International Agency for Small-Scale Mining

Agence internationale pour les petites exploitations minières

SMI SMALL MINING INTERNATIONAL

BULLETIN

Published for the information of the international small mining community

ISSN 1188-9519

Numbers 5-6
January 1993

Agrogeology and Small Scale Mining

Small scale mining has an extremely important role to play in bringing sustainability to agriculture in the developing world. It can become a principal source of local supply of agrominerals including phosphates, nitrates, liming materials, zeolites, etc. This issue is exclusively devoted to the growing field of "agrogeology."

The papers which follow were prepared by internationally recognized researchers and managers working in this field. They deal with a number of issues related to both agrogeology and small scale mining. They are by no means exhaustive, but are meant to:

° show the theoretical underpinning for the agrogeological approach (p 2-5);

° present an overview of agrogeology and give a detailed breakdown of what minerals are useful, where, etc. (p. 5-9);

° give examples of the successful production of agrominerals on a small scale (p. 11-13);

° show some new approaches being taken (p. 10, 14);

° give examples of country programs in developing countries (p. 3, 15-16);

° show that some aid agencies are indeed thinking along these lines (p. 14-15).

We would like to emphasize here that a number of international agencies have been and/or are actively involved in agrogeological programs. The International Fertilizer Development Centre has carried out extensive research on the direct application of rock phosphate in South America and West Africa, mostly related to larger phosphate deposits and large-scale exploitation and processing. The International Development Research Centre has supported a number of agrogeological projects at IFDC and elsewhere. The British Geological Survey has worked on phosphate exploration in Malawi. Appropriate Technology International has an extensive lime program in Central America; and UNESCO, the Commonwealth Science Council, the German Ministry of Economic Cooperation and the EEC have funded a number of meetings related to agrogeology. The number and variety of programs is encouraging; however, some of the other important agencies, such as the development banks, are notable by their absence.

It is our hope that this special issue will help promote a wider interest in and application of agrogeology worldwide, and make a contribution to the longer term goal of higher and sustainable food production in the developing world, particularly the poorer parts.

Calvin Pride, Peter van Straaten
Special Issue Editors.

N.B. References have been consolidated and can be found on p. 17-18. Photographs were provided courtesy of C. Pride, P. van Straaten and L. Borsch.

Contents

The First Twenty-Nine Days: Prospects for Agrogeology

by Ward Chesworth

Since the Report of the Bruntland Commission, the concept of sustainability has become a fashionable one, with the biggest question, of course, being: is human civilization itself sustainable? As things stand now, the simple answer is no, and the two major reasons have to do with population and with farming.

Paul Ehrlich uses a frightening metaphor to illustrate the predicament we face with regards to the human population on earth. Duckweed takes about 29 days to cover half the surface of a pond. Such is the acceleration of exponential growth that it takes only one day more for the weed to take over the whole pond. Metaphorically, we human beings are still in the first 29 days of our tenure of the planet. If we don't gain control of galloping population, the 30th day will dawn and it will be too late. The point has been made by Malthus in 1803, and in 1832 by John Stuart Mill, who said, "society can feed the necessitous, if it takes their multiplication under control. . . .It cannot with impunity take the feeding upon itself, and leave the multiplying free."

In the hope that population growth will yield to control, the rest of this paper will be devoted to a consideration of farming as it is currently practised in the industrialised world, how sustainable it is and what this has to do with geology along with some implications for farming practise in developing countries.

Let us start by asking the question, "What is farming for?" It's for feeding people, right? Wrong: on a planet where a billion people go hungry every day, the number one priority for agricultural research in the U.S. Department of Agriculture is the development of new non-food uses for agricultural products. In North America, even where effort and funds are being invested in food as opposed to non-food agriculture, it is mainly in terms of issues that would seem frivolous to an agriculturalist in Ethiopia or Bangladesh: producing a leaner pig, or breeding fruit that won't bruise, or engineering cuboid tomatoes that are easy to pack and transport.

Look at the farming journals and trade papers in North America and Western Europe: there is no mention of the need to feed people. The impression given is that if there had ever been a problem, it has long since been solved--hence the grain surpluses, the butter mountains and wine lakes resulting from over-production. It would seem to follow that since the North has solved the problem of feeding people, the best kind of aid we can give to developing country farmers is to export Northern farming systems wholesale to Africa, Asia and South America. That's what the Green Revolution did--high yielding varieties of staple crops, developed in the North, were farmed with liberal doses of fertilizers and pesticides, aided by elaborate irrigation schemes and supported by a highly mechanised infrastructure. Unfortunately, for whatever scientific or socio-economic reasons, it never worked in Africa. Even in those parts of the world where it does work, Northern-style farming can only be a short-term solution because it is highly dependent on the energy of fossil fuels. In no real meaning of the word can it be called sustainable.

A corollary of this, of course, is that high material input agriculture is ultimately unsustainable even in the North. It is an energy-intensive intervention into an increasingly stressed ecosystem, and with uncontrolled growth of the human population, a crash is inevitable. The whole system of agribusiness needs a radical re-thinking before it is too late. Agricultural economists need to realise that the second law of thermodynamics is as applicable to them as to the rest of us.

Let us for now be optimistic and ask whether we can devise an agricultural system that is sustainable. History might give us some clues. Farming, as a human activity, is roughly 10,000 years old. The earliest examples of well-developed agricultural systems that we know of are associated with the great river valleys, and the so-called hydraulic civilizations of what are now Iraq, Egypt, Pakistan and China. Of these, the examples of Iraq and Pakistan ultimately proved to be unsustainable, due principally to the problem of salinisation. This situation may have developed partly in response to climatic changes, although irrigation practices were certainly a major contributing factor. Only in Egypt and China do we find farming systems that have been sustained over at least the last 5,000 years.

How has this happened, how have the Egyptians and the Chinese managed so well? The answer is, quite simply, they have been fortunate enough to find themselves in environments where geological processes have been conducive to the maintenance of soil fertility. In both locations, new materials, rich in plant nutrients, have been added to farmland by geological forces. In Egypt, the Nile brought nutrients from the volcanic highlands of Ethiopia. In China, the wind brought loess from the Gobi desert. In both regions a natural fertiliser has continually and reliably been added to replace nutrients taken from the soil by cropping.

If we extend our view to take in the whole globe, we find that, historically, the most productive soils are found in areas where fresh, relatively unweathered, but eminently weatherable materials have been added to the land surface in the recent geological past (Chesworth: 1982). In most cases, the addition was "one off," without a yearly, sustained refertilisation such as the Nile provides. Consequently, most areas of productive soils have been continuously degraded by farming. Iowa, for example, has lost half its topsoil in less than a century. The organic matter content of the prairie soils of Canada has bottomed out at about 50% of its virgin value. Nutrient deficiencies are common in areas that formerly were free of them.

Assuming that the farmer's water supply is no problem (and it must be admitted that this is by no means always a fair assumption), the principal problem is one of replacing nutrients removed through cropping. Human ingenuity has devised many systems of nutrient replacement: by crop rotation, adding manures or composts, and, finally, artificial or industrial NPK fertilisers. No system has been entirely successful, although the crop rotations invented in western Europe in the 18th century are as close as we have come so far to a sustainable system. However, this hopeful experiment was largely replaced by a dependency on industrial fertilisers invented in the 19th century, a technique which encouraged the development of labour-efficient methods of monoculture. In broad terms, the result has been to produce soils with increasing micronutrient deficiencies and structural problems.

Consequently, most agronomists now are advocating a reincorporation of older techniques--such as crop rotation, manure and compost--into modern farming. In addition, there has been a revival of interest in the use of geological materials in an unprocessed (or relatively unprocessed) state. Essentially, this is a return to techniques that were the subject of a great deal of experimentation in the early part of the 19th century, and which have been revived in this century by W.D. Keller and by W.S. Fyfe (see Chesworth: 1983; Leonardos et al.: 1987). The advantages of using geological materials in this way are, first, a decreased reliance on fossil fuels; and second, the addition of a broad spectrum of nutrients in one application. The disadvantages are the bulkiness of the materials and the relatively slow reaction. The first of these disadvantages dictates that the resource should be used locally, and the second that an appropriate soil be chosen to optimise reaction, in conjunction with simple techniques of increasing reactivity, e.g., coupling phosphates with zeolites, (Lai and Eberl: 1986).

As an example, consider the Tanzania-Canada Agrogeology Project (Chesworth et al.: 1989; van Straaten et al.: 1992). The principal geological resource discovered by the geological team was an apatite-rich residual material weathered from the Panda Hill carbonatite in SW Tanzania. The soils team at the Uyole Agricultural Centre then showed that, without processing, the material could be used to fertilise ferrallitic soils in the region. There is about a 30 years' supply for farmers living within 50 miles of the source. At least two other possible sources for future development were found in the region (van Straaten et al.: 1992). Low grade deposits of this type, of no interest to the great multinationals, can have a profound impact on local economics and local self-sufficiency (Sheldon and Treharne: 1979).

Another point to consider is that traditional farming systems the world over have gone through generation after generation of experimentation. It is worth tapping into this fund of wisdom, making a search for sound techniques, and choosing those that can justifiably be transferred from one farming community to another. Again, the Guelph agrogeologists, working with Spanish and African counterparts, have a success to their credit. For about 200 years, farmers in the volcanic Canary Islands have covered their soils with a layer of scoria (Fernandez-Caldas and Tejedor-Salguero: 1989). This acts as a vapour barrier leading to a pronounced cut in moisture losses from the soil. . In 1990, the technique was transferred to Ethiopia, and has resulted in a four-fold increase in corn-yield on experimental plots, simply through conservation of water (van Straaten et al.)(see photo below). This simple technique can be applied anywhere a fragmental geological deposit exists. Gravels and coarse sands can be used to create a vapour barrier, as well as pyroclastics.

What all this suggests is that many common rocks can be used to improve the chemical and physical characteristics of soils. Being common, such rocks have a wide distribution, so that even the poorest countries contain within their borders materials of use to the farmer. Small mine technologies, under local control, offer appropriate ways of developing such resources cheaply. Each small mine would service the area immediately around it, thereby cutting down on transportation costs, as well as providing jobs and boosting the autonomy of the region served.

In summary, an inventory of what might be called alternative agrogeological resources needs to be made, especially (but not exclusively) in developing countries. Energy efficient technologies should be researched and developed for mining and using these resources. In terms of their use, appropriate techniques developed by the world's farmers over countless generations should be considered as an immense intellectual resource that may be transferred from one region to another, as the rock mulch technique has been transferred to Ethiopia from Lanzarote in Spain.

The ultimate objective is local self-sufficiency, a weaning away from agricultural systems heavily dependent on fossil fuels and wresting the economic control of farming away from places like New York, London, Paris and Tokyo. None of this guarantees sustainability, but it gives us a fighting chance. Provided, of course, that we can stop the 30th day from dawning.

Dr. Ward Chesworth is a leading light in the field of agrogeology. A lecturer in the Department of Land Resource Science at the University of Guelph, Ontario, CANADA, he has been active in studying weathering and formation of soils in Africa and North America.

Preparation of rock mulch for moisture retention, Ethiopan Rift Valley.

Sustainable Food Production and Agrogeology

by William Fyfe

The growth of human population to over five billion now, with almost 100 million added each year, has begun to make us increasingly aware of the limits of the basic parts of the planetary life support system. Bioproductivity ultimately depends on:

° solar energy and the temperature of our environment;

° the availability of water via direct precipitation, or surface or underground flow;

° the supply of nutrients for the biosphere which ultimately comes from the atmosphere, but more immediately derives from the rocks and minerals of the top kilometre or so of the planet's surface and in most cases, from the stuff called soil.

The state of world food production today gives reason for great concern. In almost all of Africa, food per capita has been declining for decades. And now, for much of the rest of the world, food output per capita has also begun to decline. The nations where this is not the case are those with advanced technologies and where the birth rate is dropping below the level of replacement. Yet, as recently reported by Moldan (1992), humanity now uses or modifies almost 40% of the total net organic productivity of Earth, making the human race the largest single appropriator of the planet's bio-productivity "since life appeared on Earth".

When we consider the problem of securing reliable, sustainable food production for humans, the dominant basic bio-physical factors are climate, water, and the quality of soil. To these must be added an array of technological influences such as farm machinery, energy availability, chemical technology, and modern biotechnology; but even with all these developments, light-soil-water still form the foundation of our agricultural systems.

Understanding the Soil

Soil is the thin interface that forms by reactions of atmosphere and hydrosphere with the rocks of the lithosphere. The rocks and minerals which occur at this interface are highly variable. Thus in Iceland or Hawaii, they are almost exclusively volcanic products, basalts, which are transported molten materials from depths of tens of kilometres from the deep earth. In regions near the edges of ice-age fluctuations like most of Canada and Scandinavia, bare rocks of many types may be exposed or covered by glacial sediments which comprise a mixture of all materials along the path of ice-water flow. In other regions, vast areas may be underlain by sediments once formed in the marine environment but now exposed by sea level change or tectonic motion. Thus, on a grand scale, there are very large differences in materials from which soil forms.

The soil forming process, called weathering, is basically simple. When rocks and minerals react with air and water, processes occur which influence the nature of soil. First some minerals, like calcite (calcium carbonate), simply dissolve in water and are transported towards the ocean. Solutions of such minerals create porosity in the soil. Minerals like feldspars ($KAlSi_3O_8$; $NaAlSi_3O_8$; $CaAl_2Si_2O_8$), which comprise almost half the Earth's crust, react to form a complex array of minerals we call clays, at the same time releasing SiO_2 and Ca-Na-K to the solutions. Clay minerals are hydrated silicates of complex chemistry with certain very important features. Typically, they are of extremely fine crystal sizes with vast surface area. They can exchange species with those in solution (ion-exchangers), they are excellent absorbers of species in solution and may contain traces of dozens of metallic elements (Mg, Ca, Na, K, Zn, Cu, etc.). They can absorb and strongly retain water on their surfaces. These complex clay minerals, called smectites, form the nutrient bank and water reservoir of the soil.

Another process of great significance is the oxidation of iron- and manganese-bearing primary minerals. Thus, during weathering, a mineral like Fe_2SiO_4 ($2FeO + SiO_2$) reacts with oxygen to form $Fe_2O_3 + SiO_2$. It is this process that leads to the red soils typical in many tropical terrains. And in the pore spaces of soil reside a host of bacteria which play vital roles in catalyzing the mineral-clay reactions, fixing nitrogen, and acting as ion-exchangers. Soil also contains various amounts of residual organic matter, plant roots, plant debris, and big complex organic molecules, which, with the living bacteria and other organisms, play a vital role in supplying plant nutrients.

The Importance of Smectite

One of the classic chemical formulae for smectite is:

$(1/2Ca,Na)_{0.7}(Al,Mg,Fe)_4(SiAl)_8O_{20}(OH)_4\ nH_2O$.

Essential trace elements such as Zn, Cu, Ni, Co, etc., may substitute for Mg, Fe. The nH_2O simply means that the mineral contains various amounts of water, depending on the humidity and temperature. Smectites form when common rock minerals are present.

But if rain water falls for millennia and leaches the soil, species are slowly removed and the smectite degrades to another clay, kaolin ($Al_2SiO_5(OH)_4$), which contains no essential trace nutrients. The soil is old and tired. This is the situation with soils in much of the stable Amazon basin where there have been few additions of new rock debris for millions of years. To assess the quality of a soil rapidly, one need only look at the chemistry of local drainage water. In regions of old leached soils, this water often approaches that of rain water, with low nutrient value (Fyfe 1989).

Study of the minerals in soil, their physical properties and contained microorganisms, clearly shows that fertile soils capable of sustained agricultural productivity are composed of a mixture of primary rock-forming minerals containing a reasonable sample of the chemistry of the Earth's crust, plus the major weathering products of smectite clays. We can assess the time needed to form a reasonable thickness of such soil by studying regions where new crustal rocks are exposed by erosion or volcanism. The time is on the order of hundreds of years, depending on rainfall and temperature. Thus, for sustained agriculture, it is necessary to protect soil from all forms of erosion. The observations of the Worldwatch Institute, which places global topsoil erosion at 0,7% per year - a rate far exceeding soil formation in most situations - must be viewed with alarm.

What information is needed to plan agricultural development?

As population increases, almost all regions of the planet capable of producing food are invaded by humanity. There are few regions now where human activities are not modifying the land surface. Our ancestors were clever farmers. When they settled a region they were quick to recognize those areas with good soils and adequate water supply. They built their villages in such regions; today vast cities occupy the same sites, often expanding over the best land for food production. When we plan for sustainable food production, what conditions must be met?

First, the climate, temperature and rainfall, and light fluxes must be suitable. If water is to be provided by unnatural methods (dams or groundwater mining), the use must not exceed the reliable supply or recharge. And the use must not disturb other regions already in production. If irrigation is used, the system must still be adequately flushed, or salting will result; most groundwaters are more salty than surface waters.

Marine fish production also depends heavily on nutrients supplied by continental runoff. Satellite observations have shown that most marine biomass lives near the continental margins. Depressing river flow by irrigation and evaporation will lead to depressed fish production, a problem now occurring at an alarming scale in many parts of the world.

There must be an adequate thickness of porous soil. Porosity is necessary for water penetration and storage, and to provide housing for an array of necessary symbiotic organisms. The composition of the soil must in general be close to that of the average continental crust, and should contain smectite clays, primary rock and mineral debris. If a harvested crop removes x kilograms of K or Mg or P per hectare per year, the soil must have the necessary reserve. If not, the minerals removed must be replaced by fertilizer additions for productivity to be sustained. Before development, the mass balance of all essential nutrient fluxes must be determined, including inputs from aerosols, dust, water, minerals, etc. These fluxes will determine which crop (or forest) is most suitable for a given regime, and what additions must be made.

Soil porosity and thickness must be maintained. Soil erosion is a natural process. But for sustained productivity, erosion rates must not exceed formation rates. Today, soil erosion can be controlled.

A soil map should be drafted containing all these essential data, including K-Ca-Mg contents, etc. As well, there is need for maps showing the nutrient requirements of various regions in constituent kilograms per hectare per year; and maps showing the most suitable biomass for a given region.

Can we renew degraded soils ?

Through general mismanagement, soils have eroded and lost adequate nutrient levels in many parts of the world. There is an urgent need to develop systems for their renewal. Such problems are complex and specific to local regions. In many natural systems, mineral renewal occurs via periodic flooding which spreads fine debris or by addition of layers of new volcanic ash, etc.

Here I suggest just a few approaches:

(a) Sediments may be pumped out of dams or overloaded river systems and onto local farmland. If locally available, ground rocks may be added. Often this process could be coupled to careful use of debris from mining and construction.

b) In many situations near giant cities, sewage may be used to add organics, nitrogen and phosphorus. Many societies have known this for centuries, but few giant modern cities (e.g. Nairobi, Bombay, Toronto) have such technology. We must become more committed to the use of compost.

(c) There must be careful local planning involving the use of plant cover to reduce erosion and reduce catastrophic runoff.

(d) There must be a careful choice of vegetation planted during a period of renewal (e.g. use of plants like lupins to recharge the soil with nitrogen and organics).

But, in the final analysis, future hopes must rest on our ability to educate all humans on how this planet functions and all the systems which control the quality of life support and the natural fluctuations in those systems. We must plan for surplus - only then can we preserve biodiversity and hope for future generations.

Dr. William Fyfe teaches in the Department of Geology, University of Western Ontario, London, Ontario, CANADA. One of the pre-eminent geochemists of the last several decades, his interests have ranged from issues on mantle geochemistry to the hydrosphere. He has been active in a variety of fields including agrogeology, for the last decade, working in a number of developing countries. During this time, he has authored numerous papers and several books.

Agrogeology Resources for Small Scale Mining

by Peter van Straaten and Calvin Pride

Introduction

Mining and agriculture are strong pillars of a nation's economy. They provide the basis for the survival, development, and comfort of people. While agricultural crop production extracts mineral nutrients from the surface, mining operations usually remove the soils and extract minerals from rocks below. Agriculture extracts renewable resources and can be sustainable; mining extracts non-renewable resources and has finite limits.

Farming is an extractive process. Plants "mine" the soil, extracting nutrients from soil solutions provided by decomposing organic materials and the breakdown of minerals. The speed of release from organic and inorganic phases differs very much, however. Organic materials decompose relatively fast, and have a relatively short recycling time. The speed of breakdown of minerals through weathering is much slower, usually too slow to provide enough nutrients from mineral sources for fast and continuous cultivation techniques.

Over the last few years a new earth science discipline has emerged: agrogeology. This new discipline is the study of geological materials and processes that contribute to the maintenance and improvement of the physical and chemical nature of soils. This inter-disciplinary approach combines the knowledge of agriculturalists with the knowledge of geologists: soil scientists define the soil limitations and needs, and geologists find, delineate and characterize the geological raw materials needed to increase soil productivity. Practical results of agrogeological research are the development of geological resources (e.g. phosphates, potassium resources, limestones, etc.) and techniques that maintain or increase the productivity of the soil.

The first phase of an agrogeological

project is usually that of soil problem identification. The most common chemical and physical problems of soils are:

° the soils are not fertile enough, i.e., they lack certain plant nutrients;

° the soils are too acid or too alkaline;

° the soils are saline;

° the moisture of the soils is excessive (soils are water-logged) or the soils lose too much moisture due to evaporation;

° the soils are being lost due to erosion.

There are many ways of improving the above-mentioned problem soils, and several modes of improvement involve the use of agrogeological resources. These agrogeological resources need to be located close to farming areas, and they have to be characterized and tested for their agronomic effectiveness.

Agrogeological resources

Agrogeological resources are those mostly non-metallic minerals and rocks from which fertilizers are synthesized or which can be applied to the soils in unmodified or modified forms to improve the nature of the soils.

The best known agrominerals are:

° saltpetre, the only naturally-occurring nitrate mineral that occurs in sizable deposits;

° apatite, the principal phosphate mineral;

° guano minerals, and complex P- and N-bearing compounds;

° sylvite (KCl) and other, more complex K-bearing salts;

° K-silicates, such as K-feldspars, K-micas, glauconite, and K-bearing zeolites, and K-rich tuffs;

° sulphur, sulphides (e.g. pyrite), and sulphates (e.g. gypsum);

° calcite and dolomite, both "liming materials";

° various silicates used to conserve nutrients (e.g. zeolite) or used to conserve soil moisture (e.g. scoria and pumice).

There are also other "agrominerals," for example, minerals used as carriers of pesticides and herbicides (e.g. diatomite, zeolites); minerals and rocks used as stock feeds and in the food industry (e.g. clays, zeolites, limestones, etc.); and "hortiminerals," minerals used in the horticultural industry as growth media (e.g. vermiculite, perlite, scoria, zeolites).

Like other rocks and minerals, agrogeological resources are not equally distributed over the earth's surface. Rather, they were deposited during certain times and occur in certain geological environments (van Straaten: 1987). To discover new agrogeological resources, it is of utmost importance to recognize these favourable geological environments, and favourable geological times of deposition, and adjust the selection of exploration targets accordingly.

Exploration for agrominerals has been carried out successfully in many countries. Most of the large deposits and several smaller deposits were discovered by classical exploration methods, such as geological mapping, geochemical surveys, radiometric surveys and even geobotanical surveys. Many other smaller deposits have been found over the last few decades, but relatively few of these small deposits are being exploited at present. Countries such as India and China make wide use of these local resources; other countries, such as Zambia, Tanzania, and Ethiopia, are at the stage of developing some of these small deposits now.

Rocks and minerals are used in farming systems for several purposes, among them:

° improving soil fertility;

° correcting the pH of soils;

° improving salt-affected soils;

° conserving nutrients and water.

Agrominerals to improve soil fertility

There are 16 elements which have been recognized as being essential for plant growth. Of these, carbon, hydrogen, and oxygen are supplied by water and air. Other elements, taken up by the plants from the soil solution, are the primary macro-nutrients N, P, K, and the secondary macronutrients Ca, Mg, S. Micro-nutrients include B, Cl, Cu, Fe, Mn, and Zinc. There are other elements, such as Mo, Na, Si, I, Se which, in certain circumstances, increase crop yields or improve the value of the crops for animals and human beings.

It should be stressed here that all nutrient resources for the production of synthetic fertilizers, with the exception of N, are of geological provenance.

Nitrogen

Of all the essential plant nutrients, nitrogen is probably the most important.

Apart from the rare occurrence of mineral nitrates, all N-fertilizers have been produced by industrial processes synthesizing nitrogen from the air ("mining the air") and hydrogen from geological fuel resources, such as natural gas or coal. Nitrates are extremely soluble and are found in their natural form mainly in areas of extreme and long lasting aridity, e.g. in the Atacama desert of Chile or in Nevada, U.S.A.

There are only a few biological nitrate deposits which are being exploited, most of them in a small way. Most of these nitrate accumulations developed from oxidizing animal excreta in caves, where the nitrates are protected from the action of water. These accumulations are usually very small. Often, instead of being used as local fertilizers for peaceful purposes, they end up being used as raw material for local gunpowder.

Phosphorus

High soil acidity and phosphorus deficiencies are common growth limiting factors in many soils, but especially in highly leached tropical soils. Low crop yields occur typically on strongly depleted reddish oxisols and ultisols ("lateritic" soils). The low fertility status of these soils is largely due to the low amount of plant-available phosphorus and the high phosphate fixing capacities of these soils. To be effective, relatively high amounts of soluble phosphate fertilizers have to be applied on tropical soils, because the phosphate ion is easily "fixed" to aluminum, iron and manganese oxide minerals. It has long been recognized that major efforts are needed to develop phosphate fertilizers with lower solubility which are better suited for tropical soils.

The agronomic effectiveness of phosphatic rocks is determined by a number of interrelated factors:

° the mineralogy and chemistry of the phosphate rock, the solubility and grain size;

° the chemical and physical status of the soils, especially its pH, moisture holding capacity, P and Ca status and the P-fixing capacity of the soil;

° the type of crops and their nutrient requirements;

° the method and time of application.

The raw materials used for commercial phosphate fertilizer production are of sedimentary, metamorphic, igneous and biogenic origin. The most extensive of these resources are mined and processed on a large scale. Large scale operations dominate phosphate mining in Morocco, the United States, Russia, and other countries.

But there are many more phosphate deposits in the world which have not yet been developed. Most of these are of medium to small size. Only a few are currently being worked, notably in China, India and Sri Lanka. In the 1960s, a small residual phosphate deposit was mined in East Uganda. Ground-up phosphates were used as direct application "fertilizer" on grassland, but also processed with soda ash into a more soluble P-fertilizer.

Considerable knowledge of the geology and mineralogy of these phosphate deposits exists. Reasons for not developing more of these locally available resources include the unfavourable geographic locations, their small size, and the complex composition of the phosphates and hence the lack of technologies to treat them. There is also an economic bias against even considering such deposits. Remote deposits have little attraction for large or small scale development; however, small deposits close to farming areas can often have significant benefits for a local community. Here, economy-of-scale considerations are often outweighed by the cost of transporting high bulk/low value fertilizers. Complex phosphate ores require special attention and the process technologies of large industries might not be suitable.

A general drawback of many of these deposits is their low grade and/or the low solubility of the phosphate mineral apatite, often too low to be agronomically effective. Over the last decade, many new and innovative modification techniques have been investigated, including phospho-composting, bioleaching, fusion, mechanical activation, heap leaching, ion-exchange with another mineral (e.g. zeolites), and in-situ acidulation by mixing the raw phosphate with acidifying minerals such as pyrites or acidifying fertilizers. Each individual phosphate resource has to be tested and in some cases one of these "new" techniques might be suitable and adaptable. It is clear that more efforts have to be made to develop these small but vital resources and adapt the extraction and modification techniques to suit the local technical capabilities.

Potassium

Many soils, apart from lacking nitrogen and phosphorus, the two main macro-nutrients, also require a large amount of potassium. Crops with a high demand for K include potatoes, bananas, and sugar cane.

K-salts: Due to their high solubility, K salts such as sylvite (63% K_2O) and carnallite (17% K_2O) rarely crop out at the surface of the earth. Associated with highly soluble evaporitic sequences, they are found at the surface only under extremely arid conditions, for example, in the Danakil depression of Ethiopia. Potash is also recovered from salt lakes, such as the Dead Sea in the Middle East or the Great Salt Lake in the US from mineral brines.

K-silicates: K-silicates are known for their low K-release rates. The use of K-rich minerals, such as leucite (20% K_2O), K-feldspars (8-14% K_2O), biotite (6-10% K_2O), K-zeolites (2-6% K_2O), and glauconite (6-8% K_2O) is severely restricted due to their low release of plant-available potassium. The direct application of ground K-feldspar has been done in several countries, including Sri Lanka and Colombia, but with limited success so far. Attempts to increase the plant availability of potassium from silicate rocks through bioleaching (Rossi 1978) and partial acidulation (Borsch 1990) have met with limited success and have not resulted in commercial small scale extraction and utilisation as yet.

Sulphur

Sulphur deficiencies in soils are becoming more and more apparent in recent years, especially in areas far away from the sea and from industry. These sulphur deficiencies are partially due to depletion of S through heavy crop removals and intensive cropping, but also due to the expanding use of S-free fertilizers such as TSP and urea, and the decreasing use of fungicides and insecticides containing sulphur.

Sulphur occurs in rocks and minerals mainly in the form of elemental sulphur (brimstone, or "burning stone"), as sulphides (e.g. pyrite, marcasite), and sulphates (e.g. gypsum, anhydrite).

In industry, elemental sulphur is mainly used to produce sulphuric acid for the manufacture of super-phosphates. It is extracted in large scale operations from underground salt domes by the hot water "Frasch" extraction process, using superheated water. Elemental sulphur is also recovered during the processing of "sour gas" from oil and gas operations. Elemental sulphur associated with volcanic deposits has been mined in Sicily, Italy, since the 15th century, and is also being mined from many other volcanic centres.

The exploitation of a small sulphur-pumice deposit in New Zealand involves the mining of several thousand tonnes of a sulphur-impregnated pumice breccia which contains approximately 10-15% elemental sulphur. It is sold as a direct application fertilizer. The role of the pumice is to retain moisture in the soil and to provide a substrate for bacterial growth which converts sulphur into plant-available sulphates.

In recent years, agricultural trials have also been conducted testing elemental sulphur mixed and granulated with phosphate rock. Results from New Zealand show increased yield responses of rye grasses following the application of these granulated blends (Rajan 1983). The results indicate that the effect of higher yields is not attributed to sulphur as plant nutrient but rather to the effects of in-situ production of sulphuric acid, which dissolves the phosphates and makes them available as plant nutrients.

In many countries, pyrite is the raw material for sulphuric acid production for the phosphate fertilizer industry. But pyrites have also been applied directly to the soil without chemical processing. In India, ground pyrites are successfully used on alluvial soils of the river Ganges and on unproductive alkaline soils. In Bihar State, sulphur-containing pyrites are either applied directly to calcareous soils or are mixed with phosphate rock. When applied to the soil, the sedimentary pyrites are rapidly oxidized to form sulphuric acid and Fe-sulphates. It is this in-situ conversion of pyrites to sulphuric acid which affects and partially acidulates the phosphate rocks, a simple in-situ phosphate acidulation process. In India, it is economic to use these local pyrites on calcareous soils because of their availability and low transport costs.

Pyrites, alone or in combination with composts, have been successfully tested in New Zealand as a cheap method of treating iron chlorosis in rice, and bear some potential for special applications.

Sulphates, such as gypsum and anhydrite, are used for two purposes in agriculture: as plant nutrients, and as a mineral which improves the physical properties of salt-affected soils. Gypsum was already used in the eighteenth century in the southern United States as "land plaster" for fertilization purposes. Direct application of gypsum for peanut farming is still practised in many countries.

Small, locally available sulphur, gypsum and pyrite resources are found in many countries. It seems obvious that more of these resources, some of which are well suited for small scale mining and processing, should be tested for their suitability to improve local S-deficient or alkaline soils.

Agrominerals to correct soil pH

Limestone/dolomite for acid soils: High soil acidity is one of the limiting factors for agriculture in many countries. High leaching rates, unfavourable parent materials, and continuous application of chemical fertilizers such as ammonium-sulphates are largely responsible for high soil acidity and correspondingly high concentrations of toxic aluminum.

Liming materials such as limestones, dolomites, and calcined and slaked limestones (lime), are used to raise the pH of acid soils and consequently decrease the Al toxicities. Finely ground liming materials have been applied to acid soils for centuries and are still being applied in many countries of the world.

The size of mining operations of limestones and dolomites for agricultural lime production ranges from several thousand tonnes per month to operations with only a few tonnes per cropping season. In cases of application to soils with low buffering capacities, it is often not advisable to calcine the limestones and dolomites; rather, they can be used directly.

The application rate of lime or limestones/dolomites depends largely on the pH and buffering capacities of soils, but is generally in the range of several tonnes per hectare. Since large quantities of liming materials are required per unit of land, and since these materials are low value, high bulk products, it is of utmost importance to find local sources in order to keep transport costs low.

Locally available carbonate resources such as calcitic and dolomitic marbles, carbonatites, sedimentary marine and lacustrine limestones, and secondary limestones (calcretes) are relatively common and are well suited for small scale mining and processing. Many more small limestone resources could be mined, and, with some advice from agricultural extension personnel, applied on many more acid soils of the world.

The case of liming materials illustrates the great advantage of active cooperation between soil scientists and geologists in agro-

Small lime operation, Iringa, Tanzania.

geology projects. Soil scientists outline the areas with high soil acidity, and geologists search for agricultural limestone/dolomite resources close to the acid soils. Even if the agricultural carbonate resources are of small extent and not of the quality required for cement manufacture, they are probably suitable for local acid soils.

Elemental sulphur and pyrites for alkaline soils: Alkaline soils can also pose considerable problems for farming, specifically for farming of crops which require a relatively low pH, such as tea, potatoes, and various berries.

To reduce the soil pH, elemental sulphur or pyrites have been used in some instances. Due to the high application rates of these sulphur sources, however, this practice is limited.

Agrominerals to improve salt-affected alkaline soils

Gypsum: The reclamation of salt-affected alkaline soils consists of the removal of soluble salts or exchangeable sodium by adding an amendment which supplies soluble calcium. Of all the calcium minerals, gypsum is considered the best for this purpose. Large amounts (5 to 10 tonnes/ha) of finely ground gypsum are applied to the soils in order to increase the water infiltration and depth of water penetration.

The application of gypsum to salt-affected soils is economically viable only when the gypsum resources are close to the problem soils.

Agrominerals to conserve soil moisture and nutrients

Water is essential for the growth of plants. It translocates and distributes the plant nutrients to the required locations and keeps the turgor of the plant cells and thus the stability of the plant. Too little or too much water are both detrimental to plant growth. Lack of water strongly influences metabolic processes in a plant: the water turgor decreases, the plant wilts and finally dies. An excess of water reduces the availability of oxygen for plant respiration in the soil. Under water-logging conditions, there is a lack of oxygen which limits plant growth and, in some cases, increases the development of toxic anaerobic metabolic products. The combination of these complex processes results in decreased growth and finally death to unspecialized plants.

Lack of moisture seriously limits crop yield. This is particularly serious in arid and semiarid zones where precipitation is limited. If there is not sufficient precipitation during the growing season, a crop is either irrigated or must rely on moisture reserves stored before the time of planting. The improvement of soil moisture storage or moisture retention is therefore of paramount importance in cropping systems. Improvements in soil management systems aim at cutting the high evaporation rate, especially in arid and semiarid areas, by many methods, including mulching and cover cropping. The effectiveness of rock mulches to reduce evaporative losses is well illustrated in the Canary Islands, where rock mulches have been applied for centuries in vegetable and crop farming (Chesworth et al.: 1983: Caldas and Tejedor Salguero: 1987). Recent results from an IDRC-supported agrogeology project in Ethiopia indicate that the soil moisture content could be conserved considerably by mulching with a 3 cm thick layer of volcanic scoria. First field observations showed maize yields increasing by up to four times the control (van Straaten et al.: 1991). The experiments are currently continuing with horticultural crops and fruit trees.

Certain minerals can also be used to conserve and store nutrients. Among the nutrient storing minerals, the zeolite group stands out as the most promising. These unique hydrated aluminosilicates, found mainly in volcanic areas, are characterized by their large cation exchange capacity, high ammonium and potassium selectivity, and high water holding capacity. In agriculture, they have been tested successfully for their NH_4^+ and K^+ storing capacity, for their slow nutrient release characteristics, and their ability to increase the solubility of phosphate minerals. One of the potential applications is to cover farmyard manure and compost piles with zeolites, trap the escaping nitrogen compounds, and use these N-zeolites in the fields as slow-release nitrogen fertilizers.

Mining of agrominerals

Fertilizer production from big mines for big farms and small farms: Agrominerals, i.e., minerals and rocks which are used to increase soil productivity, are mined on both a big scale and a small scale. Many phosphate deposits in Morocco, the US and Russia are mined on a large scale, using huge draglines and sophisticated processing plants--in fact, the quintessential large-scale, low-cost mining operations. Sulphur and potash resources are also mined and processed in this manner. The end product is usually a fertilizer material that is effective in most soils, highly concentrated (therefore economic for distant shipping), and easy to handle. Commercial fertilizers which are mined and processed on this scale are routinely used on large scale farms, but considerable amounts of commercial fertilizers are also used by small scale farmers, at least by those who can afford them.

By contrast, there are also many agromineral mines that operate on a small scale. There are several small mines that extract sedimentary and metamorphic phosphates in India, Sri Lanka and South America for local application. There are also virtually thousands of small scale guano operations which haul the phosphorus and nitrogen-rich guano from the caves to local markets and fields.

Also, small operations that produce limestones and dolomites for agricultural purposes are not uncommon. More use could certainly be made of such materials, particularly in the tropics where soil acidity is a problem.

Usually, agrominerals extracted by small scale miners are only slightly beneficiated. They are transported as bulky and unrefined materials to local markets and nearby fields where they are used directly.

Advantages and disadvantages of developing and mining small scale agromineral resources

Among the advantages of developing small scale agromineral deposits close to farming areas are that small scale mining and related small scale industries can provide some local employment while at the same time providing farmers with a valuable product to improve their soils. Some of these materials are locally available; their production price and transport costs are low; and many of them have great long-term agronomic effectiveness. On a wider scale, developing local agrogeological resources that can improve the nature of arable soils will lessen the dependence on fertilizer imports and save scarce foreign exchange. Local agromineral resources may be the only realistic option for the small scale farmer who cannot afford more expensive, mostly imported fertilizers.

It is a truism in geology that for every very large deposit, there are many orders of magnitude more small- and medium-scale deposits of similar type. From the above discussion, it is also obvious that there is enormous potential for the increased use of many readily available geological materials to improve soil fertility. What is clearly needed is a major multi-disciplinary effort to find, test and develop these resources for the use of the small-scale farmer.

There are, of course, some disadvantages in developing small deposits. Among the more obvious are their short lifetime, and their lower agronomic effectiveness.

It is clear, however, that with increasing pressure on the land and the consequent strain on the soils, more has to be done to develop local resources for the improvement and restoration of soil fertility. More agromineral resources have to be found and mined locally in order for agriculture to become less dependent on the importing of industrial fertilizers which are out of the reach of many farmers of the developing world.

The use of locally available minerals and organic materials for maintaining soil productivity is a move towards a more sustainable agricultural system. In certain areas, adaptive agricultural development will depend on the finding and extraction of local agromineral resources, and it is here that the small scale miners will be able to assist the small scale farmers. In many cases, the small scale farmer is the seasonal small scale miner anyway.

Dr. Peter van Straaten teaches in the Department of Land Resource Sciences at the University of Guelph, in Guelph, Ontario, CANADA. A pioneer in using a multidisciplinary approach, he was the driving force behind a number of Agrogeological projects in Tanzania, Ethiopia and Zimbabwe.

Dr. Calvin Pride is a geologist and private consultant based in St. Pascal Baylon, Ontario, CANADA. He is also Vice President of Small Mining International.

CURRENT OPPORTUNITIES

Ghana. Joint-venture partners and technical assistance sought to develop an alluvial gold prospect in the Dormaa District of the Brong Ahafo Region. For further information, contact Seth Oppong, Aduana Co-operative Gold Prospecting, P.O. Box 657, Kumasi.

Ghana. Machinery, financial and technical assistance sought to develop an alluvial gold working on the banks of the Birin River at Abompe, Eastern Region. Equity or joint-venture investment welcome. Contact Abdullah Abubkr, Manager, Sulemanu Mohamade Iddrisu Mining Co. Ltd., P.O. Box 11, Bunso, Eastern Region.

United Republic of Tanzania. Entrepreneur with prospecting rights for a gold deposit in the southern highlands of the country seeks financial and technical assistance on a joint-venture basis to start a small-scale gold-mining enterprise. Market, surveyed site and manpower available. Contact Christopher Sanga, Director, Lucky Investments Ltd., P.O. Box 1675, Mbeya.

Zambia. China-clay mining company seeks technical know-how, machinery and financial assistance for the processing of china clay into ceramics, paints, cisterns, floor tiles and other items. J.E.K. Sangambo, Managing Director, Jeks Enterprise, Private Bag RW 211, Redgeway, Lusaka.

Extracted in part from recent issues of the UNIDO Newsletter.

Zeo-Agriculture

by D.D. Eberl

We may view our present agricultural practice with some pride: it is a superb application of modern science and technology, giving large agricultural yields for very little human effort. But future generations may view some current practices as being wasteful, crude and environmentally unsound. For example, some of the problems facing today's agriculture include soil erosion and soil pollution; pollution of ground and surface waters by fertilizers and pesticides; drought; lack of phosphorous and trace nutrients in tropical soils; treatment and disposal of animal wastes; and the increasing cost of fossil fuels. What would be a better type of agriculture? What are desirable goals for future agricultural research and technology?

It seems clear that future agriculture needs to be sustainable. This means that the soil needs, at the least, to retain its fertility, or, better, to become increasingly fertile through the years as it is farmed. As the soil is improved with time, so must the surrounding ecosystem, to make an enjoyable, beautiful, healthy and productive community for humans and other beings. A sustainable future means that we cannot continue to be heavily dependent on cheap fossil fuel energy.

The field of "zeo-agriculture" (Pond and Mumpton, 1984; Parham, 1989) is in its infancy, but it may help move us towards more sustainable and environmentally sound farming methods. Zeolites are a family of synthetic or naturally occurring aluminosilicate compounds having the general formula:

$$(Li, Na, K)_a(Mg, Ca, Sr, Ba)_d[Al_{(a+2d)}Si_{n-(a+2d)}O_{2n}] \cdot mH_2O$$

where the part of the formula in the brackets represents the framework atoms, and the rest of the formula refers to exchangeable or fixed cations and water (Gottardi and Galli, 1985). The framework is composed of a three dimensional network of aluminum and silicon atoms that forms cages and channels having a variety of sizes and shapes, thereby giving rise to a large porosity on the molecular scale and to the mineral's use as a molecular sieve (Breck, 1974). Water may be held in the molecular pores (zeolitic water), or in the pore space between crystals (pore water). The substitution of three-valent aluminum for four-valent silicon gives rise to a negative charge on the framework that is balanced electrically by either the exchangeable or fixed cations located in the cages and channels.

Zeolites are useful in agriculture because of their large porosity and cation exchange capacity, qualities which allow them to be employed as controlled-release carriers of plant nutrients and other soil amendments such as herbicides and pesticides (Barbarick and Pirela, 1984). They can also serve to free nutrients already in a soil by ion exchange for uptake by plants (Eberl et al., 1992); to improve soil fertility and water retention capacity; to remove toxic cations from soils and animals; and to absorb odours in feed lots. Zeolites not uncommonly occur in enormous, near-surface deposits (Mumpton, 1977); therefore they could be employed at low cost on a large scale in agriculture should their use prove to be beneficial and economically justifiable.

As there are about 50 different species of zeolites having a variety of chemistries and structures, each type needs to be tested to prove its agricultural effectiveness. Zeolites can be harmful as well as helpful to plant and animal growth. For example, zeolites with sodium as the chief exchange ion can be toxic to plants (Pirela et al., 1984; Weber et al., 1984), and K-poor or Ca-poor zeolites can scavenge K^+ or Ca^{2+} ions from soil solutions and thereby limit plant growth when used in soils that are deficient in these nutrients (Barbarick et al.,1991; Marcille-Kerslake, 1991). The zeolite, erionite, is carcinogenic when inhaled by animals, but other zeolites tested show no such biological activity (Guthrie, 1992).

Despite the above warnings, the intelligent use of zeolites can give good results. For example, zeolites employed to treat swine manure in order to prevent nitrogen pollution, improve handling characteristics, and remove odour, were subsequently used as a fertilizer on crops, giving yields comparable to or better than those produced using conventional, soluble fertilizers (Mumpton, 1984, Vidic et al., 1991). NH_4^+-saturated zeolite (clinoptilolite) was used to solubilize phosphate rock in greenhouse experiments, leading to improved P-uptake and yields for sudangrass (Barbarick et al., 1990). Urea-impregnated zeolite chips can be used as a slow-release nitrogen fertilizer (Eberl and Lai, 1992). Zeolite, without soil, can be used as a growth medium for plants ("zeoponics"; Parham, 1989), and is being investigated by NASA as an artificial soil for extraterrestrial agriculture (Ming et al., 1991). Zeolite has been fed to animals to reduce the moisture content of feces, to improve weight gain and animal health (Parham, 1989), to serve as slow release carriers of pesticides, to trap heavy metal contaminants in soils (Leppert, 1990), to decrease the incidence of intestinal diseases in animals, to improve the shell strength of chicken eggs, to remove ammonia from fish tanks and the smell from feed lots and poultry houses (Mumpton, 1984).

Based on recent experiments with zeolites, one can imagine an agricultural future in which zeolite-containing fertilizers are applied only once every several years. These fertilizers would release nutrients to plants as they are needed by the plants (buffered systems), thereby eliminating fertilizer pollution and toxicity. These fertilizers also would increase soil fertility through time by increasing the soil's ability to hold nutrients and water, and by tapping the soil's own nutrients locked in sparingly soluble minerals through dissolution by ion exchange (Lai and Eberl, 1986; Chesworth et al., 1988). Whether or not such possibilities for zeo-agriculture will be realized will depend on a movement towards agricultural technologies that are advanced and fine-tuned toward ecologically friendly methods. Such advances in zeo-agriculture will require careful agricultural experiments with well-characterized zeolites (Shepard, 1984) to prove and extend this promising technology.

D.D. Eberl is a mineralogist with the US Geological Survey. He has done extensive work on the use of rock fertilizers and holds the patent on a zeolite based fertilizer.

Rock Phosphate as a Direct Application Fertilizer: A success story from India

by S.L. Chakravorty

Introduction

The story of the Beldih rock phosphate mine in the Purulia district of the state of West Bengal is a success story pointing to the immense potential to exploit agromineral deposits on a relatively small scale and by labour-intensive means. The mine was started in 1975, with the sale of rock phosphate in powder form as a direct application fertilizer. This was done against the advice of, and in spite of protests from, many modern "scientific" experts, and despite opposition from the chemical fertilizer industry. But even today, the mine is operating steadily, while providing employment to over 250 local villagers at wage levels above the local average. A large sum of money is thus being pumped into the local economy.

As a result of elaborate and comprehensive laboratory and field studies, phosphate powder is today being extensively used, either alone or mixed with other NPK fertilizers. Local demand has increased steadily and is beyond the present capacity of the mine. Above all, there is now no protest from any "experts" about misuse of the rock. The story of Beldih can therefore be considered a success story.

A detailed socio-economic study in the area is expected to be carried out soon, in order to quantify the benefits in real terms to the local people from the small scale mining and industrial activities, and to explore what more can be achieved and how.

Geology and Mineralogy

The mineralisation occurs in the form of lensoid bodies of apatite-magnetite rock in a 90 km long shear zone. The host rock is usually highly crushed or brecciated. The ore generally contains fluoro-carbonate apatite and martitised magnetite, with other accessory minerals. In spite of the high P_2O_5 content, the presence of about 10 to 15% Fe_2O_3 makes it unsuitable as a source of phosphatic chemicals. Beneficiation has proven to be uneconomical except for simple washing away some of the clay. Hence direct application was considered the most judicious use in spite of initial opposition from "experts".

One quarter of the original estimated reserve of 1.06 million tonnes of apatite (average grade of 16.34%) has above 21.10% P_2O_5. Subsequent prospecting along the shear zone has revealed new deposits which are under development now. At least one lens in Beldih mine which originally outcropped at the surface is of a fairly large size, open at depth. It is also high grade (30% P_2O_5). This material is to some extent being used to "sweeten" the lower grade material to make it marketable. This avoids wastage and allows conservation consistent with practical needs and economy. This high grade material is only used sparingly in this manner in case some other gainful use can be found for it.

Table 1 shows the results of modal analysis of one run-of-mine (ROM) sample collected in 1977 and analyzed by the International Fertilizer Development Centre (IFDC), Muscle Shoals, Alabama, U.S.A.(MR-607). (from Das, 1979; WBMDTC, 1980; WBMDTC, 1982):

Mineral/Composition	Weight %
Fluorocarbonate apatite	67.7
Mn-goethite $(Fe,Mn)_2O_3H_2O$	16.8
Phlogopite mica $(K,Na)_2Mg_5Fe(Al_2Si_6O_{20})(OH)_4$	2.0
Halloysite $Al_2Si_2O_5(OH)_4.2H_2O$	7.7
Ilmenite $FeTiO_3$	1.6
Quartz SiO_2	1.7

Table1

The principal gangue minerals of the ore are goethite and clay minerals. The phosphate mineral is fluor-apatite, with the fluorine content increasing with increasing P_2O_5 (see Table 2) :

Sample	1	2	3	4
P_2O_5%	28.78	29.95	31.99	33.97
F%	1.46	2.08	2.10	2.68
CaO	36.32	37.68	39.91	42.82

Table 2

Although the chemistry varies depending on location, one typical sample of ROM ore gave the following results :

Oxide	Wgt. %
CaO	37.3
P_2O_5	27.8 *
Fe_2O_3	15.4
SiO_2	5.7
Al_2O_3	2.9
F	2.4
TiO_2	0.9
Mn_2O_3	0.8
CO_2	0.6
MgO	0.5
SrO	0.3
Na_2O	0.2
S (total)	0.1
Cl	0.01
total	94.9

*(NAC soluble P_2O_5 1.6%)

The IFDC reported that the rock is a metamorphosed sedimentary phosphate deposit. According to a subsequent prospecting report of the Geological Survey of India, the material has an average P_2O_5 content of 21.6% of which 5.7% is soluble in neutral ammonium citrate solution.

Use of the Rock - General Considerations

Rock phosphate in powder form is widely used as direct application fertilizer all over the world, especially in the acid soils of the U.S., France, Poland, India and the former U.S.S.R. Such direct application is the result of extensive and large scale scientific and technological studies carried out all over the world in different countries under different agro-climatic conditions. The Beldih rock phosphate (sold as Purulia Phos) has also been extensively studied both chemically and agronomically.

Natural rock phosphate contains phosphorus (P) but not in water soluble form. However, a part of it may be in citrate soluble form which on reaction with acid soil promptly makes P available to plants. The non-citrate soluble phosphate, in the course of time, reacts slowly with the acid soils and P is gradually released, thus meeting both the immediate and long term needs of the plants. Many studies have noted that the residual effect of rock phosphate is greater than that of single superphosphate (SSP).

Plants need not only major nutrients such as NPK, but also micro-nutrients such as molybdenum, zinc, manganese, sulphur, copper, etc. which are usually present in rock phosphate but not necessarily in chemical fertilizers. Such micro-nutrients play an important role in plant growth.

Thus where the rock phosphate is of lower grade, it is in many cases more logical and remunerative to use it directly in powder form. Such use is more justified when a deposit is not amenable to easy beneficiation, or is too small to sustain a beneficiation plant, and is located in an area of acid soils. The presence of excessive quantities of materials deleterious to chemical processing such as calcite, dolomite, and iron bearing minerals may render a particular phosphatic rock unsuitable for making chemical fertilizer but not for direct use. This is exactly the position with the Beldih rock phosphate.

There are widely varying opinions concerning the availability of phosphorus from apatite in acid soils. Many of these opinions have yet to be verified convincingly. Owing to the wide number of variables related to soil and other agricultural conditions which control the solubility of apatite in the soil and the availability of P to plants, the determination of a rock's suitability as direct application phosphatic fertilizer should be based only on the results of field trials. In India, many such studies have been made under varied soil and climatic conditions and on a variety of crops. Against the background of world experience, strengthened by the results of local experimentation, direct application have become more and more popular in areas of acid soils because it is both relatively cheap and effective. Moreover, the total energy involved in making the raw rock phosphate powder is much less than that involved in making superphosphates. In addition, use of such material reduces rather than increases soil acidity.

Processing

It is not difficult or costly to process raw rock phosphate as a direct application fertilizer. After mining of the rock in Beldih, it is transported to the nearby processing plant, sun dried and hand crushed to less than 10 cm. size (see photo) to be fed into the jaw crushers (secondary) of appropriate size and capacity. From the secondary crusher, ore is fed into a pulveriser fitted with a dust catcher. The powder is then filled manually through a chute into polythene lined jute bags for dispatch. There is also a roller mill in use for higher

Primary crusing: Beldih Mine.

production of finer materials but the capital cost involved is also somewhat higher. In general, crushing and grinding plants of moderate or small sizes, suitable for the local requirements of small deposits and small demands, are not very costly and the technology involved does not need highly trained workers.

Rock phosphate with suitable characteristics for use as a direct application fertilizer, can in fact be applied at any grade. From a theoretical standpoint, even a rock phosphate containing only 5% P_2O_5 can be used if the site of use is near. But considering the transport costs of the material, a more practical minimum is around 20 to 22% P_2O_5. Where necessary, P_2O_5 content can be upgraded to achieve a more marketable product, using simple methods. Trying to reach a higher limit (30-32%) is usually much more difficult and costly.

From experience, it has been found that a powder product of which 90 % passes through a 40 BSS sieve would be suitable for direct application. It is not too fine to cause problems in application yet fine enough for quick dissolution in acid soil.

As regards citrate solubility, some rocks are more reactive and some are less so; but, almost all grades of rock phosphate available in a country can be gainfully utilised as direct application fertilizer in acid soil. The only difference is that the availability of P to the plant from some rock phosphates may be slower.

Regarding the effect of fluorine (F) in fluor-apatite from Beldih, it can be said that extensive use of such fluor-apatite has not given rise to any adverse effect so far. The presence of iron-bearing minerals has not had noticeable effect on the availability of P to the plant roots. A large number of agronomic studies of Beldih rock indicate that direct application of rock phosphate in lateritic soil gives as good a result as that given by single superphosphate. Where the soil is sandy and deficient in clay, the use of Beldih rock rich in clay also enriches the soil.

While acid soil reacts more quickly with rock phosphate and releases P, the rock phosphate also reduces the acidity of the soil. Thus when any land becomes too acidic with regular use of chemical fertilizer, direct use of rock phosphate will gradually restore the land to a healthy pH level, in addition to supplying P and some important micro-nutrients. The presence of free calcite and dolomite mixed with the phosphate, unless present in large proportions, may not be much of a problem in acid soil. Even where the percentage is somewhat higher, the use of such rock phosphate with green manure or compost will mitigate the problem while making more nitrogen available.

Field experiments by WBMDTC show that direct use of rock phosphate is beneficial even in near-neutral or neutral soil when used with compost or green manure. Even in alkaline soil, rock phosphate powder can be used mixed with a small quantity of pyrite powder. This also helps to increase the sulphur content of the soil and affects bacterial leaching of non-humic soils.

Method of Use and Performance

Rock phosphate powder can be used directly or mixed with compost or green manure (or even superphosphate). In acid soils, with a pH value equal to or below 5.5, the rock phosphate works very well, performing as well as SSP in the short term and much better in the long term. When mixed with green manure or compost, a better performance can be expected even is less acid or neutral soils (pH 6.1-6.6). When compost is charged with rock phosphate powder, it makes available about 20% more nitrogen than what is made available by uncharged compost. Thus this process of composting with rock phosphate powder increases both available N and P.

After broadcasting the powder in the field and ploughing/puddling, 3 to 4 weeks may be allowed under moist conditions before planting or transplanting is taken up. Since phosphate is non-migratory, it should preferably be available at root level - for young saplings, at a depth of about 5 to 7 cm.,and for more mature plants at a depth of 15 to 20 cm. If a layered application at different levels is not practical, the rock phosphate should be intimately mixed and puddled with soil down to a depth of about 20 cm.

Rock phosphate may be used at the rate of 80 to 200 kg P_2O_5 per hectare in every sowing season (during rainy season) in acid soil. In other words about 400 to 1000 kg of rock phosphate of 20% P_2O_5 grade would be required per hectare. Variation in the dose has been suggested because the response varies depending on the nature of the soil, intensity of mixing, other conditions of the soil, and also on climatic conditions. But in any case, an overdose (e.g. 200 kg. instead of 80 kg.) would not do any harm. The excess quantity will remain in the soil like a bank deposit and will not be washed away by the rains. Thus, if for any reason one is unable to buy and use rock phosphate in any year, one's cultivation would not suffer. If this practice of growing with rock phosphate during the rainy season and without it during the winter is repeated for three years in succession, the farmer can grow two crops a year in the fourth and fifth year without any phosphatic fertilizer - such is the residual effect of rock phosphate. The effect may even be noticed beyond 5 years depending on the quantity applied during the first 3 years. It must be clearly understood, however, that for every crop the requisite quantities of N and K should be applied.

Preparation of Rock Phosphate Charged Compost

While preparing compost or green manure, rock phosphate is spread in alternate layers on the compost or green manure heap. Considering the need of about 200 kg. P_2O_5 per hectare, about 4 kg. of 20-22% P_2O_5 rock powder may be mixed with every quintal (of finished dry product) of compost or green manure. Incubation studies indicate that the maximum P is released after about 4 months of composting. As already indicated, the rock phosphate charging of the compost also increases nitrogen availability from the compost by up to 20%. Thus the charging of compost by rock phosphate doubles the benefit. Twenty five tonnes of such charged compost may be used per hectare and good crops can be raised without any other fertilizer for two crop seasons.

Pisciculture

In the modern scientific method of pisciculture, calcium and phosphorus are two essential ingredients. Both of them can be supplied by rock phosphate. Rock phosphate powder spread over tanks would thus help the fish spawn grow quickly. Tests with Beldih rock phosphate powder has proved this beyond doubt. Compared to the meagre cost, the benefit is substantial.

Conclusion

Modern chemical fertilizers act quickly but are costly both in terms of money and energy. Much of their nutrient content is lost from the soil either by leaching and runoff or via volatilization, thus increasing the real cost. In a developed country where labour is very costly and agriculture is highly mechanized and carried out on a large scale, the use of fast acting chemical fertilizers may be justified. But in many developing countries where labour is cheap and capital is scarce, the situation is quite different. More time can be spent preparing the ground, as agriculture is less capital and input intensive.

Direct application of rock phosphate powder not only yields in many cases higher food production but is also much cheaper. In addition, the unutilized portion remains in the soil to be made available later. Further, a variety of necessary micro-nutrients not always available in chemical fertilizers are also present in rock phos and promote healthy plant growth.

It is therefore necessary that efforts be made to bring many more of the developing world's small phosphate deposits into production where justified by transport advantages. This could lead to enormous savings in energy and an increase in food production and employment in rural areas.

Mr. S.L. Chakravorty is the former Managing Director of the West Bengal Mineral Trading and Development Corporation. He now serves as Honorary Secretary of the National Institute of Small Mines (NISM), INDIA, and sits on the SMI's Board of Directors.

Beldih Phosphate Mine, West Bengal, India.

Using Rock Fertilizer: Successful Case Studies

by B.I. Kronberg, D.H. Lindenmayer, E. North, W. Fyfe

The global correlation of grain production with the distribution of volcanic, glacial and alluvial soils illustrates that agricultural productivity is enhanced where Nature has provided abundant fresh rock debris. Rock minerals, such as feldspar, apatite, mica and pyroxene, are the primary sources of plant nutrients other than carbon and nitrogen. These nutrients are released by weathering processes as rocks at the earth's surface are chemically transformed first to complex clays and eventually to simple clays. An abundance of complex clay minerals characterizes young, fertile soils and their presence maintains cation exchange and soil moisture retention capacity. Complex clay minerals also control chemical balance in soil waters as well as promote conditions favourable for microbiological activity needed for nitrogen fixation, and the efficient transfer of nutrients from soils to plants.

Case studies

Brazil - Traditional farmers in Amazonia practice sustainable agriculture on river floodplains, which receive fine grained, nutrient rich sediments from streams originating in the Andes mountains. Where river banks are steep, high nutrient demanding plants like (corn, beans) are grown on lower terraces where sediments are deposited each year. Less demanding plants are grown on higher ground, which are flooded periodically, and additional nutrients are made available by small scale vegetation burning. The charred biological debris is not removed. Both on the lower and upper terraces plant varieties are interdispersed.

In southern Brazil "organic" farmers have reported much higher yields and improved quality of fruits and vegetables (e.g, up to 500% increases in yields of citrus fruit relative to those obtained using conventional methods). The best results were achieved by adding a mixture of rock (phosphate rock, granite and dolomite) along with available organic material (sugar cane slash, rice husks and wood chips). These farmers maintain that composting is not necessary in these climates. Weeds are not controlled, unless they shade food plants.

Northwestern Ontario - The soils of NW Ontario have highly variable fertility because they are derived mainly from rock debris left as glaciers receded from the region approx. 10,000 years ago. Intensive farming is carried out on the extensive river flood plains covered by fine-grained glacial sediments. In these areas surface soils have been successfully renewed in situ by incorporating less weathered subsurface glacial debris into soil surface layers. This strategy in combination with use of organic material has provided enhanced quality and yields of several fruits and vegetables grown without chemical additives.

An experimental design for small farmers interested in evaluating the effects of applying locally available rocks was tested in NW Ontario by growing alfalfa in soils amended with diabase rock (basalt composition). In this experiment plants grown with diabase added contained approx. 400 % more biomass after three years growth than those grown in the control plot and 50% more biomass than those cultivated with superphosphate additions. Greater flower and seed production by plants growing in the alfalfa plot was a further indication of the higher quality of these plants.

Dr. B.I. Kronberg, D.H. Lindenmayer and E. North are with Lakehead University, Thunder Bay, CANADA. Dr. Kronberg teaches geology, and is one of a few active in applied agrogeological research in Canada. Messrs. Lindenmayer and North are students of Dr. Kronberg.

SMI News

- The SMI secretariat shifted its offices in July of 1992. The official address is now :
2020 University St. 21st floor, Rm. 149
Box 102, Montreal, PQ H3A 2A5, CANADA
phone :- (514) 398-2871 ; fax :- (514) 398-8379

- The 3rd Annual General Meeting held on October 14, 1992 saw the appointment of four new people to the Board of Directors, including Alexandra Amoako-Mensah, Director, Industrial Research Institute, Ghana; Mr. Paul Fortin, Mining Lawyer, Canada; Mr. Tomas Astorga Schneiders, Special Advisor to the Ministry of Mines, Chile; and V.S. Rao, General Manager, Mining, Tata Iron and Steel Company, India.

- Mr. Michael Allison joined the secretariat in late November 1992, taking over the position of Information Specialist. Mr. Allison has worked as a geologist for the Geological Survey of Jamaica and has experience with small-scale mining of dimension stone.

- SMI is collaborating with the United Nations Department of Economic and Social Development and the Government of Zimbabwe in the organisation of an International Seminar on Guidelines for the Development of Small/Medium Scale Mining. The seminar will be held in Harare, from 15-19 February 1993. With a focus on identifying parameters and conditions that give rise to success in various contexts, the Seminar aims to produce a set of guidelines for developing countries. The Seminar will provide a forum for participants from developing and industrialized countries to exchange views and experiences and to be exposed to new concepts and technologies. Representation from government, international organizations, and the private sector is anticipated. Additional information can be obtained from the SMI secretariat or by contacting Ms. Beatrice Labonne directly at the UN. (Tel.: (212) 963-8790, or Fax: (212) 963-4340).

- The Information System Project has begun in earnest (Issue 4, Feb. 1992). Members and readers are urged to assist the secretariat in this critical task, by providing references to documentation, equipment, manufacturers, vendors, consultants, government agencies, universities and non-government organizations and associations concerned with small-scale mining.

Development Goals at IDRC

by J.P. Hea

The International Development Research Centre (IDRC) was created by the Parliament of Canada twenty-two years ago to support research of developing countries in the health, agriculture, food, nutritional, information, social, earth and engineering, and environmental sciences. IDRC's Board of Governors has the distinction of being composed of members coming from many countries and having broad developmental experience. At the United Nations Conference of the Environment and Development in June 1992, the Prime Minister invited the United Nations to propose appointments to IDRC's board and supported the UNCED Agenda 21 program as an imperative for sustainable development and protection of the environment. IDRC's mandate towards goals of sustainable development is to pursue capacity building of institutions through partnership with researchers in developing countries and with ties to the UN and other international agencies, universities and research institutes, non-governmental organizations, and the private sector in Canada and abroad.

IDRC has funded small-scale mining projects since 1983 under a collaborative program of the Earth Sciences and Engineering Division whereby institutions of developing countries and in Canada participate jointly in research. The aims of typical projects are to help miners and their cooperatives better exploit artisanal workings and small mines through knowledge of the geology of the deposits, enhancement of labour skills and use of equipment, safety, beneficiation and processing, and marketing of ores, gems and minerals. Similar projects were supported in quarried construction materials, land use and geoenvironment, water, geotechnics and natural hazards.

In the late 1980s, priorities focused more on projects to develop the "social minerals" or those industrial minerals used by communities and small enterprises to improve living standards. Industrial minerals are relatively high-bulk and low-valued compared to metals and gemstones and thus benefit from a transportation cost advantage where produced locally and sold into nearby markets. Agrominerals are of special importance given the depletion of nutrients in soils of many developing countries which lack foreign exchange for imports of fertilizers, soil conditioners and pesticides. Recent emphasis has been on evaluating the potential for igneous phosphate rock in East Africa for direct application and low-level processing into phosphate fertilizers for communal farmers. Phosphates, clays, feldspar, carbonates, gypsum, volcanic rocks, sand and gravel, graphite and other industrial minerals which serve local agriculture and industry are labour-intensive and mined by small enterprises thus helping the economies of developing countries.

In early 1992, a restructuring took place at IDRC with the creation of the Environment and Natural Resources Division which combines the former agriculture, earth sciences and engineering, and environmental policy groups. The new division is responsive to development needs through two programs: Sustainable Production Systems and Environment and Technology Programs. Important thrusts of the divisions's mandate are institutional change to ensure the application of research results and environmentally sustainable development. Priority areas under the programs are termed Global Program Initiatives. One of these initiatives is Low-Input Sustainable agriculture which among other goals calls for the use of agrominerals such as phosphate, potash and zinc, manganese and other micronutrients produced from indigenous resources.

Other important areas related to mining are the prevention of water and other mine pollution. Projects are expected in the future to favour capacity-building of institutions, agrominerals and mining research having goals for sustainable development.

Dr. J.P. Hea is an Associate Director of Programs at IDRC, Ottawa, CANADA and is in charge of agrogeology activities in Africa, Asia and Latin America.

Exploration and Development Studies of Phosphate Resources in Zambia – A Case History

by L. Borsch

Background

In agriculture, phosphate is one of the three nutrients essential for healthy plant growth, the two others being nitrogen and potassium. Unfortunately, phosphate also is very often the limiting factor in over-acidic tropical soils. It is fixed by chemical reactions with aluminium and iron and thus made unavailable to plants. Poor growth and yield are the result, even in the presence of sufficient nitrogen and potassium.

The production of fertilizers in Zambia at present is based on imported raw material or semi-finished products of phosphate and potassium. While there appears to be little chance of finding substantial potash occurences in the country, for geological reasons, abundant phosphate resources are known and have been explored in quite some detail during the past years. Unfortunately, none of the four known occurences can be considered an economic proposition, in the conventional way.

The large Kaluwe carbonatite, near Luangwa, Lusaka Province, is too low-grade, the two syenite-related occurences at Chilembwe, near Sinda, Eastern Province, and at Sugar Loaf, North of Mumbwa, Central Province, are also too small and comparatively low-grade to justify a conventional mining operation, and the large Nkombwa Hill carbonatite near Isoka, Northern Province, has a complex composition which still poses very serious technical problems.

In addition to these resources, substantial quantities of weathered carbonatite material are found at the foothills of Kaluwe and Nkombwa Hill, enriched in phosphate but with entirely different characteristics than the original carbonatite rock. This material, known as "brown soils", also does not respond to conventional beneficiation treatment.

Given the apparent technical economic marginality of the known phosphate deposits with respect to conventional standards and the fact that agricultural requirements were being met entirely by imported material, it was logical to search for alternative, unconventional approaches to utilise these resources for the benefits of the local agriculture.

Against this background, Minex Department of ZIMCO Limited started its research and test work as early as 1987.

Research and Test Work by Minex Department of ZIMCO Limited

As it was clearly understood that the phosphate ores of the two huge carbonatite complexes of Nkombwa Hill and Kaluwe were either too complex or too poor in phosphate to be of interest at the time, Minex Department concentrated its studies on the carbonatites "brown soils" (an estimated 1,200,000t contained phosphate) and the two "vein-type" phosphate occurences at Chilembwe and Sugar Loaf (approximately 200,000t contained phosphate).

Relatively simple and cheap mechanical beneficiation methods proved effective, at laboratory scale, to produce clean concentrates of the phosphate mineral apatite, with acceptable recovery rates, from the Kaluwe brown soil, the Chilembwe and Sugar Loaf phosphate ores. These concentrates with 30-35% P_2O_5 content, however, are not suitable for "direct application", without further treatment, insofar as the stability of the mineral prevents it from releasing its phosphate content into the soil, thus the phosphorous does not become available to the plant. Research therefore concentrated on breaking down the apatite and turning it into a phosphate "fertiliser".

If the insoluble apatite is treated, under controlled conditions, with sulphuric acid, it turns into a partially soluble phosphate compound which can be taken up by plants. The process of acidulation is not allowed to go to completion. The objective being to have the phosphate released slowly, as plants require it, and not to be entirely washed out. The product is known as "partially acidulated phosphate rock" (PAPR) and has been propagated as a cheaply and easily produced alternative product to conventional superphosphates, under circumstances where large investments are not justified.

The production and use of PAPR has been strongly promoted by the International Fertiliser Development Centre (IFDC) in Muscle Shoal, Alabama, USA, and close co-operation between IFDC, Minex Department and the Mt. Makulu Research Station introduced the idea of PAPR production to Zambia at an early stage of the phosphate exploration. In 1987, Minex Department air-freighted 3 tonnes of Chilembwe ore to Alabama to produce PAPR which then was air-freighted back to Zambia and field tested. The crop yields with this material were as good as those with triple super phosphate, and in some cases even better (probably due to added trace element availabilities). These very positive results encouraged Minex Department to set up laboratory-scale production tests in 1988, at which time 500g of PAPR was prepared from unbeneficiated, rich phosphate ore and tried in pot tests. Then, in 1989, at a larger scale, test production was expanded to 300 kg PAPR, using an ordinary concrete mixer to blend apatite ore and sulphuric acid. The material then was tested by the Mt. Makulu Research Station staff under various field conditions at the Golden Valley Farms, the Kabwe Regional Research Station and the Misamfu Regional Research Centre. The results on beans, soya beans, sunflower and maize were reported as very good, again in some cases superior to triple super phosphate.

To confirm the previous results, Minex Department again produced PAPR for similar field tests in the 1990/91 planting season using approximately 1 tonne of apatite ores from Chilembwe and Sugar Loaf. Results again were consistenly positive.

At this stage, Minex Department considered its test and development work on the utilisation of these apatite ores as completed. The project has been left in the hands of the Zambian Fertiliser Technology Development Committee who, in co-operation with the School of Mines, University of Zambia, intends to set up a pilot plant.

Minex Department of Zimco Ltd., was able to demonstrate, through development and test work from 1987 to 1990, that a very effective phosphate fertiliser can be easily and cheaply produced entirely from local raw materials, phosphate ore and sulphuric acid, using the acidulation technique introduced in Zambia by the IFDC. It also has been shown by producing 1.3t of high-quality PAPR test material in 1989 and 1990 that "non-viable" (in the conventional sense) phosphate occurrences can be exploited, under certain circumstances, by a simple "technology", using a crusher, a concrete mixer and a bucket.

Further research and test work

So far, only unbeneficiated apatite ores, with 10-15% phosphate, have been used in the test production work; this means that the so produced PAPR carries over 80% barren rock material, this prevents economic transport over large distances to the potential consumer. Therefore, test series are being prepared, with several professional parties involved, to beneficiate the Chilembwe and Sugar Loaf ores to an apatite concentrate of about 30% phosphate for use in PAPR production.

Additional test work has also indicated that phosphate rock acidulation with nitric acid may be easier to perform than with sulphuric acid. Furthermore, nitric acid-PAPR has two major advantages over sulphuric acid-PAPR: plant-essential nitrogen is added to the product and potential shortages of locally produced sulphuric acid are avoided by using readily available nitric acid, also locally produced. However, further tests are required to determine economic requirements for nitric acid-PAPR production.

In another development project, the UNDESD, in co-operation with Minex Department, has prepared a feasibility study for pilot plant production of PAPR from the Kaluwe "brown soils".

Not much success has been achieved so far in utilising the Nkombwa Hill "brown soils" which show characteristics entirely different from those of Kaluwe. Apparently, acid leaching is a likely technique to extract the phosphate, yielding a highly effective phosphate compound.

Apart from research on phosphate resources and utilisation, some studies and laboratory tests have been done on potential sources of potash, the second essential plant nutrient for which no conventional resources are available in Zambia. Abundant common rocks and minerals relatively rich in potash have been tested for plant-available potassium. It was found that certain types of rocks and minerals, when finely ground, release appreciable quantities of potassium into the soil. Although these amounts are rather small, as compared to commercial fertilisers, they still may be sufficient to avert acute potassium deficiency in certain soils and for certain crops with high potassium requirements. The bulky, heavy and quite low-grade rock material certainly does not allow economic transport over longer distances but, on the other hand, these rock types are so abundant that nearby resources often may be available. Substantially more investigations into this subject of "potash from rocks" is necessary.

Conclusion

Minex Department is indeed proud to have pioneered the preparation of PAPR in Zambia from local phosphate rock and to be associated with future developments in the fertiliser industry with the utilisation of not only local phosphate deposits, but also of local sources of potassium.

It is gratifying to note that, with the advent of the formation of the Zambia Fertiliser Technology Development Committee, on which Minex Department is represented, exploration work and the discovery of the Chilembwe and the Sugar Loaf phosphate deposits have not been in vain.

L. Borsch is the head of Minex at ZIMCO. He has been active in defining and developing local agro-mineral resources in Zambia over the past two decades.

Charging the mixer with phosphate rock.

Consolidated References

Barbarick, K.A. and Pirela, H.J. 1984. "Agronomic and horticultural uses of zeolites: a review." In: Pond, W.G. and Mumpton, F.A. (eds.), p. 93-103.

Barbarick, K.A., Lai, T.M. and Eberl, D.D. 1991. "Exchange fertilizer (phosphate rock plus ammonium-zeolite) effects on sorghum-sudangrass." Soil Science Society of America Journal. v. 54, p. 911-916

Barrer, R.M. 1978. Zeolites and Clay Minerals as Sorbents and Molecular Sieves. Academic Press, New York, 497 pp.

Borsch, L. 1990. "Potential of potash-rich rocks and minerals in agriculture. Some preliminary tests." AGID News, May 1990, p. 2.

Breck, D.W. 1974. Zeolite Molecular Sieves: Structure, Chemistry and Use. Wiley, New York, 771 pp.

Caldas, E.F., Tejedor Salguero, M.L. 1987. Mulch farming in the Canary Islands. In: Agrogeology in Africa, Proceedings of seminar 23-27 June 1986, Zomba, Malawi. Commonwealth Sci. Council Technical Publications 226, p. 242-254

Chesworth, W. 1982. "Late Cenozoic geology and the second oldest profession." Geoscience Canada, v. 9, p. 54-61.

Chesworth, W. 1983. "Geological alchemy: bread from stones." Episodes, p. 32-40.

Chesworth, W., Macias Vazques, P. Acquaye, D. and Thomson, E. 1983. Agricultural alchemy : stones into bread. Episodes 1, p. 3-7.

Chesworth, W., van Straaten, P., Sadura, S. 1988. "Solubility of apatite in clay and zeolite bearing systems." Applied Clay Science. 2, p. 291-297.

Chesworth, W., van Straaten, P., and Semoka, J.M.R. 1989. "Agrogeology in East Africa: the Tanzania-Canada project." Journal of African Earth Sciences, 9: p. 357-363.

Eberl, D.D., Barbarick, K.A. and Lai, T.M. 1992. "Zeolite (NH_4^+-clinoptilolite) influence on elemental concentrations in sorghum-sudangrass." In review.

Eberl, D.D. and Lai, T.M. 1992. Slow-release nitrogen fertilizer and soil conditioner. U.S. Patent Application US 789,206, 15 April 1992.

Fernandez-Caldas, E., and Tejedor-Salguero, M.K. 1989. "Mulch farming in the Canary Islands." In Agrogeology for Africa, Commonwealth Science Council, p. 242-254.

Fyfe, W.S.; Kronberg, B.L.; Leonardos, O.H.; Olorunfemi, N. 1983. Global tectonics and agriculture: a geochemical perspective. Agriculture, Ecosystems and Environment, v. 9, p. 383-399.

Fyfe, W.S. 1989. Soil and global change. Episodes, 12. 249-254.

Gottardi, G. and Galli, E. 1985. Natural Zeolites. Springer-Verlag, New York, 409 pp.

Guthrie, G.D., Jr. 1992. "Biological effects of inhaled minerals," American Mineralogy. 77, p. 225-243.

Lai, T.M. and Eberl, D.D. 1986. "Controlled and renewable release of phosphorous in soils from mixtures of phosphate rock and NH_4^+-exchanged clinoptilolite," Zeolites 6, p. 129-132.

Leonardos, O.H., Fyfe, W.S. and Kronberg, B.I. 1987. "The use of ground rocks in laterite systems: an improvement to the use of conventional soluble fertilizers." Chemical Geology, 60, p. 361-370.

Leppert, D. 1990. "Heavy metal sorption with clinoptilolite zeolite: Alternatives for treating contaminated soil and water." Mining Engineering 42, p. 604-608.

Malthus, T.R. 1803. An Essay on the Principle of Population. Johnson, London.

Marcille-Kerslake, V. 1991. Evaluation of the Fernie phosphorite and Princeton zeolites: potential for rock phosphate-zeolite fertilizer use. MSc thesis, University of Guelph, 139 pp.

Mill, J.S. 1848. Principles of Political Economy. Murray, London

Ming, D.W., Allen, E.R., and D.C. Golden. 1991. Fertilization by mineral dissolution and ion-exchange (abs.). 83rd Annual Meeting ASA-CSSA-SSSA, Denver, CO, Meeting Program, p. 175.

Moldan, B. 1992. Geochemistry and the environment. In: Planning the use of the Earth's surface. Cendrero,A., Luttig, G.and Wolff, F.C. (eds.) Springer Verlag, Berlin, p. 237-251.

Mumpton, F.A., ed. 1977. Mineralogy and Geology of Natural Zeolites. Short Course Notes 4, Mineralogical Society of America, Washington, D.C. 233 pp.

Mumpton, F.A. 1984. "Flammae et fumus proximi sunt: the role of natural zeolites in agriculture and aquaculture." In: Pond, W.G. and Mumpton, F.A. (eds.), p. 33-44.

Parham, W. 1989. "Natural zeolites. Some potential agricultural applications for developing countries." Natural Resources Forum, p. 107-115.

Pimentel, D. 1987. Technology and natural resources. In Resources and World Development, McLaren, D.J. and Skinner, B.J. (eds.), John Wiley, New York, p. 679-695.

Pond, W.G. and Mumpton, F.A., eds. 1984. Zeo-agriculture: Use of Natural Zeolites in Agriculture and Aquaculture. Westview Press, Boulder CO, 296 pp.

Rajan, S.S.S. 1983. Effects of sulphur content of phosphate rock/sulphur granules on the availability of phosphate to plants. Fertilizer Research 4: p. 287-296.

Rossi, G. 1978. "Potassium recovery through leucite bioleaching: possibilities and limitations." In: Metallurgical Applications of Bacterial Leaching and Related Microbiological Phenomena. Murr, L.E., Torma, A.E., and J.A. Brierley (Eds.) Academic Press, p. 297-319.

Sheldon, R.P. and Treharne, R.W. 1979. "Local phosphate rock and limestone deposits as raw materials for local fertilizer supply." In: The Future of Small

Scale Mining Meyer, R.F. and Carman, J.C. (eds.) p. 365-370.

Shepard, R.A. 1984. "Characterization of zeolitic materials in agricultural research." In: Pond, W.G. and Mumpton, F.A. (eds.), p. 79-87.

van Straaten, P., Semoka, J.M.R., Kamasho, J.A.M., Mchihiyo, E.P., et al. 1992. "Report on the results of the Tanzania-Canada agrogeology project, phase II (1988-1991)." Report University of Guelph, 127pp.

van Straaten, P. 1987. "Agrogeological resources in eastern and southern Africa." In: Agrogeology in Africa (Proceedings of a Seminar held 23-27 June 1986, Zomba, Malawi). Commonwealth Science Council Technical Publication 226, p. 242-254.

van Straaten, P., Chesworth, W. and P. Groenevelt. 1991. Agrogeological projects in Ethiopia still going strong. Annual Report, Department of Land Resource Science, University of Guelph, p. 57

Vidic, N., Lobnik, F., Zupan, M., Hodnik, A. and Rus, J. 1991. "A zeolitically altered tuff from Zaloska Gorica, Yugoslavia, as a soil amendment." 83rd Annual Meeting ASA-CSSA-SSSA, Denver, CO, Meeting Program, p. 175.

Weber, M.A., Barbarick, K.A. and Westfall, D.G. 1984. "Application of clinoptilolite to soil amended with Municipal sewage sludge." In: Pond, W.G. and Mumpton, F.A. (eds.), p. 263-272.

CALENDAR OF EVENTS

January 31-February 4, 1993. 19th Annual Conference on Explosives and Blasting Research, San Diego, CA. Contact: International Society of Explosives Engineers, 29100 Aurora Rd., Cleveland, OH 44139, USA.

February 11-13. International Seminar on Mineral Sector in India. Hyderabad, India. Mr. S.K. Sharma, Federation of Indian Mineral Industries, 301 Bakshi House, 40-41 Nehru Place, New Delhi-110 019, India.

February 14-18. World Zinc '93, Tasmania, Australia. Contact: AusIMM, P.O. Box 122,3052 Parkville, Victoria, Australia.

February 15-19. Guidelines for the development of Small/Medium Scale Mining, United Nations seminar focusing on developing countries, Harare, Zimbabwe. Contact: Beatrice Labonne, Chief, Mineral Resources Branch, Department of Economic and Social Development, Room DC1-864, One United Nations Plaza, New York, NY 10017, USA.

February 21-24. 2nd Annual International Zinc Conference, Scottsdale, AZ. Contact: Joan Rinaldi, American Zinc Association, 1112 Sixteenth St. NW, Ste. 240, Washington, DC 20036, USA.

March 17-19. Mining Investment in Namibia. Contact: Conference Co-ordinator, Private Bag 13297, Windhoek, Namibia.

March 21-26. Minesafe International 1993-From Principles to Practice, second international conference on occupational health and safety in the minerals industry, Perth, Australia. Contact: Minesafe Secretariat, The Chamber of Mines and Energy of Western Australia, 7th Floor, 12 st. George's Terrace, Perth, Western Australia 6000, Australia.

April 17-20. Integrated Methods in Exploration and Discovery. Sponsored by the Society of Economic Geologists, Society of Economic Geophysicists, Assoc. of Geochemists, and the U.S. Geological Survey. Contact: SEG Conference, Box 571, Golden, CO 80402, USA.

May 23-28. XVIII International Mineral Processing Congress. Contact Congress Secretariat, AusIMM, P.O. Box 122, Parkville, Vic., Australia 3052.

May 24-27. 11th International Lead Conference, 'Pb 93'. Vienna, Austria. Contact: Lead Development Association, 42 Weymouth St., London W1N 3LQ, England.

June 7-10. Second International Symposium on Mine Mechanization and Automation. Contact: Ms. Lena Carbin, CENTEK, Lulea University of Technology, 951 87 Lulea, Sweden.

June 15-17. International Symposium on Gold Mining Technology. Contact: ISGMT, Gold Society of China, 1 North Qing Nian Hu St., An Ding Men Wai, Beijing 100011, China.

September 7-14. Industrial Minerals of the Baltic/Fennoscandian shield and new technologies, Petrozavodsk. Contact: Dr. V. Shchiptsov, Institute of Geology, Pushkinskaja street 11, Petrozavodsk, Russian Karelia, 185610.

November 24-28. Asian Mining '93, international conference and exhibition sponsored by the mining, Geological and Metallurgical Institute of India. Contact: A. Banerjee, Co-ordinator, Exhibition Committee, MGMI, 29 Chowringhee Road, Calcutta-700016.

BOOK REVIEW

Handbook of Small Scale Gold Mining for Papua New Guinea (2nd ed.)

by Mike Blowers
Pacific Resource Publications, Christchurch, 260pp, 1992
Available for $20 US from Small Mining International, 2020 University St., Box 102, Montreal, Quebec, CANADA H3A 2A5.

This monograph is 'intended for gold miners at the village level'. It is written in extremely simple language, with uncomplicated (but informative) diagrams and rudimentary (but adequate) mathematics. It covers all aspects of small-scale gold mining in Papua-New Guinea (PNG): where to find it, how to mine it, how to recover it and how to sell it (and not get ripped off !). It covers the scale of 1 to 100 tonnes per day, from the pan to the mechanized excavator. As expected, the book is eminently readable. It is not without exotic flavour, being punctuated with Pigin expressions (simok, goldston, masket, etc...) and PNG currency (Kina, Toea). The book presents a wealth of practical ideas, such as the use of cut and hammered copper wire as 'fake gold' to test one's panning abilities, and plans for assembling a home-made, relatively accurate scale.

The book is very 'protective' of small-scale miners, especially in Chapter 10, 'Buying and selling gold, its purity and value.' It is thus surprising that cyanide is presented as **even more poisonous** than mercury. The author has the insightful idea of suggesting adding a chlorine based swimming pool powder to cyanide barren solution prior to discharge to the environment (to destroy free cyanide). But cyanide also naturally degrades, and mercury is now known to to be a more serious environmental and health hazard, because it cannot be destroyed and it does not degrade naturally.

Although careful use of mercury is advocated and explained, Hg remains the most serious small-scale gold hazard. One application that is advocated in the book, at the bottom of the riffles of a sluice box, is indefensible, as discharge to the environment can hardly be monitored and prevented. It may well be that at the present time, no alternative technology is available that would replace it effectively. This clearly identifies it as both a sensitive research area and an issue where government involvement, in the form of stringent legislation and technical assistance, is most needed.

The book advocates sluice recovery for most applications, and rightly so, as sluices will recover most gold above 101 microns (150 mesh) quite successfully. Parameters of sluice operation, however, clash with published data (Clarkson, 1989, 1990 and 1992; Poling and Hamilton, 1986). For example, flow rates of 1300-2000 l/min are advocated for a 1m wide sluice, as opposed to a minimum of 2400 l/min in Clarkson. Clarkson (1992) also advocates, with a 1 m wide sluice, 20 m^3 of gravel per hour, as opposed to Blowers' 1.7 m^3. Blowers advocates rectangular riffles, 5 cm high, 2.5 cm thick, 10 cm apart. Clarkson (1989) recommended expanded metal riffles only if recoverable gold was very fine; they are clearly more difficult to operate, and can yield to packing and extreme gold losses. Regular or modified angle iron riffles should be 5 cm apart. When gold finer than 4 mm (6 mesh) is present, regular riffles are not recommended because they create extreme turbulence. Clarkson also recommended that the riffle should be vertical rather than perpendicular to the bottom of the sluices. The tilt angle of the boxes with angle iron riffles should be 12-15 degrees, which is clearly more than the 5-15 cm per metre proposed by Blowers.

Blowers also proposes the use of the undercurrent system (a screen which diverts fines to two side sluices at a lower tilt angle for fines recovery, the main sluice, steeper in angle, treating the oversize). Clarkson's work revealed that the the undercurrent, because of poor screening efficiency, could lead to under- and overloading, both conditions yielding severe gold losses. Both Clarkson and Blowers recommend strongly, the use of trommels to classify the feed as a means of significantly improving gold recovery.

The book, in its chapter on 'Advanced Methods to Catch All the Gold' presents the Knudsen Bowl as a 'recent advance.' The Knudsen Bowl was actually invented about 40 years ago. Since then, other rotating, single jacketed bowls, such as the Ainley, Johnson, Clark and Rogers, have been put on the market. All of these units suffer from packing of the riffles, which rapidly limits free gold recovery. The Knelson concentrator, presented by Blowers as a unit similar to the Knudsen, is actually a double jacketed bowl, or an inner bowl rotating in a jacket of pressurized water that is injected in the riffles to prevent packing. This makes it a very effective unit to recover free gold over a wide size range (Laplante et al., 1989; Laplante and Shu, 1992). The two units are quite different, and should not be presented as similar.

The above flaws do not detract from the wealth of information presented in the book. It is worth acquiring for the neophyte as well as the seasoned mineral processor. It is a 'textbook case' of how scientific and techical knowledge can be vulgarized (in the original meaning of the word, vulgaris - for the common people) for effective dissemination. One can hope that in a third edition, some of the weaknesses will be corrected, and the book will be made international. This would require few modifications, such as replacing PNG currency units with US dollars, dropping Pigin expressions, beefing up the reference list (which has a bit of a local flavour) and the list of useful addresses, and finally incorporating some technology that, whilst it is not common in PNG, is commonly used elsewhere in the world. This would likely incorporate spirals, more flotation technology, and the one technique that has revolutionized small-scale gold production in the U.S.A., heap leaching. The order might appear tall, but Blowers' book provides a good basis upon which to build.

References

Clarkson, R.R., 1989, Gold Losses at Klondike Placer Mines, unpub. report, NEW ERA Engineering Corp.

--, 1990, The Use of Radiotracers to Evaluate Gold Losses at Klondike Placer Mines, unpub. report, NEW ERA Engineering Corp.

--, 1992, The Use of Nuclear Tracers to Evaluate the Gold Recovery Efficiency of Sluiceboxes, unpub. report.

Laplante, A.R., Liu, L. and Cauchon, A., 1990, Gold Gravity Recovery at the Mill of Les Mines Camchib Inc., Chibougamau, Quebec, International Symposium of Gold Recovery, Salt Lake City, Feb. .

Laplante, A.R., Shu, Y., 1992, The Use of a Laboratory Centrifugal Separator to Study Gravity Recovery in Industrial Circuits, 24th Annual Meeting of Canadian Mineral Processors, Ottawa, Paper 12, 18 p.

Poling, G.W. and Hamilton, J.F., 1986, Fine Gold Recovery of Selected Sluice Box Configurations, unpub. report.

Dr. Andre Laplante teaches mineral processing in the Department of Mining and Metallurgical Engineering, McGill University, Montreal, CANADA. He specializes in beneficiation and recovery systems for gold ores.

N.B. Clarkson's reports are available form NEW ERA Engineering Corp., P.B. 4491, Whitehorse, Yukon, CANADA, Y1A 2R8 (phone 403-668-3978), or Northern Affairs Program, 200 Range Rd., Whitehorse, Yukon, CANADA, Y1A 3V1.

SMI Bulletin
Published by the
International Agency for Small-Scale Mining
L'Agence Internationale pour les Petites Exploitations Minières

SMI is a non-profit organization dedicated to strengthening and supporting the small mining sector as an aid to rural social and economic development, especially, but not exclusively, in developing countries.

Jeffrey Davidson, Michael Allison
Editors

Small Mining International - SMI
2020 University St., 21st Floor, Room 149
Montreal, Quebec
CANADA H3A 2A5
Telephone (514) 398-2871
Telefax (514) 398-8379

Jeffrey Davidson, Managing Director

Contributions in English, French, and Spanish on all aspects relating to small-scale mining, including up-coming events and new publications, as well as comments and suggestions, are welcome.

Requests for information on membership and subscription requirements can be addressed to SMI's Managing Director at the above address.