EVALUATION OF TECHNIQUES FOR PREVENTING ACIDIC ROCK DRAINAGE
FINAL REPORT

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EVALUATION OF TECHNIQUES FOR PREVENTING ACIDIC ROCK DRAINAGE

Final Research Report

by

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EXECUTIVE SUMMARY

The management of waste rock produced from mining of sulphitic ores poses a challenge to the mining industry. Acid generation occurs when sulphide minerals (principally pyrite and pyrrhotite) contained in the rock are exposed to air and water. In the absence of sufficient alkaline or buffering minerals, the resulting leach water becomes acidic, and is characterized by high sulphate, iron and metal concentrations. This water, sometimes called acid rock drainage (ARD), can contaminate surface water and ground water courses, damaging the health of plants, wild life, fish and, possibly, humans.

A study was initiated by Noranda Technology Centre (NTC) and the Centre de recherches minérales (CRM) to evaluate the relative effectiveness of various techniques for controlling ARD in waste mine rock. This study was undertaken at NTC as part of the MEND (Mine Environment Neutral Drainage) Program. The techniques investigated were water cover, soil cover, wood bark cover, and addition of limestone and phosphate rock (apatite).

Potentially acid-generating waste rock samples used in the investigation were obtained from the Stratmat site, located on the Heath Steele Mine property, near Newcastle, New Brunswick, and from Les Mines Selbaie, located near Joutel, Québec. Both types of rock samples were crushed to particle sizes between 25 and 50 mm. The investigation involved outdoor lysimeter tests and indoor or laboratory column experiments. Cover techniques investigated were a 1 m water cover, a soil cover consisting of a 150 mm thick water-saturated clay layer sandwiched between two 75 mm thick sand layers, and a 150 mm thick wood bark layer. Limestone and phosphate were added at 1 and 3% dosages. Control experiments, using waste rock without cover and additive, were also installed for comparison. The outdoor tests were subjected to natural weather conditions (rain, freeze-thaw and evaporation). The laboratory or indoor tests were run at an average temperature of 20°C and subjected to a cycle of 8 weeks of dry conditions and 8 weeks of wet conditions (water addition). Water was added to simulate the average annual precipitation for a nearby municipality, Dorval, Québec. All tests were conducted in triplicate.

Monitoring of the effluent water quality to three years (154 weeks) indicated the control waste rock started producing acid very early in the tests (about the 5th week). The rate of acid production was quantified (mg of $CaCO_3$ per day per kilogram of rock) and found to be higher in the laboratory than outside. Higher laboratory temperatures are most probably responsible for the higher rate. The Stratmat rock generated acid at a higher rate than the Selbaie rock, although the latter has a higher pyrite content. A detailed post-testing investigation of the two rock types was conducted at The University of Western Ontario, using mercury intrusion porosimetry, surface analytical techniques and x-ray fluorescence and diffraction methods. The results indicate the fresh, unoxidized Stratmat and Selbaie rocks have a similar pore structure, but different gangue mineralogy. The Stratmat rock consists of pyrite and minor amounts of metal sulphides held in a matrix of silicate minerals including illite and feldspar. The Selbaie rock, on the other hand, contains mainly pyrite and quartz. Trace amounts of metal sulphides appear to be in solid solution with the pyrite. Results of accelerated

leaching tests clearly showed that the gangue composition of the Stratmat rock has a major influence on its acid generation ability and would explain the difference in acid production between the Stratmat and Selbaie rocks.

Water cover was found to be the most effective control technique during the three years of indoor testing, followed by 3% and 1% limestone, soil cover and, finally, 3% and 1% phosphate. The effectiveness of the various techniques observed in the outdoor tests were as follows: water cover, 99%; 1% limestone, 93%; soil cover, 70%; and 1% phosphate, 9%. 10-15% increase in effectiveness was observed (from 83 to 98%) when the amount of limestone added to the rock was increased from 1 to 3%. A similar increase in the amount of phosphate yielded higher effectiveness, from 10 to 70%. All the techniques, with the exception of the water cover, were found to be slightly more effective in the laboratory than outside. The water cover maintained the same effectiveness (> 99%) in both laboratory and outside tests. The soil cover was more effective in the laboratory (98%) than outside (70%). The difference may be explained by the effects of adverse natural climatic conditions (for example, freezing and thawing) which were not present in the laboratory. It is also believed that oxygen and water enter the soil covered waste rock mostly by the side walls of the lysimeters. The phosphate was found to contain some carbonate mineral (calcite) which probably delayed acid production (at the 3% dosage) for some time. An increase in acidity and a decrease in pH were observed in both the Stratmat and Selbaie rocks when all the calcite was presumably consumed. It should be noted that the relative effectiveness of the different techniques is likely to change with time, due to depletion of alkalinity or phosphate materials.

The wood bark accelerated acid production by about 60% in the laboratory and 500% outside. The role of the iron oxidizing bacteria *(Thiobacillus ferrooxidans)* was invoked to explain this acceleration. This was confirmed when a bactericide (0.02% thymol solution), added to the wood bark cover, reduced acid generation considerably. The iron oxidizing bacteria are mostly autotrophs (that is, they require inorganic carbon for their metabolism), and would become more active by using CO_2 produced from fungal decomposition of the wood bark. Other heterotrophic iron oxidizing bacteria would use organic carbon from the wood bark for metabolism. Thus, a wood bark cover is not considered a good technique for reducing acid generation in sulphide-bearing waste mine rock.

The water covered waste rock began to release low concentrations of metals (zinc, iron and lead) after two and a half years of operation. The delay in metal release may be attributed to the presence of trace amounts of alkaline minerals which were probably depleted after the initial two and a half years. The results of the study thus far indicate that, although a water cover may not completely prevent oxidation, it will reduce acid generation considerably. In fact, when considering both feasibility and efficiency, it is the most promising ARD control technology known to the industry. The rate of oxidation is decreased in two important ways: first, the oxidation will begin much later if fresh rock is covered (two and a half years in this case), and second, the oxidation will continue at a considerably reduced rate, due to the oxygen diffusion barrier the water presents. The delay before oxidation begins is probably proportional to the neutralization potential of the rock. If oxidized waste rock is covered with a layer of water, it is likely that the alkaline materials will be depleted and that the oxidation will begin immediately.

The effectiveness of the water cover may be enhanced by increasing the depth of the water or applying an organic layer on top of the waste. With an organic layer, the oxygen may be consumed by biodegradation before it can reach the sulphides. The practical implementation of a water cover scheme presents some other questions (for example, maintaining the required depth of water and long-term stability of holding structures) which still have to be addressed through hydrological and engineering studies. Laboratory studies such as this one are also necessary to address initial uncertainties prior to implementation.

SOMMAIRE

Le traitement de la roche stérile produite par l'exploitation de gisements sulfureux pose un défi à l'industrie minière. Lorsque les minéraux sulfureux (principalement la pyrite et la pyrrhotine) contenus dans la roche sont exposés à l'air et à l'eau, ils produisent de l'acide. En l'absence d'une quantité suffisante de minéraux alcalins ou neutralisant, l'eau de drainage devient acide, et est caractérisée par de concentrations élevées de sulfate de fer et de métaux lourds. Cette eau acide peut contaminer l'eau de surface et les eaux souterraines, et nuire à la santé de la flore, de la faune terrestre et aquatique et, possiblement, à celle des humains.

Le Centre de technologie Noranda (CTN), en collaboration avec le Centre de recherches minérales (CRM), a entrepris une étude en vue d'évaluer l'efficacité relative de diverses techniques de réduction du drainage acide produit par la roche stérile. Cette étude a été réalisée au CTN dans le cadre du programme NEDEM (Neutralisation des eaux de drainage dans l'environnement minier). Les techniques étudiées comprennent les couvertures aqueuses, les barrières géologiques, les recouvrements d'écorce, ainsi que l'ajout de calcaire et de phosphate (apatite).

Des échantillons de roche stérile susceptible de produire de l'eau acide ont été obtenus du site Stratmat de Heath Steele, près de Newcastle, au Nouveau-Brunswick, et du site Les Mine Selbaie, près de Joutel, au Québec. Les deux types de roche stérile ont été broyés à une grosseur de particules de 25 à 50 mm. L'étude comprenait des essais extérieurs en lysimètres, ainsi que des essais en laboratoire (colonnes). Les expériences ont porté sur une couverture aqueuse de 1 m, une barrière géologique composée d'une couche d'argile de 150 mm, saturée d'eau, entre deux couches de sable de 75 mm, et un recouvrement de 150 mm d'écorce de bois. Des quantités de calcaire et de phosphate ont été ajoutées en doses de 1 et 3 %. Des essais témoins, c'est-à-dire de la roche stérile sans recouvrement et sans additif, ont également été installés pour fins de comparaison. Les essais réalisés à l'extérieur ont été soumis aux conditions climatiques naturelles (pluie, gel-dégel, et évaporation). Les essais en laboratoire ont été réalisés à une température moyenne de 20°C et soumis à un cycle de 8 semaine en condition sèche, et de 8 semaines en condition humide (ajout d'eau). L'eau a été ajoutée pour simuler la précipitation annuelle moyenne dans une municipalité avoisinante, soit Dorval, Québec. Tous les essais ont été réalisés en triple.

La surveillance de la qualité de l'effluent, qui s'est échelonnée sur une période de trois ans (154 semaines), a révélé que la roche stérile dans les essais témoins commençait à produire de l'eau acide très tôt (vers la cinquième semaine). On a déterminé le taux de production d'acide (mg de $CaCO_3$ par jour par kilogramme de roche); ce taux était plus élevé en laboratoire qu'à l'extérieur, ce qui est probablement dû à la température plus élevée à l'intérieur. La roche de Stratmat produisait de l'acide plus rapidement que la roche de Selbaie, même si cette dernière présentait une teneur cinq fois plus élevée en pyrite. Une étude détaillée des deux types de roches a été réalisée après les essais à l'Université de Western Ontario, par porosimétrie au mercure et à l'aide de techniques d'analyse de surface et de méthodes de fluorescence et de diffraction X. Les résultats indiquent que les roches fraîches et non oxydées de Stratmat et de Selbaie possèdent une structure de pores semblable mais une minéralogie de gangue différente. La roche de Stratmat est constituée de pyrite et de quantités moindres de sulfures métalliques dans une matrice de

minéraux silicatés comprenant l'illite et le feldspath. Par contre, la roche de Selbaie contient surtout de la pyrite et du quartz. Il semble y avoir des traces de sulfures métalliques en solution solide avec la pyrite. Les résultats des essais de lixiviation accélérée montraient clairement que la composition de la gangue de la roche de Stratmat influait considérablement sur sa capacité de production d'acide, ce qui expliquerait le taux différent de production d'acide de la roche de Stratmat et de la roche de Selbaie.

La couverture aqueuse s'est avérée la technique la plus efficace lors des essais réalisés à l'intérieur sur une période de trois ans. Venaient ensuite l'ajout de 3 % et de 1 % de calcaire, la barrière géologique et finalement l'ajout de 3 % et de 1 % de phosphate. Voici les taux d'efficacité des diverses techniques observés lors des essais à l'extérieur: couverture aqueuse, 99 %; ajout de 1 % de calcaire, 93 %; barrière géologique, 70 %; et ajout de 1 % de phosphate, 9 %. Il y avait accroissement de 10 - 15 % de l'efficacité (qui passait de 83 % à 98 %) lorsque la quantité de calcaire ajoutée à la roche était augmentée de 1 à 3 %. Un accroissement semblable de la quantité de phosphate se traduisait par une efficacité accrue qui passait de 10 % à 70 %. Toutes les techniques, à l'exception de la couverture aqueuse, étaient légèrement plus efficaces en laboratoire qu'à l'extérieur. La couverture aqueuse était aussi efficace (› 99 %) en laboratoire qu'à l'extérieur. La barrière géologique était plus efficace en laboratoire (98 %) qu'à l'extérieur (70 %). Les effets des conditions climatiques naturelles défavorables (par exemple, gel et dégel), qui sont absents lors des essais en laboratoire, peuvent expliquer cette différence. L'oxygène et l'eau, croit-on, pénètrent dans la roche stérile protégée par la barrière géologique, en passant surtout par les parois latérales des lysimètres. Il y avait dans le phosphate une certaine quantité de minéraux du groupe des carbonates (calcite), ce qui a probablement retardé pendant un certain temps la production d'acide (dans le cas de l'ajout de 3 % de phosphate). On a observé une augmentation de l'acidité et une diminution du pH dans les roches de Stratmat et de Selbaie, lorsque toute la calcite, du moins le suppose-t-on, avait été consommée. Il y a lieu de noter que l'efficacité relative des différentes techniques risque de changer avec le temps, en raison de la diminution de l'alcalinité ou de l'épuisement des substances phosphatées.

Dans le cas d'un recouvrement d'écorce, la production d'acide était accrue d'environ 60 % en laboratoire et de 500 % à l'extérieur. On a invoqué le rôle des ferrobactéries (*Thiobacillus ferrooxidans*) pour expliquer cette production accrue. Ce fait a été confirmé par la réduction considérable de la quantité d'acide produite après l'addition d'un bactéricide (solution contenant 0,02 % de thymol) à l'écorce. Les ferrobactéries sont surtout autotrophes (c.-à-d. qu'elles ont besoin de carbone inorganique pour leur métabolisme) et deviendraient plus actives en utilisant le CO_2 produit par la décomposition fongique de l'écorce. D'autres ferrobactéries hétérotrophes utiliseraient le carbone organique dans l'écorce pour leur métabolisme. Un recouvrement d'écorce ne constitue donc pas, estime-t-on, une bonne technique pour réduire la production d'acide par les roches stériles sulfurées.

Après deux ans et demi, de faibles quantités de métaux (zinc, fer et plomb) commençaient à se dégager des roches stériles recouvertes d'une couverture aqueuse. Le temps nécessaire à l'apparition de ce phénomène peut être attribué à la présence de traces de minéraux alcalins qui étaient probablement épuisés après la période de deux ans et demi. Selon les résultats de l'étude obtenus jusqu'ici, la couverture aqueuse, même si elle ne prévient pas complètement l'oxydation, permet de diminuer considérablement la quantité d'acide produite. En fait, du point de vue rentabilité et efficacité, il s'agit, pour l'industrie, de la technique la plus prometteuse de réduction du drainage acide. Le taux d'oxydation est réduit de deux façons importantes: d'abord, l'oxydation commencera beaucoup plus tard si la roche fraîche est recouverte (deux ans et demi dans le présent cas), puis l'oxydation se poursuivra à un taux considérablement moindre, en raison de la barrière de diffusion de l'oxygène que constitue l'eau. La durée de la période qui précède le début de l'oxydation est probablement proportionnelle au potentiel de neutralisation de la roche. Dans le cas d'une roche stérile oxydée que l'on recouvre d'eau, les substances alcalines seront probablement épuisées et l'oxydation commencera immédiatement.

On peut améliorer l'efficacité de la couverture aqueuse en augmentant l'épaisseur de la couche d'eau ou en appliquant une couche organique sur les roches stériles. En présence d'une couche organique, l'oxygène sera utilisé par le processus de biodégradation, avant d'atteindre les sulfures. L'aspect pratique de l'application d'une couverture aqueuse comporte certaines autres questions (par exemple, maintien d'une couche d'eau d'épaisseur appropriée et stabilité à long terme des structures nécessaires au maintien de cette couche) qu'il faudra résoudre par l'exécution d'études hydrologiques et ingénieries. Avant de mettre cette technique en application, il faudra également procéder à des études en laboratoire, comme celle-ci, pour résoudre les incertitudes initiales.

1.0 INTRODUCTION AND OBJECTIVES

1.1 Background

The management of waste rock produced from mining of sulphitic metal and uranium ores poses an environmental challenge to mining companies. Acid generation occurs when sulphide minerals (principally, pyrite and pyrrhotite) contained in the rock are exposed to oxygen and water. The primary step is the oxidation of the sulphide minerals, and subsequently the leaching of oxidized products, as rainwater and snow-melt enter the waste pile or dump. If sufficient alkaline or buffering minerals (for example, calcite) are not present to neutralize the acid, the resulting leach water becomes acidic. This water, generally known as acid rock drainage (ARD) is characterized by low pH and high concentrations of sulphate and dissolved iron and metals. If ARD is not collected and treated, it could contaminate ground water and local water courses, damaging the health of plants, wildlife, fish and, possibly, humans. Canada's current inventory of potentially acid-generating waste rock is more than 1 billion tonnes with an estimated rehabilitation cost of $3.5 billion (Wheeland and Feasby, 1991) using current technologies.

The overall sulphide oxidation process, using pyrite as the example, can be represented by the following reaction:

$$FeS_2(s) + \frac{15}{4}O_2(g) + \frac{7}{2}H_2O(l) \rightarrow Fe(OH)_3(s) + 2SO_4^{2-}(l) + 4H^+ \qquad [1]$$

The ultimate solution to the ARD problem is to prevent its formation. Since the generation of ARD is dependent on oxygen and water coming in contact with the sulphide minerals, almost all prevention and control techniques are based on excluding oxygen and water from the waste pile. Traditional prevention techniques have included disposal in open pits, flooding, and application of engineered soil covers. Complete prevention of ARD formation is almost impossible; therefore, one or several control methods (such as treatment) are used at nearly all mine operations, and inactive sites still generating ARD. The most commonly used treatment method is neutralization of ARD by reacting with an alkaline reagent (for example, sodium carbonate, sodium hydroxide, limestone and lime). Although lime is used more frequently because of its low cost and higher reactivity, a voluminous sludge is produced which, in turn, requires environmentally acceptable disposal. Limestone is cheaper and produces a denser sludge; it is, however, less effective at high pH levels (> 7) because of rapid depletion. In some cases, a two-stage treatment with limestone followed by lime has been employed (Shimoiizaka *et al.*, 1971; Veta *et al.*, 1972) in order to obtain the advantages offered by both reagents.

At operating mine sites where waste rock is stored in a pile prior to decommissioning, some attempt is made to either prevent or minimize acid generation through direct application of crushed limestone. Other ARD prevention measures have included the application of bactericides, use of organic substrates (wood chips, sawdust, etc.) to promote the growth of sulphate reducing bacteria, and use of rock phosphate (apatite). Although each of these techniques could reduce acid generation to some extent, there is no adequate information on their effectiveness.

1.2 Objectives and Scope

A project was initiated in 1991 by Noranda Technology Centre (NTC) and Centre de recherches minérales (CRM) to evaluate the relative effectiveness of various ARD prevention and control measures. The project was undertaken as part of the MEND (Mine Environment Neutral Drainage) program. MEND is a tripartite Canadian research consortium whose goal is to develop reliable and affordable technologies for decommissioning of sulphitic mine wastes. MEND participants include the Canadian mining industry and the federal and provincial governments. A detailed description of the program is presented by Wheeland and Feasby (1991).

The project consisted of a combined field and laboratory investigation. Measures or techniques investigated were: covering with compacted clay, covering with wood bark, mixing with crushed phosphate rock, mixing with crushed limestone, and covering with water. Background control tests (with no application of any prevention and control measures) were also established for comparison. A secondary objective of the study was to collect comprehensive data on effluents to permit geochemical modelling. It was believed that such modelling would enhance the value of the anticipated results by providing a greater understanding of the chemical processes controlling the effluent solution composition. Such understanding will enable the mining industry to apply any of the measures with confidence.

This document constitutes the final report on the project. The main body presents a summary of the geology, mineralogy and geochemistry of the rock samples used, a detailed description of the experimental protocol and detailed results for each the techniques tested at the Noranda Technology Centre. Appendix A presents the complete drainage water chemistry. In Appendix B, a detailed description of the post-testing characterization, performed by the University of Western Ontario, is presented. Initial geochemical and mineralogical analyses and preliminary aqueous speciation modelling conducted by McGill University are included in Appendix C. The Centre de recherches minérales performed parallel mineralogy of the rock samples and the additives during the installation of the experiments and the results are presented in Appendix D. Information from all the appendices are integrated in the presentation and discussion of results in the main body and in Appendix B.

2.0 REVIEW OF ARD CONTROL TECHNIQUES

2.1 Factors Controlling ARD Generation

The generation of ARD may be prevented or reduced by excluding one or more of the principal ingredients involved in the sulphide oxidation process. The principal ingredients are: (i) wastes containing reactive sulphide, (ii) oxygen, and (iii) water. In practice, the first stage of the oxidation reaction would not proceed and no acid generation would occur without these components. Other factors influencing acid generation, in terms of the rate of production, include bacterial activity, temperature, pH and the presence of buffer or alkaline minerals. Acid generation can also be reduced by controlling the environment at source in order to retard the rate of production to an insignificant level. If sulphide minerals in waste rock cannot be removed or isolated (say, by means of a coating), exclusion of oxygen and water and control of pH become the principal methods of reducing or controlling ARD generation.

2.2 Water Cover

The purpose of a water cover over sulphitic wastes is to exclude gaseous oxygen. The effectiveness of a water cover is based on the fact that the solubility and diffusivity of oxygen in water are both low. The dissolved oxygen concentration in natural waters is only 11 mg/L at 10°C (Truesdale *et al.*, 1955) and the diffusion coefficient of oxygen is 10,000 times less in water than in air. This means that the rate of oxygen transported through water is sufficiently slow to be of no significance in acid generation. However, care must be taken when considering placing old sulphitic wastes, that have previously generated acid, below water. Oxidized or acid products may dissolve and become mobilized.

Major factors influencing the application of a water cover include the availability of water and the cost of maintaining the required depth of water in the long term. The cover may be achieved by the disposal of wastes into natural water bodies, into engineered impoundments (such as dams or dykes) or into flooded underground mine workings and open pits (Steffen, Robertson and Kirsten, 1989). Two factors have to be carefully evaluated in the use of flooded open pits for waste disposal: exposure of pit walls and hydrogeologic containment.

2.3 Soil Covers

Soil covers are placed over mine wastes to reduce oxygen diffusion and water infiltration. The effectiveness of a soil cover as an oxygen barrier is dependent on its moisture content. A cover that can be maintained in a saturated condition will be more effective because of the low diffusivity of oxygen in the pore water and the absence of desiccation cracking. In Canadian winter conditions, the effects of freezing and thawing on a saturated soil cover is a major design factor. In order to achieve both low oxygen diffusion and low infiltration, the cover has to be constructed of fine-grained soils (clays, tills and sand-bentonite mixtures). Soils with high clay-size fractions tend to have low oxygen diffusion coefficients and hydraulic conductivities. Unfortunately, however, they also tend to be plastic and therefore more susceptible to cracking upon freezing (Chamberlain and Gow, 1979).

Composite covers with soil layers of different grain size distributions to prevent desiccation of clay and tills have been proposed as potentially beneficial (Rasmuson and Eriksson, 1987: Nicholson *et al.*, 1989). Yanful (1992) presents a detailed discussion of field and laboratory performance of a composite soil cover over reactive tailings. The cover consists of a compacted varved clay sandwiched between a coarse and fine sand layer. The clay was placed at a high water saturation

(>95%) to function as both oxygen and water barrier. An evaluation of the long-term performance of the cover with respect to freezing and thawing is in progress.

Soil covers have also been used in the decommissioning of waste rock dumps at the Rum Jungle site in Australia (Harries and Ritchie, 1981;1985) and at Mount Washington site in British Columbia, Canada. The Rum Jungle cover is a composite system consisting of a compacted clay overlain sequentially by a sandy clay loam and a gravelly sand. Published monitoring data indicate the cover has greatly reduced the temperature and gaseous oxygen levels in most regions of the dump. Bennett et al. (1989) observed that the cover has been effective in stopping convective transport of oxygen into the dumps. The cover at the Mount Washington site is a single layer consisting of compacted till. Monitoring data obtained a few months after covering indicated slight reduction in gaseous oxygen and elevation in carbon dioxide concentrations. The till also appeared to have had an insulating effect on the dump temperature (Golder Associates, 1989).

2.4 Wood Waste Cover

The potential use of wood waste as a cover for sulphitic wastes is based on the assumption that its degradation could promote the growth of sulphate-reducing bacteria. These bacteria constitute a family of obligate anaerobes including *Desulphovibrio* and *Desulphotomaculum* which obtain energy for growth by reducing sulphate at the expense of organic carbon (Grinenko and Ivanov, 1983). The requirements for microbial sulphate reduction are neutral pH conditions, low oxidation potential and high SO_4^{2-} concentration.

It is hypothesized that an oxygen-free environment can be created during aerobic degradation of wood by microorganisms (principally fungi) in which sulphate-reducing bacteria can thrive. Degradation of the wood by facultative bacteria can also provide an organic carbon source (for example, fatty acids) for the heterotrophic sulphate reducers. The biomass from microbial degradation could plug pores in the wood waste and reduce water drainage and, possibly, oxygen diffusion. In addition, if a large population of aerobic and facultative microorganisms continues to exist in the top of the cover, gaseous oxygen would be used up and the resulting oxygen flux into the underlying sulphitic material will be low.

2.5 Limestone Addition

Limestone is used in the management of ARD to minimize acid production from waste mine rock by maintaining a high pH. The high pH neutralizes acidity and also eliminates biological oxidation and, possibly, chemical oxidation. Limestone is the most inexpensive of the common neutralizing agents used in the treatment of ARD. It dissolves on contact with ARD and produces alkalinity and increased pH. The overall process of neutralization may be represented by the following reaction:

$$H_2SO_4(l) + CaCO_3(s) + H_2O(l) \dashrightarrow CaSO_4.2H_2O(s) + CO_2(g) \qquad [2]$$

As shown, the primary product of neutralization is gypsum ($CaSO_4.2H_2O$), produced largely as a precipitate. The Ca^{2+} and SO_4^{2-} concentrations in solution can exceed the solubility limits for gypsum and result in supersaturation. Gypsum can blind the limestone particle surface, thereby reducing the neutralization efficiency (Steffen, Robertson and Kirsten, 1989). The dissolution rate of limestone is partially dependent upon the proportion of the various carbonate minerals in the limestone, primarily calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and magnesite ($MgCO_3$) (Nairn et al., 1991).

In order for limestone to be effective as in the above equation, it should continue to dissolve until it is all consumed. This is not the case in practice. Coating or armouring occurs as a result of adsorption and oxidation of Fe^{2+} and Mn^{2+} on to the limestone surfaces and renders it nonreactive (Evangelou et al., 1991). Such reactions are expected to predominate in oxidizing waste rock piles in which the acidic drainage has high concentrations of dissolved iron and manganese. In such cases, the limestone particles become discoloured. Nevertheless, crushed limestone may be used to minimize the generation of ARD in waste rock during active operations when the pile is being constructed. An important requirement in such applications is to add the appropriate quantity of limestone. This information may be obtained by a small scale test.

2.6 Phosphate Rock Addition

It is believed that oxidation of pyrite by ferric iron can be stopped by the precipitation of ferric iron from solution. An examination of the various reaction steps involved in pyrite oxidation indicates ferric iron is an important oxidant. The disadvantages of limestone application, mentioned above, have led some workers (for example, Stiller et al., 1989) to investigate other ameliorants for combatting ARD. A procedure proposed for preventing pyrite oxidation by ferric iron is the addition of rock phosphate (apatite, $Ca_5(PO_4)_3(OH)$. Apatite dissolves and releases PO_4^{3-} which combines with Fe^{3+} to precipitate an insoluble ferric phosphate, strengite ($FePO_4.2H_2O$), below pH 5.5. In addition, apatite only dissolves when pH drops below 5.5 (Stumm and Morgan, 1970), becoming available at the onset of acid conditions.

In less oxidizing environments with high concentrations of ferrous iron, Fe^{2+}, addition of apatite may result in the formation of the ferrous phosphate mineral, vivianite ($Fe_3(PO_4)_2.8H_2O$). This would buffer the ferrous iron activity at a low level.

Stiller et al. (1989) showed in laboratory experiments that, even under vigorous aeration, samples of coal-derived pyrite treated with apatite did not produce acid. They also showed that rock phosphate addition to a system already producing acid terminated pyrite oxidation and subsequent acidification.

3.0 EXPERIMENTAL PROTOCOL

3.1 Selection of Candidate Waste Rocks

Waste rock samples used in the present investigation were assessed for their acid generation potential prior to the installation of the experiments. Two types of waste rock were used : Stratmat Waste Rock, obtained from the Stratmat site, Heath Steele Mines, near Newcastle, New Brunswick, and Selbaie Waste Rock, obtained from Les Mines Selbaie, near Joutel, Québec.

Two standard acid prediction tests were used: B.C. Research Initial Test (Duncan and Bruynestyn, 1979) and Humidity Cell Test (Sobek et al., 1978).

3.1.1 Acid Prediction Tests - Static Test

In the B.C. Research Initial Test, the sample is ground to minus 100 mesh and dried at 60°C. The dry sample is then used for sulphur assay and the titration test.

- The sulphur assay consists of total sulphur and sulphate analysis. The acid production potential of the sample, expressed as kg of calcium carbonate per tonne of sample, is calculated on the basis of the sulphide content of the sample, which is the total sulphur minus the sulphur as sulphate.

- In the titration test, 10 g of ground sample is suspended in 100 mL of distilled water and stirred for 15 minutes during which time the natural pH of the sample is recorded. The sample is then titrated to pH 3.5 with 1.0 N sulphuric acid. The total volume of acid added is recorded and converted to kg of calcium carbonate per tonne of sample. This is the acid-consuming ability of the material. An estimate of the potential for excess acid production is obtained by comparing the acid production potential and the acid consumption ability. A ratio smaller than one indicates the material is theoretically a potential acid producer, while a number above two may suggest that acid generation is, in theory, unlikely.

The results of the tests presented in Table 3.1 indicate the ratio of the acid consumption to acid production for both the Stratmat waste rock and Selbaie waste rock is smaller than one. Thus both materials were, theoretically, acid producers. The acid-generating potential of the Selbaie rock was found to be about 10 times greater than that of the Stratmat rock (Table 3.1). From a comparison of the Static Test results and initial pH values, it was inferred that the Selbaie rock was definitely an acid producer. The initial pH of the Stratmat rock was quite high which suggested some degree of alkalinity present. To confirm that the Stratmat rock was an acid producer, a Humidity Cell Test was performed, prior to the commencement of the experiments.

Table 3.1 Results of Chemical Prediction by B.C. Research Initial Test

Sample Number	S (t)% (1)	$S(SO_4)$% (1)	S%	Initial pH	Acid Production kg($CaCO_3$)/ton	Acid Consumption kg($CaCO_3$)/ton	AC/AP	Acid Producer
Stratmat	9.70	0.11	9.59	8.45	224	17.5	0.078	Yes
Stratmat	9.80	0.12	9.68	8.72	227	17.5	0.077	Yes
Selbaie	45.4	0.17	45.2	5.60	1059	7.00	0.007	Yes
Selbaie	45.3	0.14	45.2	6.00	1059	7.00	0.007	Yes

(1) Total Sulphur and Sulphate by Gravimetry

3.1.2 Acid Prediction Tests - Humidity Cell Test

The Humidity Cell Test consists of adding distilled water to 200 g of waste rock ground to a particle size of less than 2 mm. The sample is spread evenly across the bottom of a column 30 cm in length and 11.5 cm in diameter. Each week 200 mL of water is added to the sample and the drainage water is collected in a beaker; the pH is then measured and plotted on a graph versus time.

The plots presented in Figure 3-1 show a sharp drop in pH of the drainage water (pH 6.0 to pH 3.5) after 40 days of testing. Therefore, the Stratmat waste rock was considered suitable for the study.

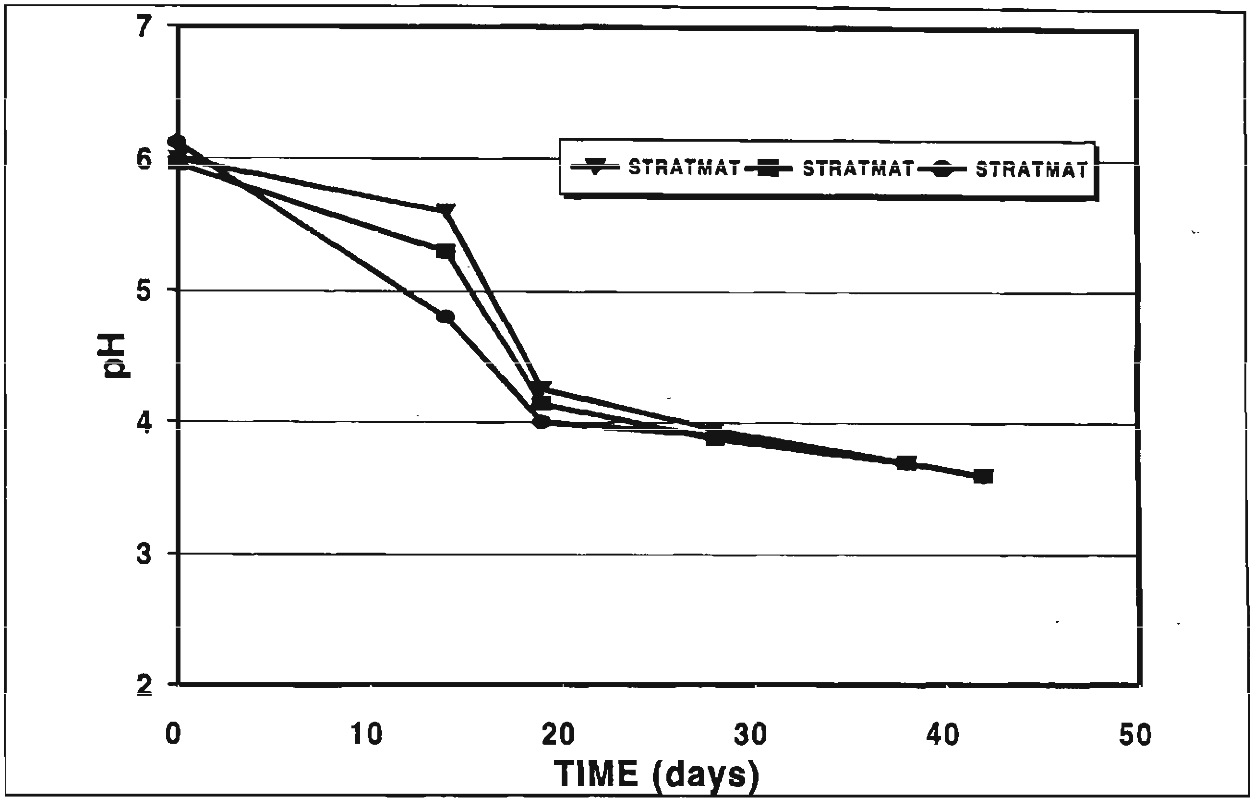


Figure 3-1 Humidity Cell Test Results on Stratmat Waste Rock

3.2 Geology, Mineralogy and Geochemistry

3.2.1 Stratmat Waste Rock

The Stratmat waste rock was derived from the footwall and, possibly, the hanging wall of the Stratmat ore zone. The ore occurs in a polydeformed volcano-sedimentary sequence that is part of the Ordovician Tetagouche Group located in the Bathurst area, New Brunswick. The footwall, also known as the Southwall sequence, is dominated by siliceous seritic pelites, quartz augen schists with white to pale grey, fine-grained siliceous or cherty layers, and mylonitic and phyllonitic bands. Disseminated pyrite (at about 2-4%) and minor amounts of sphalerite, galena and chalcopyrite occur more frequently in the pelitic layers and, occasionally, in the more cherty layers. The siliceous material is believed to be a volcanic tuff (Park, 1991; Hamilton, 1992).

The hanging wall, or Northwall sequence, consists largely of deformed feldspar-rich metavolcanic and volcaniclastic rocks (crystal tuff) with minor intrusions and small amounts of metasediment. The dominant rock type is a deformed feldspar or feldspar-quartz porphyry, grading to feldspar augen schist or gneiss that is locally mylonitic or phyllonitic, depending on the quartz or muscovite content. Pyrite is the dominant sulphide, although it typically occurs in trace amounts.

The Stratmat ore zone lies between the Northwall and Southwall sequences. It consists of metasediments characterized by talc-rich pelites, talcose cherts, foliated talc and talc-carbonate units.

Table 3.2 Average Mineralogical and Geochemical Composition of Stratmat Waste Rock

Mineralogy (% wt)

Type	CRM	McGill
Quartz	34.8	30.2
Mica (Muscovite)	29.7	45.9
Feldspar (Albite)	4.9	4.5
Carbonate (Dolomite)	0.5	1.1
Pyrite	19.7	18.3

Geochemistry (% wt)

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	CO_2	LOI	Fe	S
CRM	53.2	14.3	15.6	1.5	0.1	0.3	5.8	0.4	0.1	0.1	0.2	10.5	-	9.9
McGill	55.4	14.2	13.8	1.8	0.1	0.5	5.4	0.4	0.1	0.1	0.4	8.1	7.9	9.2

Note LOI = Loss on ignition

The ore comprises both disseminated and massive sulphides (sphalerite-galena-pyrite and chalcopyrite). In the talcose rocks the ore grade, measured as Pb and Zn combined, ranges from 2 to less than 40%. The massive ores are banded rocks consisting of sulphide gneisses and fine-grained porphyroclasts. Copper grades in the massive ore average 1-2% and local intersections grade as high as 10%.

Twelve samples of crushed (25 to 50 mm particle size) Stratmat waste rock were subjected to mineralogical, electron microprobe and geochemical analyses, as part of the present study. The results suggest the waste rock is a variably sheared, sericitized and pyritized meta-rhyolite (a low-grade metamorphosed, felsic volcanic rock). The mineralogical composition, obtained in two separate evaluations are presented in Table 3.2. The mineralogy consists of quartz, muscovite, albite, pyrite and a trace of carbonate (dolomite).

The average geochemical composition is also presented in Table 3.2. Total sulphur is present at about 9.5% and iron at 7.9%. The CO_2 content is very low and suggests the acid neutralizing capacity of the rock is low.

3.2.2 Selbaie Waste Rock

The general geology of the area is characterized by subhorizontal layers of rhyodacitic breccia and felsic tuffs with open folds. Mineralogical and microprobe analyses indicate the rock consists predominantly of massive pyrite, infilled with quartz, ankerite, chlorite and traces of sphalerite and chalcopyrite (Table 3.3).

The geochemical composition presented in Table 3.3 indicates the Selbaie rock is composed of almost 50% sulphur by weight, with the remainder being iron and silicon which is consistent with the observed mineralogy. From the CRM results, carbonate (in the form of ankerite, $CaFe(CO_3)_2$) appears to be slightly enriched over the Stratmat rock. However, iron-based carbonates dissolve in acids more slowly and provide little pH buffering relative to calcite (Morin and Cherry, 1986). Consequently, the ability of the untreated Selbaie rock to neutralize acid generated from pyrite oxidation may be minimal.

Table 3.3 Average Mineralogical and Geochemical Composition of Selbaie Waste Rock*

Mineralogy (% wt)

Type	CRM	McGill
Pyrite	78.2	74.8
Quartz	13.9	22.8
Carbonate (Ankerite)	4.2	0.3
Chlorite	3.7	2.1

* Material used for the study was not representative of the waste rock found on site

Geochemistry (% wt)

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	CO_2	Fe	S
CRM	14.6	0.2	54.4	0.3	0.8	0.0	0.0	0.0	0.1	0.0	28.6	1.7	-	47.0
McGill	23.8	0.4	46.7	0.2	0.3	0.1	0.3	0.0	0.0	0.0	27.6	0.9	36.1	48.0

The ore comprises both disseminated and massive sulphides (sphalerite-galena-pyrite and chalcopyrite). In the talcose rocks the ore grade, measured as Pb and Zn combined, ranges from 2 to less than 40%. The massive ores are banded rocks consisting of sulphide gneisses and fine-grained porphyroclasts. Copper grades in the massive ore average 1-2% and local intersections grade as high as 10%.

Twelve samples of crushed (25 to 50 mm particle size) Stratmat waste rock were subjected to mineralogical, electron microprobe and geochemical analyses, as part of the present study. The results suggest the waste rock is a variably sheared, sericitized and pyritized meta-rhyolite (a low-grade metamorphosed, felsic volcanic rock). The mineralogical composition, obtained in two separate evaluations are presented in Table 3.2. The mineralogy consists of quartz, muscovite, albite, pyrite and a trace of carbonate (dolomite).

The average geochemical composition is also presented in Table 3.2. Total sulphur is present at about 9.5% and iron at 7.9%. The CO_2 content is very low and suggests the acid neutralizing capacity of the rock is low.

3.3 Design and Construction of Test Equipment

The field and laboratory experiments consisted of 60 columns which are represented schematically in Figure 3-2. The sizes of the columns, however, differed between indoor and outdoor tests. All tests were run in triplicate to assess the variation between tests. The particle sizes of rock samples used in the tests were between 25 and 50 mm. The bulk density was measured at approximately 1.5 and 2.1 g/cc for Stratmat waste rock tests and Selbaie waste rock tests, respectively.

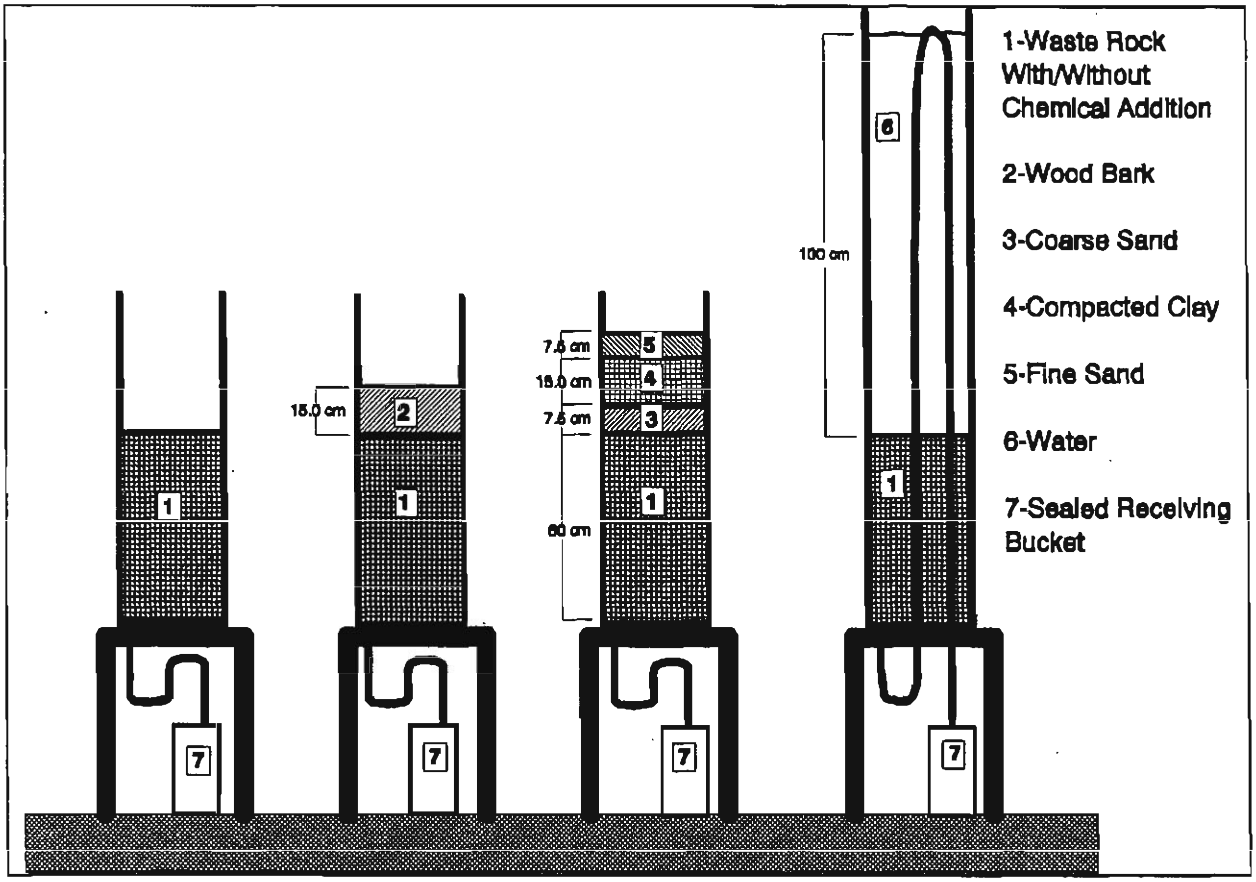


Figure 3-2 Schematic Representation of Outdoor and Indoor Lysimeters

The phosphate rock used consisted mainly of apatite (> 70% by weight) and carbonate (10% by weight) from Brunswick Mining and Smelting/Fertilizer Division, Belledune, New Brunswick. The grain size was less than 6 mm (0.25 inch). The limestone was a crushed (< 6 mm or 0.25 inch particle sizes) agricultural limestone and consisted mainly of calcite, $CaCO_3$ (> 90% by weight). Detailed mineralogical data of the phosphate and limestone are presented in Appendices B and C.

3.3.1 Outdoor Lysimeter Tests

Outdoor lysimeters were constructed of 160 L polyethylene tank, 94 cm in height and 46 cm in diameter. A hole was drilled in the bottom of the lysimeter and a 1.9 mm (3/4 inch) plastic ball-valve was installed. A geotextile filter cloth was placed at the bottom of the lysimeters to prevent plugging of the drain and promote drainage. A water trap was installed between the valve and the receiving container to prevent oxygen from entering through the drain tube. The lysimeters were then filled with 170 kg of waste rock (that is, 2/3 of the total volume). Finally, a 22-litre plastic receiving bucket was installed beneath each polyethylene tank to collect drainage water.

The lysimeters were installed outside and subjected to natural weather conditions. The receiving bucket was sampled only when a sufficient amount of drainage water (≥ one litre) had been collected. Sampling consisted of measuring the total volume of water and determining the pH and total acidity (mg of $CaCO_3$/L). Acidity was determined as total acidity by titrating to pH 8.3 (*Standard Methods*, 1975). The pH measurement involved the use of a combination electrode and suitable buffers for calibration. In addition to the samples for the pH and acidity determinations, two 500 mL unfiltered subsamples of the drainage water were also taken: one acidified with hydrochloric acid for a final acid concentration of 2% (for metal, cation and sulphate analysis) and one non-acidified (for total organic carbon and chloride determinations). After the sampling, the remainder of the drainage water was discarded and the receiving bucket was cleaned by rinsing with distilled water and then re-connected to the polyethylene tank.

All the subsamples from Stratmat control, limestone addition 1% and 3%, and water cover tests were submitted for metal and non-metal analysis. In addition, subsamples from the other preventing techniques collected weeks 1, 11, 44, 54, 67, 72 and 115 were also evaluated for metal and non-metal analysis.

The Stratmat waste rock lysimeter experiments started on June 28, 1991, with first samples taken on July 10, 1991; the Selbaie waste rock lysimeter tests started on August 12, 1991 with first samples taken on September 17, 1991.

The outside test installations were as follows (in triplicate):

Stratmat Waste Rock

- Control - Consisted of 170 kg of rock as received (crushed to 25-50 mm particle size) with no cover or additive.
- 1% Phosphate Rock Addition - Consisted of 1.7 kg of phosphate rock mixed with 170 kg of crushed waste rock during filling of the lysimeter.
- 3% Phosphate Rock Addition - Consisted of 5.1 kg of phosphate rock mixed with 170 kg of waste rock during filling of the lysimeter.
- 1% Limestone Addition - Consisted of 1.7 kg of limestone mixed with 170 kg of waste rock during filling of lysimeter.
- 3% Limestone Addition - Consisted of 5.1 kg of limestone mixed with 170 kg of waste rock during filling of lysimeter.
- Wood Bark Cover - Consisted of a 15 cm thick cover of wood bark 20-30 years old from James MacLaren Industries Inc. The wood bark was placed, as received without compaction, directly on 170 kg of waste rock. Approximately 16.5 kg of wet wood bark was used.
- Soil Cover - Consisted of a 3-layer cover over 170 kg of waste rock: a top layer of 7.5 cm of fine sand (19 kg), a middle layer of 15 cm of compacted clay (42 kg) and a bottom layer of 7.5 cm of coarse sand (19 kg). The clay was compacted in 2.5 cm lifts in a special steel mould of exactly the same diameter and shape as the lysimeter, using the modified Proctor compaction procedure (ASTM D1557). The clay was compacted at a water content of 25% (by weight) which was 2% higher than the optimum water content.
- Water Cover - Consisted of 1.0 m cover of water over 170 kg of waste rock. The depth of water was maintained constant by connecting a 0.95 cm (3/8 inch) PVC plastic pipe at the bottom valve and running the pipe up the front of the lysimeter to the required water level and then down into the receiving bucket. This set up forces rain water to go through the water layer and the waste rock before entering the bottom valve and draining out.

Selbaie Waste Rock

- Control - Consisted of 170 kg of crushed waste rock as received with no cover or additive.
- 3% Phosphate Rock Addition - Consisted of 5.1 kg of phosphate rock mixed with the 170 kg of waste rock during filling of lysimeter.

In addition, a control wood bark test (without rock) was installed 10 weeks after all the other tests had begun. This control test consisted of approximately 10 kg of uncompacted wood bark placed in a 22-litre plastic pail. A drainage outlet, installed at the bottom of the pail, allowed drainage water to be collected in a receiving bucket. The receiving bucket was sampled in a similar manner to those of the outdoor lysimeters.

3.3.2 Laboratorv Column Tests

The laboratory columns were constructed from standard 15 cm diameter PVC pipe. The pipe was cut in 100 cm lengths and one end was sealed with a standard PVC cap. A hole was drilled in the bottom of the column and a 0.95 cm (3/8 inch) male adapter compression fitting was installed. A geotextile filter cloth was placed at the bottom of the column to prevent plugging of the drain and a water trap was installed between the male adapter and the receiving container to prevent oxygen from entering through the drain tube. The columns were then filled with 20 kg of waste rock (2/3 of the total volume). Finally, a 1-litre receiving bottle was used to collect the drainage water.

The waste rock in each column was subjected to cycles of eight weeks of wet condition followed by eight weeks of dry condition. For comparison of the indoor column and outdoor lysimeter tests, the amount of water added as simulated rain was calculated from the average annual precipitation of the nearby municipality of Dorval, Québec. This annual precipitation is 946.2 mm or 18.2 mm per week. During the wet period, therefore, 650 mL of distilled water was added to each column every week. Weekly sampling of drainage water involved measuring the total volume of water, determining the pH and total acidity (mg of $CaCO_3$/L) as well as taking two 200 mL unfiltered subsamples, one acidified with hydrochloric acid for a final acid concentration of 2% (for ions analysis) and one non-acidified (for total organic carbon and chloride determinations). After sampling, each receiving bucket was cleaned, rinsed with distilled water and re-connected to the column.

All the subsamples from Stratmat control, limestone addition 1% and 3% and water cover tests collected during the second and seventh week of every eight week wet period were submitted for metal and non-metal analysis. In addition, subsamples from the other preventing techniques collected during weeks 1, 35, 41, 101, 105, 148 and 153 were also analysed for metals and non-metals. Drainage water samples from week 150 and 153 were analysed for redox and conductivity.

The Stratmat waste rock column tests started on July 4, 1991 with first samples taken on July 11, 1991. The Selbaie tests, on the other hand, were started on August 8, 1991 with first samples taken on August 16, 1991.

The installation of the laboratory column experiments was also in triplicate and consisted of the following:

Stratmat Waste Rock

- Control - Consisted of 20 kg of crushed waste rock as received (no cover, no additive).

- 1% Phosphate Rock Addition - Consisted of 200 g of phosphate rock mixed with 20 kg of waste rock during filling of lysimeter.

- 3% Phosphate Rock Addition - Consisted of 600 g of phosphate rock mixed with 20 kg of waste rock during filling of lysimeter.
- 1% Limestone Addition - Consisted of 200 g of limestone mixed with 20 kg of waste rock during filling of lysimeter.

- 3% Limestone Addition - Consisted of 600 g of limestone mixed with 20 kg waste rock during filling of lysimeter.

- Wood Bark Cover - Consisted of a 15 cm layer of wood bark 20-30 years old from James MacLaren Industries Inc. Approximately 900 g of uncompacted wood bark layer was placed as received directly on 20 kg of waste rock.

- Soil Cover - Consisted of a 3-layer cover: a top layer of 7.5 cm of tine sand (2.0 kg), a middle layer of 15 cm of compacted, nearly fully saturated clay (3.6 kg) and a bottom layer of 7.5 cm of coarse sand (2.0 kg). The clay was compacted in six 2.5 cm lifts directly in the column. Unlike the outside drums, the small size of the laboratory columns did not permit compaction to the same specifications.

- Water Cover - Consisted of 1.0 m of water over 20 kg of waste rock. The depth of water was maintained constant by using the same arrangements as the outside tests.

Selbaie Waste Rock

- Control - Consisted of 20 kg of crushed waste rock as received (no cover or ameliorant added).

- 3% Phosphate Rock Addition - Consisted of 600 g of phosphate rock mixed with 20 kg of waste rock during filling of lysimeter.

A control wood bark test (without rock) was installed on 20 March, 1992 in the same manner as the outdoor tests.

3.3.3 Post-Testing Evaluation

The tests ended June 17, 1994 after 3 years of testing. Only the indoor tests were submitted to the post-testing evaluation. One column from each triplicate set was dismantled and the rocks split in three sections: top, middle and bottom. For each section, 25% of the rocks were frozen for possible future examination. The remaining 75% was washed with deionized water until the resulting leachate gave an acidity concentration close to the detection limit of 10 mg/L of $CaCO_3$. All the leachate samples obtained from the washing of rocks from a particular column were combined (10- 15 L) for ICP scan and ferric iron determination. The density of the washed rocks was also measured.

A sample of washed rocks from the Stratmat Control, Selbaie Control and the water covered Stratmat columns were examined by scanning electron microscopy at the University of Western Ontario to obtain information on the degree of alteration of the sulphide minerals. The rock samples were also analysed using petrographic methods.

Mercury intrusion porosity was conducted on the Stratmat Control, Selbaie Control and the water covered Stratmat rocks.

4.0 RESULTS

The total cumulative acid production for each test is graphed in Figures *4-1*, *4-2* and 4-3. The data indicate some variations in the triplicates. The calculated Relative Standard Deviation (R.S.D.) averaged 49% for the outdoor tests and 33% for the indoor tests. The higher variation for outdoor triplicate tests was probably induced by natural weather. The limestone-amended indoor and outdoor tests showed the highest variation of R.S.D. ranging from 65% to 138%; however, the other techniques, such as phosphate addition and covers application, resulted in R.S.D. ranging from 5.8% to 106%. Differences between replicate tests may have been due to slight variations in the mixing of the chemical amendments or in the placement of the cover; even the control tests conducted with well homogenized waste rocks resulted in R.S.D. values ranging from 3.6% to 55%. The magnitude of the variation within a single set of replicates suggest that small differences in acid production between prevention techniques may not be significant.

The average acid generation rates and the average percent acid reductions covering the entire 3 year period of testing are summarized *in Table 4.1*. The results indicated that indoor and outdoor tests showed the same trend. The best prevention technique tested was found to be the water cover with an acid reduction of more than 99%, followed by the limestone addition with an acid reduction of 94% to 98% acid reduction for 3% dosage rate and 82% to 84% for 1% dosage rate. The soil cover results showed 98% acid reduction in the indoor tests and 46% in the outdoor tests. Deterioration of the soil cover by natural weather is probably responsible for the reduced effectiveness observed in the outdoor tests. The phosphate addition and the wood bark cover had only marginal effect on acid reduction.

TABLE 4.1 Average Weekly Acid Production in mg of CaC03 per kg of Waste Rock

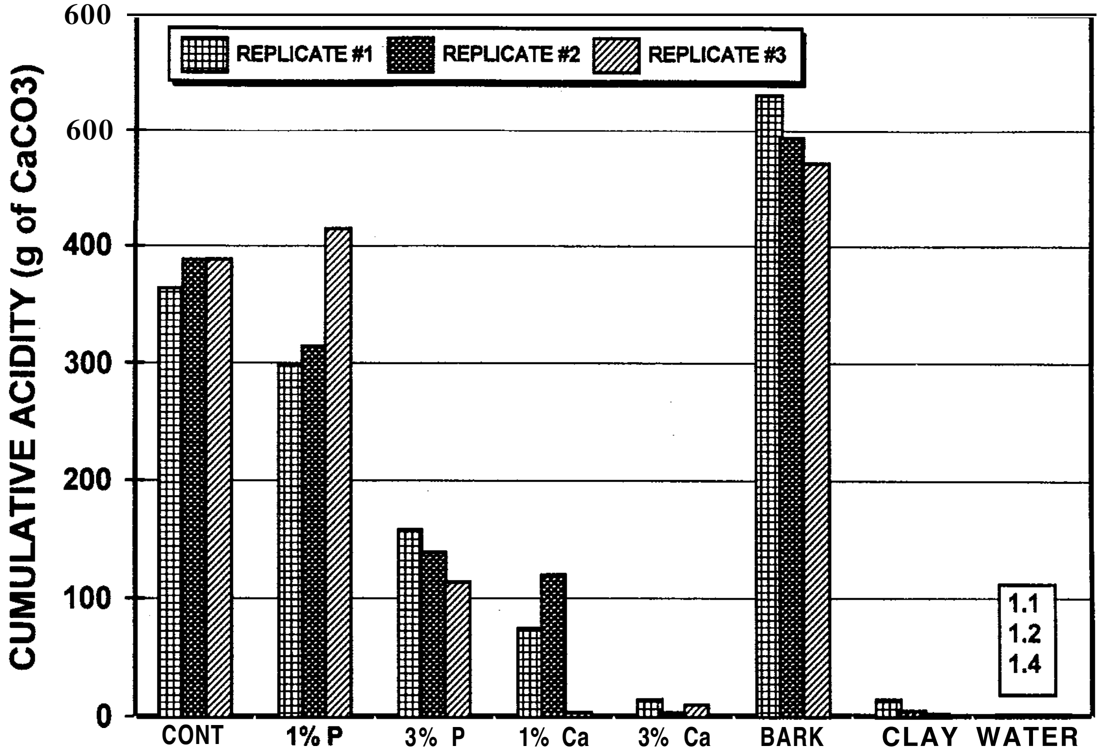
	LAB TESTS				OUTSIDE TESTS			
	STRATMAT WASTE ROCK		SELBAIE WASTE ROCK		STRATMAT WASTE ROCK		SELBAIE WASTE ROCK	
	mg/week/kg (CaC03)	acid reduction	mg/week/kg (CaC03)	acid reduction	mg/week/kg (CaC03)	acid reduction	mg/week/kg (CaC03)	acid reduction
CONTROL	123 130		34.9 35.3		41.0		6.16	
1% PHOSPHATE	111 116	10.0% 10.8%			34.2	16.7%		
3% PHOSPHATE	44.4 46.6	64.0% 64.2%	8.61 9.31	75.4% 73.7%	12.5	69.5%	2.63	57.4%
1% LIMESTONE	21.3 22.5	82.8% 82.7%			6.53	84.1%		
3% LIMESTONE	2.78 2.96	97.7% 97.7%			2.32	94.3%		
WOOD BARK	162 170	-31.7% -30.7%			111	-170%		
CLAY	2.11 2.61	98.3% 98.0%			21.9	46.6%		
WATER	0.40 0.79	99.7% 99.4%			0.08	99.8%		

Shading areas indicate oxidation rate and acid reduction that included oxidation product stored in the laboratory columns

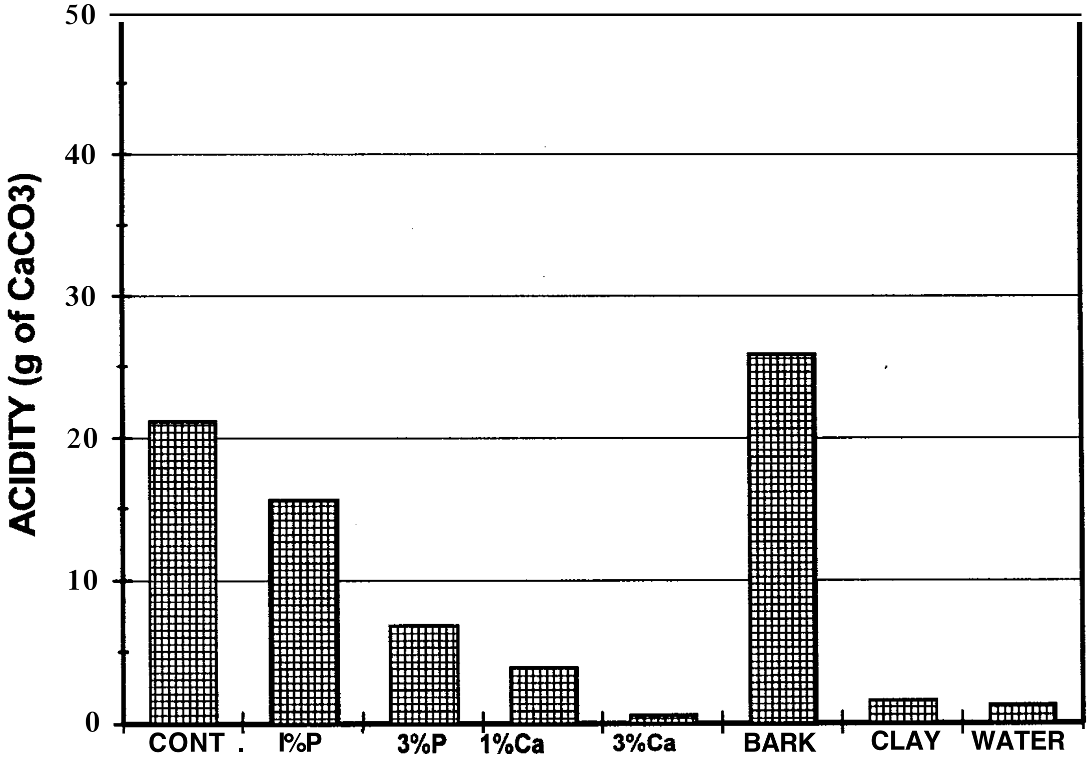
Approximately 40 and 200 L of drainage water were collected during the testing period for the indoor and outdoor tests, respectively. Samples of the drainage water were preserved and submitted to metal and non-metal determinations. The results are presented in Appendix A (Tables I to LXI). Metal and non-metal concentrations of the indoor tests were measured only on leachate collected in the second and seventh week of every eight week washing period while acidity was determined every week. To obtain a reasonable estimate of the sulphate, iron or zinc, the acidity measured weekly was plotted versus the measured concentrations of the ions mentioned previously and a strong correlation resulted. This correlation was used to calculate sulphate, iron and zinc concentrations in samples not submitted to ICP analysis and the total loading calculated.

Detailed results for each acid prevention technique are described in this section.

INDOOR STRATMAT
CUMULATIVE ACIDITY



ACIDITY IN DRAINAGE WATER (154 WEEKS)



ACIDITY STORED IN THE COLUMNS

Figure 4-l : Acidity produced in indoor Stratmat tests

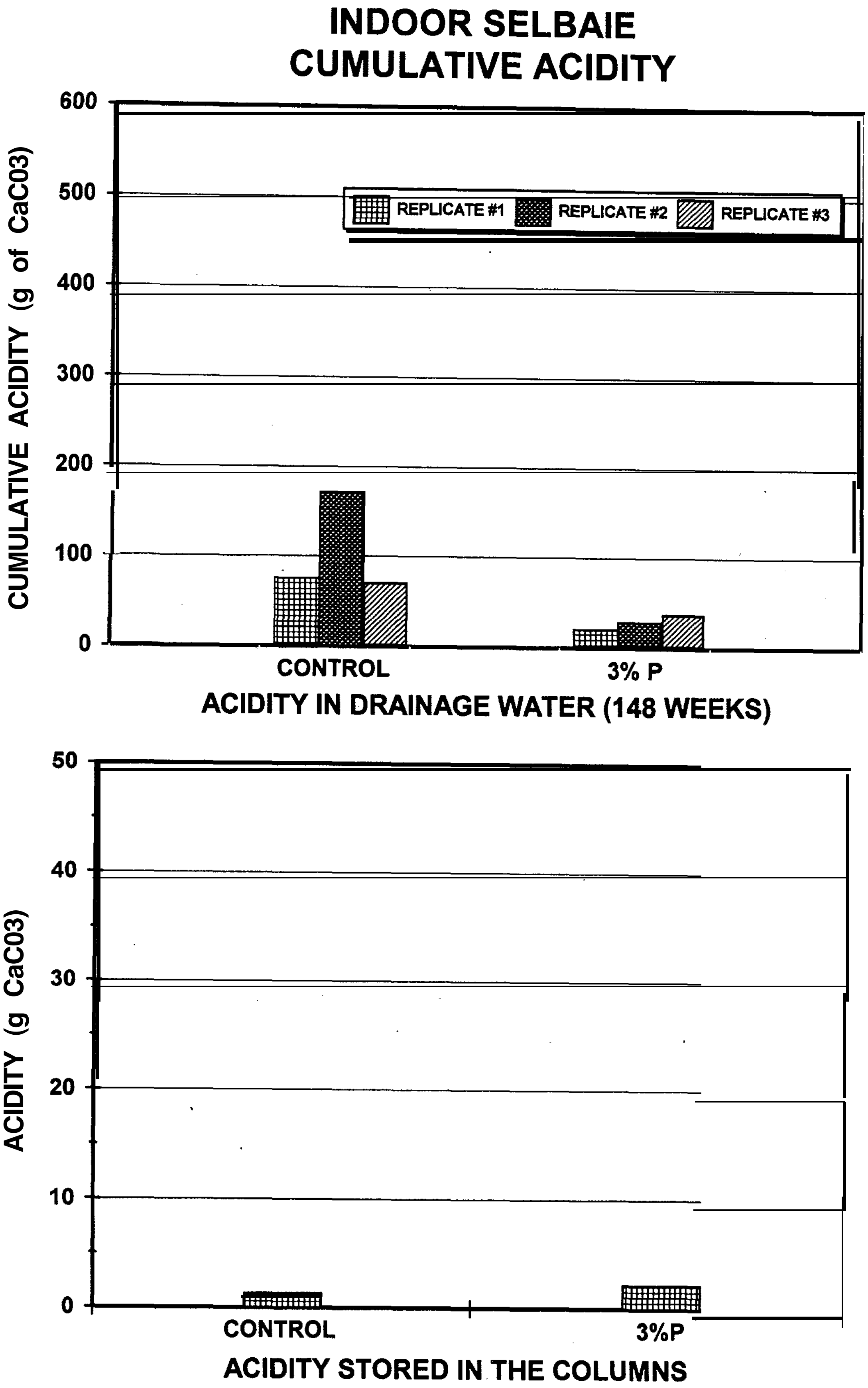
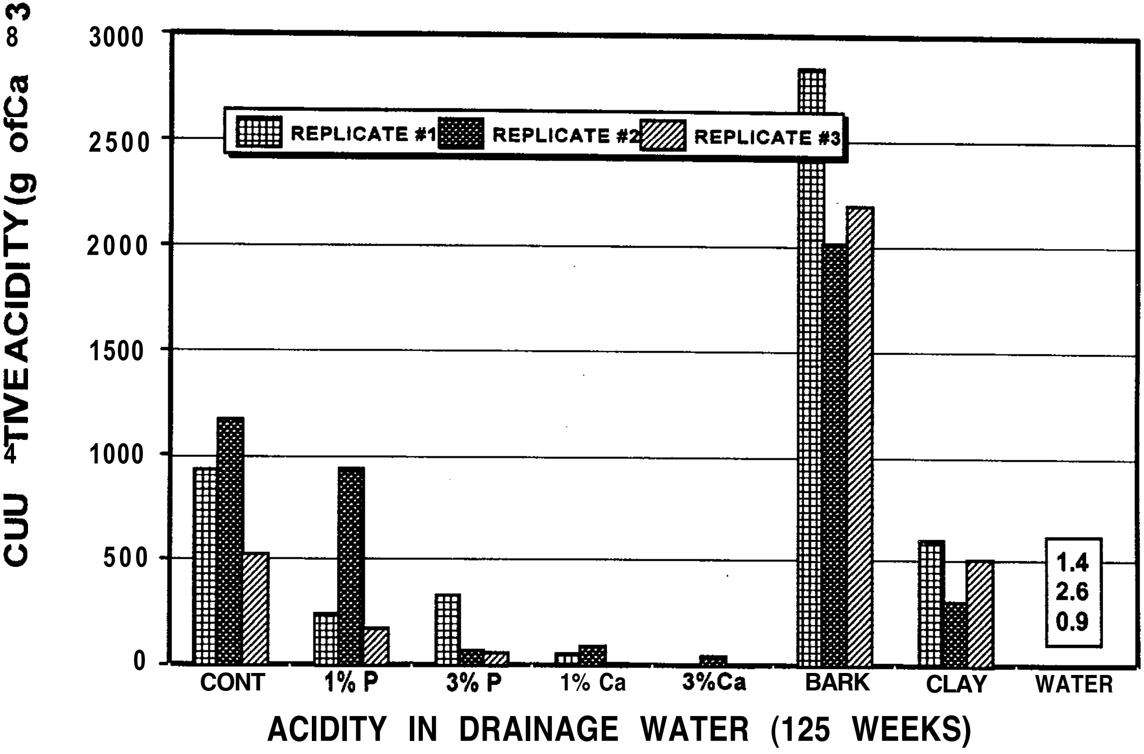


Figure 4-2: Acidity produced in indoor Selbaie tests

OUTDOOR STRATMAT CUMULATIVE ACIDITY



OUTDOOR SELBAIE CUMULATIVE ACIDITY

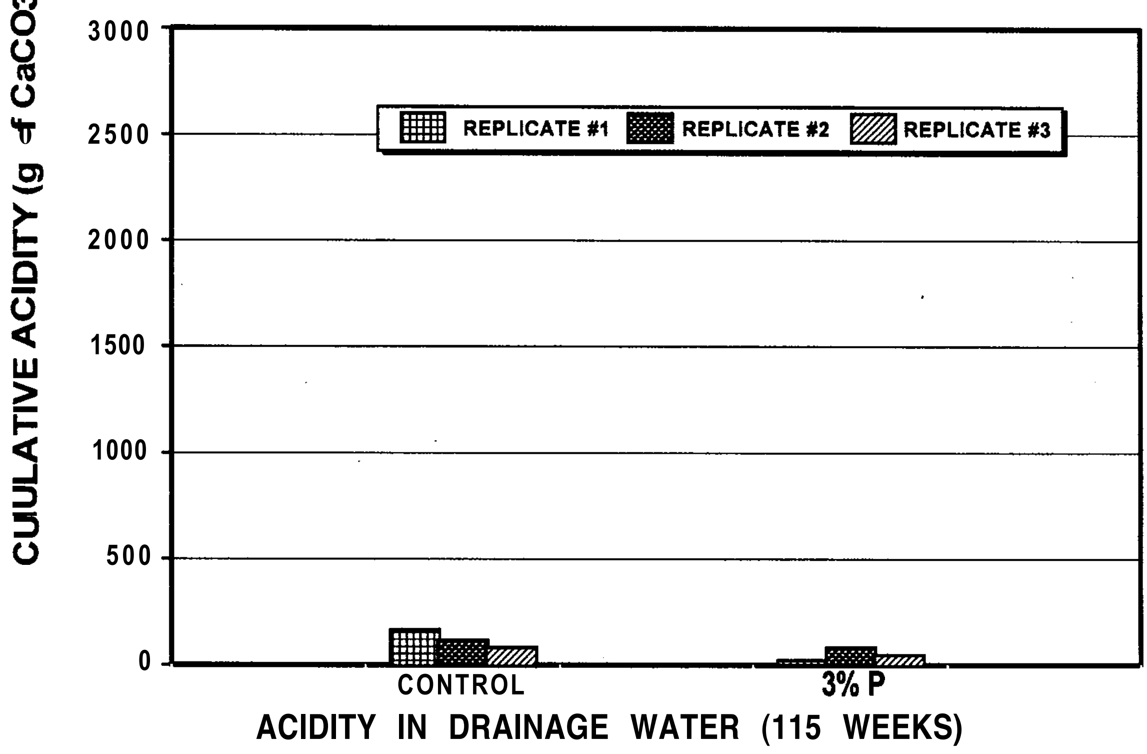


Figure 4-3: Acidity produced in outdoor Stratmat and Selbaie tests

4.1 Stratmat Control

4.1.1 Testing Results

Acid production rate and pH

The acidity measured in the drainage water from the indoor Stratmat control columns averaged 380 g of $CaCO_3$. In addition, an acidity of 21 g of $CaCO_3$ was measured as the oxidation product stored in the columns during the testing period, giving a total acid production of 401 g of $CaCO_3$. The average acid production rate was calculated at 130 mg of $CaCO_3$/kg/week during a testing period of 154 weeks. The outdoor Stratmat waste rock produced an average of 872 g of $CaCO_3$; the average acid production rate was calculated at 41 mg of $CaCO_3$/kg/week for a testing period of 125 weeks. The amount of pyrite oxidized in the indoor tests was calculated to be 320 g based on acidity measurements and 305 g based on sulphate released. This represents approximately 7.5% of the pyrite initially present in the waste rock. The same calculation done for the outdoor tests resulted in 2.1% of the pyrite being oxidized during the testing period. The results indicate that the oxidation of the waste rock was 68% slower in the outdoor tests; variation in temperature is the most probable reason for the lower acid production rate outdoors.

Acid production rates versus time for indoor and outdoor tests are presented in Figures 4-4 and 4-5, respectively. The drainage water from the indoor tests started generating acidity early in the study and the pH dropped rapidly to 2.0. After 25 weeks, the acid production rate was near 100 mg of $CaCO_3$/kg/week as shown in Figure 4-4. The acid production rate then remained constant from week 25 to the end of the study (week 154). Figure 4-5 shows that the oxidation stopped completely during the winter time. In addition, the outdoor waste rock tests did not generate significant acidity during the first summer and the pH remained between 3.0 and 4.0.

The acid production rates of the waste rock in outdoor tests during the summer months of the second and third year were similar to the acid production rates of the waste rock of the indoor tests at respectively, 100 mg of $CaCO_3$/kg/week and 135 mg of $CaCO_3$/kg/week.

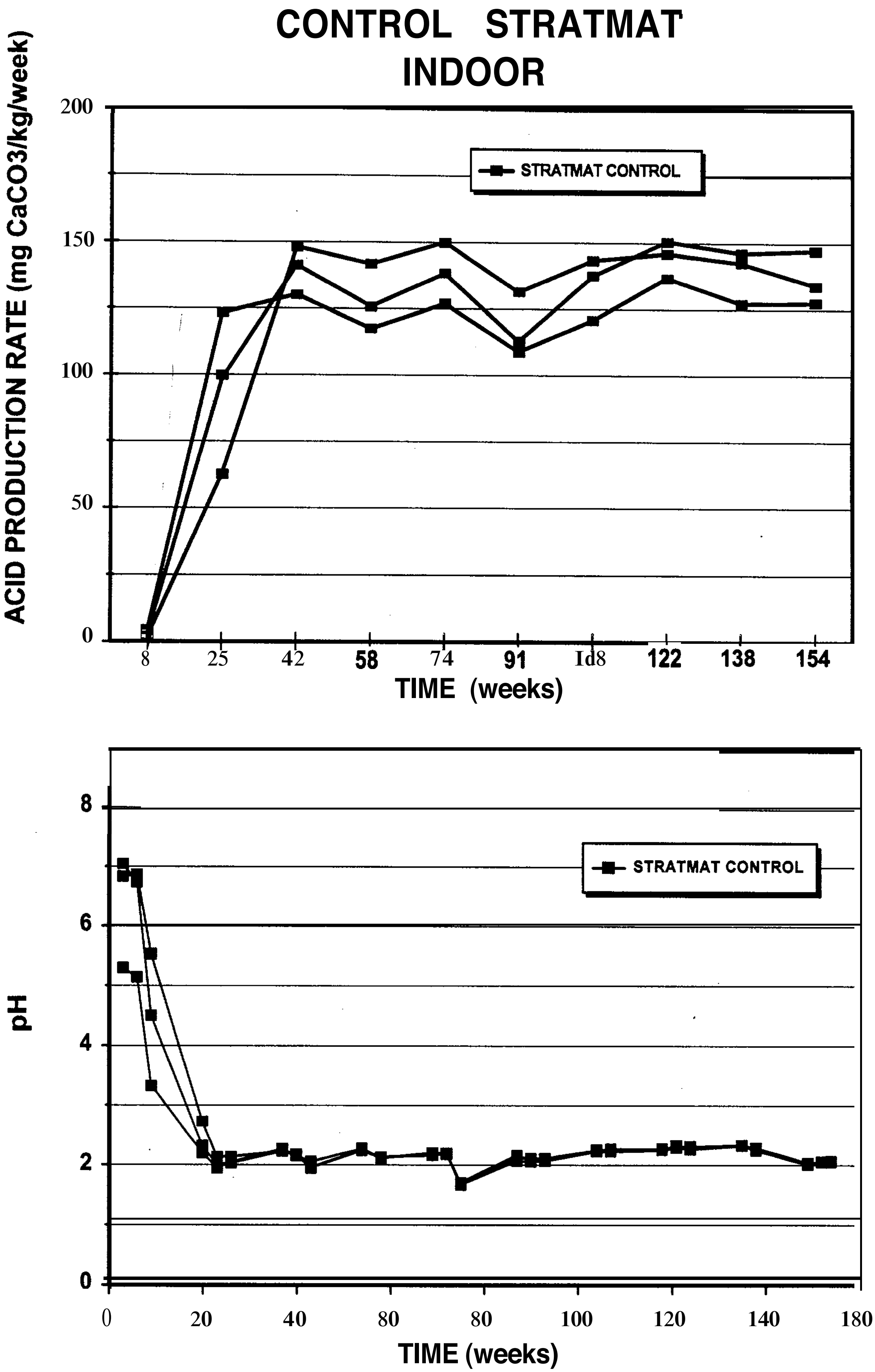


Figure 4-4: Acid production rate and pH in indoor control Stratmat drainage water

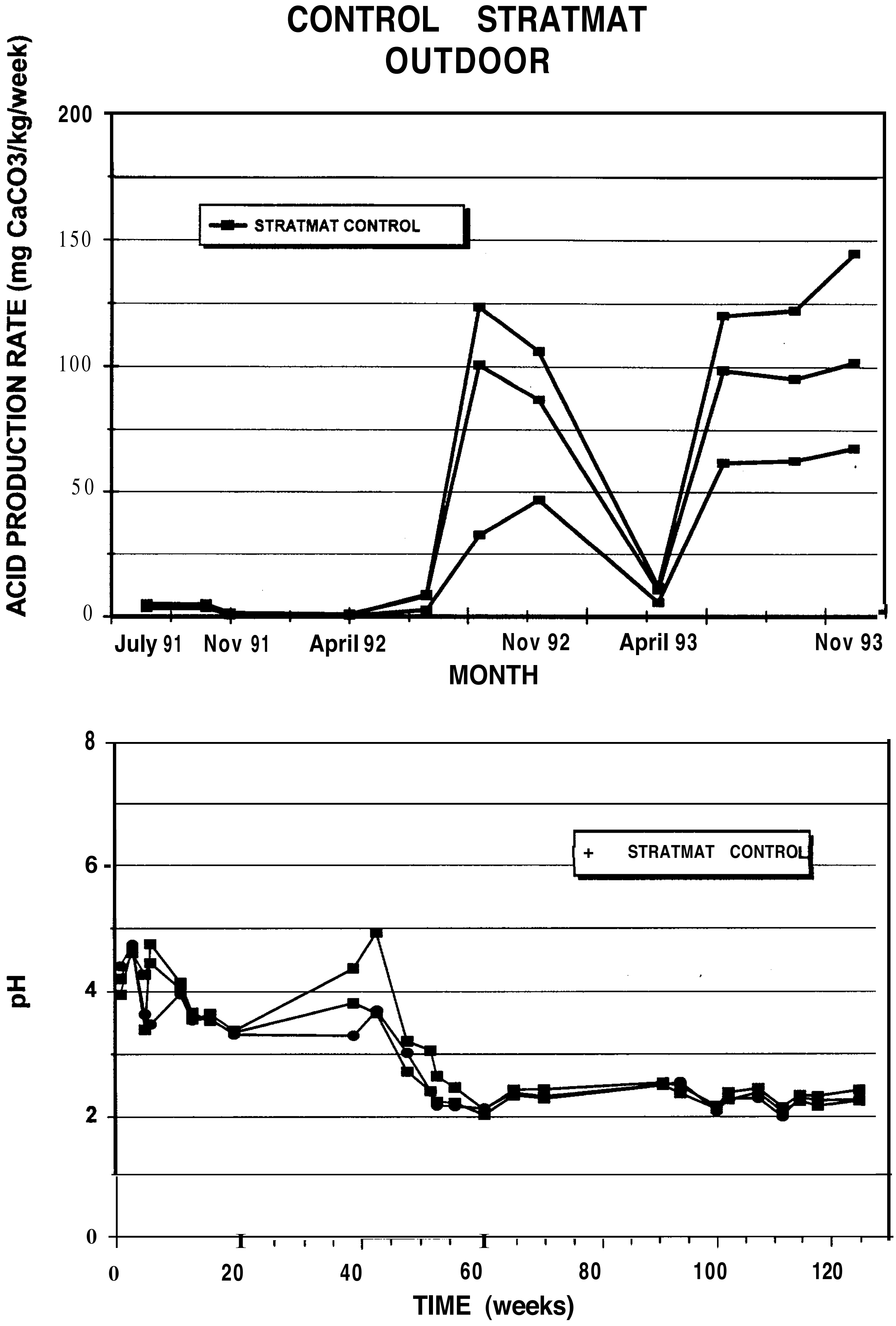


Figure 4-5 : Acid production rate and pH in outdoor control Stratmat drainage water

Metals and non-metals released

The complete chemical analysis results are presented in Appendix A, Tables I to III and XXXI to XXXIII. Metals in the indoor and outdoor drainage waters were detected as early as the first week; however, the metal concentrations in the outdoor tests remained low throughout the first summer, as observed for the acidity results shown in Figure 4-5. The metal concentrations increased rapidly in the indoor tests and stabilized around week 25. The major metals released indoor were: Fe (2000 - 4000 mg/L), Al (200 - 500 mg/L) and Zn (50 - 200 mg/L). Other species detected were SO, (5000 - 15000 mg/L), Mg (200 - 500 mg/L), Ca (50 - 100 mg/L, Mn (15 - 50 mg/L, As (10 - 25 mg/L) and Si (40 mg/L).

The drainage water for the outdoor tests showed wider variation in concentrations due to seasonal temperature changes, but the same species were present at similar concentrations during peak acid production rate which took place during summer time.

A few samples of drainage water were analysed for Fe^{+3}; the results indicated that an average of 92% of the Fe was oxidized to Fe^{+3} (ferric state).

4.1.2 Post-Testing Results

The amount of acidity stored in the indoor columns was 21 g of $CaCO_3$; this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate. The metal and non-metal loadings stored in the columns are presented in Appendix A, Table LXI.

The density profile of the waste rock showed that the surface rocks were slightly denser (2.98 g/cc) compared to the bottom rocks (2.74 g/cc). This suggests that the sulphide content of the bottom rocks was slightly lower than that of the surface rocks. This may have been due to the column configuration (Figure 3-2): reduced drainage of percolating acid at the bottom of the column may have provided a longer contact time of the acid water with the bottom rocks and could have led to a greater dissolution of sulphide minerals.

4.2 Stratmat Water Cover

4.2.1 Testing Results

The water cover on Stratmat waste rock was found to be the most efficient technique tested. Unfortunately, the outdoor lysimeters were severely damaged during the first winter, two lysimeters were torn and the bottom valve of the third one was broken because of freezing. The outdoor column water cover was therefore lost during the first winter. The lysimeters were repaired and refilled immediately with water to minimize oxidation. To avoid further damage during the following winter, the lysimeters were drained at the end of the fall; the water was kept and then returned to the lysimeters the following spring. In addition, from June 1993 to the end of the study (November 1993 for the outdoor tests), no drainage water was collected from the water cover tests because of warm, dry weather which resulted in more evaporation than precipitation. Analysis of the water cover technique presented in this report was based mainly on the indoor tests because of the above limitations in the outdoor tests. In addition, the laboratory offered a much better environment for controlling parameters such as temperature, precipitation, evaporation and collection of the samples. Nevertheless, partial outdoor results were collected and are presented in this section.

Acid production rate and pH

The indoor water covered columns produced an average of 2.44 g of $CaCO_3$ including the acidity stored in the water cover. However, the acidity from the water covered columns (indoor and outdoor) was highly overestimated because the level of acidity in the effluent was normally below the detection limit of the titration technique for measuring acidity. The detection limit was 50 mg/L of $CaCO_3$ for the first 69 weeks, based on manual titration; a more accurate method using an automatic titrator subsequently gave a lower detection limit of 10 mg/L of $CaCO_3$. The acidity of the drainage water from the water covered column was found to be below this limit as well. For a conservative estimate, the calculations assumed a value at the detection limit when no acidity was detected by either titration method, This means that, for the first one and a third years,, the acidity was overestimated at least five-fold. The acidities presented in this report for water covered columns are therefore considered as maximum possible values.

After 154 weeks, the average total acidity from the control columns (load in drainage water plus load stored) was calculated to be 401 g $CaCO_3$; the average total (overestimated) acidity from the water covered columns was calculated to be 2.44 g $CaCO_3$. This represents a minimum efficiency of 99.5% in reducing acidity in the effluent (see Table 4.2).

The acid production rate from the water covered rocks was below 1 mg of $CaCO_3$/kg/week for the indoor and the outdoor tests. Figures 4-6 and 4-7 show that the acid production rate and pH were generally constant throughout the testing period and did not change significantly toward the end of the tests. The pH of the drainage water remained around 7.0.

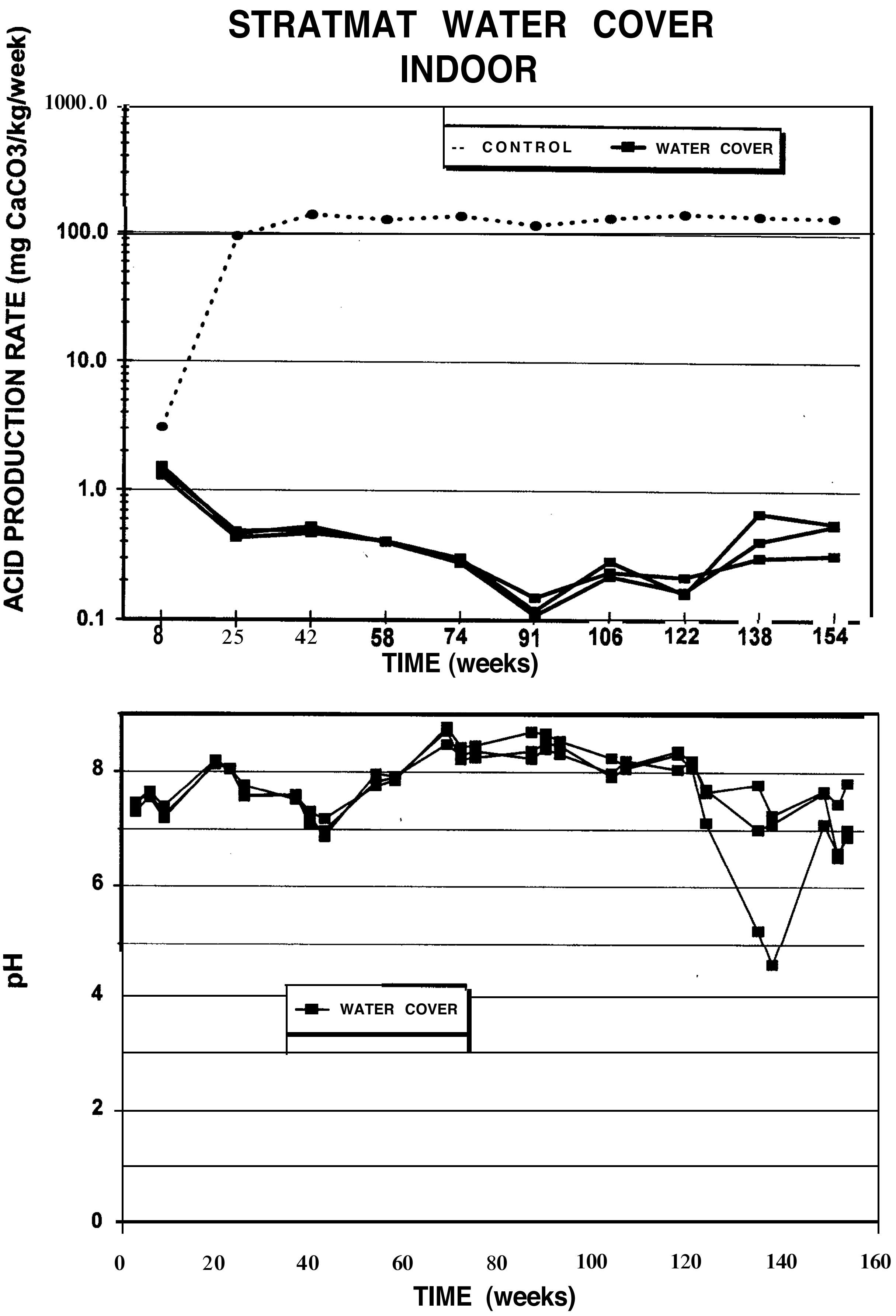


Figure 4-6: Acid production rate and pH in indoor flooded Stratmat drainage water

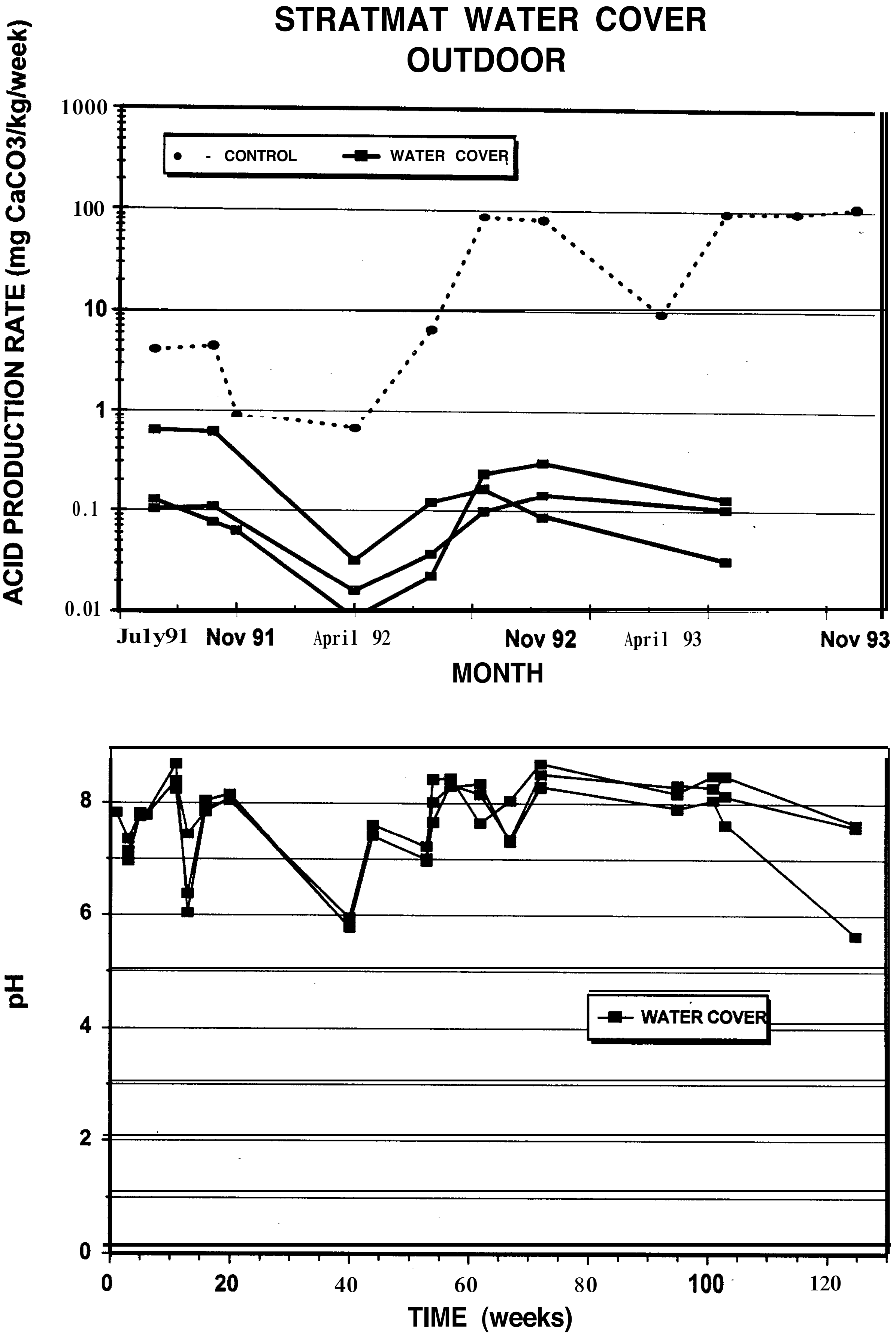


Figure 4-7: Acid production rate and pH in outdoor flooded Stratmat drainage water

Metals and non-metals released

The complete chemical analysis results are presented in Appendix A, Tables X to XII and XL to XLII. Table 4.2 shows the total release of the components considered most important in this investigation. The average percent decrease in release from the water covered columns (load in drainage water + load in cover water) over the control columns is also displayed for each component.

Table 4.3 Efficiency of the Water Cover Technique (Indoor Tests)

		Acidity	SO_4	Fe	Zn
		g of $CaCO_3$	g	g	g
CONTROL	Drainage	380	445	114	8.31
	Stored	21.2	31.9	5.05	0.58
WATER COVER	Drainage	1.24	5.34	0.031	0.080
	Water Cover	1.20	3.97	0.041	0.15
REDUCTION		99.4%	97.9%	99.9%	97.2%

The ion concentrations in the effluent from the water covered columns did not vary as much as those in the control tests, and could simply be averaged over each sampling set to obtain a reasonable estimate of the release rate. Also, since the acidity of the water covered columns was normally below the detection limit, it was impossible to obtain a correlation between acidity and other species, as was the case in the control tests.

The total mass of released acidity, Fe, Zn and SO, for both the water cover and control columns is presented in Table 4.2; they show that the acidity, Fe, Zn and SO_4 loading from the water covered columns is much smaller than that from the control columns. It is clear from the data presented in Table 4.2 that it is important to consider the amount of oxidation product retained in the water cover itself (water column above the waste rock). The mass of acidity, Fe, Zn and SO_4 measured in the water cover and in the drainage water are of the same order of magnitude.

Figure 4-8 shows the release of Zn and Fe from the water covered test columns over time. Fe and Zn concentrations in the effluent from the water covered columns did not exceed 1.0 mg/L until after one full year (Figure 4-8). Between 1 to 2 years, the concentrations of Fe and Zn remained between 1.0 and 4.0 mg/L. From week 122, to the next sampling at week 131, the average Fe and Zn concentrations more than doubled, and subsequently remained high. At the last sampling (week 154), the average concentration had reached 4.7 mg/L for Fe and 6.6 mg/L for Zn. In comparison, average Fe and Zn concentrations from the control test effluents ranged, respectively, from 2000 to 4000 mg/L and from 50 to 200 mg/L, and were at 1880 and 86 mg/L at the last sampling.

From Figure 4-8, it seems there are two separate rates of Zn and Fe release from the water columns. The first rate is constant until approximately 122 weeks of operation, while the second rate is active from week 122 to the end of the test. The two rates will be discussed further in this section of the report.

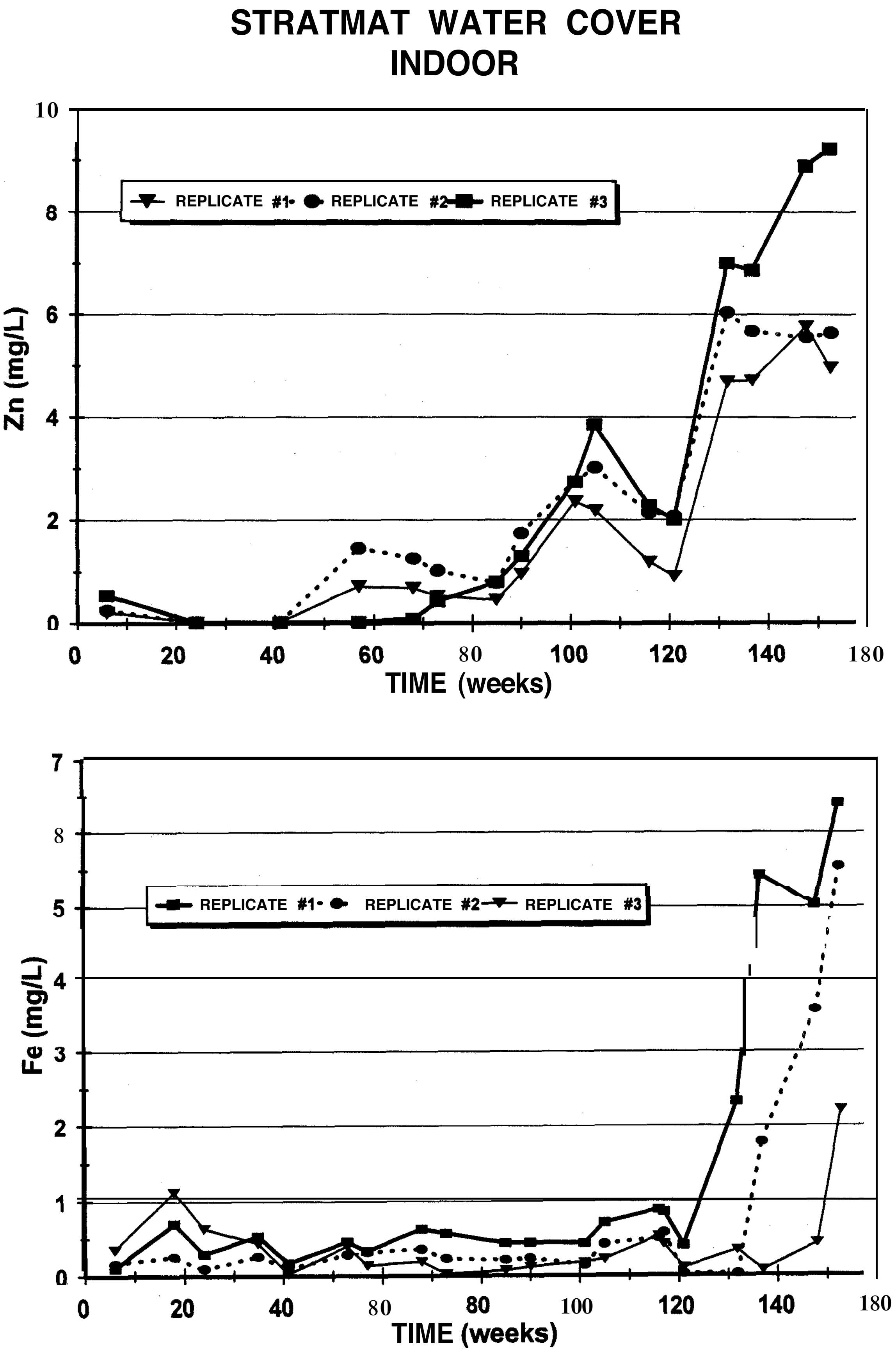


Figure 4-8: Zn and Fe concentrations in indoor flooded Stratmat drainage water

Lead release pattern was difficult to explain. Figure 4-9 shows that the concentration of Pb released from the water cover columns generally followed the same trend observed for Fe and Zn. Pb was detected in the drainage water around week 120 at an average concentration of approximately 2.0 mg/L. On the other hand, the control tests started generating Pb during the first month of the study, as observed for Fe and Zn. Whereas the mass of Fe and Zn produced by the water cover was only a fraction (1%) of the mass produced in the control tests, even with the stored oxidation product, the water cover tests produced 5 times more Pb than the control tests. The average mass of Pb including stored material was 38 mg for the control tests and 188 mg for the water cover tests. The rapid but early and short release of Pb from the control tests suggests that a soluble Pb mineral was probably initially present in the rock. The Pb released from the water covered rock was most likely a result of oxidation, as was observed for Fe and Zn. The outdoor tests showed the same tendency, as indicated in Tables XXXI toXXXII and XL toXLII in Appendix A..

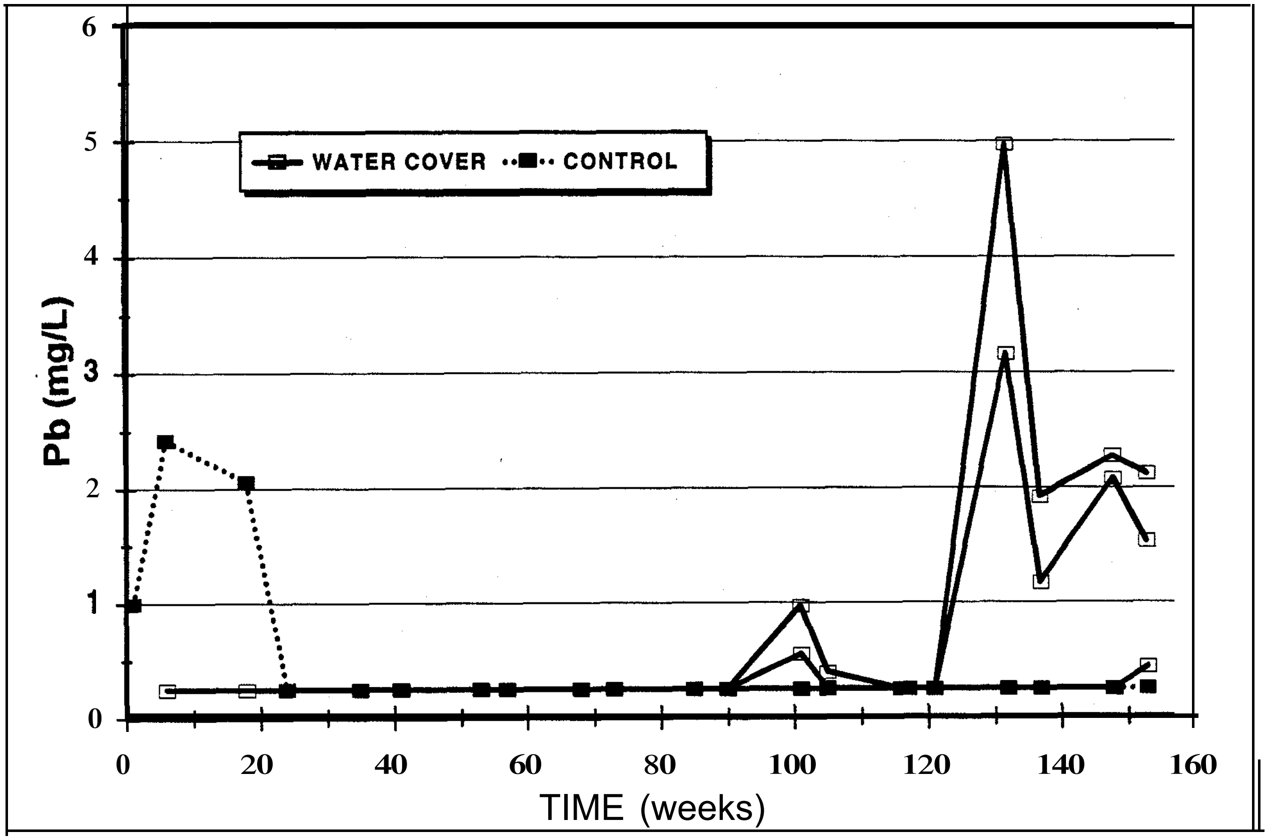


Figure 4-9 Lead in Drainage Water from Indoor Stratmat Control Water Cover Tests

In addition, flushing time was long because of the large volume of water stored in the water covered column; actually only 1.6 cover volumes of drainage were collected during the 154 weeks of testing. It was therefore unlikely that the sudden release of metals would have been due to flushing of initial pore water.

Dissolved Oxygen in Water Cover

The dissolved oxygen (DO) concentration in the Indoor water covers was measured regularly after 130 weeks of operation, both at the surface of the water and near the waste rock-water interface. The DO concentrations ranged from 6.1 to 7.4 mg/L near the surface and from 5.9 to 7.3 mg/L near the bottom of the cover. These DO concentrations are equivalent to about 75% saturation. The observed range in DO concentrations indicates a gradient of 0.1 to 0.2 mg/L per metre between the top and bottom of the water cover and it was found to be consistent in all the three water covered columns. This gradient cannot be used for flux calculations as the precision of the DO meter is of 0.1 mg/L and is not considered accurate enough for measurements of such small differences.

Rate Calculations

Morin (1993) has proposed equations for calculating the flux of oxygen into waste rock. The equations assume that the oxidation reaction is first order with respect to dissolved oxygen concentration, and that the dissolved oxygen concentration in the water cover is homogeneous and saturated throughout its depth. This is true only in well-mixed or well-aerated water covers. Other tests, using a 1 m water cover over tailings (St-Arnaud, 1994) have shown a DO gradient from 5.5 mg/L at the water surface, to 1.8 mg/L near the tailings surface.

The following equations can be found in either Morin (1993) or Lapakko (1994):

$$k = \frac{3.4 * 10^{-10}\ (1-n)\ \%PYR}{d} \qquad (3)$$

$$J = DO(cover) * 1000 * \sqrt{\frac{kDn}{T}} \qquad (4)$$

$$PR = FACT * J \qquad (5)$$

where: k = first order rate constant (s^{-1})
n = porosity (volume over volume) [0.3]
%PYR = percentage of pyrite in rock [19 %]
d = representative particle diameter (m) [0.025 to 0.051
J = oxygen flux at the water/waste rock interface (mg 0, m^{-2} s^{-1})
DO(cover) = dissolved oxygen concentration in water cover (mg O_2/L, assuming homogeneity throughout depth) [7]
D = dissolved oxygen diffusion coefficient (2x 10^{-9} m^2 s^{-1})
T = tortuosity (assume 3 for rock)
PR = production rate of acid, Fe or SO, (mg m^{-2} s^{-1})
FACT = stoichiometric factor which, when equation 1 is affecting the system is equal to 3.33 mg $CaCO_3$ equivalent per mg 0, for acid production, 1.6 for SO, production, and 0.465 for Fe production, if it is assumed that all iron leaves the system in ferric form and does not precipitate.

Using a porosity of 0.3, an average pyrite concentration of 19%, a worst-case diameter of 0.025 m and a DO concentration of 7 mg/L, an oxygen flux of 4.21×10^{-5} mg 0, m^{-2} s^{-1} is obtained. This is equivalent to an acid production rate of 1.40×10^{-4} mg $CaCO_3$ equivalent m^{-2} s^{-1}, using equation 1. The acid production rate cannot be compared to the experimental column results, as the measured acidity was often below the detection limit. The production rates of Fe and SO, obtained from the above equations are instead compared to actual rates in Table 4.3.

Also included in Table 4.3 is the result of regression analysis on partial Fe data from Figure 4-8. The overall release rate, designated as “Experimental”, was calculated using all the data and resulted in a correlation coefficient of 0.77. Linear regression done on the first 122 weeks’ data is called Rate 1, and resulted in a correlation coefficient of 0.98, while Rate 2 (122-154 weeks), gave a correlation coefficient of 0.97. These regression results suggest that separating the Fe release into two separate rates is more representative than the overall result. The difference between the two rates is more than an order of magnitude. This large increase occurred at the same time as the initial pH drop, but cannot be related directly to pH, as the pH recovered in the last sampling round whereas the Fe release continued to increase.

Table 4.4 Chemical release rates ($mg/(m^2 \cdot s)$)

	Diameter (mm)	SO_4	Fe
Water Cover - Predicted max	25	6.74×10^{-5}	1.96×10^{-5}
Water Cover - Predicted min	50	4.76×10^{-5}	1.38×10^{-5}
Water Cover - Experimental	25-50	3.05×10^{-3}	7.03×10^{-6}
Percent of Predicted max (%)		4525	36
Fe Rate 1- Weeks O-122			5.80×10^{-6}
Fe Rate 2- Weeks 122- 154			6.76×10^{-5}

The calculated Fe release rates fit reasonably well, they are actually between the two divided rates. Sulphate release rates are nearly 50 times higher than predicted. This high sulphate release is probably due to a separate source, such as the dissolution of sulphate solids already present in the waste rock. The initial characterization showed that 0.11% of the original rock contained sulphate; this represents a total mass of 22 g, while the total sulphate (both collected and stored in the water cover) accounts for only 9.3 1 g. This means that not all the soluble SO, in the rock dissolved.

The metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

4.3 **Stratmat Limestone** (3%)

Testing Results

Acid production rate and pH

Acidity measured in the drainage water from the indoor Stratmat waste rock treated with a limestone dosage of 3% averaged a cumulative value of 8.57 g of $CaCO_3$. This amount of acidity was added to the 0.53 g of $CaCO_3$ measured as the oxidation product stored in the column. After 154 weeks, the total average acidity production was 9.10 g of $CaCO_3$ which represents an acid reduction of 97.7% relative to the control tests. The acid production rate was calculated to be 2.96 mg of $CaCO_3$ /kg/week. The drainage water from the outdoor 3% limestone amended Stratmat rock, on the other hand, produced an average of 49.3 g of $CaCO_3$ with the calculated average acid production rate being 2.32 mg of $CaCO_3$ /kg/week for a testing period of 125 weeks. The acid reduction was 94.3%.

In spite of the high acid reduction, two of the indoor replicates showed a sharp drop in pH from week 140. The pH decreased from 7.0 to 3.0 within a few weeks. A similar drop in pH was observed in one of the outdoor test replicates after week 100. The acid production rate showed exactly the same trend for the indoor and outdoor tests (Figures 4-10 and 4-l 1). The effectiveness of the 3% limestone was near 100% for 100 weeks, after which period it dropped sharply to 90%, probably due to depletion of the limestone.

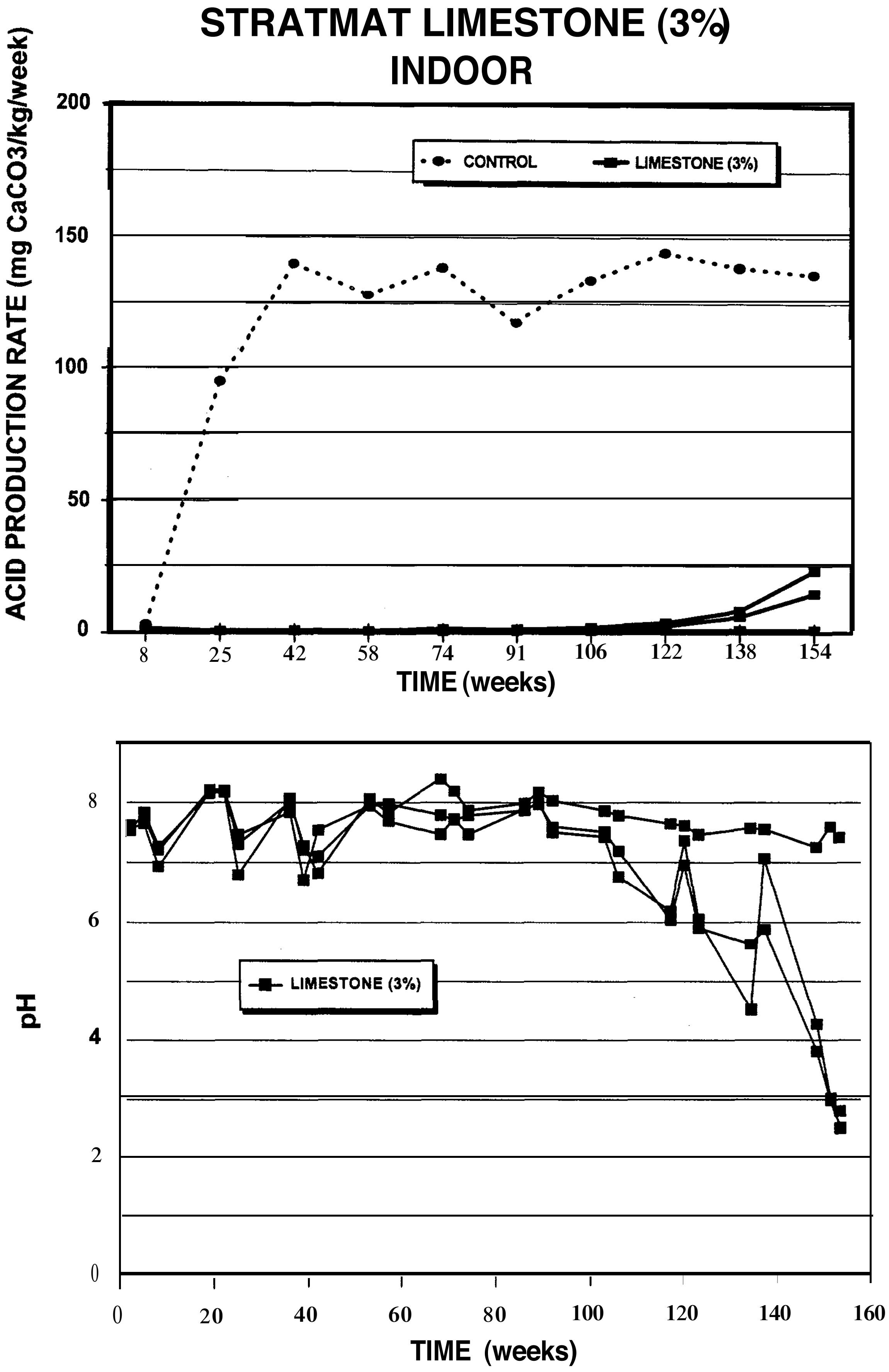


Figure 4-10: Acid production rate and pH in indoor 3% limestone-amended Stratmat drainage water

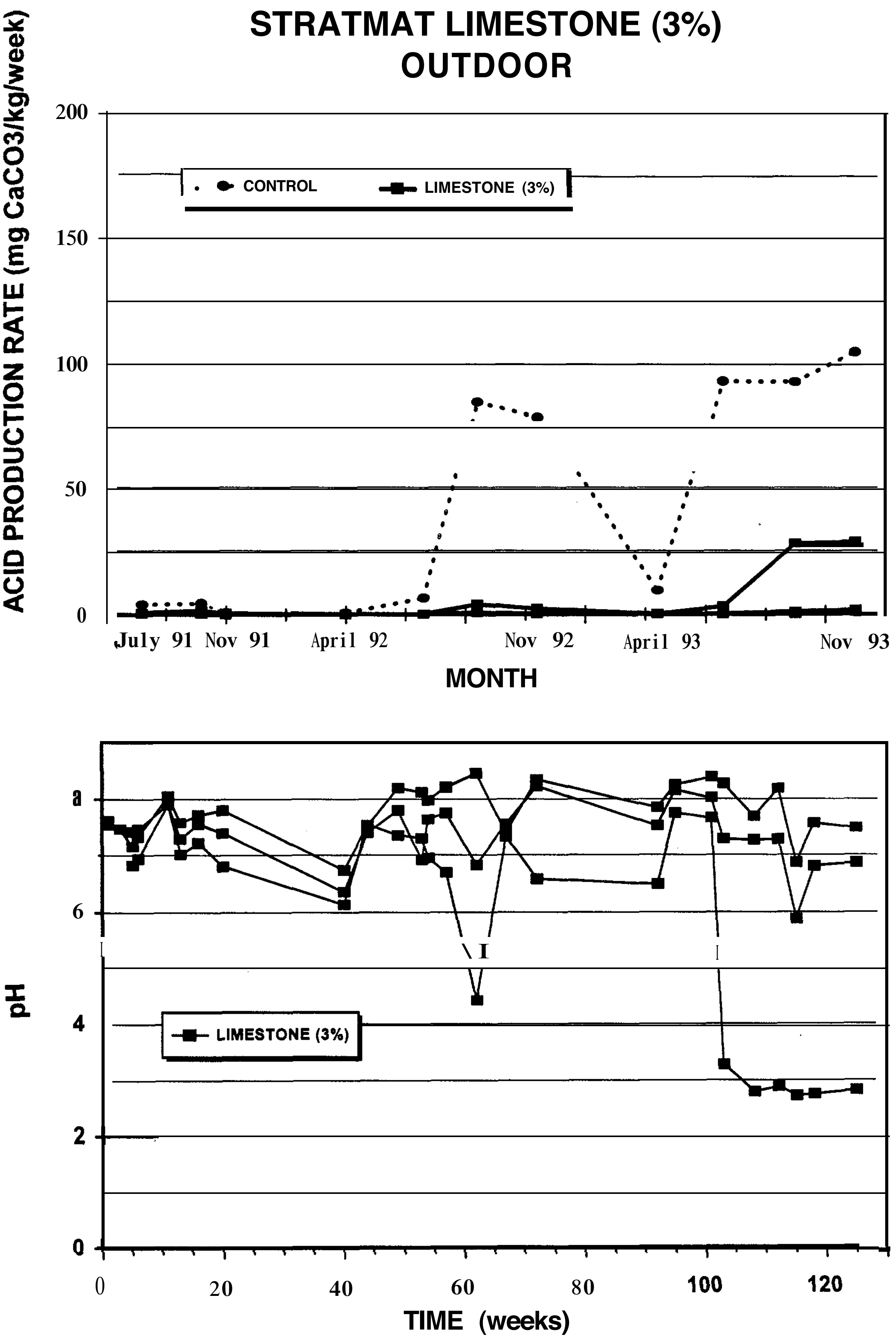


Figure 4-1 1: Acid production rate and pH in outdoor 3% limestone-amended Stratmat drainage water

To evaluate whether the limestone reacted and neutralized the oxidation products or was just washed out by regular water addition or ram, SO, concentrations measured in the drainage water were used to calculate the actual acid production rate of the waste rock. Since SO, is formed by the oxidation of sulphide mineral, according to reaction (1), and does not react with limestone, the SO, concentration was used to calculate the real amount of pyrite oxidized during the testing period. Acidity measured on the drainage water was, however, used to calculate the apparent acid production rate.

Figure 4-12 shows that the estimated amounts of pyrite oxidized in the indoor and outdoor control tests based on either acidity or sulphate are similar. The figure, also indicates that limestone treatment reduced the amount of pyrite oxidized significantly and that the limestone not only neutralized the oxidation products but also delayed pyrite oxidation by approximately three years. The sulphate loading measured in the drainage water was overestimated because of dissolution of sulphate solids already present in the waste rock. The initial characterization showed that 0.11% of the original rock contained sulphate. Since sulphate was used to calculate the amount of pyrite oxidized, the results described in Figure 4-12 can be considered to represent a maximum possible mass of pyrite oxidized. Even by assuming that all the sulphate was produced by oxidation, only 55 g and 180 g of limestone were consumed in indoor and outdoor tests respectively, to neutralize the oxidation products. These consumed amounts of limestone were equivalent to 9.1% and 3.5% of the total mass added to the waste rock.

Since the effectiveness of the limestone was decreasing toward the end of the tests, it was concluded that the limestone was not consumed but may have either being armoured through the formation of ferric hydroxide or washed through regular water addition.

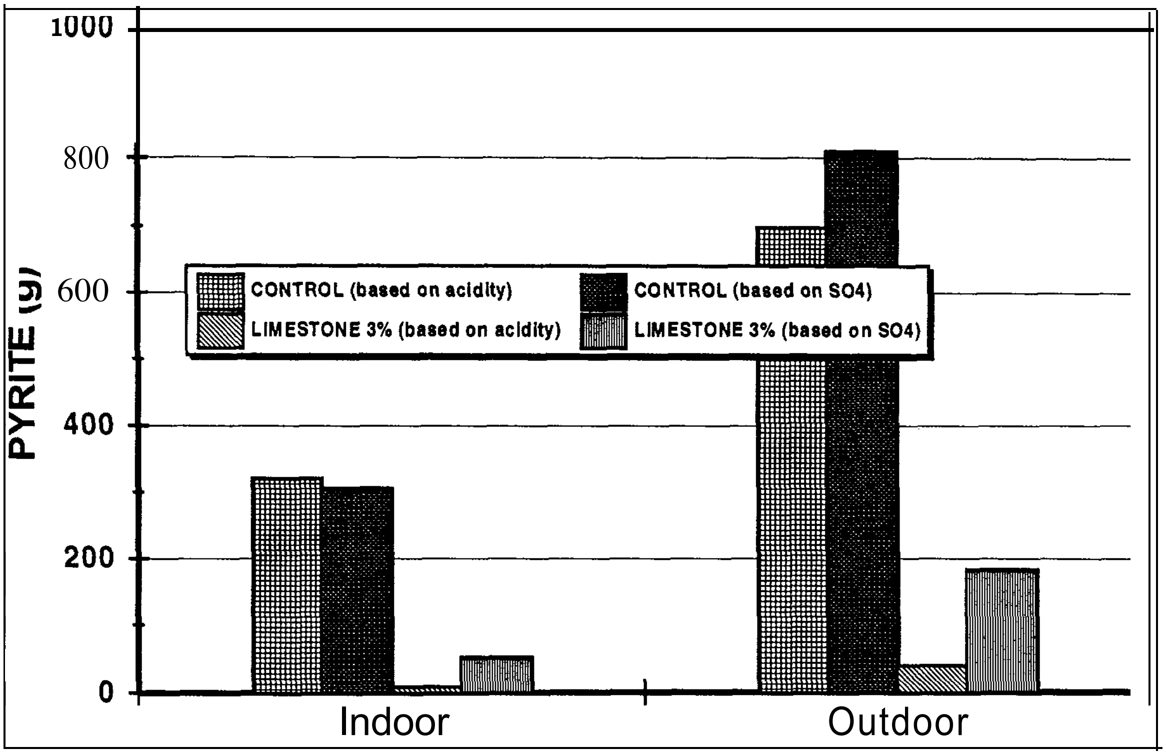
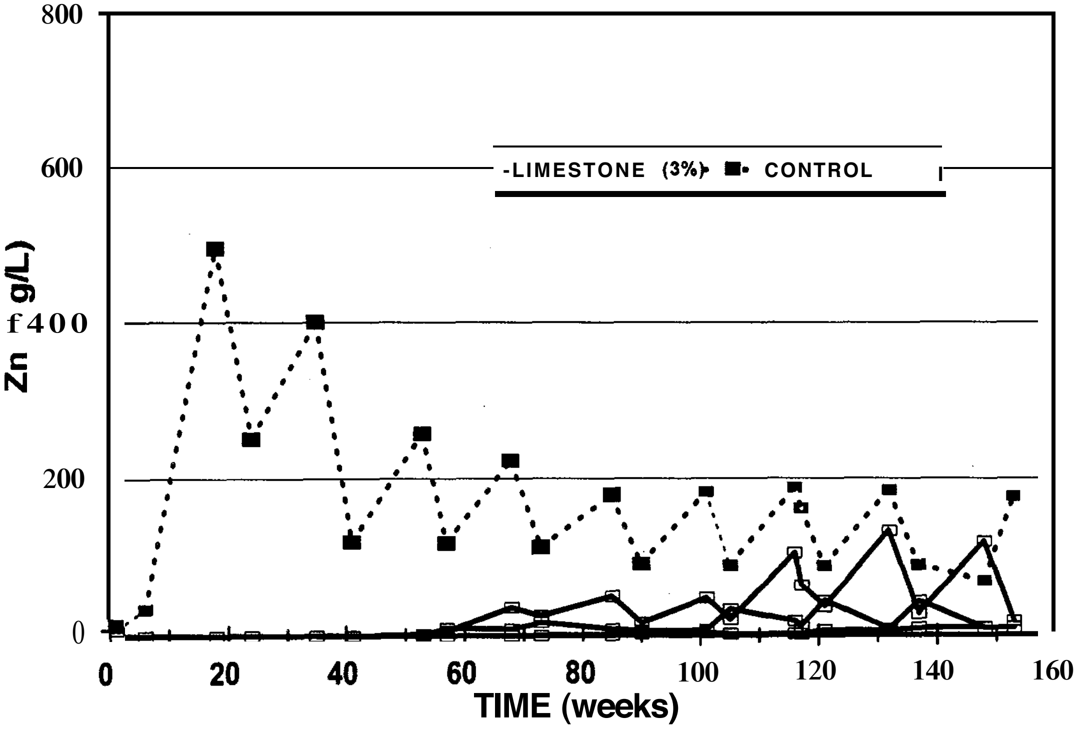


Figure 4- 12 Effect of 3% Limestone Addition on Acid production rates

Metals and Non-Metals Released

The results of complete chemical analysis of metals and non-metals released during the tests are presented in Appendix A, Tables VII to IX and XXXVII toXXXIX. Metal concentrations in the drainage water from the 3% limestone amended indoor and outdoor tests were near the detection limit for most of the testing period. Zinc, however, was released early in the study as shown in Figure 4-13, Zn concentrations of approximately 20 mg/L were found in the drainage water of the indoor tests as early as week 55. The outdoor tests released Zn even earlier; around week 20 the concentration of Zn in the drainage water in one of the replicates was as high as the Zn concentration in the control tests. (~ 150 mg/L).

STRATMAT LIMESTONE (3%)
INDOOR



OUTDOOR

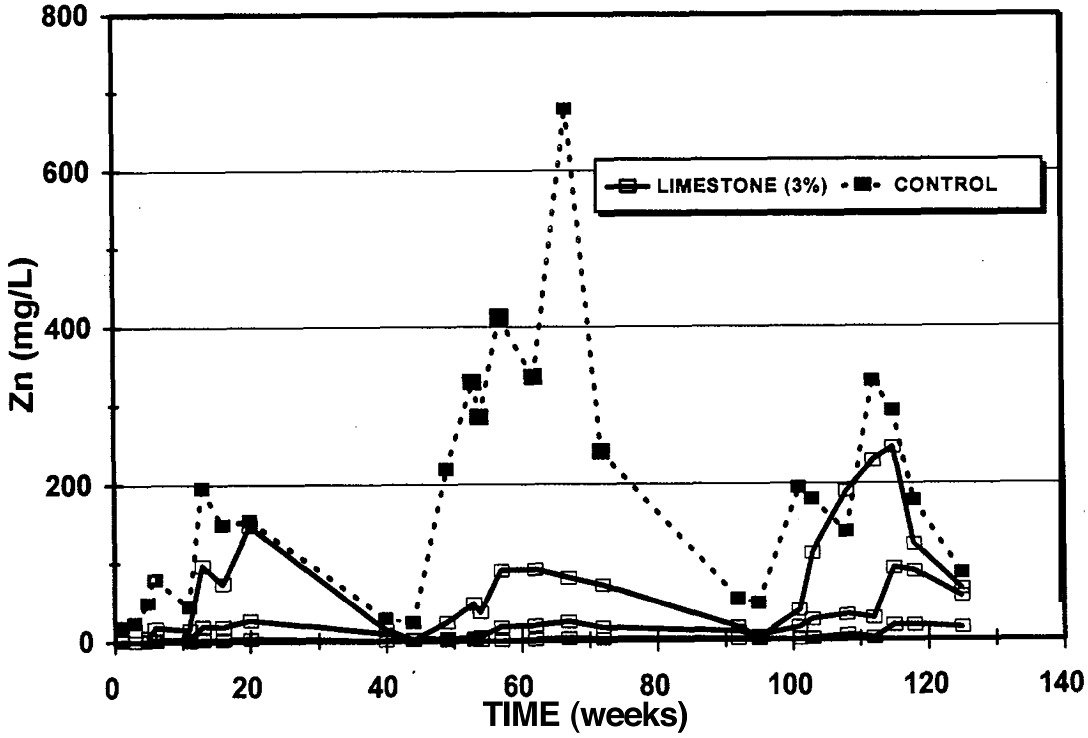


Figure 4- 13 : Zn concentrations in indoor and outdoor 3% limestone-amended Stratmat drainage waters

Post-Testing Results

The amount of acidity stored in the indoor columns was only 0.53 g of $CaCO_3$; this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate. The metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

The density profile of the waste rock showed that the surface rocks were slightly denser (2.92 g/cc) compared to the bottom rocks (2.78 g/cc). This difference in density can be explained by preferential leaching of sulphide minerals at the bottom of the column, as already noted.

4.4 Stratmat Limestone (1%)

Testing Results

Acid production rate and pH

The acidity measured in the drainage water from the indoor 1% limestone amended Stratmat waste rock averaged a cumulative value of 65.6 g of $CaCO_3$. This amount of acidity was added to the 3.82 g of $CaCO_3$ measured as the oxidation product stored in the column. After 154 weeks, the total average acid production was 69.4 g of $CaCO_3$ which represents an acidity reduction of 82.7% relative to the control tests. The acid production rate was calculated to be 22.5 mg of $CaCO_3$/kg/week. Drainage waters from the outdoor Stratmat waste rock columns produced an average of 139 g of $CaCO_3$, with the calculated average acid production rate being 6.53 mg of $CaCO_3$ /kg/week over a testing period of 125 weeks. This represents an acid reduction of 84.1% relative to the control tests.

In spite of the relatively high acid reduction, two of the indoor replicates showed a sharp decrease in pH from week 50. The pH decreased from 7.0 to 3.0 within a few weeks. A similar decrease in pH was observed in two replicates of the outdoor tests. Acid production rates showed similar trends in indoor and outdoor tests, as indicated in Figures 4-14 and 4-15. The effectiveness of the 1% limestone was near 100% during 50 weeks but subsequently dropped sharply to an average of 60% towards the end of testing, probably because of limestone depletion.

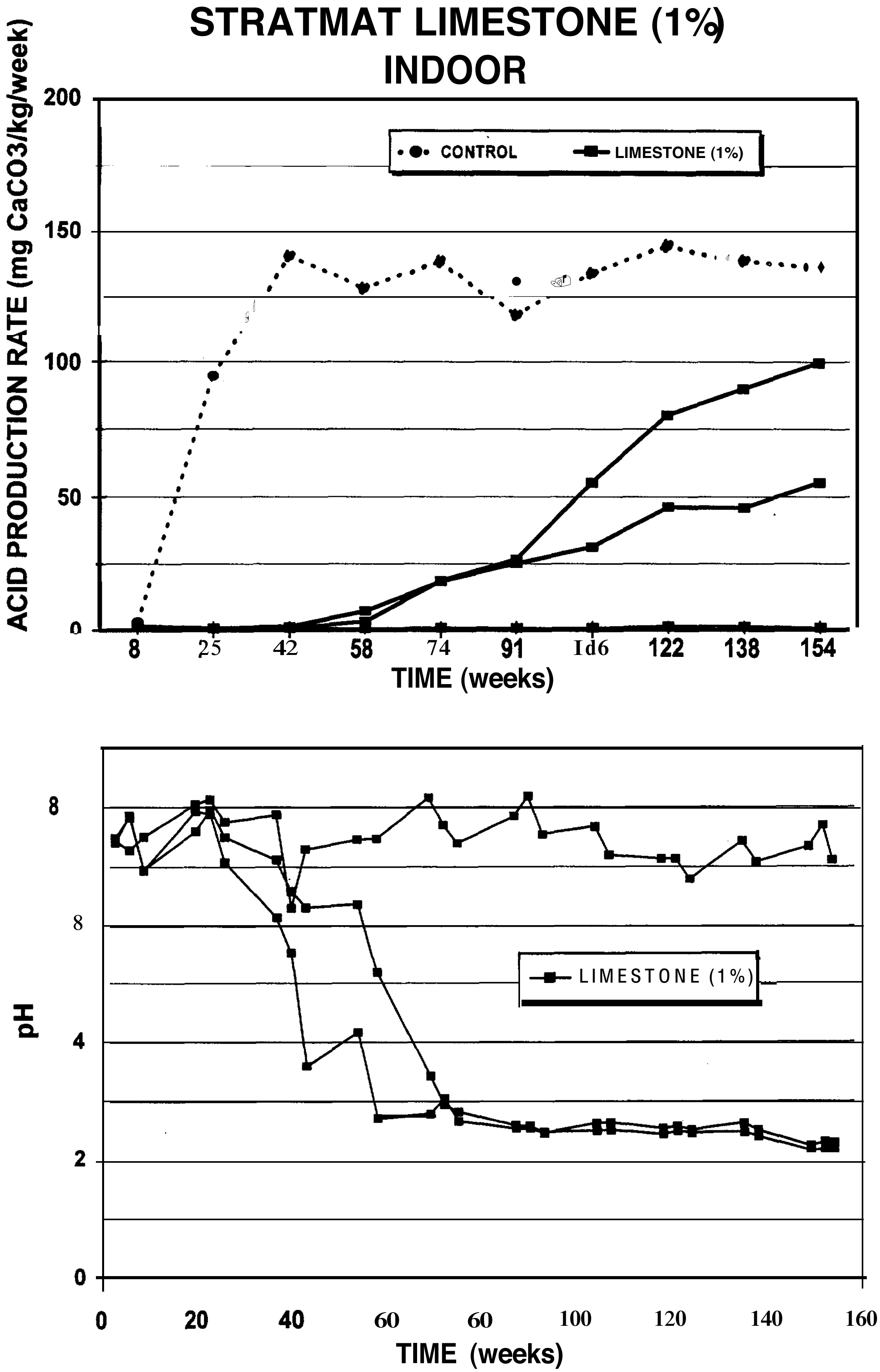


Figure 4-14: Acid production rate and pH in indoor 1% limestone-amended Stratmat drainage water

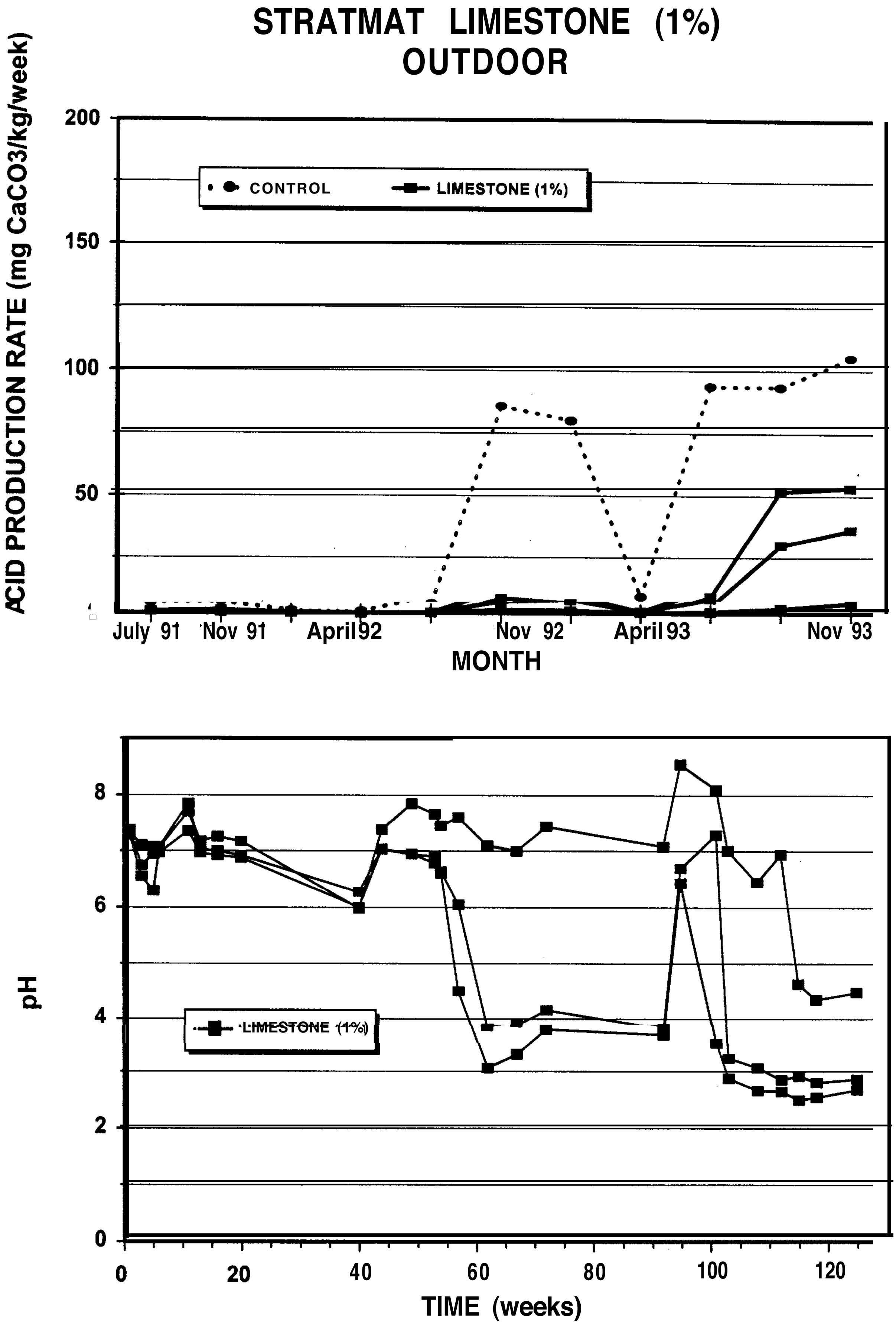


Figure 4-1 5: Acid production rate and pH in outdoor 1% limestone-amended Stratmat drainage water

In order to evaluate whether the limestone reacted and neutralized the oxidation products or was armoured or was just simply washed out by regular water addition or rain, the calculations performed previously for the 3% limestone dosage were repeated for the 1% limestone. Figure 4-16 shows that the limestone treatment reduced the amount of pyrite oxidized significantly and that the limestone not only neutralized the oxidation products but also delayed pyrite oxidation by approximately one year. As mentioned previously, the sulphate loading measured in the drainage water and attributed to pyrite oxidation was overestimated because of dissolution of sulphate solids initially present in the waste rock. The initial characterization showed that 0.11% of the original rock contained sulphate. Even by assuming that all the sulphate was produced by oxidation, only 25 g and 18 1 g of limestone would have been consumed in indoor and outdoor tests, respectively, to neutralize the oxidation products. These amounts represent 12.5% and 10.5% of the mass of limestone added to the waste rock. The reduction in limestone effectiveness towards the end of the tests suggests that it was either armoured or was simply washed out by regular water addition, as was noted for the 3% dosage.

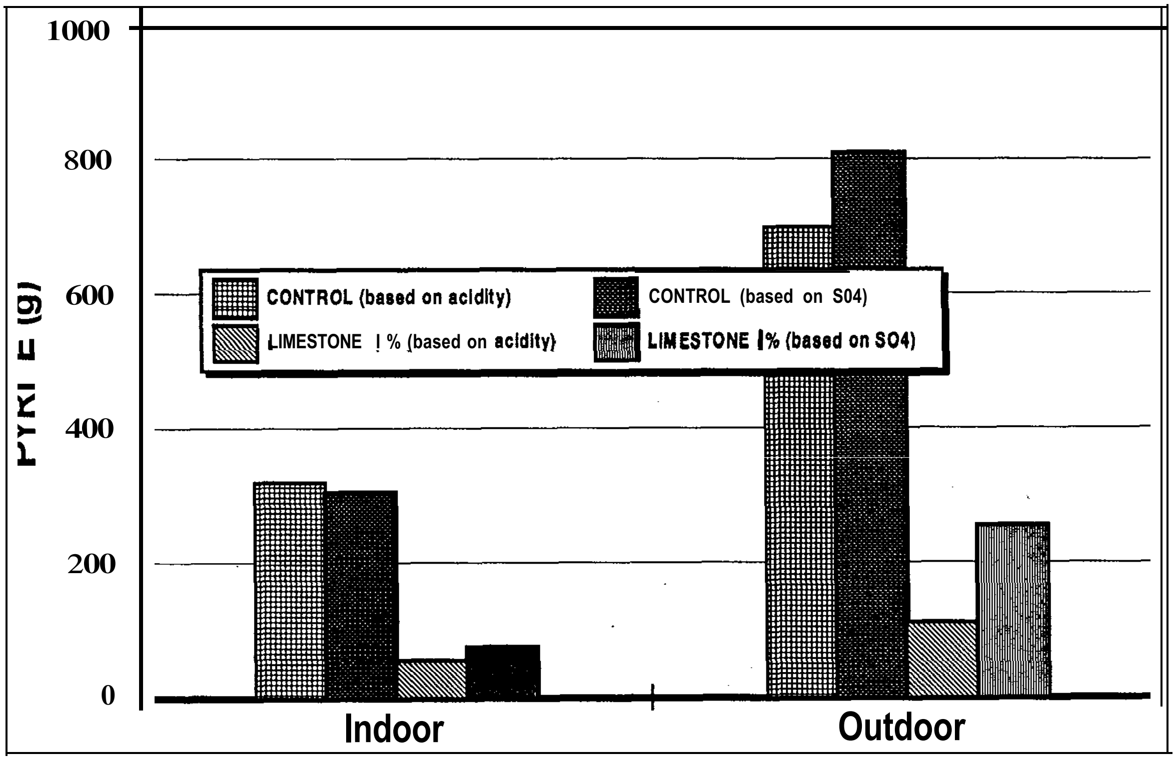
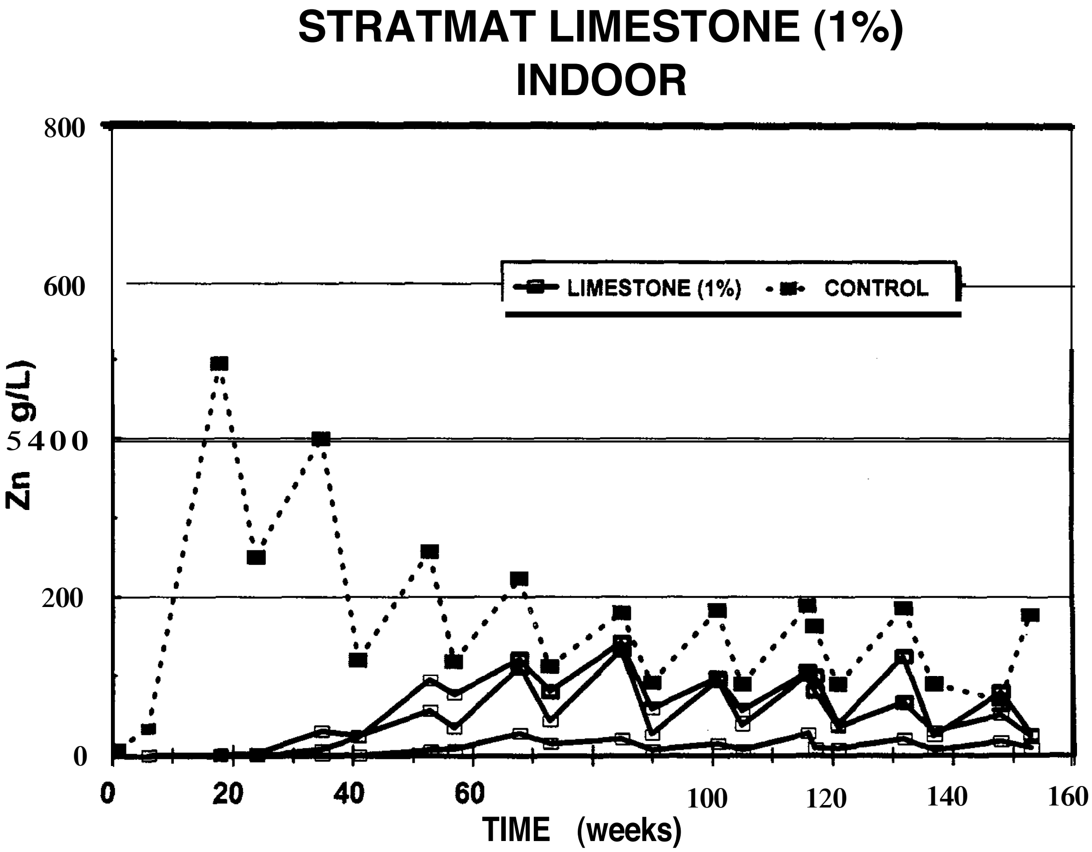


Figure 4- 16 Effect of 1% Limestone Addition on Acid production rates

Metals and Non-Metals Released

The complete results of chemical analysis conducted on drainage waters from the 1% limestone amended Stratmat rock are presented in Appendix A, Tables IV to VI and XXXIV to XXXVI. Although measured acidity was found to be at the detection limit during the first year, most of the metals present in drainage waters from the control unamended rock were also found in those of the indoor and outdoor 1% limestone amended rock, early in the tests. Zinc concentrations are graphed in Figure 4-17 to illustrate the fact that substantial concentrations of metals were detected in the drainage water early in the study. These results indicate that the 1% limestone was not as effective as the 3% in reducing acid production and metal release from the Stratmat waste,



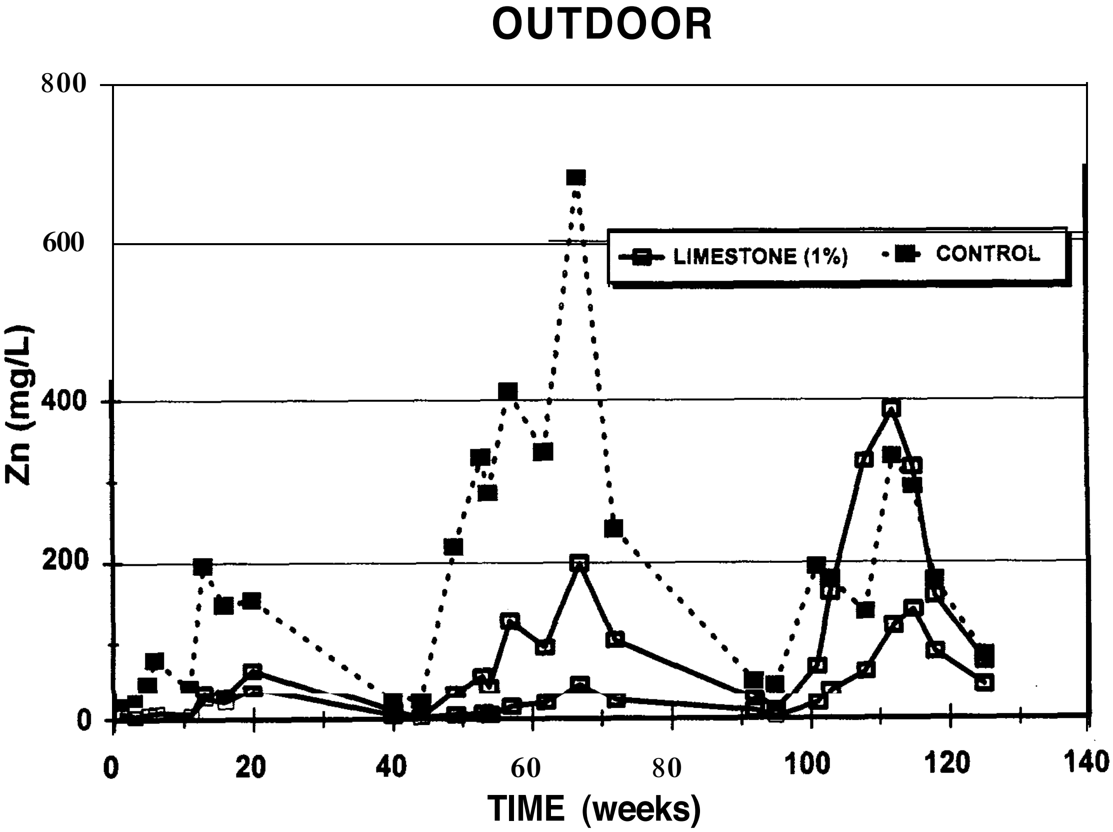


Figure 4-17: Zn concentrations in indoor and outdoor 1% limestone-amended Stratmat drainage waters

Post-Testing Results

The amount of acidity stored in the indoor columns was 3.82 g of $CaCO_3$, this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate.

Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

The density profile in the 1% limestone amended column did not indicate any significant difference between the surface rocks (2.89 g/cc) and the bottom rocks (2.80 g/cc), as was observed in the other tests.

4.5 Stratmat Phosphate (3 %)

Testing Results

Acid production rate and pH

The drainage water from the indoor Stratmat waste rock treated with 3% phosphate produced an average cumulative acidity of 137 g of $CaCO_3$. This amount of acidity was added to the 6.80 g of $CaCO_3$ estimated as oxidation product stored in the column. After 154 weeks, the total average acidity production was 144 g of $CaCO_3$ which represents an acid reduction of 64.2%. The acid production rate was calculated to be 46.6 mg of $CaCO_3$/kg/week. The drainage water from the outdoor Stratmat waste rock columns, on the other hand, produced an average of 266 g of $CaCO_3$. The calculated average acid production rate was 12.5 mg of $CaCO_3$/kg/week during 125 weeks of testing which was equivalent to 69.5% acid reduction, relative to the control tests.

The indoor replicates showed a sharp drop in pH from 7.0 to 3.0 during weeks 5 to 20. The acid production rate (Figure 4- 18) increased steadily throughout the testing period to approximately 75 mg of $CaCO_3$ /kg/week at the end of testing which established an acid reduction of only 42%. Similar results were observed for the outdoor tests, although the pH reduction was not as sharp as the pH reduction in the indoor tests. One of the replicates in the outdoor tests (Figure 4-19) showed a rapid drop in pH and an acid production rate similar to the control tests. Based on these results, the effectiveness of the 3% phosphate addition was considered marginal.

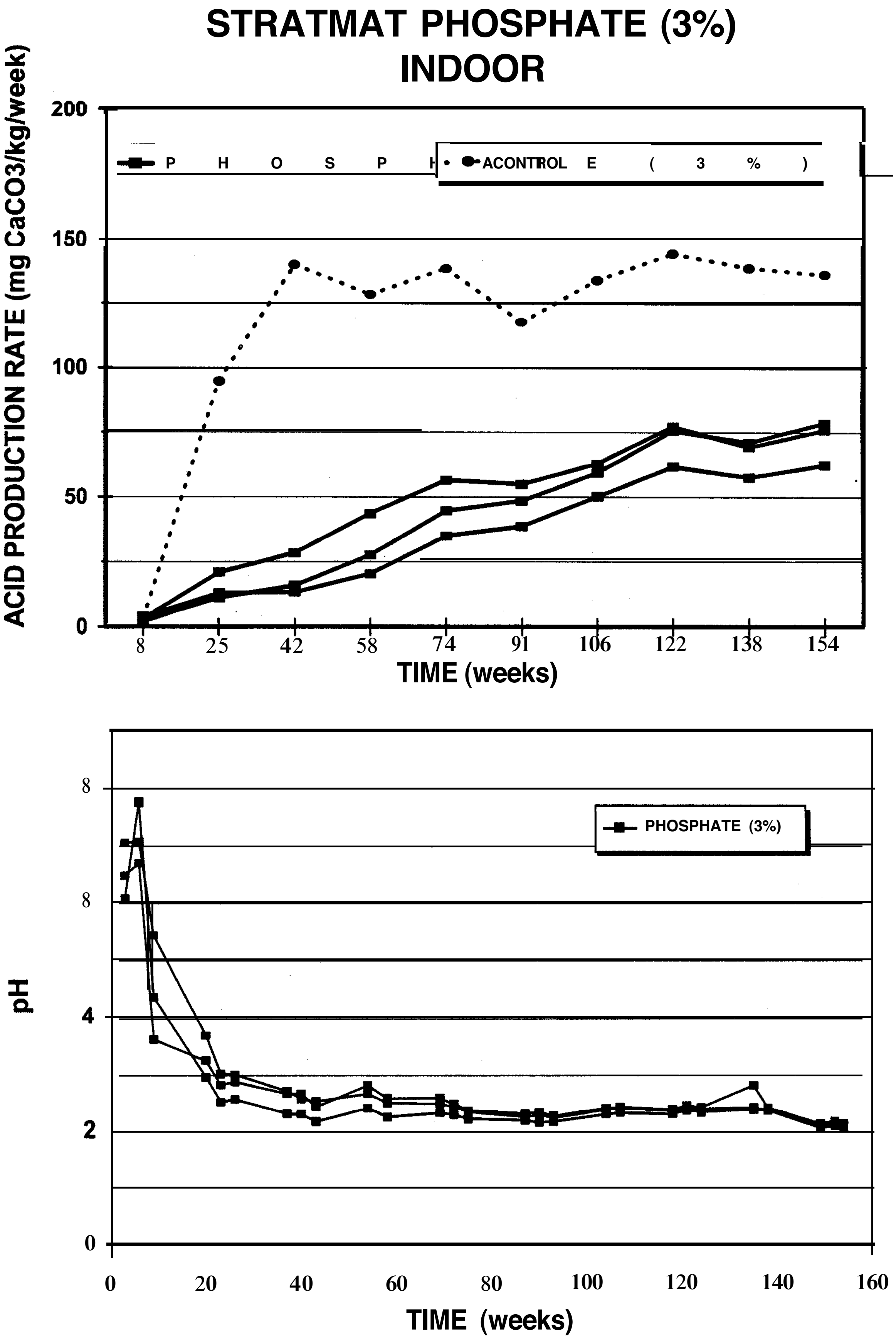


Figure 4-18: Acid production rate and pH in indoor 3% phosphate-amended Stratmat drainage water

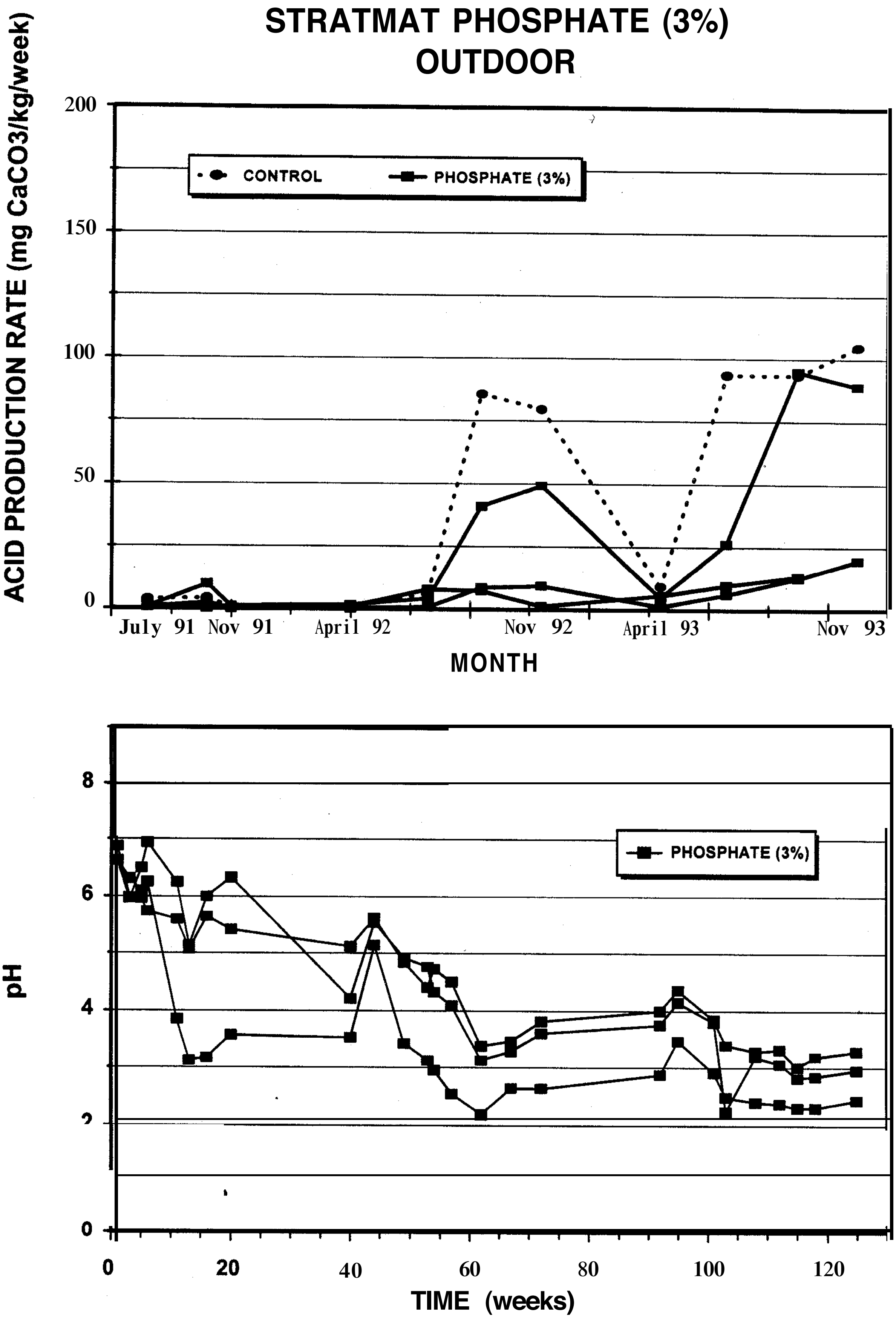


Figure 4- 19: Acid production rate and pH in outdoor 3% phosphate-amended Stratmat drainage water

Metals and Non-Metals Released

The complete results of chemical analysis obtained on drainage waters from the 3% phosphate tests are presented in Appendix A, Tables XIX to XXI and XLIX to LI. Metals in the indoor and outdoor drainage waters were detected as early as week 6; however, the metal concentrations in the outdoor tests remained low throughout the first summer as observed for the acidity results shown in Figure 4-19. The major metals released indoors were: Fe (1000 - 3000 mg/L), Al (100 - 200 mg/L) and Zn (50 - 100 mg/L). Other ions and elements detected include: SO, $^{2-}$ (3000 - 8000 mg/L), Mg (100 - 200 mg/L), Ca (300 - 500 mg/L), Mn (15 - 50 mg/L), As (10 mg/L) and Si (20 - 40 mg/L).

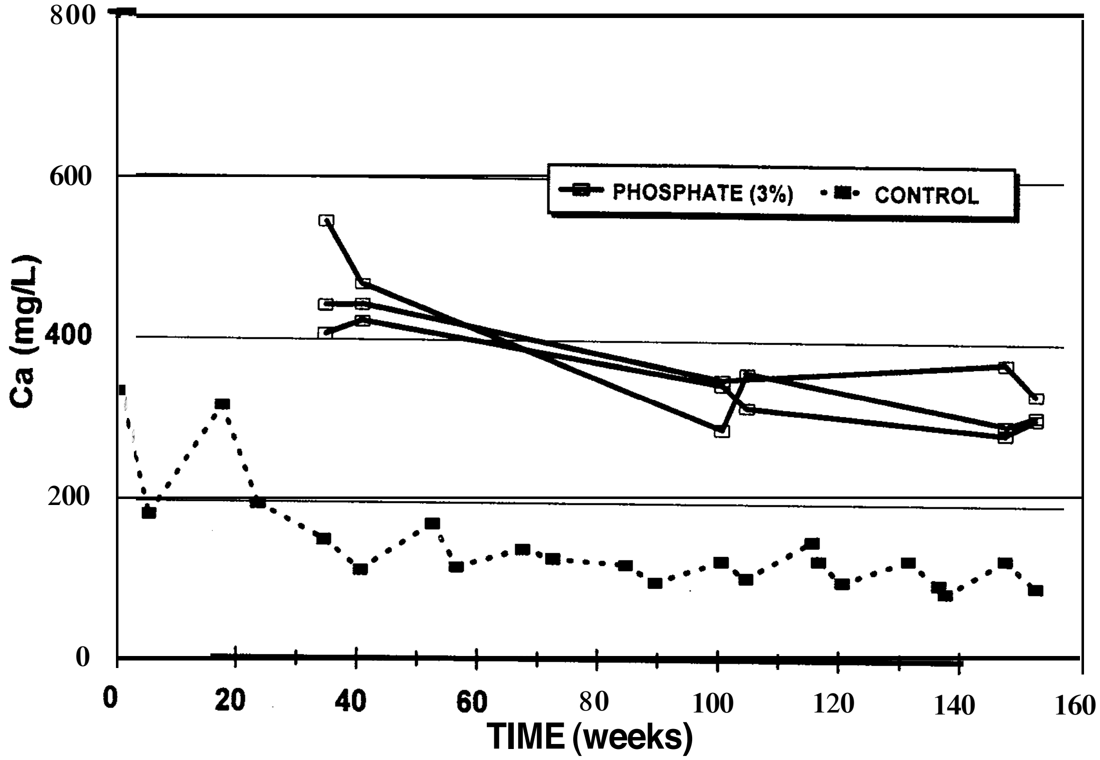
Drainage waters from the outdoor tests showed wider variation in species concentrations than those from indoor tests due to seasonal temperature changes, although the same species were found in both sets of tests.

Figure 4-20 shows that calcium concentrations in the drainage water from the 3% phosphate amended rock were higher than those from the control tests. The source of Ca could be the dissolution of the carbonate mineral initially present in the phosphate rock (10% by weight). The dissolution of this carbonate mineral could account for the 69.5% acid reduction observed in the phosphate treated tests.

A few samples of drainage water were analysed for Fe^{+3}, the results of which indicated that an average of 92% of the Fe was oxidized to Fe $^{+3}$ (ferric state).

STRATMAT PHOSPHATE (3%)

INDOOR



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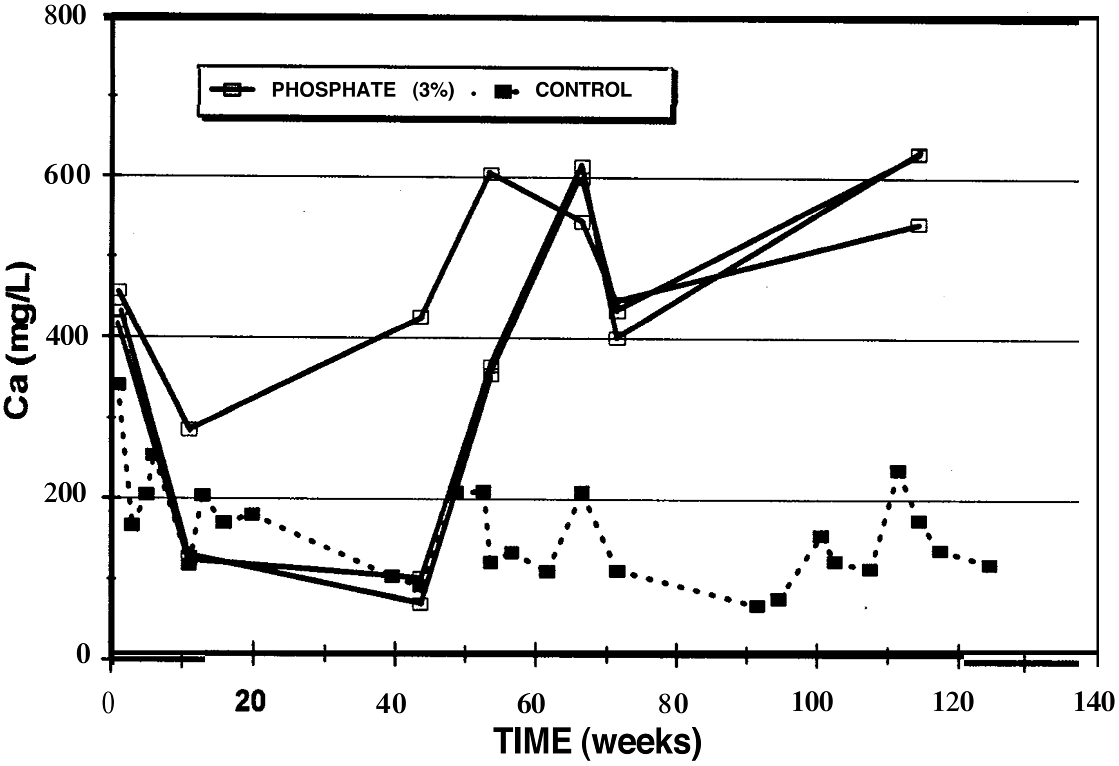

Figure 4-20: Calcium concentrations in indoor and outdoor 3% phosphate-amended Stratmat drainage waters

Post-Testing Results

The amount of acidity stored in the indoor columns was 6.80 g of $CaCO_3$, this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate.

Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI. The density profile in the 3% phosphate column showed that the surface rocks were slightly denser (2.91 g/cc) compared to the bottom rocks (2.78 g/cc), suggesting preferential sulphide leaching at the bottom, as previously noted.

4.6 Stratmat Phosphate (1%)

Testing Results

Acid production rate and pH

The drainage water from the indoor Stratmat waste rock treated with 1% phosphate dose produced an average cumulative acidity of 342 g of $CaCO_3$. This amount of acidity was added to the 15.6 g of $CaCO_3$ measured as the oxidation product stored in the column. After 154 weeks, the total average acidity production was 358 g of $CaCO_3$ which represents an acid reduction of 10.8%. The acid production rate was calculated to be 116 mg of $CaCO_3$/kg/week. The drainage water from the outdoor Stratmat waste rock columns produced an average of 726 g of $CaCO_3$, with the calculated average acid production rate being 34.2 mg of $CaCO_3$/kg/week over a 125 week testing period. The corresponding acid reduction was 16.7% relative to the control.

Acidity and pH observed in the indoor and outdoor 1% phosphate tests were almost identical to the results found for the control tests. Figures 4-2 1 and 4-22 illustrate that 1% phosphate addition had no effect on acid production from the Stratmat waste rock.

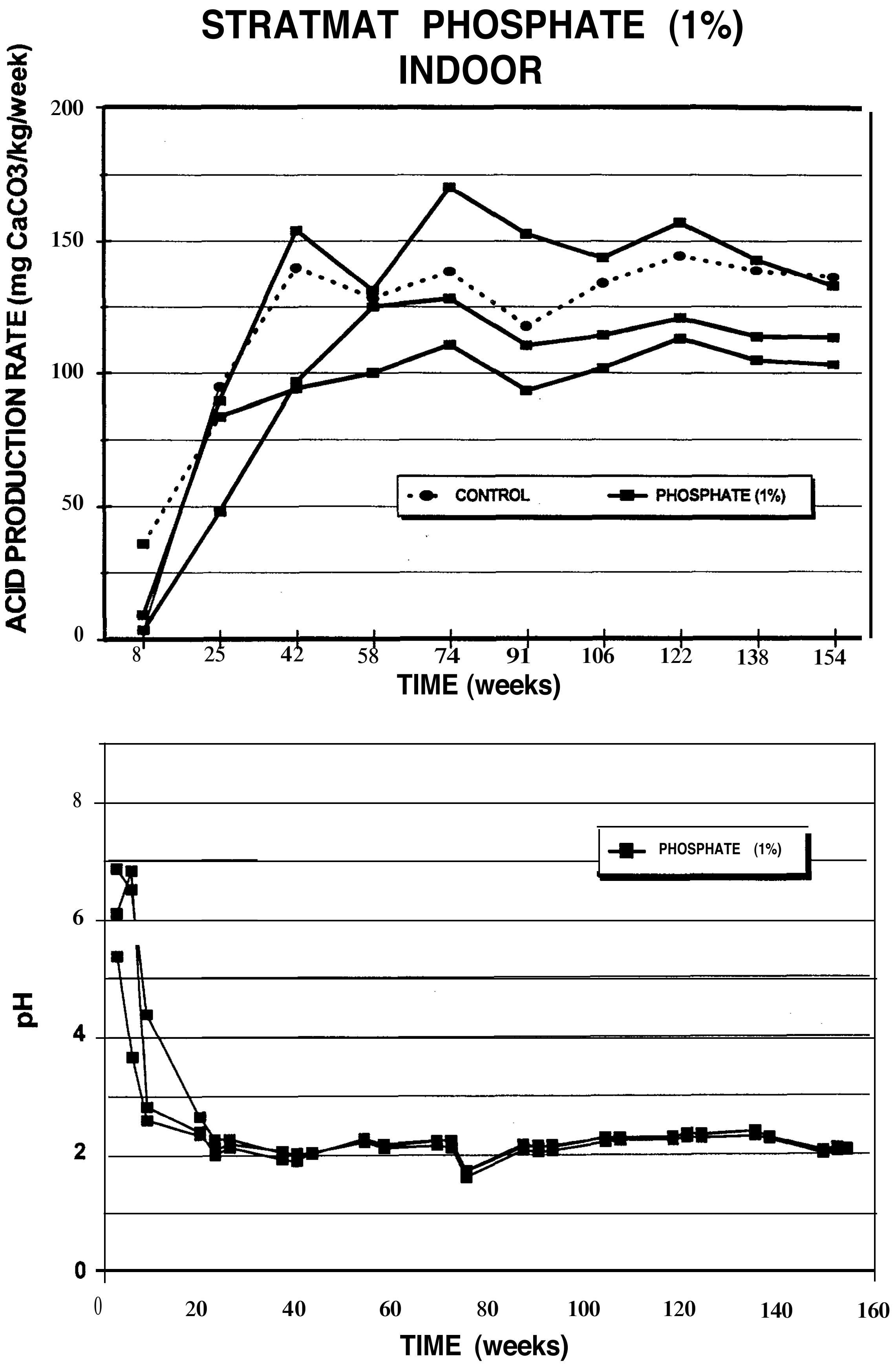

Figure 4-2 1: Acid production rate and pH in indoor 1% phosphate-amended Stratmat drainage water

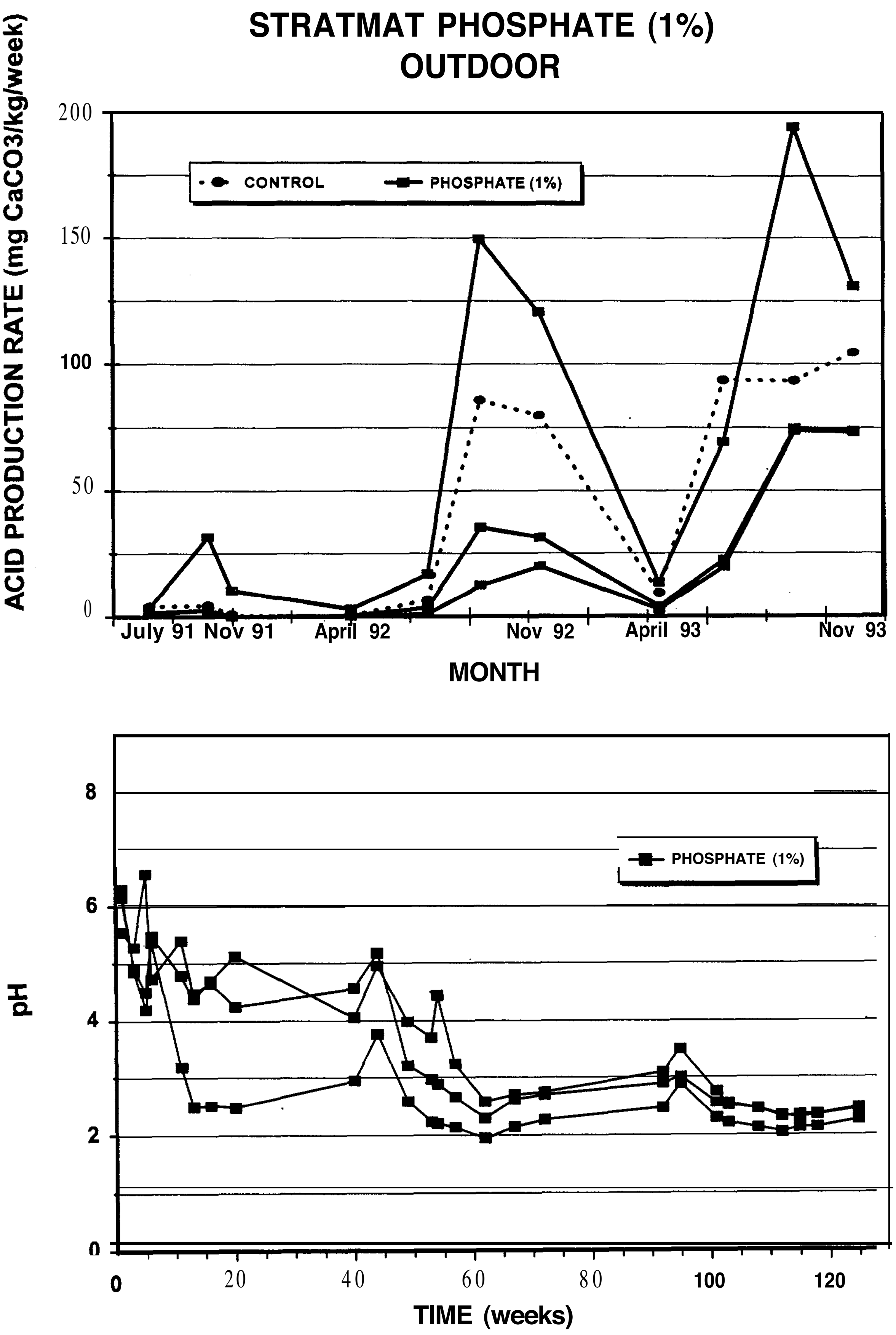

Figure 4-22: Acid production rate and pH in outdoor 1% phosphate-amended Stratmat drainage water

Metals and non-metals released

The complete chemical analysis results are presented in Appendix A, Tables XVI to XVIII and XLVI to XLVIII. Metal concentrations in the indoor and outdoor drainage water were detected early in the study and at concentrations similar to the control tests.

Post-Testing Results

The amount of acidity stored in the indoor columns was 15.6 g of $CaCO_3$, this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate.

Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

The density of the 1% phosphate amended waste rock was higher for surface rocks (2.95 g/cc) than for the bottom rocks (2.76 g/cc). This density variation may reflect greater leaching of sulphide minerals at the bottom of the columns, as previously explained for the control columns.

4.7 Stratmat Soil Cover

Testing Results

Acid production rate and pH

Drainage waters from the indoor Stratmat waste rock covered with the three-layer soil cover produced an average cumulative acidity of 6.50 g of $CaCO_3$. This amount of acidity was added to the 1.51 g of $CaCO_3$ measured as the oxidation product stored in the column. After 154 weeks, the total average acidity production was 8.01 g of $CaCO_3$ which represents an acid reduction of 98.0%. The acid production rate was calculated to be 2.61 mg of $CaCO_3$ /kg/week. The drainage water from the outdoor Stratmat waste rock columns, on the other hand, produced an average of 466 g of $CaCO_3$, with the calculated average acid production rate being 21.9 mg of $CaCO_3$/kg/week for a testing period of 125 weeks. The acid reduction was 46.6%.

In spite of the high acid reduction observed in the indoor tests, the pH fluctuated continuously between 3.0 and 7.0; however, the acid production rate remained low throughout the testing period with small variation but no clear trend, as shown in Figure 4-23. The outdoor test results showed that the effectiveness of the soil cover decreased significantly after the second winter. The acid production rates increased consistently during the third summer to reach an approximate average value of 100 mg of $CaCO_3$ /kg/week which was similar to the acid production rate in the control tests, as illustrated in Figure 4-24. These results indicate the compacted clay layer for the indoor tests probably remained intact even after 154 weeks of testing. The laboratory conditions did not involve adverse climatic cycles such as freezing and thawing and low to high evaporation rates. This suggests that, for the outdoor tests, most of the oxygen and water influx was probably occurring by sidewall passage, following freeze-thaw. Visual examination of the compacted clay following the testing period revealed that a layer of moss was growing between the compacted clay and the side of the lysimeters which would undoubtedly allow air to penetrate.

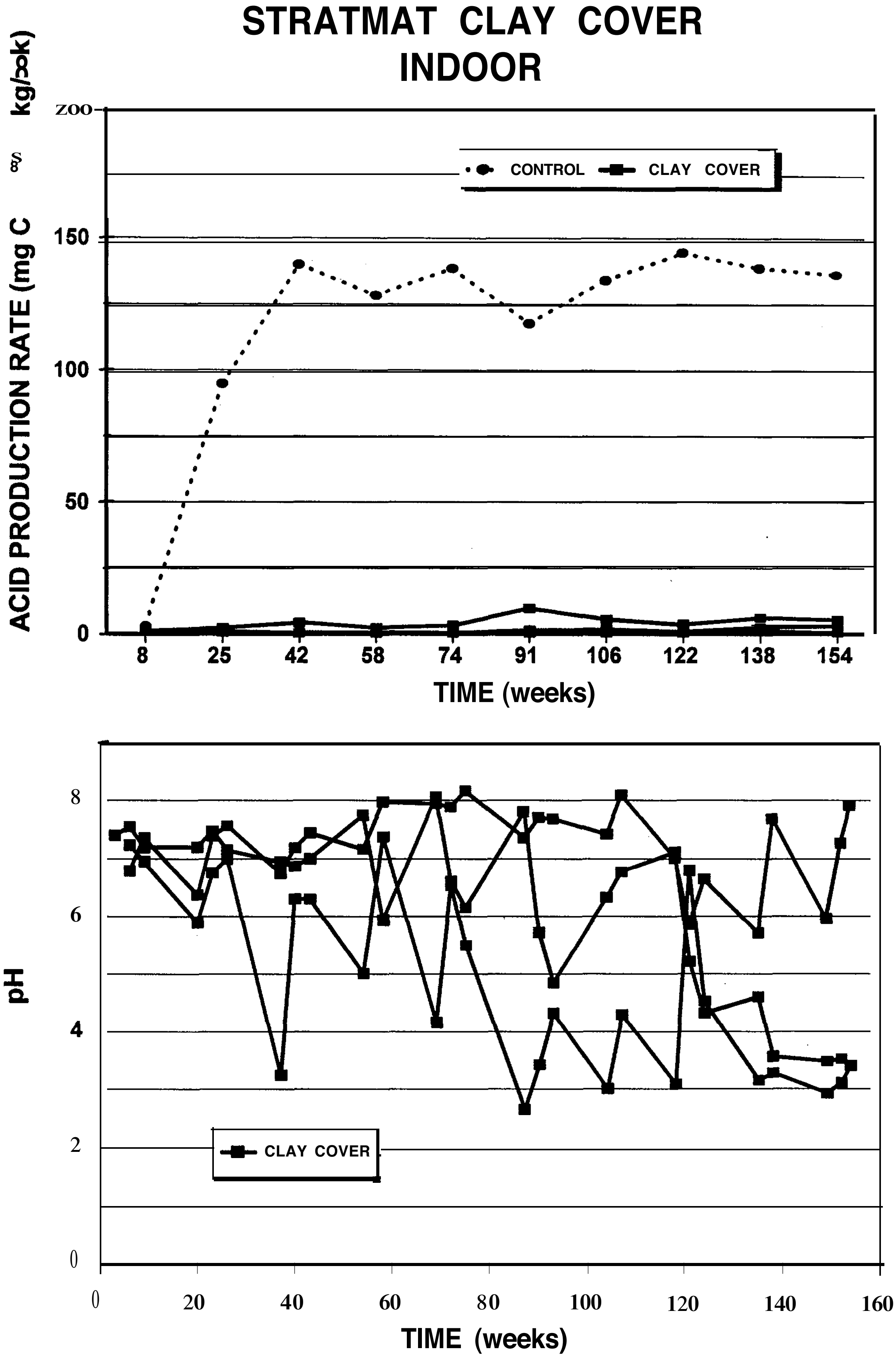

Figure 4-23: Acid production rate and pH in indoor clay covered Stratmat drainage water

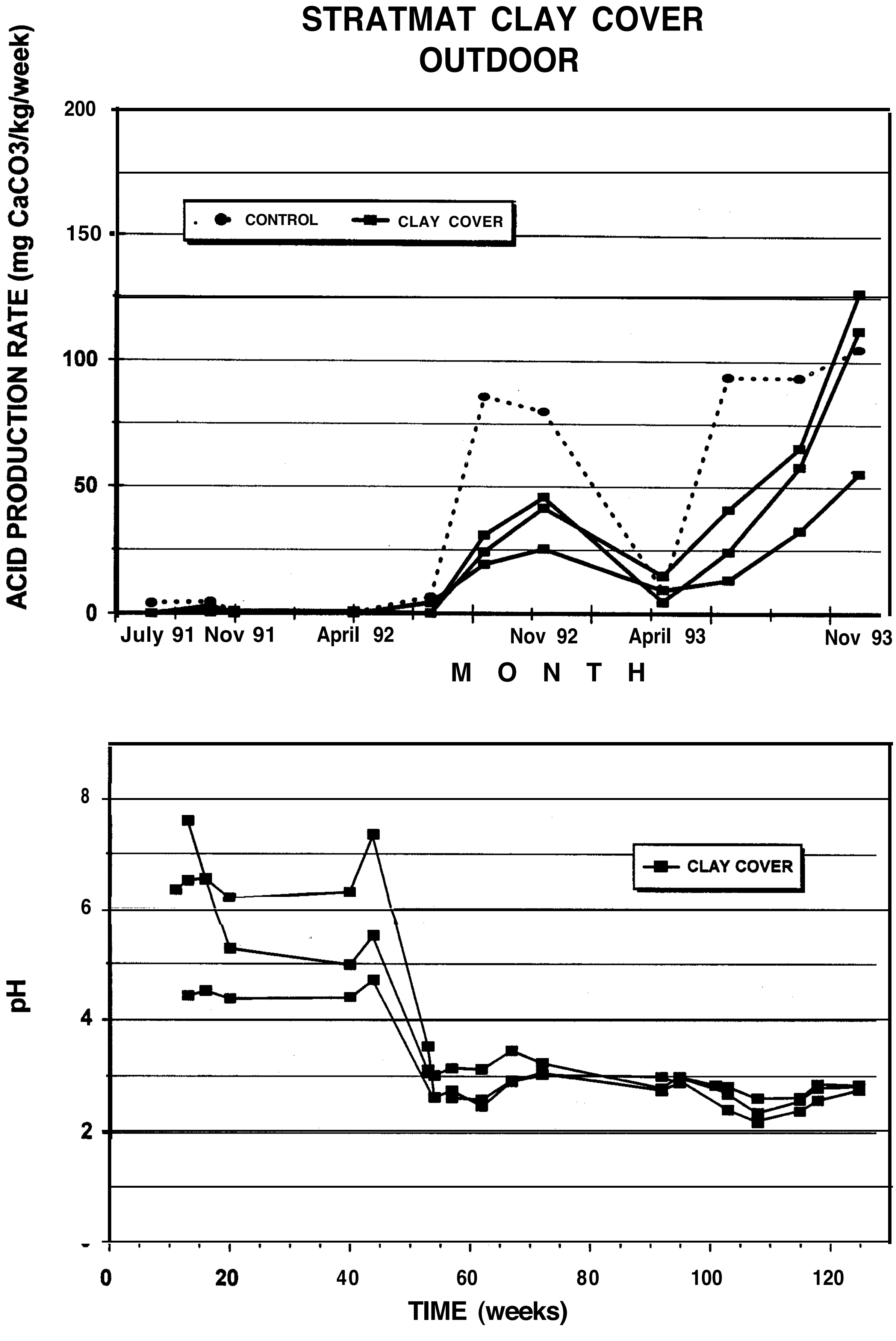

Figure 4-24: Acid production rate and pH in outdoor clay covered Stratmat drainage water

Metals and non-metals released

The complete chemical analysis results are presented in Appendix A, Tables XIII to XV and XLIII to XLV. Metals in the indoor and outdoor drainage water were detected as early as week 6, however the metal concentrations in the outdoor tests remained low throughout the first summer comparable to the acidity results shown in Figure 4-24. The major metals released indoors were: Fe (10 - 200 mg/L), Al (10 - 100 mg/L) and Zn (10 - 100 mg/L). Other species and elements detected include: SO_4^{2-} (500 - 2000 mg/L), Mg (20 - 100 mg/L), Ca (100 - 400 mg/L), Mn (15 - 30 mg/L), As (<1.0 mg/L) and Si (10 - 30 mg/L).

The drainage water for the outdoor tests showed wider variation in species concentrations due to seasonal temperature changes and higher metal concentrations, obviously because of deterioration of the compacted clay layer, as described previously. A few samples of drainage water were analysed for Fe” or Fe^{+2}, the results of which indicated that 30 to 80% of the Fe was oxidized to Fe^{+3} (ferric state).

Post-Testing Results

The amount of acidity stored in the indoor columns was 1.51 g of $CaCO_3$, this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate. Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

The density profile of the soil covered Stratmat waste rock was essentially uniform throughout the column with the surface rocks averaging 2.86 g/cc and the bottom rocks 2.88 g/cc. This suggests uniform leaching of sulphide minerals in the column.

4.8 Stratmat Wood Bark Cover

Testing Results

Acid production rate and pH

The drainage water from the indoor Stratmat waste rock covered with wood bark produced an average cumulative acidity of 499-g of $CaCO_3$. This amount of acidity was added to 25.9 g of $CaCO_3$ measured as the oxidation product stored in the column to obtain a total average acid production of 525 g of $CaCO_3$ over the 154 weeks of testing. This represents an increase of 30.7% in acidity relative to the control, unamended rock and an acid production rate of 170 mg of $CaCO_3$ /kg/week. The drainage water from the outdoor Stratmat waste rock columns produced an average of 235 1 g of $CaCO_3$, with the calculated average acid production rate being 111 mg of $CaCO_3$ /kg/week over the 125 week testing period. This represents an increase of 170% in acidity, relative to the control.

The application of the wood bark cover resulted in an obvious increase in the acid production rate, as shown in Figures 4-25 and 4-26. The pH of the drainage water from the indoor and outdoor tests decreased to 2.0 much more rapidly than the pH of the drainage water from the Stratmat control tests. The acidity was also much higher than that of the control tests, especially during the first summer of the outdoor tests, when the wood bark covered rock generated a peak acid production rate of 200 mg of $CaCO_3$ /kg/week, compared to only about 4.0 mg of $CaCO_3$ /kg/week produced by the control unamended rock.

To provide a probable explanation for the increased acid production, the population of the iron oxidizing bacteria, ***Thiobacillus ferrooxidans,*** was enumerated for one control test and one wood bark cover test (week 11). The results were 50 x 10^6 cells/mL for the control test and 147 x 10^6 cells/mL for the wood bark test, indicating only a slight increase in the bacteria population. A strong bactericide solution (0.02% thymol solution) added to the wood bark in both indoor and outdoor tests at week 100, however, resulted in a sharp decrease in acid production rate, as shown in Figures 4-25 and 4-26. This strongly suggests bacteria were playing a major role in acid generation in the wood bark covered rock.

In addition to the above, a control test containing only wood bark (without rock) was monitored in parallel with the wood bark cover tests in order to evaluate the quality of the leachate. Metal concentrations measured in the drainage water were less than 0.5 mg/L (Appendix A, Table XIV (a)). The neutral pH and low acidity displayed in Figure 4-27 show that no acid was generated from the wood bark. This rules out any possibility that low pH due to organic acids may be accelerating acid generation in the wood bark covered rock.

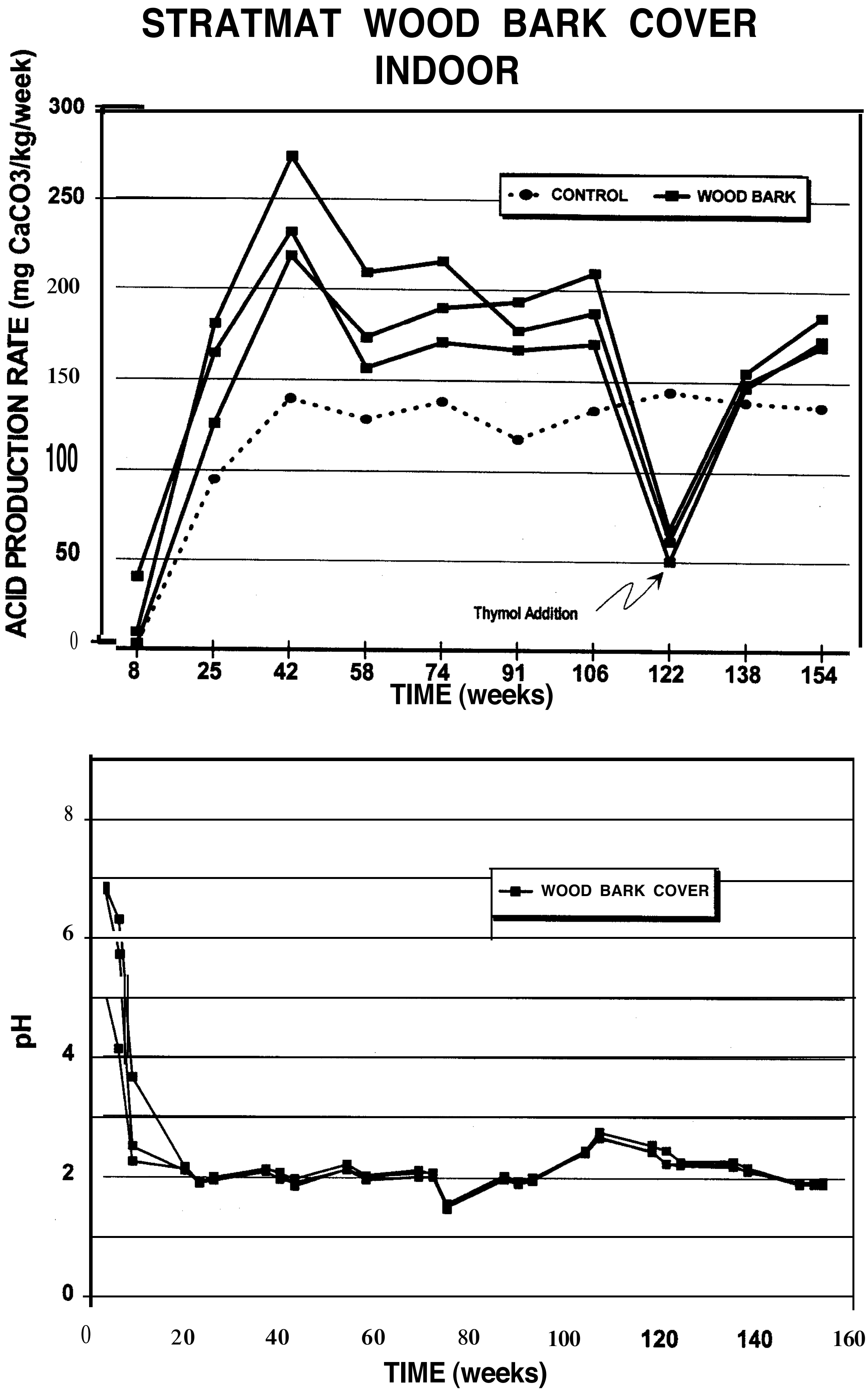

Figure 4-25: Acid production rate and pH in indoor wood bark covered Stratmat drainage water

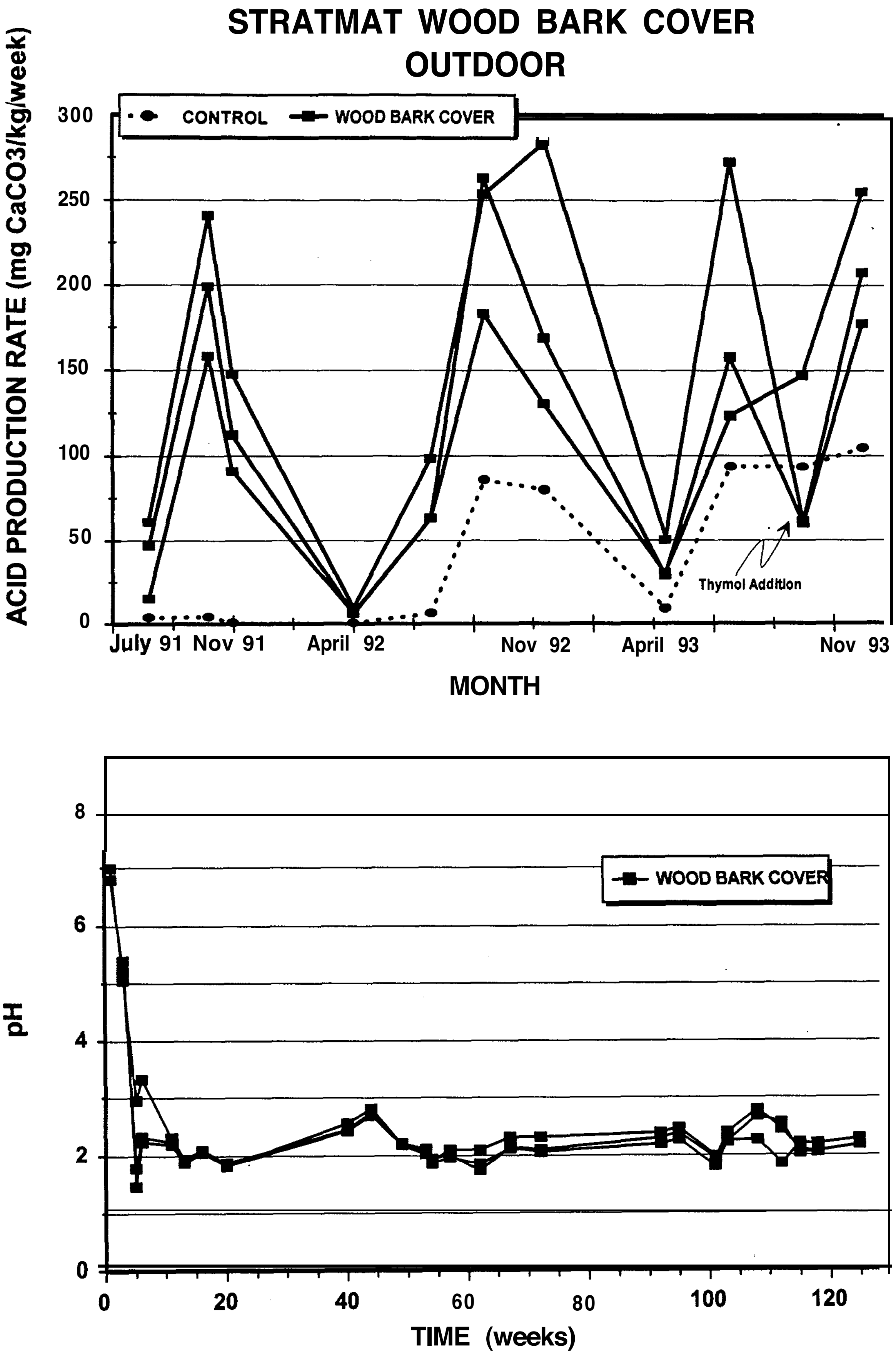

Figure 4-26: Acid production rate and pH in outdoor wood bark covered Stratmat drainage water

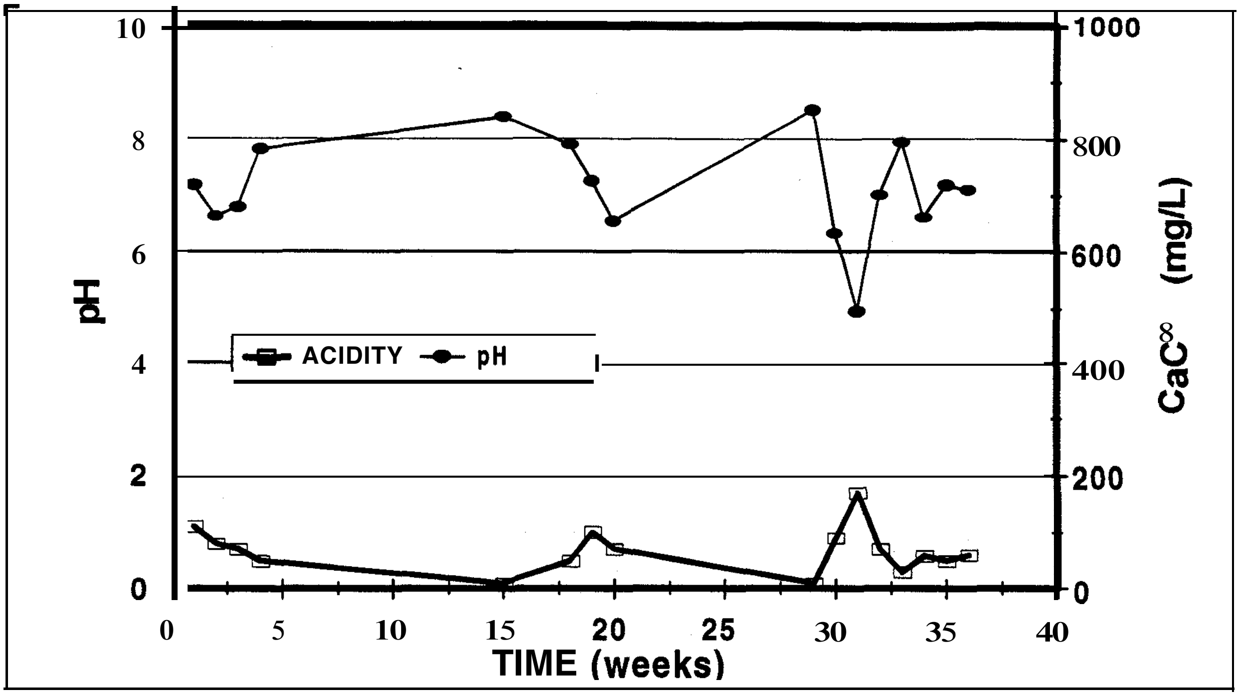

Figure 4-27: Acidity and **pH** of drainage water from wood bark (indoor, no rock)

Metals and Non-Metals Released

The complete results of chemical analysis obtained on drainage waters from the rock covered with wood bark are presented in Appendix A, Tables XXII to XIV(a) and LII to LIV.

Post-Testing Results

The amount of acidity stored in the indoor columns was 25.9 g of $CaCO_3$; this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate.
Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

As was observed in some of the other tests, the density profile in the wood bark column indicated only slightly higher values for the surface rocks (average of 2.78 g/cc) than the bottom rocks (average of 2.73 g/cc). This suggests sulphide mineral leaching was probably uniform throughout the column.

4.9 Selbaie Control

Testing Results

Acid production rate and pH

Drainage waters from the indoor Selbaie waste rock control tests produced an average cumulative acidity of 103 g of $CaCO_3$. This amount of acidity was added to the 1.31 g of $CaCO_3$ measured as the oxidation product stored in the column to give a total average acid production of 104 g of $CaCO_3$ over 148 weeks and hence an acid production rate of 35.3 mg of $CaCO_3$ /kg/week. The drainage water from the outdoor Selbaie waste rock columns produced an average of 120 g of $CaCO_3$, during 115 weeks of testing from which the average acid production rate was calculated to be 6.16 mg of $CaCO_3$/kg/week. The amount of pyrite oxidized in the indoor tests was calculated to be 83.2 g from acidity measurements and 75 g based on the amount of sulphate released. An average sulphate concentration of 3000 mg/L was observed in the tests, as presented in Appendix A, Tables XXV to XXVII. This sulphate production was calculated to be equivalent to approximately 0.5% of the mass of pyrite initially present in the waste rock. Calculations similar to those done for the outdoor tests indicated only 0.1% of the pyrite was oxidized during the testing period.

The above results clearly indicate that the acid production rate of the Selbaie waste rock was 83% slower in outdoor tests than in the indoor tests. As mentioned previously for the Stratmat control waste rock, the variation in temperature is the most probable reason for the lower outdoor acid production rate. Figure 4-28 shows that oxidation essentially stopped during winter time. In addition, the outdoor waste rock tests did not generate significant acidity during the first summer when the pH ranged between 5.0 and 6.0. The drainage water from the indoor tests started generating acidity early in the study and the pH dropped rapidly to 2.5. After 60 weeks, the acid production rate was near 25 mg of $CaCO_3$ /kg/week for two of the replicates; the acid production rate remained constant from that week till the end of the 148-week study, as shown in Figure 4-29.

Metals and Non-Metals Released

The complete results of chemical analysis are presented in Appendix A, Tables XXV to XXVII and LV to LVII. Metals in the indoor and outdoor drainage water were detected as early as week 5. The metal concentrations in the indoor drainage water increased to reach steady values around ‘week 60. The major metals released indoor were: Fe (100 - 1000 mg/L), Al (5 - 50 mg/L) and Zn (100 - 500 mg/L). Other species detected were SO,” (2000 - 5000 mg/L), Mg (50 - 100 mg/L), Ca (50 - 100 mg/L), Mn (15 - 50 mg/L), As (-1.0 mg/L) and Si (5 mg/L).

The drainage water for the outdoor tests showed wider variation in concentrations due to seasonal temperature changes; concentrations were, however, similar during peak acid production in the summer. A few drainage water samples were analysed for Fe^{+3}, the results of which indicated that an average of 92% of the Fe was present in the ferric (Fe^{+3}) state.

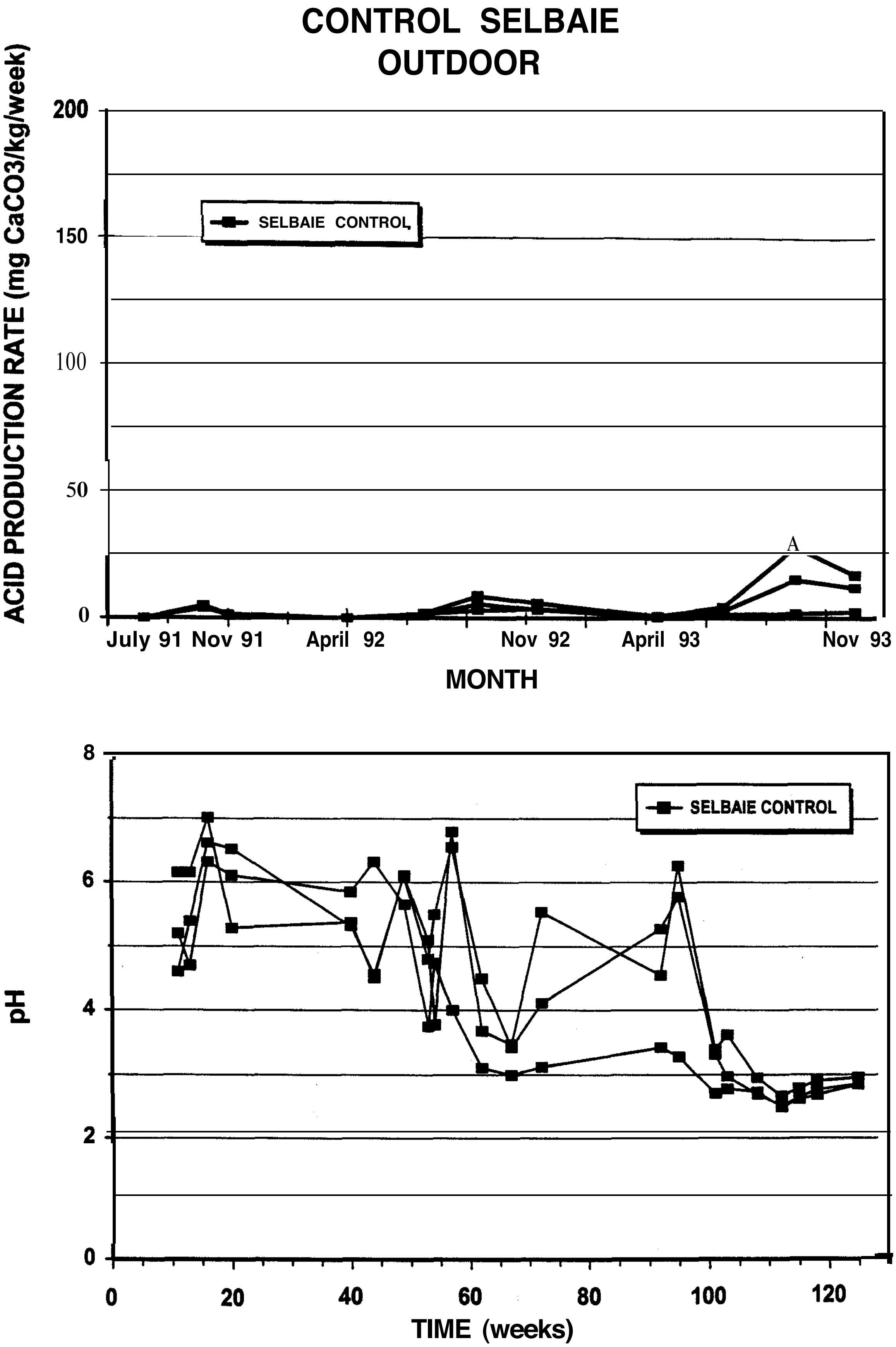

Figure 4-28: Acid production rate and pH in outdoor control Selbaie drainage water

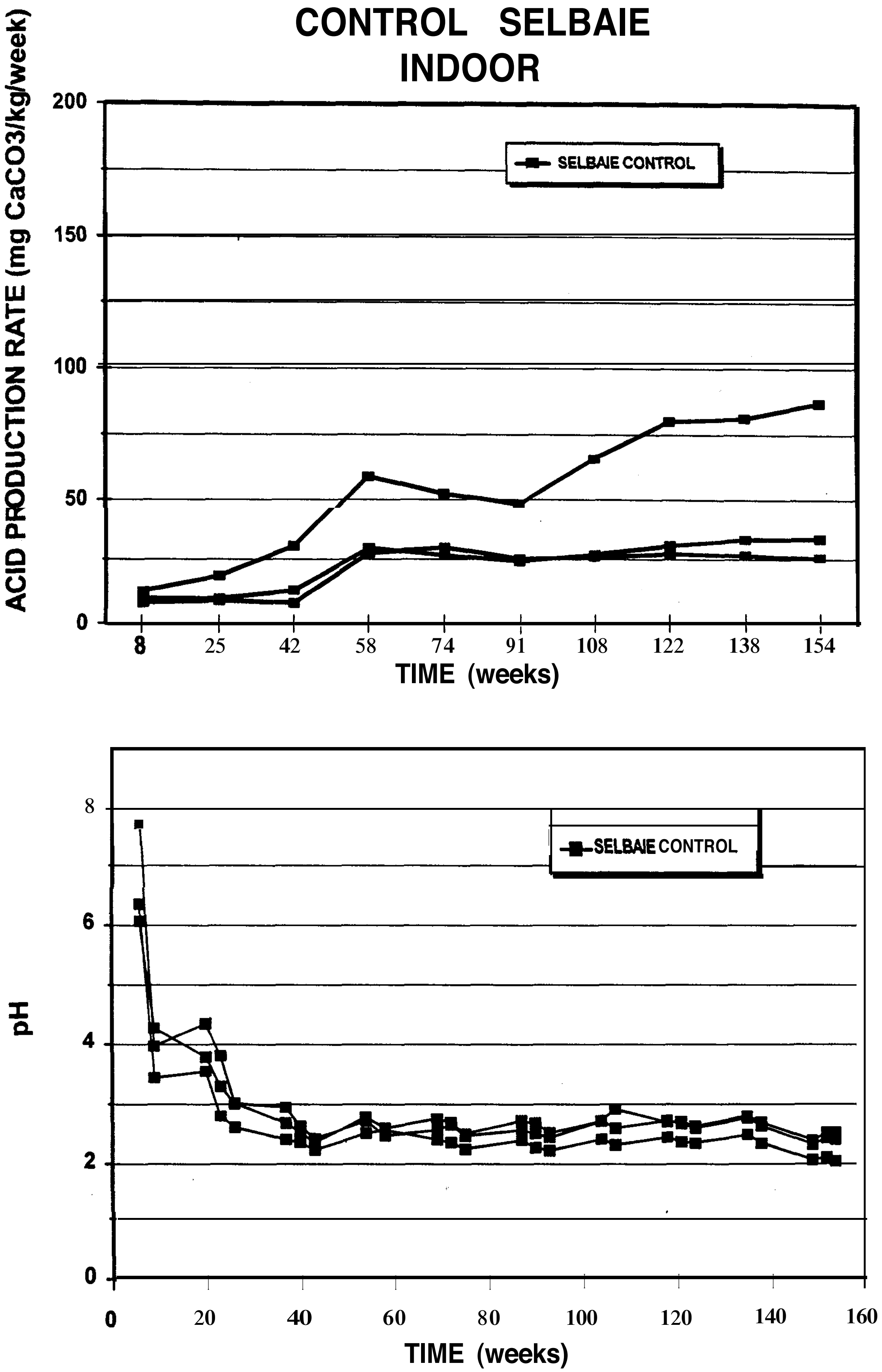

Figure 4-29: Acid production rate and pH in indoor control Selbaie drainage water

Post-Testing Results

The amount of acidity stored in the indoor columns was 1.31 g of $CaCO_3$; this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate.

Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

At the end of testing, the average density of the Selbaie control surface rocks (4.26 g/cc) was found to be similar to that of the bottom rocks (4.23 g/cc), suggesting a uniform sulphide mineralogy throughout the column.

4.10 Selbaie Phosphate (3%)

Testing Results

Acid production rate and pH

Drainage waters from the indoor Selbaie waste rock treated with phosphate dosage of 3% produced an average cumulative acidity of 25.5 g of $CaCO_3$. This amount of acidity was added to the 2.16 g of $CaCO_3$ measured as the oxidation product stored in the column to give a total average acid production of 27.7 g of $CaCO_3$ over a testing period of 148 weeks. This represents an acid reduction of 73.7% and an acid production rate of 9.31 mg of $CaCO_3$/kg/week. Drainage waters from the outdoor columns, on the other hand, produced an average of 51.3 g of $CaCO_3$, with the calculated average acid production rate being 2.63 mg of $CaCO_3$/kg/week for a testing period of 115 weeks. This is equivalent to a reduction in acid production of 57.4% relative to the control.

Acidity and pH data obtained from the indoor and outdoor columns were almost identical to those observed in the control tests. Figures 4-30 and 4-31 illustrate that 3% phosphate addition had a marginal effect on acid reduction.

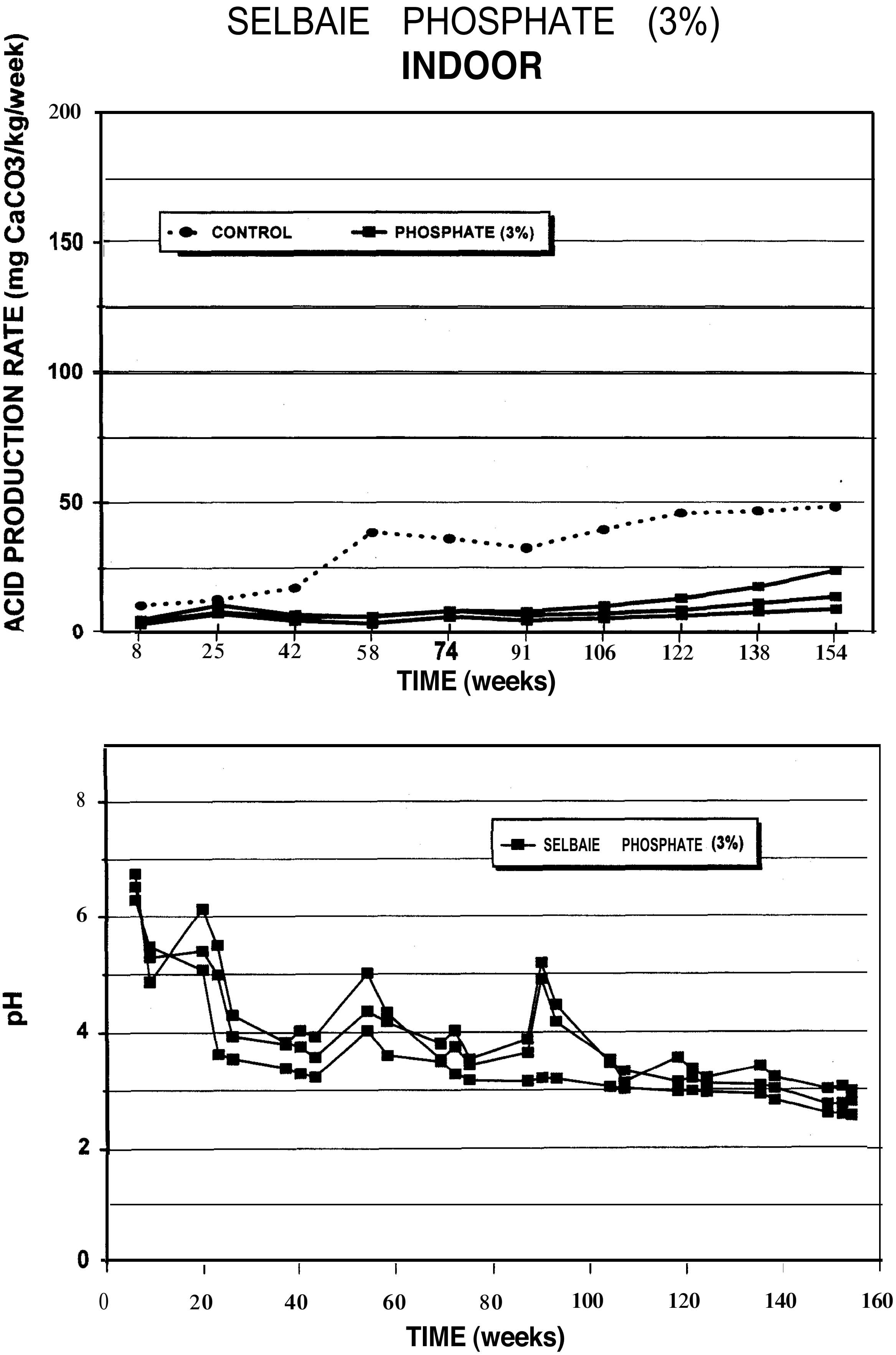

Figure 4-30: Acid production rate and pH in indoor 3% phosphate-amended Selbaie drainage water

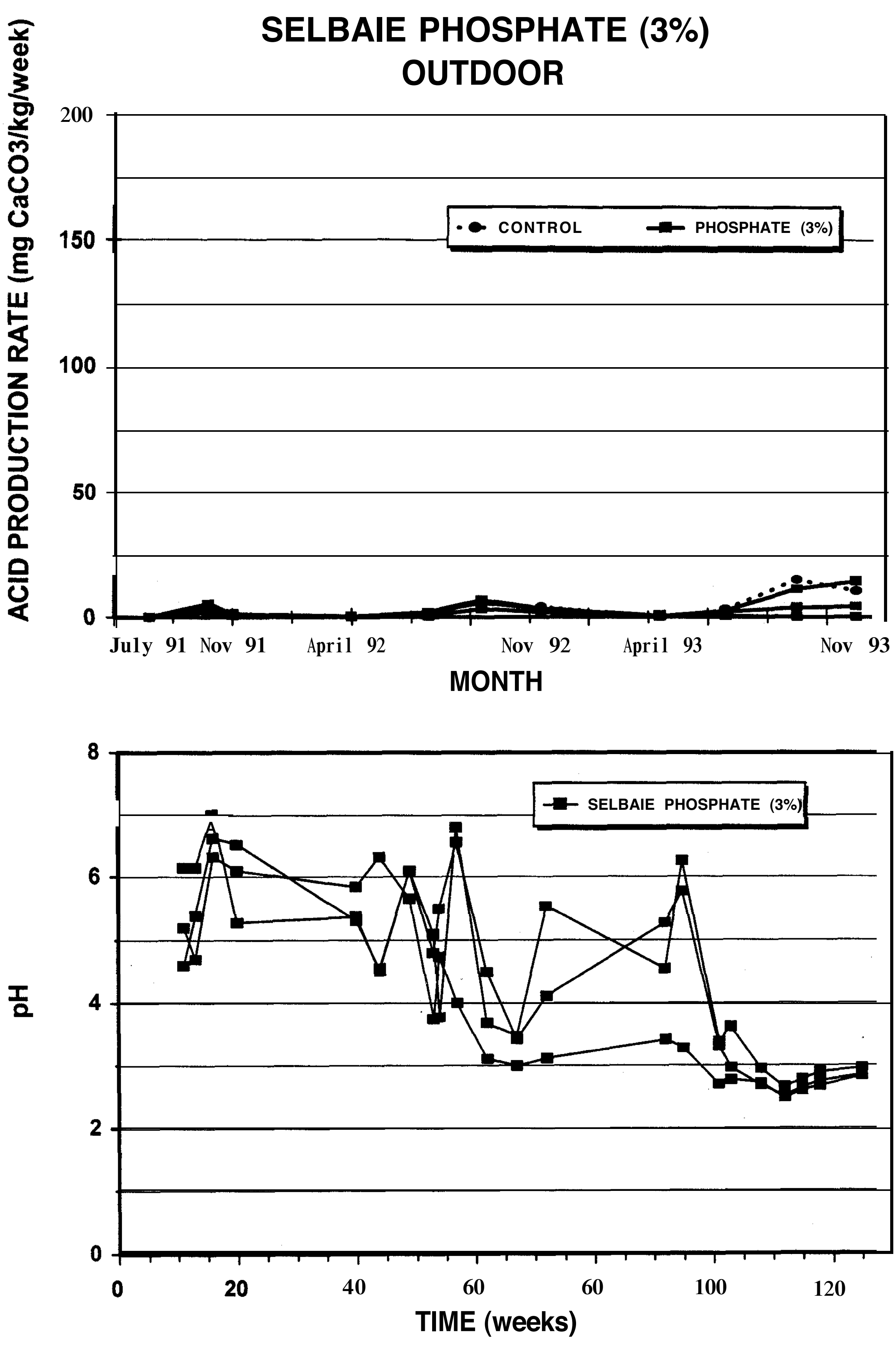

Figure 4-3 1: Acid production rate and pH in outdoor 3% phosphate-amended Selbaie drainage water

Metals and non-metals released

The complete results of chemical analysis of the 3% phosphate tests are presented in Appendix A, Tables XXIII to XXX and LVIII to LX. Metals were detected in the indoor and outdoor drainage waters early in the tests and at concentrations similar to those of the control tests.

Post-Testing Results

The amount of acidity stored in the indoor columns was 2.16 g of $CaCO_3$; this amount of acidity was added to the acidity measured in the drainage water to calculate the average total cumulative acidity and the average acid production rate.

Metal and non-metal loadings stored in the column are presented in Appendix A, Table LXI.

The density profile obtained in the 3% phosphate columns indicated that the surface rocks were similar in density (4.14 g/cc) to the bottom rocks (4.23 g/cc), suggesting uniform sulphide leaching throughout the length of the column.

DISCUSSION

The results of the three-year study indicate that, although a water cover may not completely prevent oxidation, it will reduce acid generation considerably. In fact, when considering both feasibility and effectiveness, it is the most promising ARD control technology yet known to the industry. The rate of oxidation is decreased in two important ways: first, the oxidation will begin much later if fresh rock is covered (two and a half years in this case), and second, the oxidation will continue at a considerably reduced rate, due to the oxygen diffusion barrier the water presents. The delay before oxidation begins is probably proportional to the neutralization potential of the rock. If oxidized waste rock is covered with a layer of water, it is likely that the alkaline materials will be depleted and that the oxidation will begin immediately.

There were many indications that the water covered waste rock began to oxidize after two and a half years of operation. The consistent drop in pH for all three columns, the increase in metal concentrations in the effluents (especially Zn and Pb which were leached out of the control columns early), and the increase in the Fe release rates are clear indications of early stages of oxidation. The cause of this sudden decline in effluent quality is difficult to define, but one possibility is the depletion of a buffering mineral initially present in the waste rock. The original rock pH, determined during the initial characterization, was approximately 8.5. This value agrees with the data from the water cover effluents which showed that between weeks 20 and 120, the average pH from the water covered columns was above 8.0. The deionized water used to simulate precipitation generally had a pH near 5.5. Oxygen diffusion from the surface of the water column, and low pH water used to simulate precipitation, may have been causes for alkaline mineral depletion.

The sudden decline in effluent water quality could also be caused by bacterial activity. A dissolved oxygen concentration of 6 mg/L near the surface of the water column above the waste may be sufficient for aerobic bacteria to survive. The bacteria ***Thiobacillus ferrooxidans*,** which is the species normally responsible for catalysing sulphide oxidation, is acidophilic. Thus, this strain of bacteria will not be active at a pH above 4 or 5 and, since the pH of the effluent from the water covered rock had not been that low, it is unlikely that bacteria played an important role in the initial acid generation. A subsequent decrease in pH could mean an increase in bacterial activity in the future.

Lead was released from the water covered columns at the same time as the pH decreased. It is important to note that the Zn and Pb concentrations measured in the effluents from the water covered rock would be too high to be released directly into the environment and may therefore necessitate treatment. In reality, however, the release rates could be higher or lower, depending on the retention and dilution of water.

The effectiveness of the water cover may be improved by increasing the depth of the water cover, or with the application of an organic layer on top of the waste. With an organic layer, the oxygen may be consumed by biodegradation before it reaches the sulphides. The practical implementation of a water cover scheme presents some other questions (for example, maintaining the required depth of water and long-term stability of holding structures) which still have to be addressed through hydrological and engineering studies. Laboratory studies such as those presented in this report may be useful prior to implementation in providing preliminary information for design.

CONCLUSIONS

Several techniques have been investigated for their relative effectiveness in preventing and controlling sulphide oxidation and acid production from two mine waste rocks. The waste rocks were obtained from the Stratmat mine in New Brunswick and the Selbaie mine in Quebec. The techniques tested were water cover, soil cover , wood bark cover, 1% and 3% limestone addition and 1% and 3% phosphate addition. Acid production rates and pH obtained on drainage water from each technique were compared to those from the control, uncovered and untreated rock to provide information on relative effectiveness. Metal, sulphate and other major ion concentrations were also monitored in the drainage waters. Based on the results from three years of monitoring of indoor and outdoor experiments, the following may be concluded:

1. The Stratmat rock produced more acid (130 $CaCO_3$/kg/week) than the Selbaie rock (41 $CaCO_3$/kg/week).

2. Post-testing investigation results (Appendix B) suggest the presence of greater amounts of impurities in the form of silicate gangue minerals may explain the difference in acid production.

3. Water cover was, by far, the most effective technique for preventing sulphide oxidation and acid generation. Water cover was greater than 99% effective, followed by 3% limestone addition (96%), 1% limestone (83%), 3% phosphate (67%) and 1% phosphate (14%).

4. Soil cover gave very different results in indoor and outdoor tests-98% effective in indoor tests and 47% in outdoor tests. Sidewall passage of oxygen and water aggravated by external weather conditions would explain the difference in effectiveness.

5. Wood bark cover was found to be the least effective technique. In fact it accelerated acid production and yielded a 170% increase in acid production over the control in outside tests. Indoor tests gave a 3 1% increase over the control.

6. Drainage waters from the Control Stratmat rock were characterized by high concentrations of iron (2000-4000 mg/L), sulphate (5000-15000 mg/L), aluminium (200-500 mg/L), and zinc (50-200 mg/L).

7. Drainage waters from the Control Selbaie rock were characterized by lower concentrations of iron (100-1000 mg/L), sulphate (2000-5000 mg/L), aluminium (5-50 mg/L), and zinc (100-500 mg/L).

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APPENDIX A

DRAINAGE WATER QUALITY

(Centre de **technologie** Noranda)

TABLE I Drainage Water from Inside Stratmat Control Test (Replicate #1, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.025		229	< 0.02			< 0.02	0.029	19.8	18.8	9.47	65.6	
6	2.94	< 0.25	158	0.26			0.64	0.57	20.2	28.5	16.3	31.9	
18	511	35.2	219	1.50			7.42	2350	< 5.00	416	103	6.99	
24	226	16.6	114	0.51			4.58	2330	< 5.00	224	37.4	6.60	
35	598	33.7	105	0.80			8.09	4210	< 5.00	648	62.7	7.44	
41	165	9.03	87.2	0.22			5.03	1700	< 5.00	155	21.9	6.37	
53	465	21.6	118	0.43			8.55	3670	< 5.00	449	46.4	5.96	
57	215	9.90	96.7	0.21			5.35	2030	< 5.00	199	24.2	6.22	
68	520	24.4	119	0.43			8.50	4070	< 5.00	509	49.8	6.75	
73	212	8.87	95.2	0.19			4.91	1840	< 5.00	195	24.9	6.55	
85	494	21.8	108	0.34			6.04	3910	< 5.00	495	43.5	6.49	
90	184	6.86	74.6	0.14			3.70	1420	< 5.00	174	18.7	6.44	
101	504	21.8	110	0.35			6.46	4010	< 5.00	497	41.9	6.22	
105	214	7.64	82.3	0.14			3.81	1660	< 5.00	204	20.3	6.07	
116	528	23.8	139	0.35			10.9	4470	< 5.00	514	41.8	11.2	
117	470	17.5	105	0.33	0.39	< 0.025	7.41	3798	< 5.00	456	36.0	6.14	0.16
121	243	10.4	104	0.22			5.61	1740	< 5.00	227	19.9	7.01	
132	463	20.3	107	0.37			5.52	4010	< 5.00	451	35.7	5.38	
137	201	7.06	75.5	0.12			3.04	1610	< 5.00	191	16.5	5.73	
138	178	5.67	71.1	0.13	0.15	< 0.005	3.15	1611	< 1.00	169	14.0	0.060	0.054
148	359	18.3	98.5	0.21	0.35	< 0.025	4.32	3545	< 5.00	345	27.1	6.29	0.12
153	190	7.48	72.6	0.076	0.18	< 0.025	3.09	1772	< 5.00	188	15.1	6.15	0.067

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HP04	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	2.48	644						13.2		93.7		
6	4.03	664		< 0.50				64.6				
18	< 0.25	11580		< 0.50				609				
24	< 0.25	8280		< 0.50				203				
35	< 0.25	15450		< 0.50				283				
41	< 0.25	6090		< 0.50				84.6				
53	< 0.25	13290		< 0.50				151				
57	< 0.25	7320		< 0.50				72.1				
68	< 0.25	14910		< 0.50				126				
73	< 0.25	7110		< 0.50				64.7				
85	< 0.25	13950		< 0.50				81.8				
90	< 0.25	5580		< 0.50				42.6				
101	< 0.25	14220		0.50				82.6				
105	< 0.25	6420		< 0.50				42.8				
116	< 0.25	15210		1.13				82.1				
117	< 0.25	13629	2.67	0.81	40.4	0.60	< 0.25	81.2	3370			
121	< 0.25	6750		< 0.50				44.3				
132	< 0.25	14250		0.99				70.0				
137	< 0.25	6336		< 0.50				35.0				
138	< 0.05	6313	0.90	< 0.05	32.1	0.33	< 0.05	26.6	1660	< 0.40		< 0.34
148	< 0.25	12084	2.33	< 0.50	37.1	0.24	< 0.25	48.6	3060			
153	< 0.25	6534	1.08	< 0.50	39.5	0.22	< 0.25	27.1	1630			

TABLE II Drainage Water from Inside Stratmat Control lest (Replicate **#2,** Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.025		345				< 0.020	< 0.020	26.1	30.5	10.6	77.4	
6	0.76	< 0.25	240	0.13			0.14	0.23	19.3	34.1	18.1	39.7	
18	271	6.16	294	0.73			8.48	788	< 5.00	244	84.4	9.83	
24	214	11.7	194	0.49			5.56	1800	< 5.00	200	40.7	7.19	
35	621	30.5	168	1.03			14.2	4020	< 5.00	697	76.6	8.99	
41	190	8.93	136	0.30			5.44	1710	< 5.00	191	27.2	6.34	
53	628	25.2	232	0.89			13.8	4020	< 5.00	641	77.3	6.38	
57	257	10.4	139	0.40			6.18	1980	< 5.00	254	33.3	6.58	
68	656	26.3	159	0.88			12.6	3910	< 5.00	689	79.5	7.33	
73	263	9.09	151	0.38			6.68	1740	< 5.00	261	35.0	6.92	
85	526	22.9	126	0.81			9.34	3340	< 5.00	561	64.5	7.56	
90	281	8.53	127	0.37			5.70	1560	< 5.00	288	32.8	6.38	
101	644	25.9	149	0.96			11.0	3780	< 5.00	677	72.7	6.47	
105	298	8.81	134	0.39			6.11	1640	< 5.00	305	32.8	7.02	
116	696	28.8	174	0.98			14.0	4390	< 5.00	724	75.5	10.7	
117	577	19.5	147	0.82	0.48	< 0.025	10.9	3596	< 5.00	597	59.5	6.06	0.20
121	286	9.41	131	0.40			6.32	1830	< 5.00	279	29.8	5.81	
132	616	24.4	157	1.01			11.6	4271	< 5.00	627	64.3	5.62	
137	283	8.34	126	0.41			5.95	1734	< 5.00	280	28.1	5.57	
138	248	6.52	111	0.37	0.18	< 0.005	6.34	1686	< 1.00	250	24.1	< 0.050	0.062
148	531	24.1	166	0.93	0.48	< 0.025	10.9	4189	< 5.00	539	56.5	6.34	0.17
153	267	8.92	126	0.39	0.22	< 0.025	6.33	1993	< 5.00	278	25.9	6.23	0.058

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.25	922						5.68		127		
6	2.96	810		< 0.50				35.8				
18	< 0.25	5790		< 0.50				369				
24	< 0.25	7170		< 0.50				220				
35	< 0.25	15960		< 0.50				430				
41	< 0.25	6600		< 0.50				143				
53	< 0.25	16650		< 0.50				389				
57	< 0.25	7980		< 0.50				174				
68	< 0.25	16710		< 0.50				371				
73	< 0.25	7710		< 0.50				167				
85	< 0.25	13860		< 0.50				347				
90	< 0.25	7200		< 0.50				172				
101	< 0.25	15810		< 0.50				391				
105	< 0.25	7560		< 0.50				176				
116	< 0.25	17520		0.81				414				
117	< 0.25	15258	2.60	0.94	45.1	0.58	< 0.25	339	3160			
121	< 0.25	7590		< 0.50				181				
132	< 0.25	17037		1.16				424				
137	< 0.25	7725		0.56				191				
138	< 0.05	7567	0.98	< 0.05	35.2	0.35	< 0.05	148	1790	3.00		< 0.34
148	< 0.25	15987	3.08	< 0.50	46.4	0.32	< 0.25	431	3620			
153	< 0.25	8235	1.53	< 0.50	44.4	0.24	< 0.25	197	1850			

TABLE III Drainage Water from Inside Stratmat Control Test (Replicate #3, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.025		415				< 0.020	< 0.02	33.4	38.1	12.1	1.15	
6	0.41	< 0.25	163	0.031			< 0.025	0.093	15.4	13.2	4.20	411	
18	200	1.21	442	1.00			6.57	124	16.6	209	110	119	
24 35	[illegible]	[illegible]	189	[illegible]			[illegible]	[illegible]	< 5.00	[illegible]	[illegible]	[illegible]	
41	198	12.5	129	0.33			3.96	1850	< 5.00	207	30.2	8.98	
53	638	44.0	173	0.79			9.89	4770	< 5.00	650	69.0	8.22	
57	259	15.1	130	0.32			5.36	2250	< 5.00	254	32.9	7.33	
68	686	46.2	151	0.77			10.2	5600	< 5.00	695	67.1	10.5	
73	297	14.9	149	0.31			5.74	2280	< 5.00	275	34.5	9.96	
85	664	42.5	140	0.60			11.1	5250	< 5.00	663	56.5	6.63	
90	244	11.1	110	0.20			5.25	1660	< 5.00	236	24.2	6.32	
101	573	36.3	129	0.47			9.55	4340	< 5.00	566	45.9	6.62	
105	272	11.1	112	0.18			6.03	1710	< 5.00	264	24.3	6.50	
116	594	36.8	150	0.47			13.5	4610	< 5.00	583	44.9	10.1	
117	543	26.8	138	0.43	0.43	< 0.025	11.8	3997	< 5.00	533	41.2	6.12	0.16
121	213	8.35	79.9	0.15			3.81	1820	< 5.00	194	18.0	6.02	
132	548	34.7	131	0.57			11.0	4444	< 5.00	530	38.8	5.74	
137	251	9.77	104	0.18			5.76	1667	< 5.00	246	20.0	6.32	
138	220	7.84	92.2	0.18	0.17	< 0.005	5.93	1616	< 1.00	217	16.9	0.32	0.048
148	445	31.2	135	0.31	0.41	< 0.025	10.4	3952	< 5.00	428	32.3	6.68	0.41
153	229	10.1	100	0.12	0.19	< 0.025	6.29	1875	< 5.00	231	17.7	6.54	0.087

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.25	689						6.12		2010		
6	0.26	434		< 0.50				1.45				
18	5.67	4260		< 0.50				506				
24	< 0.25	6990		< 0.50				329				
35	< 0.25	19470		< 0.50				488				
41	< 0.25	6870		< 0.50				131				
53	< 0.25	17730		< 0.50				231				
57	< 0.25	8340		< 0.50				109				
68	< 0.25	20220		< 0.50				173				
73	< 0.25	9210		< 0.50				104				
85	< 0.25	18990		0.51				107				
90	< 0.25	6930		< 0.50				58.1				
101	< 0.25	15660		< 0.50				73.9				
105	< 0.25	7140		< 0.50				48.3				
116	< 0.25	16200		0.91				68.3				
117	< 0.25	15042	2.47	1.13	51.4	0.64	< 0.25	66.1	3510	7.41	< 0.10	< 0.050
121	< 0.25	6660		0.57				39.7				
132	< 0.25	16041		1.09				60.3				
137	< 0.25	6921		0.50				41.5				
138	< 0.05	6691	0.94	< 0.050	39.3	0.32	< 0.050	32.9	1600	3.88		< 0.34
148	< 0.25	13962	2.82	< 0.500	47.6	0.33	< 0.25	50.0	3380			
153	< 0.25	7359	1.35	< 0.500	42.6	0.20	< 0.25	33.2	1710			

Drainage Water from Inside Stratmat Control Test (Replicate #1, #2 and #3, February 25, 1994)

CONT	Ag	B	Ba	Be	Li	Mo	Sn	Sr	Ti	SO4
WEEK 138	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
#1	< 0.010	0.53	< 0.010	0.15	0.11	< 0.050	< 0.050	< 0.50	0.24	6420
#2	< 0.010	4.93	< 0.010	0.14	0.17	< 0.050	< 0.050	< 0.50	0.30	7500
#3	< 0.010	0.47	< 0.010	0.15	0.14	< 0.050	0.49	< 0.50	0.38	6810

TABLE IV Drainage Water from inside Stratmat 1% Limestone Test (Replicate #1, Started July 11, 1991)

WEEK	Al	AS	Ca	cd	Co	Cr	cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	4.93	< 0.25	119	< 0.02			0.03	7.10	13.6	18.9	3.70	12.0	
18	0.42	< 0.25	155	< 0.02			< 0.02	0.09	8.78	14.4	3.85	9.19	
24	0.31	< 0.25	114	< 0.02			< 0.02	0.03	< 5.00	10.2	3.95	7.55	
35	0.60	< 0.25	302	0.06			0.13	0.20	5.69	40.5	18.1	8.44	
41	6.63	< 0.25	273	< 0.02			0.70	30.3	6.30	35.1	11.0	7.79	
53	3.38	< 0.25	557	0.07			0.56	10.5	8.75	82.5	28.1	7.70	
57	18.7	< 0.26	223	0.05			2.15	96.7	< 5.00	53.4	18.2	7.06	
68	85.8	0.81	387	0.17			4.91	272	< 5.00	138	43.3	7.28	
73	39.5	0.31	505				3.24	171	< 5.00	81.4	19.0	7.01	
88	187	2.01	395	0.08			7.60	654	< 5.00	169	42.5	7.21	
				0.21									
90	42.7	0.53	396	0.03			2.20	286	5.00	55.0	13.1	8.87	
101	147	2.43	355	0.12			8.24	882	< 5.00	165	30.1	6.80	
105	42.3	0.34	554	< 0.02			3.35	230	< 5.00	59.6	12.4	7.69	
116	231	4.94	273	0.17			8.26	1280	< 5.00	213	34.1	11.3	
117	168	1.93	389	0.17	0.24	< 0.03	7.97	772	< 5.00	203	32.8	6.43	0.13
121	88.8	1.19	455	0.06			5.07	454	< 5.00	68.8	12.6	6.80	
132	9.98	< 0.25	210	0.40	< 0.03	< 0.03	15.1	31.5	< 5.00	40.1	17.0	8.46	< 0.03
137	73	1.14	253	0.04	0.07	< 0.03	2.91	429	< 5.00	56.7	8.97	6.20	< 0.03
148	297	6.08	273	0.15	0.27	< 0.03	7.49	1785	< 5.00	236	29.0	5.71	0.11
153	101	1.04	226	0.04	0.08	< 0.03	3.22	570	< 5.00	71.8	9.94	6.38	0.03

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	0.50	327		< 0.50				0.71				
18	< 0.25	425		< 0.50				1.81				
24	< 0.25	313		< 0.50				2.60				
35	0.78	973		< 0.50				30.68				
41	2.34	888		< 0.50				24.6				
53	0.72	1768		< 0.50				56.4				
57	2.25	1278		< 0.50				35.0				
68	1.31	2763		< 0.50				111				
73	1.48	2192		< 0.50				43.1				
85	0.75	4410		< 0.50				132				
90	< 0.25	2328		< 0.50				26.5				
101	< 0.25	4620		< 0.50				94.3				
105	0.92	2552		< 0.50				37.3				
116	< 0.25	6030		< 0.50				101				
117	< 0.25	4592	0.79	< 0.50	32.0	< 0.50	< 0.25	99.7	703	8.06	< 0.10	< 0.05
121	0.58	3150		< 0.50				39.1				
132	< 0.25	1066	< 0.25	< 0.50	4.46	< 0.10	< 0.25	124	1360			
137	< 0.25	2549	0.30	< 0.50	22.5	< 0.10	< 0.25	23.6	398			
148	< 0.25	7758	1.29	< 0.50	37.7	0.19	< 0.25	79.0	1560			
153	< 0.25	3010	0.30	< 0.50	31.1	0.13	< 0.25	26.8	526			

TABLE V Drainage Water from Inside Stratmat 1% Limestone Test (Replicate #2, Started July 11, 1991)

WEEK	Al	AS	ca	cd	Co	Cr	cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.38	< 0.25	114	< 0.02			< 0.02	0.15	11.3	13.8	2.34	13.2	
18	0.63	< 0.25	134	< 0.02			< 0.02	0.39	8.47	12.0	2.36	9.16	
24	0.36	< 0.25	84.6	< 0.02			< 0.02	< 0.02	< 5.00	9.02	1.32	8.06	
35	0.40	< 0.25	158	< 0.02			< 0.02	0.07	5.36	15.9	2.88	8.27	
41	0.36	< 0.25	197	< 0.02			< 0.02	0.04	< 5.00	25.5	7.12	8.70	
53	5.70	< 0.25	461	0.18			1.17	7.56	< 5.00	94.0	36.6	8.13	
57	2.80	< 0.25	542	0.14			0.87	1.63	6.51	84.4	32.4	7.01	
68	68.2	0.55	557	0.20			3.50	179	< 5.00	127	40.1	7.16	
73	64.6	0.46	575	0.12			3.31	149	< 5.00	95.7	29.7	7.03	
85	114	0.97	555	0.23			4.69	240	< 5.00	158	41.9	6.76	
90	78.0	0.75	417	0.09			3.27	340	< 5.00	85.3	19.6	7.85	
101	221	4.05	387	0.14			6.46	1210	< 5.00	152	26.5	7.36	
105	141	2.30	320	0.07			4.14	853	< 5.00	103	18.8	7.12	
116	356	9.39	353	0.24			7.24	2360	< 5.00	236	36.1	11.0	
117	295	5.44	333	0.19	0.30	< 0.03	6.67	1897	< 5.00	205	29.6	5.97	0.17
121	129	2.67	316	0.08			3.06	954	< 5.00	95.4	15.3	9.70	
132	273	7.68	298	0.15	0.28	< 0.03	4.98	2249	< 5.00	205	25.1	5.47	0.14
137	140	3.83	287	0.22	0.30	0.05	3.16	1229	< 5.00	117	14.9	6.06	0.28
148	260	9.48	286	0.21	0.34	< 0.03	4.58	2526	< 5.00	217	24.2	6.17	0.16
153	142	4.44	268	0.06	0.17	< 0.03	2.65	1416	< 5.00	130	15.0	6.16	0.05

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	302		< 0.50				< 0.02				
18	< 0.25	354		< 0.50				0.51				
24	< 0.25	229		< 0.50				< 0.02				
35	< 0.25	442		< 0.50				7.85				
41	0.44	606		< 0.50				23.4				
53	4.35	1715		< 0.50				94.8				
57	2.16	1782		< 0.50				76.8				
68	4.40	2911		< 0.50				121				
73	2.19	2612		< 0.50				79.7				
85	2.58	3570		< 0.50				142				
90	1.26	2896		< 0.50				57.9				
101	< 0.25	5880		< 0.50				97.4				
105	< 0.25	4140		< 0.50				55.3				
116	< 0.25	9480		< 0.50				105				
117	< 0.25	8070	1.22	0.59	34.5	< 0.50	0.25	80.3	1630	3.12	< 0.10	< 0.05
121	< 0.25	4290		< 0.50				35.5				
132	< 0.25	8577	1.32	< 0.50	31.5	0.21	< 0.25	66.0	1900			
137	< 0.25	4921	0.88	< 0.50	30.8	0.17	0.27	30.2	1080			
148	< 0.25	8940	1.71	< 0.50	35.4	0.25	< 0.25	50.2	4350			
153	< 0.25	5553	0.79	< 0.50	34.3	0.17	< 0.25	23.9	1270			

TABLE VI Drainage Water from Inside Stratmat 1% Limestone Test (Replicate #3, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.36	< 0.25	89.3	< 0.025			< 0.025	0.088	6.78	11.3	1.77	10.5	
18	0.34	< 0.25	127	< 0.025			< 0.025	0.052	7.03	11.1	1.95	8.31	
24	0.40	< 0.25	76.8	< 0.025			< 0.025	< 0.025	< 5.00	8.56	0.65	7.17	
35	0.38	< 0.25	187	< 0.025			< 0.025	< 0.025	< 5.00	16.4	2.64	8.05	
41	0.48	< 0.25	118	< 0.025			< 0.025	0.22	< 5.00	11.5	1.48	8.41	
53	0.32	< 0.25	211	< 0.025			< 0.025	0.27	< 5.00	21.8	4.46	7.85	
57	0.28	< 0.25	255	< 0.025			< 0.025	< 0.025	< 5.00	20.7	4.06	7.93	
68	0.34	< 0.25	426	0.050			0.19	0.12	< 5.00	49.2	15.5	6.67	
73	0.39	< 0.25	417	< 0.025			0.19	0.067	< 5.00	28.5	7.69	6.60	
85	0.47	< 0.25	405	0.033			0.18	1.15	< 5.00	42.6	13.7	7.12	
90	0.44	< 0.25	362	< 0.025			0.07	0.24	< 5.00	23.3	6.05	7.22	
101	0.54	< 0.25	515	< 0.025			0.11	0.85	< 5.00	46.4	11.6	6.96	
105	0.42	< 0.25	391	< 0.025			0.10	0.45	< 5.00	25.9	6.41	7.60	
116	1.20	< 0.25	539	0.040			0.83	1.47	< 5.00	57.9	15.4	11.1	
117	< 0.25	< 0.25	587	< 0.025	0.030	< 0.025	0.079	0.10	5.06	63.9	11.9	7.62	< 0.025
121	0.41	< 0.25	538	< 0.025			0.11	0.45	< 5.00	32.8	7.59	6.93	
132	1.88	< 0.25	489	0.049	0.085	< 0.025	1.33	6.60	< 5.00	56.5	12.8	5.82	0.065
137	0.42	< 0.25	481	0.073	0.10	< 0.025	0.20	1.20	< 5.00	28.8	6.25	6.23	0.073
148	1.91	< 0.25	558	0.048	0.087	< 0.025	1.12	3.36	< 5.00	59.0	12.6	6.45	0.044
153	4.01	< 0.25	539	< 0.025	< 0.025	< 0.025	1.02	9.58	< 5.00	35.6	7.76	6.49	< 0.025

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	230		< 0.50				< 0.025				
18	< 0.25	334		< 0.50				0.38				
24	< 0.25	203		< 0.50				< 0.025				
35	< 0.25	506		< 0.50				1.33				
41	< 0.25	309		< 0.50				0.75				
53	< 0.25	577		< 0.50				6.91				
57	< 0.25	674		< 0.50				8.08				
68	< 0.25	1201		< 0.50				27.7				
73	< 0.25	1018		< 0.50				14.7				
85	< 0.25	1139		< 0.50				20.9				
90	< 0.25	923		< 0.50				7.37				
101	< 0.25	1392		< 0.50				14.4				
105	< 0.25	993		< 0.50				7.01				
116	< 0.25	1544		< 0.50				28.0				
117	< 0.25	1522	< 0.25	< 0.50	5.79	< 0.50	< 0.25	9.65	< 0.050	3.26	< 0.10	< 0.050
121	< 0.25	1305		< 0.50				8.47				
132	< 0.25	1448	< 0.25	< 0.50	7.37	< 0.10	< 0.25	20.6	3.35			
137	< 0.25	1193	< 0.25	< 0.50	5.91	< 0.10	0.26	6.03	< 0.050			
148	0.41	1533	< 0.25	< 0.50	8.00	< 0.10	< 0.25	17.6	2.59			
153	0.71	1444	< 0.25	< 0.50	8.82	< 0.10	< 0.25	9.03	8.60			

TABLE VII Drainage Water from Inside Stratmat 3% Limestone Test (Replicate #1, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.31	< 0.25	129	< 0.025			< 0.025	0.082	13.5	16.5	3.68	12.3	
18	0.34	< 0.25	133	< 0.025			< 0.025	< 0.025	7.62	11.9	0.95	8.87	
24	0.34	< 0.25	95.4	< 0.025			< 0.025	< 0.025	5.38	8.92	0.23	7.53	
35	0.74	< 0.25	142	< 0.025			< 0.025	0.35	< 5.00	11.7	0.45	8.50	
41	1.73	< 0.25	102	< 0.025			< 0.025	2.16	< 5.00	8.71	0.31	8.23	
53	0.54	< 0.25	204	< 0.025			< 0.025	0.14	< 5.00	17.1	1.40	8.41	
57	0.47	< 0.25	241	< 0.025			< 0.025	0.15	< 5.00	18.1	1.62	8.18	
68	0.29	< 0.25	520	0.066			< 0.025	< 0.025	< 5.00	63.1	17.5	7.06	
73	0.33	< 0.25	495	0.039			0.14	0.075	< 5.00	38.4	8.94	6.97	
85	0.32	< 0.25	608	0.082			0.12	0.045	< 5.00	81.5	26.7	6.96	
90	0.26	< 0.25	586	< 0.025			0.070	0.047	< 5.00	33.7	8.23	7.10	
101	0.54	< 0.25	661	0.058			0.25	< 0.025	< 5.00	74.6	21.4	7.15	
105	0.41	< 0.25	702	< 0.025			0.12	0.050	< 5.00	35.4	8.68	6.99	
116	40.5	< 0.25	639	0.18			4.17	37.1	< 5.00	103	32.5	10.9	
117	1.34	< 0.25	672	0.13	0.13	< 0.025	0.34	1.55	< 5.00	111	27.2	7.15	0.057
121	1.77	< 0.25	728	0.074			0.74	0.030	< 5.00	43.8	11.28	6.43	
132	101	0.69	789	0.26	0.19	< 0.025	6.65	296	< 5.00	135	28.6	5.82	0.066
137	3.58	< 0.25	738	0.085	0.12	< 0.025	0.88	27.7	< 5.00	50.0	9.06	6.33	0.049
148	175	2.38	605	0.23	0.19	< 0.025	6.84	756	< 5.00	144	22.7	6.31	0.10
153	33.3	0.63	445	0.026	0.054	< 0.025	1.12	406	< 5.00	56.4	7.19	6.54	< 0.025

WEEK	Pb	so4	sb	se	Si	Te	Tl	Zn	Fe+3	Cl	HP04	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	347		< 0.50				0.21				
18	< 0.25	349		< 0.50				0.39				
24	< 0.25	248		< 0.50				< 0.02				
35	< 0.25	379		< 0.50				< 0.02				
41	< 0.25	237		< 0.50				< 0.02				
53	< 0.25	520		< 0.50				2.01				
57	< 0.25	626		< 0.50				5.15				
68	< 0.25	1447		< 0.50				36.2				
73	< 0.25	1233		< 0.50				25.5				
85	< 0.25	1776		< 0.50				49.6				
90	< 0.25	1489		< 0.50				15.8				
101	< 0.25	1922		< 0.50				47.4				
105	< 0.25	1717		< 0.50				20.2				
116	1.28	2561		< 0.50				105				
117	< 0.25	1984	< 0.25	< 0.50	11.5	< 0.50	< 0.25	64.0	1.15	3.40	< 0.10	< 0.050
121	< 0.25	1845		< 0.50				36.6				
132	3.37	4079	0.41	< 0.50	24.1	< 0.10	< 0.25	133	215			
137	< 0.25	2067	0.29	< 0.50	16.2	< 0.10	< 0.25	27.7	8.53			
148	4.12	4943	0.63	< 0.50	29.8	0.14	< 0.25	119	607			
153	< 0.25	2608	0.34	< 0.50	17.9	< 0.10	< 0.25	17.5	379			

TABLE VIII Drainage Water from Inside Stratmat 3% Limestone Test (Replicate #2, Started July 11, 1991)

WEEK	Al	AS	Ca	cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	ma/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	1.14	< 0.25	97	< 0.025			< 0.025	0.99	9.5	12.4	2.38	10.9	
18	0.62	< 0.25	117	< 0.025			< 0.025	0.30	6.12	10.7	0.71	8.48	
24	0.39	< 0.25	80.2	< 0.025			< 0.025	< 0.025	< 5.00	8.20	0.069	7.29	
35	0.35	< 0.25	146	< 0.0,25			< 0.025	< 0.025	< 5.00	12.2	0.49	8.45	
41	0.38	< 0.25	96	< 0.025			< 0.025	< 0.025	< 5.00	8.8	0.060	7.79	
53	0.44	< 0.25	150	0.045			0.055	0.068	< 5.00	14.2	0.40	7.35	
57	0.36	< 0.25	129	< 0.025			< 0.025	0.032	< 5.00	10.8	0.26	8.10	
68	0.41	< 0.25	353	0.028			< 0.025	0.038	< 5.00	39	5.94	7.09	
73	0.32	< 0.25	305	< 0.025			< 0.025	< 0.025	< 5.00	27.4	2.96	7.70	
85	0.30	< 0.25	403	0.036			< 0.025	0.15	< 5.00	48	12.4	7.17	
90	< 0.25	< 0.25	374	< 0.025			< 0.025	< 0.025	< 5.00	29.5	4.30	6.92	
101	0.35	< 0.25	425	< 0.025			< 0.025	0.074	< 5.00	48	7.08	7.15	
105	0.30	< 0.25	454	< 0.025			< 0.025	< 0.025	< 5.00	32	3.97	7.07	
116	0.45	< 0.25	662	0.059			0.090	0.030	< 5.00	97	17.6	10.7	
117	0.27	< 0.25	640	0.033	< 0.025	< 0.025	0.027	0.030	< 5.00	84	12.0	7.57	< 0.025
121	0.33	< 0.25	584	0.046			0.075	< 0.025	< 5.00	47.1	6.09	7.19	
132	0.51	< 0.25	735	0.084	0.10	< 0.025	0.16	0.270	< 5.00	122	20.8	5.98	0.10
137	< 0.25	< 0.25	596	0.032	< 0.025	< 0.025	< 0.025	0.049	< 5.00	40	4.16	6.04	< 0.025
148	1.02	< 0.25	761	0.085	0.086	< 0.025	0.25	0.13	< 5.00	115	19.1	6.53	0.071
153	0.36	< 0.25	612	< 0.025	< 0.025	< 0.025	0.069	0.086	< 5.00	47	4.89	6.53	< 0.025

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.25	82		< 0.50				0.14				
6	< 0.25	101		< 0.50				0.29				
18	< 0.25	69		< 0.50				< 0.025				
24	< 0.25	129		< 0.50				< 0.025				
35	< 0.25	79		< 0.50				< 0.025				
41	< 0.25	133		< 0.50				0.56				
53	< 0.25	113		< 0.50				0.55				
57	< 0.25	313		< 0.50				9.6				
68	< 0.25	252		< 0.50				8.40				
73	< 0.25	367		< 0.50				17.0				
85	< 0.25	325		< 0.50				8.35				
90	< 0.25	389		< 0.50				5.87				
101	< 0.25	381		< 0.50				7.01				
105	< 0.25	635		< 0.50				33.5				
116	< 0.25	574	< 0.25	< 0.50	7.32	< 0.50	< 0.25	18.0	< 0.050	3.43	< 0.10	< 0.050
117	< 0.25	500		< 0.50				11.3				
121	< 0.25	723	< 0.25	< 0.50	11.9	< 0.10	< 0.25	43.7	0.057			
132	< 0.25	490	< 0.25	< 0.50	6.81	< 0.10	< 0.25	8.02	< 0.050			
137	< 0.25	718	0.26	< 0.50	13.5	< 0.10	< 0.25	43.1	< 0.050			
148	< 0.25	517	< 0.25	< 0.50	8.55	< 0.10	< 0.25	9.09	< 0.050			
153	< 0.25	517	< 0.25	< 0.50	8.55	< 0.10	< 0.25	9.09	< 0.050			

TABLE IX Drainage Water from Inside Stratmat 3% Limestone Test (Replicate #3, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.51	< 0.25	131	< 0.025			< 0.025	0.19	11.2	15.0	2.42	19.2	
18	0.40	< 0.25	134	< 0.025			< 0.025	0.15	8.47	11.4	1.49	11.3	
24	0.28	< 0.25	82.1	< 0.025			< 0.025	< 0.025	< 5.00	6.54	0.23	8.68	
35	3.38	< 0.25	111	< 0.025			< 0.025	3.51	6.64	10.3	0.64	9.44	
41	20.3	< 0.25	153	< 0.025			0.14	24.7	10.7	25.8	1.20	10.2	
53	0.31	< 0.25	128	< 0.025			< 0.025	0.084	< 5.00	9.86	0.29	7.78	
57	0.50	< 0.25	136	< 0.025			< 0.025	0.21	< 5.00	10.0	0.27	8.43	
88	0.39	< 0.25	288	0.043			< 0.025	0.053	< 5.00	28.0	4.49	8.07	
73	0.37	< 0.25	318	0.038			0.18	< 0.025	< 5.00	28.8	3.53	9.70	
85	0.29	< 0.25	490	0.088			0.17	0.15	< 5.00	59.4	14.4	8.98	
90	0.29	< 0.25	454	0.039			0.24	< 0.025	< 5.00	35.2	8.83	7.78	
101	0.51	< 0.25	587	0.10			0.96	< 0.025	< 5.00	82.3	20.2	7.27	
105	0.51	< 0.25	594	0.028			0.81	0.08	< 5.00	42.4	12.0	7.79	
116	14.3	< 0.25	636	0.11			3.67	2.00	< 5.00	122	30.4	10.9	
117	< 0.25	< 0.25	683	0.10	0.15	< 0.025	0.093	0.13	7.82	136	29.0	8.19	0.057
121	0.45	< 0.25	733	0.063			0.43	< 0.025	< 5.00	63.9	16.1	7.89	
132	71.5	0.67	707	0.15	0.20	< 0.025	12.2	117	< 5.00	135	30.8	6.38	0.13
137	0.58	< 0.25	762	0.069	0.11	< 0.025	0.17	1.86	< 5.00	53.6	13.5	6.44	0.060
148	123	1.68	568	0.13	0.19	< 0.025	11.7	530	< 5.00	134	24.6	6.34	0.084
153	36.0	0.29	551	0.038	0.057	< 0.025	3.21	147	< 5.00	61.9	11.0	6.53	< 0.025

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	331		< 0.50				0.072				
18	< 0.25	348		< 0.50				0.42				
24	< 0.25	208		< 0.50				< 0.025				
35	0.30	269		< 0.50				0.11				
41	1.84	275		< 0.50				2.87				
53	< 0.25	331		< 0.50				0.76				
57	< 0.25	352		< 0.50				1.35				
68	0.28	718		< 0.50				17.2				
73	< 0.25	820		< 0.50				17.1				
85	< 0.25	1352		< 0.50				25.3				
90	0.26	1245		< 0.50				23.0				
101	0.65	1773		< 0.50				43.1				
105	0.51	1587		< 0.50				28.1				
116	2.14	2281		< 0.50				76.1				
117	< 0.25	2081	0.31	< 0.50	9.34	< 0.50	< 0.25	40.4	0.11	4.23	< 0.10	< 0.050
121	< 0.25	1931		< 0.50				25.0				
132	6.22	3252	< 0.25	< 0.50	25.8	< 0.10	< 0.25	84.6	103			
137	< 0.25	1989	0.30	< 0.50	13.5	0.14	< 0.25	24.9	0.84			
148	4.23	4030	0.50	< 0.50	28.2	< 0.10	< 0.25	72.0	458			
153	2.14	2282	< 0.25	< 0.50	20.7	< 0.10	< 0.25	23.7	134			

TABLE X Drainage Water from Inside Stratmat Water Cover Test (Replicate #1, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.37	< 0.25	88.1	< 0.025			< 0.025	0.10	14.9	14.2	5.34	24.7	
18	< 0.25	< 0.25	69.7	0.042	0.039	< 0.025	< 0.025	0.70	13.8	13.3	4.87	16.6	< 0.025
24	0.28	< 0.25	43.8	< 0.025			< 0.025	0.30	8.06	8.11	2.68	11.4	
35	< 0.25	< 0.25	40.7	< 0.025	< 0.025	< 0.025	< 0.025	0.53	6.13	7.16	2.36	8.19	< 0.025
41	0.44	< 0.25	35.7	< 0.025			< 0.025	0.17	< 5.00	6.34	2.36	8.83	
53	< 0.25	< 0.25	38.7	< 0.025	< 0.025	< 0.025	< 0.025	0.46	< 5.00	6.95	3.41	5.97	< 0.025
57	0.32	< 0.25	37.1	< 0.025			< 0.025	0.33	< 5.00	8.06	4.80	8.07	
68	0.29	< 0.25	36.6	< 0.025			< 0.025	0.63	< 5.00	8.78	6.01	7.27	
73	0.29	< 0.25	38.5	< 0.025			< 0.025	0.56	< 5.00	8.94	6.16	7.86	
85	0.31	< 0.25	34.6	< 0.025			< 0.025	0.44	< 5.00	8.58	5.76	7.12	
90	0.28	< 0.25	35.8	< 0.025			< 0.025	0.44	< 5.00	8.67	5.97	7.16	
101	0.38	< 0.25	33.1	< 0.025			< 0.025	0.44	< 5.00	9.16	6.18	7.26	
105	< 0.25	< 0.25	36.6	< 0.025			< 0.025	0.71	< 5.00	9.96	6.92	8.19	
116	0.32	< 0.25	36.6	< 0.025			< 0.025	0.89	< 5.00	10.6	7.20	7.93	
117	< 0.25	< 0.25	37.0	< 0.025	< 0.025	< 0.025	< 0.025	0.85	< 5.00	10.6	7.32	7.00	0.027
121	0.35	< 0.25	41.4	< 0.025			< 0.025	0.41	< 5.00	10.5	7.43	7.82	
132	0.66	< 0.25	39.6	< 0.025			< 0.025	2.32	< 5.00	13.6	8.78	6.04	
137	< 0.25	< 0.25	39.8	< 0.025			< 0.025	5.43	< 5.00	14.4	9.24	6.21	
148	0.88	< 0.25	43.9	< 0.025	< 0.025	< 0.025	< 0.025	5.02	6.37	16.0	9.98	6.87	< 0.025
153	0.65	< 0.25	40.3	< 0.025	< 0.025	< 0.025	< 0.025	6.41	5.70	16.4	9.74	7.19	< 0.025

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HP04	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	248		< 0.50				0.22				
18	< 0.25	181	< 0.25	< 0.50	8.00	< 0.10	< 0.25	0.37				
24	< 0.25	99.2		< 0.50				< 0.025				
35	< 0.25	68.9	< 0.25	< 0.50	6.26	< 0.10	< 0.25	0.091				
41	< 0.25	82.3		< 0.50				< 0.025				
53	< 0.25	99.0	< 0.25	< 0.50	4.71	< 0.10	< 0.25	< 0.025				
57	< 0.25	118		< 0.50				0.72				
68	< 0.25	112		< 0.50				0.69				
73	< 0.25	112		< 0.50				0.53				
85	< 0.25	104		< 0.50				0.45				
90	< 0.25	121		< 0.50				0.96				
101	0.56	128		< 0.50				2.36				
105	0.26	137		< 0.50				2.18				
116	< 0.25	131		< 0.50				1.19				
117	< 0.25	126	< 0.25	< 0.50	5.28	< 0.50	< 0.25	1.19	0.64	2.01	< 0.10	< 0.050
121	< 0.25	137		< 0.50				0.92				
132	3.17	196		< 0.50				4.70				
137	1.17	200		< 0.50				4.72				
148	2.08	210	< 0.25	< 0.50	10.1	< 0.10	< 0.25	5.77	0.086			
153	1.53	201	< 0.25	< 0.50	10.1	< 0.10	< 0.25	4.96	< 0.050			

TABLE XI Drainage Water from Inside Stratmat Water Cover Test (Replicate #2, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.40	< 0.25	63.6	< 0.025			< 0.025	0.17	13.2	11.3	4.33	16.4	
18	< 0.25	< 0.25	59.7	< 0.025	< 0.025	< 0.025	< 0.025	0.26	11.6	12.2	4.65	12.1	< 0.025
24	< 0.25	< 0.25	39.4	< 0.025			< 0.025	0.10	6.44	7.72	2.70	9.71	
35	< 0.25	< 0.25	42.9	< 0.025	< 0.025	< 0.025	< 0.025	0.26	6.41	7.56	2.71	7.54	< 0.025
41	0.43	< 0.25	36.5	< 0.025			< 0.025	0.10	< 5.00	6.33	3.10	7.68	
53	< 0.25	< 0.25	40.5	< 0.025	< 0.025	< 0.025	< 0.025	0.28	< 5.00	6.94	5.02	6.03	< 0.025
57	0.48	< 0.25	35.4	< 0.025			< 0.025	0.31	< 5.00	7.30	5.39	7.84	
68	< 0.25	< 0.25	37.4	< 0.025			< 0.025	0.35	< 5.00	7.68	6.38	7.03	
73	0.27	< 0.25	40.4	< 0.025			< 0.025	0.23	< 5.00	7.95	6.51	7.76	
85	< 0.25	< 0.25	36.5	< 0.025			< 0.025	0.21	< 5.00	7.59	5.98	7.09	
90	0.33	< 0.25	33.3	< 0.025			< 0.025	0.23	< 5.00	7.30	5.91	7.91	
101	0.38	< 0.25	33.7	< 0.025			< 0.025	0.14	< 5.00	7.98	6.42	7.16	
105	0.32	< 0.25	37.3	< 0.025			< 0.025	0.42	< 5.00	8.69	7.20	8.51	
116	0.29	< 0.25	37.1	< 0.025			< 0.025	0.50	< 5.00	9.22	7.60	7.42	
117	< 0.25	< 0.25	37.1	0.038	0.048	< 0.025	< 0.025	0.57	< 5.00	9.08	7.88	6.72	< 0.025
121	0.26	< 0.25	41.2	< 0.025			< 0.025	< 0.025	< 5.00	9.19	7.90	7.59	
132	1.72	< 0.25	37.0	< 0.025			< 0.025	< 0.025	< 5.00	10.9	8.39	6.09	
137	0.62	< 0.25	38.4	< 0.025			< 0.025	1.78	< 5.00	11.9	9.41	6.18	
148	1.06	< 0.25	37.8	< 0.025	0.039	< 0.025	< 0.025	3.57	< 5.00	13.1	9.74	6.64	0.044
153	0.95	< 0.25	37.9	< 0.025	< 0.025	< 0.025	< 0.025	5.55	< 5.00	13.2	9.71	6.90	< 0.025

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	185		< 0.50				0.26				
18	< 0.25	164	< 0.25	< 0.50	6.74	< 0.10	< 0.25	0.30				
24	< 0.25	94.2		< 0.50				< 0.025				
35	< 0.25	88.7	< 0.25	< 0.50	5.47	< 0.10	< 0.25	0.088				
41	< 0.25	89.8		< 0.50				< 0.025				
53	< 0.25	110	< 0.25	< 0.50	4.56	< 0.10	< 0.25	< 0.025				
57	< 0.25	115		< 0.50				1.46				
68	< 0.25	115		< 0.50				1.26				
73	< 0.25	115		< 0.50				1.02				
85	< 0.25	107		< 0.50				0.78				
90	< 0.25	114		< 0.50				1.74				
101	0.97	127		< 0.50				2.75				
105	0.39	138		< 0.50				3.02				
116	< 0.25	132		< 0.50				2.13				
117	< 0.25	128	< 0.25	< 0.50	5.27	< 0.50	< 0.25	2.26	0.37	1.80	< 0.10	< 0.050
121	< 0.25	138		< 0.50				2.09				
132	4.97	182		< 0.50				6.04				
137	1.92	190		< 0.50				5.68				
148	2.28	180	< 0.25	< 0.50	8.76	< 0.10	< 0.25	5.55	0.12			
153	2.12	185	< 0.25	< 0.50	9.24	< 0.10	< 0.25	5.64	< 0.050			

TABLE XII Drainage Water from Inside Stratmat Water Cover Test (Replicate **#3,** Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
6	0.34	< 0.25	88.9	< 0.025			< 0.025	0.35	16.0	14.6	7.03	19.1	
18	< 0.25	< 0.25	66.7	< 0.025	< 0.025	< 0.025	< 0.025	1.13	12.3	12.9	6.17	13.4	< 0.025
24	0.29	< 0.25	53.0	< 0.025			< 0.025	0.63	10.1	9.89	4.49	12.3	
35	< 0.25	< 0.25	46.1	< 0.025	< 0.025	< 0.025	< 0.025	0.43	6.65	7.46	3.36	8.64	< 0.025
41	< 0.25	< 0.25	37.6	< 0.025			< 0.025	< 0.025	< 5.00	5.42	2.37	8.07	
53	< 0.25	< 0.25	42.8	< 0.025	< 0.025	< 0.025	< 0.025	0.39	< 5.00	5.49	3.22	6.54	< 0.025
57	0.41	< 0.25	42.3	< 0.025			< 0.025	0.14	< 5.00	6.29	3.90	8.26	
68	0.31	< 0.25	43.0	< 0.025			< 0.025	0.19	< 5.00	6.09	4.51	7.44	
73	0.37	< 0.25	42.0	< 0.025			< 0.025	< 0.025	< 5.00	6.34	4.76	8.37	
85	< 0.25	< 0.25	38.7	< 0.025			< 0.025	0.072	< 5.00	5.98	4.64	7.49	
90	< 0.25	< 0.25	40.2	< 0.025			< 0.025	0.12	< 5.00	6.36	5.05	7.51	
101	< 0.25	< 0.25	39.5	< 0.025			< 0.025	0.18	< 5.00	6.78	5.60	7.69	
105	0.27	< 0.25	42.7	< 0.025			< 0.025	0.21	< 5.00	7.48	6.05	8.80	
116	< 0.25	< 0.25	43.8	< 0.025			< 0.025	0.52	< 5.00	7.70	6.38	7.61	
117	< 0.25	< 0.25	43.2	< 0.025	< 0.025	< 0.025	< 0.025	0.42	< 5.00	7.77	6.42	7.06	< 0.025
121	0.36	< 0.25	46.2	< 0.025			< 0.025	0.11	< 5.00	7.75	6.42	7.86	
132	< 0.25	< 0.25	37.7	< 0.025			< 0.025	0.34	< 5.00	7.80	6.11	6.51	
137	< 0.25	< 0.25	38.8	< 0.025			< 0.025	0.068	< 5.00	8.35	6.54	6.46	
148	< 0.25	< 0.25	37.6	< 0.025	< 0.025	< 0.025	< 0.025	0.42	< 5.00	9.45	6.64	6.93	< 0.025
153	0.26	< 0.25	38.8	< 0.025	< 0.025	< 0.025	< 0.025	2.21	< 5.00	9.78	6.96	7.13	0.21

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3	Cl	HPO4	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
6	< 0.25	259		< 0.50				0.55				
18	< 0.25	169	< 0.25	< 0.50	7.89	< 0.10	< 0.25	0.26				
24	< 0.25	127		< 0.50				< 0.025				
35	< 0.25	85.4	< 0.25	< 0.50	6.00	< 0.10	< 0.25	0.045				
41	< 0.25	74.2		< 0.50				< 0.025				
53	< 0.25	97.0	< 0.25	< 0.50	4.10	< 0.10	< 0.25	< 0.025				
57	< 0.25	109		< 0.50				0.027				
68	< 0.25	104		< 0.50				0.087				
73	< 0.25	104		< 0.50				0.42				
85	< 0.25	103		< 0.50				0.80				
90	< 0.25	115		< 0.50				1.30				
101	< 0.25	122		< 0.50				2.75				
105	< 0.25	134		< 0.50				3.85				
116	< 0.25	129		< 0.50				2.28				
117	< 0.25	122	< 0.25	< 0.50	4.62	< 0.50	< 0.25	2.26	0.30	2.21	< 0.10	< 0.050
121	< 0.25	132		< 0.50				2.01				
132	< 0.25	150		< 0.50				7.01				
137	< 0.25	155		< 0.50				6.87				
148	< 0.25	154	< 0.25	< 0.50	6.87	< 0.10	< 0.25	8.92	< 0.050			
153	0.44	160	< 0.25	< 0.50	7.25	< 0.10	< 0.25	9.25	< 0.050			

TABLE X(a) Water Quality Profile from Inside Stratmat Water Cover Test (Replicate #1, Started July 11, 1991)

WEEK	DEPTH	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
132	2	2.01	< 0.25	27.7	< 0.025			0.044	< 0.025	< 5.00	10.7	6.52
	75	2.07	< 0.25	28.1	< 0.025			0.041	< 0.025	< 5.00	10.9	6.60
137	2	2.37	< 0.25	26.4	< 0.025			0.039	< 0.025	< 5.00	11.0	6.42
	75	2.38	< 0.25	26.3	< 0.025			0.038	< 0.025	< 5.00	11.0	6.38
148	2	3.23	< 0.25	29.3	< 0.025	< 0.025	< 0.03	0.046	0.10	< 5.00	12.4	7.11
	75	3.19	< 0.25	26.8	0.19	0.21	0.14	0.20	0.25	5.09	12.7	7.12
153	2	2.71	< 0.25	24.2	< 0.025	0.028	< 0.03	0.051	< 0.025	< 5,00	11.0	6.05
	75	2.64	< 0.25	24.0	< 0.025	< 0.025	< 0.03	0.032	< 0.025	5.03	10.8	6.05

WEEK	DEPTH	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
132	2	5.91		6.43	162		< 0.50				3.98	
	75	6.09		6.47	163		< 0.50				4.04	
137	2	6.26		6.54	165		< 0.50				3.85	
	75	6.32		6.50	164		< 0.50				3.85	
148	2	6.76	< 0.03	6.74	174	< 0.25	< 0.50	8.92	< 0.10	< 0.25	5.05	< 0.050
	75	6.99	0.19	6.28	165	< 0.25	< 0.50	8.86	0.18	< 0.25	4.50	< 0.050
153	2	6.92	0.026	5.99	145	< 0.25	< 0.50	7.83	< 0.10	< 0.25	3.86	< 0.050
	75	6.68	< 0.025	5.91	146	< 0.25	< 0.50	7.78	< 0.10	< 0.25	3.80	< 0.05

TABLE XI(a) Water Quality Profile from Inside Stratmat Water Cover Test (Replicate #2, Started July 11, 1991)

WEEK	DEPTH	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
132	2	2.17	< 0.25	26.2	< 0.025			0.040	< 0.025	< 5.00	8.27	5.98
	75	2.13	< 0.25	26.1	< 0.025			0.042	< 0.025	< 5.00	8.29	5.96
137	2	2.43	< 0.25	25.0	< 0.025			0.044	< 0.025	< 5.00	8.39	5.77
	75	2.39	< 0.25	25.0	< 0.025			0.043	< 0.025	< 5.00	8.35	5.73
148	2	1.06	< 0.25	37.8	< 0.025	0.039	< 0.025	< 0.025	3.57	< 5.00	13.1	9.74
	75	3.32	< 0.25	25.3	< 0.025	< 0.025	< 0.025	0.063	< 0.025	< 5.00	10.0	6.09
153	2	2.89	< 0.25	23.3	< 0.025	< 0.025	< 0.025	0.034	0.11	< 5.00	8.61	5.38
	75	2.92	< 0.25	23.1	< 0.025	< 0.025	< 0.025	0.034	0.24	< 5.00	8.62	5.37

WEEK	DEPTH	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
132	2	5.89		6.11	146		< 0.50				3.93	
	75	5.89		6.06	147		< 0.50				3.92	
137	2	6.35		6.15	149		< 0.50				3.88	
	75	5.95		6.12	149		< 0.50				3.86	
148	2	6.64	0.044	2.28	180	< 0.25	< 0.50	8.76	< 0.10	< 0.25	5.55	0.12
	75	6.68	< 0.025	5.78	148	< 0.25	< 0.50	7.56	< 0.10	< 0.25	4.33	< 0.050
153	2	6.95	< 0.025	5.49	136	< 0.25	< 0.50	6.99	< 0.10	< 0.25	3.92	< 0.050
	75	6.84	< 0.025	5.42	136	< 0.25	< 0.50	6.96	< 0.10	< 0.25	3.87	< 0.050

TABLE XII(a) Water Quality Profile from Inside Stratmat Water Cover Test (Replicate #3, Started July 11, 1991)

WEEK	DEPTH	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
132	2	1.01	< 0.25	25.4	< 0.025			0.067	< 0.025	< 5.00	5.88	4.27
	75	1.00	< 0.25	25.7	< 0.025			0.071	< 0.025	< 5.00	6.01	4.29
137	2	1.29	< 0.25	24.8	< 0.025			0.085	< 0.025	< 5.00	6.10	4.13
	75	1.22	< 0.25	24.7	< 0.025			0.083	< 0.025	< 5.00	6.05	4.14
148	2	1.71	< 0.25	25.7	< 0.025	< 0.025	< 0.025	0.090	< 0.025	< 5.00	7.16	4.55
	75	1.71	< 0.25	26.0	< 0.025	< 0.025	< 0.025	0.089	< 0.025	< 5.00	7.10	4.59
153	2	1.52	< 0.25	23.7	< 0.025	< 0.025	< 0.025	0.072	0.12	< 5.00	6.26	4.08
	75	1.52	< 0.25	23.6	< 0.025	< 0.025	< 0.025	0.072	< 0.025	< 5.00	6.20	4.03

WEEK	DEPTH	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
132	2	6.34		3.61	122		< 0.50				6.21	
	75	5.86		3.72	125		< 0.50				6.34	
137	2	6.15		3.73	124		< 0.50				6.70	
	75	6.02		3.76	124		< 0.50				6.70	
148	2	6.71	< 0.025	3.40	127	< 0.25	< 0.50	5.89	< 0.10	< 0.25	7.87	< 0.050
	75	6.72	< 0.025	3.51	127	< 0.25	< 0.50	5.87	< 0.10	< 0.25	7.98	< 0.050
153	2	6.79	0.034	3.39	116	< 0.25	< 0.50	5.35	< 0.10	< 0.25	7.40	< 0.050
	75	6.81	< 0.025	3.34	114	< 0.25	< 0.50	5.33	< 0.10	< 0.25	7.30	< 0.050

TABLE XIII Drainage Water from Inside Stratmat Clay Cover Test (Replicate #1, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	103	0.83	265	0.11	0.13	< 0.025	2.11	149	7.76	90.3	22.1
41	0.64	< 0.25	135	< 0.025	< 0.025	< 0.025	< 0.025	6.27	< 5.00	29.9	4.60
101	80.1	0.67	166	0.054	0.082	< 0.025	1.28	182	< 5.00	80.1	16.1
105	0.97	< 0.25	97.0	< 0.025	< 0.025	< 0.025	< 0.025	8.46	< 5.00	27.7	4.82
148	85.4	0.78	159	0.076	0.081	< 0.025	0.98	165	< 5.00	79.0	17.8
153	3.26	< 0.25	115	< 0.025	< 0.025	< 0.025	0.026	17.5	< 5.00	38.3	7.41

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	24.9	0.052	3.73	2106	0.25	< 0.50	32.0	0.22	< 0.25	61.1	
41	17.8	< 0.025	< 0.25	318	< 0.25	< 0.50	10.6	< 0.10	< 0.25	1.53	
101	10.1	0.038	< 0.25	1674	< 0.25	< 0.50	24.3	< 0.10	< 0.25	27.5	
105	9.06	< 0.025	< 0.25	395	< 0.25	< 0.50	10.4	< 0.10	< 0.25	3.73	
148	8.81	0.083	< 0.25	1580	< 0.25	< 0.50	23.6	< 0.10	< 0.25	28.1	65.3
153	8.98	< 0.025	< 0.25	512	< 0.25	< 0.50	11.7	< 0.10	< 0.25	8.89	6.16

TABLE XIV Drainage Water from Inside Stratmat Clay Cover Test (Replicate #2, Started July 11; 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	0.45	< 0.25	269	0.031	0.053	< 0.025	< 0.025	1.06	11.4	70.7	21.5
41	< 0.25	< 0.25	155	< 0.025	0.030	< 0.025	< 0.025	22.2	6.10	46.6	11.4
101	80.1	0.67	166	0.054	0.082	< 0.025	1.28	182	< 5.00	80.1	16.1
105	2.36	< 0.25	115	0.031	0.034	< 0.025	0.029	23.6	< 5.00	53.3	9.67
148	95.7	0.44	176	0.10	0.10	< 0.025	1.21	15.6	< 5.00	125	26.5
153	6.91	< 0.25	116	< 0.025	< 0.025	< 0.025	0.12	5.60	< 5.00	59.1	9.15

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	31.8	< 0.025	< 0.25	865	< 0.25	< 0.50	11.0	< 0.10	< 0.25	17.1	
41	21.4	0.028	< 0.25	452	< 0.25	< 0.50	9.82	< 0.10	< 0.25	14.4	
101	10.1	0.038	< 0.25	1674	< 0.25	< 0.50	24.3	< 0.10	< 0.25	27.5	
105	9.68	< 0.025	< 0.25	579	< 0.25	< 0.50	8.03	< 0.10	< 0.25	18.4	
148	9.13	0.066	4.14	1655	< 0.25	< 0.50	15.1	0.32	< 0.25	61.9	13.0
153	9.12	< 0.025	0.43	646	< 0.25	< 0.50	9.35	< 0.10	< 0.25	18.5	4.79

TABLE XV Drainage Water from Inside Stratmat Clay Cover Test (Replicate #3, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	0.67	< 0.25	361	0.082	0.063	< 0.025	0.047	0.54	17.1	79.6	22.4
41	< 0.25	< 0.25	136	< 0.025	< 0.025	< 0.025	< 0.025	0.86	6.60	26.1	3.86
101	1.89	< 0.25	224	0.044	0.035	< 0.025	0.12	1.37	8.21	59.7	16.1
105	< 0.25	< 0.25	104	< 0.025	< 0.025	< 0.025	< 0.025	0.22	< 5.00	18.7	1.82
148	19.3	< 0.25	328	0.093	0.054	< 0.025	0.88	27.4	7.47	102	26.5
153	< 0.25	< 0.25	100	< 0.025	< 0.025	< 0.025	< 0.025	0.13	< 5.00	23.7	3.61

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	41.4	< 0.025	0.94	1304	< 0.25	< 0.50	19.3	< 0.10	< 0.25	38.1	
41	22.2	< 0.025	< 0.25	224	< 0.25	< 0.50	12.3	< 0.10	< 0.25	4.84	
101	13.0	< 0.025	< 0.25	879	< 0.25	< 0.50	15.8	< 0.10	< 0.25	30.5	
105	10.5	< 0.025	< 0.25	103	< 0.25	< 0.50	9.85	< 0.10	< 0.25	2.06	
148	11.2	0.044	3.21	1520	< 0.25	< 0.50	24.5	< 0.10	< 0.25	59.4	6.78
153	9.47	< 0.025	< 0.25	240	< 0.25	< 0.50	10.3	< 0.10	< 0.25	1.44	0.12

TABLE XVI Drainage Water from Inside Stratmat 1% Phosphate Test (Replicate #1, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	346	19.3	339	0.57	0.45	0.036	9.48	3579	< 5.00	339	46.6
41	119	7.82	335	0.21	0.20	< 0.025	4.56	1819	< 5.00	116	18.0
101	377	32.3	256	0.60	0.41	< 0.025	10.4	5246	< 5.00	362	37.8
105	144	8.68	235	0.20	0.18	< 0.025	4.94	1841	< 5.00	137	16.3
148	347	22.6	248	0.50	0.35	< 0.025	10.9	4103	< 5.00	332	32.9
153	124	6.31	214	0.14	0.13	< 0.025	4.21	1484	< 5.00	121	13.3

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	13.6	0.16	< 0.25	10185	2.06	< 0.50	24.7	0.38	< 0.25	220	
41	10.6	0.060	< 0.25	5559	1.11	< 0.50	31.2	< 0.10	< 0.25	79.3	
101	9.17	0.18	< 0.25	13026	3.14	< 0.50	30.8	0.47	< 0.25	180	
105	8.27	0.071	< 0.25	5736	1.06	< 0.50	30.1	0.15	< 0.25	68.4	
148	7.94	0.12	< 0.25	11754	2.75	< 0.50	34.8	0.38	< 0.25	179	3530
153	7.36	0.026	< 0.25	5124	0.96	< 0.50	30.8	0.20	< 0.25	60.7	1340

TABLE XVII Drainage Water from Inside Stratmat 1% Phosphate Test (Replicate #2, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	417	17.1	424	0.76	0.59	0.088	7.10	3402	5.41	417	64.7
41	148	7.50	366	0.29	0.24	< 0.025	3.50	1852	< 5.00	146	23.0
101	464	31.9	323	0.56	0.41	< 0.025	8.72	5030	< 5.00	457	40.9
105	191	10.3	294	0.23	0.20	< 0.025	5.02	1999	< 5.00	184	17.8
148	425	29.1	280	0.44	0.36	< 0.025	9.44	4421	< 5.00	417	33.7
153	163	8.95	259	0.16	0.15	< 0.025	4.84	1708	< 5.00	160	14.2

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	24.1	0.28	0.90	10794	2.08	< 0.50	36.6	0.37	0.36	343	
41	13.5	0.087	< 0.25	6099	1.11	< 0.50	36.1	0.22	< 0.25	130	
101	8.96	0.15	< 0.25	13926	3.07	< 0.50	37.8	0.42	< 0.25	169	
105	7.92	0.09	< 0.25	6627	1.37	< 0.50	34.7	0.25	< 0.25	78.6	
148	7.33	0.13	< 0.25	13041	2.77	< 0.50	44.8	0.40	< 0.25	120	3850
153	7.09	0.059	< 0.25	5988	1.04	< 0.50	38.5	0.23	< 0.25	54.9	1520

TABLE XVIII Drainage Water from Inside Stratmat 1% Phosphate Test (Replicate #3, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	551	30.2	391	1.10	0.81	0.20	9.00	6758	5.46	533	69.2
41	203	10.2	423	0.44	0.36	0.038	4.18	2978	< 5.00	196	26.9
101	516	30.5	303	0.42	0.50	< 0.025	7.39	6443	< 5.00	497	39.6
105	269	13.0	366	0.19	0.26	< 0.025	4.58	3100	< 5.00	258	20.8
148	428	23.6	283	0.27	0.38	< 0.025	8.51	4584	< 5.00	406	30.8
153	208	9.10	298	0.10	0.18	< 0.025	4.61	2084	< 5.00	203	16.3

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	29.1	0.36	2.08	16626	3.91	< 0.50	44.1	0.76	0.39	467	
41	18.2	0.17	0.26	8538	2.04	< 0.50	46.1	0.37	0.27	176	
101	10.1	0.22	< 0.25	16623	3.78	< 0.50	44.4	0.56	< 0.25	95.3	
105	8.67	0.10	< 0.25	9354	1.91	< 0.50	46.4	0.26	< 0.25	52.7	
148	7.58	0.12	< 0.25	13431	2.73	< 0.50	48.9	0.42	< 0.25	50.7	3930
153	6.95	< 0.025	< 0.25	7314	1.34	< 0.50	47.2	0.22	< 0.25	24.6	1880

TABLE XIX Drainage Water from Inside Stratmat 3% Phosphate Test (Replicate #1, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	240	2.23	547	0.22	0.38	< 0.025	5.46	299	6.55	288	48.1
41	84.5	1.14	469	0.10	0.13	< 0.025	2.47	311	< 5.00	96.8	19.1
101	189	6.44	291	0.12	0.23	< 0.025	3.78	2244	< 5.00	192	22.8
105	97.1	2.79	362	0.062	0.13	< 0.025	2.73	1176	< 5.00	105	13.2
148	215	8.80	298	0.11	0.23	< 0.025	4.28	2726	< 5.00	209	22.4
153	78.7	2.72	311	0.031	0.090	< 0.025	1.96	1061	< 5.00	81.6	9.61

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
35	45.4	0.24	< 0.25	4275	0.56	< 0.50	40.6	< 0.10	< 0.25	136	
41	23.0	0.079	< 0.25	2737	0.26	< 0.50	35.1	< 0.10	< 0.25	52.9	
101	13.7	0.091	< 0.25	6750	1.32	< 0.50	20.7	0.15	< 0.25	38.7	
105	14.0	0.042	< 0.25	4331	0.72	< 0.50	25.7	0.18	< 0.25	24.7	
148	12.9	0.11	< 0.25	7689	1.66	< 0.50	23.6	0.20	< 0.25	30.3	2320
153	10.9	0.092	< 0.25	3889	0.69	< 0.50	23.9	0.17	< 0.25	13.5	971

TABLE XX Drainage Water from inside Stratmat 3% Phosphate Test (Replicate #2, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	154	1.22	443	0.16	0.29	< 0.025	8.89	80.1	6.60	217	46.1
41	74.4	0.90	444	0.082	0.11	< 0.025	5.58	89.0	< 5.00	85.0	19.2
101	186	5.50	353	0.18	0.20	< 0.025	10.3	2012	< 5.00	178	19.8
105											
146	234	8.21	375	0.16	0.24	< 0.025	10.8	2993	< 5.00	218	19.7
153	80.9	2.84	336	0.055	0.12	< 0.025	4.09	1198	< 5.00	80.9	8.25

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L									
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	34.7	0.20	< 0.25	2913	0.32	< 0.50	29.0	< 0.10	< 0.25	120	
41	22.9	0.11	< 0.25	2068	< 0.25	< 0.50	30.4	< 0.10	< 0.25	50.7	
101	14.3	0.080	< 0.25	6345	1.12	< 0.50	18.3	0.23	< 0.25	73.1	
105											
148	15.0	0.091	< 0.25	8280	2.07	< 0.50	23.0	0.29	< 0.25	59.3	2300
153	12.1	0.048	< 0.25	4108	0.83	< 0.50	24.9	0.17	< 0.25	18.0	1100

TABLE XXI Drainage Water from Inside Stratmat 3% Phosphate Test (Replicate #3, Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	121	1.06	407	0.12	0.25	< 0.025	2.56	40.0	< 5.00	191	35.3
41	63.9	0.59	423	0.060	0.086	< 0.025	1.76	53.8	< 5.00	77.3	15.0
101	159	4.35	346	0.14	0.18	< 0.025	4.53	1649	< 5.00	156	20.3
105	76.2	1.88	318	0.093	0.13	< 0.025	3.57	805	< 5.00	85.4	11.9
148	191	6.79	288	0.15	0.21	< 0.025	5.67	2416	< 5.00	182	19.7
153	67.4	1.95	306	0.037	0.093	< 0.025	3.15	945	< 5.00	72.1	8.60

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	33.4	0.16	< 0.25	2454	< 0.25	< 0.50	28.1	< 0.10	< 0.25	92.4	
41	21.5	0.048	< 0.25	1821	< 0.25	< 0.50	30.0	< 0.10	< 0.25	36.3	
101	14.1	0.076	< 0.25	5631	1.08	< 0.50	17.3	0.22	< 0.25	51.3	
105	13.3	0.072	< 0.25	3330	0.567	< 0.50	21.4	0.11	< 0.25	28.6	
148	13.3	0.080	< 0.25	6915	1.63	< 0.50	19.9	0.24	< 0.25	41.6	2090
153	10.9	< 0.025	< 0.25	3500	0.624	< 0.50	21.2	0.13	< 0.25	17.5	886

TABLE **XXII** Drainage Water from Inside Stratmat Wood Bark Cover Test (Replicate **#1,** Started July 11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	764	40.9	259	1.13	0.89	< 0.025	10.9	7815	< 5.00	826	98.9
41	452	24.8	313	0.69	0.60	< 0.025	10.8	5940	< 5.00	464	66.3
101	763	33.7	293	0.48	0.72	< 0.025	10.7	7555	< 5.00	783	70.5
105	38.7	0.50	234	< 0.025	0.044	< 0.025	1.06	332	< 5.00	72.3	10.0
148	543	25.5	235	0.34	0.55	< 0.025	7.13	6021	< 5.00	544	44.1
153	334	13.1	240	0.19	0.34	< 0.025	5.70	3687	< 5.00	348	29.7

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	ma/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ma/L	mg/L	mg/L
1											
35	7.53	0.30	< 0.25	25872	4.56	< 0.50	43.8	0.90	0.49	457	
41	6.34	0.21	< 0.25	20169	3.41	< 0150	60.9	0.57	0.45	276	
101	5.46	0.26	< 0.25	26151	4.61	< 0.50	58.9	0.63	< 0.25	139	
105	7.22	0.029	< 0.25	1838	< 0.25	< 0.50	40.6	< 0.10	< 0.25	12.0	
148	6.12	0.22	< 0.25	20451	3.61	< 0.50	59.8	0.59	< 0.25	91.7	5210
153	6.78	0.094	< 0.25	13314	2.18	< 0.50	68.8	0.34	< 0.25	63.9	3330

TABLE XXIII Drainage Water from Inside Stratmat Wood Bark Cover Test (Replicate **#2,** Started July **11, 1991)**

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	928	68.1	251	1.55	0.91	< 0.025	19.0	7505	< 5.00	948	98.9
41	498	30.3	270	0.69	0.55	< 0.025	8.62	5113	< 5.00	462	54.6
101	745	36.6	228	0.68	0.67	< 0.025	9.03	5890	< 5.00	730	60.2
105	58.0	0.80	235	0.070	0.094	< 0.025	1.06	426	< 5.00	98.1	14.7
148	474	27.5	181	0.28	0.49	< 0.025	5.56	5139	< 5.00	454	34.9
153	461	21.4	241	0.37	0.44	< 0.025	5.75	4421	< 5.00	459	36.1

WEEK	Na	Ni	Pb	so4	Sb	se	Si	Te	Tl	Zn	Fe
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ma/L	mg/L	mg/L
1											
35	7.05	0.39	< 0.25	26865	4.56	< 0.50	59.6	0.97	0.70	580	
41	6.01	0.19	< 0.25	17976	3.02	< 0.50	62.7	0.52	0.44	263	
101	5.87	0.33	< 0.25	21333	3.77	< 0.50	53.5	0.64	< 0.25	175	
105	7.00	0.05	< 0.25	2237	0.34	< 0.50	48.3	< 0.10	< 0.25	17.7	
148	5.85	0.15	< 0.25	17022	3.29	< 0.50	52.0	0.46	< 0.25	56.5	5740
153	6.46	0.14	< 0.25	16203	2.63	< 0.50	70.8	0.44	< 0.25	113	3970

TABLE XXIV Drainage Water from Inside Stratmat Wood Bark Cover Test (Replicate **#3,** Started July **11, 1991)**

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	882	65.0	258	1.07	0.84	< 0.025	11.3	8558	15.9	817	102
41	469	32.6	258	0.62	0.52	< 0.025	9.14	5049	< 5.00	428	61.0
101	780	39.3	243	0.47	0.66	< 0.025	9.42	6641	< 5.00	755	63.4
105	34.5	0.64	157	0.028	0.059	< 0.025	1.05	328	< 5.00	68.3	9.09
148	486	27.3	180	0.38	0.59	< 0.025	5.82	5292	< 5.00	468	35.7
153	315	16.4	181	0.21	0.34	< 0.025	3.98	3520	< 5.00	319	25.3

WEEK	Na	Ni	Pb	so4	Sb	se	Si	Te	Tl	Zn	Fe
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
35	7.24	0.32	< 0.25	27882	4.73	< 0.50	58.6	0.93	0.37	321	
41	5.87	0.18	< 0.25	17211	3.09	< 0.50	48.7	0.45	< 0.25	198	
101	5.76	0.24	< 0.25	23304	4.04	< 0.50	56.5	0.65	< 0.25	93.1	
105	7.30	0.051	< 0.25	1560	< 0.25	< 0.50	39.0	< 0.10	< 0.25	8.56	
148	6.20	0.22	< 0.25	17649	3.19	< 0.50	52.4	0.62	< 0.25	56.8	4620
153	6.63	0.13	< 0.25	12039	2.15	< 0.50	55.7	0.33	< 0.25	49.6	2860

TABLE XXIV(a) Drainage Water from Inside Blank Wood. Bark Test (Started July11, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
121	0.45	< 0.25	36.3	< 0.025			< 0.025	0.38	< 5.00	3.61	1.28
148	0.26	< 0.25	34.6	< 0.025	< 0.025	< 0.025	< 0.025	0.56	< 5.00	3.47	0.59
153	< 0.25	< 0.25	21.8	< 0.025	< 0.025	< 0.025	< 0.025	0.64	< 5.00	2.23	0.56

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
121	8.20		< 0.25	3.53		< 0.50				0.13	
148	6.87	< 0.025	< 0.25	2.46	< 0.25	< 0.50	3.58	< 0.10	< 0.25	< 0.025	0.14
153	6.69	< 0.025	< 0.25	1.87	< 0.25	< 0.50	1.75	< 0.10	< 0.25	0.16	0.15

TABLE XXV Drainage Water from Inside Selbaie Control Test (Replicate #1, Started August 8, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	1.71	< 0.25	153	0.74	0.039	< 0.025	9.98	45.0	< 5.00	134	54.7
35	1.79	< 0.25	119	0.29	< 0.025	< 0.025	4.14	279	< 5.00	40.5	14.1
95	12.4	< 0.25	89.3	0.68	0.030	< 0.025	21.3	275	< 5.00	87.4	29.2
99	4.06	< 0.25	108	0.27	< 0.025	< 0.025	5.26	226	< 5.00	45.0	13.3
142	19.1	0.54	83.6	0.60	0.027	< 0.025	19.5	538	< 5.00	89.7	26.4
147	5.23	< 0.25	82.8	0.22	< 0.025	< 0.025	4.57	297	< 5.00	35.2	10.4

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	5.43	0.058	< 0.25	1495	< 0.25	< 0.50	2.69	< 0.10	< 0.25	254	
35	5.53	< 0.025	< 0.25	1414	< 0.25	< 0.50	2.02	< 0.10	< 0.25	86.4	
95	5.51	< 0.025	< 0.25	1845	< 0.25	< 0.50	2.92	0.11	< 0.25	235	
99	5.99	< 0.025	< 0.25	1324	< 0.25	< 0.50	2.86	< 0.10	< 0.25	87.0	
142	6.28	< 0.025	< 0.25	2410	0.37	< 0.50	4.30	< 0.10	< 0.25	207	440
147	6.80	< 0.025	< 0.25	1415	< 0.25	< 0.50	3.62	< 0.10	< 0.25	81.4	265

TABLE XXVI Drainage Water from Inside Selbaie Control Test (Replicate #2, Started August 8,1SSI)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	11.3	0.28	182	1.86	0.11	0.074	134	466	< 5.00	157	65.1
35	7.95	0.69	183	0.96	0.10	0.056	45.3	676	< 5.00	80.4	33.4
95	30.3	1.04	86.3	1.13	0.071	< 0.025	29.9	863	< 5.00	94.9	33.1
99	15.5	0.92	117	0.88	0.067	< 0.025	17.7	899	< 5.00	76.9	26.2
142	40.6	2.31	117	1.57	0.11	< 0.025	41.8	1682	< 5.00	123	42.0
147	12.7	1.35	83.8	0.72	0.19	0.042	11.3	1092	< 5.00	42.9	14.2

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	5.61	0.14	< 0.25	3244	0.61	< 0.50	6.03	< 0.10	< 0.25	510	
35	5.61	0.083	< 0.25	3063	0.52	< 0.50	6.42	< 0.10	< 0.25	261	
95	6.10	0.060	< 0.25	3602	0.53	< 0.50	5.53	< 0.10	< 0.25	369	
99	5.86	0.026	< 0.25	3650	0.53	< 0.50	6.78	< 0.10	< 0.25	274	
142	6.35	0.066	< 0.25	5973	0.96	< 0.50	7.45	0.19	< 0.25	492	1450
147	6.61	0.13	< 0.25	3759	0.72	< 0.50	6.23	0.19	< 0.25	190	1070

TABLE XXVII Drainage Water from Inside Selbaie Control Test (Replicate #3, Started August 8, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	3.06	< 0.25	94.5	0.49	0.036	< 0.025	10.5	76.2	< 5.00	95.1	36.8
35	7.95	0.69	183	0.96	0.10	0.056	45.3	676	< 5.00	80.4	33.4
95	15.2	< 0.25	66.6	0.49	0.035	< 0.025	30.1	311	< 5.00	73.5	25.2
99	4.14	< 0.25	83.4	0.20	0.025	< 0.025	11.7	175	< 5.00	41.8	13.4
142	23.1	0.66	69.3	0.49	0.085	< 0.025	27.3	582	< 5.00	81.1	24.8
147	6.53	< 0.25	70.3	0.21	< 0.025	< 0.025	9.86	187	< 5.00	38.6	12.1

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	5.73	0.046	< 0.25	1092	< 0.25	< 0.50	3.09	< 0.10	< 0.25	165	
35	5.61	0.083	< 0.25	3063	0.52	< 0.50	6.42	< 0.10	< 0.25	261	
95	5.52	0.038	< 0.25	1760	< 0.25	< 0.50	3.06	< 0.10	< 0.25	174	
99	5.91	< 0.025	< 0.25	1103	< 0.25	< 0.50	2.66	< 0.10	< 0.25	66.5	
142	6.33	0.066	< 0.25	2337	0.45	< 0.50	4.19	0.11	< 0.25	155	928
147	6.36	< 0.025	< 0.25	1069	< 0.25	< 0.50	2.96	< 0.10	< 0.25	67.1	179

TABLE XXVIII Drainage Water from Inside Selbaie 3% Phosphate Test (Replicate #1, Started August 8, 1991)

WEEK	Al	AS	Ca	Cd	Co	Cr	cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	8.42	< 0.25	204	0.29	0.054	< 0.025	18.6	1.05	< 5.00	110	41.2
35	4.10	< 0.25	212	0.18	< 0.025	< 0.025	7.27	2.50	< 5.00	39.7	16.2
95	19.6	< 0.25	275	0.37	< 0.025	< 0.025	20.8	23.9	< 5.00	60.9	21.2
99	7.36	< 0.25	233	0.22	< 0.025	< 0.025	8.40	7.62	< 5.00	31.8	11.5
142	25.1	0.26	293	0.47	0.033	< 0.025	26.4	83.8	< 5.00	63.3	20.0
147	9.35	< 0.25	251	0.24	< 0.025	< 0.025	10.3	30.8	< 5.00	27.7	8.89

WEEK	Na	Ni	Pb	so4	Sb	se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	14.1	0.060	< 0.25	1295	< 0.25	< 0.50	5.53	< 0.10	< 0.25	186	
35	8.53	< 0.025	< 0.25	818	< 0.25	< 0.50	2.80	< 0.10	< 0.25	81.2	
95	12.9	< 0.025	< 0.25	1321	< 0.25	< 0.50	4.78	< 0.10	< 0.25	150	
99	9.73	< 0.025	< 0.25	872	< 0.25	< 0.50	3.89	< 0.10	< 0.25	71.6	
142	14.9	0.10	< 0.25	1555	< 0.25	< 0.50	7.52	< 0.10	< 0.25	170	74.9
147	10.7	< 0.025	< 0.25	976	< 0.25	< 0.50	5.62	< 0.10	< 0.25	75.0	29.0

TABLE XXIX Drainage Water from Inside Selbaie 3% Phosphate Test (Replicate #2, Started August 8, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	10.4	< 0.25	223	0.47	0.066	< 0.025	12.0	16.6	< 5.00	155	58.2
35	4.93	< 0.25	199	0.27	0.029	< 0.025	7.29	2.49	< 5.00	56.2	20.3
95	25.2	< 0.25	362	0.87	0.031	< 0.025	39.5	36.1	< 5.00	87.2	36.0
99	13.0	< 0.25	303	0.40	< 0.025	< 0.025	14.5	0.42	< 5.00	49.3	15.3
142	34.1	0.39	213	0.66	< 0.025	< 0.025	19.8	136	< 5.00	86.0	23.8
147	21.0	< 0.25	385	0.47	< 0.025	< 0.025	14.1	35.5	< 5.00	45.0	12.6

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	13.3	0.089	< 0.25	1603	0.33	< 0.50	8.45	< 0.10	< 0.25	255	
35	9.33	< 0.025	< 0.25	891	< 0.25	< 0.50	3.48	< 0.10	< 0.25	104	
95	11.7	< 0.025	< 0.25	1952	< 0.25	< 0.50	7.48	< 0.10	< 0.25	302	
99	9.94	< 0.025	< 0.25	1188	< 0.25	< 0.50	4.57	< 0.10	< 0.25	128	
142	11.5	0.041	< 0.25	1702	< 0.25	< 0.50	7.42	< 0.10	< 0.25	245	117
147	10.7	< 0.025	< 0.25	1570	< 0.25	< 0.50	8.09	< 0.10	< 0.25	137	33.9

TABLE XXX Drainage Water from inside Selbaie 3% Phosphate Test (Replicate #3, Started August 8, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	12.1	< 0.25	445	0.55	0.051	< 0.025	42.5	0.57	< 5.00	144	50.6
35	5.22	< 0.25	263	0.33	< 0.025	< 0.025	21.0	1.48	< 5.00	53.8	19.8
95	30.6	< 0.25	277	0.65	< 0.025	< 0.025	29.6	25.0	< 5.00	101	29.8
99	9.98	< 0.25	210	0.40	< 0.025	< 0.025	15.1	31.5	< 5.00	40.1	17.0
142	30.1	0.50	198	0.95	0.034	< 0.025	38.3	410	< 5.00	86.6	32.3
147	15.2	0.43	174	0.48	0.039	< 0.025	18.6	282	< 5.00	44.9	15.9

WEEK	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											
29	14.3	0.085	< 0.25	2202	0.26	< 0.50	7.99	< 0.10	< 0.25	271	
35	9.97	< 0.025	< 0.25	1100	< 0.25	< 0.50	3.52	< 0.10	< 0.25	121	
95	12.1	< 0.025	< 0.25	1680	< 0.25	< 0.50	5.35	< 0.10	< 0.25	254	
99	8.46	< 0.025	< 0.25	1066	< 0.25	< 0.50	4.46	< 0.10	< 0.25	124	
142	9.29	< 0.025	< 0.25	2394	< 0.25	< 0.50	7.56	< 0.10	< 0.25	323	371
147	8.75	< 0.025	< 0.25	1622	< 0.25	< 0.50	6.08	< 0.10	< 0.25	145	266

TABLE XXXI Drainage Water from Outside Stratmat Control Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.25		474	0.030			< 0.020	1.44	70.0	80.8	43.0	53.1	
3	24.2	< 0.25	280	0.25			0.47	3.92	36.1	44.5	29.8	24.1	
5	10.1	< 0.25	222	0.18			0.70	2.66	30.2	64.9	41.3	29.1	
6	13.2	< 0.25	281	0.28			1.15	10.3	34.6	84.7	53.0	32.4	
11	11.6		173	0.16			1.55	3.43	14.0	33.7	22.1	14.4	
13	47.5	< 0.25	224	0.45			3.73	6.46	13.9	103	75.9	21.3	
16	37.9	< 0.25	180	0.34			3.09	3.84	14.0	91.1	61.3	20.8	
20	68.3	< 0.25	233	0.41			4.76	15.8	11.9	87.0	58.8	16.1	
40	9.53	< 0.25	123	0.86			0.82	2.94	< 5.00	16.8	11.8	14.1	
44	8.48		98.2				0.61	2.92	3.36	15.2	8.64	4.35	
49	138	0.73	264	0.55			3.46	129	< 5.00	92.0	54.9	10.3	
53	219	1.81	224	0.65			4.51	431	< 5.00	126	54.1	10.6	
54	235		130	0.56	0.35		4.96	852	1.60	158	47.1	3.05	0.27
57	319	7.55	120	0.77			6.17	1590	< 5.00	276	54.1	7.76	
62	381	9.02	108	0.75			7.15	1760	< 5.00	400	51.7	6.99	
67	839	11.3	212	1.43	1.08	0.53	19.8	3800	0.87	872	115		0.47
72	293	7.70	116	0.46	0.40		9.05	1810	1.17	293	45.6		
92	61.7	1.37	84.7	0.11			2.59	354	< 5.00	64.4	12.9	11.7	
95	52.3	0.84	90.1	0.071			2.46	295	< 5.00	46.6	11.2	11.9	
101	334	20.5	162	0.57	0.47	< 0.025	9.04	3981	< 5.00	377	37.9	5.52	0.16
103	320	16.0	130	0.47	0.40	< 0.025	7.93	2993	< 5.00	377	38.0	5.73	0.11
108	391	12.9	118	0.38	0.42	< 0.025	7.46	2736	< 5.00	457	32.7	6.09	0.19
112	863	30.4	225	0.79	0.86	< 0.025	16.9	6797	< 5.00	931	73.8	6.65	0.35
115	803	25.0	176	0.70	0.69	< 0.025	16.4	4443	< 5.00	826	75.6	6.40	0.31
118	457	13.9	139	0.43	0.44	< 0.025	11.6	2726	< 5.00	411	44.6	6.22	0.21
125	177	6.47	122	0.23	0.23	< 0.025	5.91	1558	< 5.00	137	20.0	7.23	0.088

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P	TCO
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.99	1840						23.5	0.21	4.00	< 0.10	4.60
3	4.11	1077		< 0.50				51.9				
5	5.00	1106		< 0.50				64.3				
6	4.63	1467		< 0.50				108				
11	3.95	832						73.7	0.97	1.10	< 0.10	4.60
13	2.13	1818		< 0.50				224				
16	2.18	1401		< 0.50				170				
20	1.30	1749		< 0.50				225				
40	1.52	488		< 0.50				39.7				
44	2.77	420			9.57			24.3	< 0.05	40.4	< 0.03	
49	< 0.25	2539		< 0.50				308				
53	< 0.25	3930		< 0.50				359				
54	0.97	5950			52.3			318	6.60	< 1.00	0.68	
57	< 0.25	7740		< 0.50				369				
62	< 0.25	8790		0.53				359				
67		19000			98.5			759	< 400	190	< 0.03	
72		9900			34.2			301	< 40.0	54.0	0.43	
92	< 0.25	1677		< 0.50				63.2				
95	< 0.25	1510		< 0.50				45.7				
101	< 0.25	14112	2.28	0.68	85.9	0.59	0.36	203				
103	< 0.25	11346	1.99	< 0.50	63.8	0.46	0.30	178				
108	< 0.25	10965	1.95	< 0.50	47.1	0.43	< 0.25	145				
112	< 0.25	26637	4.07	1.01	108	0.99	< 0.25	306				
115	< 0.25	19719	2.89	0.68	56.7	0.72	< 0.25	275				
118	< 0.25	11931	1.81	< 0.50	51.1	0.49	< 0.25	175				
125	< 0.25	6138	0.97	< 0.50	47.3	0.33	< 0.25	90.5				

TABLE XXXII Drainage Water from Outside Stratmat Control Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	ca	cd	ccl	Cr	cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	4.84		371	0.040			< 0.020	5.35	7.01	79.4	35.5	52.7	
3	11.7	< 0.25	148	0.071			0.13	2.03	20.4	20.3	10.6	17.7	
5	9.23	< 0.25	276	0.22			0.40	2.46	41.7	86.6	52.8	37.3	
6	10.4	< 0.25	294	0.27			0.68	0.95	44.8	104	60.1	40.0	
11	8.09		126	0.11			0.78	4.65	12.2	28.5	17.7	15.9	
13	49.7	< 0.25	241	0.62			3.00	6.88	16.0	138	99.5	28.3	
16	40.6	< 0.25	213	0.45			2.69	7.58	16.3	116	15.6	25.7	
20	39.1	< 0.25	189	0.29			2.56	25.1	9.29	60.3	39.2	12.3	
40	7.23	< 0.25	121	0.045			0.29	2.38	< 5.00	11.9	8.38	12.3	
44	11.0		120				0.64	3.32	3.59	18.6	11.3	5.46	
49	142	1.18	204	0.49			3.57	205	< 5.00	83.9	45.6	10.0	
53	339	5.78	244	1.00			6.61	751	< 5.00	226	78.0	9.37	
54	334	4.95	157	0.75	0.40		7.58	992	0.58	254	69.2	2.06	
57	634	15.1	198	1.58			14.0	1920	< 5.00	554	119	6.64	
62	535	16.9	161	1.23			11.7	2370	< 5.00	514	79.7	7.70	
67	1010	24.5	270	1.84	1.21	1.34	29.8	4560	0.57	960	144		0.74
72	284	10.3	150	0.48	0.38		8.49	1850	0.95	249	43.2		
92	66.5	1.97	83.7	0.13			2.38	415	< 5.00	63.4	12.1	12.7	
95	73.1	3.27	98.7	0.15			3.00	716	< 5.00	62.2	13.1	9.26	
101	422	34.2	198	0.79	0.57	< 0.025	11.3	4856	< 5.00	469	50.2	5.59	0.16
103	442	25.8	158	0.71	0.56	< 0.025	10.9	3775	< 5.00	519	48.9	5.69	0.19
108	502	17.2	141	0.47	0.45	< 0.025	10.2	2522	< 5.00	598	44.6	6.06	0.20
112	1409	52.9	313	1.32	1.17	< 0.025	29.9	8090	< 5.00	1519	122	5.85	0.52
115	1015	37.1	215	1.03	0.89	< 0.025	22.9	5773	< 5.00	1016	88.4	5.96	0.36
118	531	21.2	172	0.61	0.53	< 0.025	12.5	3788	< 5.00	476	46.0	6.10	0.22
125	185	9.66	154	0.29	0.25	< 0.025	5.08	2126	< 5.00	145	18.3	6.54	0.11

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P	TOC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	2.83	1540						20.6	1.08	1.60	0.25	2.90
3	4.72	549		< 0.50				11.5				
5	5.95	1379		< 0.50				57.3				
6	5.86	1564		< 0.50				75.1				
11	4.56	644						45.0	1.25	1.00	< 0.10	4.80
13	2.63	2190		< 0.50				267				
16	2.10	1701		< 0.50				207				
20	1.37	1230		< 0.50				153				
40	1.34	436		< 0.50				31.9				
44	2.10	530			10.4			36.8	< 0.05	< 5.00	< 0.03	
49	< 0.25	2640		< 0.50				269				
53	< 0.25	5940		< 0.50				517				
54		6340			39.2			458	4.60	< 1.00	0.53	
57	< 0.25	11970		< 0.50				745				
62	< 0.25	12210		< 0.50				528				
67		27000			107			942	< 400	160	0.30	
72		9300			39.0			299	40.0	160	0.34	
92	< 0.25	1863		< 0.50				67.6				
95	< 0.25	2719		< 0.50				67.0				
101	< 0.25	16728	2.62	0.98	84.9	0.73	0.39	247				
103	< 0.25	14505	2.70	< 0.50	69.9	0.60	0.35	256				
108	< 0.25	11718	1.77	0.65	43.7	0.39	< 0.25	180				
112	< 0.25	35670	4.94	1.10	115	1.08	0.53	476				
115	< 0.25	24948	3.94	0.56	69.5	0.73	0.27	399				
118	< 0.25	15384	2.35	0.56	64.0	0.57	< 0.25	239				
125	< 0.25	7827	1.28	< 0.50	56.6	0.24	< 0.25	106				

TABLE XXXIII Drainage Water from Outside Stratmat Control Test (Replicate #3, Started July 10, 1991)

WEEK	A1	AS	Ca	Cd	Co	Cr	GU	Fe	K	Mg	Mn	Na	Ni
	mg/L	ma/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	4.04		176	< 0.020			< 0.020	5.36	39.7	36.7	14.2	34.3	
3	6.92	< 0.25	72.3	0.035			0.16	2.31	13.6	10.1	5.01	14.5	
5	10.2	< 0.25	116	0.072			0.53	6.74	23.1	39.6	20.6	30.2	
6	15.2	< 0.25	166	0.14			1.11	3.67	33.3	72.3	39.6	41.7	
11	6.11		54.4	< 0.025			0.67	6.62	< 5.00	13.3	7.31	13.2	
13	44.3	< 0.25	4°C 146	0.20			2.27	14.5	12.0	85.5	54.6	27.3	
16	29.3	< 0.25	117	0.12			1.77	6.19	11.0	55.8	33.4	19.6	
20	35.0	< 0.25	120	0.15			2.42	17.3	7.37	47.3	26.4	16.6	
40	5.90	< 0.25	67.3	< 0.025			0.26	1.87	< 5.00	9.55	5.70	13.2	
44	4.90		58.0				0.34	2.65	2.88	9.14	4.14	6.03	
49	48.0	< 0.40	156	0.13			2.24	35.6	< 5.00	32.2	20.9	12.2	
53	62.0	< 0.41	161	0.18			2.69	80.6	< 5.00	44.9	27.1	10.4	
54	57.2		78.8				2.55	60.1	1.31	42.1	20.6		
57	101	0.73	85.6	0.21			3.65	191	< 5.00	68.3	26.3	6.27	
62	138	2.24	61.7	0.22			4.39	600	< 5.00	101	25.1	8.32	
67	387	5.99	145	0.52	0.48		15.4	237	1.02	319	76.9		0.25
72	140		68.7				5.31	902	0.92	105	27.9		
92	27.3	0.72	38.3	0.032			1.29	181	< 5.00	24.7	7.74	12.0	
95	33.2	0.93	44.1	0.036			1.56	355	< 5.00	25.2	8.32	11.5	
101	215	13.2	108	0.37	0.33	< 0.025	6.78	2743	< 5.00	223	30.9	5.89	0.11
103	190	8.92	83.1	0.29	0.29	< 0.025	5.31	1847	< 5.00	202	27.0	5.51	0.12
108	270	6.71	83.0	0.21	0.24	< 0.025	7.14	1188	< 5.00	311	28.2	6.09	0.12
112	605	19.6	173	0.52	0.58	< 0.025	16.3	4081	< 5.00	625	61.2	5.97	0.21
115	494	16.2	134	0.48	0.49	< 0.025	12.8	6942	< 5.00	472	57.1	6.03	0.14
118	246	7.91	100	0.28	0.28	< 0.025	7.50	1842	< 5.00	208	31.7	6.18	0.12
125	86.3	3.42	83.5	0.14	0.13	< 0.025	3.58	986	< 5.00	66.6	14.1	6.65	0.056

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P	TOC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	2.01	728						11.8	0.77	1.30	< 0.10	3.90
3	5.12	288		< 0.50				7.67				
5	5.59	673		< 0.50				27.5				
6	6.46	1131		< 0.50				54.8				
11	5.20	323						15.2	4.56	1.30	< 0.10	5.10
13	3.07	1406		< 0.50				98.8				
16	2.79	899		< 0.50				67.3				
20	1.83	908		< 0.50				82.1				
40	2.22	268		< 0.50				15.0				
44	2.67	240			7.37			9.7	< 4.00	33.2	< 0.03	
49	1.57	1045		< 0.50				81.0				
53	0.63	1316		< 0.50				114				
54		1120			14.8			79.5	0.76	< 1.00	0.016	
57	< 0.25	1913		< 0.50				121				
62	< 0.25	3150		< 0.50				123				
67		16000			72.3			335	< 40.0	70.0	0.049	
72		4000			25.4			124	40.0	110	0.16	
92	< 0.25	853		< 0.50				27.2				
95	< 0.25	1377		< 0.50				29.9				
101	< 0.25	9561	1.63	< 0.50	58.4	0.57	0.27	135				
103	< 0.25	6870	1.21	< 0.50	43.8	0.38	< 0.25	107				
108	< 0.25	5793	0.84	< 0.50	33.3	0.25	< 0.25	91.7				
112	< 0.25	17124	2.62	< 0.50	83.4	0.59	< 0.25	210				
115	< 0.25	24882	2.01	< 0.50	45.8	0.59	< 0.25	205				
118	< 0.25	7389	1.18	< 0.50	39.5	0.31	< 0.25	121				
125	< 0.25	3559	0.58	< 0.50	31.7	0.16	< 0.25	58.4				

TABLE XXXIV Drainage Water from Outside Stratmat 1% Limestone Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.44		413	< 0.020			< 0.020	2.83	59.3	69.0	23.8	65.1
3	3.74	< 0.25	222	< 0.025			< 0.025	0.19	22.1	20.9	7.87	16.7
5	2.13	< 0.25	264	0.052			0.027	0.13	34.8	54.9	20.2	29.1
6	2.17	< 0.25	376	0.035			< 0.025	0.33	43.2	70.4	24.5	35.0
11	< 0.25		149	< 0.025			< 0.025	< 0.025	10.5	15.4	5.94	10.5
13	1.25	< 0.25	337	0.091			< 0.025	0.055	24.3	68.4	30.3	18.2
16	1.57	< 0.25	256	0.052			< 0.025	0.063	20.5	47.3	19.7	16.4
20	1.88	< 0.25	274	0.073			< 0.025	0.61	16.5	40.3	19.8	13.0
40	1.03	< 0.25	180	< 0.025			< 0.025	0.052	7.90	15.0	6.78	13.0
44			107						3.52	5.78	26.2	4.35
49	1.35	< 0.25	409	0.056			< 0.025	0.14	12.8	33.9	13.8	12.2
53	1.30	< 0.25	336	0.067			< 0.025	0.19	8.58	31.7	13.7	9.74
54			370						8.61	45.7	18.0	3.17
57	10.9	< 0.25	586	0.22			0.64	1.77	5.48	75.2	28.3	8.61
62	24.7	0.60	580	0.26			1.34	1.36	7.06	102	30.7	7.95
67	18.8		706	0.37	0.23		1.39	0.60	5.48	166	45.5	1.20
72	17.3		477				1.33	1.55	4.18	92.0	26.2	
92	5.24	< 0.25	372	0.034			0.34	4.47	< 5.00	26.6	8.09	12.3
95	3.02	< 0.25	400	0.026			0.21	0.81	< 5.00	20.7	6.34	13.0
101	0.92	< 0.25	685	0.10	0.10	< 0.025	0.03	0.87	6.92	63.0	18.0	8.31
103	44.0	0.28	654	0.29	0.23	< 0.025	2.59	33.8	< 5.00	141	33.0	6.20
108	230	1.59	689	0.41	0.32	< 0.025	7.34	216	< 5.00	310	46.7	6.62
112	282	1.81	690	0.52	0.44	< 0.025	10.3	168	6.07	411	65.3	6.68
115	412	3.09	594	0.64	0.52	< 0.025	12.9	615	< 5.00	443	69.0	6.44
118	280	2.11	519	0.33	0.27	< 0.025	8.84	413	< 5.00	215	35.6	6.56
125	95.0	0.87	516	0.16	0.13	< 0.025	3.94	277	< 5.00	72.9	14.7	7.00

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	HCO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.25	1420						3.12	0.79	2.40	15.90
3		< 0.25	664		< 0.50				2.03			
5		< 0.25	984		< 0.50				4.96			
6		< 0.25	1308		< 0.50				4.06			
11		< 0.025	446						3.59	< 0.025	11.0	17.70
13		< 0.25	1236		< 0.50				21.9			
16		< 0.25	869		< 0.50				20.4			
20		0.29	905		< 0.50				34.5			
40		< 0.25	516		< 0.50				12.2			
44			270			3.01			1.92	< 0.050	< 5.00	
49		0.35	1123		< 0.50				18.2			
53		< 0.25	923		< 0.50				26.1			
54			1550			7.42			36.2	< 0.050	16.0	
57		2.38	1946		< 0.50				93.2			
62		1.94	2155		0.89				120			
67		1.76	2600			19.8			149	0.080	36.0	
72		1.45	1820			12.2			99.0	0.62	17.0	
92		< 0.25	1081		< 0.50				28.4			
95		< 0.25	1101		< 0.50				21.9			
101	0.037	< 0.25	1998	< 0.25	< 0.50	10.1	< 0.10	< 0.25	46.4			
103	0.25	1.64	2786	0.35	< 0.50	30.0	0.13	< 0.25	155			
108	0.30	< 0.25	4927	0.35	< 0.50	51.1	0.13	< 0.25	231			
112	0.36	1.82	5867	0.49	< 0.50	62.0	0.19	< 0.25	302			
115	0.43	< 0.25	7075	1.04	< 0.50	70.1	0.25	< 0.25	340			
118	0.24	< 0.25	4742	0.52	< 0.50	55.9	< 0.10	< 0.25	190			
125	0.077	0.27	2842	0.27	< 0.50	37.0	0.14	< 0.25	85.5			

TABLE XXXV Drainage Water from Outside Stratmat 1% Limestone Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.90		502	< 0.020			< 0.020	2.31	67.8	80.5	33.3	33.9
3	3.10	< 0.25	312	0.029			< 0.025	0.13	27.6	28.2	10.4	15.0
5	1.99	< 0.25	302	0.040			< 0.025	0.089	33.5	51.7	19.9	20.8
6	1.70	< 0.25	397	0.074			< 0.025	0.072	43.2	68.5	25.5	21.6
11	< 0.25		189	< 0.025			< 0.025	< 0.025	12.9	19.3	7.06	10.4
13	1.36	< 0.25	334	0.15			0.047	0.084	23.0	68.1	27.3	15.0
16	1.70	< 0.25	258	0.11			0.036	0.083	14.7	43.3	17.3	11.9
20	1.50	< 0.25	405	0.18			0.10	0.18	17.3	53.7	24.6	12.2
40	1.50	< 0.25	222	0.034			< 0.025	0.17	5.50	11.6	4.99	10.5
44			145						2.86	5.6	23.2	3.39
49	1.80	< 0.25	536	0.13			0.081	0.10	11.4	37.9	14.3	11.7
53	2.90	< 0.25	474	0.18			0.14	0.17	11.6	46.4	17.1	9.67
54			512				0.18		8.50	53.0	16.7	2.11
57	22.4	< 0.25	673	0.31			1.35	5.89	7.68	102	30.0	9.39
62	28.2	< 0.25	521	0.19			1.94	13.1	5.75	81.0	21.8	7.92
67	4.39		705	0.48	0.34		0.90		5.93	229	57.9	1.25
72	19.2		457				1.62	4.14	3.84	91.1	23.2	
92	7.66	< 0.25	448	0.054			0.60	5.75	< 5.00	32.0	8.73	13.6
95	3.47	< 0.25	428	< 0.025			0.29	0.83	< 5.00	16.0	4.25	12.9
101	20.2	< 0.25	610	0.16	0.15	< 0.025	2.56	4.72	5.28	72.4	18.4	6.86
103	92.4	0.63	611	0.26	0.24	< 0.025	5.28	209	< 5.00	146	32.5	6.12
108	442	3.72	617	0.55	0.51	< 0.025	15.4	915	< 5.00	431	62.3	6.70
112	548	4.47	654	0.66	0.61	< 0.025	20.3	932	< 5.00	531	83.7	6.57
115	554	6.28	529	0.58	0.58	< 0.025	16.4	2070	< 5.00	485	68.1	6.27
118	242	3.03	486	0.31	0.31	< 0.025	8.15	1093	< 5.00	202	33.1	6.41
125	96.2	1.37	472	0.16	0.17	< 0.025	4.18	667	< 5.00	79.4	15.8	6.50

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	HCO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.90	1770						6.64	0.69	< 0.10	11.0
3		0.48	921		< 0.50				3.38			
5		0.47	1064		< 0.50				6.09			
6		0.35	1358		< 0.50				8.12			
11		0.26	566						5.64	< 0.025	< 0.10	15.9
13		0.72	1182		< 0.50				38.4			
16		0.44	859		< 0.50				33.7			
20		1.26	1306		< 0.50				66.9			
40		< 0.25	578		< 0.50				10.4			
44			370			2.47			1.95	< 0.050	5.90	
49		1.81	1470		< 0.50				37.1			
53		1.98	1431		< 0.50				59.0			
54		1.29	2700			7.93			45.5	< 0.050	14.0	
57		2.82	2341		< 0.50				128			
67		2.50	1354		< 0.50				95.2			
			[illegible]			18.8			199	< 0.050	14.0	
72		1.05	1800			10.5			104	0.84	25.0	
92		0.69	1320		< 0.50				30.3			
95		0.41	1131		< 0.50				10.2			
101	0.070	2.24	2046	< 0.25	< 0.50	20.5	0.11	< 0.25	71.0			
103	0.13	1.31	3469	0.31	< 0.50	42.0	0.23	< 0.25	163			
108	0.40	< 0.25	8766	0.86	< 0.50	75.9	0.25	< 0.25	326			
112	0.40	< 0.25	10386	1.12	< 0.50	109	0.30	< 0.25	388			
115	0.34	< 0.25	12285	1.76	< 0.50	83.4	0.44	0.26	318			
118	0.18	< 0.25	5962	1.00	< 0.50	54.0	0.31	< 0.25	158			
125	0.094	< 0.25	3585	0.56	< 0.50	38.1	0.19	< 0.25	77.8			

TABLE XXXVI Drainage Water from Outside Stratmat 1% Limestone Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	4.14		62.1	< 0.020			< 0.020	4.32	62.1	72.40	24.0	40.2
3	3.00	< 0.25	194	< 0.025			< 0.025	0.19	18.5	18.16	5.85	15.9
5												
6	1.76	< 0.25	442	0.11			< 0.025	0.059	42.4	75.6	25.0	27.9
11	< 0.25		208	0.030			< 0.025	< 0.025	11.7	19.5	6.38	10.4
13	1.52	< 0.25	355	0.12			< 0.025	0.039	22.8	75.8	25.0	19.1
16	1.27	< 0.25	268	0.070			< 0.025	0.070	15.5	45.1	15.5	13.0
20	1.38	< 0.25	382	0.13			< 0.025	0.25	15.7	50.6	19.9	12.7
40	1.31	< 0.25	144	< 0.025			< 0.025	0.11	< 5.00	6.58	2.42	9.58
44			218					0.33	5.02	11.2	10.1	5.92
49	1.30	< 0.25	425	< 0.025			< 0.025	0.10	11.4	25.5	5.06	12.0
53	1.50	< 0.25	360	0.045			< 0.025	0.13	10.9	26.4	5.11	10.6
54			447						8.71	31.5	6.42	3.30
57	1.91	< 0.25	381	0.056			< 0.025	1.02	8.59	35.6	8.62	8.98
62	1.42	< 0.25	314	0.043			0.061	0.96	6.06	33.6	8.39	8.26
67			684				0.19		8.49	91.2	23.5	2.18
72			304						5.20	36.0	10.1	
92	1.50	< 0.25	376	< 0.025			0.058	0.76	< 5.00	16.0	4.40	14.8
95	0.79	< 0.25	222	< 0.025			< 0.025	< 0.025	< 5.00	7.68	1.52	11.4
101	0.54	< 0.25	548	0.082	0.055	< 0.025	0.031	0.86	6.27	29.4	8.33	8.87
103	1.04	< 0.25	554	0.12	0.064	< 0.025	0.22	0.17	6.26	45.4	12.8	7.23
108	4.62	< 0.25	586	0.16	0.11	< 0.025	0.86	1.46	7.86	84.8	19.2	6.89
112	2.51	< 0.25	709	0.34	0.27	< 0.025	0.49	0.89	14.1	226	48.7	8.42
115	14.38	< 0.25	718	0.37	0.28	< 0.025	1.75	0.85	6.32	197	41.5	7.51
118	13.95	< 0.25	628	0.21	0.18	< 0.025	1.43	6.47	5.60	100	22.7	6.64
125	7.53	< 0.25	549	0.12	0.076	< 0.025	1.08	0.44	< 5.00	42.9	11.4	6.98

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	HC03
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.46	1540						4.14	1.37	40.5	17.7
3		c 0.25	575		c 0.50				2.03			
5												
6		0.31	1520		< 0.50				8.12			
11		< 0.25	599						5.04	< 0.025	1.20	15.9
13		0.37	1256		< 0.50				26.1			
16		< 0.25	875		< 0.50				21.3			
20		0.54	1194		< 0.50				39.5			
40		< 0.25	368		< 0.50				4.56			
44			570			4.56			1.38	< 0.050	8.90	
49		< 0.25	1098		< 0.50				5.00			
53		0.27	960		< 0.50				6.92			
54			1800			5.13			5.00	< 0.050	< 10.0	
57		0.48	1069		< 0.50				14.8			
62		0.98	920		< 0.50				20.9			
67			1600			11.4			48.7	< 0.050	< 10.0	
72			980			4.41			22.8	0.050	17.0	
92		0.27	952		< 0.50				9.85			
95		< 0.25	551		< 0.50				1.77			
101	0.027	< 0.25	1466	< 0.25	< 0.50	8.11	< 0.10	< 0.25	19.6			
103	< 0.025	1.30	1590	< 0.25	< 0.50	10.5	< 0.10	< 0.25	40.4			
108	0.048	2.76	1884	< 0.25	< 0.50	13.2	< 0.10	< 0.25	65.2			
112	0.10	1.20	2822	< 0.25	< 0.50	20.1	< 0.10	< 0.25	121			
115	0.13	1.91	2820	0.28	< 0.50	20.8	< 0.10	< 0.25	141			
118	0.086	0.94	2093	< 0.25	< 0.50	17.2	< 0.10	< 0.25	89.1			
125	0.036	1.07	1558	< 0.25	< 0.50	12.7	< 0.10	< 0.25	48.6			

TABLE XXXVII Drainage Water from Outside Stratmat 3% Limestone Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.30		385	< 0.020			< 0.020	2.39	46.4	55.2	9.09	35.7
3	3.95	< 0.25	257	< 0.025			< 0.025	1.11	25.2	27.6	4.54	18.7
5	2.19	< 0.25	240	< 0.025			< 0.025	0.11	25.6	40.6	7.59	23.8
6	1.65	< 0.25	351	< 0.025			< 0.025	0.15	31.3	54.3	10.0	24.1
11	< 0.25		154	< 0.025			< 0.025	< 0.025	< 5.00	13.5	2.39	9.84
13	1.69	< 0.25	288	< 0.025			< 0.025	0.035	20.3	56.1	11.1	18.1
16	1.20	< 0.25	203	< 0.025			< 0.025	0.042	13.6	31.8	6.87	12.4
20	1.17	< 0.25	261	< 0.025			< 0.025	0.09	12.9	31.3	7.74	10.2
40	1.38	< 0.25	86.6	< 0.025			< 0.025	0.14	< 5.00	6.11	1.28	11.1
44			175					0.58	3.15	6.22	3.27	3.72
49	1.64	< 0.25	370	< 0.025			< 0.025	0.70	12.3	21.3	3.41	12.9
53	1.31	< 0.25	236	< 0.025			< 0.025	0.21	7.83	14.9	2.27	9.70
54			217						7.17	14.4	1.94	2.10
57	0.79	< 0.25	231	< 0.025			< 0.025	< 0.025	7.67	18.7	3.00	9.45
62	1.00	< 0.25	204	< 0.025			< 0.025	< 0.025	5.65	16.8	2.42	7.85
67			445						7.65	38.6	5.46	2.03
72			216						5.12	15.0	3.27	
92	0.91	< 0.25	176	< 0.025			< 0.025	0.24	5.48	8.33	1.29	15.9
95	0.84	< 0.25	101	< 0.020			< 0.025	0.27	< 5.00	4.62	0.49	10.6
101	0.27	< 0.25	258	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	11.4	1.21	8.18
103	< 0.25	< 0.25	293	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	5.47	13.8	2.01	6.71
108	0.28	< 0.25	376	< 0.025	< 0.025	< 0.025	< 0.025	0.071	7.47	27.3	4.36	7.01
112	< 0.25	< 0.25	479	< 0.025	< 0.025	< 0.025	< 0.025	0.31	8.95	45.8	3.97	7.95
115	0.57	0.40	603	0.079	0.045	0.058	0.063	0.13	7.35	71.6	7.75	7.88
118	< 0.25	< 0.25	430	0.043	< 0.025	< 0.025	0.041	< 0.025	5.00	46.2	5.46	6.98
125	< 0.25	< 0.25	490	0.032	< 0.025	< 0.025	0.066	0.10	6.32	27.0	3.95	7.48

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	HCO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		< 0.25	1170						0.67	0.37	1.60	79.3
3		< 0.25	727		< 0.50				0.23			
5		< 0.25	786		< 0.50				0.68			
6		< 0.25	1083		< 0.50				0.68			
11		< 0.25	413						0.36	< 0.025	2.50	28.1
13		< 0.25	915		< 0.50				2.61			
16		< 0.25	614		< 0.50				2.17			
20		< 0.25	735		< 0.50				3.91			
40		< 0.25	219		< 0.50				0.65			
44			400			4.11			2.16	< 0.050	< 5.00	
49		< 0.25	909		< 0.50				0.65			
53		< 0.25	597		< 0.50				0.63			
54			604			2.75			0.57	< 0.050	1.20	
57		< 0.25	602		< 0.50				0.39			
62		< 0.25	540		< 0.50				1.18			
67			1000			4.76			3.24	< 0.050	31.0	
72			420			1.39			2.28	0.10	15.0	
92		< 0.25	425		< 0.50				1.18			
95		< 0.25	234		< 0.50				0.59			
101	< 0.025	< 0.25	640	< 0.25	< 0.50	2.69	< 0.10	< 0.25	0.79			
103	< 0.025	< 0.25	737	< 0.25	< 0.50	3.63	< 0.10	< 0.25	2.07			
108	< 0.025	< 0.25	989	< 0.25	< 0.50	4.02	< 0.10	< 0.25	6.36			
112	< 0.025	< 0.25	1287	< 0.25	< 0.50	4.11	< 0.10	< 0.25	2.55			
115	0.13	0.34	1688	< 0.25	< 0.50	6.50	< 0.10	0.32	18.3			
118	0.035	< 0.25	1171	< 0.25	< 0.50	5.39	< 0.10	< 0.25	18.3			
125	0.026	< 0.25	1221	< 0.25	< 0.50	5.53	< 0.10	< 0.25	15.4			

TABLE XXXVIII Drainage Water from Outside Stratmat 3% Limestone Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.66		575	< 0.020			< 0.020	1.98	73.9	107	28.4	41.3
3												
5	1.92	< 0.25	438	0.042			< 0.025	0.060	42.5	67.9	19.7	22.2
6	1.36	< 0.25	639	0.077			< 0.025	0.083	49.2	87.9	29.1	21.5
11	< 0.25		285	0.040			< 0.025	< 0.025	14.8	31.5	9.73	9.70
13	1.51	< 0.25	521	0.21			< 0.025	0.035	20.4	121	38.6	13.9
16	1.43	< 0.25	474	0.15			0.10	0.079	11.7	72.9	24.4	10.1
20	3.97	< 0.25	555	0.26			0.27	2.04	12.5	106	41.6	10.1
40	1.56	< 0.25	351	< 0.025			< 0.025	0.25	< 5.00	15.4	5.75	10.8
44			462					0.30	3.21	8.54	16.1	5.43
49	1.34	< 0.25	638	0.074			0.031	0.18	8.9	54.8	10.7	11.0
53	1.85	< 0.25	670	0.13			0.12	0.23	9.56	74.2	13.7	9.64
54			623						6.55	79.0	13.7	1.47
57	9.78	< 0.25	681	0.18			0.53	6.00	< 5.00	108	19.1	8.90
62	15.4	< 0.25	679	0.16			0.91	1.22	< 5.00	109	17.2	7.38
67			679						4.07	144	21.6	
72	5.06		494				0.67		2.98	94.5	16.1	
92	2.59	< 0.25	414	< 0.025			0.18	2.47	< 5.00	26.7	5.18	13.2
95	1.03	< 0.25	455	< 0.020			< 0.025	< 0.020	< 5.00	14.0	2.16	12.1
101	3.60	< 0.25	661	0.071	0.069	< 0.025	0.46	1.87	< 5.00	69.1	10.6	7.23
103	44.7	< 0.25	775	0.21	0.16	< 0.025	2.68	39.3	< 5.00	134	21.4	6.60
108	172	1.89	762	0.35	0.30	< 0.025	5.99	471	5.93	299	35.4	6.89
112	157	1.02	639	0.43	0.40	< 0.025	4.85	143	6.84	491	58.4	6.87
115	275	2.61	646	0.49	0.42	< 0.025	9.27	798	< 5.00	473	51.4	6.71
118	113	1.22	590	0.25	0.22	< 0.025	4.18	489	< 5.00	187	24.8	6.67
125	46.2	0.40	555	0.13	0.11	< 0.025	2.16	312	< 5.00	72.2	12.5	6.65

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	HCO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		< 0.25	1980						2.32	0.45		
3												
5		0.25	1400		< 0.50				6.31			
6		0.39	1988		< 0.50				17.6			
11		0.330	832						14.7	< 0.025	< 0.10	22.6
13		0.33	1911		< 0.50				96.9			
16		0.28	1551		< 0.50				74.1			
20		1.09	1981		< 0.50				147			
40		< 0.25	876		< 0.50				14.3			
44			1100			2.27			1.69	< 0.050	14.8	
49		0.39	1709		< 0.50				24.3			
53		0.57	1946		< 0.50				47.8			
54			1860			8.87			36.6	< 0.050	< 10.0	
57		0.85	2233		< 0.50				90.2			
62		0.83	2269		< 0.50				91.4			
67			2000			12.5			80.5	< 0.050	22.0	
72			1780			12.0			70.7	< 0.050	14.0	
92		< 0.25	1124		< 0.50				16.5			
95		< 0.25	1137		< 0.50				2.8			
101	< 0.025	0.28	1919	< 0.25	< 0.50	12.6	< 0.10	< 0.25	38.5			
103	0.12	2.46	2941	< 0.25	< 0.50	33.8	< 0.10	< 0.25	112			
108	0.13	1.74	5365	0.78	< 0.50	47.0	0.11	< 0.25	190			
112	0.21	0.46	5278	0.51	< 0.50	53.9	< 0.10	< 0.25	229			
115	0.21	0.47	6900	1.00	< 0.50	67.7	0.13	< 0.25	246			
118	0.12	0.28	4032	0.46	< 0.50	42.8	0.12	< 0.25	122			
125	0.072	< 0.25	2699	< 0.25	< 0.50	29.4	0.10	< 0.25	65.9			

TABLE XXXIX Drainage Water from Outside Stratmat 3% Limestone Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.80		582	< 0.020			< 0.020	2.22	71.2	88.8	22.0	39.2
3												
5	1.63	< 0.25	401	< 0.025			< 0.025	0.063	42.0	86.8	18.7	26.2
6	1.40	< 0.25	478	< 0.025			< 0.025	0.059	45.0	77.5	19.2	29.5
11	< 0.25		260	< 0.025			< 0.025	< 0.025	19.3	29.0	7.53	12.5
13	1.32	< 0.25	407	0.052			< 0.025	0.029	30.2	78.2	22.7	21.7
16	1.26	< 0.25	331	0.036			< 0.025	0.19	24.1	56.8	16.9	17.2
20	1.48	< 0.25	397	0.031			< 0.025	0.33	21.3	50.1	16.8	36.7
40	1.31	< 0.25	340	< 0.025			< 0.025	0.14	11.4	22.2	6.88	14.1
44			226					0.38	4.74	8.51	2.31	5.18
49	1.37	< 0.25	500	< 0.025			< 0.025	0.63	16.0	33.8	5.32	14.1
53	1.34	< 0.25	486	< 0.025			< 0.025	0.19	16.6	40.4	6.03	12.2
54			348						10.8	34.5	4.71	3.25
57	1.35	< 0.25	489	0.063			< 0.025	0.16	10.4	62.4	11.8	9.46
62	1.17	< 0.25	475	0.074			< 0.025	0.029	10.6	75.1	9.71	9.12
67			1710						22.2	136	15.2	2.79
72			363						7.45	70.7	10.7	
92	0.79	< 0.25	371	< 0.025			< 0.025	0.12	6.60	24.9	5.28	12.1
95	0.79	< 0.25	416	< 0.020			< 0.025	< 0.020	6.35	18.6	3.57	15.9
101	0.48	< 0.25	750	0.069	< 0.025	< 0.025	< 0.025	0.22	12.2	68.0	9.69	12.4
103	0.30	< 0.25	645	0.10	0.060	< 0.025	< 0.025	< 0.025	6.78	66.2	10.2	8.53
108	1.00	< 0.25	632	0.17	0.10	< 0.025	0.048	1.32	10.4	116	14.6	8.04
112	0.31	< 0.25	762	0.18	0.069	< 0.025	< 0.025	0.21	13.8	217	19.1	8.52
115	0.55	< 0.25	629	0.26	0.15	< 0.025	0.097	0.11	8.89	262	28.2	7.50
118	1.29	< 0.25	654	0.21	0.16	< 0.025	0.30	0.11	8.75	169	21.7	7.79
125	0.38	< 0.25	608	0.13	0.080	< 0.025	0.20	< 0.025	5.49	76.5	13.8	6.88

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	HCO3
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		< 0.25	1920						1.16	0.53		
3												
5		< 0.25	1296		< 0.50				2.71			
6		< 0.25	1521		< 0.50				2.71			
11		< 0.025	749						3.18	< 0.025	< 0.10	25.6
13		< 0.25	1330		< 0.50				19.5			
16		< 0.25	1057		< 0.50				18.7			
20		< 0.25	1192		< 0.50				26.5			
40		< 0.25	885		< 0.50				8.91			
44			570			3.59			2.72	< 0.050	< 5.00	
49		< 0.25	1274		< 0.50				3.69			
53		< 0.25	1304		< 0.50				3.99			
54			1050			3.98			5.09	< 0.050	2.30	
57		0.26	1452		< 0.50				17.9			
62		0.36	1454		< 0.50				19.7			
67			1600			7.70			24.5	< 0.050	< 10.0	
72			1730			3.78			16.8	< 0.050	24.0	
92		< 0.25	986		< 0.50				11.4			
95		< 0.25	1055		< 0.50				5.12			
101	< 0.025	< 0.25	2099	< 0.25	< 0.50	6.80	< 0.10	< 0.25	16.5			
103	< 0.025	0.35	1853	< 0.25	< 0.50	8.26	< 0.10	< 0.25	25.8			
108	0.088	< 0.25	2009	< 0.25	< 0.50	9.51	< 0.10	< 0.25	32.4			
112	0.028	< 0.25	2743	0.31	< 0.50	6.97	< 0.10	< 0.25	27.9			
115	0.060	0.33	2663	0.40	< 0.50	10.9	< 0.10	< 0.25	91.9			
118	0.061	0.52	2280	< 0.25	< 0.50	11.6	< 0.10	< 0.25	88.0			
125	< 0.025	< 0.25	1765	< 0.25	< 0.50	9.81	< 0.10	< 0.25	55.7			

TABLE XL Drainage Water from Outside Stratmat Water Cover Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
3	0.38	< 0.25	7.39	0.13	0.14	0.10	0.12	0.16	< 5.00	0.74	0.20	8.38
5	< 0.25	< 0.25	5.12	< 0.025	< 0.025	< 0.025	< 0.025	0.17	< 5.00	0.63	0.14	17.4
6	< 0.25	< 0.25	7.16	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	0.61	0.015	18.3
11	< 0.25		6.26	< 0.025			0.030	0.090	< 5.00	0.52	0.030	17.0
13	< 0.25	< 0.25	7.57	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	0.95	0.023	12.6
16	< 0.25	< 0.25	1.45	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	< 0.50	< 0.005	12.0
20	0.69	< 0.25	5.43	< 0.025	< 0.025	< 0.025	< 0.025	0.81	< 5.00	0.93	0.051	17.6
40	1.44	< 0.25	9.66	< 0.025	< 0.025	< 0.025	< 0.025	1.55	< 5.00	1.41	0.063	21.5
44												
49												
53	0.39	< 0.25	21.7	< 0.025	< 0.025	< 0.025	< 0.025	0.50	< 5.00	1.83	0.20	9.36
54			4.39					0.060	0.46	0.21	0.040	
57	< 0.25	< 0.25	27.4	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	5.12	0.73	13.1
62	0.28	< 0.25	13.7	< 0.025	< 0.025	< 0.025	< 0.025	0.16	< 5.00	2.54	0.24	9.73
67												
72			17.7						2.25	2.85	0.58	4.1
92												
95	< 0.25	< 0.25	21.7	< 0.025	< 0.025	< 0.025	< 0.025	0.075	< 5.00	3.85	0.64	13.7
101	< 0.25	< 0.25	17.4	< 0.025	< 0.025	< 0.025	< 0.025	0.094	< 5.00	2.89	0.33	12.4
103	< 0.25	< 0.25	4.38	< 0.025	< 0.025	< 0.025	< 0.025	0.64	< 5.00	0.67	0.086	10.6
108												
112												
115												
118												
125	< 0.25	< 0.25	33.6	0.028	< 0.025	< 0.025	< 0.025	0.063	6.56	7.06	1.55	17.1

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1											0.90
3	0.14	< 0.25	7.63	< 0.25	< 0.50	0.41	0.17	< 0.25	1.32		
5	0.13	< 0.25	5.88	< 0.25	< 0.50	0.38	< 0.10	< 0.25	0.057		
6	< 0.025	< 0.25	18.1	< 0.25	< 0.50	0.29	< 0.10	< 0.25	< 0.025		
11		< 0.25	17.4						0.13	0.050	1.20
13	< 0.025	< 0.25	16.4	< 0.25	< 0.50	0.32	< 0.10	< 0.25	< 0.025		
16	< 0.025	< 0.25	3.95	< 0.25	< 0.50	0.24	< 0.10	< 0.25	< 0.025		
20	< 0.025	< 0.25	9.50	< 0.25	< 0.50	1.13	< 0.10	< 0.25	< 0.025		
40	< 0.025	< 0.25	13.2	< 0.25	< 0.50	2.95	< 0.10	< 0.25	1.03		
44											
49											
53	< 0.025	< 0.25	28.9	< 0.25	< 0.50	2.17	< 0.10	< 0.25	0.034		
54			2.30						0.19	< 0.050	< 0.20
57	< 0.025	< 0.25	56.2	< 0.25	< 0.50	2.68	< 0.10	< 0.25	0.85		
62	< 0.025	< 0.25	28.8	< 0.25	< 0.50	1.54	< 0.10	< 0.25	0.28		
67											
72			56.4			1.15			1.64	0.16	18.0
92											
95	< 0.025	< 0.25	49.2	< 0.25	< 0.50	3.06	< 0.10	< 0.25	2.95		
101	< 0.025	< 0.25	33.5	< 0.25	< 0.50	2.33	< 0.10	< 0.25	0.81		
103	< 0.025	< 0.25	4.42	< 0.25	< 0.50	0.53	< 0.10	< 0.25	0.50		
108											
112											
115											
118											
125	0.028	0.47	115	< 0.25	< 0.50	4.00	< 0.10	< 0.25	7.84		

TABLE XLI Drainage Water from Outside Stratmat Water Cover Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.25		3.23	< 0.020			< 0.020	0.19	5.16	< 0.50	< 0.010	11.0
3	< 0.25	< 0.25	1.06	0.050	0.059	< 0.025	0.032	0.074	< 5.00	< 0.50	0.076	7.76
5	< 0.25	< 0.25	0.67	< 0.025	< 0.025	< 0.025	< 0.025	0.091	< 5.00	< 0.50	0.018	8.58
6	< 0.25	< 0.25	1.04	< 0.025	< 0.025	< 0.025	< 0.025	0.082	< 5.00	≤ 0.50	< 0.005	8.42
11	< 0.25		2.72	< 0.025			< 0.025	0.040	< 5.00	0.51	0.010	9.00
13	< 0.25	< 0.25	0.67	< 0.025	0.033	< 0.025	< 0.025	< 0.025	< 5.00	< 0.50	0.033	9.48
16	0.27	< 0.25	0.064	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	< 0.50	< 0.005	8.25
20	< 0.25	< 0.25	3.01	< 0.025	< 0.025	< 0.025	< 0.025	0.14	< 5.00	0.63	0.055	10.8
40	< 0.25	< 0.25	2.48	< 0.025	< 0.025	< 0.025	< 0.025	0.59	< 5.00	< 0.50	0.064	12.8
44			24.5						2.79	0.97		5.06
49												
53	< 0.25	< 0.25	11.3	< 0.025	< 0.025	< 0.025	< 0.025	0.31	< 5.00	0.83	0.010	8.19
54			3.29						0.11	0.19		
57	< 0.25	< 0.25	28.6	< 0.025	< 0.025	< 0.025	< 0.025	0.38	< 5.00	5.46	1.33	12.5
62	0.29	< 0.25	3.68	< 0.025	< 0.025	< 0.025	< 0.025	0.39	< 5.00	0.73	0.075	6.60
67												
72			39.6						4.51	7.05	2.47	7.75
92												
95	0.33	< 0.25	20.8	< 0.025	< 0.025	< 0.025	< 0.025	0.31	< 5.00	4.33	1.02	13.6
101	0.31	< 0.25	18.1	< 0.025	< 0.025	< 0.025	< 0.025	0.26	< 5.00	3.37	0.76	12.8
103	0.36	< 0.25	5.27	< 0.025	< 0.025	< 0.025	< 0.025	0.26	< 5.00	0.83	0.16	8.03
108												
112												
115												
118												
125	4.84	< 0.25	60.7	0.050	0.031	< 0.025	1.01	0.38	8.75	16.0	7.83	17.78

WEEK	Ni	Pb	S04	Sb	Se	Si	Te	Tl	Zn	Fe+2	C1
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		< 0.25	6.50						< 0.020	0.17	0.10
3	0.044	< 0.25	2.34	< 0.25	< 0.50	0.18	< 0.10	< 0.25	0.56		
5	< 0.025	< 0.25	0.83	< 0.25	< 0.50	0.15	< 0.10	< 0.25	< 0.025		
6	< 0.025	< 0.25	< 0.75	< 0.25	< 0.50	0.11	< 0.10	< 0.25	< 0.025		
11		< 0.25	7.28						0.14	0.050	0.30
13	< 0.025	< 0.25	3.68	< 0.25	< 0.50	0.19	< 0.10	< 0.25	< 0.025		
16	< 0.025	< 0.25	1.63	< 0.25	< 0.50	0.14	< 0.10	< 0.25	< 0.025		
20	< 0.025	< 0.25	8.43	< 0.25	< 0.50	0.30	< 0.10	< 0.25	< 0.025		
40	< 0.025	< 0.25	4.87	< 0.25	< 0.50	0.42	< 0.10	< 0.25	0.17		
44						1.82				≤ 0.050	
49											
53	c 0.025	< 0.25	8.28	< 0.25	c 0.50	0.92	< 0.10	< 0.25	0.12		
54			3.62						0.28	< 0.050	< 1.00
57	< 0.025	< 0.25	74.1	< 0.25	c 0.50	3.58	< 0.10	< 0.25	2.98		
62	< 0.025	< 0.25	4.75	< 0.25	c 0.50	0.38	< 0.10	< 0.25	< 0.025		
67											
72			130			3.40			8.60	0.080	27.0
92											
95	< 0.025	1.27	67.2	< 0.25	< 0.50	3.49	< 0.10	< 0.25	4.83		
101	< 0.025	1.48	55.8	< 0.25	< 0.50	3.28	< 0.10	< 0.25	3.24		
103	< 0.025	1.77	8.45	< 0.25	< 0.50	0.67	< 0.10	< 0.25	0.85		
108											
112											
115											
118											
125	< 0.025	5.50	279	< 0.25	< 0.50	12.4	< 0.10	< 0.25	23.9		

TABLE XLII Drainage Water from Outside Stratmat Water Cover Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	< 0.25		12.2	< 0.020			< 0.020	1.95	8.02	1.71	0.15	15.5
3	< 0.25	< 0.25	5.63	< 0.025	< 0.025	< 0.025	< 0.025	0.11	< 5.00	0.60	0.094	7.64
5	0.32	< 0.25	10.8	< 0.025	< 0.025	< 0.025	< 0.025	0.28	< 5.00	0.67	0.068	9.16
6	< 0.25	< 0.25	6.08	< 0.025	< 0.025	< 0.025	< 0.025	0.03	< 5.00	0.53	0.031	9.27
11	< 0.25		8.09	< 0.025			< 0.025	< 0.025	< 5.00	0.60	< 0.005	8.29
13	< 0.25	< 0.25	4.25	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	0.53	0.023	9.51
16	0.25	< 0.25	3.44	< 0.025	< 0.025	< 0.025	< 0.025	0.151	< 5.00	0.64	0.019	10.2
20	1.73	< 0.25	7.76	< 0.025	< 0.025	< 0.025	< 0.025	2.45	5.70	2.15	0.10	14.6
40	0.44	< 0.25	4.01	< 0.025	< 0.025	< 0.025	< 0.025	0.51	5.88	0.65	0.057	20.2
44			31.8					0.43	4.84	1.29	0.040	10.5
49												
53	0.59	< 0.25	11.2	< 0.025	< 0.025	< 0.025	< 0.025	0.49	< 5.00	0.85	0.013	7.50
54			3.84						0.18	0.18		
57	0.26	< 0.25	28.9	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 5.00	5.49	0.90	13.5
62	< 0.25	< 0.25	1.94	< 0.025	< 0.025	< 0.025	< 0.025	0.472	< 5.00	0.56	0.03	6.00
67												
72			27.20						3.08	4.96	1.13	12.8
92												
95	< 0.25	< 0.25	21.17	< 0.025	< 0.025	< 0.025	< 0.025	< 0.03	< 5.00	3.74	0.39	13.7
101												
103	0.45	< 0.25	7.09	0.10	0.14	0.076	0.10	0.377	< 5.00	1.37	0.16	6.95
108												
112												
115												
118												
125	< 0.25	< 0.25	46.7	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	6.36	9.29	2.07	19.8

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.27	12.00						0.29	1.36	0.40
3	< 0.025	< 0.25	5.58	< 0.25	< 0.50	0.30	< 0.10	< 0.25	0.12		
5	< 0.025	0.31	4.05	< 0.25	< 0.50	0.57	< 0.10	< 0.25	< 0.025		
6	< 0.025	< 0.25	0.83	< 0.25	< 0.50	0.18	< 0.10	< 0.25	< 0.025		
11		< 0.03	9.40						0.070	< 0.025	< 0.10
13	< 0.025	< 0.25	6.76	< 0.25	< 0.50	0.24	< 0.10	< 0.25	< 0.025		
16	< 0.025	< 0.25	7.41	< 0.25	< 0.50	0.35	< 0.10	< 0.25	< 0.025		
20	< 0.025	< 0.25	15.9	< 0.25	< 0.50	2.93	< 0.10	< 0.25	0.15		
40	< 0.025	< 0.25	10.8	< 0.25	< 0.50	0.67	0.14	< 0.25	0.34		
44			31.0			3.30			0.17	< 0.050	13.8
49											
53	< 0.025	< 0.25	2.92	< 0.25	< 0.50	1.63	< 0.10	< 0.25	1.18		
54			3.43						0.32	< 0.050	0.63
57	< 0.025	< 0.25	62.1	< 0.25	< 0.50	3.25	< 0.10	< 0.25	1.07		
62	< 0.025	< 0.25	2.72	< 0.25	< 0.50	0.25	< 0.10	< 0.25	< 0.025		
67											
72			81.3			2.81			2.19	0.060	23.0
92											
95	< 0.025	< 0.25	36.4	< 0.25	< 0.50	3.03	< 0.10	< 0.25	1.10		
101											
103	0.12	< 0.25	12.3	< 0.25	< 0.50	0.77	0.14	< 0.25	0.41		
108											
112											
115											
118											
125	< 0.025	0.47	154	< 0.25	< 0.50	5.65	< 0.10	< 0.25	9.27		

TABLE XLIII Drainage Water from Outside Stratmat Clay Cover Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
11												
44	16.5		252				0.32	5.52	6.49	61.7	26.7	23.8
54												
67												
72	543		268	0.97	0.57		18.3	346	4.32	485	90.0	11.1
115	1994	69.2	458	2.66	2.06	< 0.025	58.2	9795	< 5.00	1956	176	12.0

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
11												
44		2.60	1100			6.91			61.6	< 0.50	34.5	< 0.03
54												
67												
72	0.42		7600			29.8			476	10.0	135	0.07
115	1.13	< 0.25	44940	6.02	1.02	99.1	1.40	0.47	1081			

TABLE XLIV Drainage Water from Outside Stratmat Clay Cover Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
11												
44	4.38		321				0.16	6.40	12.8	74.6	23.5	59.3
54	317		273	1.23	0.99		5.83	39.5	12.5	390	122	52.9
67	276		170	0.64	0.46		4.70	19.1	6.30	288	69.3	28.2
72	369		145	0.83	0.63		10.5	160	3.61	340	60.9	17.1
115	407	7.01	297	0.64	0.65	< 0.025	12.0	1414	< 5.00	401	47.9	19.1

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
11												
44		2.58	1400			10.0			61.7	1.00	57.2	0.03
54	0.32	4.30	5020			30.3			595	< 0.05	14.8	< 0.02
67		2.83	3700			29.6			349	< 0.05	50.0	0.13
72		1.33	4400			20.3			453	6.00	40.0	< 0.020
115	0.27	< 0.25	8859	1.14	< 0.50	55.5	0.32	< 0.25	336			

TABLE XLV Drainage Water from Outside Stratmat Clay Cover Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
11	0.69		575	0.84			< 0.025	2.10	135	409	224	229
44	2.41		396					2.11	9.29	37.7	10.3	31.1
54	643		584	0.29	1.86		7.88	468	14.2	797	286	44.2
67	842		515	2.08	1.03		16.4	603	3.98	871	192	10.8
72	344		212	0.57	0.30		8.00	260	3.85	308	53.3	12.1
115	1402	28.9	385	2.66	2.25	5.88	33.4	4299	< 5.00	1484	126	12.1

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1												
11		< 0.25	4070						199	< 0.010		
44		1.23	1200			7.51			23.4	< 0.05	10.8	0.030
54	0.93		10900			76.1			1390	< 0.05	2.30	< 0.010
67	0.71		12000			79.8			1020	< 40.0	120	< 0.020
72		1.54	4300			31.6			309	14.0	43.0	0.021
115	0.70	< 0.25	27195	3.50	< 0.50	93.3	0.84	0.29	1228			

TABLE XLVI Drainage Water from Outside Stratmat 1% Phosphate Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.55		422	< 0.020			< 0.020	2.65	59.6	133	29.2	39.9
11	3.87		140	0.040			0.53	1.98	12.7	33.6	12.4	140
44	3.92		95.6				0.27	0.49	4.55	13.1	6.0	5.57
54	162		605	0.38	0.33		6.57	67.1	8.50	161	57.1	24.4
67	451	4.50	612	0.79	0.67		19.6	1250	5.06	449	114	37.9
72	161		414	0.32	0.22		6.72	376	3.90	135	36.5	13.9
115	542	22.4	522	0.77	0.67	< 0.025	19.5	4791	5.91	573	72.5	21.2

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		1.29	1680						13.4	0.040	0.30	< 0.10
11		3.28	584						25.1	0.72	2.20	< 0.10
44			400			6.81			13.0	< 0.50	50.3	< 0.03
54	0.28		9740			32.3			212	< 0.05	< 10.0	0.34
67	0.41		8500			77.9			504	< 40.0	140	0.78
72			3450			26.3			163	< 40.0	38.0	7.27
115	0.26	< 0.25	15687	2.98	< 0.50	66.1	0.67	0.29	319			

TABLE XLVII Drainage Water from Outside Stratmat 1% Phosphate Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	2.73		490	< 0.020			< 0.020	3.77	65.7	155	40.1	45.4
11	51.0		397	0.27			2.60	8.32	11.7	80.2	40.1	18.0
44	34.4		566				1.44	11.50	3.41	32.3	13.4	12.7
54	382	4.03	537	0.63	0.52		14.2	1520	4.22	372	72.4	25.8
67	1080	45.9	606	1.10	0.94		40.0	11000	5.15	1110	121	19.5
72	283	9.88	400	0.33	0.38	0.42	10.5	282	3.41	290	33.3	8.61
115	791	42.7	516	1.02	0.94	0.045	21.5	10290	< 5.00	826	65.2	15.6

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		1.64	1930						18.9	0.70	0.30	< 0.10
11		1.41	1940						167	0.24	2.00	< 0.10
44			1800			27.7			56.9	0.28	25.6	< 0.03
54	0.34		7620			60.2			366	3.0	< 1.00	43.7
67			26000			1119			817	< 400	190	540
72			8800			38.2			230	118.0	58.0	117
115	0.30	< 0.25	28812	5.66	1.60	97.5	1.34	< 0.25	313			

TABLE XLVIII Drainage Water from Outside Stratmat 1% Phosphate Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	5.51		361	< 0.020			< 0.020	5.55	54.3	114	21.7	32.6
11	2.81		98.0	< 0.025			0.31	1.98	10.5	24.6	8.23	12.7
44	2.50		55.2				0.24	0.70	3.19	7.95	3.02	4.36
54	31.2		263				1.44	2.47	4.74	44.0	16.2	8.03
67	226		583	0.40	0.41		10.1	378	6.27	233	70.0	29.0
72	106		356				4.66	250	4.56	102	30.4	* 16.0
115	460	17.9	514	0.65	0.62	< 0.025	15.7	4678	5.34	448	59.9	26.2

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		1.48	1400						11.3	1.04	0.20	< 0.10
11		2.61	416						16.3	0.77	4.00	< 0.10
44			170			4.71			7.24	< 0.05	< 5.0	< 0.03
54			1070			11.3			49.2	2.60	< 1.00	0.08
67	0.28		4600			51.3			243	1.20	80.0	0.24
72			2400			18.9			116	140	41.0	4.10
115	0.26	< 0.25	14415	2.56	< 0.50	56.2	0.73	< 0.25	275			

TABLE XLIX Drainage Water from Outside Stratmat 3% Phosphate Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.98		457	< 0.020			< 0.020	3.65	52.5	207	13.8	48.1
11	12.3		286	0.080			0.70	0.53	13.8	68.3	20.1	17.2
44	17.8		426				0.46	0.47	3.73	28.4	8.65	10.6
54	170		604	0.23	0.41		0.41	54.7	4.88	224	42.9	38.6
67	340		545	0.48	0.50		10.3	775	4.09	391	62.1	47.2
72	223		444	0.36	0.34		6.42	671	4.53	233	36.7	40.3
115	522	19.4	544	0.66	0.66	0.051	12.0	6035	7.17	583	54.2	36.6

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.33	1740						2.25	< 0.040	1.90	< 0.10
11		5.42	1290						51.0	0.15	9.00	< 0.10
44			1400			11.8			31.6	< 0.05	10.8	0.14
54			3280			53.7			172	< 0.05	81.0	< 0.27
67	0.32		5700			84.0			322	< 40.0	*	0.38
72	0.27		4500			37.6			224	2.30	33.0	19.6
115	0.33	< 0.25	16692	3.14	0.88	68.2	0.76	< 0.25	262			

TABLE L Drainage Water from Outside Stratmat 3% Phosphate Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	5.05		419	< 0.020			< 0.020	6.89	50.2	197	10.1	39.5
11	1.08		127	< 0.025			0.13	0.43	11.8	34.4	6.20	12.3
44			70.2						4.34	11.5	3.05	4.03
54	21.1		354				1.27	0.17	9.40	55.2	20.6	12.8
67	121		599	0.25	0.35		4.98	1.97	7.62	184	47.7	33.1
72	65.9		434				2.77	0.44	4.99	86.8	24.1	19.7
115	225	1.66	631	0.47	0.52	0.076	8.47	102	6.30	277	42.2	50.2

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.54	1560						2.44	< 0.040	7.10	< 0.10
11		1.15	488						13.6	0.20	7.60	< 0.10
44			230			4.76			7.42	< 0.050	< 5.00	< 0.03
54			1250			15.2			40.7	< 0.050	< 1.00	0.16
67	0.31		2800			43.5			143	0.18	48.0	0.93
72			1700			18.2			78.4	0.14	24.0	1.70
115	0.40	< 0.25	3855	0.53	< 0.50	51.9	0.19	< 0.25	158			

TABLE LI Drainage Water from Outside Stratmat 3% Phosphate Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.42		432	< 0.020			< 0.020	3.32	49.3	216	12.7	46.6
11	1.37		124	< 0.025			0.20	0.78	11.8	37.6	7.86	12.7
44	1.60		102				0.18		7.78	17.0	5.24	7.72
54	24.6		365				1.51	0.15	10.8	63.5	24.1	15.1
67	122		614		0.39		5.84	1.21	9.17	186	48.6	36.7
72	64.6		400				3.03		7.81	92.8	25.4	16.0
115	249	1.76	632	0.33	0.42	< 0.025	10.3	57.1	7.16	331	47.1	48.8

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1		0.33	1640						3.1	< 0.040	3.50	< 0.10
11		0.93	500						18.3	0.41	8.10	< 0.10
44			360			6.58			14.4	< 0.05	19.7	< 0.03
54			1970			15.4			61	< 0.05	< 0.20	0.007
67			3000			36.7			146	< 0.05	81.0	0.85
72			1600			16.2			82	0.26	32.0	0.88
115	0.28	< 0.25	4150	0.46	< 0.50	47.1	< 0.10	< 0.25	200			

TABLE LII Drainage Water from Outside Stratmat Wood Bark Cover Test (Replicate #1, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1													
11	1330		502	4.87			28.1	4280	< 5.00	1120	364	10.3	
44	122		392	0.31			3.45	560	0.25	164	29.1	3.03	
54	1640	43.1	338	1.48	1.41	1.45	36.6	9510	0.58	1700	151	2.71	0.69
67	3380	87.2	578	1.74	2.13	2.32	63.6	25600	1.02	3310	303		1.19
72	1070	34.2	274	0.39	1.05	1.73	23.7	8250	0.90	1080	95.6		0.39
115	672	26.0	486	0.41	0.64	< 0.025	11.7	6942	< 5.00	642	54.6	6.00	0.29

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P	TOC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1										2.00		32.6
11	< 0.25	29100						2050	2.73	< 0.10		38.3
44		4000			64.9			143	< 40.0	66.0	< 0.03	
54		35900			128			848	16.0	< 1.00	7.57	
67		80000			187			1710	< 400	440	1.08	
72		13000			66.0			535	100	380	32.4	
115	< 0.25	24882	3.77	1.03	113	0.84	0.29	121				

TABLE LIII Drainage Water from Outside Stratmat Wood Bark Cover Test (Replicate #2, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	5.03		412	< 0.020			< 0.020	5.88	47.9	45.7	23.7	29.2	
11	593		430	2.24			13.4	1640	< 5.00	469	223	19.2	
44	40.7		327				1.65	154	0.27	54.1	11.7	4.55	
54	1110	27.3	315	0.74	0.72	0.42	27.4	5840	0.41	1190	111	2.58	0.37
67	1390	41.3	584	0.71	1.18	1.49	30.9	11300	1.06	1320	132		0.56
72	667	20.3	362		0.47	0.84	14.4	4820	0.75	655	70.9		
115	695	26.9	421	0.42	0.59	< 0.025	9.67	6455	< 5.00	661	65.8	6.30	0.19

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P	TOC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.82	1330						13.7	0.32	0.20		28.4
11	< 0.25	13300						1040	7.59	4.00		33.8
44		1700			30.5			44.4	< 40.0	44.3	< 0.03	
54		28200			119			575	7.80	< 1.00	8.83	
67		40000			117			580	< 400	49.0	1.12	
72		20000			61.6			269	< 400	280	26.2	
115	< 0.25	23418	3.57	1.15	101	0.79	< 0.25	110				

TABLE LIV Drainage Water from Outside Stratmat Wood Bark Cover Test (Replicate #3, Started July 10, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	2.81		236	< 0.020			< 0.020	3.88	32.6	32.5	14.4	22.2	
11	681		355	2.13			15.2	3070	< 5.00	578	188	16.1	
44	99.4		300				2.56	510	0.31	137	27.6	3.00	
54	1390	48.8	424	0.82	1.19	0.96	32.4	8920	0.40	1380	141	276	0.59
67	1630	39.8	404	0.87	0.76		38.9	10600	2.96	1540	159		0.65
72	761	19.3	190	0.31	0.45	0.58	15.4	4140	1.24	729	72.5		0.28
115	1603	55.1	260	1.25	1.09	< 0.025	25.9	9980	< 5.00	1658	127	6.16	0.44

WEEK	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P	TOC
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	1.68	811						12.2	0.85	4.30		26.1
11	< 0.25	17700						975	3.51	1.20		22.9
44		3500			41.9			94.6	< 40.0	35.5	< 0.03	
54		36700			116			616	16.0	< 1.00	9.17	
67		35000			105			709	< 400	270	0.34	
73		15000			31.1			266	600	200	24.4	
115	< 0.25	40110	6.17	1.51	67.6	1.22	< 0.25	439				

TABLE LV Drainage Water from Outside Selbaie Control Test (Replicate #1, Started August 14, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5	0.93			1.05			23.4	18.3		245	146	
38			93.0				5.56	0.54	0.35	22.7	8.48	4.03
48	2.2		117				15.4	34.5	0.20	67.6	30.9	0.13
61	15.5		271	0.60			54.6	112	1.26	165	64.7	
66	2.50		94.8				17.6	22.9	1.75	41.6	16.6	
109	28.7	0.78	108	0.48	0.08	< 0.025	29.7	907	< 5.00	104	35.3	5.95

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5		< 0.25	2320						235	10.4		
38			320			1.67			18.7	< 0.050	35.5	< 0.030
48			825			1.89			52.7	4.00	1.50	0.011
61			1500			4.52			153	0.26	< 0.10	0.030
66			290			1.23			43.1	0.76	24.0	< 0.020
109	< 0.025	< 0.25	3277	0.58	< 0.50	5.21	< 0.10	< 0.25	139			

TABLE LVI Drainage Water from Outside Selbaie Control Test (Replicate #2, Started August 14, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5	0.61			0.74			19.2	15.6		150	80.7	
38			101				2.48	0.36	0.41	26.2	9.87	4.67
48			112				6.90	9.41	0.32	53.9	24.2	1.42
61	4.84		275	0.49			29.9	35.6	1.05	135	55.2	
66			93.4				6.77	1.29	1.84	35.4	15.1	
109	14.5	0.52	123	0.42	0.04	< 0.025	24.1	519	< 5.00	90.8	33.3	6.34

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5		< 0.25	1510						141	5.85		
38			400			1.61			20.5	< 0.05	15.8	< 0.030
48			662			1.42			37.7	3.80	2.60	0.021
61			820			3.50			123	6.20	< 0.10	< 0.030
66			340			0.69			34.0	0.48	34.0	< 0.020
109	0.037	< 0.25	2330	0.27	< 0.50	3.92	< 0.10	< 0.25	120			

TABLE LVII Drainage Water from Outside Selbaie Control Test (Replicate #3, Started August 14, 1991)

WEEK	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5	< 0.25			0.70			11.8	< 0.025		101	56.8	
38			80.0				1.15	0.43	0.53	19.7	16.3	3.10
48			92.2				7.03	5.89	0.31	48.6	23.8	1.60
61	6.68		197	0.55			31.6	101	1.19	115	54.6	
66			65.4				6.20	5.49	1.49	34.0	16.3	
109	20.2	0.43	140	0.54	0.09	< 0.025	28.0	529	< 5.00	97.5	36.9	6.37

WEEK	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+2	Cl	P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5		< 0.25	1190						123	< 0.025		
38			290			1.44			16.2	< 0.050	44.3	< 0.030
48			596			1.62			48.6	< 0.050	1540	0.004
61			1000			3.08			132	3.90	< 0.10	< 0.030
66			270			0.52			41.0	3.10	35.0	< 0.030
109	0.059	< 0.25	2260	0.46	< 0.50	3.21	0.11	< 0.25	134			

TABLE LVIII Drainage Water from Outside Selbaie 3% Phosphate Test (Replicate #1, Started August 14, 1991)

WEEK	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L
5	0.32			0.12			0.97	1.29		415	75.2	
38			284				0.22		0.68	22.0	15.1	7.60
48			299				1.37	0.060	0.77	93.2	25.9	5.49
61	1.99		378				3.84	0.47	1.03	128	37.3	5.21
66			179				2.07		0.77	45.5	15.1	2.53
109	4.28	< 0.25	284	0.14	0.030	< 0.025	4.27	3.60	< 5.00	107	24.3	11.6

WEEK	Ni mg/L	Pb mg/L	SO4 mg/L	Sb mg/L	Se mg/L	Si mg/L	Te mg/L	Tl mg/L	Zn mg/L	Fe+2 mg/L	Cl mg/L	P mg/L
5		< 0.25	2700						45.3	0.57		
38			770			1.61			14.7	< 0.050	18.7	< 0.030
48			1130			2.31			37.6	0.52	11.5	0.17
61			1100			3.79			81.8	0.16	< 0.10	< 0.030
66			570			1.14			41.8	0.10	56.0	0.047
109	< 0.025	< 0.25	1239	< 0.25	< 0.50	3.28	< 0.10	< 0.25	75.6			

TABLE LIX Drainage Water from Outside Selbaie 3% Phosphate Test (Replicate #2, Started August 14, 1991)

WEEK	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L
5	1.34			0.38			8.74	5.87		630	182	
38	1.87		463				4.19	0.56	0.84	35.3	16.8	8.45
48	5.32		521				7.96	2.47	0.89	118	40.0	9.11
61	14.6		667	0.49			31.5	9.20	0.81	188	58.0	10.3
66	3.64		440				10.6	0.43	0.97	50.6	16.8	2.97
109	42.0	0.30	542	0.86	0.10	< 0.025	71.4	178	< 5.00	205	53.9	31.4

WEEK	Ni mg/L	Pb mg/L	SO4 mg/L	Sb mg/L	Se mg/L	Si mg/L	Te mg/L	Tl mg/L	Zn mg/L	Fe+2 mg/L	Cl mg/L	P mg/L
5		< 0.25	3990						200	1.17	1.17	
38			1440			4.21			31.2	< 0.050	13.8	< 0.030
48			2010			5.04			101	0.14	1.60	0.008
61			2300			8.82			190	0.40	< 0.10	< 0.030
66			1120			1.85			56.8	0.44	28.0	0.090
109	0.19	< 0.25	3251	0.49	< 0.50	16.5	< 0.10	< 0.25	348			

TABLE LX Drainage Water from Outside Selbaie 3% Phosphate Test (Replicate #3, Started August 14, 1991)

WEEK	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L
5	0.65			0.28			3.10	1.47		638	187	
38	2.15		325				0.67	1.21	0.98	32.4	20.7	10.2
48	3.10		331				6.20	1.11	0.82	121	40.5	8.29
61	18.7		596	0.44			20.5		1.29	179	63.8	9.21
66	4.46		248				7.25	0.78	2.76	52.8	20.7	4.50
109	15.9	< 0.25	416	0.35	0.053	< 0.025	18.1	1.25	< 5.00	156	44.4	14.7

WEEK	Ni mg/L	Pb mg/L	SO4 mg/L	Sb mg/L	Se mg/L	Si mg/L	Te mg/L	Tl mg/L	Zn mg/L	Fe+2 mg/L	Cl mg/L	P mg/L
5		< 0.25	4010						129	0.31		
38			900			6.44			25.4	< 0.080	19.8	< 0.030
48			1540			3.42			95.8	0.14		0.047
61			2100			7.51			196	1.30	< 0.10	< 0.030
66			830			2.13			65.7	0.42	31.0	0.043
109	0.043	< 0.25	1963	< 0.25	< 0.50	5.43	< 0.10	< 0.25	178			

TABLE LXI ions!Stored in the Waste Rock (mg)

LOCATION	TECHNIQUE	Al	As	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn
		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
STRATMAT	CONTROL	973	18.0	2686	2.76	2.56	1.36	24.8	5053	271	963	99.4
STRATMAT	WOOD BARK	833	25.3	933	1.53	1.53	1.53	13.4	7471	307	891	69.6
STRATMAT	CLAY	138	8.67	894	0.87	0.87	0.87	1.92	8.66	173	201	31.1
STRATMAT	PHOSPHATE (1%)	620	15.5	19033	1.55	1.68	1.55	17.3	3685	310	580	59.8
STRATMAT	PHOSPHATE (3%)	371	12.0	13595	1.20	1.20	1.20	13.3	1304	240	284	40.5
STRATMAT	LIMESTONE (1%)	154	10.5	7337	1.06	1.05	1.05	6.40	498	209	232	45.1
STRATMAT	LIMESTONE (3%)	15.0	13.9	11675	1.39	1.39	1.39	1.39	1.39	277	211	39.1
STRATMAT	WATER *	63.5	14.5	705	1.45	1.45	1.45	1.45	41.1	290	315	166
SELBAIE	CONTROL	17.9	7.6	2611	0.87	0.76	0.76	11.7	147	153	156	61.7
SELBAIE	PHOSPHATE (1%)	73.3	11.5	4811	1.66	1.15	1.15	36.4	66.1	229	244	89.6

LOCATION	TECHNIQUE	Na	Ni	Pb	SO4	Sb	Se	Si	Te	Tl	Zn	Fe+3
		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
STRATMAT	CONTROL	321	1.36	25.9	31855	13.6	27.1	256	5.43	13.6	581	3945
STRATMAT	WOOD BARK	351	1.53	15.3	32528	16.1	30.7	255	6.13	15.3	217	6234
STRATMAT	CLAY	206	0.87	13.5	4086	8.67	17.3	68.2	3.47	8.67	86.5	9.85
STRATMAT	PHOSPHATE (1%)	378	1.55	15.5	63328	16.4	31.0	232	6.20	15.5	233	2936
STRATMAT	PHOSPHATE (3%)	316	1.20	12.0	39903	12.0	24.0	139	4.80	12.0	121	638
STRATMAT	LIMESTONE (1%)	248	1.05	10.5	21413	10.5	20.9	107	4.19	10.5	108	2.09
STRATMAT	LIMESTONE (3%)	330	1.39	13.9	26696	13.9	27.7	60.7	5.55	13.9	36.0	2.77
STRATMAT	WATER *	350	1.45	173	3974	14.5	29.0	208	5.79	14.5	145	7.29
SELBAIE	CONTROL	180	0.76	7.63	7818	7.63	15.3	12.1	3.05	7.63	247	123
SELBAIE	PHOSPHATE (1%)	289	1.15	11.5	14319	11.5	22.9	31.6	4.59	11.5	545	62.2

LOCATION	TECHNIQUE	ACIDITY (Load)
		a CaC03 (Total)
STRATMAT	CONTROL	21.2
STRATMAT	WOOD BARK	25.9
STRATMAT	CLAY	1.51
STRATMAT	PHOSPHATE (1%)	15.6
STRATMAT	PHOSPHATE (3%)	6.80
STRATMAT	LIMESTONE (1%)	3.82
STRATMAT	LIMESTONE (3%)	0.53
STRATMAT	WATER *	1.20
SELBAIE	CONTROL	1.31
SELBAIE	PHOSPHATE (1%)	2.16

- Including Water Cover (23.0 L)

APPENDIX B

A COMPARATIVE STUDY OF PORESIZE DISTRIBUTION, MINERALOGY AND LEACHING OF STRATMAT AND SELBAIE ROCKS

(University of Western Ontario)

A COMPARATIVE STUDY OF PORESIZE DISTRIBUTION, MINERALOGY AND LEACHING OF STRATMAT AND SELBAIE ROCKS

by

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1.0 POST-TESTING CHARACTEFUZATION

1.1 Introduction and Objectives

After 2.96 years of the indoor column leach tests, the Stratmat Control, Selbaie Control and the Stratmat Water Cover columns were disassembled and split into top, middle and bottom sections. Approximately 1.2 kg of rock, obtained from each section, was washed and sampled for poresize and porosity measurements, surface and mineralogical analyses, and simulated leaching. The objectives of the post-testing study were to:

(a) identify and characterize weathered surfaces and mineral coatings and salt deposits on the rock samples,
(b) compare the mineralogy of oxidized and unoxidized or partially oxidized rock samples,
(c) re-interpret the drainage water quality data and relate them to the surface and bulk mineralogy in both the Stratmat and Selbaie rocks, and
(d) provide an explanation for the difference in acid generation between the Stratmat and Selbaie rocks, by focusing on rock structure and minerolgy and leach data.

The rock samples analyzed were Stratmat Control (LWR02), flooded Stratmat (LWR22), and Selbaie Control (LWR25). The Stratmat and Selbaie Control rocks had been cyclically leached with deionized distilled water and allowed to dry during laboratory column testing for nearly three years. The flooded Stratmat rock was permanently placed under water and also leached with deionized water during the same period.

1.2 Mercury Intrusion Porosimetry

The poresize distribution of the rock samples was measured by mercury intrusion using a Micrometrics Poresizer Model 93 10. The principle of the mercury porosimeter is similar to the rise of water in the pores of rocks and soils by capillary action:

$$h \propto \frac{P}{r}$$

where h = height of capillary rise; P = surface tension of water; and r = capillary radius. The relationship indicates that the smaller the capillary radius, the greater the capillary rise. In mercury porosimetry, a non-wetting fluid, mercury, is used. Positive presure, rather than suction, is used to force the mercury into rock pores. The size of pore tilled is a function of the pressure applied, and from this the total volume of different pore size distribution can be calculated.

The rock sample was oven-dried to remove excess water and then placed in a penetrometer cell installed in the poresizer. Mercury was intruded into the pores of the sample by an applied pressure that reached 207 MPa (30,000 psi). The volume of mercury forced into the pores was measured by the change in electrical capacitance of the falling mercury column in the penetrometer. The capacitance changes were converted to volume changes, using appropriate conversion factors. Applied pressures and other test parameters were used to calculate pore diameters. Porosity was also calculated from the porosimetry data.

1.3 Water Absorption

Two types of water absorption tests were carried out on the rock samples. Normal absorption was obtained by determining the mass difference between an oven dry sample and the same sample soaked in water for 24 hours. Vacuum saturation was determined from the mass difference between an oven dried sample and the same sample boiled in water for approximately four hours (Hudec, 1989).

1.4 Bulk Density

Bulk density was determined by measuring the volume of rock samples using a volumetric water displacement method and the oven-dry mass:

$$Bulk\ Density\ =\ \frac{Mass\ of\ oven\ dry\ rock\ sample}{Volume\ of\ rock\ sample\ soaked\ for\ 24\ hours}$$

Additional bulk density data were obtained from calculations performed as part of the porosimetry tests.

1.5 Results

1.51 Poresize Distribution

Control and Flooded Stratmat Rocks: The results of mercury intrusion porosimetry are compared in Figs l-l and l-2 for samples of Stratmat Control (LWR-02) and flooded Stratmat (LWR-22) rocks. The data indicate there is a wide distribution of pore sizes (0.007-100 μm), although smaller pores < 10 μm seem to be dominant. The Control Stratmat rock which was allowed to oxidize and then leached during the three years of testing has nearly 50% more of the < 10 μm pores than the Stratmat rock flooded or covered with water during the same period. The results also indicate more < 10 μm pores in the the Control rock than in the flooded rock.

Flooded Stratmat and Control Selbaie Rocks: The laboratory leach test results previously discussed indicated sulphide oxidation and acid generation from the Control Selbaie rock was much lower than the Control Stratmat rock. As noted, some oxidation of the flooded Stratmat rock occurred and resulted in acid generation during the three-year testing period, although the quantity of acid produced was significantly smaller than the Control or uncovered rock. From the limited acid production in both the flooded Stratmat and Control Selbaie rocks, it was inferred a comparative study of the bulk and surface mineralogy and structure of the two rock types would provide insight into their differences in acid generation.

Porosimetry data obtained on the flooded Stratmat (LWR-22) and Control Selbaie (LWR-25) rocks are presented in Figs. 1-3 and 1-4. The results indicate a similar number of 0.007-100 μm pores in both rock types, suggesting that poresize distribution has limited influence on the rates and extent of acid generation.

1.5.2 Porosity, Bulk Density and Water Absorption

Table 1.1 summarizes total intrusion volume, percent water absorption and bulk density measured on the flooded Stratmat, Control Selbaie, and Control Stratmat rocks.

Rock Sample	Total Intrusion Volume (x 10” mL/g)	Water Absorption (%)	Bulk Density (Mg/m^3)	Porosity
Flooded Stratmat Top	2.2-2.4	0.44-0.62	2.83-2.86	0.006-0.008
Flooded Stratmat Bottom	1.6-2.2	0.30-0.54	3.03-3.08	0.006-0.007
Control Selbaie Top	1.6-2.4	0.23-0.48	4.15-5.09	0.009
Control Selbaie Bottom	0.8-1.8	0.25-0.35	4.40-4.73	0.006-0.009
Control Stratmat Top	8.5-9.4	0.30-1.78	2.86-3.11	0.024-0.030
Control Stratmat Bottom	4.0-5.0	0.38-0.98	2.72-2.73	0.011-0.014

Table 1.1: Total Intrusion Volume, Absorption and Bulk Density of Stratmat and Selbaie Rocks

The above data indicate the total intrusion volume and porosity of the flooded Stratmat and Control Selbaie rocks are similar. Total intrusion volume average about2.1 x 10” mL/g for rock samples from the top section of each laboratory column and 1.6 x 10^{-3} mL/g for bottom samples. The porosity of the flooded Stratmat rock is about 0.006-0.008 for both top and bottom samples, while that of the Selbaie rock is 0.009 at the top and 0.006-0.009 at the bottom. The average

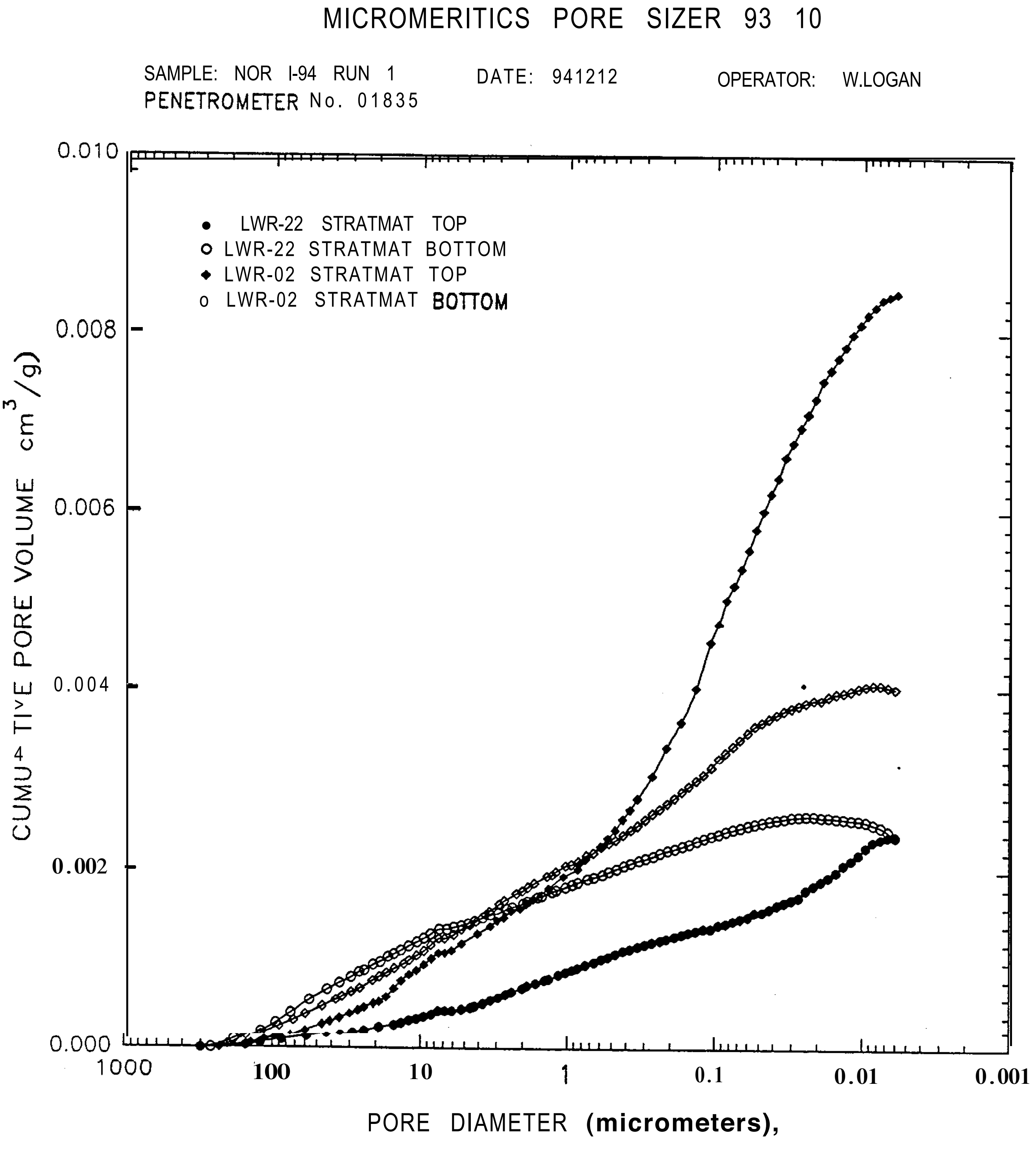


Figure 1-1: A comparison of mercury intrusion porosimetry for oxidized Stratmat rock (LWR02) and unoxidized Stratmat rock (LWR22) Test #1

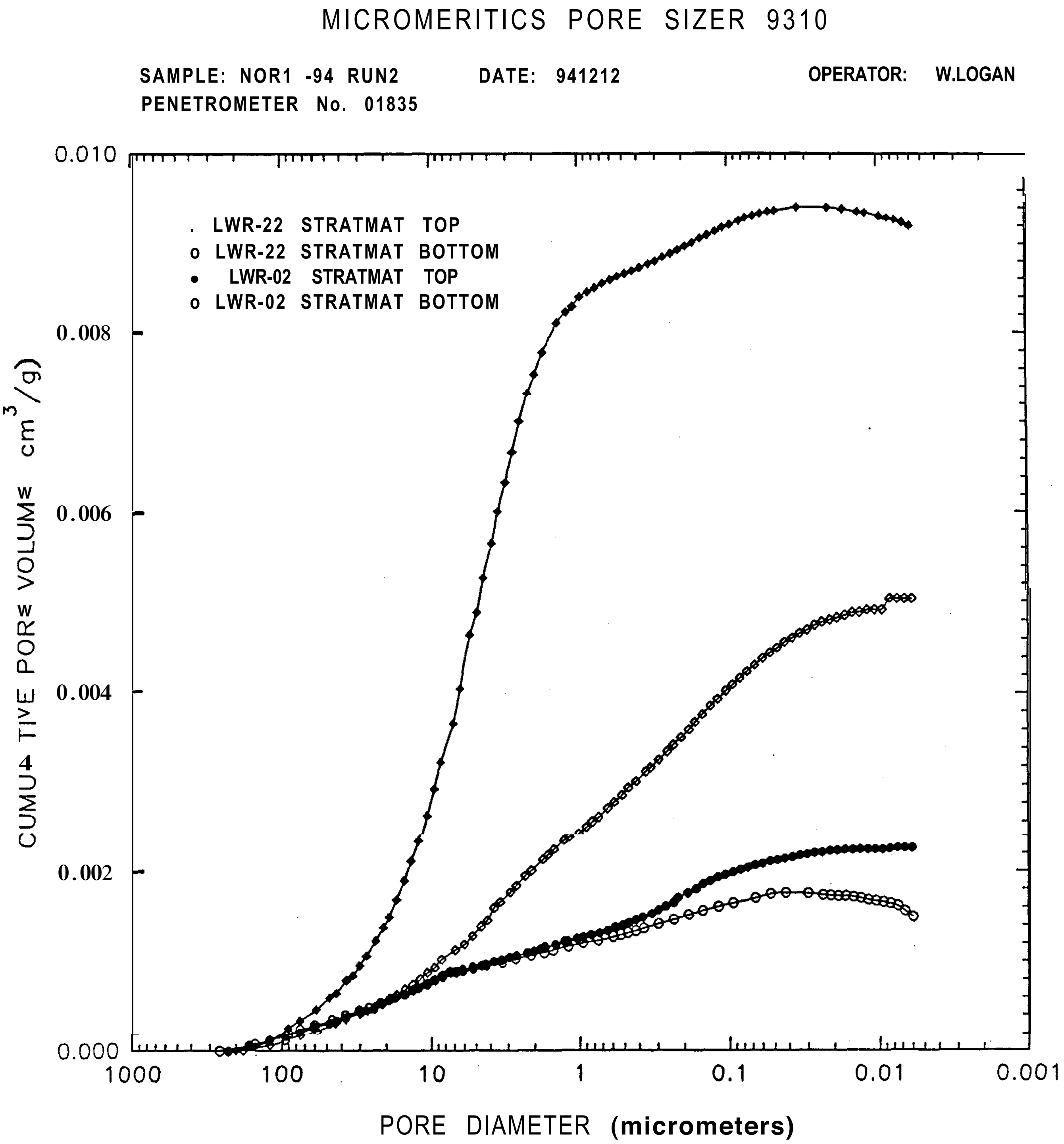


Figure 1-2: A comparison of mercury intrusion porosimetry for oxidized Stratmat rock (LWR02) and unoxidized Stratmat rock (LWR22) Test #2

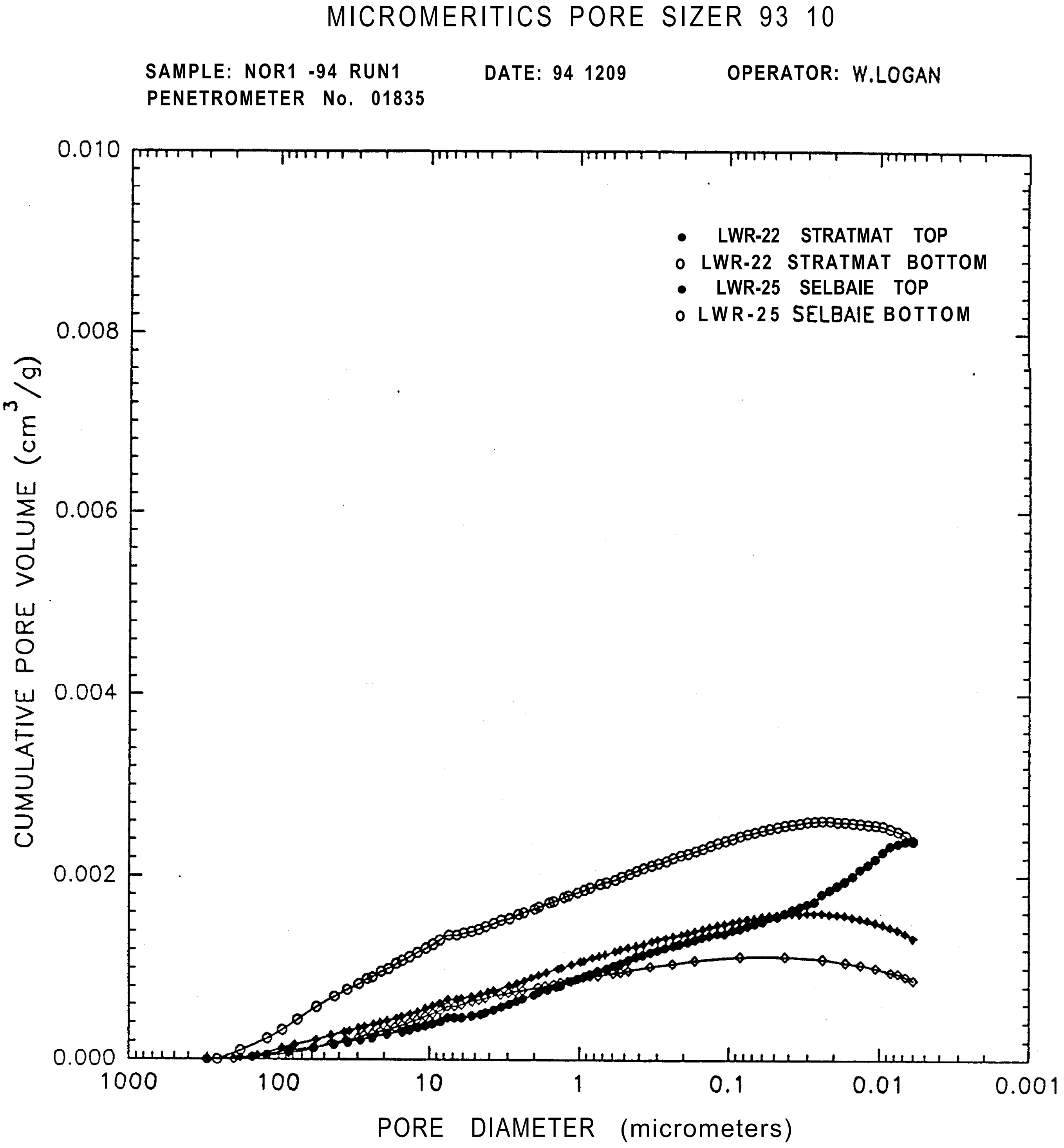


Figure 1-3: A comparison of mercury intrusion porosimetry for unoxidized Stratmat (LWR22) and Selbaie rocks (LWR25) Test #1

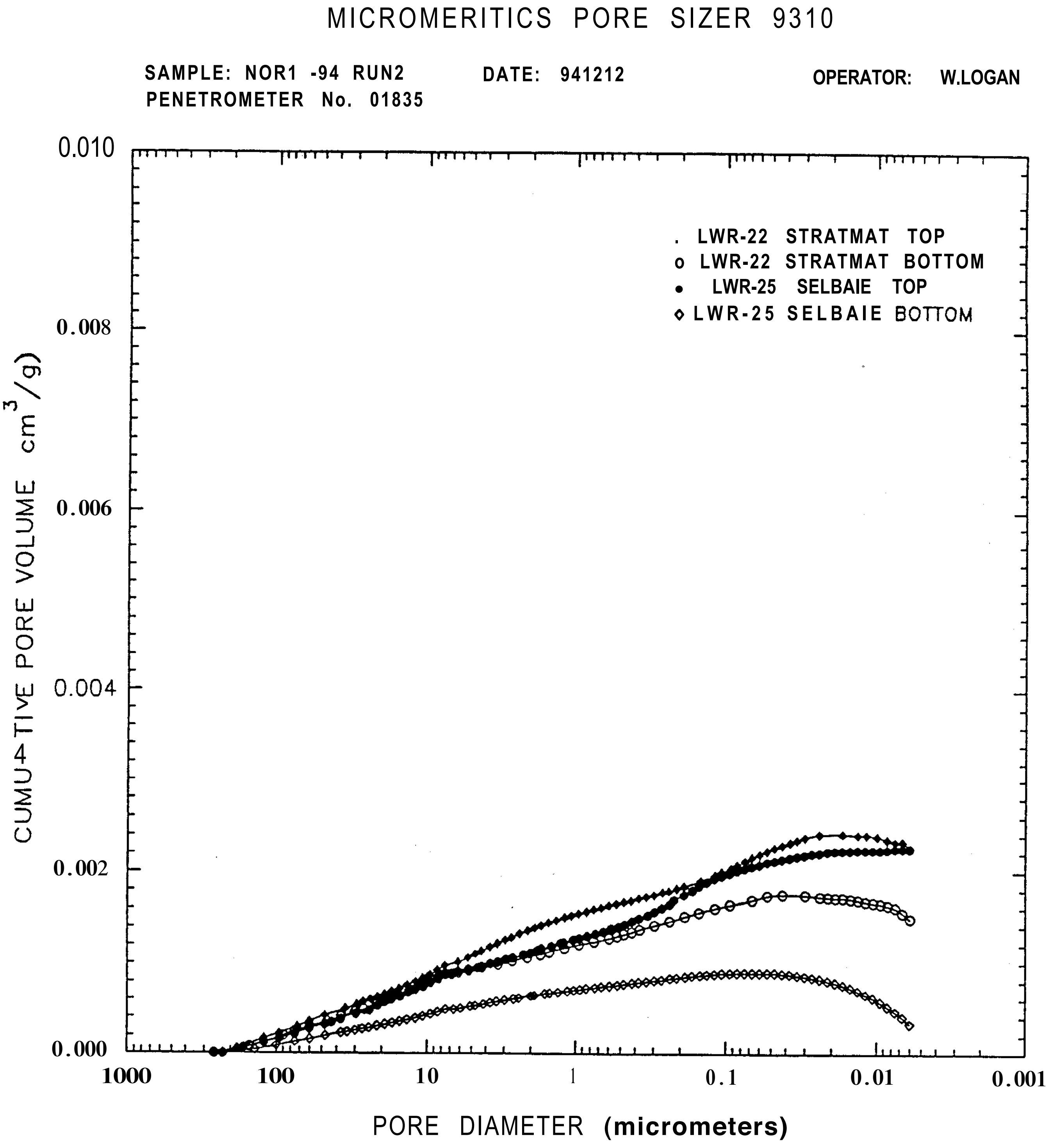


Figure 1-4: A comparison of mercury intrusion porosimetry for unoxidized Stratmat (LWR22) and Selbaie rocks (LWR25) Test #2

absorption for the flooded Stratmat rock is 0.53% at the top and 0.42% at the bottom of the column. The absorption for the Control Selbaie rock is slightly lower and average 0.396% at the top and 0.30% at the bottom. Total intrusion volume, porosity and water absorption of the Control Stratmat rock are all higher than those measured for the other two rocks. The average total intrusion volume is 9.0 x 10^{-3} mL/g, the porosity 0.027 at the top and 0.012 at the bottom and water absorption approximately 1% for top and bottom samples. The porosity and absorption values reported for the flooded Stratmat and Selbaie rocks are typical of dense crystalline rocks.

The bulk density of the flooded and Control Stratmat rocks has average values of 2.72-3.06 Mg/m^3. The Control Selbaie rock is much denser than both the flooded and Control or leached Stratmat rocks and has an average bulk density in the range of 4.15 to 5.09 Mg/m^3.

The above results would suggest that a more extensive sulphide mineral oxidation and leaching of oxidized products has resulted in the formation of a higher number of voids in the Control Stratmat rock than the flooded Stratmat and Control Selbaie rocks. The increased pores would lead to a higher porosity and water absorption.

2.0 Surface and Bulk Mineralogy

2.1 Introduction

The principal purpose of the surface and bulk minerological study was to discern any differences in pyrite morphology and distribution of surface and gangue minerals present in the Stratmat and Selbaie rocks. These differences would shed light on the reason(s) for the different acid production rates observed in the two rocks during the three-year laboratory leaching tests. The study involved several experimental analysis.

2.2 Experimental Methods

2.2.1 Petrography

Thin sections were analyzed using transmitted and reflected light techniques. The microscope used was a Zeiss Axioplan equipped with a 10x ocular and 5x to 100x objectives. All thin section photomicrographs shown in this report were taken using the 5x objective.

Three sets of pyritic waste rock, each consisting of a series of three samples were analyzed for this report. Sample sets LWR22 and LWR02 originated from the Stratmat site, Bathurst, N.B.. The third set, LWR25, was from the Selbaie mine site, Quebec.

2.2.2 Scanning Electron Microscopy

Scanning electron photomicrographs were taken from the lower stage of an IS1 DS 130 microscope. Energy dispersive X-ray (EDX) measurements were made with a Tracor Northern EDX analysis software.

Representative rock samples from each of LWR22, LWR02 and LWR25 were taken as received and mounted on an aluminiurn SEM stub. The surface of each grain was lightly coated in gold to increase their conductivity. The samples from LWR22 were to be the blank for which LWR02 were to be compared. Analysis of LWR22Top showed that the surface was oxidized. In order to determine what the unreacted rock was like, the rock samples were split in half to reveal a pristine rock.

2.2.3 X-ray Fluorescence

Trace element analyses of the rock samples were determined using a Philips PW – 1450 sequential wavelength X-ray Fluorescence (XRF) spectrometer. Representative rock samples, weighing greater than 25 g, were chosen from each of LWR02, LWR22 and LWR25. The rock samples were crushed to a fine powder using a tungsten carbide rock crusher. Eight gram samples were used for each analysis. The samples labelled "ALL" are equal mixtures, by weight, of each of the Top, Middle and Bottom samples from a particular LWR series.

2.2.4 X-ray Diffraction

Representative rock samples were chosen from the Top of LWR22, LWR02 and LWR25. The surfaces of the rock samples were scrapped with a diamond scribe until the altered surface of the rock was completely removed. The scrapped material was ground into a fine powder with an agate mortar and pestle. The remaining rock was wrapped in plastic and crushed with a sledge hammer. The crushed rock was also ground to a fine powder with a mortar and pestle. Powder diffractograms were recorded from each the altered surface and bulk of each of the rock samples.

2.2.5 X-ray Photoelectron Spectroscopy

The X-ray photoelectron spectrometer was a modified Surface Science Laboratories SSX-100, with a monochromatized AI Kα X-ray source and base pressure of $1x10^{-9}$ Ton in the analytical chamber (CHANEY, 1987). The XPS take-off angle (ASTM, 1991), measured with respect to the sample surface, is 35°. The high vacuum dosing chamber had a base pressure of $3x10^{-8}$ Torr. The spectrometer work function was adjusted to give a value of 84.00±0.05 eV for the Au $4f_{7/2}$ peak of metallic gold. The energy dispersion was set to give an energy difference of 857.5±0.1 eV between the Cu $2p_{3/2}$ and Cu 3p line. Fractured pyrite specimens had an Fe $2p_{3/2}$ binding energy of 707.00f0.05 eV and a S $2p_{3/2}$ disulphide peak binding energy of 162.6±0.1 eV (MYCROFT et *al.,* 1990; NESBITT and MUIR, 1994). Low energy (O-6 eV) electrons were applied to the surface using a flood-gun in order to neutralize local surface charging (PRATT *et al.,* 1994; KNIPE *et al.,* 1995).

The survey scans were recorded using a 600 or 300 μm spot size depending on the sample size and a fixed-pass energy of 160 eV, while narrow scan spectra were recorded using a 300 or 150 μm X-ray spot and a fixed pass energy of 50 eV or 150 eV in order to achieve acceptable signal noise in a reasonable length of time.

The LWR02 sample ‘was a single pyrite crystal removed from the exterior of a rock sample; a photomicrograph of the crystal surface can be seen in Fig. 2 - 10. The LWR25 sample used for XPS analysis was a chip (5mm X 5mm) from the exterior of a rock sample. This same crystal and rock chip were also used in the Auger analyses (see below).

2.2.6 Auger Electron Spectroscopy

Auger survey spectra and depth profiles were recorded on a Perkin-Elmer PHI 600 scanning Auger microprobe. The base pressure of the analytical chamber was 10^{-6} Pa (while sputtering). Survey analyses were recorded under the following conditions: 1) electron beam acceleration potential of 3.0 kV or 5.0 kV; 2) electron beam current of 20 nA; 3) spot size of 1 µm; 4) sample tilt of 30°; 5) kinetic energy range of 30 to 1030 eV and the energy resolution of the cylindrical mirror analyzer was $\Delta E/E = 1.2$ percent. No charging was detected at this low beam current. Depth profile conditions were as above and in addition a 2 kV Ar^+ ion beam was rastered over a surface area of 2x2 mm for a period of 10 to 20 s. Sputter rates were determined for pyrrhotite by PRATT et *al.* (1994) to be 40 ± 4 Å min^{-1}; this sputter rate was determined on the same instrument and under identical conditions to those above. Analysis for carbon KLL, sulphur LMM, oxygen KLL and iron (Fe $L_3N_1N_1$ at 703 eV) and, in some cases, silicon (KLL) and potassium (KLL) were recorded for several (3 -6) points on each surface.

2.2.7 Secondary Ion Mass Spectroscopy

Secondary ion mass spectroscopy (SIMS) was used to determine trace elements present in pyrite grains from LWR22 and LWR25. In addition to trace analyses, the distribution of the trace elements could also be determined from SIMS maps. Rock samples from the LWR22 and LWR25 series were fractured in two pieces and single pyrite cubes were chosen from these interior surfaces. The single pyrite grains were mounted in a graphite epoxy and polished to produce a fresh pyrite surface. The polished surfaces were liberally coated with gold to increase the samples conductivity.

All SIMS measurements were performed using a Cameca IMS 3f secondary ion microscope (microprobe). Separate surface analyses were performed using a rastered O^- and Cs' primary ion beam. The mass spectra of secondary ions were recorded from 1 to 250 A.M.U.; all imaging was done using an O^- primary ion beam..

2.3 Results and Interpretation

2.3.1 Petrography

Stratmat Flooded LWR22: Samples from the top, middle and bottom are all foliated white mica schists, consisting of similar mineralogies: mainly sericite (tine grained muscovite; $(K,Na)Al_2(AlSiO_3)O_{10}(OH,F)$), quartz ($SiO_2$) and pyrite ($FeS_2$). Minor amounts of K-feldspar ($KAlSi_3O_8$), titanate ($CaTiO(SiO_4)$) and apatite ($Ca_5(PO_4)_3(F,Cl,OH)$) also occur in the rock sample (see Table 2.1).

Foliations in the rocks are defined by the platy sericite mineralization (Fig. 2 – la). Sericite is also found in randomly oriented anhedral masses, possibly a metasomatic product of feldspar alteration (Fig. 2 – 1 b) Quartz occurs as an anhedral polycrystalline masses located in the pressure shadow regions adjacent to pyrite grains (Fig. 2 – la). Generally, K-feldspar is present as ragged phenocrysts heavily altered to sericite. Pyrite appears as euhedral cubic grains (Fig. 2- 1 c). The pyrite grains contain few inclusions, fractures and have well defined straight edges (Fig. 2 – 1c,d). The pyrite cubes have an average width ≥300 pm.

Stratmat Control LWR02: The samples originating from the bottom and middle are essentially the same as those described above, for LWR22. The top sample, however, is significantly different and will be described in detail.

LWR02Top is a friable strongly banded rock 'with considerable (10%) sulphide mineralization. The minerals identified are sericite, chlorite $(Mg,Al,Fe)_6(Si,Al)_4O_{10}(OH)_8$, unidentified clay minerals, quartz, pyrite and sphalerite (ZnS). Foliations in the rock are defined by the platy minerals, i.e. chlorite, and the unidentified clay minerals (sericite) (Fig. 2 – 2a+2b). The clay minerals appear to occur as sericite alteration products (Fig. 2 -2b; Table 2.1).

The pyrite grains have a range of shapes, from euhedral cubes to anhedral masses (Fig. 2 – 2c,d). All pyrite grains have ragged edges and rounded corners. Grain size is also distinctly bimodal with one group ≥400 μm and the other group ≤100 μm. The smaller grain size fraction also tends to be more heavily altered (Fig. 2 – 2d). The sphalerite is found as ragged anhedral masses in close association with the smaller sized pyrite.

Selbaie L WR25: The LWR25 samples from the top, middle and bottom are all virtually identical. The rock samples contain massive pyrite with quartz veining along fractures. Associated with the quartz veining is a small ankerite ($CaFe(CO_3)_2$) component. In thin section, the sample consists of massive sulphide formed by an agglomeration of small (≤ 100 μm) pyrite cubes (Fig. 2–3a,b).

Sample	Mineral	Modal Volume (Percent)		
		Top	Middle	Bottom
	%	%	%	
STRATMAT FLOODED (LWR22)	Sericite	35	60	65
	Quartz	10	10	10
	Pyrite	50	25	20
	Chlorite	<5	<5	<5
	K-feldspar	<3	<3	<3
	Titanate	<1	<1	<1
	Apatite	<1	<1	<1
STRATMAT CONTROL (LWR02)	Sericite	50	65	40
	Quartz	10	10	10
	Chlorite	15	<3	<5
	Clays	10	<2	<2
	Pyrite	10	20	40
	Sphalerite	3	<1	<1
	K-feldspar	<2	<2	<2
	Titanate	<1	<1	<1
	Apatite	<1	<1	<1
SELBAIE CONTROL (LWR25)	Pyrite	90	90	90
	Quartz	10	10	10
	Ankerite	<2	<2	<2

Table 2.1 Summary of mineralogical composition of mine waste rock samples,

Fig. 2 – 1 a: Photomicrograph showing foliation, sericite (fine grained platy phase) and polycrystalline quartz. Opaque phases are pyrite. Sample LWR22Top

Fig. 2 – 1 b: Photomicrograph showing sericite after feldspar. Opaque phases are pyrite. Sample LWR22Middle

Fig. 2 – 1 c: Photomicrograph showing euhedral pyrite. Sample LWR22Bottom.

Fig. 2 – 1 d: Photomicrograph showing euhedral pyrite. Sample LWR22Middle.

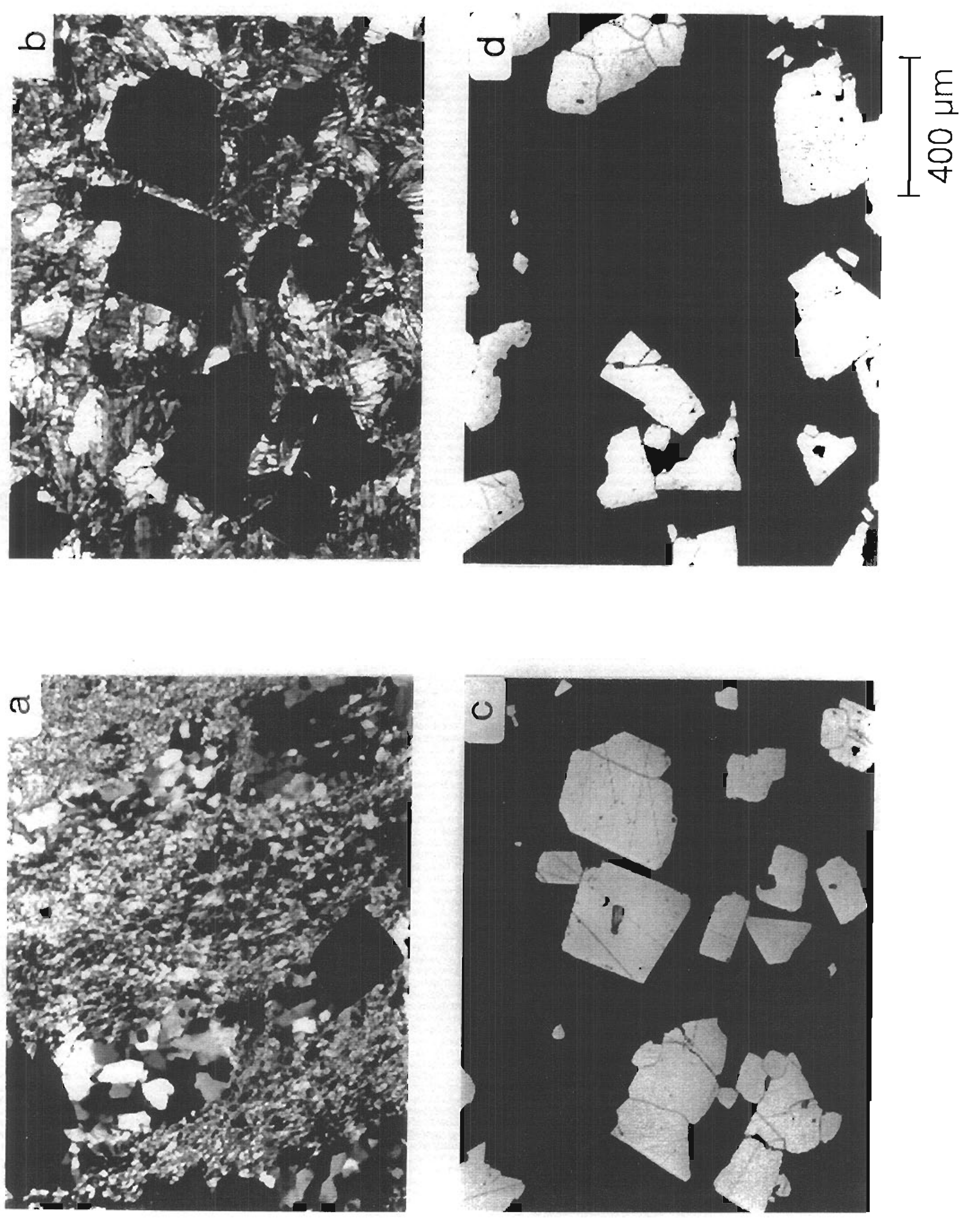

a
b
c
d
400 μm

Fig. 2 -2a: Photomicrograph showing foliation, sericite and polycrystalline quartz. Opaque phases are pyrite. Photomicrograph representative of LWR02Middle and LWR02Bottom

Fig. 2 -2b: Photomicrograph showing foliation, sericite, chlorite (bluish colour), unidentified clay minerals (small grains a dark colour) and polycrystalline quartz. Opaque phases are pyrite. Sample LWR02Top

Fig. 2-2c: Large size group pyrite grains with ragged edges and rounded corners. Sample LWR02Top

Fig. 2-2d: Small size group pyrite grains. Shapes tend to be anhedral and ragged. Sphalerite is the low dark gray phase. Sample LWR02Top.

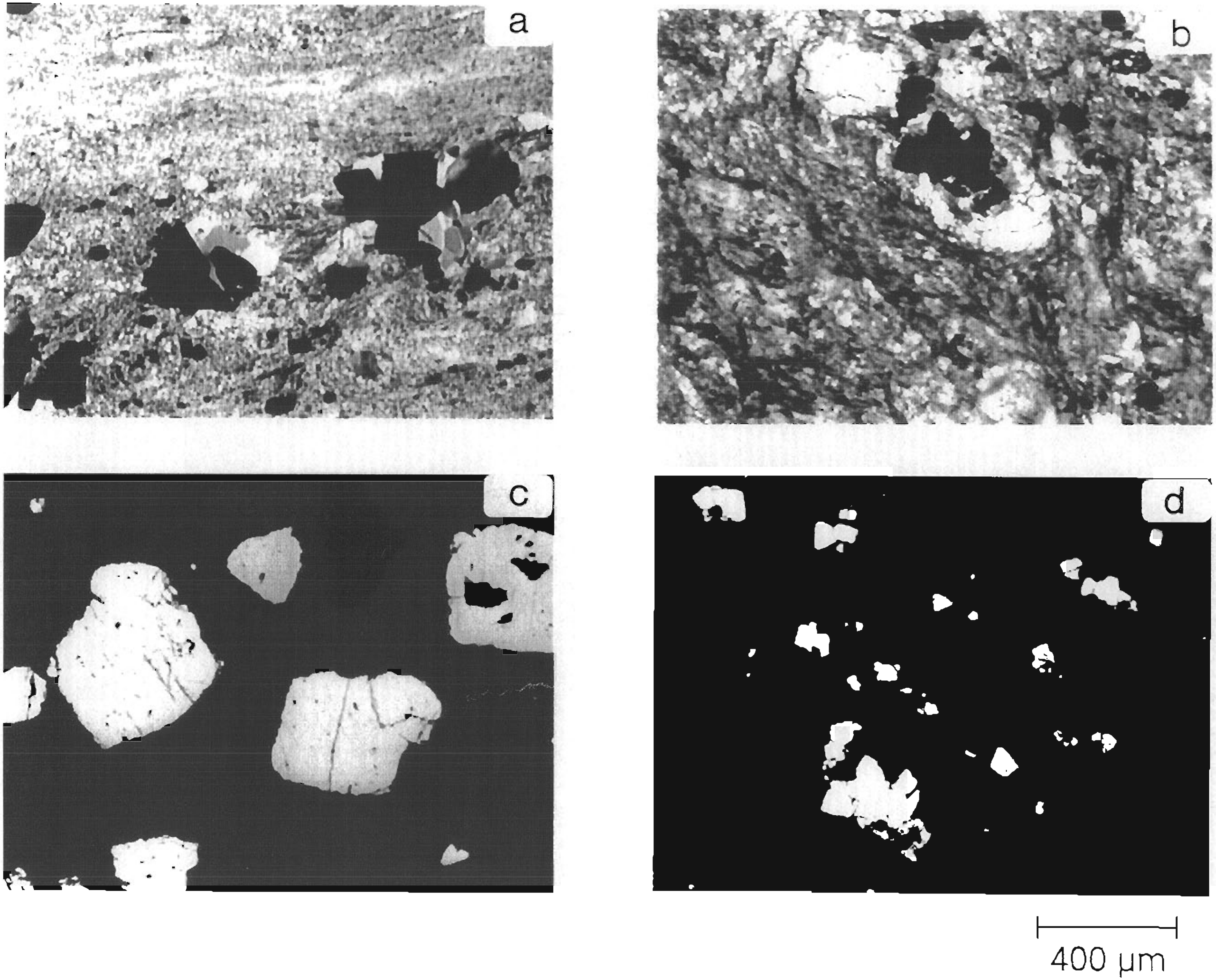
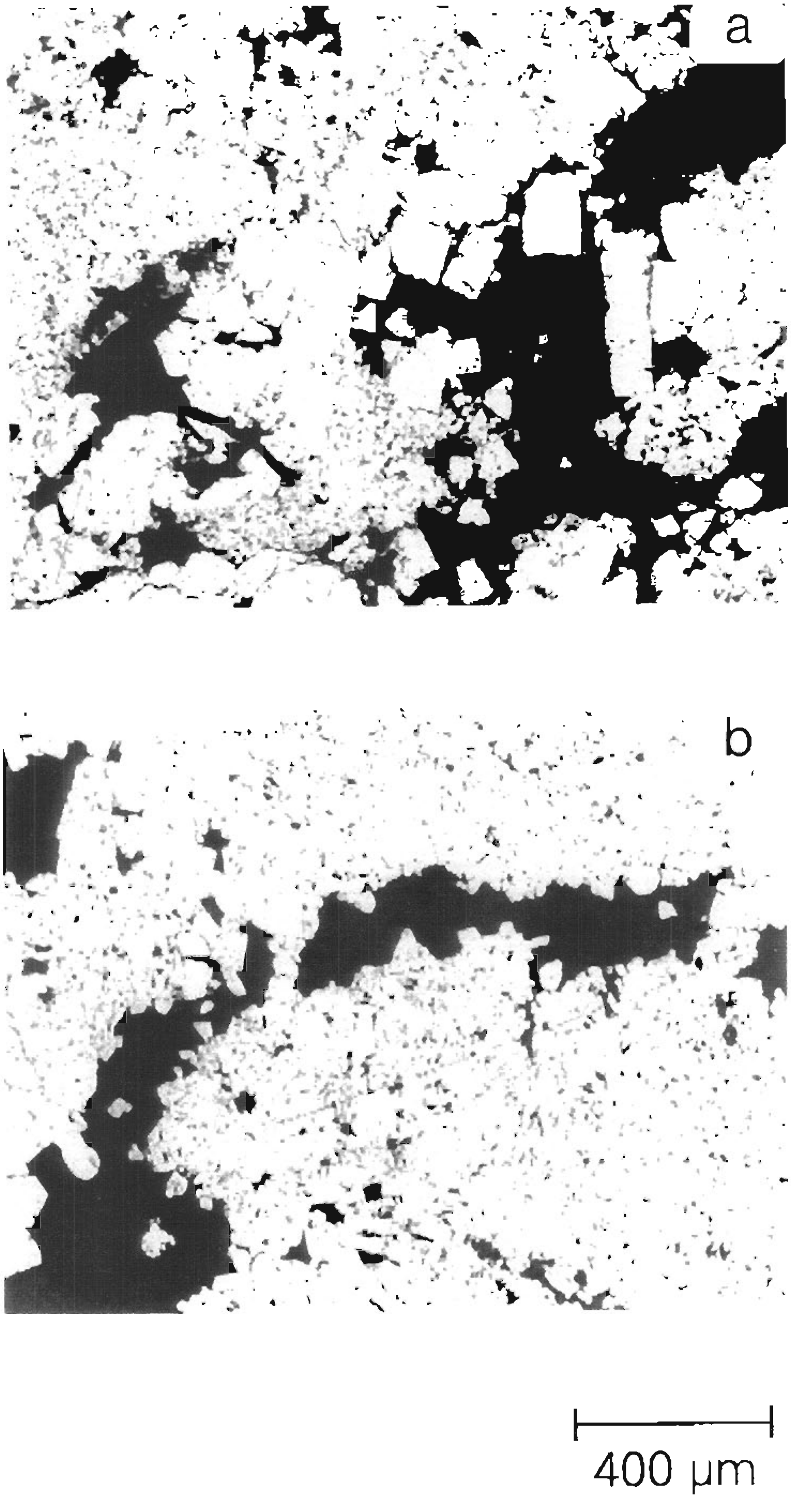

a
b
c
d
400 µm

Fig. 2 -3a: Photomicrograph showing massive pyrite and quartz veining. Note the well formed cubes in the upper right hand corner. Sample LWR25.

Fig. 2-3b: Photomicrograph showing massive pyrite and quartz veining. Sample LWR25.


a
b
400 µm

2.3.2 Scanning Electron Microscopy

Results: Scanning electron photomicrographs (SEM) were taken from the surface of each of the rock sample. The surface of LWR22Top (as received) is shown in Figs. 2 -4 and 2 -5. The interior of grains of LWR22 and these fractured grains reveal the pristine rock; these photomicrographs for LWR22Top, LWR22Middle and LWR22Bottom can be found in Figs. 2 -6 to 2 – 8, respectively. Photomicrographs for LWR02Top, LWR02Middle and LWR02Bottom can be found in Figs. 2 -9 to Figs. 2 – 12. The surface of a single pyrite crystal (LWR02Top) showing the tiny pits and the area between the pits are shown in Fig. 2 – 1 0a,b, respectively. Photomicrographs showing the surface of LWR25Top, LWR25Middle and LWR25Bottom can be found in Figs. 2 – 13 to 2 – 15, respectively.

Interpretation

Stratmat Flooded L WR22: Scanning electron photomicrographs of LWR22 (Fig. 2 -4) show a surface which has been mildly altered with respect to the highly altered LWR02 series. Many of the pyrite grains are surrounded by clays/micas and are covered with a considerable amount of detrital material. The pyrite grains are somewhat rounded, but, in general, show no obvious pitting. Having said this, one grain was found which showed very small pits beginning to form on pyrite twin plains (Fig.:!-5). No pits analogous to this were found on any other parts of the same crystal.

If the images in Fig. 2 -4 are compared with photomicrographs taken from a fresh surface from the same rock (Fig. 2 –6), it can be seen that the grains from the rock interior have sharp edges and are unreacted. The micas appear fresh and unreacted. EDX analyses performed on pyrite grains from both interior and exterior can be found in Table 2.2.

The observations made above for the top of LWR22 can also generalized to the samples from the middle and bottom of the LWR22 series. Micas and potassic feldspar make up much of the gangue supporting the euhedral pyrite grains. The exterior faces of the rock showed a similar overall chemistry, but different mineralogy from the freshly fractured surfaces. The pyrite grains from the exposed surface were rounded with low levels of 0, K, Al and Si on the pyrite surface. The surrounding gangue minerals are fine grained and in some cases are enriched in Mg; the minerals having high concentrations of Mg are probably chlorite.

STRATMAT FLOODED (LWR22) TOP

Element Figs.	Pyrite Grain (Exterior) Atom % Fig. 2-4b	Pyrite Grain (Interior) Atom % Fig. 2-6d
0	31.7	---
Na	2.2	---
Mg	1.7	---
Al	5.2	1.2
Si	8.0	1.9
K	2.5	---
S	21.2	71.8
Fe	27.5	25.03

Table 2.2: EDX analyses from the surfaces of pyrite which were reacted (i.e., from the grain exterior) and those from the pristine surface (i.e., grain interior), Stratmat Flooded (LWR22) Top

Stratmat Control L WR02: The photomicrographs in Figs. 2 - 9 to 2 - 12 show the surfaces of the rock samples are extensively reacted. These photomicrographs can be compared with those of Figs. 2−6(a−c), 2−7(d,e) and 2−8(a−c) which are taken from grains that were unreacted. It is apparent that gangue minerals have all been altered to fine grain silicates, possibly chlorite.

The pyrite grain in the upper left corner of Fig. 2 -9a is characterized by two textures: first, much of the pyrite grain is highly pitted (Fig 2 −9c) and striated, while a second area is characterized by a flaky crust which is spalling off the surface. Higher magnification images of both these areas can be seen in Figures 2 - 9c and 2 -9d, respectively. Both of these textures can be observed in Figure 2 -9d which shows a spall pealing off the surface and that under the spall the mineral surface is also pitted. The observations made above would suggest that the spall material is not passivating the surface from further oxidation and that the spall is not’ well attached to the surface. Another spall area can also viewed down its length in Fig 2 -9e. The results of the EDX analyses for the pyrite, the spall and the rosettes shown in Fig. 2 - 9f, are summarized in Table 2.3. The composition of the spall is consistent with a mixture of iron sulphate or iron oxide and pyrite. The chemical composition and the morphology of the rosettes, in Fig. 2 -9f, is consistent with that of jarosite ($KFe_3(SO_4)_2(OH)_6$).

STRATMAT CONTROL (LWR02) TOP

Element	Pyrite	Spall #1 (1)	Spall #2 (2)	Spall Length	Rosette
	Atom %	Atom %	Atom %	Atom %	Atom %
Figs.	2-9b,c	2-9d	2-9d	2-9e	2.3-9%
0	4.6	43.7	46.3	44.3	56.9
Mg	---	2.5	3.3	3.6	---
Na	---	4.3	4.2	---	---
Al	---	1.6	2.2	2.8	---
K	---	0.9	1.7	3.0	5.9
Si	---	0.6	1.7	6.3	0.9
S	70.6	25.1	21.3	26.0	16.7
Fe	24.8	21.3	19.5	14.1	19.5

(1) magnification 22kX
(2) magnification 7.6kX

Table 2.3: EDX analyses for the surfaces of the photomicrographs in Fig. 2-9(c-f), STRATMAT CONTROL (LWR02) TOP

Figure 2 - 10 shows the surface of another pyrite crystal. The surface can be characterized by three different morphologies. First, the surface is covered in a fairly uniform, although not regular manner by highly prismatic etch pits (see Fig. 2 - 10). The etch pits appear to be oriented with respect to the natural crystallographic direction; the pits have formed in the (110) crystallographic direction. It is not possible to see the bottom of the pits and some may have formed in the (111) crystallographic direction. Second, between the pits one can see a fairly flat and homogeneous surface. At very high magnification (50 kX; see Fig. 2-10), it is apparent that the surface is not pitted but has small nodules and other areas which are etched parallel to the (110) pits (Fig 2 - 10a). Third, areas between the pits are raised and appear to be platy deposits, which are possibly iron oxides. Scanning electron photomicrographs and EDX analyses for LWR02Middle show very similar trends and compositions to LWR02Top, described above. The composition of the gangue minerals and the highly pitted pyrite can be found in Table 2.4. The EDX analyses would indicate that at least two different gangue minerals are present, possibly one or two different chlorites and a feldspar ((Na,K)AlSi3O8).

The photomicrographs in Fig. 2 - 12 were taken from the surface of LWR02Bottom series. The photomicrographs in Fig. 2 - 12a,b show two very different surface morphologies. The surface in (a) shows what appears to be a clump of fine grained clays which have formed or precipitated on the surface of the rock; the composition of the clays would suggest an iron aluminosilicate containing traces of magnesium and potassium. The large prismatic crystal in the centre right of the photomicrograph is gypsum ($CaSO_4 \cdot 2H_2O$). Similar gypsum crystals can be found also in Figs. 2 - 12(b-d).

The large pyrite cube in Fig. 2 - 12b can be seen at increasing magnification in Fig. 2 - 12(c -e). It is immediately apparent that this pyrite crystal is highly pitted and eroded. The pyrite surface appears to have lost much of its texture and may be covered in fine grained clays as can be observed in Fig. 2 - 12a. In this clay material, a number of very fine needle like crystals are forming. These crystals are not apparent in the gangue minerals.

STRATMAT CONTROL (LWRO2) MIDDLE

Element	Pyrite Atom % 2-11d,f	Gangue #1 Atom % 2-11b	Gangue #2 Atom % 2-11b
O	2.4	38.4	57
Mg	---	---	≈2
Na	1.9	4.6	---
Al	0.6	12.5	4.5
K	---	1.7	4.5
Si	0.8	41.7	20.3
S	67.1	---	3.4
Fe	27.2	1.1	8.0

Table 2.4: EDX analyses for the surfaces of the photomicrographs in Fig. 2-11(a,f)(LWR02 MIDDLE)

EDX analyses for the fine grained clay (a) the gangue minerals (b) and surface of the pyrite crystal at two different locations can be found in Table 2.5.

Selbaie LWR2.5: In general, the chemistry of the samples from the LWR25 series is much simpler and more homogeneous than that of samples from LWR02 and LWR22. The photomicrographs in Figs. 2 - 13 to 2 - 15 all show the same general features. The surface of the rocks have considerably more pyrite present. Also, the pyrite in the LWR25 series seems to be finer grained (3 -20 µm diameter) by about an order of magnitude, when compared to the LWR22 series (66-300 µm diameter).

STRATMAT CONTROL (LWR02) BOTTOM

Element Figs.	Clay Atom % 2-12a	Gangue Atom % 2-12b	Pyrite #1 Atom % 2-12c	Pyrite #2 Atom % 2-12c,d
O	50.2	41.8	4.5	37.2
Ca	1.0	5.6	---	---
Mg	4.0	7.1	---	2.9
Na	4.2	2.5	---	4.6
Al	6.4	8.4	---	2.8
K	1.9	1.5	---	1.0
Si	8.8	10.8	---	2.0
S	11.7	12.0	69.4	35.6
Fe	11.9	10.3	26.1	13.9

Table 2.5: EDX analyses for the surfaces of the photomicrographs in Fig. 2-12(a-d) (STRATMAT CONTROL (LWR02) BOTTOM).

Typically, the pyrite grains are either coated with a material (Figs.2 − 13b, 2 − 14(c −f), 2 − 15d) similar in appearance and composition to the spalls in the LWR02 series or they are bare and very lightly etched (Figs. 2 − 13d, 2 − 15c). Surrounding the pyrite, one can identify a few different mineral morphologies. A fine grained clay or chlorite surrounds and coats much of the pyrite. Also, the pyrite is often found in association with large, euhedral gypsum crystals (Fig. 2 − 13f).

The EDX analyses for the various images in Figures 2 − 13 to 2 − 15 can be found in Tables 2.6 and 2.7.

(a) SELBAIE CONTROL (LWR25) TOP

Element Figs.	Gangue Atom % 2-13a	Pyrite Atom % 2-13c	Spall Atom % 2-13c	Coliform Atom % 2-13e
0	39.3	20.1	31.1	30.6
Mg	1.8	2.0	1.8	1.8
Na	3.4	3.7	4.3	3.3
Al	0.8	1.0	1.4	1.6
Ca	4.1	---	0.4	0.2
Si	8.5	1.2	2.1	4.9
S	22.5	45.7	29.9	10.1
Fe	19.8	26.4	29.0	47.5

(b) SELBAIE CONTROL (LWR25) MIDDLE

Element Figs.	Gangue Atom % 2.3-14a,d	Pyrite Atom % 2.3-14c	Spall Atom % 2.3-14c	Pyrite Atom % 2.3-14f	Spall Atom % 2.3-14e,f
0	31.4	3.4	22.6	21.2	14.6
Mg	2.1	---	---	me-	---
Na	4.0	---	---	---	---
Al	1.2	---	---	---	---
Si	9.9	0.1	0.3	2.1	2.3
S	27.5	71.0	51.3	48.5	33.2
Fe	23.8	25.5	25.7	28.3	49.9

Table 2.6: EDX analyses for the surfaces in photomicrographs in Fig. 2-1 3, 23-14 (LWR25TOP, MIDDLE).

SELBAIE LWR25 BOTTOM

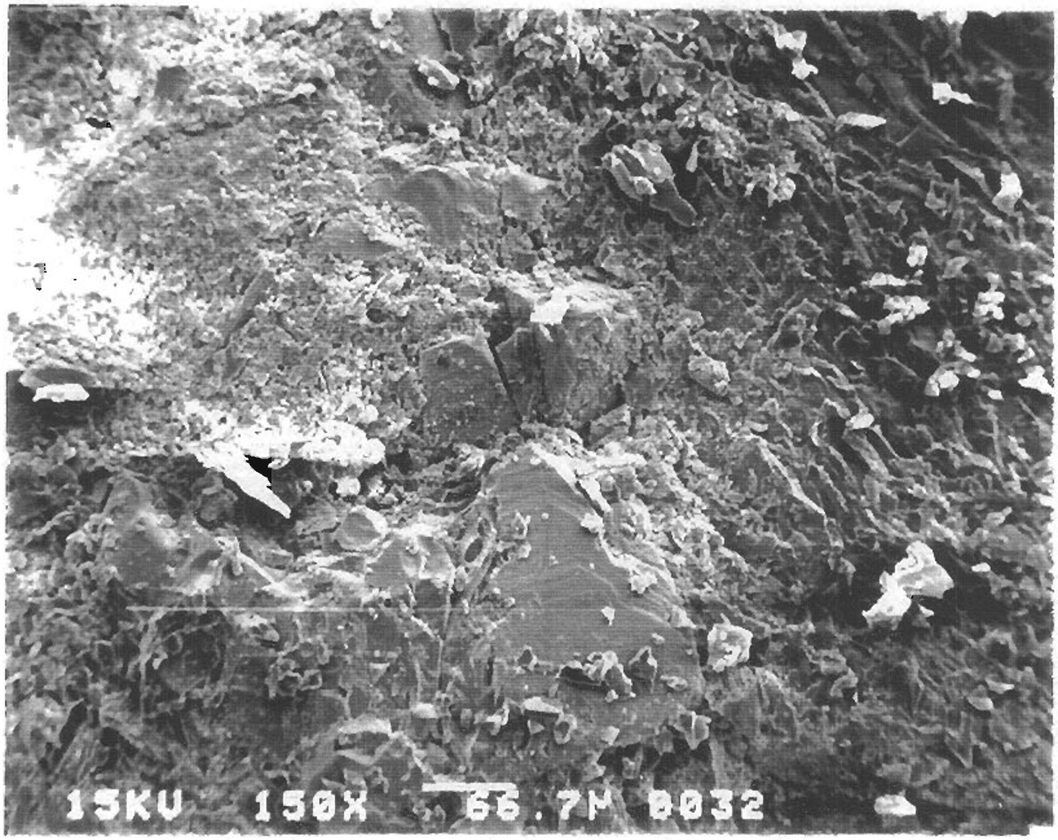
Element Fig.	Gangue Atom % 2-15a,b	Pyrite Atom % 2-15c	Pyrite Atom % 2-15d	Spall Atom % 2-15e	Spall * Atom % 2-15e
O	38.6	26.4	5.4	30.9	51.2
Mg	1.2	---	---	0.6	0.2
Na	3.3	1.0	---	---	---
Al	---	--s	---	0.5	0.3
Si	9.7	1.6	0.8	1.0	24.1
S	24.3	45.5	67.9	37.4	5.2
Fe	22.9	25.4	25.9	29.7	19.1

* EDX analysis of one of the white nodules on the spall.

Table 2.7: EDX analyses for the surfaces in the photomicrographs in Fig. 2- 15 (SELBAIE LWR25 BOTTOM).

Figure 2 -4: Scanning electron photomicrographs taken from the surface of LWR22; the area in (a) is a low magnification (150X) photomicrograph of the same area shown in (b), at higher magnification (600X).

a

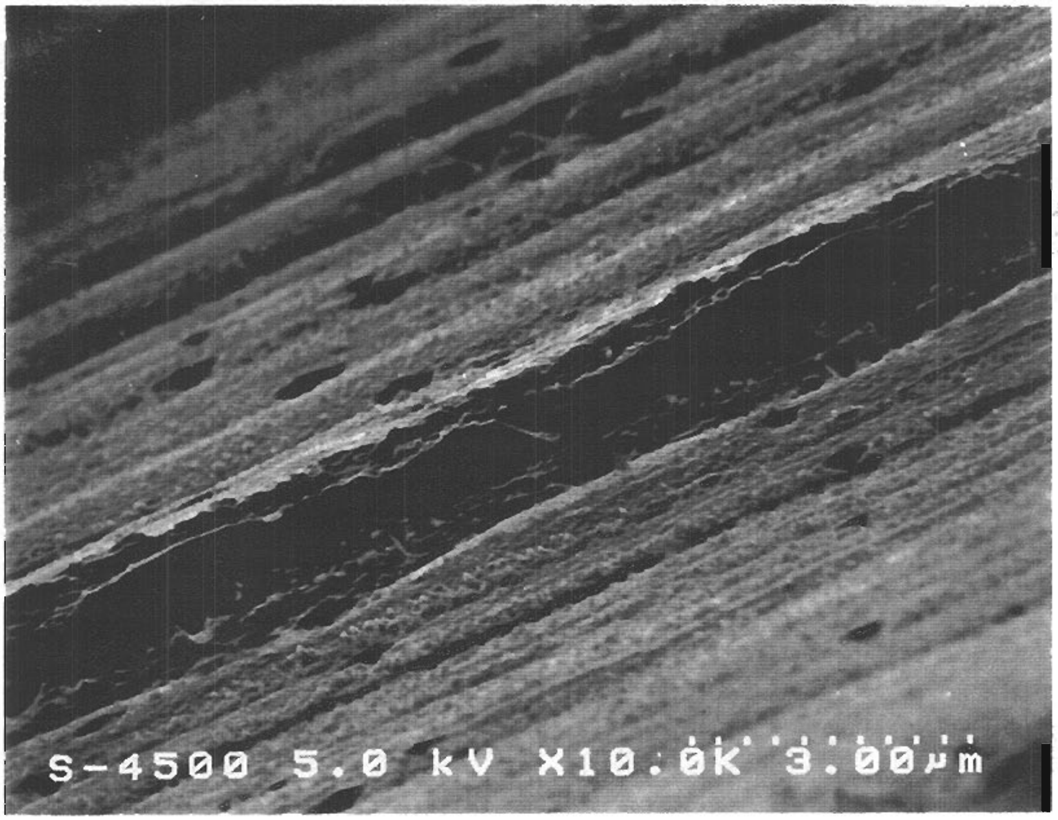


b

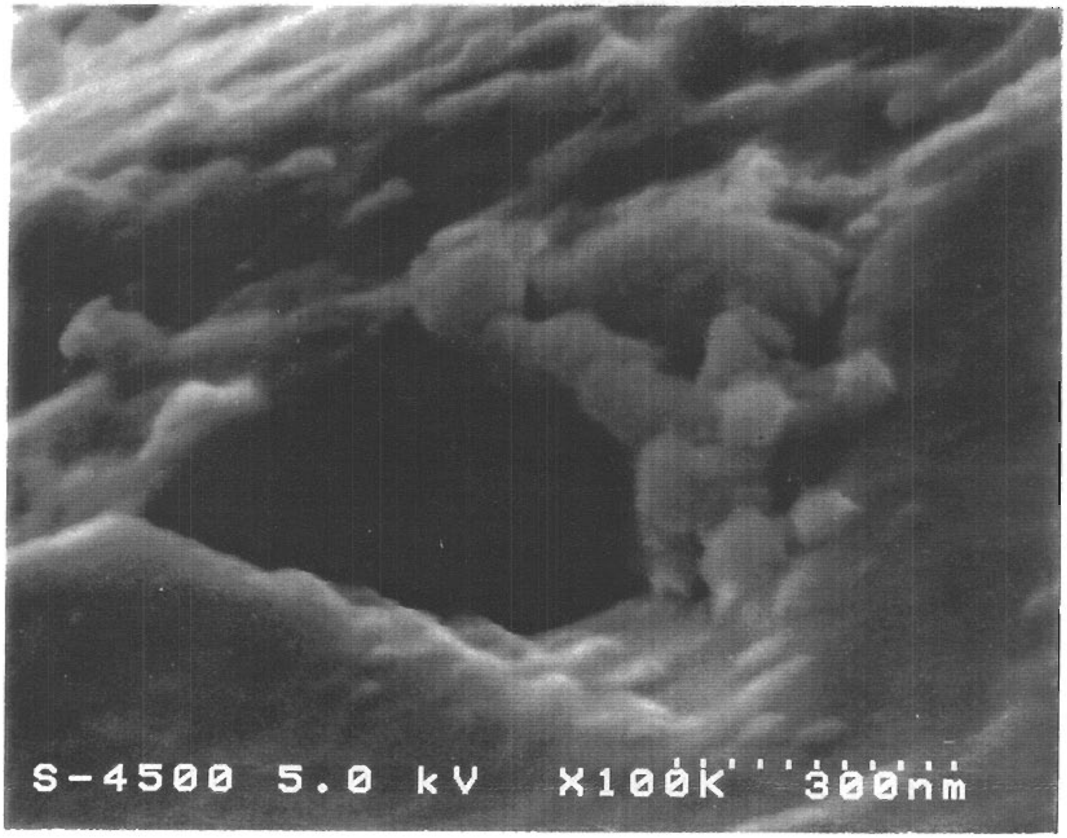
LWR22TOP

Figure 2 -5: Scanning electron photomicrographs of the twin planes on the surface of a single pyrite crystal chosen from LWR22Top. The twinning can be clearly seen in (a) at a magnification of 10 kX. The photomicrograph in (b) is a very high magnification (100 kX) photomicrograph of one of the pits near the centre of the photomicrograph in (a).

a



b

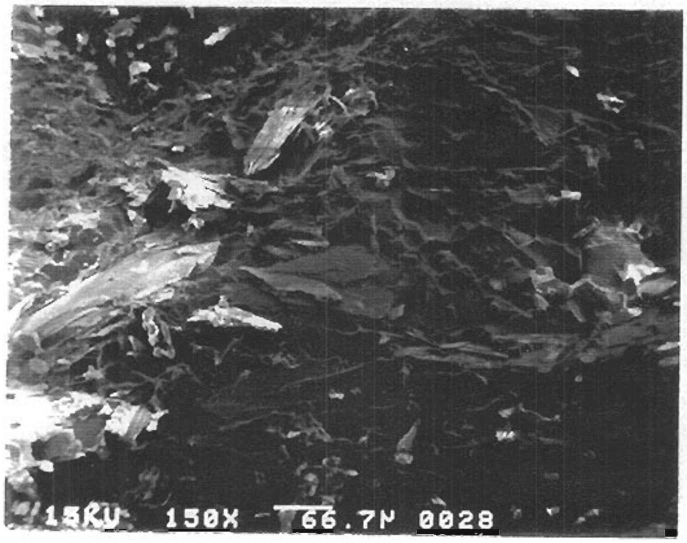


LWR22TOP

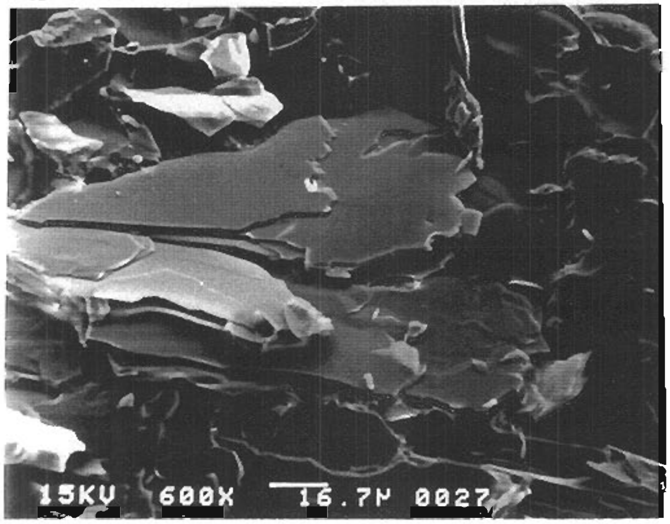
Figure 2-6: The mineralogy of a fractured rock from LWR22Top series can be seen in (a-d). The photomicrographs in Figs. 2 −6a,b were taken from the same area of LWR22 at 150X and 600X magnification, respectively. Similarly, the photomicrographs in Fig. 2 −6c,d were taken from a separate area of the surface and show the morphology of the pyrite crystals.

Figure 2 -7: The photomicrographs in Figs. 2 – 7(a – c) were taken from the reacted surface of LWR22Middle at 150X, 300X and 600X magnification, respectively. The morphology/mineralogy of a freshly fractured rock from LWR22Middle series can be seen in Figs. 2 – 7d,e.

a



b

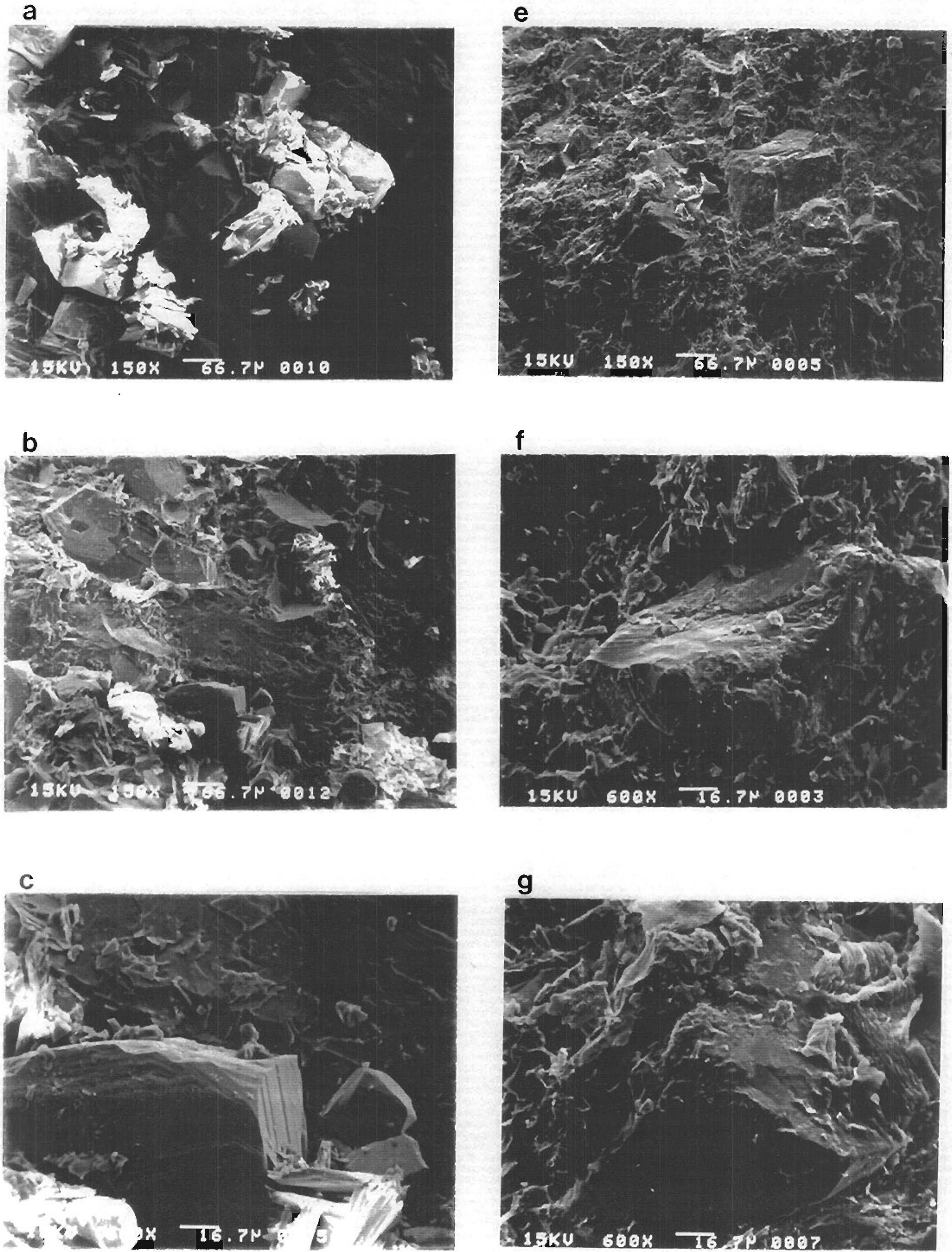


c

d

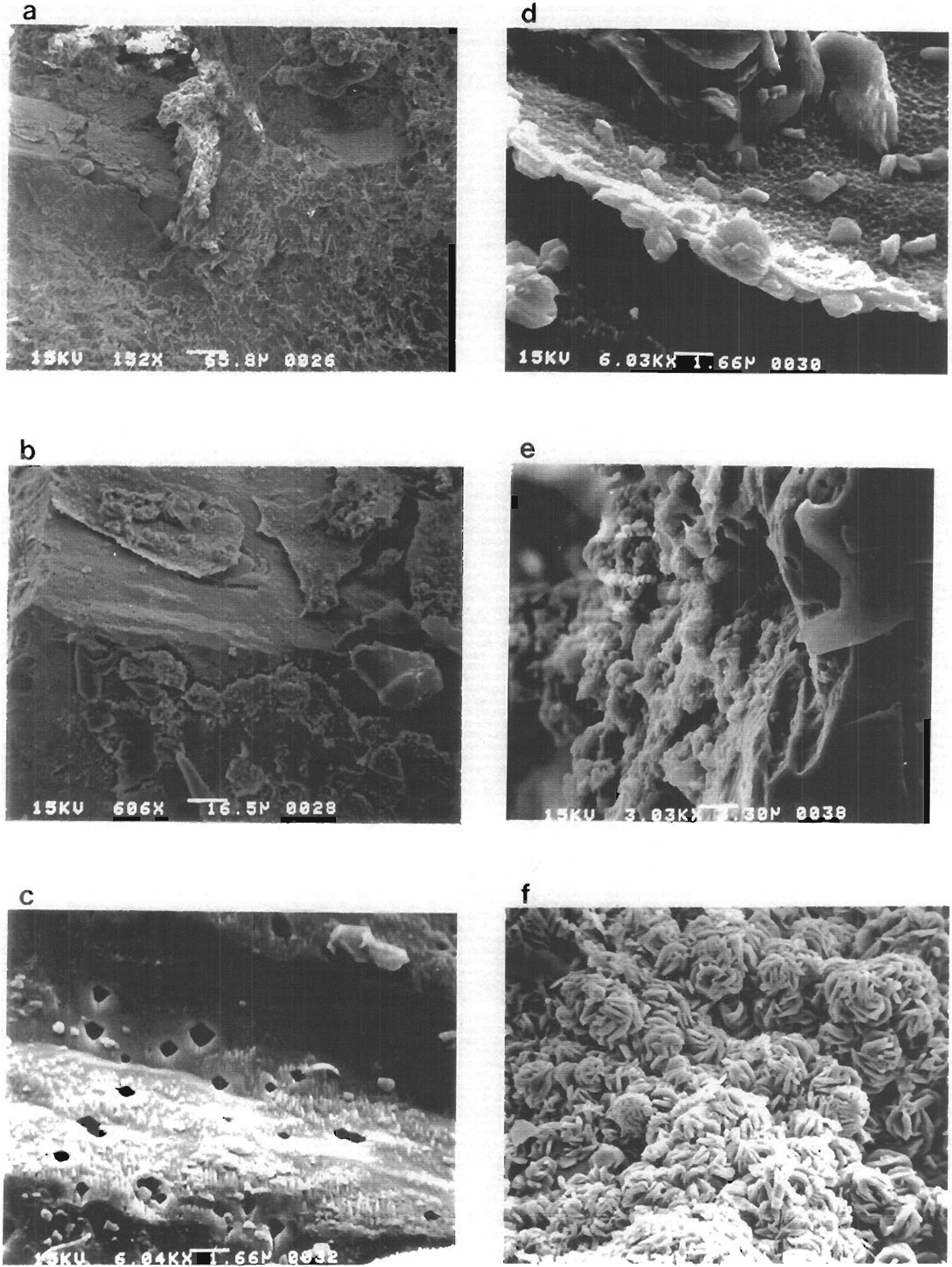
LWR22TOP
int.

Figure 2 -8: The mineralogy of a freshly fractured rock from the LWR22Bottom series can be seen in Figs. 2 −8(a−c). The photomicrographs in Fig. 2 −8(e−f) are taken from the surface of a rock which was reacted with environment; the surface morphology of a reacted pyrite grain can be seen in (f,g).



LWR22BOT
int.

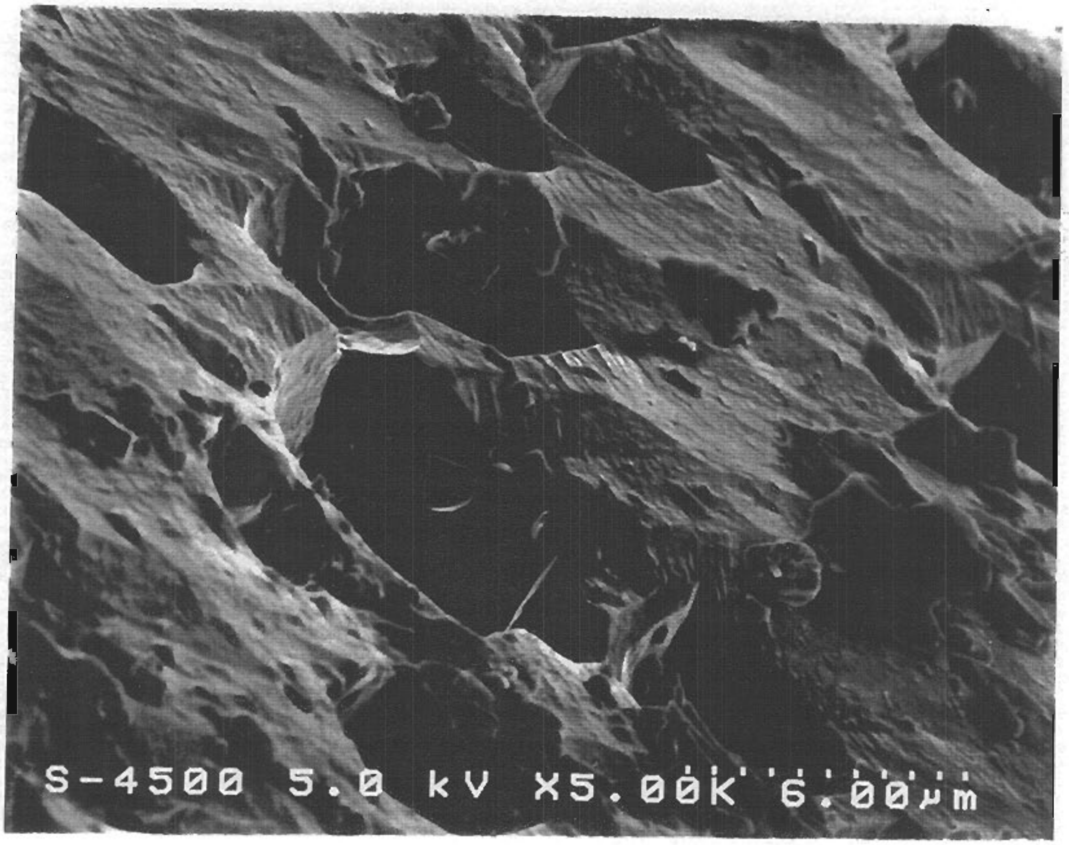
Figure 2 -9: Photomicrograph (a) shows a low magnification overview of a typical area on the surface of a rock (LWR02Top). The photomicrographs in (b-d) show high magnification images of the surface of the pyrite grain on the upper left side of (a). The photomicrograph in (e) shows a cross -section down the length of the altered pyrite grain in (a). Fig. 2 – 9 shows rosettes on another area of the rock surface.


a
15KV 152X 65.8µ 0026
d
15KV 6.03KX 1.66µ 0030
b
15KV 606X 16.5µ 0028
e
15KV 3.03KX 3.30µ 0038
c
15KV 6.04KX 1.66µ 0032
f

LWR02TOP

Figure 2 – 10: The photomicrographs in Fig. 2 – 10a,b show the surface of a single pyrite grain (LWR02Top) that was very highly pitted; (b) shows the morphology of the surface between the pits. This same pyrite grain was used for the XPS and Auger analyses.

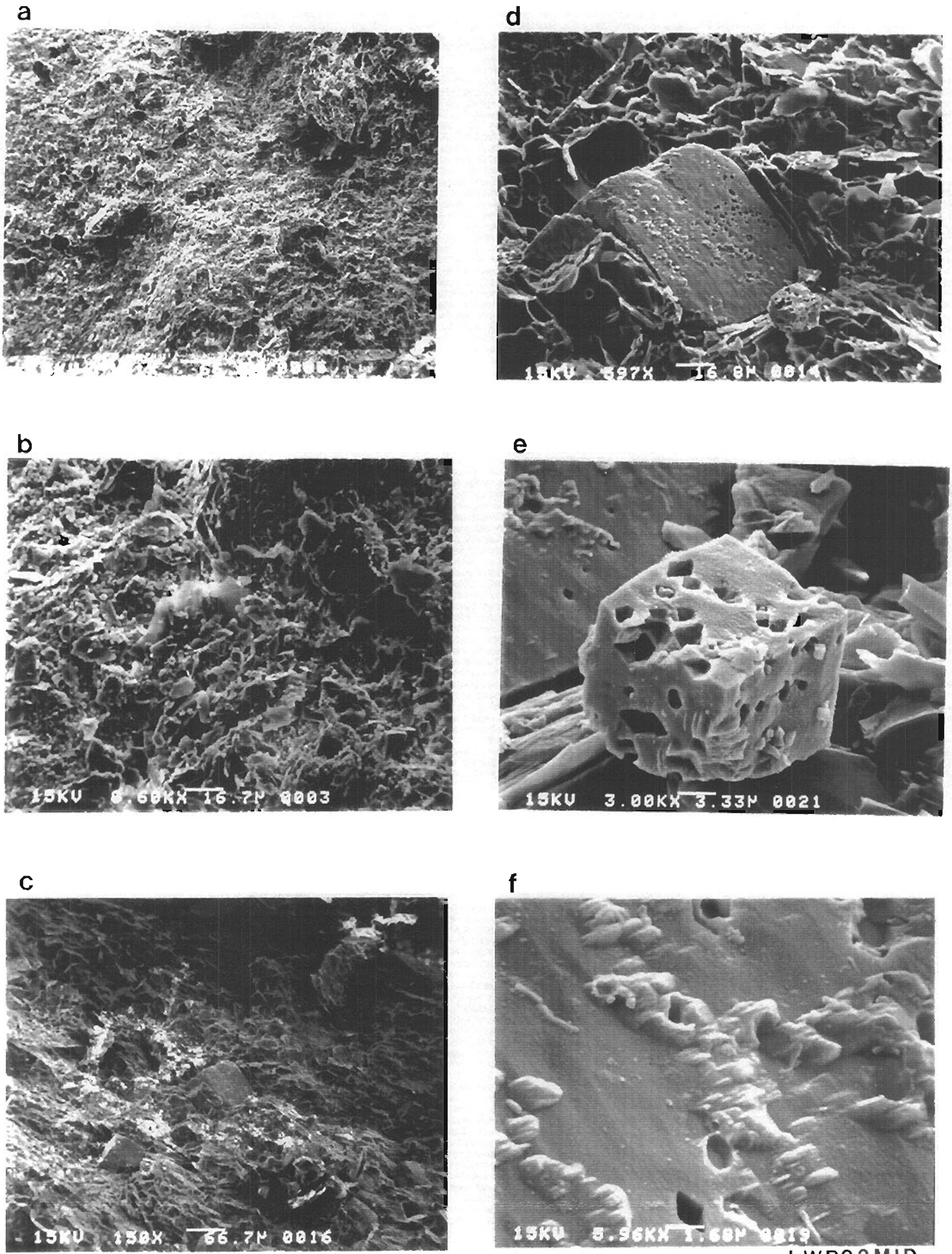
a



b

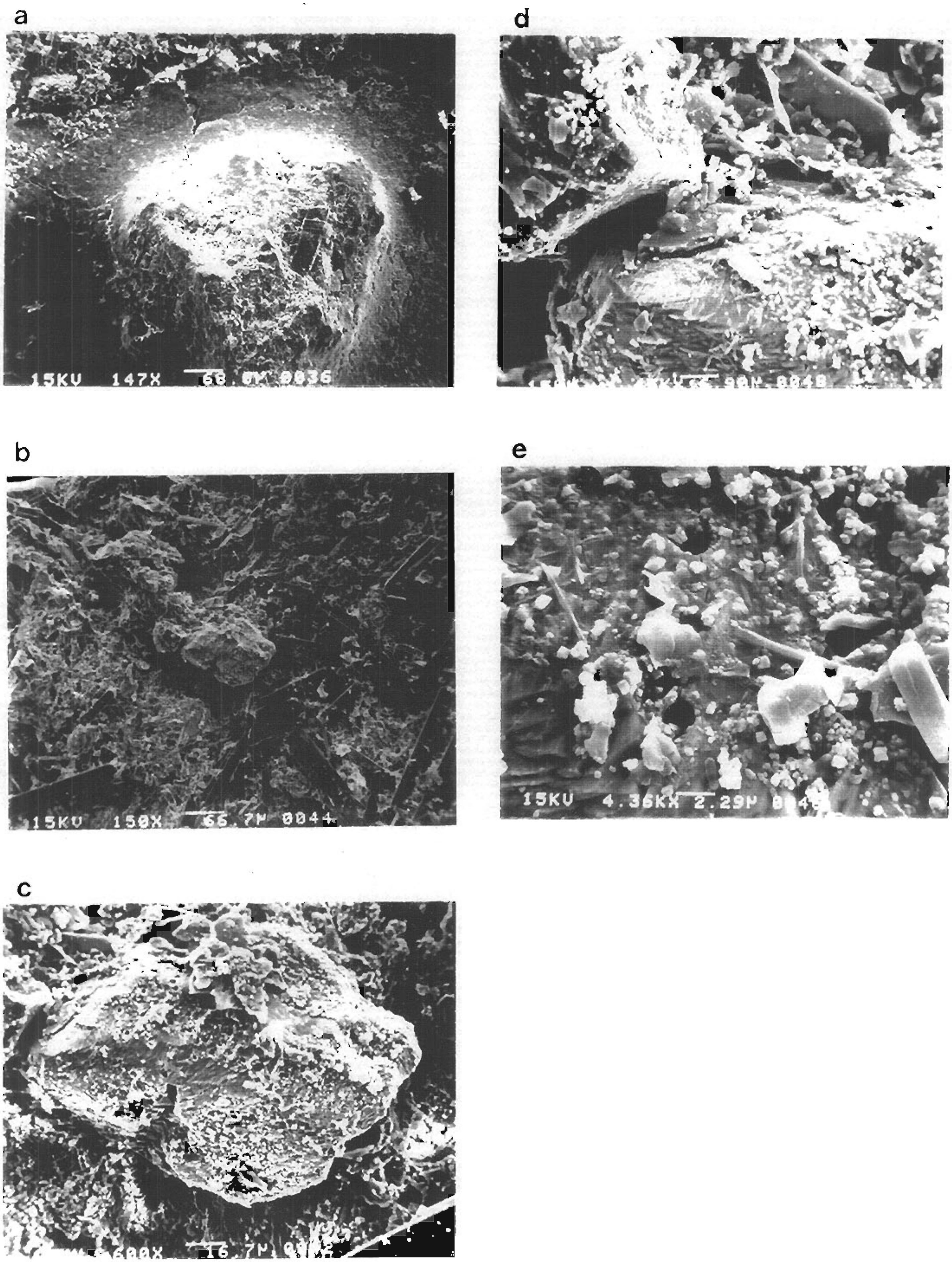
LWR02 TOP

Figure 2 − 11: The mineralogy of the surface from **LWR02Middle** series can be seen in Fig. 2 − 11 a,b. The photomicrographs in Figs. 2 − 11(c − f) were taken from a separate area on the same grain, at increasing magnification, showing the surface morphology of the pyrite.


a
d
15KV 597X 16.8µ 0014
b
15KV 0.60KX 16.7µ 0003
e
15KV 3.00KX 3.33µ 0021
c
15KV 150X 66.7µ 0016
f
15KV 5.96KX 1.68µ 0019

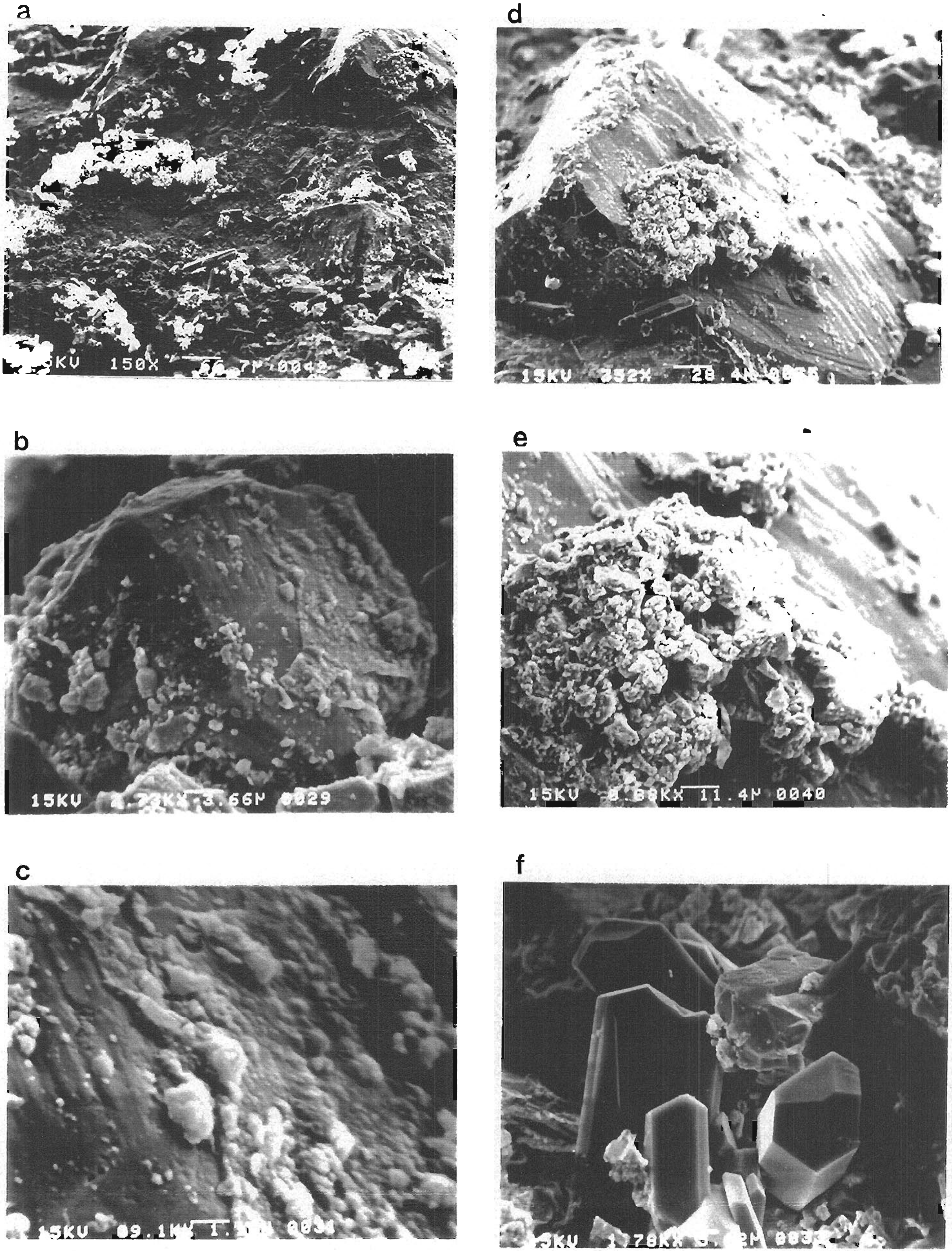
LWR02MID

Figure 2 – 12: The mineralogy of the surface of LWR02Bottom can be seen in Fig. 2 – 12a,b; these photomicrographs were taken from separate areas on the surface. The photomicrographs in Figs. 2 – 11(b-e) were taken from a separate area on the rock surface; the surface of the grain in the centre of (b) is shown at increasing magnification in (d) and (e).


a
15KV 147X 68.0µ 0036
d
b
15KV 150X 66.7µ 0044
e
15KV 4.36KX 2.29µ
c
600X 16.7µ

LWR02BOT

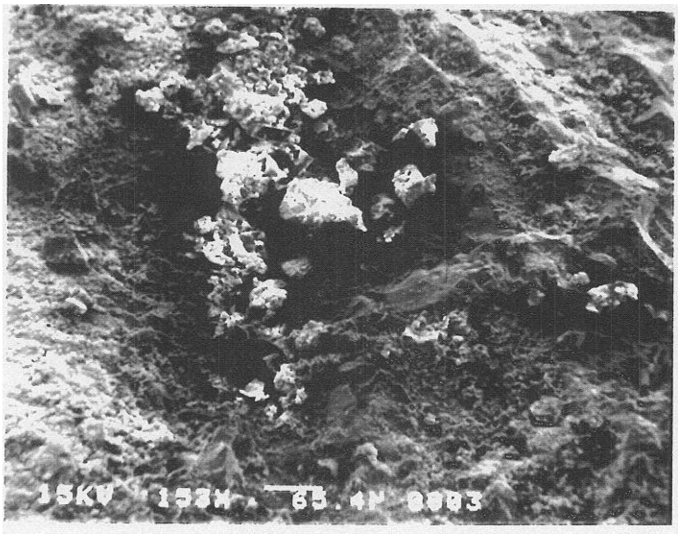
Figure 2 – 13: The overall mineralogy and textures of the rock surface (LWR25Top) is shown in (a). Figures (b-e) show higher magnification images of specific grains shown on the right hand side of (a). Figure (f) shows some euhedral gypsum crystals growing on the rock surface.


a
KV 150X 0042
d
15KV 352X
b
15KV 3.66µ 0029
e
15KV 11.4µ 0040
c
15KV 89.1K
f
1.78KX

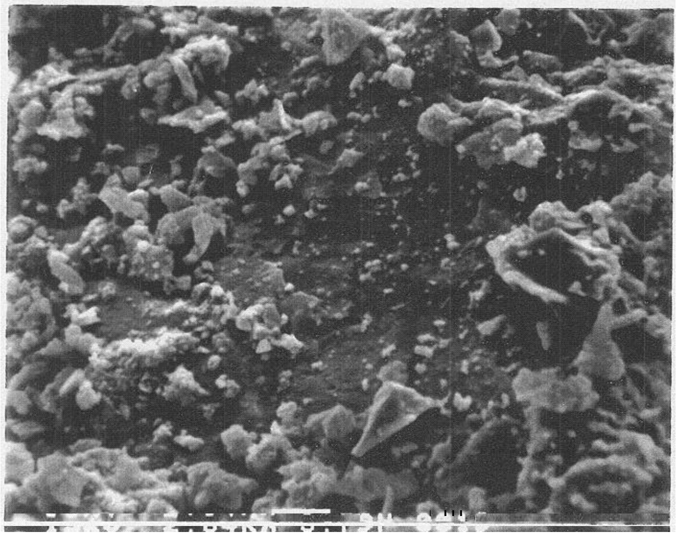
LWR25TOP

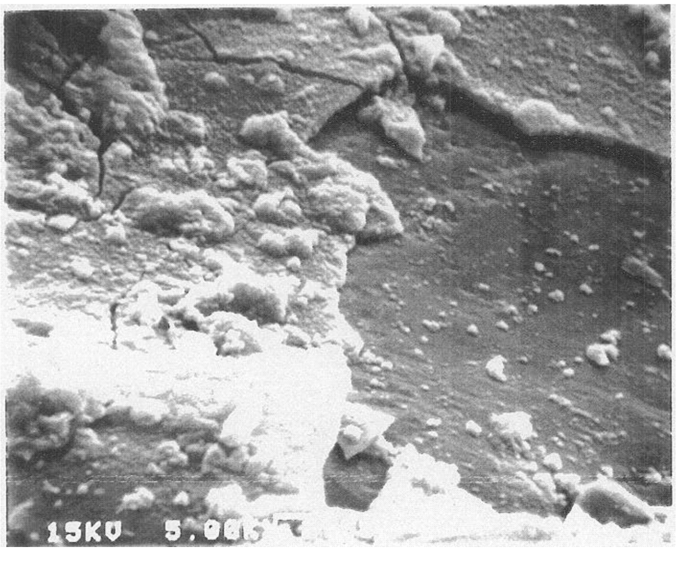
Figure 2 – 14: Figures (a-c) show images of the rock/pyrite surface at increasing magnification (150X, 2.6 kX and 5.0 kX, respectively) of LWR25Middle. Figures (d-f) show images of the rock/pyrite surface at increasing magnification (600X, 2.3 kX and 13.2 kX, respectively); these images were taken at another location on the same rock.

a



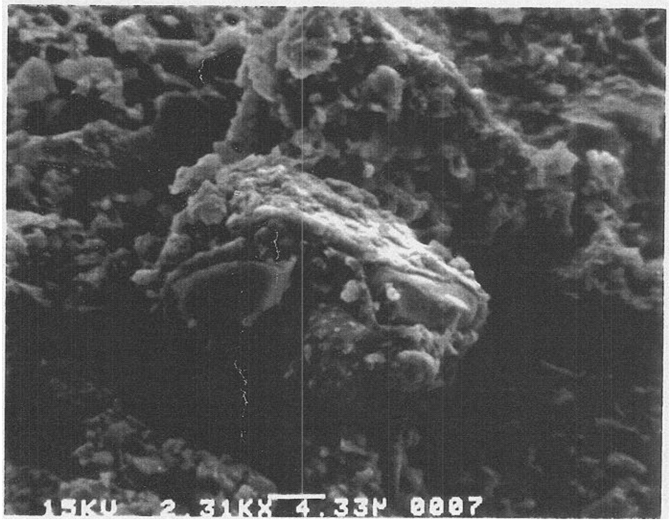
b

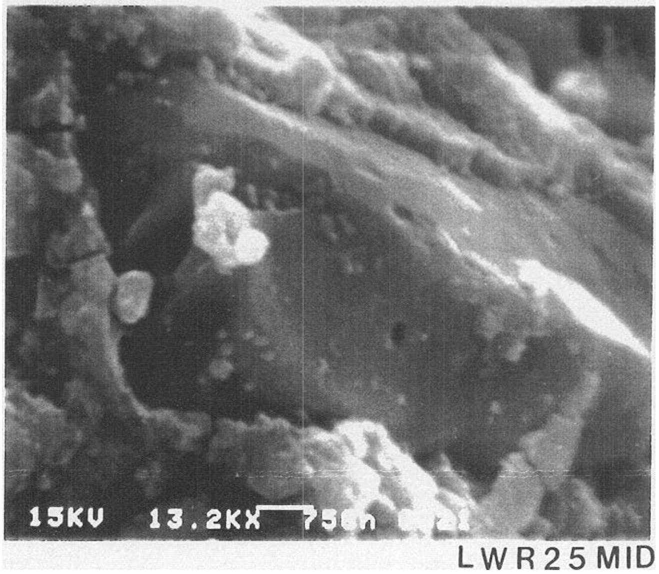




d

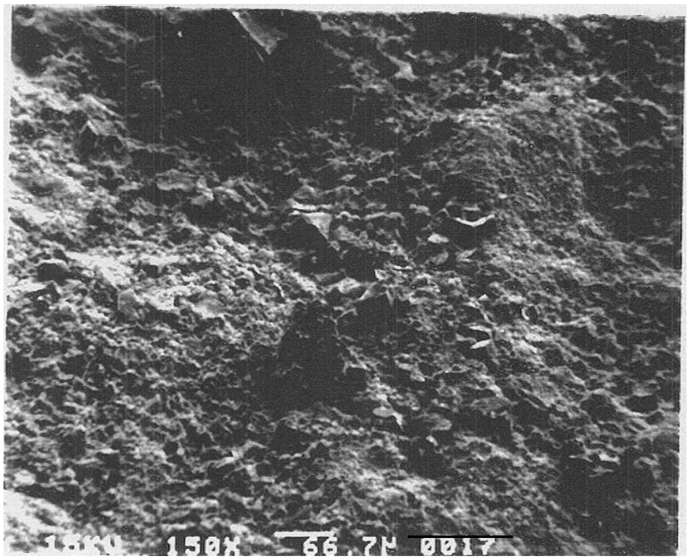
e



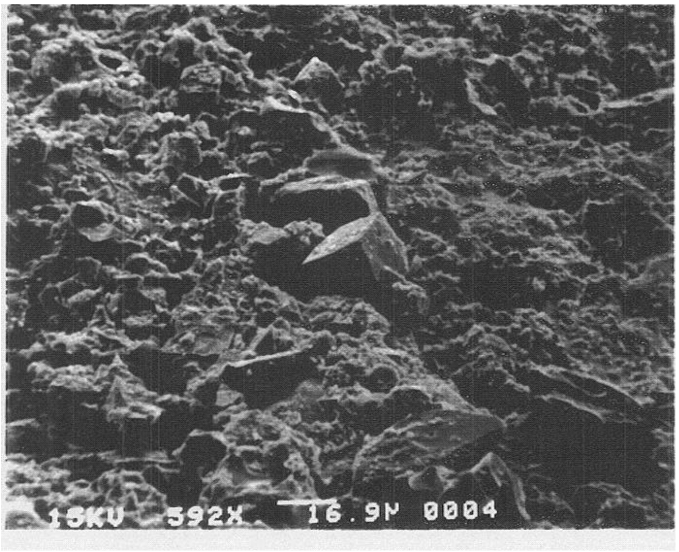


LWR25MID

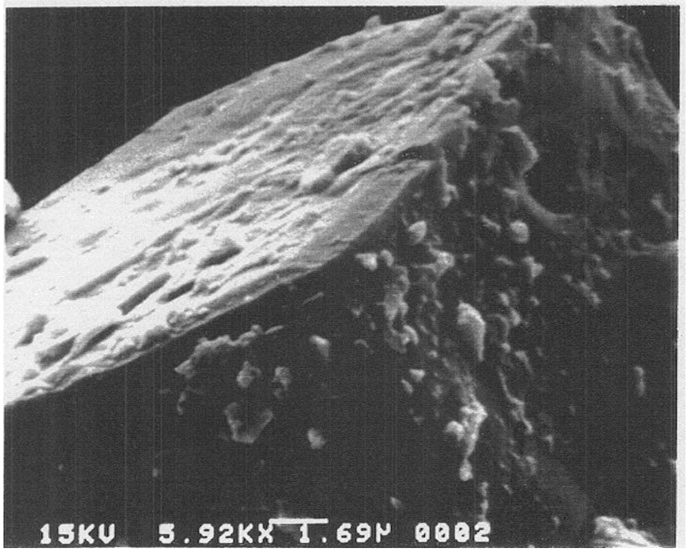
Figure 2 – 15: Figures (a-c) show images of the rock/pyrite surface at increasing magnification (150X, 600X and 5.9 kX, respectively) of LWR25Bottom. Figures (d,e) show images of the pyrite and spall at increasing magnifications 664X and 11.1 kX, respectively; the image in (e) is a high magnification of the crust/spall formed on the surface of the large pyrite crystal in the centre left of (d).



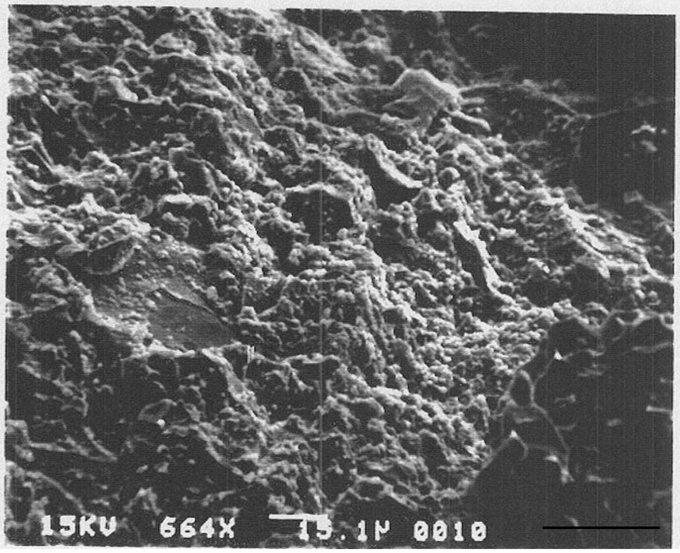
b



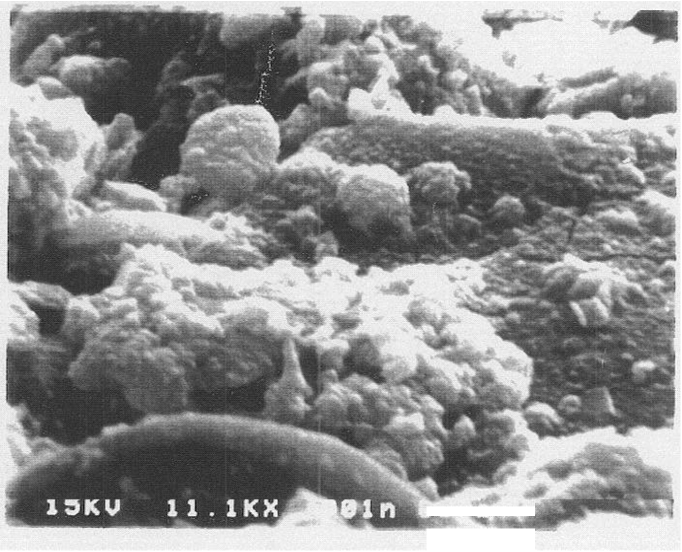
c



d



e



LWR25BOT

2.3.3 X-ray Fluorescence

Results. Trace metal analyses were performed on each of the samples using X-ray fluorescence. The trace metals analyzed were: Pb, As, Zn, Cu, Ni, Co, Mn, Cr, V and Ba; the raw data for each rock sample can be found in Table 2.8.

Interpretation. The whole rock samples in LWR25 have significantly higher concentrations of Pb, As, Zn Cu and Co, while Ni Mn Cr and V are about the same in all rock samples. The rock samples chosen from LWR02 and LWR22 are significantly higher in Ba than found in LWR25. These results are probably not all that surprising based on the mineralogy determined by both petrography (Table 2.1) and scanning electron microscopy/EDX. The rocks containing very high levels of sulphides would be very good hosts for transition metals as metal sulphides, like Pb (galena, PbS), Zn (sphalerite, ZnS) and Cu (copper sulphides) either as separate phases such as is the case with sphalerite or in solid solution with the dominant pyrite phase. The alkali and alkaline earth elements such as K, Ba or Ca would be expected to be found in, or associated with, the silicate minerals. The data in Table 2.1 clearly indicate that the Stratmat rocks (samples LWR02 and LWR22) are much richer in silicate minerals than the Selbaie rock (sample LWR25).

It is important to know what trace metals are present in the whole rock analysis, but XRF does not provide specific information about the location of the trace metals. We can surmise that the zinc is associated with sphalerite (Table 2.1), but are the other trace metals present in a separate phase? If these trace metals are in solid solution, with the pyrites, then the chemistry of the pyrites from the two locations (i.e., Stratmat and Selbaie) may be fundamentally different. It has never been clearly established in the literature whether the solid state chemistry of the pyrite will affect the leach rate.

It would be very valuable to confirm whether the trace metals from the whole rock analyses are associated with the sulphide phase or with the more abundant silicate phase. If these metals are associated with sulphides then this may provide a clue as to the different leach rates in similar environments.

Sample	Pb ppm	As ppm	Zn ppm	Cu ppm	Ni ppm	Co ppm	Mn ppm	Cr ppm	V ppm	Ba ppm
LWR25 All	1666	337	8052	494	<5	228	3254	<5	<5	<5
LWR25 Top	4392	708	18620	424	50	620	465	<5	<5	<5
LWR25 Mid.	196	196	3608	63	<5	202	127	<5	<5	10
LWR25 Bot.	144	111	1757	812	<5	60	6363	<5	<5	<5
LWR22 All	43	170	95	11	16	27	1703	<5	14	831
LWR22 Top	63	450	51	27	10	80	546	<5	19	1290
LWR22 Mid.	50	63	132	8	6	35	1750	<5	17	1076
LWR22 Bot.	17	8	143	<5	14	30	2884	<5	8	203
LWR02 All	60	135	303	12	14	210	1779	<5	46	1459
LWR02 Top	112	234	253	22	12	79	1349	13	99	1481
LWR02 Mid.	14	26	154	<5	17	98	3422	<5	19	917
LWR02 Bot.	67	154	583	15	9	129	524	<5	28	1898
LWR02 Sand	124	49	151	60	7	769	1523	<5	22	1621

Table 2.8: X-ray fluorescence analyses for trace metals on whole rock samples. "ALL" refers to mixtures of equal masses of top, middle and bottom samples of Stratmat Flooded (LWR22), Selbaie Control (LWR25) and Stratmat Control (LWR02) rocks.

2.3.4 **X-ray Photoelectron Spectroscopy**

Results: Surface stoichiometry and high resolution narrow scans were recorded from the surface of Stratmat Control rock (LWR02) and Selbaie Control rock (LWR25). The surface stoichiometry will show the presence of all elements with atomic mass greater than Li and concentrations greater than ≈0.4%. XPS survey scans can be found in Fig. 2 – 16 and the surface stoichiometry data can be found in Table 2.9. The high resolution narrow scans for Fe $2p_{3/2}$, S 2p and 0 1s and fitted data are shown in Figs. 2 – 17 to 2 – 19, respectively. The gold (Au 4f) in the LWR02 survey scan (Fig. 2 – 16a) is associated with the mounting material and is not from the sample itself.

Interpretation: The photoelectron survey scans in Fig. 2 – 16a,b show the elements present on the surfaces of LWR02 and LWR25. As was mentioned in the experimental section the LWR02 sample was a single pyrite grain (Fig. 2–5), while the LWR25 sample was a chip from the surface of one of the rocks. The XPS and EDX may seem to provide redundant data; however, XPS is much more surface sensitive than EDX. The sampling depth of the EDX is 1-3 μm (1000–3000 A), while the sampling depth for the XPS is (10–60 A). In terms of surface analysis, the EDX is a near-bulk technique, while the XPS provides a true measure of the surface chemistry (HOCHELLA, 1988).

The surface of the pyrite crystal from LWR02 is very depleted in iron and, but seems to be covered in silicates, carbon and oxygen. In contrast, the surface of LWR25 contains. relatively high levels of Si, 0 and Al, and has much less carbon. The atom % of each of the elements on the surface can be found in Table 2.9.

The survey analyses only provide semiquantitative information regarding elements on the surface and their relative concentrations. The higher resolution narrow scans (Figs. 2 – 17 to 2 – 19) provide information about the relative abundance of various chemical species. Fig. 2 – 17a,b shows the Fe $2p_{3/2}$ spectra for LWR02 and LWR25, respectively. The fitted data can be found in Table 2.10. The ratios of Fe(II) -S, Fe(III) – S and Fe(III) -0 are greatly different for the two samples. The surface of LWR02 is covered in considerably more ferric oxyhydroxide

(McINTRYE and ZETARUCK, 1977), while the surface of LWR25 has considerably more of the ferric iron bonded to sulphur (PRATT et al., 1994a-c).

A comparison of the S 2p data for LWR02 and LWR25, in Fig. 2 - 17 and Table 2.10, appears to indicate very different surface chemistry. The sample in LWR02 has greater than 50% of the sulphur as sulphate, while the surface of LWR25 is dominantly pyritic sulphur, that is, disulphide, with only minor quantities of oxysulphur species (MYCROFT et al., 1990,; KARTHE et al., 1993 and PRATT et al., 1994b,c).

The 0 1s spectra (Fig. 2 - 19) provide very little new information. The 0 1 s spectrum in Fig. 2-1 9a is typical for that of an iron oxide or iron sulphate. The spectrum in Fig. 2-19b is too badly distorted by charge broadening to derive any useful information. The overall structure of the peak, however, qualitatively indicates similar oxygen species exist on both sample sets, that is, oxide, hydroxide and attached water. The more pronounced shoulder on the high binding energy side of Fig. 2-1 9b demonstrates near equal quantities of OH^-(532 eV) and O^{2-} (53 1 eV). The water peak at 533 eV is greatly attenuated which qualitatively indicates the Selbaie rock (LWR25) is less hydrated than the Stratmat Control rock (LWR02).

The foregoing observations would suggest that any alteration products of the LWR25 sample were very thin (<20 Å) or that the oxidation products are unevenly distributed about'the surface. The alteration of the LWR02 sample is either much thicker or that the alteration covers considerably more of the surface.

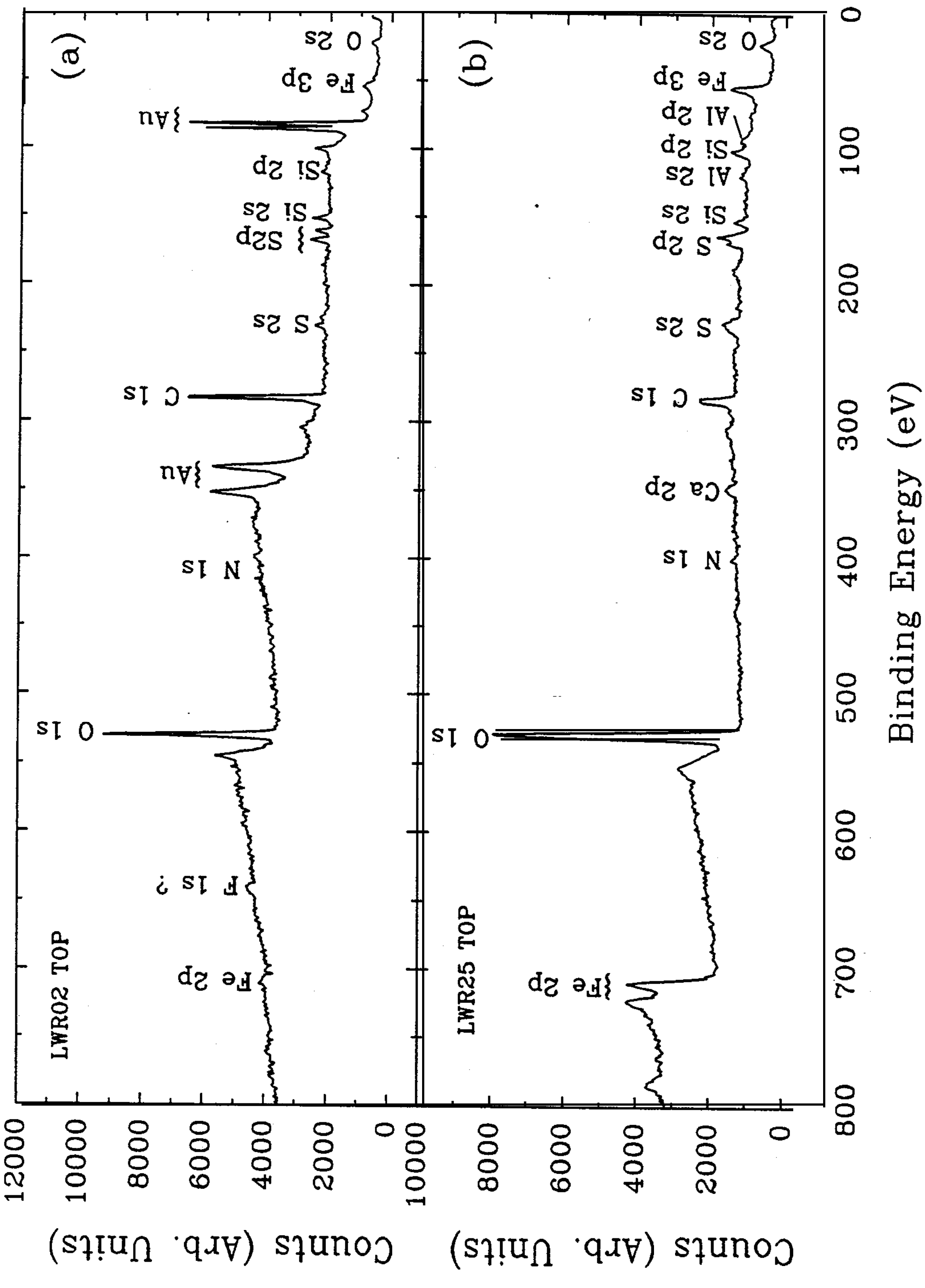


Figure 2-16: X-ray photoelectron survey scans for (a) LWR02 and (b) **LWR25**. The quantified data can be found in Table .

Element	XPS Atom %	
	LWR02Top	LWR25Top
Fe	3.30	10.06
S	5.19	7.96
Si	12.04	5.10
Al	6.16	6.92
K	---	---
N	2.95	1.61
C	35.66	20.04
0	33.29	46.95
Mg	1.42	---
Ca	---	1.36
Zn	---	---

Table 2.9: Atomic % of elements detected on the surfaces of rock samples. The LWR02 analysis was performed on a single pyrite crystal.

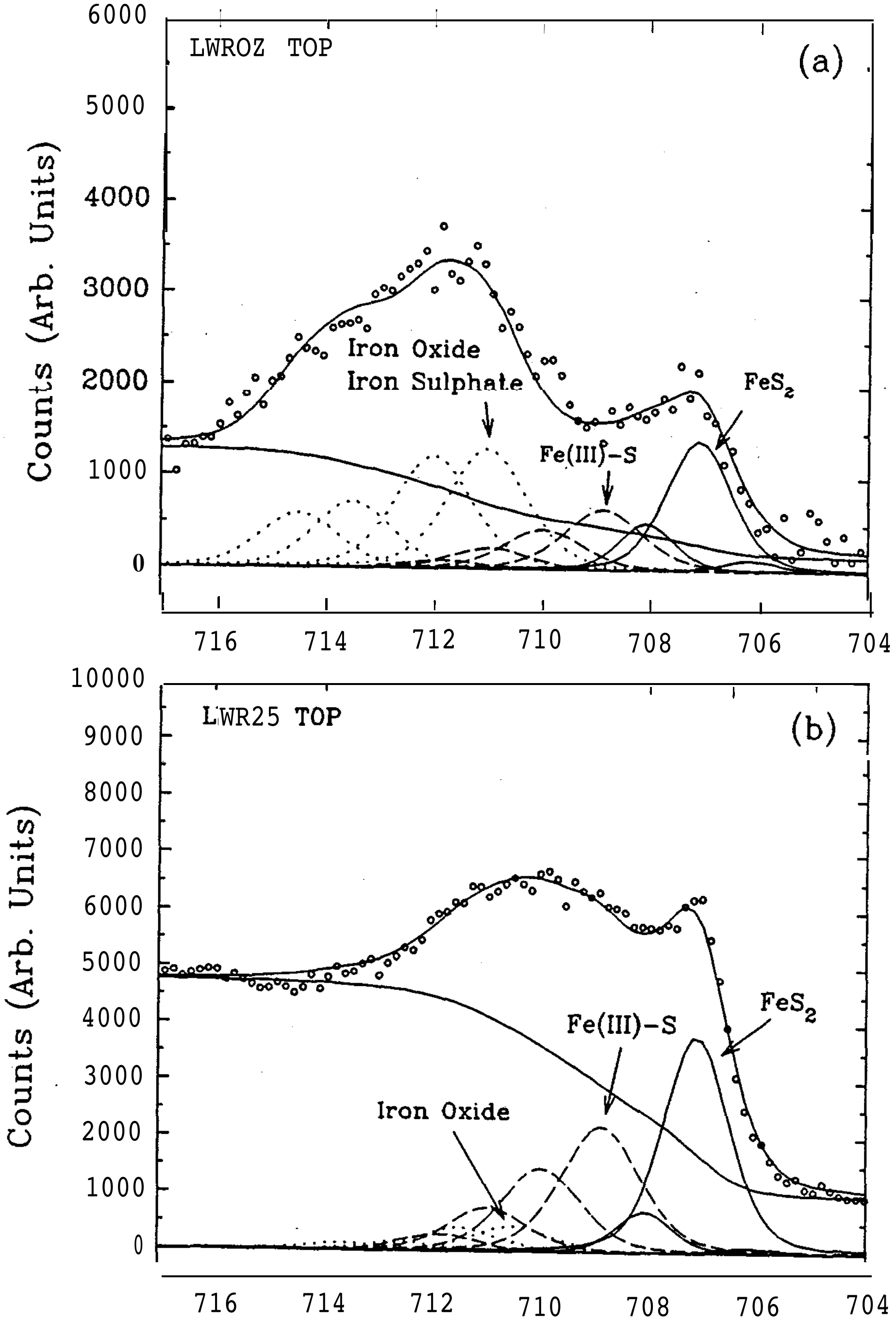


Figure 2-17: Fe 2p Photoelectron data for (a) LWR02 and (b) LWR25. The spectra were fitted for iron(II) sulphide, iron(III) sulphide, and iron(III) oxide and the species are labelled on the figure.

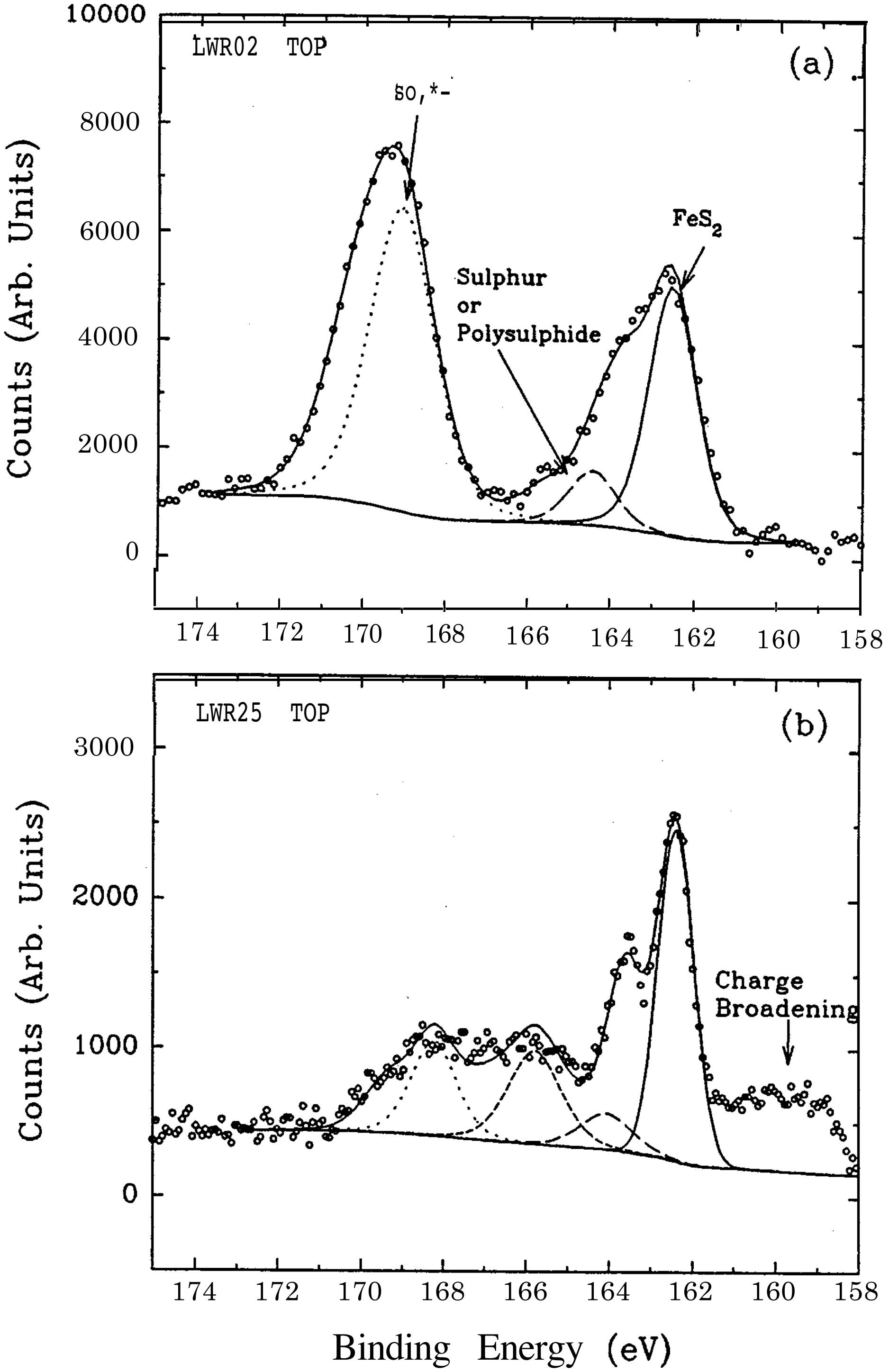


Figure 2-18: S 2p Photoelectron spectra for (a) LWR02 and (b) LWR25. The fitted spectra show sulphide, polysulphide(sulphur) and oxysulphur species.

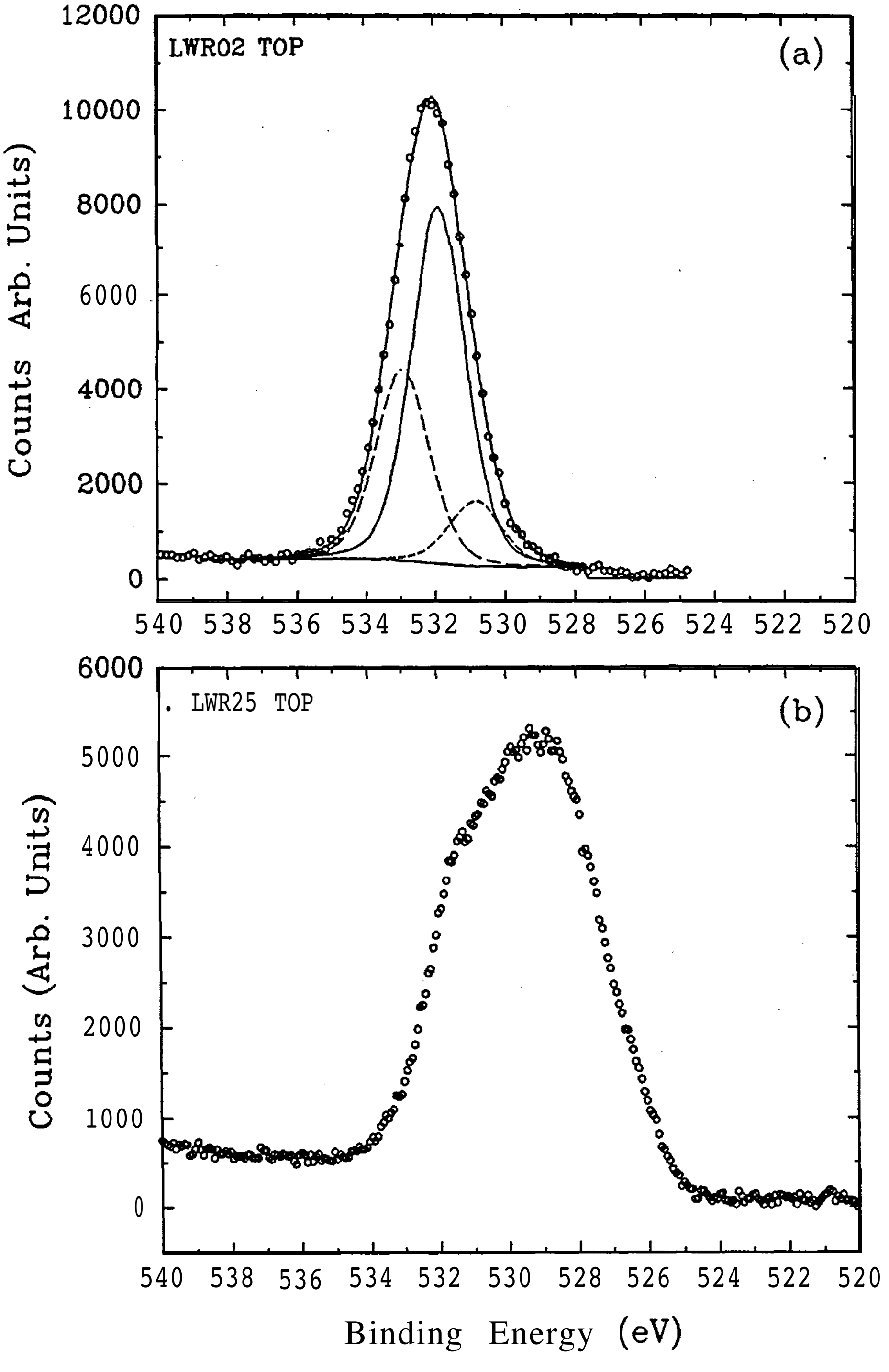


Figure 2-19: 0 1s photoelectron spectra recorded from the surfaces of (a) LWR02 and (b) LWR25. Only (a) was fitted. Charge broadening has made (b) impossible to fit.

	LWR02		LwR25	
Species	B.E. (eV)	Atom %	B.E. (eV)	Atom %
disulphide	162.5	34.4	162.5	50.1
polysulphide (sulphur)	164.4	7.5	164	8.4
oxysulphur	169	58.1	165-169	41.5
iron(II)-S	707.1	31.6	707.1	43.2
Iron(III)-S	709.2	18.2	709.2	49.7
iron(III)-0 or iron(III)-SO,”	711	50.2	710.5	7.1
oxide	**531**	10.4	---	---
hydroxide	532	58.7	am-	-..-
water	533	31.0	---	---

Table 2.10: The relative percentages of surface species were calculated from the fitted Fe2p, S2p and 0 1s data for the surfaces of of (a) LWR02 Top and (b) LWR25 Top.

2.3.5 Auger Electron Spectroscopy

Results: The surface stoichiometry and depth profiles were recorded from the surface of LWR22, LWR02 and LWR25. The surface stoichiometry will show the presence of all elements with atomic mass greater than Li and concentrations greater than ≈0.4%. The survey scans can be found in Figs. 2-20, 2-22 and 2-24 and the relative concentrations can be found in Table 2.11. The Auger depth profiles for LWR22, LWR02 and LWR25 (i.e., the change concentration of elements with depth) can be found in Figs. 2 -21, 2 -23 and 2 -25, respectively.

Interpretation: The survey analyses were performed on at least three spots on the surface of each sample. One can see by comparing the two spectra from each sample that the chemistry of the surface of each sample is quite. variable. For example, the spectra from the surfaces of LWR22(a) and LWR22(b) seem to indicate that the chemistry is dominantly iron sulphides and iron oxides, respectively. A considerable length of time was spent analyzing various areas of the surface in order to insure that the analyses were representative.

Stratmat Flooded LWR22: Survey scans were recorded on the surface of LWR22 at three different locations. The data indicate that iron and sulphide are not the only elements present, but Si, Cl, K, C, Ca, N, 0 and Zn were also detected. It is not that unusual to find C and little 0 on the surface as they are regular vacuum contaminants during analysis. The Auger depth profile at two of the locations are presented in Fig. 2-21 (see Table 2.1 1), which shows the distribution of S, Fe, 0, Ca and K with depth, up to 80 A. The distribution of Fe appears flat and its concentration does not appear to change much with depth indicating uniform distribution of Fe, as would be expected in pyrite. The Ca, K and 0 signals are flat and surprisingly do not change with depth. These elements would be expected to occur at the surface in precipitates formed from leaching solutions. Their persistence to such great depths as shown in Fig. 2-21 may result from the fact that the lines for these elements overlie the C line; the ability of the computer to distinguish the C signal from the K and Ca signals may artificially elevate the levels of these elements at depth. The C and S signals change in an antipathetic manner.

The presence of nitrogen on the surface of these minerals at these levels (Table 2.11) is highly unusual. Unless these rocks have been exposed to high levels of inorganic compound like nitrates, one must assume that the source of the nitrogen is organic, such as an amino acid. This leads to the obvious question, could the nitrogen on the mineral surface be an indication of bacterial presence? From a careful examination of the survey scans from the LWR02 and LWR25 samples, it is apparent that only the Stratmat samples contain measurable quantities of N.

One can conclude that the pyrite crystal analyzed here has not been altered to any great depth. No elements have been selectively leached from the surface and no easily identifiable overlayer has formed. Although, this type of analysis will provide no indication of congruent dissolution of the iron and sulphur from the surface.

Stratmat Control LWR02: Auger survey scans were recorded on three areas of the pyrite grain shown in Figure 2 – 10. The analyses at points #1 and #2 on the pyrite surface, see Figure 2 -23 and Table 2.11, show that two distinct areas are present on the surface, an iron sulphide and an iron oxide, respectively. The area analyzed in Figure 2–22a,b (analyses #1, #3) are typical of the flat regions between the etch pits (see Figure 2 – 1 Ob), while the area analyzed at point #2 is typical of the platy material found between the pits (see Figure 2 – 1 Oa). The data for area (#2) is typical for a silicate (data not shown).

The depth profile for points #1 and #3 show that the surface is covered.with what appears to be an iron oxide or a mixed iron oxide/iron sulphate. The thickness of the iron oxide, in Figure 2 -23a (point #1), is only about 25 A, while the thickness of the iron oxide, Figure 2 -23b (point #3), is in excess of 600 A. The profile for point #1 shows a relatively flat iron profile, while the near surface is very depleted in sulphur, indicating that sulphur has been lost to the environment. Under the oxide layer is a region of slight sulphur enrichment, typical of what has been reported for pyrrhotite (PRATT et al. 1994, MYCROFT et al. 1995).

Selbaie Control LWR25: The Auger survey scans for the Selbaie samples are shown in Figure 2-24 and the data is summarized in Table 2.11. The survey scans recorded from the surface of a pyrite grains show that the surface is covered with a iron oxide (≈ 15 Å thick) and that the iron sulphide mineral lies below this iron oxide. The surface is also very depleted in sulphur indicating that sulphur has been lost to the environment. Even though the depth profiles appear similar, the profile Figure 2-25b is much more depleted in sulphur than the surface in Figure 2 -25a. Based on the data in Table 2.11, the surface is not very homogeneous, although more so than that of the Stratmat samples. The data in Figure 2-25 indicate that the pyrite surfaces are much less altered than in the case of the Stratmat samples. Lastly, the lack of nitrogen on the surfaces of the Selbaie pyrite may indicate a lower level of biological activity on these surfaces.

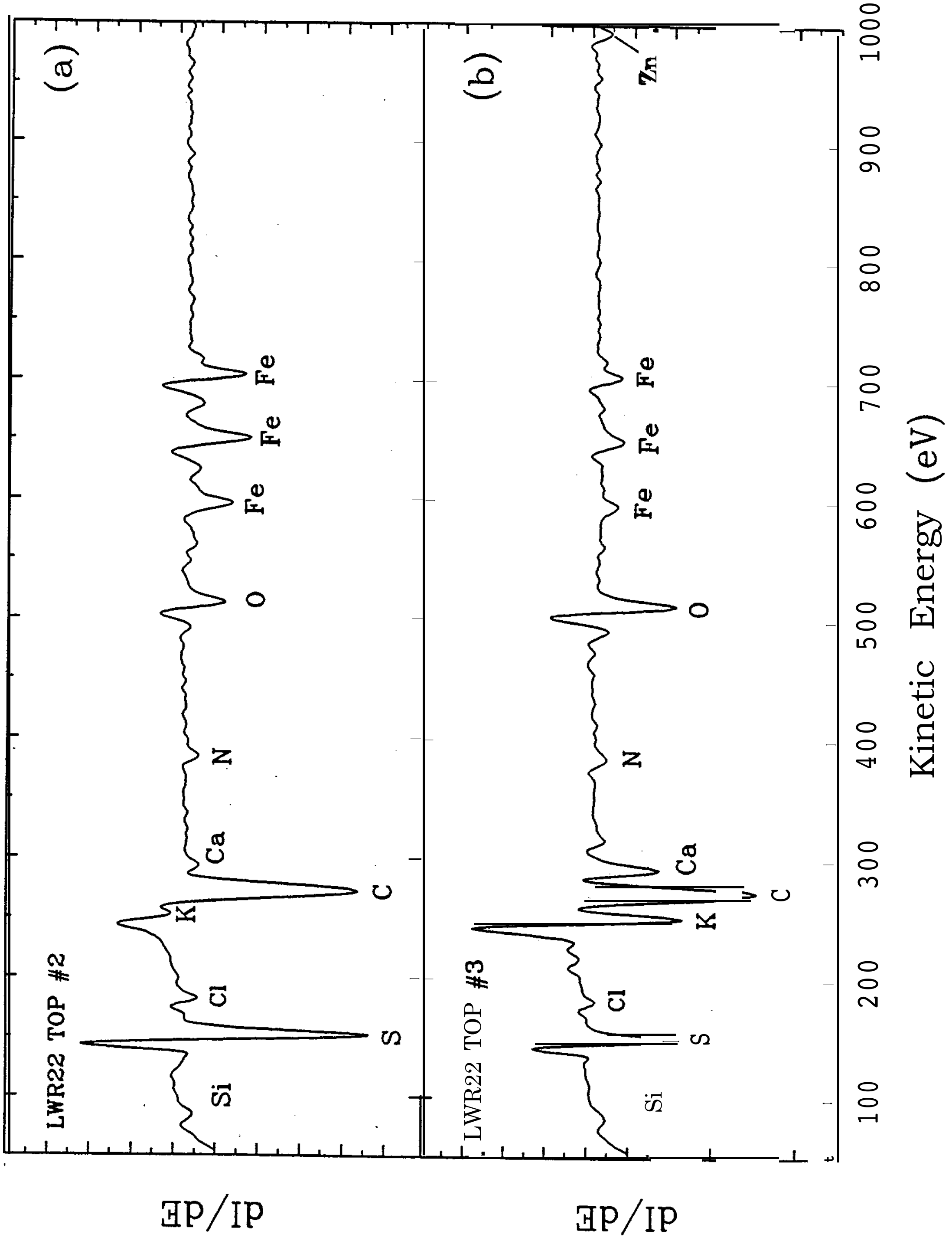


Figure 2-20: Auger survey scans recorded at two different points on the surface of a single pyrite crystal chosen from LWR22 Top.

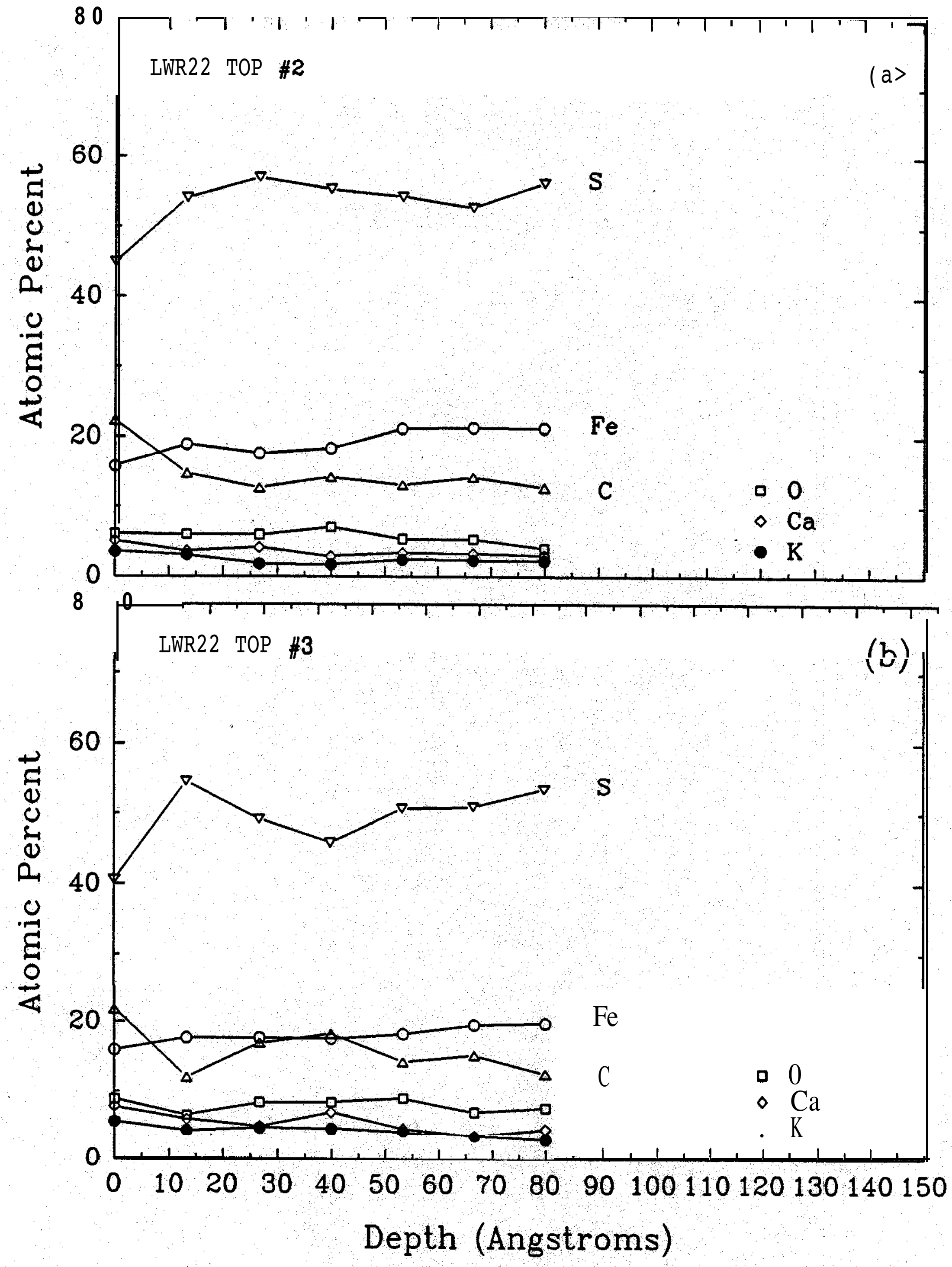


Figure 2-21: Depth profile through the near surface of LWR22. The points correspond to same points in the LWR22 survey scans.

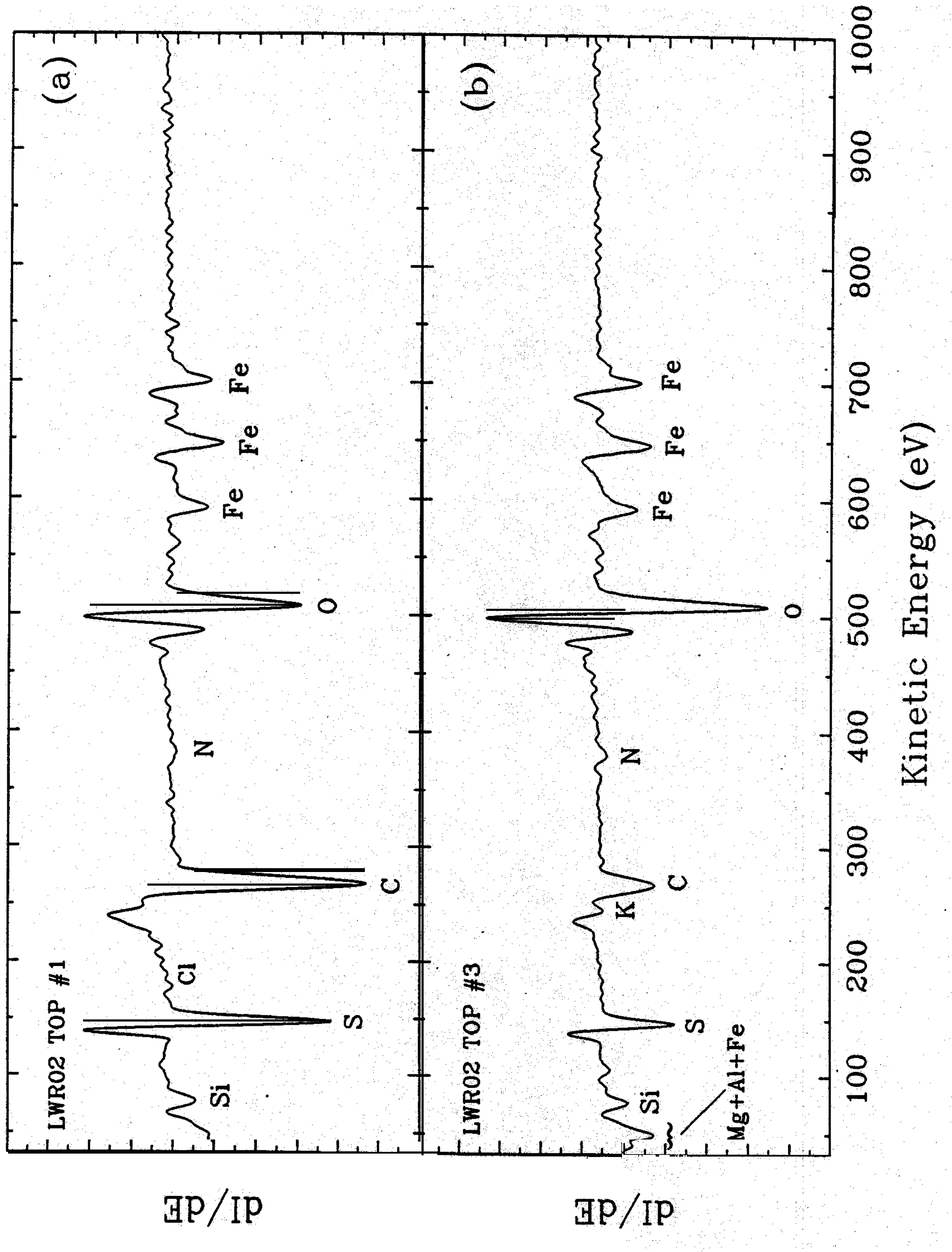


Figure 2-22: Auger survey scans recorded at two different points on the surface of a single pyrite crystal chosen from LWR02 Top; the surface of the single pyrite grain is shown in Figure 2-10.

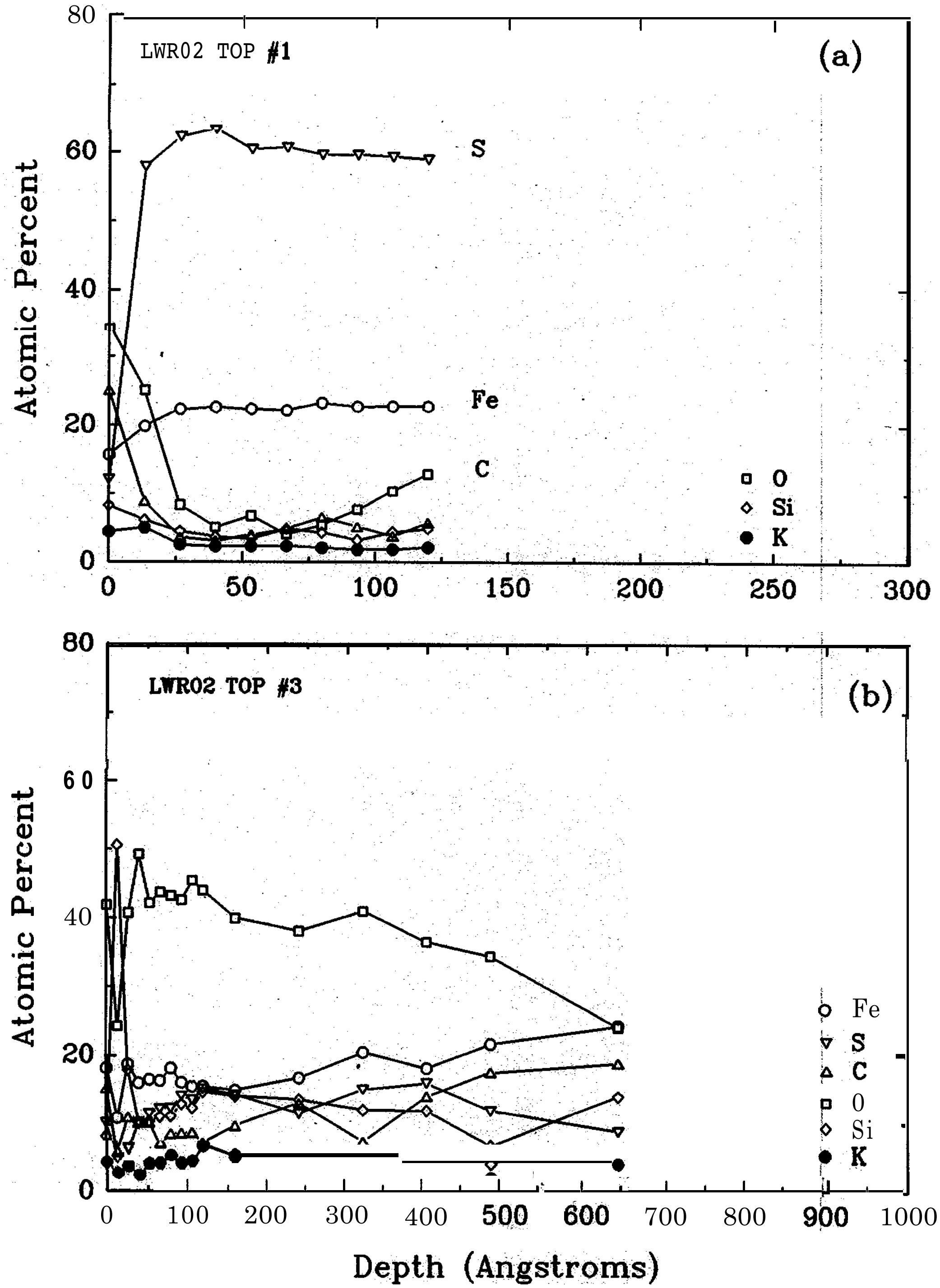


Figure 2-23: Auger depth profile throughout the near surface of LWR02. The points analyzed were the same as in the LWR02 survey scans.

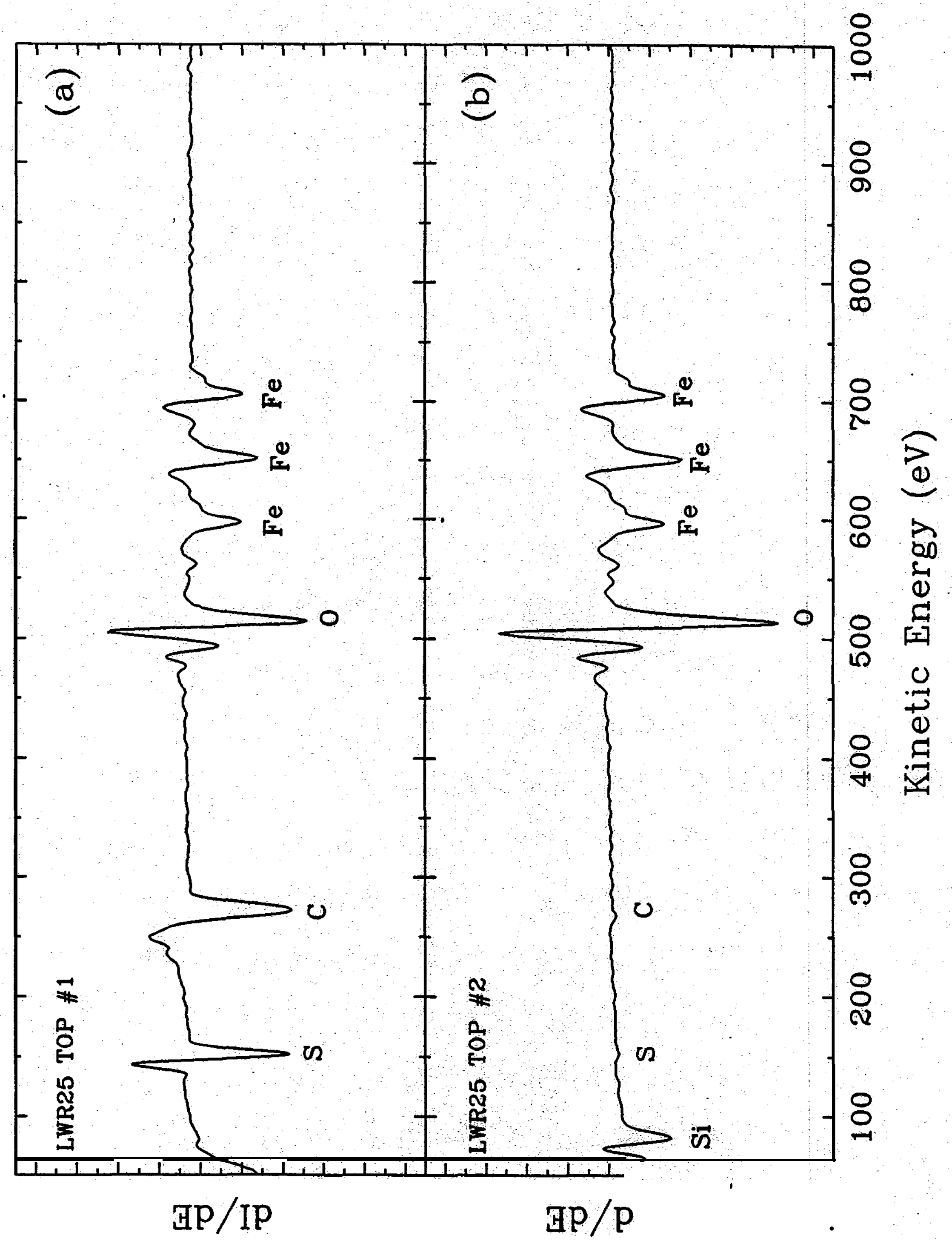


Figure 2-24: Auger survey scans recorded from two separate points on the surface of LWR25 Top.

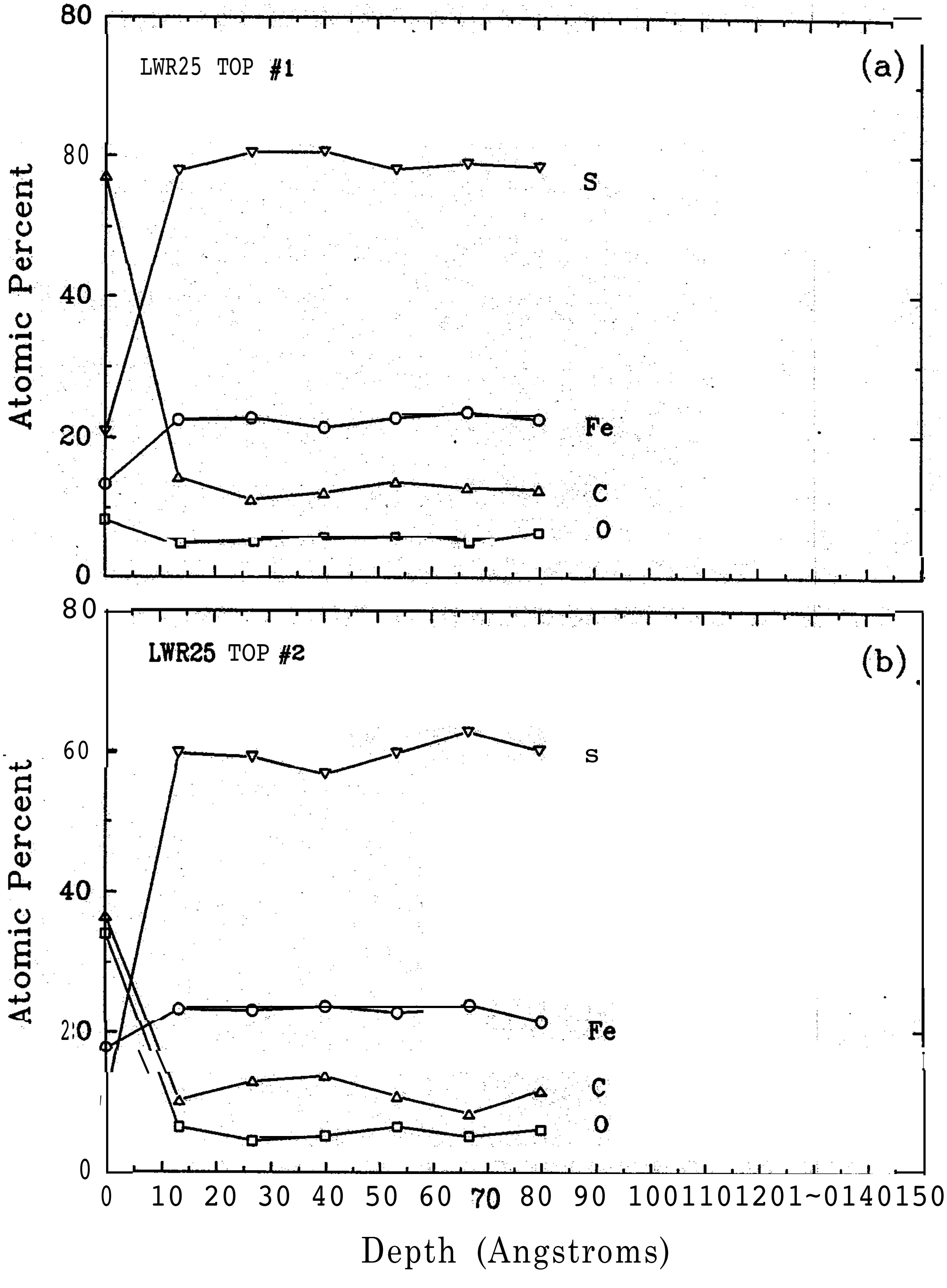


Figure 2-25: Auger depth profiles recorded through near surface of LWR25 Top.

Element	LWR22			LWR02			LWR25		
	1	2	3	1	2	3	1	2	3
Fe	9.7	8.4	5.2	6.9	0	13.0	12.6	35.8	8.8
S	51.2	74.7	56.1	70.6	21.8	54.5	65.1	4.2	76.7
Si	1.1	0.8	1.2	0	0	4.0	0	23.4	0
K	0.7	0.2	3.9	0.1	0	0.5	0	0	0
N	3.1	1.8	2.8	1.1	0	2.2	0	0	0.8
C	20.7	9.6	14.6	12.2	30.1	6.5	12.8	1.4	10.4
O	6.9	1.9	5.7	7.3	33.4	16.7	9.5	35.2	3.3
Mg+Al	0	0	0	1.8<	14.7<	2.5<	0	0	0
Ca	2.9	0.8	6.3	0	0	0	0	0	0
Cl	0.9	0.6	0.5	0	0	0	0	0	0
Zn	2.9	1.2	3.8	0	0	0	0	0	0

Table 2.11: Atomic % of elements detected on the surfaces of rock samples. Analyses for LWR22 and LWR02 were performed on single pyrite crystals.

2.3.6 X-ray Diffraction

Results: Diffractograms from the altered surface and underlying bulk rock are shown for LWR22, LWR02 and LWR25 in Figs. 2-26 to 2-29. The material scrapped from the rock surface and the bulk rock are labelled as (a) and (b) in the Figure so that the alteration products can be readily identified. A summary of the identified minerals can be found in Table 2.12.

Interpretation: When the X-ray diffractograms of the surface oxidation/alteration products are compared to those of the bulk rock sample one can potentially identify which mineral phases are participating in the alteration reaction. In addition, the remobilization of chemical species and elements should provide valuable information into the reaction chemistry.

Stratmat Flooded L WR22: The diffractograms in Figure 2 -26 indicate that the bulk of the rock is composed mainly of illite. Having reviewed the diffraction pattern for five different illites, it was found that the illite with composition $(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$ matched the XRD pattern almost precisely. Both quartz and pyrite were also identified in the surface alteration products and in the bulk rock. The minerals identified by XRD are in reasonable agreement with the mineral phases identified by petrographic means (Table 2.1). Some of the trace minerals like apatite, and titanate were not identified by XRD.

XRD analyses of the surface alteration products indicate that the surface oxidation products could not be detected (Table 2.12). Since the surface alteration can be seen in hand samples, some alteration must have occurred. The SEM/EDX analysis also failed to detect significant differences between the fresh and altered surfaces, one must conclude that the alteration products are very thin and of an insufficient quantity to be detected by XRD.

Stratmat Control LWR02: The XRD data in Figure 2-27 shows the diffraction patterns of the surface alteration products and the bulk rock. Illite, pyrite and quartz (see Table 2.12) are the minerals common to both samples. Again, these minerals are in agreement with the petrographic study described previously. In addition, the XRD pattern for the bulk LWR02 sample show lower peak illite heights than those of the LWR22 sample, suggesting that silicate minerals present in the Stratmat rock are used up in neutralizing acid resulting from sulphide oxidation.

The data from the surface clearly shows that clinochlore and jarosite are important alteration products of the rock surface that has been exposed to oxidation and leaching. Of the eight different clinochlore minerals whose spectra were compared to that of the alteration product, three gave reasonable matches (see Table 2.12). Two separate samples were run and compared to determine if the XRD spectra and hence the alteration products on LWR02 surface are representative of the LWR02 series. It appears that clinochlores that formed on the two surfaces had similar diffraction patterns, although not identical, but both clinochlores have the same chemical formulae $(Mg,Fe,Al)_6(SiAl)_4O_{10}(OH)_8$. Minor phases of talc and gypsum have also been identified as likely alteration products.

It should be noted in the one LWR02 bulk sample that the diffraction pattern for the pyrite peaks were abnormal. The ratios of the intensities did not agree with all the other samples or with the ASTM standards. The peak at 66.5” (20; data not shown) is approximately 20% of its usual intensity. This may be an experimental abberation or an indication that the pyrite is somewhat anomalous.

Selbaie LWR25: The XRD data taken from the surface and bulk from the LWR25 samples are virtually identical. Pyrite and quartz are the major phases detected. Minor phases of clinochlore, calcite and ankerite were detected only in the bulk phase. Based on the relative peak intensity of these minor phases, their significance is questionable.

2.3.7 Secondary Ion Mass Spectroscopy

Results: Secondary ion mass spectra (SIMS) were recorded from the surface of single pyrite crystals (Figs. 2 -29 or 2-30); these crystals were selected from the fresh surface of LWR22 or LWR25. The mass spectra were recorded using a Cs^+ and O^- primary ion beams. The

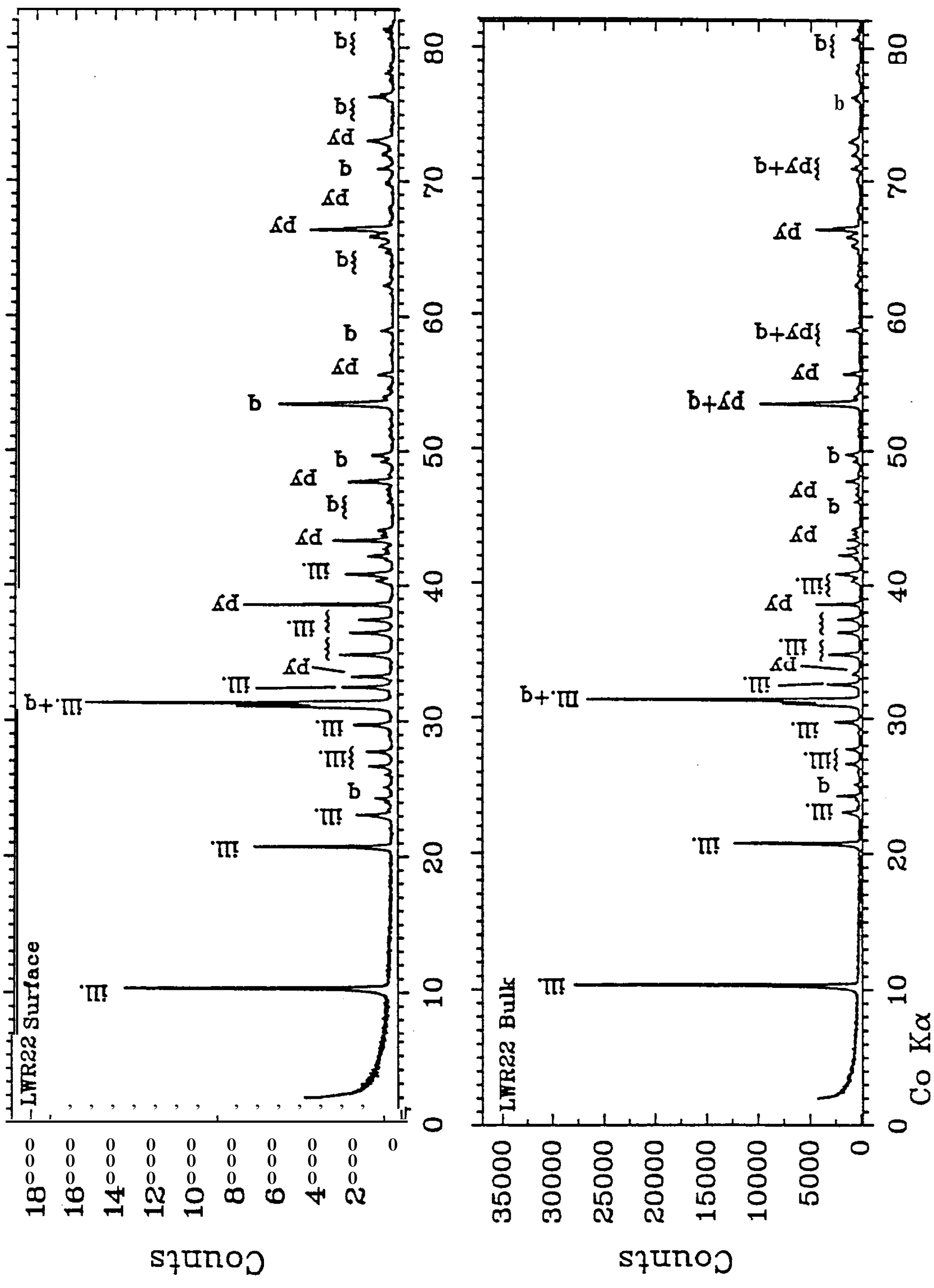


Figure Z-26: XRD diffractograms from (a) the scraped surface and (b) the bulk rock sample (LWR22 TOP)

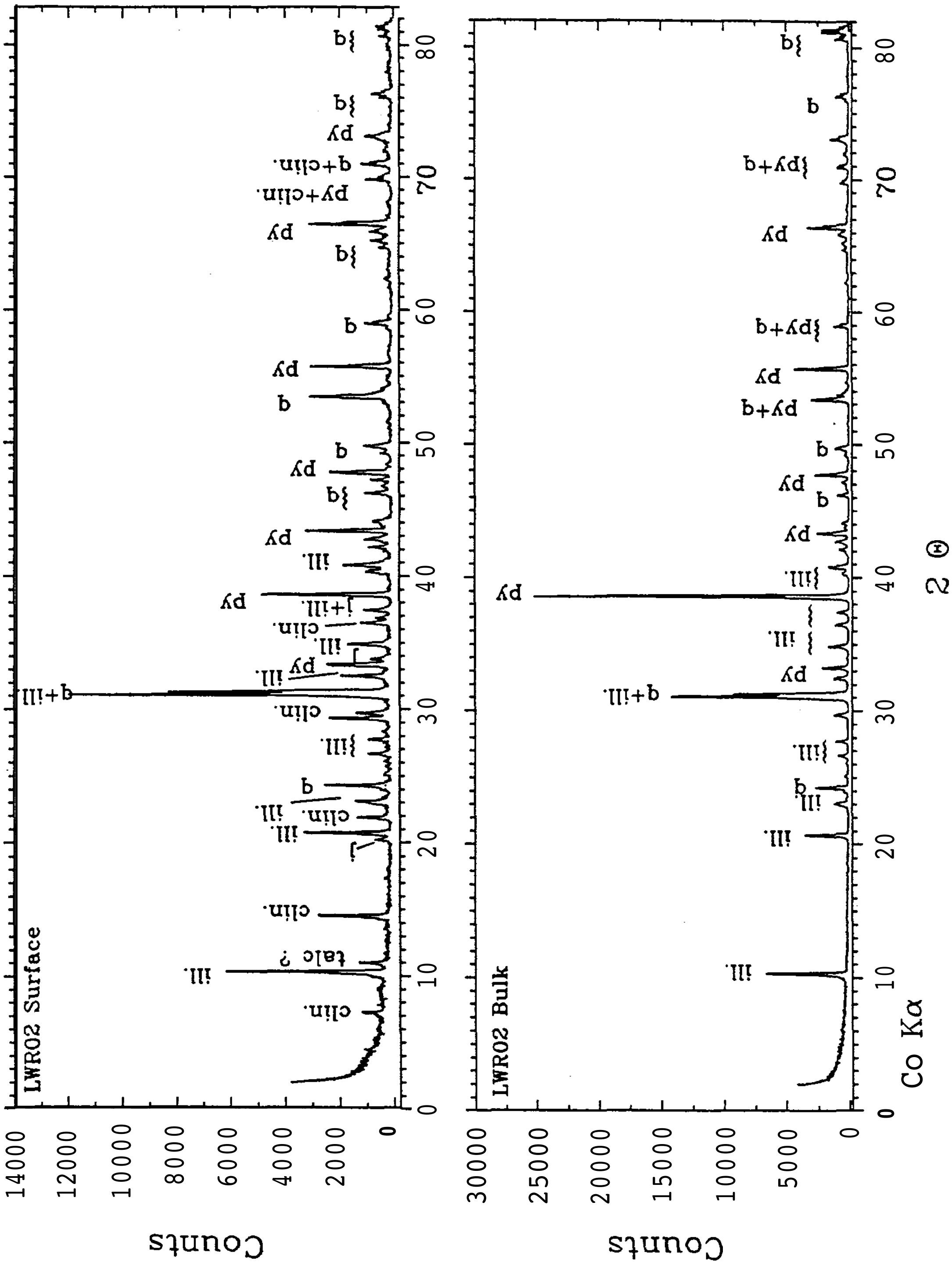


Figure 2-27: XRD diffractograms from (a) the scrapped surface and (b) the bulk rock sample (LWR02 TOP).

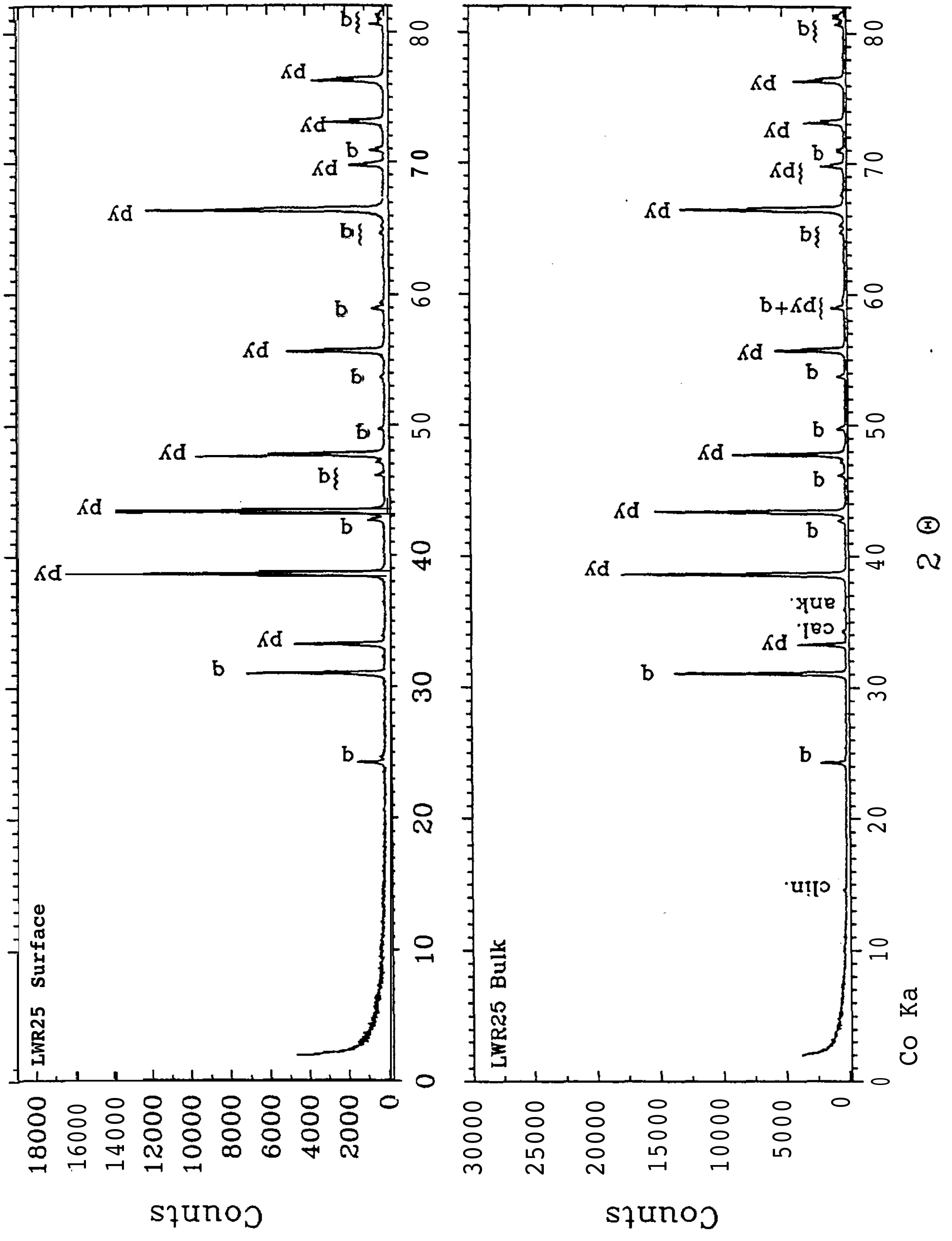


Figure 2-28: XRD diffractograms from (a) the scrapped surface and (b) the bulk rock sample (LWR25 TOP).

Sample		Mineral	Symbol	Formula	ASTM Card #
LWR22	Surface	illite	ill	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$	26-911
		quartz	q	SiO_2	s-490
		pyrite	py	FeS_2	6-710
	Bulk	illite	ill	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$	26-911
		quartz	q	SiO_2	S-490
		pyrite	py	FeS_2	6-710
LWR02	Surface	quartz	q	SiO_2	5-490
		illite	ill	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$	26-911
		clinochlore	clin	$(Mg,Fe,Al)_6(SiAl)_4O_{10}(OH)_8$	7-78,16-362, 7-165
		pyrite	py	FeS_2	6-710
		jarosite	j	$KFe_3(SO_4)_2(OH)_6$	22-827
		talc	talc	$Mg_3Si_4O_{10}(OH)_2$	6-46,21-816
		gypsum (trace)	g	$CaSO_4 \cdot 2H_2O$	6-46,21-816
	Bulk	quartz	q	SiO_2	S-490
		pyrite	PY	FeS_2	6-710
		illite	ill	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$	26-911
		clinochlore (trace)	clin	$(Mg,Fe,Al)_6(SiAl)_4O_{10}(OH)_8$	7-78
LWR25	surface	pyrite	py	Fes,	6-710
		quartz	a	SiO_2	S-490
	Bulk	pyrite	py	FeS_2	6-710
		quartz	q	SiO_2	S-490
		ankerite (trace)	ank	$CaFe(CO_3)_2$	12-88
		calcite (trace)	cal	$CaCO_3$	5-586

Table 2.12: Minerals identified in the XRD diffractograms from the surface alteration products and bulk rock for the Top samples of LWR22, LWR02 and LWR25.

two different primary ions were used, since the elemental sensitivity, and hence the detection limit, of a particular secondary ion can vary by orders of magnitude from one primary ion to another. It is the relative differences in intensity at each mass that is of particular interest here.

Photomicrographs of the pyrite grains analyzed by SIMS were taken using an optical microscope (see Figures 2 -3 1 a,b and 2 −34a,b). The dark coloured rectangles or squares on the bottom right corner of the pyrite grains (Fig. 2-3 la) shows the crater created when the primary ion beam strikes the sample surface. The SIMS maps or images show the distribution of ions, of a particular mass, over the sample surface. SIMS maps of ions with masses of 24, 27, 28 and 32 can be found in Figs. 2-32 and 2-34 for pyrite grains from LWR22 and LWR25, respectively. Similarly, SIMS maps of ions with masses of 40, 56, 75 and 208 can be found in Figs. 2 -33 and 2-36 for pyrite grains from LWR22 and LWR25, respectively.

Interpretation: SIMS data are generally used to study trace element distribution in solids, but in general, are not quantitative. In this case, the SIMS data were recorded from the same matrix and mounted in exactly the same manner, and therefore, the relative peak intensities for a particular element will give relative concentrations.

The question is raised; what are the differences in the solid state chemistry of the pyrites from Selbaie and Stratmat? If one pyrite is very pure, while another has significantly higher levels of impurities, then the two pyrites may have very different leaching characteristics. Figure 2-29 shows SIMS data. recorded from the two different pyrite crystals. Careful analysis of the data shows that LWR22 seems to have higher levels of impurities. When the same type of comparison is made between the two SIMS spectra in Figure 2 - 30, it is apparent that the pyrite crystal from LWR22 contains much-more Al, Ca, As, Zr (mass 90 AMU; this may or may not be Zr) and slightly more Pb than LWR25.

It is known that LWR22 contains higher concentrations of various impurities, but how are these impurities distributed? Maps were recorded of the surfaces of the two pyrite crystal to determine the distributions of certain masses. It was decided to examine the relative distribution of the following masses: 24, 27, 28, 32, 40, 56, 75, and 208 AMU; imaging the surfaces at these masses should indicate the relative distributions of Mg, Al, Si, S, Ca, Fe, As, and Pb.

Stratmat Flooded L WR22: A comparison of the photomicrographs in Figure 2 -3 1 and the SIMS maps in Figs. 2 -32 and 2 – 33 can provide elemental information regarding some of the visible features in the photomicrographs. The imaged area, indicated by a red arc in the lower right comer of Fig. 2 -3 1, is compared to the SIMS map of masses 32 (sulphur) and 56 (iron) AMU one can immediately distinguish the edge of the pyrite grain; this provides a good frame of reference to begin relating features on the photomicrographs to those in the SIMS images.

One can immediately see that the iron and sulphur are reasonably well distributed over the analyzed area. There are some small areas on the surface which contain Mg, Al, Si and Ca, yet are devoid of iron and sulphur and these areas represent inclusions of a separate mineral phase, either a pyroxene or an amphibole. The Ca map shows a strong delineation from the upper right to the lower left and this feature can be correlated with a scratch on the surface of the pyrite (see Figs. 2 -3 lb and 2 -33a). The Pb map (Fig. 2-33d) shows that Pb is randomly or evenly distributed throughout the pyrite grain and that its presence is independent of any obvious surface feature. The As map (Fig. 2 –33c) is certainly the most interesting; the distribution of As in the pyrite appears to be distributed in patches, which are independent of secondary mineral phases. One can see that As is very depleted around the entire perimeter of the pyrite grain. This would suggest that the As was in some manner removed from the outer surface of the grain. It must be pointed out that this pyrite grain was removed from the pristine interior of the rock sample and that its exposure to aqueous solutions is unlikely. Also, one can see that large areas on the interior of the pyrite grain also are devoid of As and that many of these areas which are depleted in As appear to be interconnected by areas of low As.

Selbaie L WR25: A comparison of the photomicrographs in Figure 2 – 34 and the SIMS maps in Figs. 2 -35 and 2 -36 can provide elemental information about some. of the visible features in the photomicrographs. The imaged area, which is indicated by a red arc in the lower right comer of Fig. 2-34, is compared to the SIMS map of masses 32 (sulphur) and 56 (iron) AMU one can immediately distinguish the edge of the pyrite grain. The photomicrograph of the pyrite grain will show that this grain has a considerable number of inclusions. In general, the Mg, Al and

Si maps have corresponding regions of higher concentrations and this is probably indicative of secondary mineral inclusions such as amphiboles and pyroxyenes. The distribution of Ca is somewhat more prevalent than was found in the LWR22 series. Much of this Ca appears to be associated with inclusions within the pyrite.

Careful examination of the S and Fe maps (Figs. 2–35d and 2 -36b) will show that some of the inclusions contain suiphur but not iron. This would indicate that other sulphides phases are present, possibly ZnS or PbS (Figs. 2-36d). The Pb map shows several areas which appear to correspond to regions of low iron. The Pb in the pyrite from the LWR22 series appeared to be totally random, while in this case the Pb is found in very definite bands in the surface. This would indicate that either a separate galena phase is present or that Pb is substituting for Fe in the pyrite structure (i.e., $(Fe,Pb)S_2$).

The distribution and prevalence of As (Figs. 2–36c) is very much different in this sample than in the last. Both the SIMS images and the mass spectra (Figs. 2-29 and 2-30) indicate that the level of As in the LWR25 series is much lower. This is quite the opposite of the X-ray fluorescence data (Table 2.8), which indicates that the LWR25 sample contain about twice the amount of As as the LWR22 series. It may be concluded from these data that either more of the As in the Selbaie LWR25 sample is located in the gangue or that the As concentrations vary greatly from grain to grain. Also, the As in the LWR25 sample is located mainly along the grain exterior. The SIMS maps from the LWR22 grain showed that the As was depleted from the grain boundaries.

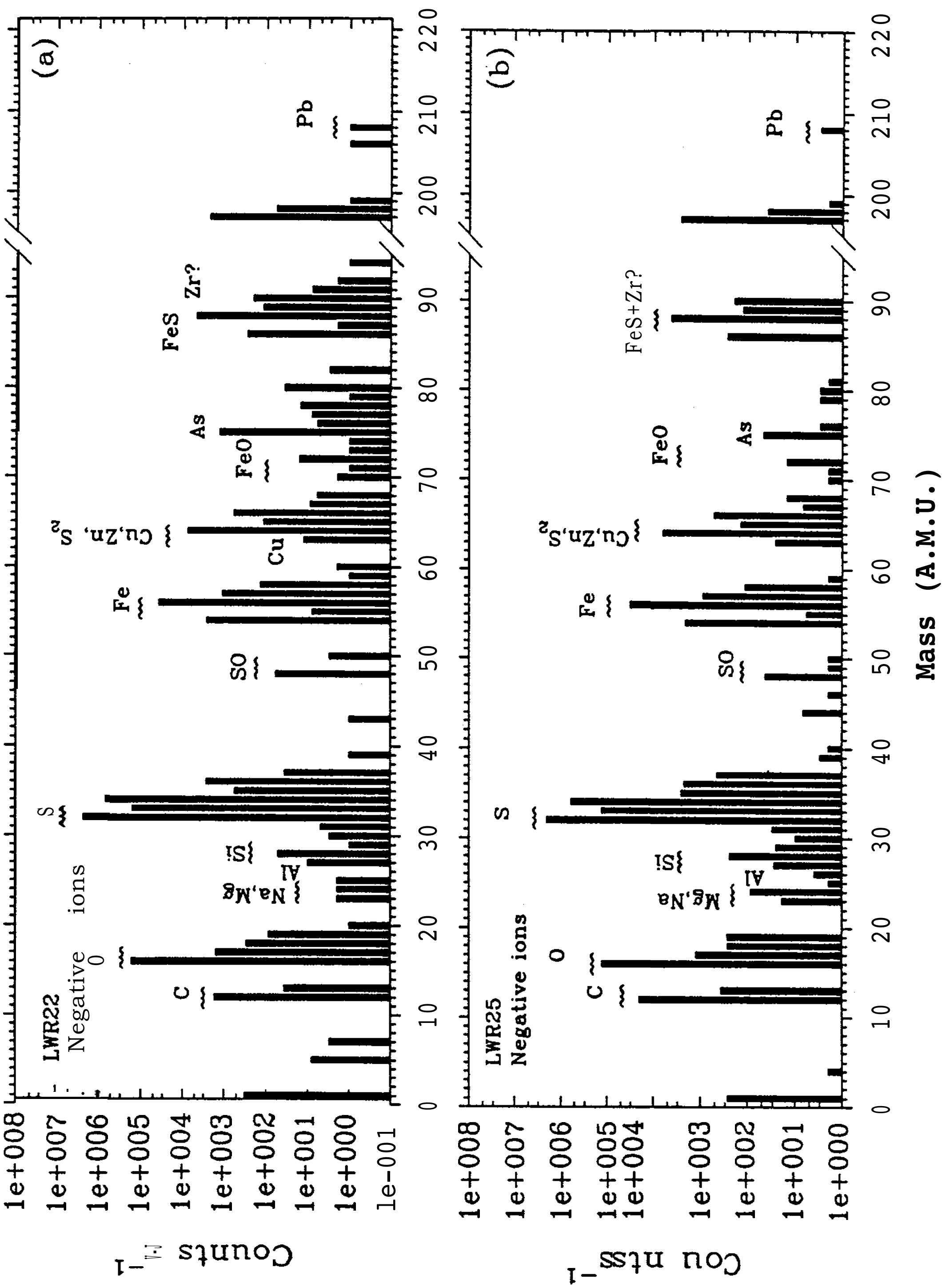


Figure 2-29: Secondary ion mass spectra of unaltered pyrite crystals chosen from LWR22 and LWR25; the primary ion beam used was Cs^+.

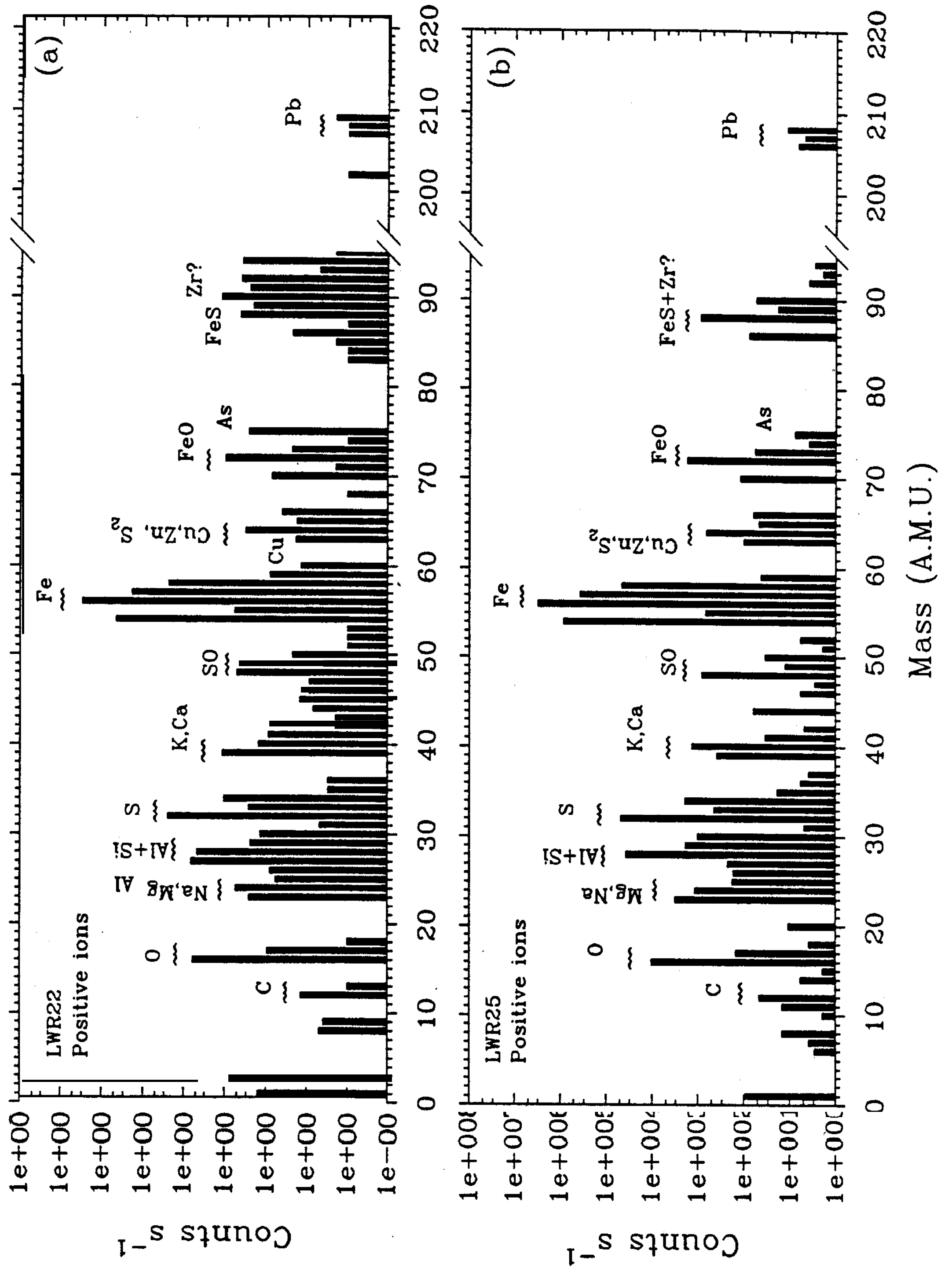
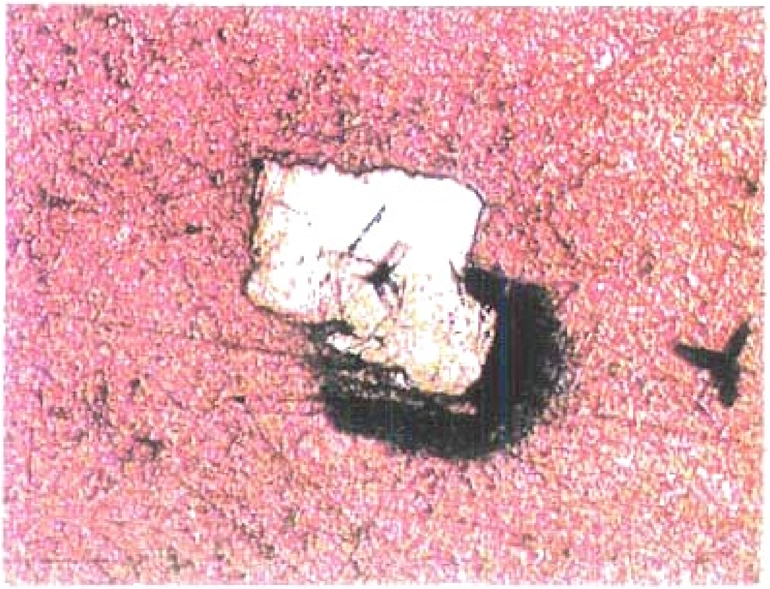


Figure 2-30: Secondary ion mass spectra of unaltered pyrite crystals chosen from LWR22 and LWR2.5; the primary ion beam used was O^-.

Figure 2 -3 1: Photomicrographs of the pyrite grain from the LWR22 series that was used for SIMS imaging. The pyrite grain in the centre of (a) is shown at higher magnification in (b). The black area (crater) in the lower right comer of the pyrite grain in (a) was created by the SIMS primary ion beam; for the purpose of scale, the diameter of this crater is ≈ 250 μm). The arc (drawn in red) in the bottom right comer of the pyrite grain in (b) shows SIMS analysis area for the purpose imaging.

a



b

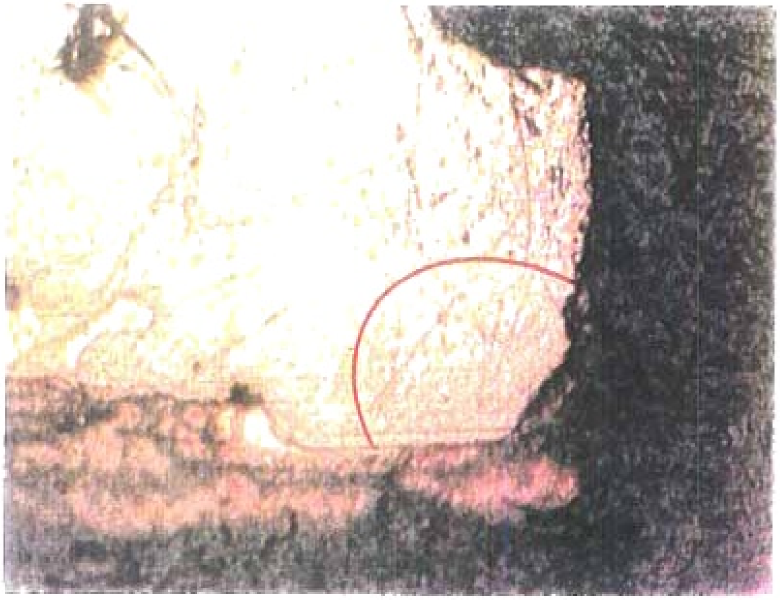


Figure 2-32: SIMS maps or images are shown in (a-d). These maps correspond to the same area outlined in the bottom right comer of the pyrite grain shown in Figure 2-31. Each map shows the distribution of secondary ions, of a particular mass, as a function of position of the analyzed surface. The masses that are imaged in this figure are (a) 24, (b) 27, (c) 28 and (d) 32 AMU.

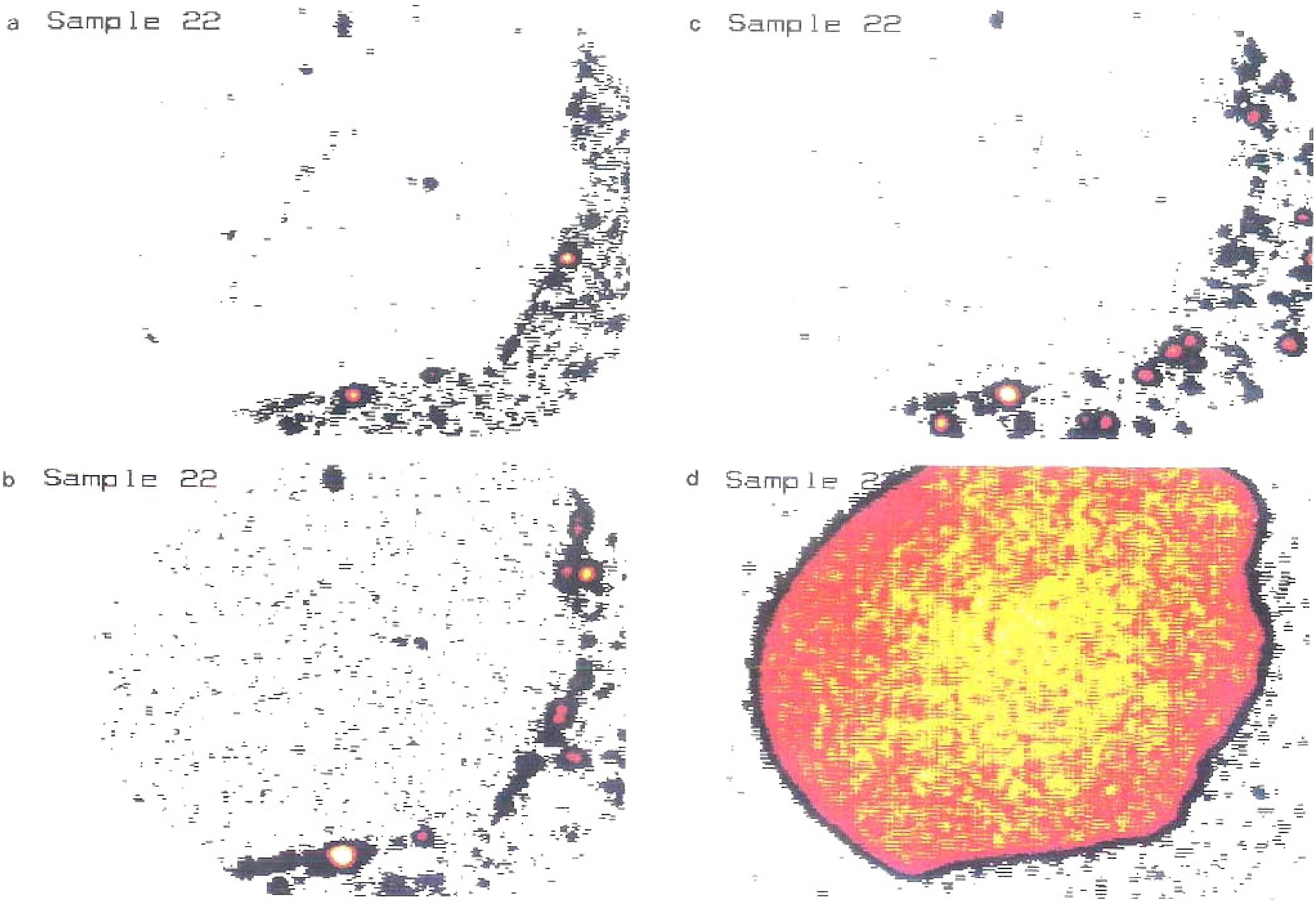

a Sample 22
c Sample 22
b Sample 22
d Sample 22

Figure 2-33: SIMS maps or images are shown in (a-d). These maps correspond to the same area outlined in-the bottom right corner of the pyrite grain shown in Figure 2-3 1. Each map shows the distribution of secondary ions, of a particular mass, as a function of position of the analyzed surface. The masses that are imaged in this figure are (a) 40, (b) 56, (c) 75 and (d) 208 AMU.

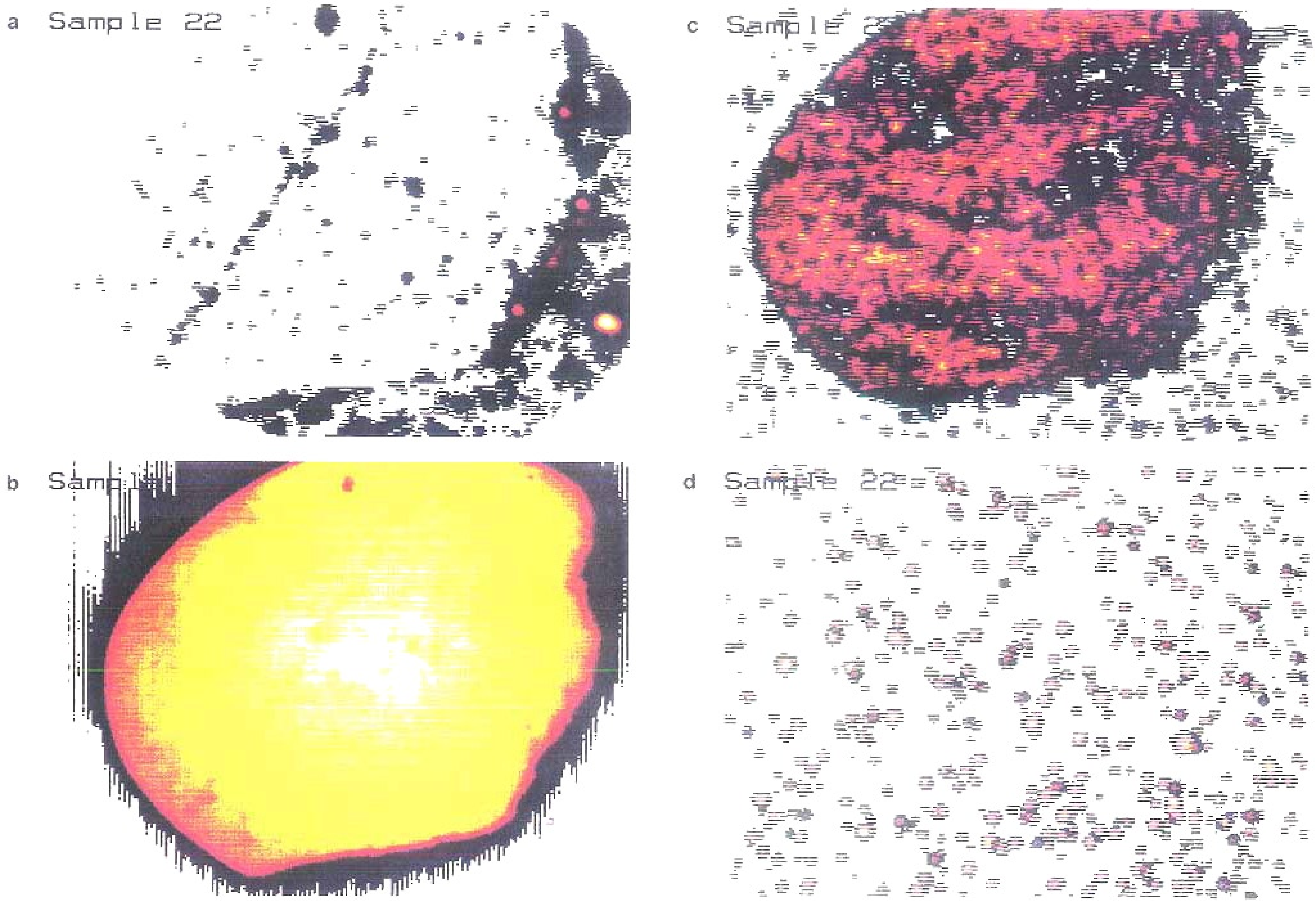
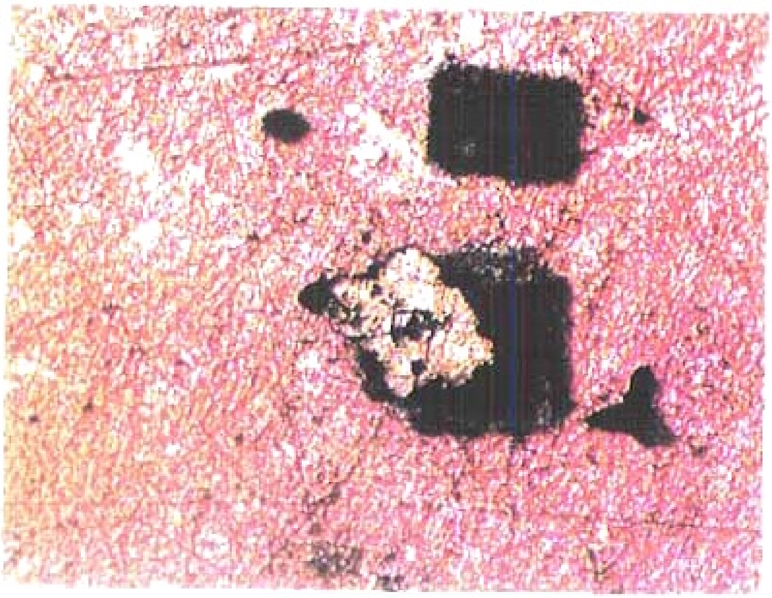

a
Sample 22
c
Sample 22
b
Samp
d
Sample 22

Figure 2-34: Photomicrographs of the pyrite grain from the LWR25 series that was used for SIMS imaging. The pyrite grain in the centre of (a) is shown at higher magnification in (b). The black area (crater) in the lower left comer of the pyrite grain in (a) was created by the SIMS primary ion beam; for the purpose of scale, the diameter of this crater is $\approx$ 250 μm). The arc (drawn in red) in the bottom left corner of (b) shows the SIMS analysis area for the purpose imaging.

a



b

Figure 2-35: SIMS maps or images are shown in (a-d). These maps correspond to the same area outlined in the bottom right corner of the pyrite grain shown in Figure 2-34. Each map shows the distribution of secondary ions, of a particular mass, as a function of position of the analyzed surface. The masses that are imaged in this figure are (a) 24, (b) 27, (c) 28 and (d) 32 AMU.

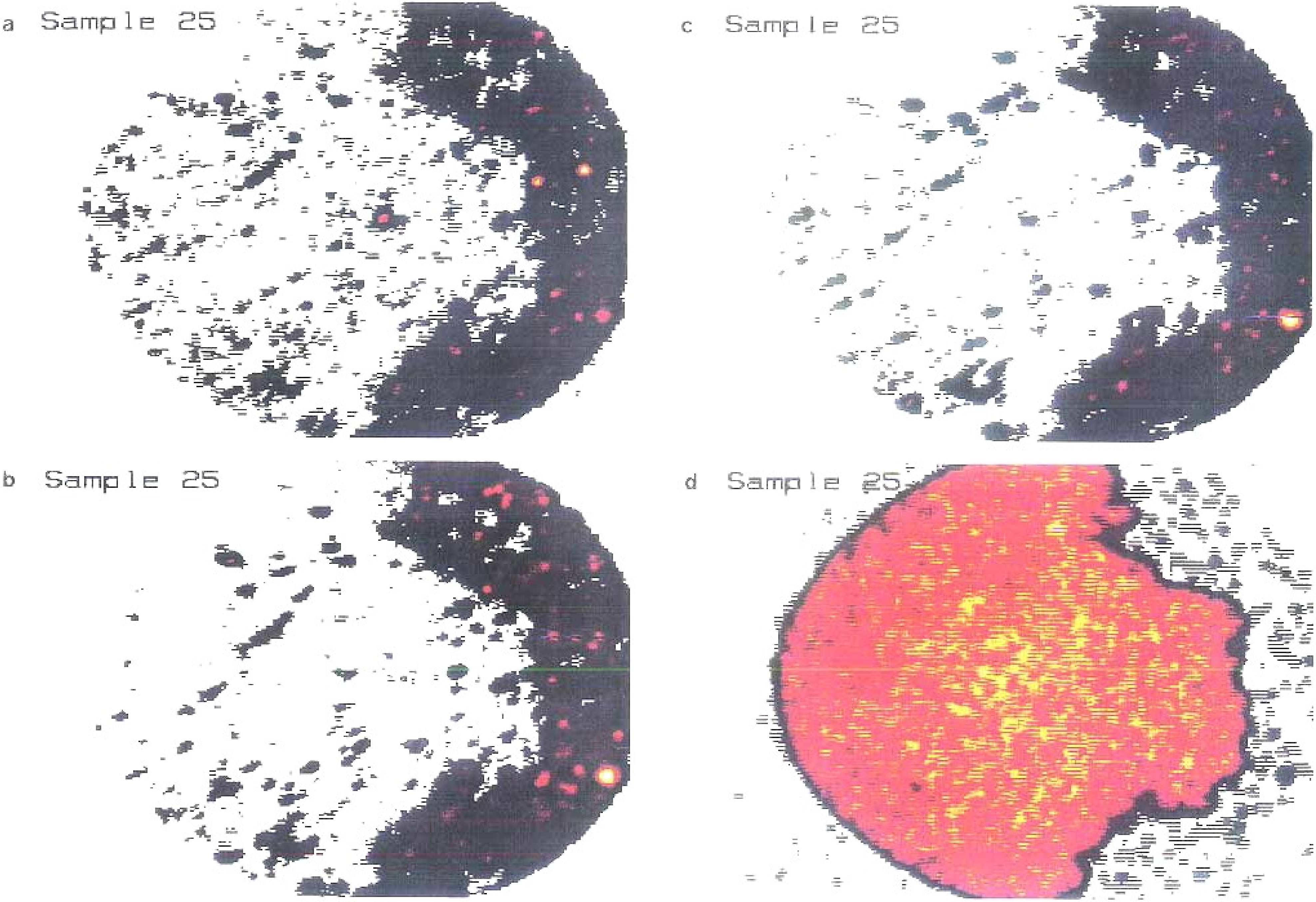
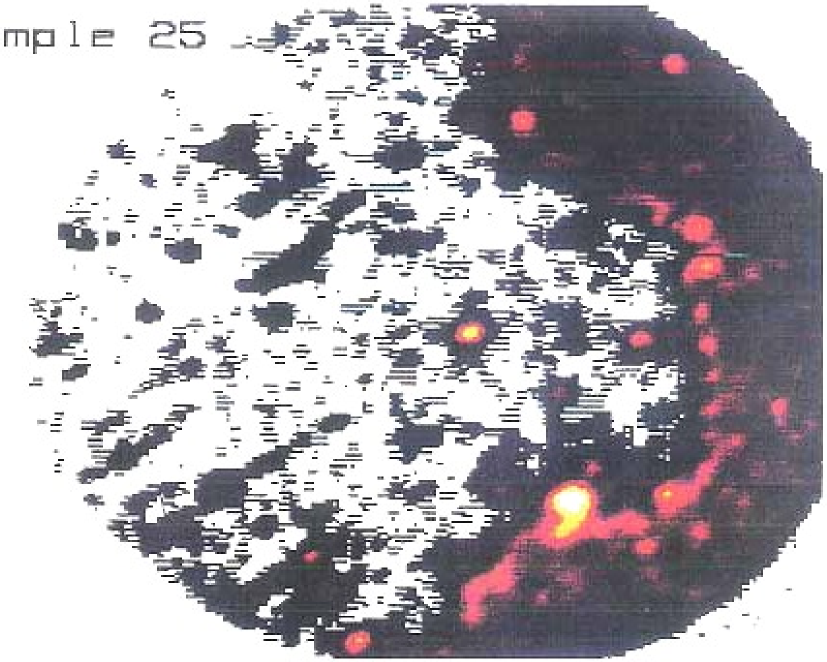
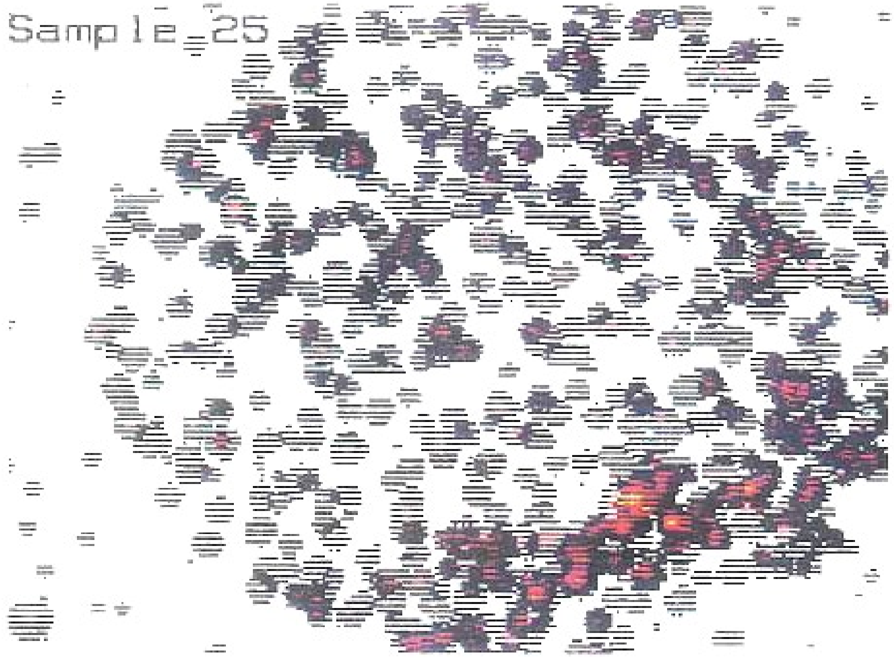

a Sample 25
c Sample 25
b Sample 25
d Sample 25

Figure 2-36: SIMS maps or images are shown in (a-d). These maps correspond to the same area outlined in the bottom right corner of the pyrite grain shown in Figure 2-34. Each map shows the distribution of secondary ions, of a particular mass, as a function of position of the analyzed surface. The masses that are imaged in this figure are (a) 40, (b) 56, (c) 75 and (d) 208 AMU.

a Sample 25

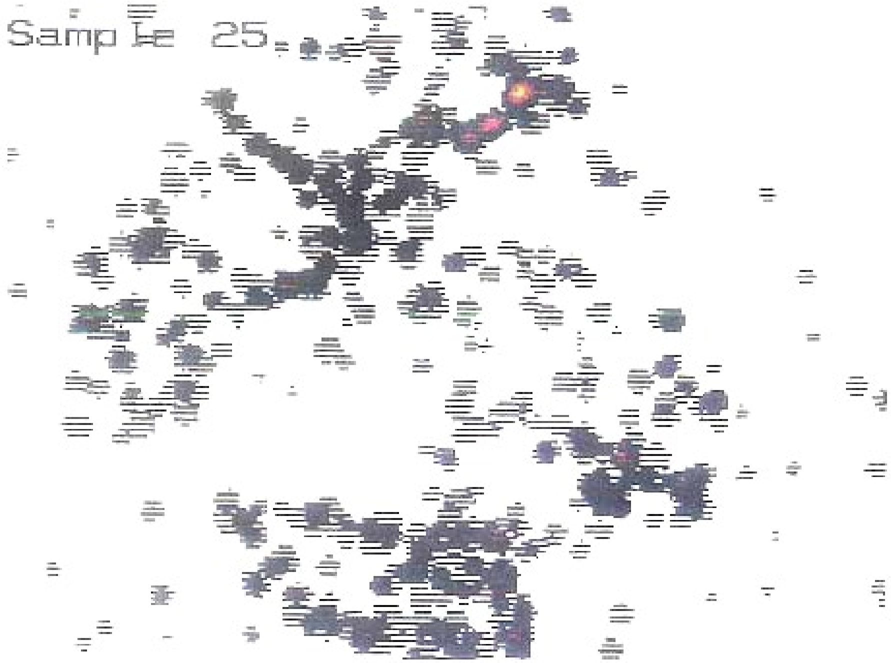


c Sample 25



b Sample 1

d Sample 25



3.0 Leaching Simulations

Leaching of the rocks were simulated in tests involving the exposure of a known mass of rock to acidified distilled water and then monitoring the concentrations of leached cations and pH versus elapsed time. Test samples were cut using a water-cooled diamond saw to remove oxidized faces. Three tests, involving the bulk Stratmat and Selbaie rocks and pyrite crystals separated from a sample of crushed Stratmat rock, were performed. Each sample was crushed to pass sieve No. 40 (0.425 mm). Using the estimated percent pyrite in the Selbaie and Stratmat rocks, the required amount of sample was placed in a glass beaker so that the mass of pyrite in each of the three test samples were the same. The equivalent mass of pyrite used was 3.42 g.

Leach solutions were prepared by acidifying 2 L of distilled water with sulphuric acid to a pH of about 2.3. One liter of leach solution was added to each beaker containing a test sample and then leached by stirring at 6 rpm using a teflon paddle similar to the system used by Barone et al. (1989). Each beaker was sampled over a period of time (approximately 75 days) and analyzed for pH and dissolved iron, lead, copper and zinc by atomic absorption spectrophotometry.

3.1 Results

The results of the simulation leach tests performed on the flooded Stratmat and Control Selbaie rocks and pyrite crystals isolated from the flooded Stratmat rocks are presented in Figs. 3-1 to 3-6. The pH of the the pyrite and the Selbaie rock leachate averaged ~ 2.20 and was only 0.1 units below the pH of the starting leach solution. The average pH of the Stratmat rock was ~ 2.25 during the first 40 days of leaching and increased slightly to 2.30 at the end of the 75 days (Fig 3-l).

Iron concentrations in the leachate reached 2 mg/L in the pyrite, 24 mg/L in the Stratmat rock and 53 mg/L in the Selbaie rock during ~ 75 days of leaching (Fig. 3-2). The rate of release of iron from the two rocks was similar during the first 20 days of leaching. After the 20th day, the Selbaie rock released iron at a rate that was nearly five times that of the Stratmat rock. Since samples used in the leach simulation tests were all thoroughly washed and therefore devoid of products or coatings from any previous oxidation, the iron concentrations in the leachate would be derived from pyrite dissolution or leaching. The iron data suggest that pyrite in the Selbaie rock was more leachable than the pyrite in the bulk Stratmat rock, under the aggressive conditions (pH of 2.3) used in the simulation tests. Pyrite isolated from the Stratmat rock did not dissolve or leach as rapidly as the pyrite in the bulk rock which suggests that gangue minerals (mostly silicates such as illite) have a major influence on acid generation in the Stratmat rock.

Zinc and lead concentrations observed in leachates from the simulation tests are plotted against iron concentrations in Figs 3-3 and 3-4. Zinc release does not correlate with iron release and, therefore, pyrite leaching in the Stratmat rock (LWR22), as shown in Fig 3-3. A lead-iron release relationship seems to characterize the Stratmat rock, although the low lead concentrations (0.1-0.25 mg/L) are close enough to the detection limit to probably render such a relationship inconclusive. Figure 3-4 indicates strong correlations between zinc and iron release and lead and iron release in the Selbaie rock (LWR25). Zinc release from the pyrite isolated in the Stratmat rock was quite low and nearly constant during the first 20 days of leaching, but increased slightly and correlated with iron release during the following 55 days (Fig 3-5).

Copper concentrations in the leachates from the Stratmat and Selbaie rocks and the pyrite are presented in Fig. 3-6. With the exception of the first six days' data, copper concentrations were nearly constant (≤ 0.1 mg/L) in the two rock leachates but were very close to zero in the leachate from the pyrite during the 75 days of leaching.

4.0 DISCUSSION

The post-testing surface and bulk mineralogical and chemical data discussed in Section 2 indicate the flooded Stratmat rock consists of 66-300 μm euhedral pyrite grains held in a matrix of gangue minerals which comprise a micaceous clay mineral (most probably illite), quartz and minor chlorite and K-feldspar. The bulk composition is illite, quartz and pyrite (in order of abundance). Pyrite grains at the surface of the rock are only slightly altered and surrounded by clays, with a few of the grains showing signs of pitting. The interior of the Stratmat rock contains fresh, unreacted pyrite grains with sharp edges. Auger electron spectroscopy indicate the atomic composition of the surface of the flooded Stratmat rock consists of 1.8-3.1% nitrogen.

The Control Stratmat rock, having been much more extensively oxidized and weathered, contains pyrite grains at the surface that are striated and much more heavily pitted than the flooded rock. The pyrite grains are coated with spalling flaky crusts. The spall material does not appear to be passivating the rock surface from further oxidation. The surface coating consists of a 25-600 Å thick iron oxyhydroxide layer and iron sulphate (possibly jarosite), gypsum and iron aluminosilicates containing K and Mg. Surface minerals identified include quartz, illite, clinochlore, pyrite, gypsum and talc. In comparison to the flooded rock which was only slightly oxidized or weathered, the Control Stratmat rock yielded lower illite peak heights on x-ray diffractograms. The reduced quantities of illite and other silicates would suggest their consumption in acid neutralizing reactions following sulphide oxidation. Sulphur is depleted in the surface 10 A. Nitrogen was also detected on the Control Stratmat rock (1.1-2.2 atomic percent).

The Selbaie rock contains massive pyrite with quartz veining along fractures. A small ankerite component is associated with the quartz veining. Much of the pyrite is still present in the Selbaie rock, indicating less extensive oxidation and leaching than the Control Stratmat rock. The euhedral pyrite grains in the Selbaie rock are finer-grained (3-20 μm) than the Stratmat rock and are only lightly etched. The pyrite is associated with euhedral or prismatic gypsum crystals and coated with tine-grained clayey material similar to chlorite. Iron oxide coating on the surface is only 15 A. Little or no nitrogen was found in the atomic composition of the rock surface.

The secondary ion mass spectroscopy (SIMS) data indicate the pyrite in the unoxidized Stratmat rock contains higher levels. of impurities (aluminium, calcium, arsenic and lead) than the unoxidized Selbaie rock. The source of these impurities would include silicates present in the gangue minerals. Lead, in particular, is found to be randomly or evenly distributed throughout the pyrite grain and not related to any surface feature. Arsenic is distributed in patches within the pyrite grain but depleted around the perimeter of the grain. The Selbaie rock, on the other hand, is observed to contain pyrite grains with a number of inclusions including magnesium, aluminium and silicon, suggesting the presence of secondary mineral inclusions such as amphiboles and pyroxenes. The sulphur distribution map consists of several areas where iron is depleted but dominated by lead. Lead is found in well defined bands in the surface of the pyrite grain, unlike the randomly-distributed lead present in pyrite grains from the Stratmat rock. This would indicate either a separate galena (PbS) phase or Pb substituting for Fe in the pyrite structure (that is, $[Fe,Pb]S_2$) in the Selbaie rock.

The oxidized or Control Stratmat rock has a slightly higher Pb concentration than the unoxidized or unleached rock, indicating that Pb was not leached during the three years of testing. This conclusion is consistent with drainage water quality data presented in Table 3.1.

	Copper	Lead	zinc	Iron	pH	Acid production (mg $CaCO_3$/ wk/day)
Stratmat I	10.9	< 0.25	609	4470	2.5	
Stratmat II	10.9	< 0.25	431	4390	2.2	126
Stratmat III	13.5	< 0.25	506	5500	2.2	
Selbaie I	21.3	< 0.25	235	538	2.8	
Selbaie II	45.3	< 0.25	492	1682	2.8	35
Selbaie III	45.3	< 0.25	261	676	2.8	

Table 3.1: Maximum metal concentrations (mg/L) and pH of drainage water (Indoor Column Tests)

The data indicate the Stratmat rock produced more acid than the Selbaie rock. Maximum iron and zinc concentrations were also higher in the Stratmat drainage water than those in the Selbaie drainage water. Copper concentrations were, on the other hand, higher in the Selbaie drainage water and lead was undetected in both drainage waters throughout the laboratory column tests, indicating that lead present in both Selbaie and Stratmat rocks was not leached during the leach tests.

The above results are, however, different from those of the simulation leach tests which were conducted under more aggressive leaching conditions (leach solution pH of ~ 2.3 and rock samples with particle sizes < No. 40 or 0.425 mm). In the simulation tests, some Pb was released from both the Stratmat and Selbaie rocks, with the Selbaie rock yielding higher leachate Pb concentrations after the initial 20 days of leaching. The higher iron and metal release rates may observed in the simulation tests may be explained by the finer particle size of < 0.425 mm compared to the 25-50 mm particles leached with deionized, distilled water.
The surface analytical and simulation leach data would suggest that Pb, As, Zn and Cu may be in solid solution with the pyrite in the Selbaie rock and are released upon leaching of the pyrite. In the Stratmat rock, these elements may, on the other hand, be present as separate sulphide phases along with pyrite in a matrix of predominantly silicate gangue minerals such as illite, chlorite and K-feldspar and/or albite. Disintegration of the matrix would expose these sulphides to oxygen and leaching fluids. Under the more aggressive simulated leaching, the pyrite in the Selbaie rock dissolved and yielded more Fe (along with metals such as Pb and Zn) than pyrite in the Stratmat rock. In fact, single pyrite grains isolated from the Stratmat rock dissolved only slightly and produced Fe concentrations of < 2 mg/L (compared to ~ 25 mg/L for the whole rock including the gangue minerals), during the 75 days of leaching. This would suggest that gangue minerals have a major influence on acid generation in the Stratmat rock. The nitrogen detected on the surface of the Stratmat rocks could be derived from an organic source such as an amino acid. If this is true, the nitrogen data would indicate a higher level of biological activity and on the surface of the Stratmat rock than on the Selbaie rock. Increased biological activity, especially that of iron-oxidizing bacteria, could increase sulphide oxidation rate. Although the Selbaie rock is denser and contains more fine-grained pyrite than the Stratmat rock, both rocks have essentially similar pore size distribution and porosity.

The results of the post-testing study suggest that pyrite content and morphology, rock density, grain size and porosity cannot explain the difference in acid production between the Stratmat and Selbaie rocks, observed during the three-year column leach tests. The presence of higher concentrations of impurities such as silicate minerals in the gangue contained in the Stratmat rock appears to be a more likely explanation for the difference in acid production. Bacteria could also be playing a role in the difference in acid generation.

5.0 CONCLUSIONS

1. The Stratmat rock produces nearly four times more acid than the Selbaie rock during laboratory leaching (deionized distilled water) of 25-50 mm particles.

2. The difference in acid production can be explained by the presence of greater amounts of impurities in the form of gangue minerals (predominantly silicates such as illite) present in the Stratmat rock.

3. During 75 days of more aggressive laboratory leaching (dilute sulphuric acid solution at pH of 2.3) of -0.420 mm particles, the Selbaie rock released more iron, zinc and lead than the Stratmat rock.

4. The Selbaie rock contains finer-grained pyrite in solid solution with other sulphides (ZnS and PbS). The pyrite and the associated with sulphides exposed a larger surface area when particle size is small, resulting in a higher rate of leaching.

5. At the end of the three years of leaching, the flooded Stratmat rock showed higher amounts of residual acid-consuming silicates (mainly illite) than the control Stratmat rock. The surface coating reached 600 Å in some samples.

6. Oxidation products present on the surface of the Stratmat rock consist of iron sulphate (possibly jarosite), gypsum and iron aluminosilicates containing K and Mg.

7. Predominantly iron oxide coating present on the surface of the Stratmat rock is only 15 Å thick.

8. The unoxidized Stratmat and Selbaie rocks have similar porosities (0.006-0.009) and pore size distribution (O.Ol- 100 μm). The oxidized Stratmat rock is more porous with porosities in the range of 0.01 l-0.030 and a higher proportion of 0.01-100 μm pores.

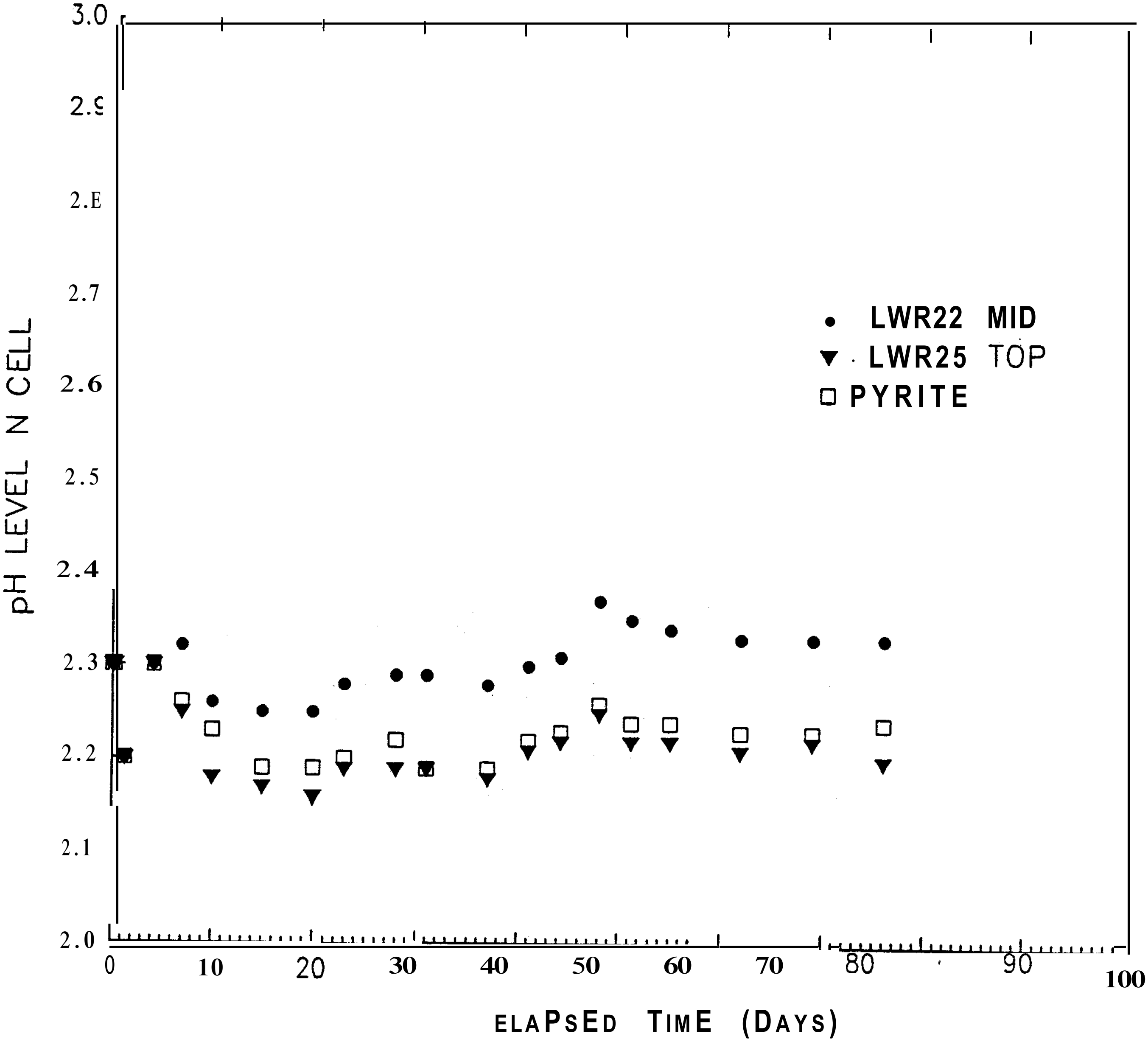


Figure 3-1.: pH versus elapsed time during leaching of unoxidized Stratmat and Selbaie rocks and Stratmat pyrite

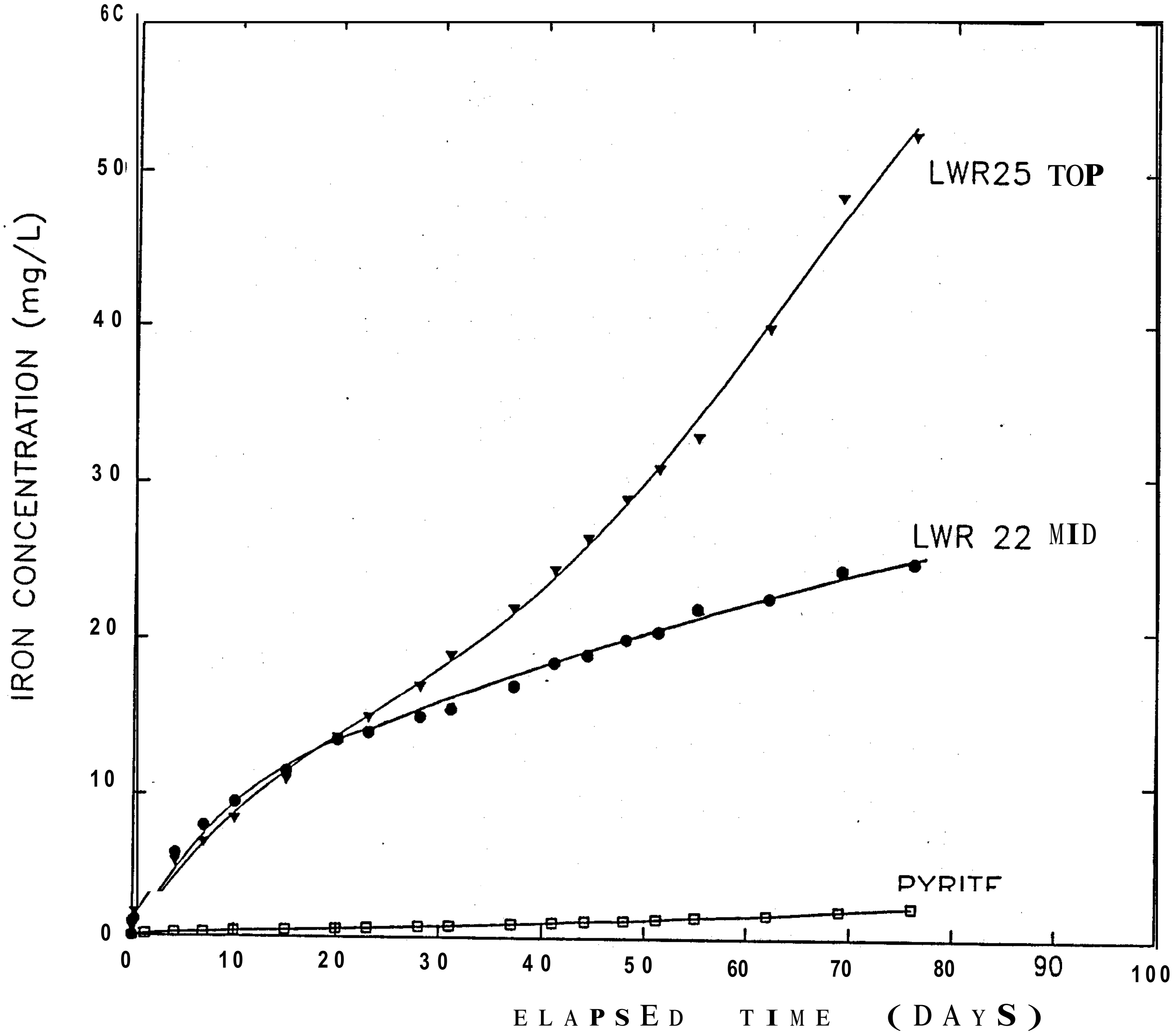


Figure 3-2: Iron concentrations versus elapsed time during leaching of unoxidized Stratmat and Selbaie rocks and Stratmat pyrite

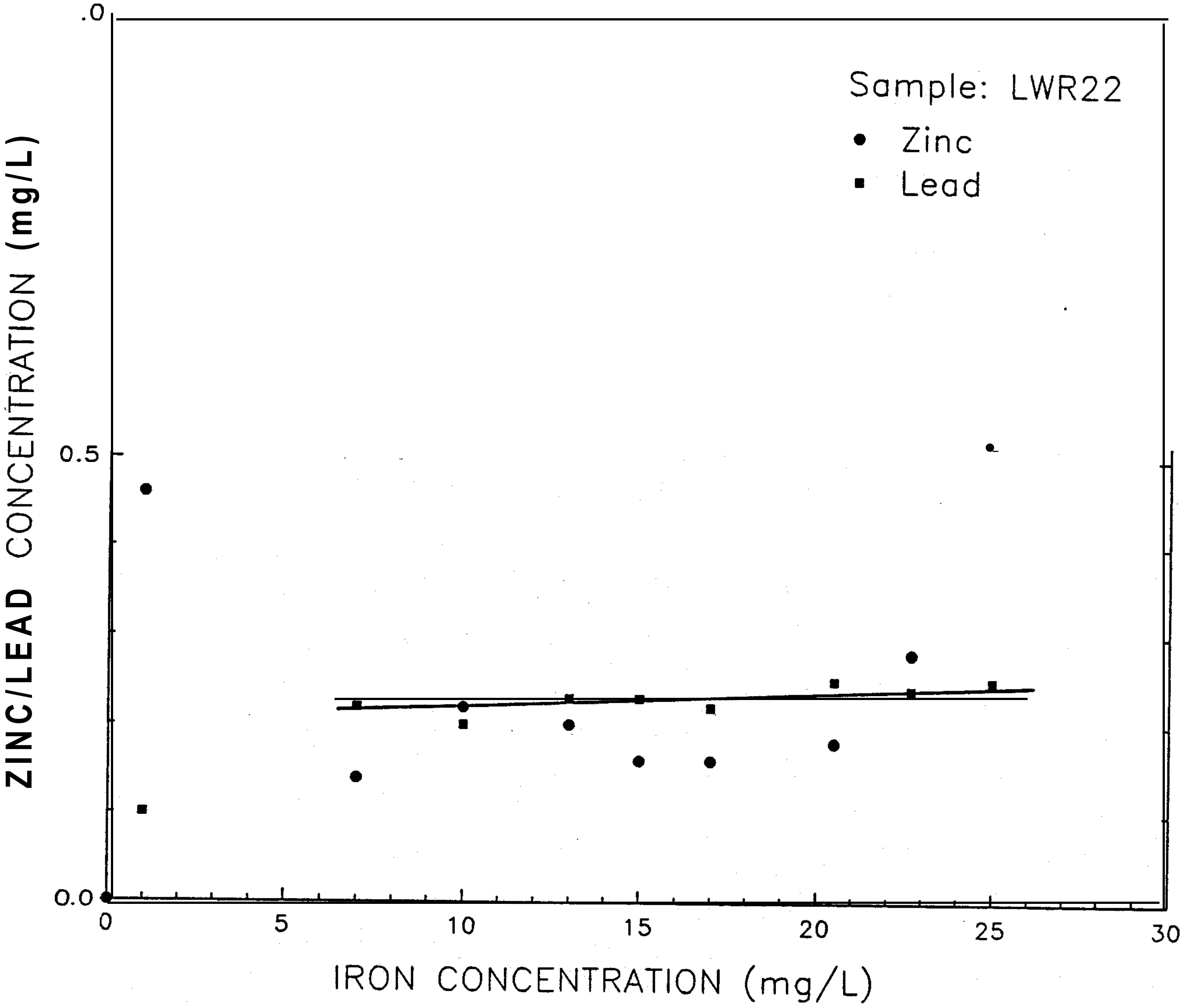


Figure 3-3: Zinc and lead concentrations versus iron concentrations during leaching of unoxidized Stratmat rock (LWR22)

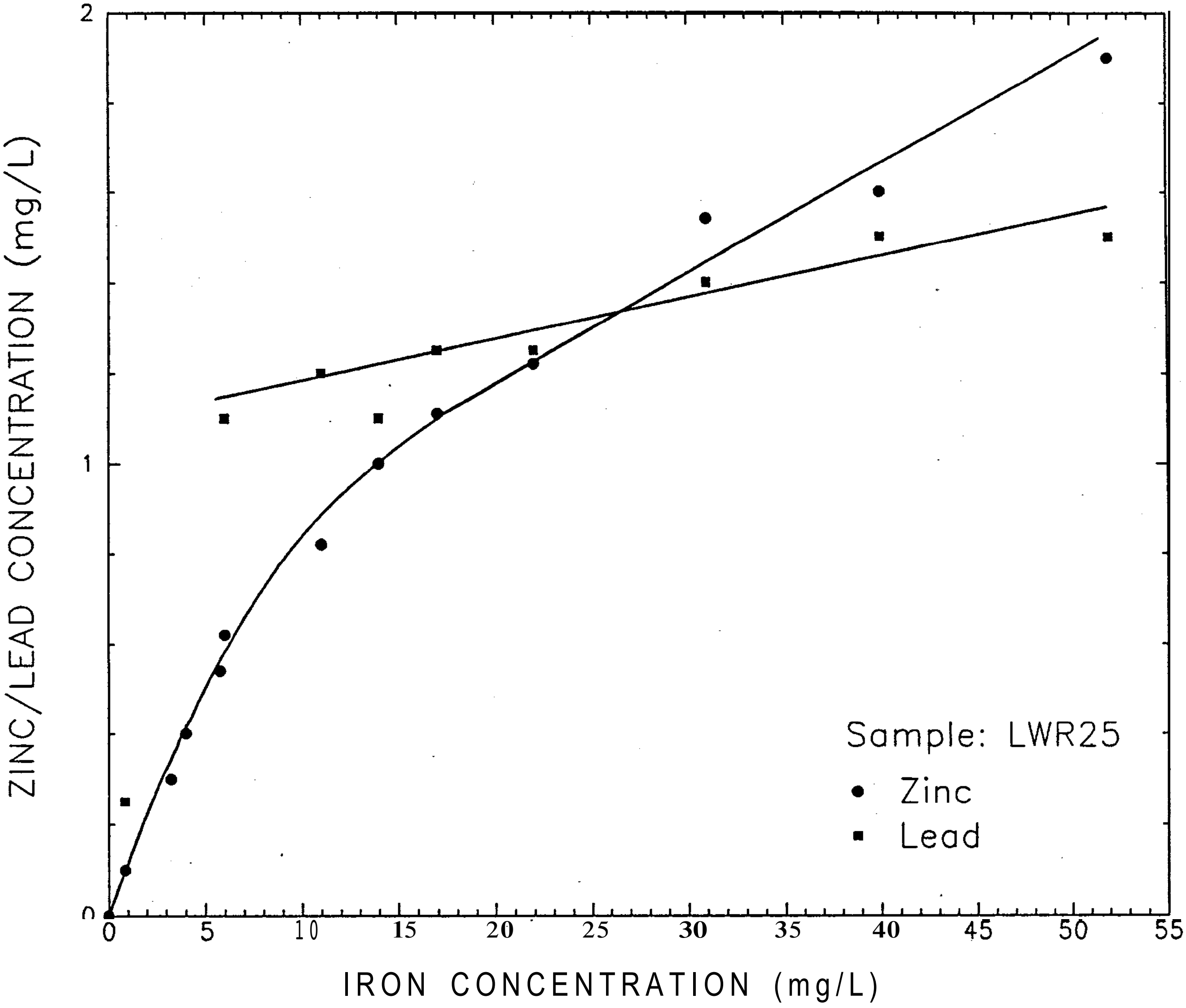


Figure 3-4: Zinc and lead concentrations versus iron concentrations during leaching of unoxidized Selbaie rock (LWR25)

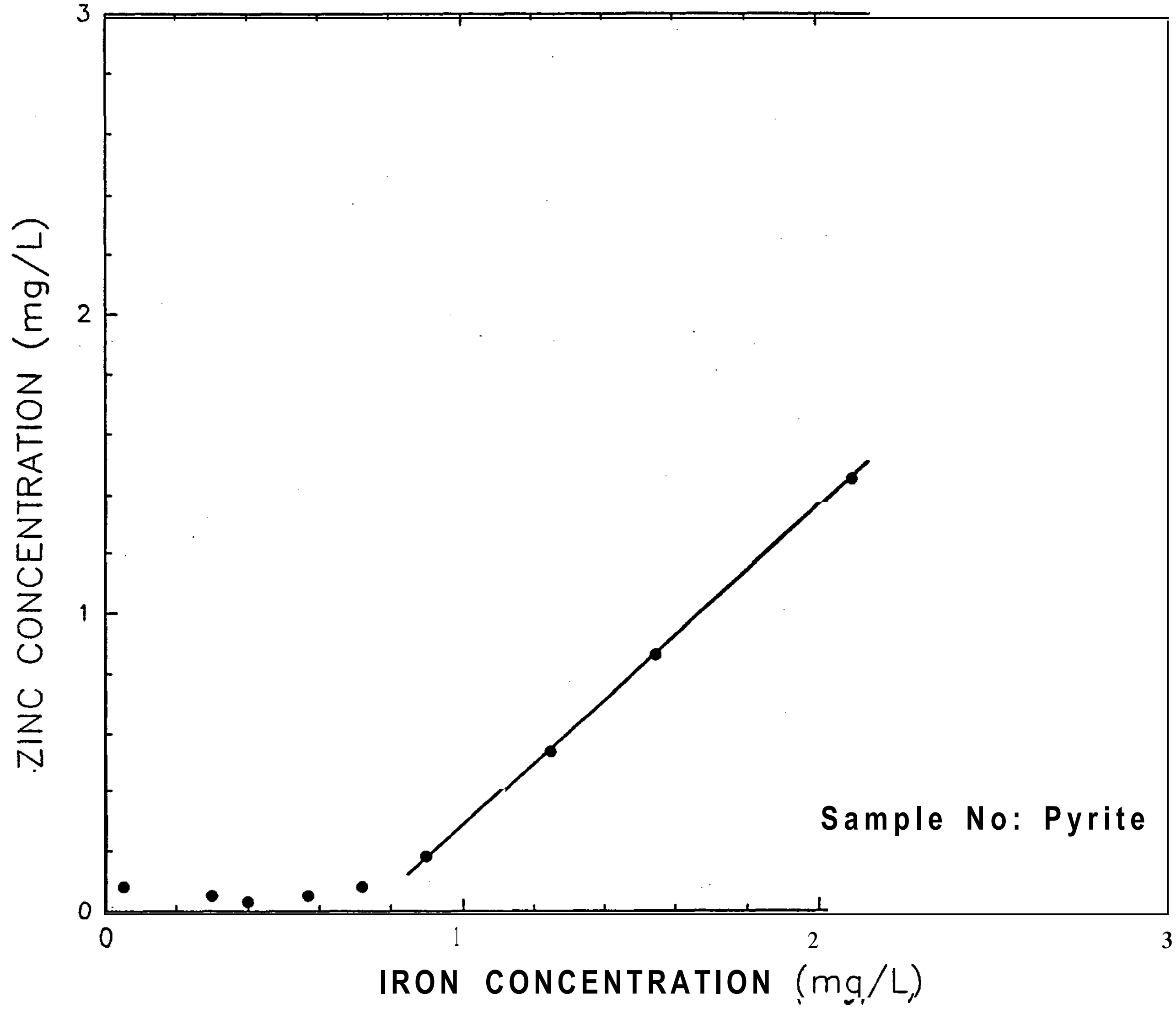


Figure 3-5: Zinc concentrations versus iron concentrations during leaching of Stratmat pyrite

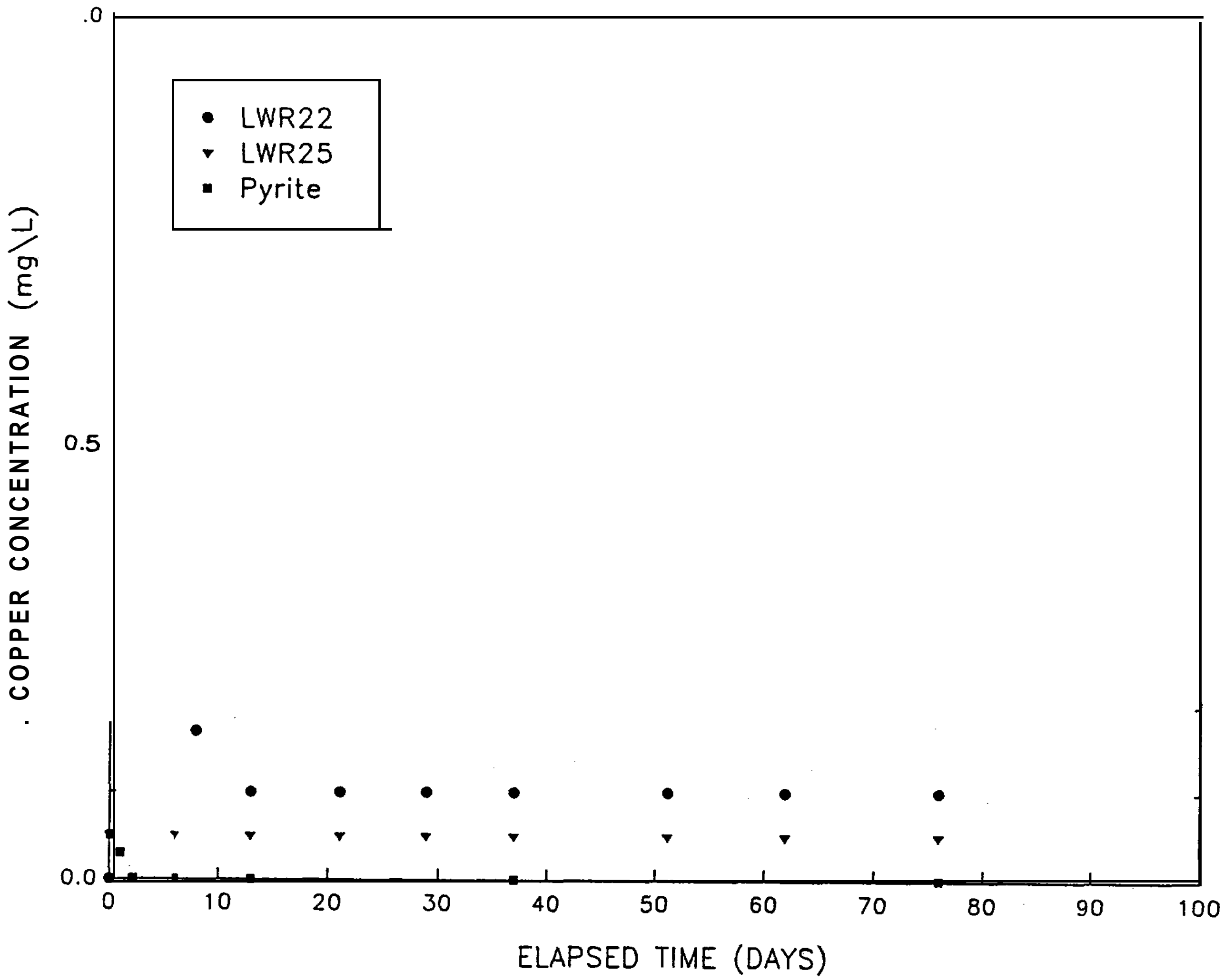


Figure 3-6: Copper concentrations during leaching of unoxidized Stratmat rock (LWR22), Selbaie rock (LWR25) and Stratmat pyrite

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APPENDIX C

A MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION OF MINE WASTE AND TREATMENT MATERIALS

(McGill University)

A Mineralogical and Geochemical Characterization of Mine Waste and Treatment Materials: Prevention and Control of Acid Generation in Waste Rock Experiment, Noranda. Technology Centre

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Summary

Thin section and chemical analyses were performed on eight rock samples from the Noranda Technology Centre's lysimeter experiments in order to determine their mineralogical content and geochemical composition. Six samples from the Stratmat site, Bathurst, New Brunswick are variably sheared, sericitized and pyritized meta-rhyolite composed of muscovite, quartz and pyrite with minor amounts of micro&e, albite, chlorite, dolomite, chalcopyrite, sphalerite and magnetite. A single sample from Salbaie, Quebec consists of dominantly pyrite and quartz with minor amounts of ankerite and chlorite. Two treatment materials were also studied. The first, a limestone from Montreal, consists of sparry and micritic calcite with minor amounts of quark. Limestone fragments are coated with microbreccia cemented with an iron-rich matrix. The second treatment material is a phosphorite from New Brunswick which is composed of predominantly cryptocrystalline hydroxyl-apatite with lesser amounts of quartz and carbonate. The phosphorite appears to contain abundant organic material which may have important implications for the phosphorite's long term ability as a acid neutralizer.

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1.0 Introduction

A comprehensive mineralogical and geochemical study has been undertaken to determine the characteristics of mine waste and treatment materials being used in the Noranda Technology Centre's lysimeter experiments. These experiments are designed to determine the efficacy of various treatment materials as neutralizers of acid mine drainage. Geochemical modelling of effluents, which is being performed at this time, are studying the aqueous reactions which are occurring in the lysimeters. In order to completely characterize the water-rock interactions taking place it is necessary to have complete mineralogical and geochemical information on the various rock materials involved.

This report describes results from thin section, chemical analyses and microprobe work performed on the above materials.

2.0 Sample Material and Preparation

2.1 Sample Material

Six samples of coarsely crushed mine waste rock were received for this study. Five of these samples originated from the Stratmat site, Bathurst, N.B. (Stratmat 1-5) while the sixth was from Salbaie, Quebec. Approximately five kilograms of each waste rock sample were received.

The five samples from Stratmat 'consist of gray-green, variably sheared, sericitized and pyritited, greenschist facies meta-rhyolite (meta-rhyolite is here classified as a low-grade metamorphosed, felsic volcanic rock). Minor rock types also found in these samples include several pieces of quartz-chlorite vein as well as one piece of concrete. The Salbaie sample consists of massive sulphide with appreciable quartz veining and visible sphalerite mineralization. Table 1 summarizes the lithological composition of the above six samples.

Two samples of treatment materials, each weighing approximately three kilograms were also studied. The samples were a finely crushed pink limestone from Montreal and

Table 1

Distribution of Waste Rock Lithological Types

Sample	Lithology	Volume % of Sample
Stratmat 1	Moderately sheared., sericitized, pyritiied meta-rhyolite (mr)	74%
	Moderately sheared, chbritic mr	19%
	Heavily sheared, sericii mr	5%
	Quartz Vein	2%
stratmat 2	Moderately sheared, sericitic mr	4%
	Moderately sheared, sericitic pyritic mr	58%
	Moderately sheared, chbriiic pyritii mr	11%
	Moderately sheared, chbritic mr	24%
	Quartz Vein	3%
Stratmat 3	Moderately sheared, sericitic pyritic mr	71%
	Moderately sheared, chbriiic mr	21%
	Heavily sheared, sericitii mr	5%
	Quartz Vein	3%
Stratmat 4	Moderately sheared, sericitic pyritii mr	78%
	Moderately sheared, chbriiic biititic, pyritii mr	15%
	Moderately sheared, chbritic mr	6%
	Quartz Vein	1%
Stratmat 5	Moderately sheared, sericitic pyritii mr	80%
	Moderately sheared, chloritic biititic, pyritii mr	15%
	Moderately sheared, chloritic mr	4%
	Concrete	1%
Salbaie	Massive Sulphide with quartz veining	98%
	Quartz Vein	2%

beige, hydraulically-processed phosphorite from New Brunswick.

2.2 Sample Preparation

In order to obtain a representative geochemical analysis for each sample all eight samples were prepared as follows:

1. Sample was split into two equal portions and one half was crushed using a jaw crusher;

2. The coarsely crushed material was split using a riffle and one half was finely crushed using an alumina disc mill;

3. The finely crushed material was split and one half was ground to powder using a hardened steel puck grinder;

4. A sample of approximately 100 g of this powder was submitted for geochemical analysis.

A single piece of waste material from each Stratmat and the Salbaie sample was taken for thin sectioning. Samples were chosen such that each thin section represented an apparently different lithology. It should be noted, therefore, that the geochemical analyses (Section 4.0) represent the overall composition of the larger waste rock sample while the thin section descriptions represent the lithology of only one piece of waste rock from each of the larger samples. For this reason the thin sections are identified by the sample names NOR1-NOR8 to avoid confusion.

Thin sections of single pieces of treatment material, i.e. limestone and phosphorite, could not be made because of their small grain size and low durability. To avoid this problem several grains of each treatment material were first mounted in epoxy which allowed them to be then made into a polished thin section.

3.0 Mineralogy

3.1 General Statement

The eight samples are divided into three groups: the Stratmat samples (NOR1-NOR5); the Salbaie sample (NOR6); and the treatment materials (NOR7-NOR8). The following are brief descriptions which serve to introduce the more detailed mineralogy described in the next section.

The Stratmat samples can be classified as meta-rhyolites which have undergone variable amounts of sericitization (potassium metasomatism) and pyritization (addition of iron and sulphur) as a result of hydrothermal fluid circulation during the formation of the accompanying massive sulphide deposit. After mineralization the host lithologies were deformed during the multiple deformation episodes characteristic of the Bathurst Camp. This resulted in the variable degrees of shear present in the Stratmat samples.

The Salbaie sample (NOR6) consists of massive pyrite, again of volcanogenic origin, which must have been deposited as a stratiform sulphide layer. After deposition this massive pyrite was extensively fractured and an episode of quartz deposition accompanied by ankerite, sphalerite and chalcopyrite filled these fractures.

The limestone treatment material consists of sparry and micritic calcite with variable amounts of silt-sized quartz grains. Limestone fragments are coated with iron-enriched microbreccia probably of man-made origin. Phosphorite consists of a mixture of massive and brecciated, extremely fine hydroyxl-apatite with variably amounts of sand-sized quartz grains. Table 2 lists the minerals found in each sample along with each minerals' composition.

3.2 Detailed Descriptions

39.1 NOR1 (from Stratmat 1)

In hand sample NOR1 is a graygreen muscovite-pyrite schist with a pronounced foliation. In thin section the sample consists of platy and acicular preferentially-oriented muscovite 10 to 200 µm in size (Fig. 1). Massive radiating areas of muscovite represent pseudomorphs after potassium feldspar and plagioclase phenocrysts. Pyrite and quartz are the only other major phases present with pyrite occurring as subhedral to euhedral grains

Table 2

Summary of **Mineralogical Composition** of Mine **Waste** Samples

sample	**Mineral**	**Composition**
NOR1 (from Stratmat 1)	Muscovite	$KFe_{0.14}Mg_{0.31}Al_{1.55}Si_{3.37}Al_{0.63}O_{10}(OH)_2$
	Chbriie	$Fe_{6.17}Mn_{0.14}Mg_{3.34}Al_{2.35}Si_{5.60}Al_{2.40}O_{20}(OH)_{16}$
	Pyrite	FeS_2
	Quartz	SiO_2
	Magnetite	Fe_3O_4
	Chabopyrite	CuFeS,
	Sphalerite	ZnS
	Bornite	$CuFe_5S_4$
NOR2 (from Stratmat 2)	**Muscovite**	$KFe_{0.13}Mg_{0.28}Al_{1.58}Si_{3.35}Al_{0.65}O_{10}(OH)_2$
	Microcline	$KAlSi_3O_8$
	Albite	$NaAlSi_3O_8$
	Quartz	SiO_2
	Pyriie	FeS_2
	Chalcopyrite	CuFeS,
	Sphalerite	ZnS
NOR3 (from Stratmat 3)	Muscovite	$KFe_{0.17}Mg_{0.34}Al_{1.53}Si_{3.37}Al_{0.63}O_{10}(OH)_2$
	Biotite	$KFe_{1.04}Mg_{1.51}Mn_{0.03}Al_{0.99}Si_{2.80}O_{10}(OH)_2$
	Microcline	$KAlSi_3O_8$
	Albite	$NaAlSi_3O_8$
	Ferroan Dolomite	$Ca_{0.52}Mg_{0.30}Fe_{0.09}Mn_{0.08}CO_3$
	Quartz	SiO_2
	Pyrite	FeS_2
NOR4 (from Stratmat 4)	Muscovite	$K_{0.85}Fe_{0.12}Mg_{0.19}Al_{1.69}Si_{3.37}Al_{0.63}O_{10}(OH)_2$
	Microcline	$KAlSi_3O_8$
	Albite	$NaAlSi_3O_8$
	Quartz	SiO_2
	Pyrite	FeS_2
	Chalcopyriie	CuFeS,
	Magnetite	Fe_3O_4
NOR5 (from Stratmat 5)	Muscovite	$K_{0.83}Fe_{0.22}Mg_{0.34}Al_{0.23}Si_{3.44}Al_{0.56}O_{10}(OH)_2$
	Biotite	$K_{0.97}Fe_{0.86}Mn_{0.04}Mg_{1.71}Al_{1.25}Si_{2.98}O_{10}(OH)_2$
	Microcline	$KAlSi_3O_8$
	Albite	$NaAlSi_3O_8$
	Quartz	SiO_2
	Pyrite	FeS_2
	Chalcopyrite	$CuFeS_2$
NOR6 (from Salbaie)	Chlorite	$Fe_{6.64}Mn_{0.02}Mg_{2.63}Al_{2.72}Si_{5.20}Al_{2.80}O_{20}(OH)_{16}$
	Ankerite	$Ca_{0.51}Mg_{0.20}Fe_{0.25}Mn_{0.03}CO_3$
	Quartz	SiO_2
	Sphalerite	ZnS
	Chabopyrite	$CuFeS_2$
	Pyrite	FeS_2
NOR7 (Limestone)	Calcite	$Ca_{0.99}Mg_{0.01}CO_3$
	Quartz	SiO_2
NOR6 (Phosphate)	**Apatite**	$Ca_5(PO_4)_3(OH)$
	Quartz	SiO_2
	Bitumen	?
	Carbonate	?

up to 1000 μm in size. Quartz (20 - 300 pm) is closely associated with pyrite where it occurs as pressure shadows (pressure shadows result when a rock containing a competent mineral such as pyrite is deformed). Other phases of minor importance in this sample include isolated patches of subhedral chlorite (10 - 200 μm) associated with pyrite, magnetite as anhedral polycrystalline aggregates (<50 pm), and trace amounts of chalcopyrite/bornite (<50 pm) as exsolutions in pyrite. Sample NOR1 is an excellent example of a thoroughly sercitized and pyritized metavolcanic, the original phenoctysts and groundmass having been completely replaced by secondary minerals.

3.2.2 NOR2 (from Stratmat 2)

NOR2 is a finegrained, relatively massive white to beige rock with spaced greenish foliations. In thin section it is composed of very fine equant quartz,, microdine and plagiodase about 20 μm in size as well as isolated microcline and rare plagioclase phenocrysts up to 600 μm in size. Phenocrysts contain abundant flecks of muscovite indicating that they have undergone the beginning stages of potassium metasomatism. The greenish foliations consist of platy anhedral seams of muscovite (up to 800 μm). Pyrite, occurring as subhedral crystals (up to 500 pm), is only a minor phase in this sample. Other minor phases present are sphalerite and chalcopyrite which are associated with a single quartz vein cutting the sample. The well-preserved primary textures and the relative lack of pyrite indicates that this sample is meta-rhyolite which has undergone very limited hydrothermal alteration.

3.2.3 NOR3 (from Stratmat 3)

In hand sample NOR3 consists of a moderately to poorly-foliated beige to green schist containing minor sulphides. In thin section this sample has zones composed of finely intergrown quartz, microdine and plagioclase (about 20 μm in size) with isolated microcline and plagioclase phenocrysts much like sample NOR2, however, in other areas, extensive replacement by anhedral masses of muscovite and suhedral pyrite has occurred (Fig. 3).

Ferroan dolomite occurs as rims around pyrite (Fig. 3) most likely as a replacement phase. Minor phases present include magnetite and biotite. This sample is an example of meta-rhyolite which has undergone incomplete potassium metasomatism. It has abundant areas where the meta-rhyolitic texture was preserved but other areas where metasomatism was extensive.

39.4 NOR4 (from Stratmat 4)

NOR4 is a strongly banded gray to beige schist with abundant pyrite mineralization. In thin section it can be seen that this sample displays the two extremes in potassium metasomatism and deformation. The beige bands consist of well-preserved meta-rhyolite composed of very fine-grained (20 - 100 pm) equant intergrowths of quartz, plagioclase and microcline as well as phenocrysts of microdine (Fig. 4). Microcline phenocrysts (<600 µm) contain abundant replacement muscovite. The grayish bands are zones of well-foliated, platy muscovite with associated crystals of pyrite (up to 1000 pm). Pyrite has adjacent pressure shadows of quark indicative of continued deformation after pyrite growth. Minor phases present include chalcopyrite and magnetite. This sample shows shearing controlled by earlier metasomatism. Areas of potassium metasomatism created zones of weakness which were then preferentially sheared during deformation.

32.5 NOR5 (from Stratmat 5)

Sample NOR5 is a massive, green, soft rock with considerable pyrite (1520%). In thin section it consists of platy muscovite either as very fine-gained masses aligned in sheared areas or as a strawlike sheaths which have replaced microcline phenocrysts (20 • 200 µm). The second most abundant phase is pyrite which occurs as subhedral to euhedral grains (50 - 2000 pm) containing rings of solid indusions. Quartz occurs as anhedral polycrystalline masses associated with pyrite. Most of the quartz grew due to pressure shadowing during deformation. Minor phases include biotite and chalcopyrite. This sample is similar to NOR1 except that the degree of deformation is less.

32.6 NOR6 (from Saibaie)

Sample NOR6 is massive sulphide composed predominantly of pyrite but with minor amounts of sphalerite associated with extensive quartz veining. In thin section the sample consists of pyrite formed by agglomerations of small pyrite cubes. The massive pyrite has been extensively fractured (Fig. 6) and infilled with coarse quartz and ankerite (up to 2000 µm, Fig. 7). Minor amounts of coarse brown sphalerite with exsolved blebs of chalcopyrite ("chalcopyrite disease") are present in the quartz veins (Fig. 8); An iron-rich chlorite is a very minor vein phase in this sample.

32.7 Limestone Treatment Material

The limestone treatment material consists of previously crushed, rounded pebbles which are pink in colour and up to 2 cm in diameter. in thin section the mineralogy is simple consisting of over 90% calcite with the remainder being quartz. Trace amounts of very fine magnetite/hematite and sericite were observed. Two types of limestone fragments are present; fragments composed of sparry calcite (up to 1000 µm, Fig. 9) and fragments containing up to 20% silt-sized quartz grains (Fig. 10). Most fragments were coated with microbreccia which was cemented with a reddish, iron-rich matrix (Fig. 9). Because this microbreccia is present only on the outside edges of the pebbles it is concluded that it was created during processing and not natural in origin.

32.6 Phosphorite Treatment Material

The phophorite treatment material consists of processed, rounded pebbles which are up to 1 cm in diameter and beige in colour. In thin section this material is composed of three distinct textures: wispy, brown-orange, cryptocrystalline material with very minor quartz; breccia-textured material with large sand grains of quark (up to 2000 µm, Fig. 1 1); and very finegrained, crystatiine material with abundant black inclusions (Fig. 12). Blue-green fluorescence in these black areas during microprobe work indicates the presence of hydrocarbons. The morphology of some of these hydrocarbon-rich areas suggests pseudomorphs after fossiliferous material.

3.3 Electron Microprobe Analyses

Electron microprobe analyses were performed on selected minerals from each polish thin section in order that these may be used to calculate the overall mineralogical composition of the waste and treatment rocks. A CAMEBAX electron microprobe, operated at 15 kV with a specimen current of 20 nA was used. Electron beam was defocussed to 2 µm for silicates and 8 µm for carbonates and phosphates. Results are listed in Tables 3 - 8. In total 110 points were analyzed with 73 analyses used in this study. The remainder were test results and standards. Only minerals considered highly variable in composition were analyzed. These include muscovite, biotite, chlorite, plagioclase, microdine. carbonates, and phosphates. Minerals such as quartz, pyrite and chalcopyrite are invariably stoichiometric and therefore it was considered unnecessary to analyze them.

Figure 13 and Tables 1 - 6 show the composition of the phyllosilicates present in samples NOR1 -NOR6. It can be seen that all muscovites are phengitic in composition (they contain high Si to Al and a significant ferromagnesian component). Biotites from NOR3 and NOR5 are high in aluminium relative to end member biotite. Chlorite in NOR1 and NOR3 are on the high aluminium side of clinochlore. All this is consistent with growth from a felsic precursor. The tectosilicates, microcline and albite, are extremely pure end member feldspars with no significant calcium component as is expected for a highly evolved greenschist facies metavolcanic. The carbonates from NOR3 are highly manganoan ferrodolomites while those from NOR6 (Salbaie) are ankerites. Although the high ferromagnesian content of dolomite in NOR3 is somewhat difficult to explain, the ankeritic composition of Salbaie carbonates is not. Mineralizing fluids would have been highly . enriched in Fe^{2+} and thus ankerite would have been stable over calcite or dolomite.

Table 1

oranda Project-Microprobe Analyses
ample: NOR1 (from Stratmat1)

Fluid-Rock Interactio Laborator
McGill Universit

Mineral Analysis	Muscovite 1	Muscovite 2	Muscovite 3	Muscovite 4	Chlorite 1	Chlorite 2	Chlorite 3	Chlorite 4	Chlorite 5
wt. %									
FeO	2.56	2.41	2.47	2.17	34.83	34.14	31.45	30.94	33.91
MnO	0.07	0.08	0.08	0.06	0.67	0.75	0.80	0.72	0.69
Na2O	0.16	0.12	0.13	0.15	0.00	0.00	0.02	0.02	0.01
SIO2	50.43	50.15	50.13	48.67	25.68	25.69	24.73	24.82	24.56
Al2O3	27.03	27.24	27.22	27.96	17.31	17.70	18.45	18.35	18.44
MgO	3.28	3.09	3.20	2.86	8.95	9.67	11.02	11.29	9.33
K2O	11.53	11.62	11.65	11.66	0.02	0.02	0.02	0.05	0.02
CaO	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.04	0.00
TIO2	0.36	0.33	0.32	0.42	0.09	0.11	0.05	0.07	0.11
Total	95.42	95.03	95.20	93.95	87.55	88.09	86.54	86.30	87.05
	Formula based on 11 oxygen8				Formula based on 28 oxygen8				
Fe	0.14	0.14	0.14	0.12	6.52	6.33	5.86	5.77	6.37
Mn	0.00	0.00	0.00	0.00	0.13	0.14	0.15	0.14	0.13
Na	0.02	0.02	0.02	0.02	0.00	0.00	0.01	0.01	0.00
SI	3.39	3.39	3.38	3.33	5.75	5.69	5.51	5.54	5.52
Al	2.14	2.17	2.16	2.25	4.57	4.62	4.05	4.02	4.66
Mg	0.33	0.31	0.32	0.29	2.99	3.19	3.66	3.75	3.12
K	0.99	1.00	1.00	1.02	0.00	0.01	0.00	0.01	0.00
ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
TI	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
let. Al	0.61	0.61	0.62	0.67	2.25	2.31	2.49	2.46	2.46
Oct.Al	1.54	1.55	1.55	1.56	2.32	2.31	2.36	2.36	2.40
Oct. Cations	2.01	2.01	2.01	2.00	11.95	11.97	12.04	12.02	12.02
Fe/(Fe+Mg)	0.30	0.30	0.30	0.30	0.69	0.66	0.62	0.61	0.67

Table 2

Notanda Project: Microprobe Analyses
Sample: NOR2 (from Stratmat 2)

Fluid-Rock Interaction Laboratoq
McGill Universit

Mineral Analysis	Muscovite 1	Muscovite 2	Muscovite 3	Muscovite 4	Albite 1	Albite 2	Albite 3	Albite 4	Microcline 1	Microcline 2
wt. %										
FeO	2.26	2.55	2.46	1.96	0.00	0.00	0.00	0.00	0.06	0.01
MnO	0.15	0.12	0.09	0.09	0.01	0.00	0.00	0.01	0.02	0.00
Na_2O	0.16	0.12	0.14	0.13	11.86	11.87	11.84	11.42	0.23	0.25
SiO_2	48.64	49.72	49.29	49.41	69.54	66.60	66.77	68.05	63.18	62.80
Al_2O_3	26.17	26.98	28.02	28.29	19.25	19.49	19.46	19.47	18.24	18.58
MgO	2.72	2.97	2.75	2.75	0.01	0.00	0.01	0.00	0.01	0.00
K_2O	11.45	11.55	11.31	11.72	0.09	0.08	0.09	0.74	16.68	16.90
CaO	0.00	0.00	0.02	0.01	0.03	0.04	0.06	0.16	0.00	0.00
TiO_2	0.40	0.42	0.56	0.34	0.00	0.00	0.01	0.00	0.00	0.00
Total	93.95	94.42	94.64	94.70	100.60	100.07	100.23	99.64	96.41	96.64
	Formula based on 11 oxygens				Formula based on 8 oxygens				Formula based on 8 oxygens	
Fe	0.13	0.14	0.14	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na	0.02	0.02	0.02	0.02	1.00	1.00	1.00	0.97	0.02	0.02
Si	3.32	3.36	3.34	3.34	3.01	2.99	3.00	2.99	2.96	2.96
Al	2.27	2.17	2.24	2.26	0.98	1.00	1.00	1.01	1.01	1.03
Mg	0.28	0.30	0.28	0.28	0.00	0.00	0.00	0.00	0.00	0.00
K	1.00	1.00	0.98	1.01	0.00	0.00	0.00	0.04	1.00	1.02
ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Ti	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Tot. Al	0.68	0.62	0.66	0.66						
Oct.Al	1.59	1.55	1.56	1.60						
Oct. Cations	2.01	2.00	2.01	1.99						
Fe/(Fe+Mg)	0.32	0.33	0.33	0.29						

Table 3a

Noranda Project-Microprobe Analyses
Sample: NOR3 (from Stratmat 3)

Fluid-Rock Interaction Laboratory
McGill University

Mineral Analysis	Muscovite 1	Muscovite 2	Muscovite 3	Muscovite 4	Muscovite 5	Biitite 1	Biotite 2	Biotite 3	Microcline 1	Microcline 2	Microcline 3
wt. %											
FeO	2.50	2.69	2.25	3.67	3.54	16.32	16.50	16.14	0.01	0.01	0.03
MnO	0.02	0.10	0.06	0.08	0.09	0.43	0.36	0.45	0.00	0.00	0.00
Na2O	0.11	0.12	0.14	0.16	0.12	0.03	0.05	0.06	0.21	0.18	0.22
SiO2	51.43	50.63	50.80	49.01	47.79	36.54	35.46	37.73	65.95	64.44	64.09
Al203	26.14	27.79	27.16	26.37	28.19	16.87	17.03	15.73	17.66	18.22	18.34
MgO	3.68	3.17	3.07	4.10	3.06	12.84	13.89	13.14	0.00	0.00	0.00
K2O	11.19	11.43	11.26	11.46	11.34	10.27	10.42	10.25	16.66	16.80	17.21
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TiO2	0.23	0.31	0.20	0.45	0.52	1.58	0.86	1.82	0.00	0.00	0.00
Total	95.29	96.23	94.93	95.31	94.65	94.88	94.61	95.32	100.51	99.65	99.89
	Formula based on 11 oxygens					Formula based on 11 oxygens			Formula based on 8 oxygens		
Fe	0.14	0.15	0.13	0.21	0.20	1.04	1.06	1.03	0.00	0.00	0.00
Mn	0.00	0.01	0.00	0.01	0.00	0.03	0.02	0.03	0.00	0.00	0.00
Na	0.01	0.02	0.02	0.02	0.02	0.00	0.01	0.01	0.02	0.02	0.02
Si	3.45	3.37	3.42	3.33	3.27	2.79	2.72	2.87	3.03	3.00	2.96
Al	2.07	2.18	2.15	2.11	2.27	1.52	1.54	1.41	0.96	1.00	1.01
Mg	0.37	0.31	0.31	0.42	0.31	1.46	1.59	1.49	0.00	0.00	0.00
K	0.96	0.97	0.97	0.99	0.99	1.00	1.02	0.99	0.98	1.00	1.02
Ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.01	0.01	0.00	0.01	0.01	0.05	0.02	0.05	0.00	0.00	0.00
Tot. Al	0.55	0.63	0.56	0.67	0.73	1.21	1.26	1.13			
Oct. Al	1.51	1.56	1.57	1.45	1.54	0.32	0.27	0.28			
Oct. Cations	2.02	2.03	2.01	2.08	2.06	2.85	2.94	2.82			
Fe/(Fe+Mg)	0.28	0.32	0.29	. 0.33	0.39	0.42	0.40	0.41			

Table 3b

Noranda Project ▪ Microprobe Analyses
Carbonates: NOR3 (from Stratmat3) and NOR6 (from Salbaie)

Fluid-Rock Interaction **Laboratory**
McGill University

Sample **Mineral** **Analysis**	Stratmat 3 Dolomite 1	Stratmat 3 Dolomite 2	Stratmat 3 Dolomite 3	Salbaie Ankerite 4	Salbaie Ankerite 5	Salbaie Ankerite 6	Salbaie Ankerite 7	Salbaie Ankerite 8	Salbaie Ankerite 9
wt. %									
FeO	4.07	3.71	11.78	19.37	12.77	18.61	18.97	18.63	18.50
MnO	7.05	6.79	3.64	2.09	3.12	1.98	2.08	2.17	2.14
MgO	13.14	11.65	12.02	7.49	11.33	6.82	6.84	7.59	7.14
CaO	30.94	30.67	26.51	27.38	28.22	28.66	28.48	27.78	27.70
Total	55.19	52.82	53.86	56.32	55.44	56.07	56.36	56.18	55.48
	Based on 1 CO2			Based on 1 CO2					
Fe	0.05	0.05	0.17	0.28	0.18	0.27	0.27	0.27	0.27
Mn	0.10	0.10	0.05	0.03	0.04	0.03	0.03	0.03	0.03
Mg	0.32	0.29	0.30	0.19	0.28	0.17	0.17	0.19	0.18
Ca	0.53	0.56	0.48	0.50	0.50	0.53	0.52	0.51	0.52

Table 4

Noranda Project - Microprobe Analyses
Sample: NOR4 (from **Stratmat** 4)

Fluid-Rock Interaction Laboratory
McGill University

Mineral Analysis	Muscovite 1	Muscovite 2	Muscovite 3	Muscovite 4	Microcline 1	Microcline 2	Microcline 3	Albite 1	Albite 2
wt. %									
FeO	2.22	2.18	2.18	2.32	0.02	0.02	0.01	0.09	0.01
MnO	0.04	0.08	0.08	0.07	0.00	0.02	0.00	0.01	0.00
Na2O	0.12	0.12	0.09	0.09	0.21	0.21	0.24	11.67	11.40
SiO2	50.46	51.75	52.39	52.22	63.67	64.84	64.89	65.69	69.71
Al2O3	30.16	30.39	30.33	30.06	18.53	18.45	18.40	19.86	19.40
MgO	1.86	1.89	1.93	2.06	0.00	0.00	0.01	0.32	0.00
K2O	10.07	10.11	10.28	10.53	17.11	17.10	17.09	0.17	0.13
CaO	0.01	0.01	0.02	0.03	0.00	0.00	0.00	0.05	0.01
TiO2	0.75	0.70	0.80	0.84	0.00	0.01	0.02	0.13	0.02
Total	95.69	97.22	96.09	98.21	99.44	100.63	100.66	97.99	100.67
	Formula based on 11 **oxygens**				Formula based on 8 **oxygens**			Formula based on 8 **oxygens**	
Fe	0.12	0.12	0.12	0.13	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na	0.01	0.01	0.01	0.01	0.02	0.02	0.02	1.01	0.96
Si	3.34	3.37	3.36	3.36	2.97	2.99	2.99	2.94	3.02
Al	2.36	2.33	2.31	2.29	1.02	1.00	1.00	1.05	0.99
Mg	0.18	0.18	0.19	0.20	0.00	0.00	0.00	0.02	0.00
K	0.65	0.84	0.85	0.87	1.02	1.01	1.01	0.01	0.01
ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Tet. Al	0.66	0.63	0.62	0.62					
Oct. Al	1.70	1.70	1.69	1.67					
Oct. **Cations**	2.01	2.00	2.00	2.00					
Fe/(Fe+Mg)	0.40	0.39	0.39	0.39					

Table 5

Noranda Project • Microprobe **Analyses**
Sample: NOR5 (from **Stratmat** 5)

Fluid-Rock Interaction Laboratory
McGill University

Mineral Analysis	Muscovite 1	Muscovite 2	Muscovite 3	Muscovite 4	Muscovite 5	Muscovite 6	Biotite 1	Biotite 2	Microcline 1	Microcline 2	Microcline 3	Microcline 4
wt.%												
FeO	4.54	3.90	3.58	3.85	3.56	4.01	13.97	13.53	0.02	0.02	0.03	0.10
MnO	0.13	0.11	0.07	0.11	0.06	0.08	0.56	0.63	0.01	0.02	0.00	0.01
Na2O	0.07	0.11	0.09	0.10	0.10	0.10	0.09	0.06	0.29	0.25	0.31	0.27
SiO2	51.36	51.54	51.66	51.55	52.32	52.26	40.13	39.86	64.76	63.89	64.96	63.88
Al2O3	26.18	26.32	26.32	26.36	27.08	26.52	14.26	14.28	18.25	18.47	18.59	18.60
MgO	3.53	3.48	3.35	3.58	3.20	3.56	15.35	15.51	0.00	0.01	0.00	0.00
K2O	9.29	9.63	9.96	10.09	9.70	9.90	10.12	10.25	17.19	16.82	16.89	16.56
CaO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
rio2	0.60	0.58	0.46	0.56	0.51	0.20	1.37	1.25	0.00	0.00	0.00	0.00
Total	95.72	95.67	95.51	96.19	96.61	96.65	95.84	95.37	100.51	99.49	100.78	99.43
	Formula based on 11 oxygen8								Formula based on 8oxygens			
Fe	0.25	0.22	0.20	0.21	0.20	0.22	0.07	0.84	0.00	0.00	0.00	0.00
Mn	0.01	0.01	0.00	0.01	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00
Na	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.03	0.02
Si	3.43	3.44	3.45	3.43	3.45	3.45	2.98	2.97	2.99	2.96	2.99	2.98
Al	2.06	2.07	2.07	2.07	2.10	2.06	1.25	1.26	0.99	1.02	1.01	1.02
Mg	0.35	0.35	0.33	0.36	0.31	0.35	1.70	1.72	0.00	0.00	0.00	0.00
K	0.79	0.82	0.05	0.06	0.82	0.83	0.96	0.97	1.01	1.00	0.99	0.99
ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.02	0.01	0.01	0.01	0.01	0.01	0.04	0.04	0.00	0.00	0.00	0.00
let. Al	0.57	0.56	0.55	0.57	0.55	0.55	1.02	1.03				
Oct. Al	1.49	1.51	1.52	1.50	1.55	1.51	0.23	0.23				
Oct. **Cation**	2.11	2.08	2.06	2.07	2.06	2.09	2.83	2.84				
Fe/(Fe+Mg)	0.42	0.39	0.38	0.38	0.38	0.39	0.34	0.33				

Table 6

Noranda Project**-** Microprobe **Analyses**
Sample: NOR6 (from **Salbale**)

Fluid-Rock **Interaction** Laboratory
McGill University

Mineral Analysis	Chlorite 1	Chlorite 2
wt. %		
FeO	36.65	34.71
MnO	0.11	0.14
Na2O	0.01	0.05
SiO2	23.25	23.51
Al2O3	21.12	20.98
MgO	7.57	8.27
K2O	0.00	0.02
CaO	0.00	0.06
TiO2	0.04	0.06
Total	88.74	87.79
	Formula based on 28 **oxygens**	
Fe	6.82	6.46
Mn	0.02	0.03
Na	0.00	0.02
Si	5.17	5.23
Al	5.54	5.51
Mg	2.51	2.75
K	0.00	0.01
Ca	0.00	0.01
Ti	0.00	0.01
Tet. Al	2.83	2.77
Oct. Al	2.71	2.74
Oct. Cations	12.05	11.98
Fe/(Fe+Mg)	0.73	0.70

Table 7

Nomnda Project. Microprobe **Analyses**
INOR7 **(Limestone)**

Fluid-Rock Interaction Laboratory
McGill University

Sample **Mineral** **Analysis**	Limestone Calcite 1	Limestone Calcite 2	Limestone Calcite 3	Limestone Calcite 4	Limestone Calcite 5	Limestone Matrix 6	Limestone Matrix 7
wt. %							
FeO	0.03	0.13	0.06	0.25	0.03	10.34	3.30
MnO	0.01	0.05	0.00	0.00	0.02	0.08	0.06
MaO	0.20	0.30	0.36	0.23	0.24	0.76	0.53
CaO	55.51	54.83	55.01	53.25	55.08	18.28	18.24
Total	55.74	55.30	55.43	53.73	55.38	28.44	22.13
	Based on 1 CO2			Based on 1 CO2			
Fe	0.00	0.00	0.00	0.00	0.00	n.a.	n.a.
Mn	0.00	0.00	0.00	0.00	0.00		
Mg	0.01	0.01	0.01	0.01	0.01		
Ca	0.99	0.99	0.99	0.99	0.99		

Table 8

Wanda Project-Microprobe Analyses
NOR8 (Phosphorite)

Fluid-Rock Interaction Laboratory
McGill University

Sample Mineral Analysis	Phosphate Breccia 1	Phosphate Breccia 2	Phosphate Breccia 3	Phosphate Granule 4	Phosphate Matrix 5	Phosphate Matrix 6	Phosphate Matrix 7	Phosphate Matrix 8	Phosphate Matrix 9	Phosphate Brainy 10	Phosphate Centre 11
wt. %											
FeO	2.26	2.49	2.93	1.02	0.36	0.33	0.31	0.37	0.27	1.68	0.95
SiO_2	0.70	2.48	1.27	0.32	0.41	0.37	1.15	1.37	0.49	0.02	2.04
Al_2O_3	0.43	0.97	0.76	0.26	0.44	0.40	0.47	0.55	0.34	0.97	0.95
CaO	51.57	49.70	49.98	52.96	53.88	53.09	50.66	50.67	48.16	49.76	45.93
P_2O_5	36.49	35.15	35.64	37.78	40.26	39.06	32.83	33.22	33.66	37.67	31.24
Total	91.46	90.79	90.58	92.33	95.34	93.26	85.62	86.18	82.91	90.09	81.10
					Based on 12.5 oxygens						
Fe	0.17	0.18	0.22	0.07	0.02	0.02	0.02	0.03	0.02	0.12	0.08
Si	0.06	0.22	0.11	0.03	0.03	0.03	0.11	0.13	0.05	0.00	0.20
Al	0.04	0.10	0.08	0.03	0.04	0.04	0.05	0.06	0.04	0.10	0.11
Ca	4.86	4.68	4.75	4.91	4.78	4.83	5.13	5.06	4.97	4.70	4.85
P	2.72	2.62	2.68	2.77	2.82	2.81	2.62	2.62	2.74	2.81	2.60

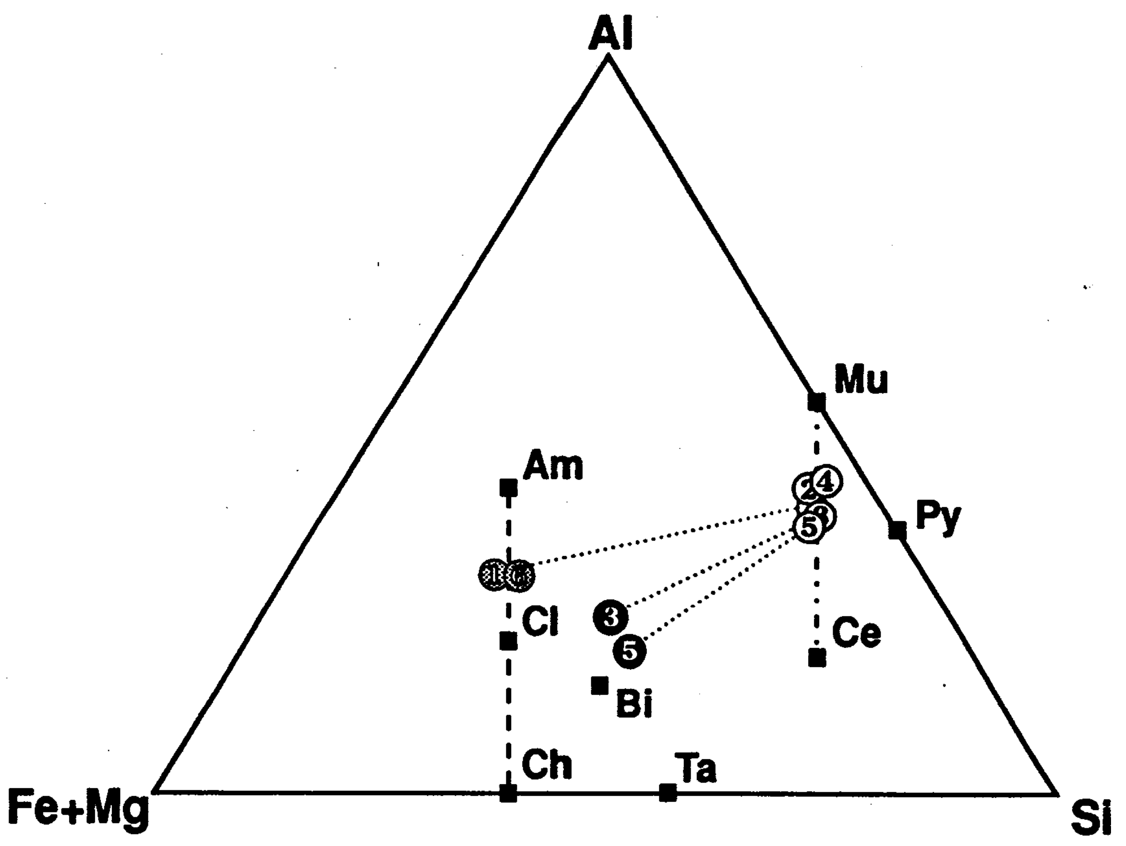

Fig. 13. Mole proportions of di-, tri- and quadrivalent cations in phyllosilicate minerals projected from H. Numerals on circles represent NOR sample number. Open circles are muscovite. Black circles are biotite. Gray circles are chlorite. Black squares represent end-member mineral compositions of muscovite (Mu), pyrophyllite (Py), celadonite (Ce), amesite (Am), clinochlore (Cl), chamosite (Ch), biotite (Bi) and talc (Ta).

Electron microprobe analysis of carbonate in the limestone treatment material shows it to be almost pure calcite (Table 7, Pt. I-5). However, analysis of the fine-grained matrix of the microbreccia indicates a high concentration of iron (which explains the red coloration of the limestone). This armouring of the limestone clasts may have potential importance to the long term abilii of the limestone to neutralize acid.

Analysis of selected points in the phosphorite indicates that the compositions are very dose to hydroxyl-apatite. The extremely fine-grained nature of the phosphate crystals make it difficult to get a dean analysis and therefore there appears significant SiO_2 and Al_2O_3 in these analyses. In order to verify the presence of hydroxyl-apatite a X-ray diffraction scan was performed. This scan verifies the presence of apatite as well as quartz (Appendix

1). If the phosphate was amorphous no apatite peaks should appear on the X-ray diffraction scan.

4.0 Geochemical Analyses

4.1 Analytical Techniques

For major and minor element analyses 0.200 g of rock powder were fused with 1.2 g of $LiBO_2$ and then dissolved in 100 ml of 5% HNO_3. This solution is then analyzed using an inductively-coupled plasma atomic emission spectrometer (ICP-AES). Trace element analysis for all other elements except gold were performed by leaching 1 g of rock powder with 50 ml of aqua regia and then analysis of the solution by ICP-AES. For gold, 10 g of rock powder are leached with aqua regia and then analysis by atomic absorption spectroscopy. Carbonate and total sulphur were determined by the induction method and FeO was determined by titration. The results from these geochemical analyses are reported in Table 9. It should be noted that the FeO reported includes only the FeO component in silicates, carbonates and phosphates and not in sulphide. The iron from sulphides is incorporated into the Fe_2O_3 value.

42 Geochemical Results

The following interpretations can be made on the Stratmat samples based on the geochemical results:

1. The Stratmat samples are essentially identical in compositon. The major variation is a minor spread in the SiO_2 values (51.87-57.96%). As SiO_2 decreases there is a corresponding increase in Fe_2O_3 (10.23 to 15.14%) and total S (7.95 to 10.8%). This is expected because as pyritization and potassium metasomatism increases a rock typically loses more quartz.

2. Na_2O contents are very low while K_2O contents are quite high. This is clearly indicative of the breakdown of feldspar and the addition of muscovite.

3. CO, contents are very low and therefore the analyses may not be reliable. This indicates that the waste material itself has little ability to neutralize acid generation from the pyrite.

4. Except for Zn, Ag and As, trace element contents are below detection limit.

However, analyses of effluents show measurable concentrations of Cu, Pb, Ni, and Cd. It may be necessary to analyze for these elements by another technique.

5. If SiO_2, Al_2O_3, Fe_2O_3, K_2O and S are added together these totals would comprise over 95% of the rock. Therefore it can be safely concluded that the Stratmat samples if taken as a single lithology can be represented by muscovite-pyrite-quartz schist. Other phase do not contribute significantly to the compostion.

The following observation can be made on the Salbaie sample:

1. The sample is composed of almost 50% S by weight with the remainder being Fe and Si. This supports the observed mineralogy of massive pyrite with quartz abundant quartz veining.

2. Carbonate is slightly enriched over the Stratmat samples. This would suggest that the Salbaie waste rock may initially have some ability to neutralize acid. This interpretation is supported by the near neutral pH's found in the effluents of the Salbaie control experiments relative to the acidic pH's from the Stratmat controls.

3. The Salbaie sample is enriched in Cu, Pb, Zn and Ag but the remaining trace elements were below detection limit. Again, it is suggested that another technique be used to analyze for these elements.

The following observations can be made about the treatment materials based on the geochemical results:

1. The limestone composed of dominantly of end member calcite and minor quartz. The origin of the iron-rich matrix of the microbreccia is perhaps due to the dissolution of calcite leaving a residual cement of ferric hydroxide. This is typical behaviour displayed by carbonates when exposed to groundwater.

2. The phosphorite contains a significant amount of carbonate, however no carbonate phases were observed. This may suggest an irregular distribution of carbonate minerals in the phosphorite.

3. Interestingly, the phosphorite contains a high Zn and Ag content. These elements may be associated with the abundant hydrocarbons found in thin section.

49 Weight and Volume Percent Composition of Waste and Treatment Rock

Estimates of the amount of each mineral present were made by combining the electron microprobe analyses with the whole rock geochemical data. This is done by using a least squares fitting technique where the matrix equation

$$[A][X]=[B] \tag{1}$$

is solved. The column vector X represents the molar proportion of each mineral in the rock.

The column vector B represents the molar proportion of the major elements contained in the rock. The coefficient matrix A contains the stoichiometric coefficients for each major element in each mineral. The coefficients in the A matrix are assumed for simple minerals (such as quartz and pyrite) and measured, using the electron microprobe, for complex minerals (such as muscovite and plagioclase). The B vector is calculated from the whole rock analysis. Therefore the vector of unknowns, X, contains the mole proportions of each mineral. The matrix equation is solved by first multiplying both sides by A^t giving

$$[A^tA][X]=[A^tB]. \tag{2}$$

The both sides of this equation are multiplied by $[A^tA]^{-1}$ to give

$$[A^tA]^{-1}[A^tA][X]=[A^tA]^{-1}[A^tB] \tag{3}$$

which equals $$[I][X]=[A^tA]^{-1}[A^tB] \tag{4}$$

therefore $$[X]=[A^tA]^{-1}[A^tB] \tag{5}$$

Equation (5) is the least squares solution for the number of moles of each mineral in the rock. This type of calculation was performed for the five Stratmat samples using the average muscovite compostion from Stratmat I-3 and the carbonate composition of Stratmat. Microcline, chlorite and biotite were not included because they are not significant phases and their introduction would serve only to increase error. Albite and carbonate must be used if Na_2O and C are included in the B vector. For Salbaie and the treatment rocks the above technique was not used because of their simple mineralogy. Results from these calculations can be found in Table 10 and an example of the matrix calculation is given in Appendix 2.

Inspection of Table 10 shows that the predicted mineral content of the Stratmat is dominated by muscovite, quartz and pyrite (in order of abundance) with minor albite and carbonate (note that accessory phases such as microcline, biotite, chlorite, etc. were not included in these calculations). When compared with the actual C content measured in whole rock analyses it would appear that the least squares fit method overestimates the

Table 10

Weight and Volume Percent Mineralogical Compostion of Waste Rock and Treatment Materials

Sample	**Mineral**	Weight **g/100 g**	Normalized Weight **%**	**Specific Gravity g/cm3**	Volume cm3	Normalized Volume %
Stratmat 1	Quart.2	31.6	33.5	2.65	12.6	37.4
	Muscovite	43.1	45.7	2.83	16.2	47.8
	Albite	3.5	3.7	2.63	1.4	4.1
	Dobmite	1.0	1.1	2.90	0.4	1.1
	Pyrite	15.1	16.0	4.95	3.2	9.6
	Total	94.3	100.0		33.8	100.0
		Density=	2.96	**g/cm3**		
Stratmat2	Quartz	27.6	29.4	2.65	11.1	32.8
	Muscovite	44.3	47.2	2.83	16.7	49.5
	Albite	5.7	6.0	2.63	2.3	6.8
	Dolomite	1.2	1.3	2.90	0.4	1.3
	Pyrite	15.2	16.1	4.95	3.3	9.7
	Total	93.9	100.0		33.8	100.0
		Density=	2.96	g/cm3		
Stratmat3	Quartz	30.2	31.8	2.65	12.0	35.9
	Muscovite	43.8	46.1	2.83	16.3	48.8
	Albite	2.9	3.1	2.63	1.2	3.5
	Dolomite	1.0	1.0	2.90	0.3	1.0
	Pyrite	17.1	18.0	4.95	3.6	10.9
	Total	95.1	100.0		33.5	100.0
		Density=	2.99	g/cm3		
Stratmat 4	Quartz	28.1	29.6	2.65	11.2	33.6
	Muscovite	42.1	44.4	2.83	15.7	47.3
	Albite	5.2	5.4	2.63	2.1	6.2
	Dobmite	0.9	1.0	2.90	0.3	1.0
	Pyrite	18.6	19.6	4.95	4.0	11.9
	Total	94.9	100.0		33.2	100.0
		Density=	3.01	g/cm3		
Stratmat 5	**Quartz**	25.1	26.8	2.65	10.1	30.8
	Muscovite	43.3	46.2	2.83	16.4	49.9
	Albite	3.9	4.2	2.63	1.6	4.8
	Dolomite	0.8	0.9	2.90	0.3	0.9
	Pyrite	20.6	22.0	4.95	4.4	13.5
	Total	93.7	100.0		32.8	100.0
		Density=	3.05	g/cm3		
Salbaie	Pyrite	76.4	74.8	4.95	15.1	61.7
	Ankerite	0.3	0.3	2.90	0.1	0.4
	Chbrite	2.1	2.1	3.00	0.7	2.8
	Quartz	23.3	22.8	2.65	8.6	35.1
		102.1	100.0		24.5	100.0
		Density=	4.08	g/cm3		

Table 10 (cont'd)

Sample	Mineral	Weight g/100 g	Normalized Weight %	Specific Gravity g/cm3	Volume cm3	Normalized Volume %
Limestone	Calcite	97.7	93.4	2.72	34.3	93.2
	Quartz	7.0	6.6	2.65	2.5	6.8
		104.6	100.0		36.8	100.0
		Density=	2.72 g/cm3			
Phosphate	Calcite	2.2	2.6	2.7	1.0	2.9
	Apatite	70.1	84.7	3.1	27.3	82.6
	Quartz	10.5	12.7	2.7	4.8	14.5
		82.7	100.0		33.1	100.0
		Density=	3.02 g/cm3			

amount of carbonate. The true carbonate contents of the Stratmat samples should **bemuch** less. The Salbaie waste rock is dominated by pyrite with subordinate quartz and minor carbonate and chlorite. The carbonate content for Salbaie is based on the assumption that all C in the whole rock analysis is as CO,, therefore, 0.4% is very close to the true carbonate content.

The mineralogy of the treatment materials is simple. The limestone consists of dominantly end member calcite with subordinate quartz. The phosphorite is comprised of predominantly apatite with subordinate quartz and calcite ($CaCO_3$ is the assumed carbonate composition).

5.0 Conclusions

Both mineralogical and **geochemical** results give sufficient evidence that the samples Stratmat I-5 from Bathurst, New Brunswick represent variably deformed **meta-rhyolites** which have undergone, prior to deformation, a potassic and **pyritic** metasomatic event. Thin sections showed a range of intensity **of** alteration from single muscovite seams and minor pyrite to complete replacement of all **meta-rhyolite** minerals by massive muscovite and pyrite. Geochemically Stratmat 1-5 are essentially the same in composition with the only significant variations occurring in SiO_2, Fe_2O_3 and S.

The Salbaie sample consist of massive pyrite which was extensively fractured and **infilled** with quartz, ankerite, sphalerite and chalcopyrite.

The limestone treatment material consists of essentially pure calcite with minor quartz. The rims of limestone fragments are coated with microbreccia which is cemented with an iron-rich matrix. The phosphorite treatment material consists predominantly of cryptocrystalline hydroxyl-apatite with minor amounts of quartz and carbonate.

The following interpretations or observations have implications to the iysimeter experiments:

1. Because of the predominance of muscovite, quartz and pyrite in the Stratmat samples, they can represented in a modeliing program such as EQ3/6 as rocks of that simple assemblage.

2. Carbonate contents of the Stratmat samples are low (probably lower than estimated in the least squares fit) and therefore they should have little ability to neutralize acid produced from the breakdown of pyrite. This is evident in the low pH's of effluents from the Stratmat control samples.

3. An important observation is the high volume proportion of pyrite. In the Stratmat samples it varies from 10 to 14%. In the Saibaie sample it comprises 62% of the volume of the rock.

4. A small amount of coarse ankerite present in the quartz veining in the Saibaie sample may explain the near neutral pH's found in the effluents from the Saibaie control lysimeters. It is not expected that this small amount of carbonate will be able to maintain these pH's for long.

5. The microbreccia coating the limestone treatment material may have two opposing effects on its efficiency as a acid neutralizer. The porous nature of the microbreccia may serve to increase the surface area of carbonate and therefore more efficiently trap and neutralize acid. However, neutralizing of acid is expected to produce more iron-rich residuum which may coat calcite and therefore reduce its efficiency as a neutralizer with time.

6. The phosphate treatment material appears to contain a significant amount of hydrocarbons. What will be the tong term effect of these on acid production and neutralization?

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Appendix A

XRD Scan of Phosphorite

Appendix 2

Example of Matrix Calculation

	Wt. %	Moles	Element	Moles
SiO2	57.96	0.9646	**Si**	0.9646
A1203	13.90	0.2727	Al	0.2727
Fe203	10.23	0.1281	Fe	0.1518
FeO	1.70	0.0237	**Mg**	0.0558
MgO	2.25	0.0558	ca	0.0020
CaO	0.11	0.0020	Na	0.0142
Na2O	0.44	0.0142	K	0.1151
K2O	5.42	0.1151	C	0.0075
C	0.09	0.0075	S	0.2480
S	7.95	0.2460		

= **[B]**

Multiply At by B

$$[AtB] = \begin{bmatrix} 0.96455 \\ 3.99175 \\ 3.18057 \\ 0.03891 \\ 0.64772 \end{bmatrix}$$

Multiply At A- ' by **AtB**

$$[AtA]^{-1}\,[AtB] = \begin{bmatrix} 0.5253 \\ 0.1189 \\ 0.0132 \\ 0.0110 \\ 0.1260 \end{bmatrix}$$

= least squares fit to mole3 of minerals

	Moles	Mole. Wt. g/mol	Wt. g	Norm. wt. %	**Spec.** Gmv. **g/cm3**	Vol. cm3	Norm. Vol. %
Quartz	0.5253'	60.08	31.56	33.46	2.65	12.6	37.4
Muscovite	0.1189	362.8	43.15	45.75	2.83	16.2	47.8
Albite	0.0132	262.2	3.47	3.68	2.63	1.4	4.1
Dobmfte	0.0110	93.17	1.02	1.08	2.90	0.4	1.1
Pyrite	0.1260	119.97	15.12	16.03	4.95	3.2	9.6
			94.3195	100.00		33.8	100.0
			Density=		2.96	g/cm3	

Noranda Project- Example of Least Squares Fitting of **Geochemical** Data
Fluid- Rock **Interaction** laboratory- McGill University

Stoichiometric Coefficient Matrix

$$[A] = \begin{array}{c|ccccc|} & \text{Quartz} & \text{Musc.} & \text{Albite} & \text{Dolomite} & \text{Pyrite} \\ \text{Si} & 1.00 & 3.36 & 3.00 & 0.00 & 0.00 \\ \text{Al} & 0.00 & 2.19 & 1.00 & 0.00 & 0.00 \\ \text{Fe} & 0.00 & 0.14 & 0.00 & 0.09 & 1.00 \\ \text{Mg} & 0.00 & 0.31 & 0.00 & 0.30 & 0.00 \\ \text{Ca} & 0.00 & 0.00 & 0.00 & 0.52 & 0.00 \\ \text{Na} & 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ \text{K} & 0.00 & 1.00 & 0.00 & 0.00 & 0.00 \\ \text{C} & 0.00 & 0.00 & 0.00 & 1.00 & 0.00 \\ \text{S} & 0.00 & 0.00 & 0.00 & 0.00 & 2.00 \end{array}$$

Transpose Matrix

$$[At] = \begin{bmatrix} 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 3.36 & 2.19 & 0.14 & 0.31 & 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 3.00 & 1.00 & 0.00 & 0.00 & 0.00 & 1.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.09 & 0.30 & 0.52 & 0.00 & 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 2.00 \end{bmatrix}$$

Multiply At by A

$$[AtA] = \begin{bmatrix} 1.00 & 3.36 & 3.00 & 0.00 & 0.00 \\ 3.36 & 17.20 & 12.27 & 0.11 & 0.14 \\ 3.00 & 12.27 & 11.00 & 0.00 & 0.00 \\ 0.00 & 0.11 & 0.00 & 1.37 & 0.09 \\ 0.00 & 0.14 & 0.00 & 0.09 & 5.00 \end{bmatrix}$$

Invert AtA

$$[AtA]^{-1} = \begin{bmatrix} 5.50 & -0.02 & -1.48 & 0.00 & 0.00 \\ -0.02 & 0.29 & -0.31 & -0.02 & -0.01 \\ -1.48 & -0.31 & 0.34 & 0.02 & 0.01 \\ 0.00 & -0.02 & 0.02 & 0.73 & -0.01 \\ 0.00 & -0.01 & 0.01 & -0.01 & 0.20 \end{bmatrix}$$

APPENDIX D

CARACTÉRISATION DE DOUZE ÉCHANTILLONS DE STÉRILES

(Centre de recherches minérales)

SERVICE DES PROJETS DE DÉVELOPPEMENT TECHNOLOGIQUE

PROJET 7215 K **002**

CARACTÉRISATION DE DOUZE ÉCHANTILLONS DE STÉRILES

Préparé par :
Pierre Lacoste
et
Jean-Fran@ Wilhelmy

Rapport final
Le 13 novembre 1991

CENTRE DE RECHERCHES MINÉRALES

Québec

Ministère de **l'Énergie** et des **Ressources**

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SERVICE' DES **PROJETS** DE **DÉVELOPPEMENT** TECHNOLOGIQUE

PROJET 7215 K 002

CARACTÉRISATION DE DOUZE ÉCHANTILLONS DE STÉRILES

RAPPORT FINAL
LE 13 NOVEMBRE 1991

COPIE NO : 2

Rapport destine **à** :

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Chef de service
Service du **développement** des **procédés** .

Signature :

Date : **Le 13** novembre **1991**

TABLE DES **MATIÈRES**

PAGE

1. INTRODUCTION

M. François Belle-Isle nous a soumis douze échantillons de stériles prélevés dans le cadre d'un projet entrepris par la compagnie Noranda. Cette etude inclut l'analyse modale (identification et calcul des proportions des minéraux presents) de même que l'observation des états d'altération des sulfures de fer (pyrite, pyrrhotite, marcasite).

2. CONCLUSIONS

Les kchantillons soumis sont massivement frais, ne presentant que très peu de marques d'altération météorique. Dans l'ensemble des échantillons, les phases minerales non-métalliques sont constituées de quartz, de mica, de chlorite, de feldspaths et de carbonate. La pyrite constitue la phase minérale métallique prédominante; seulement de rares traces de sphalérite et d'oxydes de fer ont Cd observées dans quelques échantillons.

3. PRINCIPAUX RÉSULTATS

Les 12 **échantillons** de **stériles** soumis appartiennent **à** la compagnie Noranda et sont **désignés** :

STRATMAT ROCK - CONTROL TEST IN
STRATMAT ROCK - CONTROL TEST OUT
STRATMAT ROCK - PHOSPHATE IN, TEST 37
STRATMAT ROCK - PHOSPHATE OUT, TEST 37
STRATMAT ROCK - LIMESTONE IN, TEST 37
STRATMAT ROCK - LIMESTONE OUT, TEST 37
LIMESTONE (STRAMAT)
PHOSPHATE (N.B.)
PHOSPHATE 1 - **12/8/91**
CONTROL - **12/8/91**
PHOSPHATE 2 - **12/8/91**
CONTROL 2 - **12/8/91**

[illegible]

Ces **échantillons** ont **subi** l'ensemble des **étapes présentées à** la section suivante.

3.1 Méthodologie

Les **échantillons** soumis furent d'abord **broyés, homogénéisés** et **tamisés à 200** mailles. Une portion des fractions **générées** de **+200** et -200 mailles furent **pulvérisées** aux fins d'analyses chimiques (oxydes majeurs, **carbone** total **exprimé** en CO, et soufre) et de la diffraction des rayons-X (identification formelle des phases presentes). Ces **résultats** ont permis, par la suite, **d'établir** les proportions de chacune des phases **présentes** (analyses **modales)** .

Des sections polies furent préparées à partir de la fraction +200 mailles afin de determiner la nature et la proportion des phases métalliques. Cette étape était particulierement nécessaire pour reconnaître adéquatement les différents sulfures, oxydes et hydroxydes de fer (pyrite, pyrrhotite, sphalérite, hematite, magnetite, limonite et goethite) qui ne pouvaient être «séparés» par l'analyse modale. Ces sections polies furent, de plus, examinées à l'analyseur d'images afin de determiner la granulométrie des phases minérales métalliques.

Les photomicrographies #1 à 32, présentées à l'annexe 1, montrent les textures typiques de ces échantillons.

3.2 Résultats des observations

Les résultats des observations et des analyses modales sont présentés et compiles aux tableaux I à XXIV, de l'annexe II, pour chacun des échantillons. On retrouve sur ces tableaux, la cartouche d'identification des échantillons, leur composition chimique (constituants et teneurs) dans la par-tie gauche de ces tableaux. La section de droite présente l'analyse modale des minéraux non-métalliques telle qu'interprétée d'après les résultats d'analyses chimiques. Des notes pertinentes aux pourcentages et granulométries et degré de liberation des phases métalliques sont présentées au tableau suivant et à l'annexe III.

4. COLLABORATION

Les auteurs de ce rapport tiennent à souligner la collaboration de MM. Bertrand Paquet, Jacques Cantin, et Daniel Moisan, techniciens, qui ont effectué les travaux de laboratoire. Également, il faut mentionner l'apport du personnel du laboratoire d'analyses et celui du secrétariat pour le travail de dactylographie.

Pourcentage des phases métalliques dans les échantillons

Échantillon	PYRITE			SPHALÉRITE		
	Total	Libre	Ass.	Total	Libre	Ass.
Strat. Control test in	99,9	99,9	0	0,1	0,1	0
Strat.Control test out	86,9	86,9	0	0,1	0,1	0
Start. Phosphate in	99,9	99,5	0,4	0,1	0	0,1
Strat. Phosphate out	100	100	0	0	0	0
Start. Limestone in	99,8	98,6	1,2	0,2	0,1	0,1
Strat. Limestone out	100	100	0	0	0	0
Limestone (*)						
Phosphate, N.B. (*)						
Phosphate 1, 12-8-91	99,9	99,7	0,2	0,1	0	0,1
Control, 12-8-91	99,1	98,6	0,5	0,9	0,5	0,4
Phosphate 2, 12-8-91	99,9	99,8	0,2	0,1	0	0,1
Control 2, 12-8-91	100	100	0	0	0	0

(*) Phase métallique en trop faible quantité pour une détermination

ANNEXE I
PHOTOMICROGRAPHIES

LÉGENDE

Lorsque l'échelle sur les photomicrographies est absente, on doit considérer que lcm = 200μm (soit un grossissement de X50).

Ces photomicrographies présentent les textures typiques de chacun des échantillons et permettent de les comparer entre eux. Quelques notes complètent les observations présentées aux tableaux du rapport.

 # 1 à 3 - Échantillon STRATMAT ROCK - CONTROL TEST IN; La pyrite constitue la phase métallique prédominante (en blanc). Des traces de spalérite (en gris) sont en inclusions dans la pyrite ou en grains libres (photo #1).

 # 4 à 6 - Échantillon STRATMAT ROCK - CONTROL TEST OUT; L'échantillon ressemble beaucoup à l'échantillon precedent, la pyrite semble Ctre un peu moins fine.

 # 7 à 9 - Échantillon STRATMAT ROCK - PHOSPHATE IN, TEST 37; La pyrite (en blanc) contient parfois des inclusions de silicates. Des traces de limonite sont en grains agglomérés avec les silicates (photo #8).

#10 à 12 - Échantillon STRATMAT ROCK - PHOSPHATE OUT, TEST 37; La pyrite est idiomorphe et contient à l'occasion des traces de sphalérite.

#13 à 15 - Échantillon STRATMAT ROCK - LIMESTONE IN, TEST 37; Des traces d'oxydes de fer et de sphène ont été observées dans cet échantillon.

#16 à 18 - Échantillon STRATMAT ROCK - LIMESTONE OUT, TEST 37; La pyrite montre des traces de fracture (photo #18) contenant de la limonite.

#19 à 21 - Échantillon LIMESTONE (STRAMAT) ; L'échantillon est constitué majoritairement 'de carbonate. On note l'absence de sulfure.

#22 à 23 - Échantillon PHOSPHATE (N.B.) ; L'échantillon contient seulement des traces de minéraux métalliques (pyrite).

#24 à 26 - Échantillon PHOSPHATE 1 - 12/8/91 ; Notez l'abondance des minéraux métalliques. La pyrite y est parfois constituée d'une agglomération de fins grains. De la sphalérite (en gris), en traces, y est associées.

#27 à 29 - Échantillon CONTROL - 12/8/91 ; La pyrite montre parfois la presence de fines fractures remplies de limonite (photo #28). La spalérite (en gris) est associée à la pyrite et se présente en fins grams.

#30 à 32 - Échantillon CONTROL 2 - 12/8/91 ; Notez la forme des particules de pyrite. On note la presence, en traces, de chalcopyrite et de spalérite.

NOTE : L'échantillon PHOSPHATE 2 - 12/8/91 presente un habitus semblable à celui de l'échantillon PHOSPHATE 1 - 12/8/91.

ANNEXE II

ANALYSES CHIMIQUES ET MODALES DES ÉCHANTILLONS

LISTE DES TABLEAUX DE L'ANNEXE II

TABLEAU I

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :	STRAT. CONTROL TEST IN (+200 M)
No. lab.	91-014765
No. DRX	C00872

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	52,0	Quartz	35,6
Al_2O_3	12,0	Feldspaths	7,5
Fe_2O_3	18,5	Amphibole	0,0
MgO	1,1	Chlorite	4,1
CaO	0,5	Mica	23,6
Na_2O	0,5	Apatite	0,2
K_2O	4,9		
TiO_2	0,4	Carbonates	0,9
MnO	0,1		
P_2O_5	0,1	Pyrite	26,6
PAF	10,5		
CO_2	0,4		
S	14,1		
Total	100,4	Total	98,6

TABLEAU II

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :	STRAT. CONTROL **TEST** IN **(-200 M)**
No. lab.	91-014777
No. DRX	C00884

Constituant	Teneur **(%)**	Phase	Proportion **(%)**
SiO_2	**51,9**	**Quartz**	**31,3**
Al_2O_3	**16,6**	Feldspaths	**4,3**
Fe_2O_3	**13,6**	Amphibole	**0,0**
MgO	**1,4**	Chlorite	**5,8**
CaO	**0,3**	Mica	**36,2**
Na_2O	**0,4**	Apatite	**0,2**
K_2O	**6,5**		
TiO_2	**0,4**	Carbonates	**0,5**
MnO	**0,1**		
P_2O_5	**0,1**	Pyrite	**18,5**
PAF	**8,6**		
CO_2	**0,2**		
S	**9,8**		
Total	**99,8**	**Total**	**96,6**

TABLEAU III

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :	STRAT. CONTROL TEST OUT (+200 M)
No. lab.	91-014766
No. DRX	C00873

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	51,1	Quartz	36,3
Al_2O_3	11,7	Feldspaths	3,8
Fe_2O_3	20,0	Amphibole	0,0
MgO	1,0	Chlorite	4,5
CaO	0,1	Mica	24,8
Na_2O	0,2	Apatite	0,1
K_2O	5,3		
TiO_2	0,3	Carbonates	0,3
MnO	0,0		
P_2O_5	0,0	Pyrite	27,8
PAF	10,6		
CO_2	0,1		
S	15,3		
Total	100,5	Total	97,6

TABLEAU IV

ANALYSE **MODALE** DE **L'ÉCHANTILLON**

Désignation :	STRAT. CONTROL TEST OUT (-200 M)
No. lab.	91-014778
No. DRX	C00885

Constituant	Teneur **(%)**	Phase	Proportion **(%)**
SiO_2	**54,1**	**Quartz**	**33,5**
Al_2O_3	**16,6**	Feldspaths	**4,0**
Fe_2O_3	**12,5**	Amphibole	**0,0**
MgO	**1,5**	Chlorite	**9,1**
CaO	**0,1**	Mica	**34,6**
Na_2O	**0,2**	Apatite	**0,1**
K_2O	**6,9**		
TiO_2	**0,4**	Carbonates	**0,3**
MnO	**0,1**		
P_2O_5	**0,1**	Pyrite	**14,8**
PAF	**7,7**		
CO_2	**0,1**		
S	**8,1**		
Total	**100,2**	Total	**96,5**

TABLEAU V

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :	STRAT. PHOSPHATE IN TEST 37 (+200 M)
No. lab.	91-014767
No. DRX	C00874

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	57,2	Quartz	42,5
Al_2O_3	11,7	Feldspaths	3,0
Fe_2O_3	15,6	Amphibole	0,0
MgO	2,3	Chlorite	11,3
CaO	0,1	Mica	21,9
Na_2O	0,2	Apatite	0,1
K_2O	4,3		
TiO_2	0,3	Carbonates	0,2
MnO	0,1		
P_2O_5	0,1	Pyrite	17,3
PAF	8,2		
CO_2	0,1		
S	9,5		
Total	100,1	Total	96,4

TABLEAU VI

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :	STRAT. PHOSPHATE IN TEST 37 (-200 M)
No. lab.	91-014779
No. DRX	C00886

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	54,9	Quartz	36,8
Al_2O_3	14,5	Feldspaths	3,2
Fe_2O_3	15,2	Amphibole	0,0
MgO	2,9	Chlorite	17,5
CaO	0,1	Mica	25,7
Na_2O	0,2	Apatite	0,2
K_2O	5,2		
TiO_2	0,4	Carbonates	0,7
MnO	0,2		
P_2O_5	0,1	Pyrite	14,0
PAF	6,7		
CO_2	0,3		
S	7,7		
Total	100,2	Total	98,0

TABLEAU VH

ANALYSE **MODALE** DE **L'ÉCHANTILLON**

Désignation :	STRAT. PHOSPHATE OUT TEST 37 (+200 M)
No. lab.	91-014768
No. DRX	C00875

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	48,7	Quartz	34,4
Al_2O_3	11,0	Feldspaths	4,5
Fe_2O_3	21,6	Amphibole	0,0
MgO	0,8	Chlorite	5,1
CaO	0,1	Mica	22,4
Na_2O	0,3	Apatite	0,1
K_2O	5,1		
TiO_2	0,3	Carbonates	0,2
MnO	0,0		
P_2O_5	0,1	Pyrite	29,5
PAF	11,5		
CO_2	0,1		
S	16,2		
Total	99,4	Total	96,2

TABLEAU VIII

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :	STRAT. PHOSPHATE OUT TEST 37 (-200 M)
No. lab.	91-014780
No. DRX	C00887

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	**54,7**	**Quartz**	33,0
Al_2O_3	**15,2**	Feldspaths	**6,2**
Fe_2O_3	13,0	Amphibole	**0,0**
MgO	**1,1**	Chlorite	**6,6**
CaO	**0,1**	Mica	**35,6**
Na_2O	**0,4**	Apatite	**0,2**
K_2O	**6,6**		
TiO_2	**0,4**	**Carbonates**	**0,3**
MnO	**0,0**		
P_2O_5	**0,1**	Pyrite	**16,3**
PAF	**7,6**		
CO_2	**0,1**		
S	**9,0**		
Total	**99,1**	Total	**98,1**

TABLEAU IX

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :		STRAT. LIMESTONE IN TEST 37 (+200 M)	
No. lab.		91-014769	
No. DRX		C00876	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	53,6	**Quartz**	37,6
Al_2O_3	12,5	Feldspaths	4,3
Fe_2O_3	17,6	Amphibole	0,0
MgO	1,1	Chlorite	6,8
CaO	0,1	Mica	25,4
Na_2O	0,3	Apatite	0,1
K_2O	5,2		
TiO_2	0,3	Carbonates	0,6
MnO	0,1		
P_2O_5	0,1	Pyrite	23,8
PAF	9,1		
CO_2	0,2		
S	13,1		
Total	99,9	Total	98,7

TABLEAU X

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :		STRAT. LIMESTONE IN TEST 37 (-200 M)	
No. lab.		91-014781	
No. DRX		Coo888	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	56,4	**Quartz**	33,7
Al_2O_3	17,9	Feldspaths	5,7
Fe_2O_3	10,2	Amphibole	0,0
MgO	1,6	Chlorite	9,6
CaO	0,1	Mica	36,7
Na_2O	0,3	Apatite	0,2
K_2O	7,0		
TiO_2	0,4	Carbonates	0,4
MnO	0,1		
P_2O_5	0,1	Pyrite	12,0
PAF	6,5		
CO_2	0,1		
S	6,6		
Total	100,6	Total	98,2

TABLEAU XI

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :	STRAT. LIMESTONE OUT TEST 37 (+200 M)
No. lab.	91-014770
No. DRX	C00877

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	51,2	Quartz	34,2
Al_2O_3	13,4	Feldspaths	4,3
Fe_2O_3	17,5	Amphibole	0,0
MgO	1,3	Chlorite	7,9
CaO	0,1	Mica	27,1
Na_2O	0,3	Apatite	0,1
K_2O	5,8		
TiO_2	0,3	Carbonates	0,4
MnO	0,1		
P_2O_5	0,1	Pyrite	21,8
PAF	9,9		
CO_2	0,2		
S	12,0		
Total	100,0	Total	95.8

TABLEAU XH

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation : No. lab. No. DRX		STRAT. LIMESTONE OUT **TEST** 37 (-200 M) 91-014782 C00889	
Constituant	Teneur **(%)**	Phase	Proportion **(%)**
SiO_2	**53,2**	**Quartz**	**28,6**
Al_2O_3	**18,2**	Feldspaths	**4,7**
Fe_2O_3	**11,6**	Amphibole	**0,0**
MgO	**1,8**	Chlorite	**10,4**
CaO	**0,2**	Mica	**41,8**
Na_2O	**0,3**	Apatite	**0,2**
K_2O	**7,1**		
TiO_2	**0,4**	Carbonates	**0,4**
MnO	**0,1**		
P_2O_5	**0,1**	Pyrite	**13,8**
PAF	**7,3**		
CO_2	**0,2**		
S	**7,6**		
Total	**100,2**	Total	**99,9**

TABLEAU XHI

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :		LIMESTONE (+200 M)	
No. lab. No. DRX		91-014771 C00878	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	5,6	**Quartz**	3,0
Al_2O_3	1,0	Feldspaths	2,2
Fe_2O_3	0,4	Amphibole	0,0
MgO	0,5	Chlorite	1,0
CaO	52,1	Mica	1,9
Na_2O	0,0	Apatite	0,0
K_2O	0,2		
TiO_2	0,1	Carbonates	93,2
MnO	0,1		
P_2O_5	0,1	Pyrite	0,0
PAF	35,0		
CO_2	41,0		
S	0,0		
Total	95,0	Total	101,4

TABLEAU XIV

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :		LIMESTONE (-200 M)	
No. lab. No. DRX		91-014783 COO890	
Constituant	Teneur **(%)**	Phase	Proportion **(%)**
SiO_2	**7,8**	**Quartz**	**2,7**
Al_2O_3	**2,0**	Feldspaths	**4,2**
Fe_2O_3	**0,9**	Amphibole	**0,0**
MgO	**0,6**	Chlorite	**2,1**
CaO	**50,3**	Mica	**3,6**
Na_2O	**0,0**	Apatite	**0,0**
K_2O	**0,4**		
TiO_2	**0,1**	Carbonates	**88,9**
MnO	**0,1**		
P_2O_5	**0,2**	Pyrite	**0,0**
PAF	**30,9**		
CO_2	**39,1**		
S	**0,0**		
Total	**93,3**	Total	**101,9**

TABLEAU XVI

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :		PHOSPHATE, N.B. (-200 M)	
No. lab.		91-014784	
No. DRX		C0089 1	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	7,6	**Quartz**	0,2
Al_2O_3	2,3	Feldspaths	9,5
Fe_2O_3	3,1	Amphibole	0,0
MgO	0,8	Chlorite	0,0
CaO	44,9	Mica	2,5
Na_2O	0,7	Apatite	72,2
K_2O	0,3		
TiO_2	0,1	Carbonates	11,7
MnO	0,0		
P_2O_5	29,6	Pyrite	1,1
PAF	8,3		
CO_2	5,2		
S	0,6		
Total	97,7	Total	97,2

TABLEAU XVH

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :	PHOSPHATE 1, 12/8/91 (+200 M)
No. lab. No. DRX	91-014773 Coo880

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	18,1	**Quartz**	17,3
Al_2O_3	0,2	Feldspaths	0,4
Fe_2O_3	53,3	Amphibole	1,0
MgO	0,1	Chlorite	0,0
CaO	0,2	Mica	0,1
Na_2O	0,0	Apatite	0,0
K_2O	0,0		
TiO_2	0,0	Carbonates	1,6
MnO	0,0		
P_2O_5	0,0	Pyrite	79,6
PAF	27,9		
CO_2	0,6		
S	44,0		
Total	99,9	Total	99,9

TABLEAU **XVIII**

ANALYSE **MODALE** DE **L'ÉCHANTILLON**

Désignation :		**PHOSPHATE 1, 12/8/91 (-200 M)**	
No. lab. No. DRX		91-014785 C00892	
Constituant	Teneur **(%)**	Phase	Proportion **(%)**
SiO_2	**16,7**	**Quartz**	**15,5**
Al_2O_3	**0,3**	Feldspaths	**0,4**
Fe_2O_3	**53,4**	Amphibole	**1,5**
MgO	**0,2**	Chlorite	**0,0**
CaO	**0,2**	Mica	**0,3**
Na_2O	**0,0**	Apatite	**0,0**
K_2O	**0,1**		
TiO_2	**0,0**	Carbonates	**2,0**
MnO	**0,0**		
P_2O_5	**0,0**	Pyrite	**80,2**
PAF	**27,7**		
CO_2	**0,8**		
S	**48,2**		
Total	**98,6**	Total	**100,0**

TABLEAU XIX

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :		CONTROL, 12/8/91 (+200 M)	
No. lab.		91-014774	
No. DRX		C0088 1	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	12,7	Quartz	11,4
Al_2O_3	0,1	Feldspaths	0,7
Fe_2O_3	56,1	Amphibole	1,7
MgO	0,2	Chlorite	0,0
CaO	0,3	Mica	0,0
Na_2O	0,0	Apatite	0,0
K_2O	0,0		
TiO_2	0,0	Carbonates	1,9
MnO	0,1		
P_2O_5	0,0	Pyrite	84,3
PAF	29,6		
CO_2	0,8		
S	48,6		
Total	99,1	Total	100,0

TABLEAU XX

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :		CONTROL, 12/8/91 (-200 M)	
No. lab. No. DRX		91-014786 C00893	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	12,7	Quartz	10,2
Al_2O_3	0,2	Feldspaths	0,4
Fe_2O_3	55,6	Amphibole	4,3
MgO	0,3	Chlorite	0,0
CaO	0,6	Mica	0,0
Na_2O	0,0	Apatite	0,0
K_2O	0,1		
TiO_2	0,0	Carbonates	3,5
MnO	0,1		
P_2O_5	0,0	Pyrite	81,6
PAF	28,8		
CO_2	1,3		
S	47,4		
Total	98,3	Total	100,0

TABLEAU XXI

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :		PHOSPHATE 2, 12/8/91 (+200 M)	
No. lab. No. DRX		91-014775 C00882	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	16,0	Quartz	13,9
Al_2O_3	0,1	Feldspaths	0,7
Fe_2O_3	54,6	Amphibole	3,2
MgO	0,3	Chlorite	0,0
CaO	0,6	Mica	0,0
Na_2O	0,0	Apatite	0,0
K_2O	0,0		
TiO_2	0,0	Carbonates	2,8
MnO	0,1		
P_2O_5	0,0	Pyrite	69,3
PAF	28,5		9,6
CO_2	1,3		
S	47,6		
Total	100,2	Total	99,5

TABLEAU XXII

ANALYSE MODALE DE L'ÉCHANTILLON

Designation :	PHOSPHATE 2, 12/8/91 (-200 M)
No. lab. No. DRX	91-014787 C00894

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	15,4	Quartz	11,1
Al_2O_3	0,2	Feldspaths	0,4
Fe_2O_3	55,5	Amphibole	7,7
MgO	0,4	Chlorite	0,0
CaO	1,0	Mica	0,0
Na_2O	0,0	Apatite	0,0
K_2O	0,0		
TiO_2	0,0	Carbonates	5,2
MnO	0,1		
P_2O_5	0,0	Pyrite	75,6
PAF	27,7		
CO_2	2,0		
S	46,4		
Total	100,3	Total	100,0

TABLEAU XXHI

ANALYSE MODALE DE L'ÉCHANTILLON

Désignation :		CONTROL 2, 12/8/91 (+200 M)	
No. lab. No. DRX		91-014776 C00883	
Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	13,3	Quartz	7,8
Al_2O_3	0,2	Feldspaths	0,7
Fe_2O_3	53,3	Amphibole	9,6
MgO	0,5	Chlorite	0,0
CaO	1,6	Mica	0,0
Na_2O	0,0	Apatite	0,0
K_2O	0,0		
TiO_2	0,0	Carbonates	6,5
MnO	0,1		
P_2O_5	0,0	Pyrite	75,4
PAF	29,5		
CO_2	2,9		
S	47,5		
Total	98,5	Total	100,0

TABLEAU XXIV

ANALYSE MODALE DE L'ÉCHANTILLON

Dbignation :	CONTROL 2, 12/8/91 (-200 M)
No. lab. No. DRX	91-014788 CO0895

Constituant	Teneur (%)	Phase	Proportion (%)
SiO_2	11,6	Quartz	2,9
Al_2O_3	0,3	Feldspaths	0,4
Fe_2O_3	53,4	Amphibole	15,9
MgO	0,8	Chlorite	0,0
CaO	1,9	Mica	0,0
Na_2O	0,0	Apatite	0,0
K_2O	0,0		
TiO_2	0,0	Carbonates	9,9
MnO	0,1		
P_2O_5	0,0	Pyrite	70,9
PAF	28,8		
CO_2	3,8		
S	45,9		
Total	97,0	Total	100,0

ANNEXEIII

GRANULOMÉTRIE DES PHASES MÉTALLIQUES DANS LES ÉCHANTILLONS

Correspondance dea numéros avec la désignation

#　　Designation

1 = STRATMAT ROCK - CONTROL TEST IN
2 = STRATMAT ROCK - CONTROL TEST OUT
3 = STRATMAT ROCK - PHOSPHATE IN, TEST 37
4 = STRATMAT ROCK - PHOSPHATE OUT, TEST 37
5 = STRATMAT ROCK - LIMESTONE IN, TEST 37
6 = STRATMAT ROCK - LIMESTONE OUT, TEST 37
7 = LIMESTONE (STRAMAT)
8 = PHOSPHATE (N.B.)
9 = PHOSPHATE 1 - 12/8/91
10 = CONTROL - 12/8/91
11 = PHOSPHATE 2 - 12/8/91
12 = CONTROL 2 - 12/8/91

CENTRE DE RECHERCHES MINÉRALES, 2700, RUE EINSTEIN, SAINTE-FOY, QUÉBEC G1P 3W8 TÉLÉPHONE (418) 643-4540 TÉLÉCOPIEUR (418) 643-6706

```
                        LECO 2001 IMAGE ANALYSIS REPORT

Company name : CRM - Quebec                          Date :  10-11-91
User name    : J.F. Wilhelmy                         Mag. :    50X
Input        : 1                                     Cal. :  2.469 mic/Pixel

                    PY TOTAL Count vs Length distribution
                                 in mic


    From        To        Count

      0.       50.0       302    **************************************
    50.0       100.       306    **************************************
    100.       150.       316    ***************************************
    150.       200.       147    ******************
    200.       250.        52    ******
    250.       300.        21    **
    300.       350.        11    *
    350.       400.         3    *
    400.       450.         1    *
    450.       500.         0
    500.       550.         0
    550.       600.         0
    600.       650.         0
    650.       700.         0
    700.       750.         0
    750.       800.         0
    800.       850.         0
    850.       900.         0
    900.       950.         0
    950.       1000         0


  Sample Id               : 15K002 #1
  Average                 : 102.8
  Standard Deviation      : 67.36
  Fields analysed         : 100
  Field area              : 1.31038e+06
  Total area surveyed     : 1.31038e+08
  Total # of features     : 1159
  Under size features     : 0
  Over size features      : 0
  Features accepted       : 1159
  %  accepted             : 100. %
```

```
                         LECO 2001 IMAGE ANALYSIS REPORT

Company name : CRM - - Quebec                          Date : 10-11-91
User name    : J.F. Wilhelmy                           Mag. :  50X
Input        : 1                                       Cal. : 2.469 mic/Pixel

                     SF TOTAL Count vs Length distribution
                                   in mic

    From        To        Count.

      0.       50.0        8     ***************************************
    50.0       100.        1     ****
    100.       150.        0
    150.       200.        1     ****
    200.       250.        0
    250.       300.        0
    300.       350.        0
    350.       400.        0
    400.       450.        0
    450.       500.        0
    500.       550.        0
    550.       600.        0
    600.       650.        0
    650.       700.        0
    700.       750.        0
    750.       800.        0
    800.       850.        0
    850.       900.        0
    900.       950.        0
    950.       1000        0

 Sample Id            : 15K002 #1
 Average              : 46.17
 Standard Deviation   : 48.32
 Fields  analysed     : 100
 Field   area         : 1.31038e+06
 Total area surveyed  : 1.31038e+08
 Total # of features  : 10
 Under size features  : 0
 Over size features   : 0
 Features  accepted   : 10
 %   accepted         : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name  : CRM - Quebec                                  Date :  10-11-91
User name     : J.F. Wilhelmy                                 Mag. :    50X
Input         : 1                                             Cal. :  2.469   mic/Pixel

                        PY TOTAL Count vs Length distribution
                                     in    mic


    From          To       Count

      0.         50.0      301      ***************
    50.0         100.      477      ************************
    100.         150.      776      ****************************************
    150.         200.      342      *****************
    200.         250.       68      ***
    250.         300.       14      *
    300.         350.        6      *
    350.         400.        1      *
    400.         450.        0
    450.         500.        0
    500.         550.        0
    550.         600.        0
    600.         650.        0
    650.         700.        0
    700.         750.        0
    750.         800.        0
    800.         850.        0
    850.         900.        0
    900.         950.        0
    950.         1000        0


  Sample Id               : 15K002 #2
  Average                 : 111.5
  Standard Deviation      : 54.99
  Fields analysed         : 100
  Field area              : 1.31038e+06
  Total area surveyed     : 1.31038e+08
  Total # of features     : 1985
  Under size features     : 0
  Over size features      : 0
  Features accepted       : 1985
  % accepted              : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                    Date : 10-11-91
User name    : J.F. Wilhelmy                   Mag. :    50X
Input        : 1                               Cal. : 2.469  mic/Pixel

                 SF' TOTAL Count vs Length distribution
                               in  mic


   From       To       Count

     0.       50.0       3     ***************************************
    50.0     100.        1     *************
   100.      150.        0
   150.      200.        0
   200.      250.        0
   250.      300.        0
   300.      350.        0
   350.      400.        0
   400.      450.        0
   450.      500.        0
   500.      550.        0
   550.      600.        0
   600.      650.        0
   650.      700.        0
   700.      750.        0
   750.      800.        0
   800.      850.        0
   850.      900.        0
   900.      950.        0
   950.      1000        0


  Sample Id            : 15K002 #2
  Average              : 43.82
  Standard Deviation   : 26.04
  Fields analysed      : 100
  Field area           : 1.31038e+06
  Total area surveyed  : 1,31038e+08
  Total # 'of features : 4
  Undersize features   : 0
  Over size features   : 0
  Features accepted    : 4
  % accepted           : 100. %
```

```
                    LECO 2001 IMAGE ANALYSIS REPORT

Company name ·CRM-   -   Quebec                   Date : 10-17-91
User name    | Pierre Lacoste                     Mag. :   50X
Input        : 1                                  Cal. : 2.469  mic/Pixel

              PY TOTAL Count vs Length distribution
                           in mic

  From       To       Count

    0.       10.0       0
   10.0      20.0       5     ********
   20.0      30.0      15     **************************
   30.0      40.0      12     ********************
   40.0      50.0      15     **************************     .
   50.0      60.0      20     ***************it-****.**************
   60.0      70.0      19     *********************************
   70.0      80.0      16     ***************************
   80.0      90.0      15     **************************
   90.0     100.       16     ***************************
  100.      110.       22     **************************************
  110.      120.       21     ************************************
  120.      130.       23     ****************************************
  130.      140.       16     ***************************
  140.      150.       13     **********************
  150.      160.       10     *****************
  160.      170.       11     *******************
  170.      180.        6     **********
  180.      190.        2     ***
  190.      200.        4     ******
  200.      210.        7     ************
  210.      220.        2     ***
  220.      230.        5     ********
  230.      240.        2     ***
  240.      250.        1     *

 Sample Id                : 7215K002-03
 Average                  : 103.4
 Standard Deviation       : 52.25
 Fields analysed          : 25
 Field area               : 1.31038e+06
 Total area surveyed      : 3.27595e+07
 Total # of features      : 280
 Under size features      : 0
 Over size features       : 2
 Features accepted        : 278
 % accepted               : 99.2 %
```

LECO 2001 IMAGE ANALYSIS REPORT

Company name : CRM -- Quebec
User name : **Pierre** Lacoste
Input : 1

Date : 10-17-91
Mag. : 50x
Cal. : 2.469 mic/Pixel

SF' TOTAL Count vs Length **distribution** in mic

From	To	Count
0.	10.0	0
10.0	20.0	0
20.0	30.0	0
30.0	40.0	0
40.0	50.0	0
50.0	60.0	0
60.0	70.0	0
70.0	80.0	0
80.0	90.0	0
90.0	100.	0
100.	110.	0
110.	120.	0
120.	130.	0
130.	140.	0
140.	150.	0
150.	160.	0
160.	170.	0
170.	180.	0
180.	190.	0
190.	200.	0
200.	210.	0
210.	220.	0
220.	230.	0
230.	240.	0
240.	250.	0

Sample Id : 7215K002-03
Average : 0.
Standard Deviation : 0.
Fields analysed : 25
Field area : 1.31038e+06
Total area surveyed : 3.27595e+07
Total # of features : 0
Under size features : 0
Over size features : 0
Features accepted : 0
% accepted :

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                      Date : 10-10-91
User name    : J.F. Wilhelmy                     Mag. :   25X
Input        : 1                                 Cal. : 4.902  mic/Pixel

                    PY TOTAL Count vs Length distribution
                                in  mic


  From        To        Count

    0.        20.0        0
   20.0       40.0       28     **
   40.0       60.0      104     ********
   60.0       80.0      342     **************************
   80.0       100.      508     ****************************************
   100.       120.      478     *************************************
   120.       140.      292     **********************
   140.       160.      157     ************
   160.       180.       96     *******
   180.       200.       55     ****
   200.       220.       48     ***
   220.       240.       27     **
   240.       260.       16     *
   260.       280.        5     *
   280.       300.        3     *
   300.       320.        3     *
   320.       340.        1     *
   340.       360.        0
   360.       380.        0
   380.       400.        0
   400.       420.        0
   420.       440.        0
   440.       460.        0
   460.       480.        0
   480.       500.        0


Sample Id               : 15K002 - 4
Average                 : 111.4
Standard Deviation      : 42. 70
Fields   analysed  :  25
Field   area            : 5.16472e+06
Total area surveyed : 1.29 118e+08
Total # of features : 2163
Under size features : 0
Over size features :0
Features  accepted : 216.3
%    accepted           : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

Company name : CRM – Quebec
User name : J.F. Wilhelmy
Input : 1

Date : 10-10-91
Mag. : 25X
Cal. : 4. 902 mic/Pixel

SP TOTAL Count vs Length distribution in mic

From	To	Count
0.	20.0	0
20.0	40.0	0
40.0	60.0	0
60.0	80.0	0
80.0	100.	0
100.	120.	0
120.	140.	0
140.	160.	0
160.	180.	0
180.	200.	0
200.	220.	0
220.	240.	0
240.	260.	0
260.	280.	0
280.	300.	0
300.	320.	0
320.	340.	0
340.	360.	0
360.	380.	0
380.	400.	0
400.	420.	0
420.	440.	0
440.	460.	0
460.	480.	0
480.	500.	0

Sample Id :	15K002 - 4
Average	0.
Standard Deviation :	0.
Fields analysed :	25
Field area :	5.16472e+06
Total area surveyed :	1.29118e+08
Total # of features :	0
Under size features :	0
Over size features :	0
Features accepted :	0
% accepted :	

```
                         LECO 2001 IMAGE ANALYSIS REPORT

Company name : CRM - Quebec                        Date :  10-17-91
User name    : Pierre Lacoste                      Mag. :    25X
Input        : 1                                   Cal. : 4.902  mic/Pixel

                   PY TOTAL Count vs Length distribution
                                 in   mic


   From        To       Count

     0.       20.0        0
    20.0      40.0        4    *
    40.0      60.0       50    **************
    60.0      80.0       95    ***************************
    80.0     100.       130    *************************************
   100.      120.       138    ***************************************
   120.      140.        91    **************************
   140.      160.        57    ****************
   160.      180.        37    **********
   180.      200.        36    **********
   200.      220.        19    *****
   220.      240.        10    **
   240.      260.        14    ****
   260.      280.         4    *
   280.      300.         2    *
   300.      320.         4    *
   320.      340.         1    *
   340.      360.         0
   360.      380.         3    *
   380.      400.         0
   400.      420.         0
   420.      440.         0
   440.      460.         0
   460.      480.         0
   480.      500.         0


  Sample Id              : 7215Z002-5
  Average                : 120.2
  Standard Deviation     : 53.81
  Fields analysed        : 25
  Field area             : 5.16472e+06
  Total area surveyed    : 1.29118e+08
  Total # of features      695
  Under size features    : 0
  Over size features     : 0
  Features accepted      : 695
  %   accepted           : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name  : CRM - Quebec                              Date : 10-17-91
User name     : Pierre Lacoste                            Mag. :   25X
Input         : 1                                         Cal. : 4. 902  mic/Pixel

                    SP TOTAL Count vs Length distribution
                                 in  mic

   From        To        Count

     0.       20.0         0
    20.0      40.0         0
    40.0      60.0         1      *************
    60.0      80.0         3      ***************************************
    80.0      100.         0
    100.      120.         0
    120.      140.         0
    140.      160.         0
    160.      180.         0
    180.      200.         0
    200.      220.         0
    220.      240.         0
    240.      260.         0
    260.      280.         0
    280.      300.         0
    300.      320.         0
    320.      340.         0
    340.      360.         0
    360.      380.         0
    380.      400.         0
    400.      420.         0
    420.      440.         0
    440.      460.         0
    460.      480.         0
    480.      500.         0


 Sample Id              : 7215Z002-5
 Average                : 66.17
 Standard Deviation     : 10.09
 Fields    analysed     : 25
 Field    area          : 5.16472e+06
 Total area surveyed    : 1.29118e+08
 Total  #  of features  : 4
 Under 5ize features    : 0
 Over size features     : 0
 Features  accepted     : 4
 %    accepted          : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                         Date : 10-17-91
User name    : Pierre Lacoste                       Mag. :   25X
Input        : 1                                    Cal. : 4.902  mic/Pixel

                       PY TOTAL Count vs Length distribution
                                  in   mic


   From        To       Count

     0.       10.0        0
   10.0       20.0        0
   20.0       30.0        0
   30.0       40.0        5     *****
   40.0       50.0        9     *********
   50.0       60.0       25     *************************
   60.0       70.0       26     **************************
   70.0       80.0       27     ***************************
   80.0       90.0       33     *********************************
   90.0       100.       39     ***************************************
   100.       110.       32     ********************************
   110.       120.       33     *********************************
   120.       130.       25     *************************
   130.       140.       30     ******************************
   140.       150.       18     ******************
   150.       160.       22     **********************
   160.       170.       15     ***************
   170.       180.       21     *********************
   180.       190.       10     **********
   190.       200.       13     *************
   200.       210.       10     **********
   210.       220.       17     *****************
   220.       230.        7     *******
   230.       240.        7     *******
   240.       250.        9     *********


 Sample Id              : 7215Z002-6
 Average                : 125.0
 Standard Deviation     : 52.21
 Fields   analysed      : 25
 Field    area          : 5.16472e+06
 Total area surveyed    : 1.29118e+08
 Total # of features    : 460
 Under size features    : 0
 Over size feature5     : 27
 Features  accepted     : 433
 %    accepted          : 94.1 %
```

LECO 2001 IMAGE ANALYSIS REPORT

Company name	: CRM - Quebec		Date	:	10-17-91
User name	: Pierre Lacoste		Mag.	:	25X
Input	: 1		Cal.	:	4.902 mic/Pixel

SP TOTAL Count vs Length distribution in mic

From	To	Count
0.	10.0	0
10.0	20.0	0
20.0	30.0	0
30.0	40.0	0
40.0	50.0	0
50.0	60.0	0
60.0	70.0	0
70.0	80.0	0
80.0	90.0	0
90.0	100.	0
100.	110.	0
110.	120.	0
120.	130.	0
130.	140.	0
140.	150.	0
150.	160.	0
160.	170.	0
170.	180.	0
180.	190.	0
190.	200.	0
200.	210.	0
210.	220.	0
220.	230.	0
230.	240.	0
240.	250.	0

Sample Id : 7215Z002-6
Average : 0.
Standard Deviation : 0.
Fields analysed : 25
Field area : 5.16472e+06
Total area surveyed : 1.29118e+08
Total # of features : 0
Under size features : 0
Over size features : 0
Features accepted : 0
% accepted :

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                          Date : 10-17-91
User name    : Pierre Lacoste                        Mag. :    25X
Input        : 1                                     Cal.  : 4.902  mic/Pixel

                     PY TOTAL Count vs Length distribution
                                in  mic

  From         To       Count

     0.       24.0        0
   24.0       48.0      226    *********************
   48.0       72.0      360    **********************************
   72.0       96.0      415    ****************************************
   96.0       120.      355    **********************************
   120.       144.      304    *****************************
   144.       168.      244    ***********************
   168.       192.      181    *****************
   192.       216.      188    ******************
   216.       240.       98    *********
   240.       264.      126    ************
   264.       288.       92    ********
   288.       312.       68    ******
   312.       336.       57    *****
   336.       360.       56    *****
   360.       384.       32    ***
   384.       408.       20    *
   408.       432.       25    **
   432.       456.       16    *
   456.       480.       13    *
   480.       504.       11    *
   504.       528.        6    *
   528.       552.        6    *
   552.       576.        8    *
   576.       600.        2    *


 Sample  Id                : 7215k002-09
 Average                   : 154.8
 Standard  Deviation       : 101.4
 Fields    analysed        : 25
 Field    area             : 5.16472e+06
 Total  area surveyed      : 1.29118e+08
 Total  # of features      : 2917
 Under  size  features     : 0
 Over  size  features      : 8
 Features   accepted       : 2909
 %    accepted             : 99.7 %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                          Date : 10-17-91
User name    : Pierre Lacoste                        Mag. :    25X
Input        : 1                                     Cal. : 4.902  mic/Pixel

                 SP TOTAl Count vs Length distribution
                              in  mic


   From         To       Count

     0.        24.0        0
   24.0        48.0        0
   48.0        72.0        3     ****************************************
   72.0        96.0        0
   96.0        120.        0
   120.        144.        0
   144.        168.        0
   168.        192.        0
   192.        216.        0
   216.        240.        0
   240.        264.        0
   264.        288.        0
   288.        312.        0
   312.        336.        0
   336.        360.        0
   360.        384.        0
   384.        408.        0
   408.        432.        0
   432.        456.        0
   456.        480.        0
   480.        504.        0
   504.        528.        0
   528.        552.        0
   552.        576.        0
   576.        600.        0


  Sample Id              : 7215k002-09
  Average                : 65.35
  Standard Deviation     : 6.564
  Fields  analysed       : 25
  Field   area           : 5.16472e+06
  Total. area surveyed   : 1.29118e+08
  Total # of features    : 3
  under size features    : 0
  Over size features     : 0
  Features  accepted     : 3
  %  accepted            : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                         Date : 10-18-91
User name    : Pierre Lacoste                       Mag. :   25X
Input        : 1                                    Cal. : 4.902  mic/Pixel

                    FY TOTAL Count vs Length distribution
                                in   mii


   From         To       Count

     25.0       44.0      135     ****
     44.0       63.0      360     ***********
     63.0       82.0      958     *****************************
     82.0       101.     1308     ***************************************
     101.       120.     1187     ************************************
     120.       139.      720     **********************
     139.       158.      435     *************
     158.       177.      240     *******
     177.       196.      135     ****
     196.       215.      121     ***
     215.       234.       65     *
     234.       253.       42     *
     253.       272.       19     *
     272.       291.       20     *
     291.       310.        8     *
     310.       329.       10     *
     329.       348.        2     *
     348.       367.        1     *
     367.       386.        0
     386.       405.        2     *
     405.       424.        3     *
     424.       443.        0
     443.       462.        0
     462.       481.        0
     481.       500.        0


 Sample Id               : 7215K002-11
 Average                 : 109.8
 Standard Deviation      : 44.22
 Fields   analysed       : 25
 Field   area            : 5.16472e+06
 Total area surveyed     : 1.29118e+08
 Total # of features     : 5771
 Under size features     : 0
 Over size features      : 0
 Features  accepted      : 5771
 %   accepted            : 100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                                Date : 10-18-91
User name    : Pierre Lacoste                              Mag. :   25X
Input        : 1                                           Cal. : 4.902  mic/Pixel

                      SP TOTAL Count vs Length distribution
                                  in  mic


     From          To         Count

      25.0         44.0         0
      44.0         63.0         2     ***************************************
      63.0         82.0         1     *******************
      82.0         101.         0
      101.         120.         0
      120.         139.         0
      139.         158.         0
      158.         177.         0
      177.         196.         0
      196.         215.         0
      215.         234.         0
      234.         253.         0
      253.         272.         0
      272.         291.         0
      291.         310.         0
      310.         329.         0
      329.         348.         0
      348.         367.         0
      367.         386.         0
      386.         405.         0
      405.         424.         0
      424.         443.         0
      443.         462.         0
      462.         481.         0
      481.         500.         0


   Sample Id               :  7215K002-11
   Average                 :  60.45
   Standard Deviation      :  10.99
   Fields   analysed       :  25
   Field   area            :  5.16472e+06
   Total area surveyed     :  1.29118e+08
   Total # of features     :  3
   Under size features     :  0
   Over size features      :  0
   Features  accepted      :  3
   %   accepted            :  100. %
```

LECO 2001 IMAGE ANALYSIS REPORT

```
Company name : CRM - Quebec                        Date : 10-18-91
User name    : Pi erre Lacoste                     Mag. :    25X
Input        : 1                                   Cal . : 4.902  mic/Pixel

                   PY TOTAL  Count  vs Length distribution
                                 in  mic


    From        To       count

     25.0       44.0     147     *****
     44.0       63.0     390     **************
     63.0       82.0     898     ********************************
     82.0       101.    1111     ****************************************
     101.       120.     965     **********************************
     120.       139.     559     ********************
     139.       158.     369     *************
     158.       177.     24 1    ********
     177.       196.     134     ****
     196.       215.     141     *****
     215.       234.      98     ***
     234.       253.      58     **
     253.       272.      4;'    *
     272.       291.      19     *
     291.       310.      26     *
     310.       329.      10     *
     329.       348.      16     *
     348.       367.       8     *
     367.       386.       7'    *
     386.       405.       7     *
     405.       424.       6     *
     424.       443.       5     *
     443.       462.       2     *
     462.       481.       1     *
     481.       500.       4     *


  Sample Id             : 7215Z002-12
  Average               : 114.6
  Standard Deviation    : 56.77
  Fields   analysed     : 25
  Field   area          : 5.16472e+06
  Total area surveyed   : 1.29118e+08
  Total # of features   : 5272
  Under size features   : 0
  Over size features    : 3
  Features   accepted   : 5269
  %   accepted          : 99.9 %
```

```
                         LECO 2001 IMAGE ANALYSIS REPORT

Company name : CRM - Quebec                              Date : 10-18-91
User name    : Pierre Lacoste                            Mag. :   25X
Input        : 1                                         Cal. : 4.902  mic/Pixel

                       SP TOTAL Count vs Length distribution
                                  in  mic


    From        To       Count

     25.0       44.0       0
     44.0       63.0       0
     63.0       82.0       0
     82.0       101.       0
     101.       120.       0
     120.       139.       0
     139.       158.       0
     158.       177.       0
     177.       196.       0
     196.       215.       0
     215.       234.       0
     234.       253.       0
     253.       272.       0
     272.       291.       0
     291.       310.       0
     310.       329.       0
     329.       348.       0
     348.       367.       0
     367.       386.       0
     386.       405.       0
     405.       424.       0
     424.       443.       0
     443.       462.       0
     462.       481.       0
     481.       500.       0


  Sample Id              : 7215Z002-12
  Average                : 0.
  Standard Deviation     : 0.
  Fields analysed        : 25
  Field area             : 5.16472e+06
  Total area surveyed    : 1.29118e+08
  Total # of features    : 0
  Under size features    : 0
  Over size features     : 0
  Features accepted      : 0
  %  accepted            :
```