# New Dimensions for Mineral Resources Studies

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# NEW DIMENSIONS FOR MINERAL RESOURCES STUDIES[1]

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ABSTRACT

Education for a role in industrial mineral development involves the interplay of interdisciplinary thought and technique in order to bring closer the goal of planned, efficient, industrial mineral development. Techniques from geology, geophysics, statistics, engineering, and econometrics can be combined to analyze aspects of industrial minerals in a region's economy. These include refinement of methods for studying the impact on a region of industrial mineral development, determination of projects most likely to produce maximum returns, techniques for exploration and development, methods of forecasting regional transfers of industrial minerals, and economic model building. Decisions are based ultimately on economics rather than geology and depend upon operations research and systems analysis. The demands on geological education are thus demands for versatility, and for capability for transference of ideas from one field to another.

## INTRODUCTION

Since February, 1962, I have been deeply involved with improvement of geological education; first as Director of Geo-Study, an enterprise of the American Geological Institute, and then as Chairman of the Council on Education in the Geological Sciences, the successor to Geo-Study. In addition, as a Director of the Kansas Geological Survey, I have devoted much attention to long-range planning for mineral resource investigations and to staff development. It is against this background that I presume to say something to you on the demands upon geological education, especially as these demands are generated by the industrial minerals sector of our economy.

I confess that I have not emerged from these activities with a high confidence level about my ability to forecast the future. I reflected upon this condition when I happened upon the original of a Peanuts cartoon that Schultz had given to one of my colleagues. Lucy is instructing Linus "Here's a nice pebble, Linus...take it home and observe it. The fascinating thing about pebbles is their growth; for some grow up to be stones, while others grow up to be rocks. You shall hope of course, that it grows up to be a rock, for a pebble that grows up to be a stone is like a youth that has gone astray. Linus responds with *SIGH* I have so much to learn."

Let me see if I can get at this subject by first looking at some of the demands upon industrial minerals in the future; then by reviewing just a few of the techniques by which industrial mineral problems are being solved today; and finally by saying something about educational patterns that might help to satisfy future needs in industrial minerals.

## THE FUTURE

As to the future, suppose that we adopt the year 2000 as a reference point. Not too long ago the year 2000 seemed to be something out of George Orwell. I have suddenly realized that the year 2000 is only 34 short years away, and that with some careful planning and a little bit of luck I might even be around at that time. What about the year 2000? The Rand Corporation predicts that the world population will be 5.1 billion, up 63 percent from 1963. New food sources will have been opened up through large-scale ocean farming and the fabrication of synthetic protein. Controlled thermonuclear power will be an important source of energy. New raw materials will be derived from the oceans, and regional weather control will be past the experimental stage. Commercial global ballistic transport will have been instituted, and United States industrial production will have increased 430 percent for chemical,

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petroleum, plastic, and rubber products over 1960, 513 percent for industrial chemicals, and 344 percent for clay, stone, and glass products. Thus, many of the great increases will take place in the low unit cost industrial minerals category.

The posture of the agricultural industry must be reckoned with in the future scheme of things for industrial minerals. World food output must expand at a faster rate in the years and decades ahead than ever before in history if projected populations are to be sustained. As the world looks more and more to rising yields for future increases in the food supply, capital output requirements will climb rapidly. Stated another way, capital will be substituted for land in the production mix. Increasing the cultivation of the limited land supply implies more multiple cropping and irrigation and the greater use of fertilizers, pesticides, improved seeds and machinery. The use of more fertilizer in combination with other improved technology will undoubtedly be an important means of expanding production. Thus agriculture-related minerals are high on any list. Nonceramic uses for clays for parting agents for fertilizer, toxicant carriers, and diluents loom large as do lime, phosphates, and other industrial minerals.

A projection based on a study called Resources in America's Future (Landsberg, Fischman, and Fisher, 1963) shows that the United States has ample natural resources to support sustained economic growth until the year 2000 provided that (1) technological advances and their economic adaptation continue, (2) foreign sources of raw materials remain open through a world trading and investment system, and (3) government resource policies and private management of resources improve in farsightedness, flexibility, and consistency.

If these future requirements and demands are to be satisfied, then I foresee increasing emphasis on decisions that will optimize the goals of industry and society. Industry will be increasingly concerned with optimization of return on investment through optimization of exploration, production, processing, and sales, and will depend heavily upon management decisions that rely upon highly sophisticated computers. It has been predicted that we may see the virtual elimination of middle management from the corporate structure by virtue of these changes. However, the goals of optimized economic return for industry will increasingly compete with society's goals of optimized return. P. T. Flawn (1966) recently directed attention to the new conservation movement, which stresses stewardship over the land through science and engineering, and he has suggested that the industrial minerals industry will have to recover from income the costs of land restoration and of elimination and disposal of pollutants of both air and water.

Optimized economic return or yield must include consideration of land uses for population expansion, recreation, and aesthetic aspects, as well as for natural resource development. It is entirely conceivable to me that optimized yield for society may be the single most important criterion for land use in the future. Today we speak about city zoning, or at best, county zoning. For the most efficient use by future generations, I am sure that by the year 2000 we will see regional land zoning, and many of us who are geologists will be concerned with this aspect of what one might call environmental geology. Regional land zoning may well assign land for optimized economic return, whether for dwellings, gravel pits, or parks. Wisconsin has recently completed a statewide environmental study under the direction of Phillip Lewis, Jr.; we will see more of this kind of activity. Furthermore, in order to plan effectively, government and industry will have to know a great deal more about the mineral resources of the United States and will need to make a modern inventory of the various kinds of resources left for future use.

## THE TECHNIQUES

What then are some of the tools and techniques that will permit optimization for the future? It seems to me that the first and foremost of these is the computer. C. P. Snow (1966) has said that the computer will cause the biggest technological revolution men have known, far more intimately affecting men's daily lives than either the agricultural transformation in Neolithic time or the early industrial revolution which made the present shape of the United States. What about this computer? What kind of a tool is it? Certainly, it provides rapid data access and problem-solving capability. It is becoming much more accessible to the average problem solver as languages have been simplified and machine compatibility has been developed. In its third generation, the computer is remarkably fast and efficient. It offers time sharing and remote access terminals; it has large disc file memory. The Kansas Geological Survey is not a large organization by industry standards, but we plan to have a remote access terminal in our quarters to be able to write programs in a conversational mode with the computer. We will have rapid access to large quantities of data that can be called from storage, for example, on a geographic basis. Visual display devices will be common, and we will be able to see data input and output without benefit of punch cards or printers. This new generation of computers is able to learn. Thus, it is now possible to write programs involving numerical statements of probabilities. The computer is able to change the probabilities, depending upon the outcome of an event. However, the most significant aspect of the computer lies in the fact that its use forces careful and thorough analysis of every problem and a logical step-by-step solution to that problem. For many of us, this is a new and unsettling experience. The techniques of optimization for exploration, production and distribution depend fundamentally upon this important tool.

How do these techniques apply to exploration? At the Kansas Survey we are writing programs and developing systems for data storage and retrieval. We are studying applications of computer techniques to stratigraphic, structural, petroleum, hydrologic, and economic problems. Tests for similarity in geologic information have become of great interest and statistical methods involving correlation functions, factor analysis, and analysis of variance are being applied. These studies, in turn, have led to greater interest in validity tests of techniques of analysis and in the design of data collection systems. Incidentally, the Kansas Survey as a service to the profession is publishing its computer programs in a Computer Contribution series. These documented and validated programs, along with card decks, are available at nominal cost.

However, this is just the first step in manipulation and interpretation of industrial mineral information and geologic data. We are not only using clustering techniques, but we now have, for example, programs for trend-surface analysis, single and double Fourier analysis, power-spectrum analysis, and auto- and cross-correlation and cross-association analyses. Mathematical simulation models based on probability have provided great insight into geologic and economic problems. Furthermore, we are investigating the use of operations research and systems analysis in exploration programs. One needs an inventory of the entire natural resources of a region in order to plan systematic development; unit value maps are very useful for this purpose as they represent the likely return of investment for any specified area. At the Kansas Survey, in collaboration with staff of the U.S. Bureau of Mines, we have developed a procedure for estimating the mineral value of a cubic mile of Kansas. The value of all mineral production, with and without the value of agricultural products due to irrigation, and with and without fuels production, is divided by the area of each county to obtain the average value of mineral production per unit area. This value is further divided by a measure of the thickness of the sedimentary crust to obtain the value of production per cubic mile. These values are assigned to sets of grid coordinates. Based upon these assigned values, a trend-surface is derived by the computer. Areas are delineated that have produced the least in terms of mineral resources. These areas are the most potentially promising for future exploration and development. The intensity of exploration efforts in such areas are checked in order to determine whether they are, in fact, devoid of resources or whether they are underdeveloped.

At present, exploration programs are held up for lack of knowledge about the worth of any particular region, so that if we had value maps for the United States we could make a good guess about any new area which resembled, in geological terms, some specific area in the United States of known value. Value of a square mile and of a cubic mile arising from mathematical models of exploration would seem to suggest that there is no sizeable area of the earth's crust which is devoid of value in terms of mineral resources of all kinds. If we add renewable to nonrenewable resources we would know the potential value of any piece of the earth. Such information would help in deciding where to explore next and optimum economic return for any land use. It would help in deciding what we are losing when a large dam floods a big area of potential mineral value. It could be compared with the value of land for dwellings or recreational returns.

J. C. Griffiths and L. J. Drew (1964) speak about prizes in exploration and note that it seems evident that we have ample grounds for a new look at improving success ratios. Systematic and optimized grid drilling to a specified depth could be a basis for a complete inventory of the natural resources of a region. The discovery of a few large deposits of almost any kind would insure the economic success of the venture and many smaller prizes of all kinds of resources would effectively add to the success. As an example, Griffiths and Drew report using a random grid across Pennsylvania and Ohio to represent a systematic drilling pattern. Since the selection of the initial point and the orientation are not related to geologic trends, this may be looked upon as a random sampling procedure. On the basis of this sampling, grid points falling on known oil and gas fields were counted as successes and those on barren areas as failures. The overall success ratio was 1 in 6. This result is surprisingly good and may well suggest that systematic grid patterns may be of value in exploration programs for large areas.

There are other exploration techniques that depend fundamentally upon data analysis. J. W. Tukey (1965) has pointed out that enhanced geophysical exploration will probably come through spectrum analysis of information; particularly information having a distribution that is not Gaussian or Laplacian. The art and science of frequency analysis, combined with the power of digital computers, is becoming an excellent exploration tool.

I mention one other aspect of industrial mineral exploration that may become of surpassing importance. I refer to remote sensing. Actually, aerial photography is a form of remote sensing that we have used with considerable success in the past and this technique has been enhanced through use of color photography. Today, however, radar and infra-red studies are coming into their own. Imagine if you will, radar and infra-red investigations which are not circumscribed by weather conditions or cover. Instruments can be placed in high-flying airplanes or satellites. Consequently, tremendous quantities of geological information will be generated by these sensors in several passes around the earth. I have seen some of the radar imagery developed by a group working at The University of Kansas. Detail is excellent and structural features are revealed that cannot be seen on aerial photographs. This tool, coupled with infra-red sensing and the computer, may soon provide a whole new avenue for exploration.

The tools of systems analysis and operations research, stemming largely from the power of the computer, are being used to forecast development, growth, and regional movement of industrial minerals. At the Kansas Survey we have undertaken studies that include methodologies for forecasting inter- and intra-regional transfers of industrial minerals, and economic model building as it might be applied to industrial mineral production. Regional economic growth is not simply a consequence of a discrete set of local decisions and every sizeable injection of new investment brings wit it a train of related economic events character ized by a multiplier effect. We first looked at the interdependency among the various time series commonly used as independent or dependent variables in regression forecasting methods. Our first success came in a very limited way when we discovered that we were able to predict sand and gravel production accurately through a regression analysis of construction data with a one year time lag. We later attempted to describe and quantify the factors determining regional production of mineral commodities. Regional output might be accounted for by a function called regional share of total production, which is dependent upon a conceptual variable called geologic advantage, a regional advantage in cost of mining, processing, and transportation, and a regional advantage related to location with respect to markets. Geologic advantage was estimated by several numerical indicators such as ratio of dollar reserves to dollar exploration, miles of igneous-sedimentary contact, and a probability estimate for discovery of a specific mineral based upon given levels of exploration investment and results in similar geologic areas. Costs of mining, processing, or transportation depend upon good estimates of regional cost including those determined by public policy, private policy, and technology. Regional advantage due to location with respect to markets was based on trend-surface analysis of distribution of regional mineral outputs. Data were developed for sand, gravel, and stone, and an attempt was made to predict the flows of industrial minerals from one region of the country to others where transportation costs were of major importance. Transportation cost was based on the assumption that separate companies are not involved in optimizing a total operation, but instead are interested in maximizing their own efficiency. Accordingly, a program was used which assumed the lowest cost operation would take place first. In the calculations, the smallest entry was searched for in the cost matrix. When it was found it was presumed that the supplier and the customer would do as much business as they could. The program was used to compute the present flow of aluminum from manufacturer to customer and all possible locations for increased production were investigated. If the future location of suppliers is made in the most efficient manner, and if the total regional demand for aluminum is known, this program can predict the regional future production of aluminum.

Mathematical model building and simulation studies were used to maximize industrial development in a specified area in terms of capital investments and labor employed, and to maximize profits from particular industrial applications. The following methodologies were used: (1) isolate principal economic variables which were retained to industrial development, (2) develop mathematical models which would review how these economic variables interact, and (3) determine which government and industry policies would most effectively accomplish these objectives.

Furthermore, our work has encompassed product development, market analysis, capital investment analysis, and measures of profitability. For example, we have completed a study of volcanic ash; we have reserves of about 23 million tons of this material. Technical studies show that the ash can be expanded in a flame at about 1500°F and that the resulting spheres can be used to produce filter aids and thermal and acoustical tile. Comparisons with diatemaceous earth show it has excellent filtration properties. We have made a detailed market analysis for use in dry cleaning, brewing, swimming pools, and for other uses and have determined the capital investment necessary to satisfy this market and have applied measures of profitability.

## THE DEMANDS ON EDUCATION

The developments that I have outlined, although scarcely comprehensive in scope, are characterized by change, urgency, and involvement in the scientific, social, economic, and political problems of states, regions, and the nation. Change is not new for Nicholas Murray Butler used to insist that in the Garden of Eden, Adam paused at one point to say "Eve, we are living in a period of transition." However, urgency and involvement are new. Many developments involve transference of ideas from one discipline to another. The systems approach of the engineer is evident; we have drawn heavily upon management science, the clustering and correlation techniques of psychology and biometrics; upon mathematics, particularly in the area of linear algebra, probability, statistics, and difference equations. How then can these interdisciplinary aspects of our methods and techniques be incorporated into the education process?

For many of us, a retooling operation seems essential. A number of organizations are attempting such a process through special short courses and seminars. The Council on Education in the Geological Sciences sponsored two of these courses in connection with the Geological Society of America meeting during this past year. Furthermore, there are efforts afoot to determine new and better ways to transfer the results of investigation to industry through new kinds of publications, seminars, and conferences. New assistance is forthcoming through the recently passed Technical Services Act of 1965 which provides states with matching funds in partnership with the federal government. It has as its objective the wider use of new technology, improvement of industrial products and processes, and solution of industry problems.

As to the education of geologists and others who may participate in a future industrial minerals development, I find an identical problem that I faced when I was asked to speak on the subject of education of geologists for geological surveys at a meeting some months ago. I concluded that the education of a geologist for a geological survey should not differ from education for other purposes; I hold to that judgement for industrial minerals. Gardner (1963) has said that one of the virtues of formal schooling is that it requires the student to test himself in a variety of activities that are of his own choosing. The adult can usually choose the kinds of activities in which he allows himself to be tested and he takes full advantage of that freedom of choice. He tends increasingly to confine himself to those things he does well and avoid those things that he has failed or never tried. The future mineral industries employee should be the kind who will continue to test himself in a great variety of activities that are of his own choosing, who will avoid progressive narrowing that prevents exploration and experimentation, the kind of person who will engage in a life-long learning process. What kind of educational pattern can assure that students will have these qualities? None, obviously. However, education for this kind of person is evidently education for versatility. Patterns of flexibility, versatility and capacity for transference of ideas must begin at the formal education stage. The educational pattern should be one that permits the student to test himself in a great variety of activities that are of his own choosing. A department should make sure that its own requirements are not too rigidly devised and that the student has opportunity to sample widely. In the long run, it is the individual faculty member who must set the scene for education of this kind.

Some points I would emphasize especially. Geology curricula often contain excessively overlapping courses, the subject matter is repetetious and redundant, and there is too little emphasis on problem solving and numerical techniques. The average required curriculum could be pruned substantially without great loss. I would especially like to see additional mathematics in the curriculum, for I feel that mathematics is the key to other sciences and to problem solving. I am in sympathy with the recommendations of Harbaugh and others (1965), which were developed in collaboration with a committee on undergraduate program in mathematics. These would include a first year of calculus and analytical geometry along with an introduction to computer programming. A second year would include linear algebra and combined probability and statistics. Additional mathematics including ordinary and partial differential equations along with applied mathematics might be taken by students interested especially in geophysics, geochemistry or engineering geology. Such mathematics would permit students to deal with deterministic and stochastic problems of organized or disorganized complexity in many variables and would promote problem solving through rigorous analysis and logical solution. Beyond this I would not be too specific and course selections could be made in the other sciences and engineering. Furthermore, we should never lose sight of the fact that we are dealing with field relations and far more emphasis should be placed on this *kind of training than is now the case*.

In conclusion, might I say that if you are dismayed, distressed, or intrigued by the kind of future that I have sketched, then I suggest that you enroll in the next <u>Annual Symposium and Short Course on Computers and Operations Research in the Mineral Industries</u>. This event is sponsored by The Society of Mining Engineers of the AIME along with the University of Arizona, Stanford University, Colorado School of Mines, and the Pennsylvania State University. Symposium subjects include exploration for mineral resources, mine planning and scheduling, investment planning, computers in plant operations, statistical treatment of geologic data, surface fitting, mathematical methods in mineral preparations, and mine system simulation.

I close with a paraphase from Linus: *SIGH* we have so much to learn.

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