and oil water emulsions (oil-base muds) are reportedly effective. However, applications underground with oil or oil water mixtures do not appear attractive and have not been pursued in this report.

Zeinalov et al. (34) also describe gypsum mud, with a recommended Ca concentration of 900-1100 mg/l.

MacLauchlin (35) describes a class of agents known as surfactants which impart oil wetness to the clay surface so that water will not wet it. This treatment will, in principle, deal effectively with humid air or dust-laying water; however, it will have no effect on swelling by uptake of formation water. Organic amine surfactants act by the attachment of nitrogen atoms at the cation exchange sities of the particle or layer surface.

What emerges from these reports is that a small variety of water-based chemical additives have been used repeatedly, with success, primarily potassium salts, inorganic polymers and organic polymers. However, a variety of other chemicals can also be used.

Potassium

As a dissociated cation in an electrolyte, potassium will displace the sodium or calcium on the clay surface and because of its extremely low hydrational energy and high bonding energy will initiate dehydration of the platelets. The potassium ion causes the clay plates to be pulled closer and closer together meanwhile forcing out the attached water molecules. The smaller diameter of the potassium ion allows the contraction to continue until the clay lattices and layers reach minimal dimensions.

O'Brien and Chenevert (5) recommend testing to determine the effectiveness of inhibitive fluids, although as a guide, KCl concentrations in water at between 3 to 5% for illites and 10% for montmorillonites are suggested.

KOH may be used for alkalinity control. Maintaining pH levels in the 10-12 range will reduce the level of corrosion. Foaming can be a problem with KCl concentrations above 5%. A defoamer, such as IMCO "Defoam-L" should be used. Potassium is available as nondispersed KCl, dispersed KCl, KOH-lignite and KOH-lignosulphonate. Nondispersed KCl is seldom used at concentrations above 4%. KOH is desirable when high Cl-ion concentration is objectionable.

Potassium test strips are used much like litmus paper and will measure concentrations between 300 and 1000 ppm. They are easy to use and relatively accurate.

Polymers

MacLaughlin et al. (35) note that sodium clays are the major source of swelling in rocks or soils. A successful method of treatment is replacement of the Na^+ by K^+, Ca^{++} or NH_4^+ ions. The sodium ion hydrates to many times its size, while the others do not; thus there is less swelling. However, this is temporary protection in oil field production, since sodium ion from the formation water quickly replaces the ion induced from the drilling fluid. Therefore, for long-term stability during hydrocarbon production, polymers are advocated.

A new series of polymer materials has proved to be effective in treating water sensitive formations. These polymers adsorb tenaciously to the surfaces of clay minerals and other formation fines, via multiple ionic attachments, helping to prevent clays from swelling and fines from migrating should foreign water be introduced into the formation. The polymers win easily in competition with other simple ions (such as ammonium, calcium or potassium) for being deposited on clay surfaces. Furthermore, once deposited on clay surfaces, the polymers are not easily replaced by exchange with other ions. Subsequent acidizing treatments cause no detectable harm to the ability of the polymers to protect the clay.

Inorganic Polymers

Inorganic polymers such as hydroxyl aluminum and zirconium oxychloride provide stable treatment materials. Many cations are united in a complex structure in the polymer and these fill many cation exchange sites on the particle or layer surface. The resulting product is difficult to dislodge. Mildly acidic conditions (pH 4 to 5) are necessary to keep the chemical in solution, and acid treatment of the clay can remove these polymers. The pH control of mine water is therefore indicated, which may not be possible in circumstances where carbonates in the stratum may interfere with the reactions (35).

Peters and Stout (6) report successful results with zirconium salts, which in water produce hydrolyzed polynuclear ions that perform as ions of much higher charge.

Coppel et al. (36) describe results from wells treated with hydroxy-aluminum, which they refer to as slightly acidic, nonhazardous, colorless, odorless, nontoxic and requiring no unusual handling procedures. Laboratory evidence is that polymerization on the clay mineral surfaces takes place rapidly during the first few hours and becomes slower after about 12 hours.

Both the zirconium and hydrolyzed aluminum were used in the cases reported by Peters and Stout (6) and Coppel et al. (36) to control dispersion and maintain or improve well production rates. Although swelling and dispersion are often described as to manifestations of the same clay-cationic reactions, it may be that these chemicals are less effective in swelling control than in preventing dispersion.

Organic Polymers

Certain organic polymers have been found to be effective and long lasting for treating exposed surfaces of clays. They are characterized by multiple nuclei or groups which can react with cation exchange sites on the particle or layer surfaces. The result is a connected assembly of ionic nuclei (rather than cations) linked together like a chainlink fence.

Organic polymers are not acidic nor do they require an acidic pH whilst in solution. Carbonate components in the clay have no effect. The organic polymers can be used with solutions of NH_4Cl, KCl, $CaCl_2$ and HCl, all of which are themselves used as clay stabilizing agents (35).

The organic polymer can be mixed by simply stirring it into clear water. Quantity and concentration have to be determined for each given clay to be treated.

POTENTIAL APPLICATIONS IN COAL MINES

The foregoing review has pointed to two swelling mechanisms:

swelling due to stress relief (rebound)
swelling due to ion exchange

In the underground mine situation, two possibilities can then be identified:

- polymers which seal the surface to which they are applied, thus limiting swelling to that associated with uptake of formation water.

- cation treatments which prevent or inhibit ion exchange related swelling, thus limiting swelling to that associated with stress relief: the water may be either formation water or mine water.

It would seem that rebound is difficult to prevent because stress relief and formation water are largely unavoidable; however, there is a possibility that the right kind of cation used as a treatment could actually prevent rebound (and potentially strengthen the clay shale).

The principal questions to be addressed in using chemical treatments in coal mines are:

1. What is the goal of the treatment - to stabilize in situ material, to improve it or to minimize degradation?
2. What chemical treatments would provide the best results?
3. How much chemical should be used and how can it be applied?
4. What are the environmental consequences?
5. How permanent is the treatment?

These questions cannot be answered solely from a literature review. It is clear that the underground moisture environment and details of the softening process, to name only two questions, need clarification and that in situ studies should receive a high priority in any future work.

Toxicity and Costs

Application of the shale stabilizers in the mine environment will expose the miners to any hazardous characteristics of the chemicals which must also be considered as criteria in the selection process.

The safety characteristics of some shale stabilizers are summarized in Table 1. Only two of the products are classified as hazardous and most are general food additives. It is recommended, however, that Material Safety Data Sheets be requested when purchasing a specific chemical.

The cost of oil well chemicals is dependent upon availability, demand, packaging, format and size of the purchase. Most suppliers are reluctant to quote price verbally, stating that prices are negotiable. One supplier did give prices for several products, but states that these may be variable with a firm order.

This review indicates that potassium is the primary form of cation treatment, with calcium a somewhat distant second, although calcium in the form of lime is quite clearly cheap and nontoxic. These are obvious first choices for chemicals to test. In the polymer field, proprietary products such as Haliburton's Sta-Cla and Technifluids's SS-100 polyacrylamide are candidates. The other materials referred to have not been described in the literature we have reviewed and some further inquiries are called for.

CONCLUSION AND FURTHER WORK

The study has shown that the transference of oil well clay stabilization technology to the problems encountered with swelling clay floors in coal mining is worthy of pursuit. Results of the literature review suggest that potassium treatment is the preferred method, due to its availability as KCL, with calcium a distance second although it is cheap and non-toxic.

Before a definitive answer to the applicability of this technology to coal mining can be given, knowledge of underground moisture conditions and details of the softening process require clarification and these questions should be addressed in conjunction with laboratory determination of the properties and effects of the various chemicals available. It is not anticipated that laboratory tests would give an absolute assurance that any selected treatment would work in the mine due to the wide differences in laboratory and mine conditions. However, realistic comparative test results would be obtained, or benefit to future in situ trials of the chemical swelling inhibitor.

As a result of the success of this work in confirming that the technology is appropriate, a laboratory test programme comprising the physical properties testing of a range of seat earths from the Sydney Coalfield will be initiated. The programme will include the treatment of seat earths with a range of chemicals and the determination of the effects of these chemicals on the degradation of the test specimens with the aim of identifying the most appropriate treatment method and applicable chemical concentrations.

Table 1 - Shale stabilizers safety data

Product/ Supplier	Chemistry	Hazardous Ingredients	Hazardous Decomposition Products	Health Hazard Data	Fire and Explosion Data	Special Precautions	Incompatibility	Hazard Class	Comments
Calcium Chloride NL Baroid	$CaCl_2$	None	None	Eye and skin irritation	Non combustible	Avoid eye & prolonged skin contact	Corrodes metal	Not hazardous	A food additive
Gypsum NL Baroid		None	None	Nuisance dust	Non combustible and explosive	None	None	Not hazardous	
EZ Mud NL Baroid	Polyacrylamide Polyacrylate	None	None	May cause eye & skin irritation	Flash point 200°F. Extinguish with chemical foam	Do not take internally Avoid skin & eye contact Causes slippery floors	None	Not hazardous	A food additive
Potash NL Bariod	KCl	None	None	Minor skin, inhalation, gastro-intestinal, severe eye irritant	Non combustible or explosive does not support combustion	Avoid prolonged eye & skin contact	None	Not hazardous	
Stabil Hole Dresser-Magcobar	Naturally occurring asphalt	None	CO_2,CO	Fumes, dust may irritate eyes & upper respiratory tract, may photosensitize skin	Flash point 700°F. Extinguish with water, fog, CO, dry chemical	Avoid prolonged eye and skin contact	None	Not hazardous	
Percol 156 Dresser-Magcobar	Anionic Polyacrylamide	None	None	Slight skin and eye irritant	Flash point 100°C will support combustion	Avoid prolonged eye and skin contact	Cationic polymers	Not hazardous	A food additive

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