5-1974

Phosphate Exploration and Property Evaluation in Southeastern Idaho, Illustrated by the Dry Valley Area

James Simon Spalding
Utah State University

PHOSPHATE EXPLORATION AND PROPERTY EVALUATION
IN SOUTHEASTERN IDAHO, ILLUSTRATED
BY THE DRY VALLEY AREA

by

James Simon Spalding

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

UTAH STATE UNIVERSITY
Logan, Utah

1974

ACKNOWLEDGMENTS

The writer wishes to acknowledge the technical assistance received from the staff of the Mineral Development Department of FMC Corporation, and FMC Corporation for allowing the contained information to be published. Appreciation is expressed particularly to Dr. V. E. Larsen, Mr. R. J. Hayden, Mr. H. N. Hurst, and Mr. M. L. Newell for their review of the manuscript. Thanks also go to Ms. G. A. Stoll for her help in drafting the figures and to Ms. Dawn Cassell for typing the many rough drafts of this work.

Appreciation is also expressed to the staff of the Department of Geology of Utah State University for their assistance in the preparation and presentation of this work. Dr. Donald R. Olsen, Dr. Clyde T. Hardy, and Dr. Robert Q. Oaks, Jr., provided much needed assistance on the form and composition of the manuscript.

The writer wishes to thank his wife, Donna Lee, and children for the patience and considerations shown during the construction of this work.

James Simon Spalding

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF PLATES

ABSTRACT

Phosphate Exploration and Property Evaluation in Southeastern Idaho, Illustrated by the Dry Valley Area

by

James Simon Spalding, Master of Science

Utah State University, 1974

Major Professor: Dr. Donald R. Olsen
Department: Geology

The western phosphate field produced about 15 percent, in 1970, of the nation's domestically consumed phosphate rock and contains an estimated 58 percent of the nation's indicated phosphate reserves. The central portion of the western phosphate field, which contains the Dry Valley area of southeastern Idaho, encompasses the greatest amount of mineable phosphate reserves in the smallest geographic area within the western field.

Exploration of properties in the area should follow an orderly sequence of literature search, area reconnaissance, detailed target appraisal, and detailed three-dimensional sampling to effectively evaluate each property. Present exploration techniques include topographic analysis, vegetative investigation, profile drilling patterns using a portable rotary-table drilling rig, geophysical logging of the drill holes including gamma-radiation logs, neutron logs, temperature gradient and differential temperature

logs, and bulk density logs, trenching, tunneling, and test mining. The economic analysis of exploration programs embodies bookkeeping, project cost forecasting and an economic analysis of alternate methods of exploration.

The evaluation of individual phosphate properties includes such variables as geology, mining characteristics, alternate concepts in reserve calculation, transportation and governmental policies.

The structural geology of the Dry Valley area is less complex than the structural geology of other phosphate deposits in the western phosphate field. Yet most structural features outlined by drilling in Dry Valley occur elsewhere in the western phosphate field. The stratigraphy of the Phosphoria Formation and its Meade Peak Phosphatic Shale Member is simple and correlatable throughout southeastern Idaho through the use of gamma-radiation logs.

The history of land acquisition and property evaluation by FMC in Dry Valley covers a relatively short eight-year period. Future plans for companies operating in the western phosphate field include trading and selling of properties to build mineable units covering large volumes of the estimated 300,000,000 tons of economically surface extractable ore in the Dry Valley vicinity.

(132 pages)

INTRODUCTION

Strange things are done
In the midnight sun
By the men who moil for gold ...
R. W. Service

Purpose

The purpose of this study is to treat the variables and factors encountered in phosphate exploration and property evaluation with reference to the western phosphate field using as an example an eight-year exploration and development program just completed by the Mineral Development Department of FMC Corporation. By narrowing the geographic scope of this study to the Dry Valley area of southeastern Idaho, it is hoped that the information herein presented will benefit students in the geological sciences by acquainting them with the routines, techniques, and requirements of an industrial minerals exploration geologist.

Location

The western phosphate field encompasses areas of western Montana, western Wyoming, northeastern Utah and eastern Idaho. The western phosphate field produces about 15 percent, in 1970, of the nation's domestically consumed phosphate rock and contains an estimated 58 percent of the nation's indicated phosphate reserves (Service and Popoff, 1964).

The central region of the western phosphate field contains the greatest amount of mineable phosphate reserves in the smallest geographic area within the western field. The Dry Valley area, in southeastern Idaho, is situated near the heart of the central region (Figure 1).

FMC Corporation's Dry Valley phosphate deposit is located 55 miles east-northeast of Pocatello, in southeastern Idaho. This area is situated in the northern and central portions of Dry Valley, which lies between Dry and Schmid Ridges. The two ridges are subdivisions of and comprise a major portion of the Pruess Range, a subdivision of the Peale Mountains. The Peale Mountains are the largest of the mountain groups that comprise the Idaho-Wyoming chain.

Mabey and Oriel (1970) indicated that the presently accepted physiographic boundary between the Basin and Range and Middle Rocky Mountain provinces is at the western edge of the Bear River Range, about 30 miles west of Dry Valley, placing Dry Valley in the Middle Rocky Mountain physiographic province. The drainage of Dry Valley via Dry Creek and the Blackfoot River is to the Pacific Ocean (Figure 1).

Access to Dry Valley is via State Highway 34, north of Soda Springs, for 13 miles, thence, 5 miles east on a blacktop road to Monsanto Chemical Corporation's abandoned Ballard Mine, continuing southeasterly about 11 miles on a

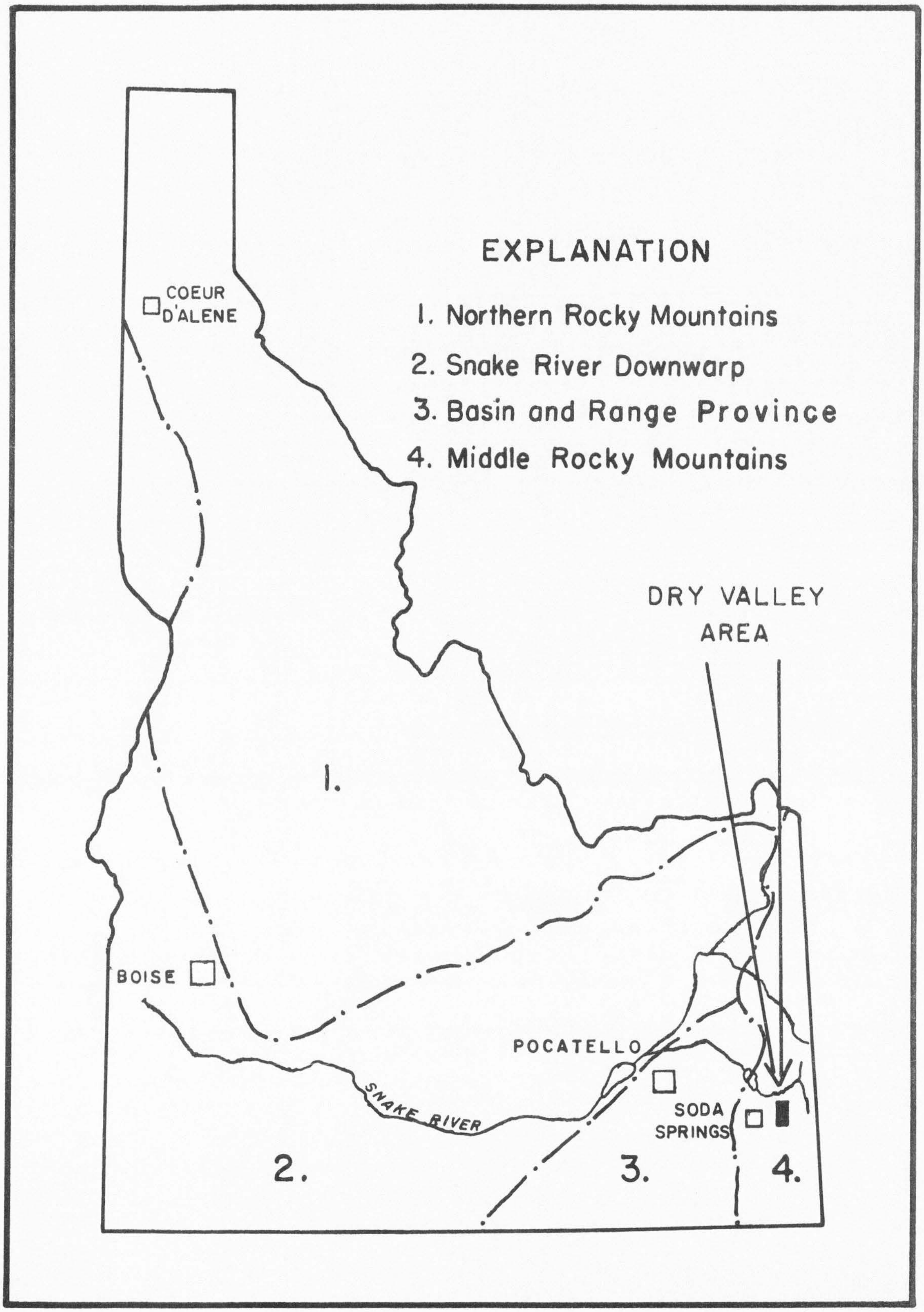


Figure 1. Physiographic divisions of Idaho.

dirt road into the north-central portion of Dry Valley as noted on Figure 2 which also locates the operating phosphate mines in southeastern Idaho. Alternate routes into Dry Valley are via Slug Creek and Trail Creek by unimproved dirt roads.

Facilities in Dry Valley include a railspur and loading facility, rated at 1.2 million tons per month, built in 1965 by El Paso Agri-products and now a common carrier, an underground phone cable, surface electrical power supply lines, and a well-maintained dirt road.

The FMC properties are in sec. 31, T. 7 S., R. 44 E., and secs. 4, 5, 6, 8, 9, 16, 22, and 35, T. 8 S., R. 44 E., Boise Meridian.

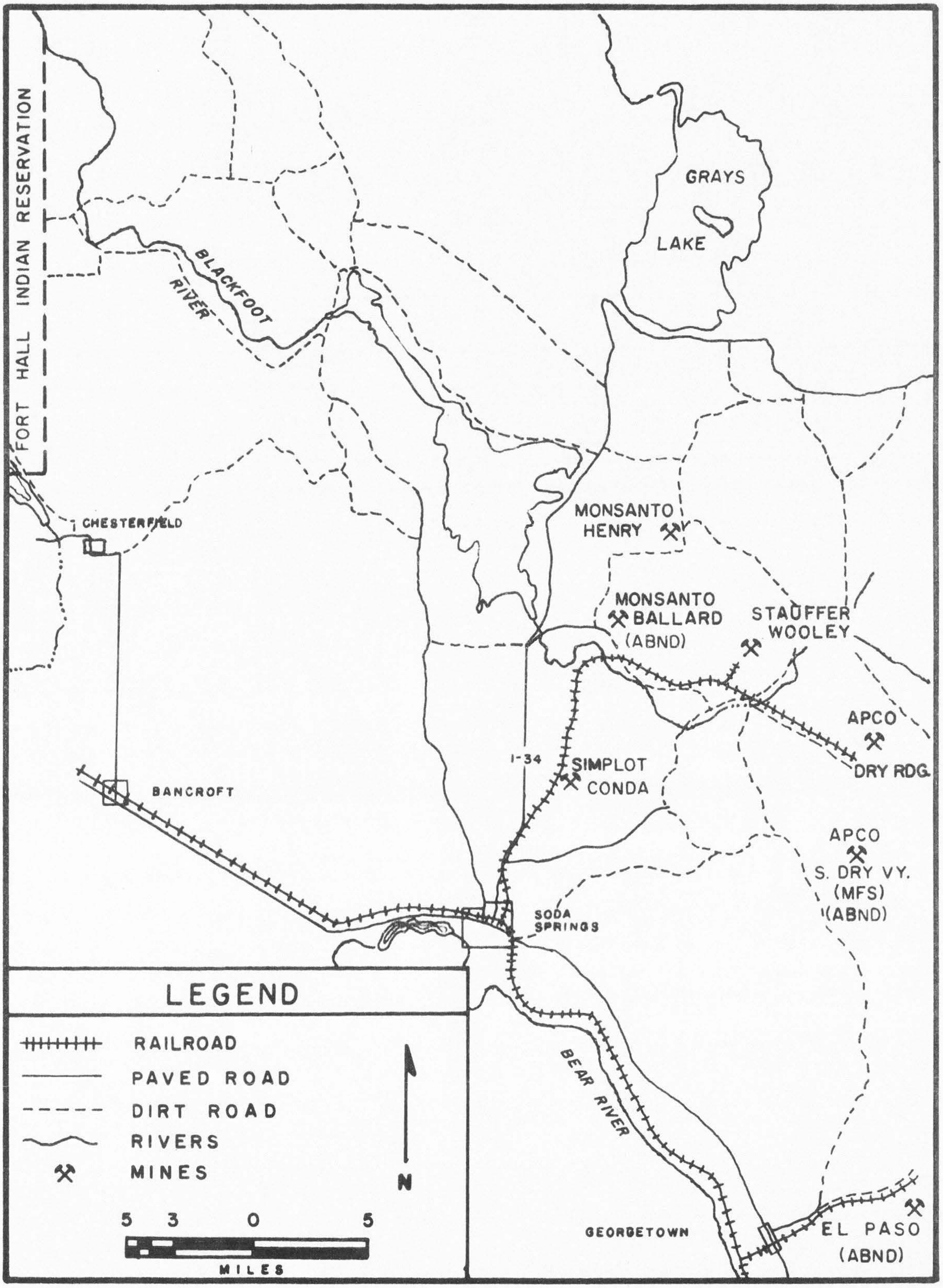


Figure 2. Location of phosphate mines in southeastern Idaho.

EXPLORATION IN SOUTHEASTERN IDAHO

General Statement

Success in exploration depends on many factors, both tangible and intangible, but it is always dependent on the political and economic situations within the mineral industry and without. For example, recent restrictions on phosphates in detergents, along with other economic factors, at one time curtailed phosphate exploration because of an uncertain future market for phosphorus within the United States. Yet even more recent high world-wide prices have served to revitalize the industry.

The same laws and restrictions can add incentives to other portions of the mineral industry. For example, the restrictions on phosphate, along with the natural growth of the soda ash market, have added so much incentive to Wyoming's soda ash industry that the state's production of this material will have trebled from 1968 to 1975. Soda ash, which is processed from trona, is used as a filler in the new phosphate-free detergents.

Dependent as it is on so many factors, the objective of exploration in the mineral industry, according to Bailly (1968:19), remains the same: "... to find and acquire a maximum number of new economic mineral deposits with a minimum cost in a minimum time."

This, however, is not a totally correct picture of an exploration venture. Each venture is unique in terms of profit to the parent company, the need for the mineral and/or potential benefit to the company.

As Bailly (1968:20) so aptly said: "... a mineral occurrence is found through prospecting; but an economic mineral deposit is 'made' through imaginative and effective exploration ..."

Three major occurrences in the late 1950's and early 1960's served to add impetus to the search for phosphate in the western phosphate field. First was the great increase in the quantities of phosphates being consumed by the detergent industries. Second was the passage of the Act of March 18, 1960 (74 Stat. 7, Title 30 United States Code 211), which allowed a person or company to obtain a prospecting permit for up to six years on a property which had no phosphate mapped by the U.S. Geological Survey. After exploring the property, the permittee had the right to drop the property or to apply for a preference right lease on all or a portion of the property. Prior to passage of this act a person or company had to have a phosphate mineral lease to explore the property. All leases, prior to 1960, were issued only to the bidders who submitted the highest, sealed, competitive bids.

The third occurrence which added impetus to the phosphate industry in the western field, was the rising need for phosphate-based fertilizers and the consequent rise in the selling price of those products. Low-cost transportation and more efficient open-pit mining made fertilizer produced in the western field competitive with Florida rock products over most of the Great Plains. In addition, markets were developed by the companies operating in or initiating operations in the West.

Most recent endeavors to locate unmapped phosphate deposits in southeastern Idaho follow the same general guidelines. First, a literature search is conducted. This consists of examining existing reports and maps for possible areas of incorrect geology, incorrect geologic interpretation, or incorrect mapping, in order to locate unknown or unmapped phosphate deposits. Once the older data are evaluated then a field examination is made of the target areas, searching for the presence of the phosphate-bearing stratum, the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, either in new geologic interpretations or actual physical evidence such as float. If the Meade Peak Member is found on withdrawn lands, a prospecting permit application is filed with the U.S. Bureau of Land Management in Boise, Idaho. Upon issuance of a prospecting permit, field examination and exploration, including detailed mapping, drilling and/or trenching, and sampling, is conducted. Compilation of these data into a geologic report with preliminary ore-reserve estimates follows. If a favorable report is issued, an application for a mineral lease on the property is filed, and, upon issuance of the lease, development work begins.

Phosphate land withdrawals are made to aid land classification and to prevent improper use of the mineral resources of the federal government. Once lands have been mapped and classified as either containing phosphate or not containing phosphate, they are restored to public use. Because certain lands are withdrawn does not mean that they are valuable for phosphate, and, furthermore, it does not mean that all phosphate lands are withdrawn.

First withdrawals of phosphate lands were made by the Department of the Interior on December 9, 1908. The first act authorizing these withdrawals was confirmed by Congress on June 25, 1910, and amended August 24, 1912, and February 25, 1920. Since 1908, there has been a total of 1,823,545 acres of public lands withdrawn in the western phosphate field; 280,829 acres in Montana, 276,239 acres in Idaho, 989,133 acres in Wyoming, and 277,344 acres in Utah. As a result, the phosphate withdrawals now preserve phosphate lands from all forms of entry, location or disposition except metalliferous claims, pre-existing homesteads, desert land entries, valid settlements, and gold placers which were being worked at the time of withdrawal. Much of the land withdrawn in Idaho was surveyed and studied in the first two decades of the twentieth century by G. R. Mansfield.

The following discussion on exploration is based on common practices in use during the "phosphate rush" of the mid-1960's in the search for new phosphate properties. Figure 3 illustrates the four stages of full-sequence exploration to be discussed.

Stage 1

In this stage of the search, the literature of the entire region must be scrutinized and studied from aspects of pertinent geological history, paleogeography and paleoenvironments with primary interest in areas which had the necessary conditions for deposition or emplacement of the desired mineral. It is obvious that an intimate knowledge of the depositional history and geochemistry of the desired mineral is necessary.

One of the most important Stage 1 search functions of a geologist is to ascertain the grade parameters needed in the ore. These grade parameters depend in part on the anticipated extraction process. An ore which has characteristics outside these parameters will sometimes render a given extraction process helpless, at other times it will cause severe restraints on, or cause changes in, the flowsheet of the process; sometimes it will cause economic hardships and possibly place the product at a cost level too high to be competitive, although some elements outside the given parameters might prove beneficial to the process.

Today it is necessary to process for elements in smaller and smaller quantities in larger bulk deposits. Minor elements have a great bearing on whether a mineral

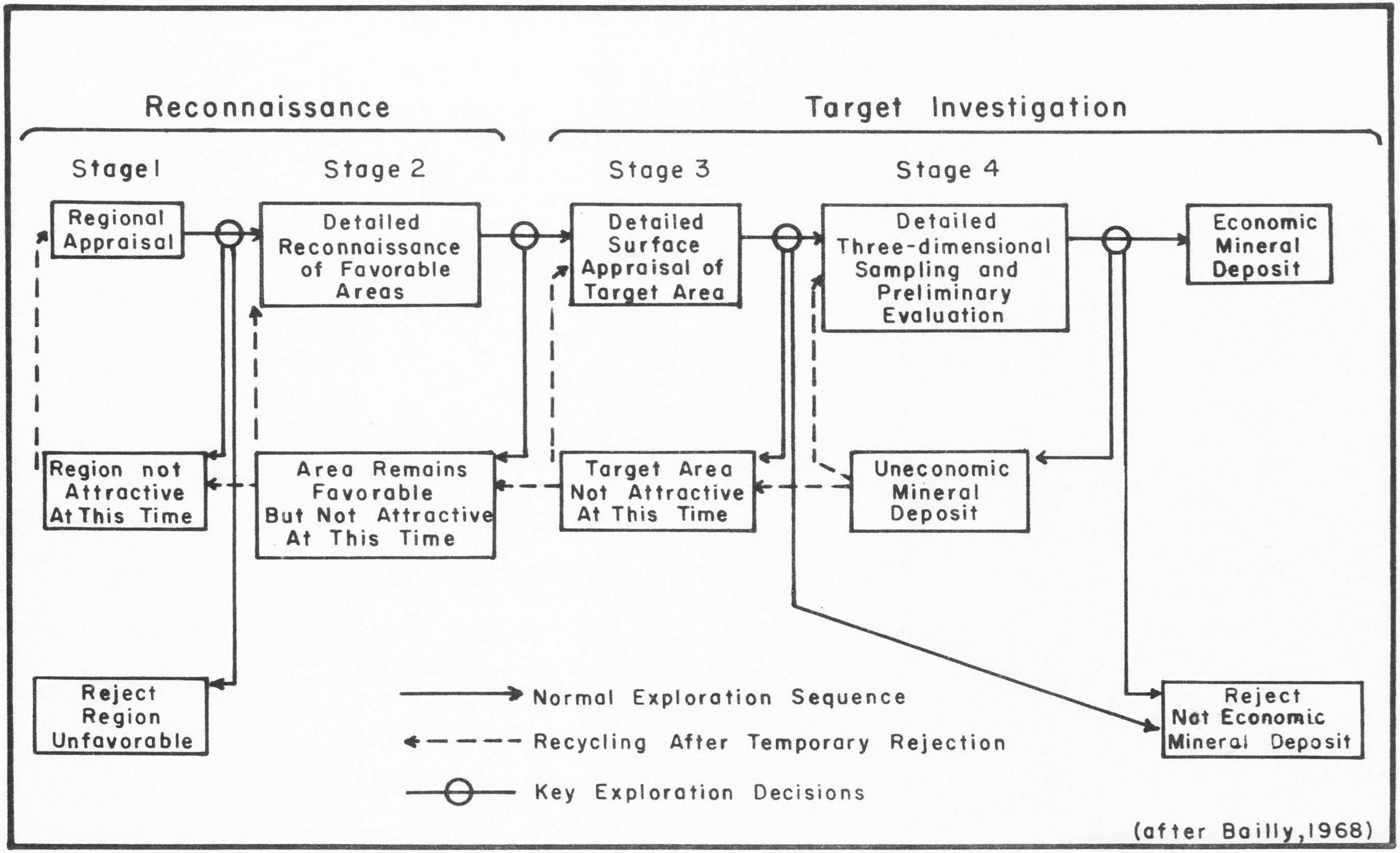


Figure 3. Four stages of full-sequence exploration.

deposit is economic and which extraction processes will be used. Environmental issues, effluents from processing and their subsequent removal, must now be considered in determining which mineral bodies are to be considered as ore. A recent example of this problem occurred in the western phosphate field. El Paso Agricultural Products Company at Conda, Idaho, encountered an area of high iron and alumina concentration in its Dry Ridge mine in 1966. El Paso, in order to use this ore, had to beneficiate the phosphate rock. They induced Mountain Fuel Supply Company to build the beneficiation plant next to El Paso's Conda facility in 1967 and were then able to use the same ore with the addition to the processing flowsheet.

As in the great majority of mineral deposits, tonnage and grade are the primary parameters in the economic evaluation of phosphate deposit. However, because of its generally low market prices, phosphate rock deposits are subject to, and sensitive to, a long list of additional parameters before they are considered economic.

The following discussion deals only with those ores which are shipped directly to the extraction plants. No consideration is given to the beneficiation or blending of ores.

The parameters necessary in the chemical processing of phosphate rock are numerous (Brinkerhoff, 1967; Goldstein, 1962a, 1962b, 1963; Howard, 1971; Hsiao, 1966; Ilardi, 1966; Lang, 1965, 1966a, 1966b):

1. The grade of phosphate rock must be at least 30 percent P_2O_5.

2. Combined iron and aluminum oxides greater than 3.5 to 5 percent are generally prohibitive.

3. A CaO to P_2O_5 weight ratio greater than 1.7 to 1 will generally eliminate the prospective area due to the high cost of acid consumption.

4. Acidulation in wet acid plants can commonly tolerate no more than 0.12 percent sodium chloride because of the severe corrosion problems in processing equipment.

5. More than 0.25 percent MgO will result in an intolerable viscosity index in super phosphoric acid produced by the wet acid process.

6. A P_2O_5 to F ratio of less than 8:1 may indicate fluorine problems in processing.

7. Organic matter in phosphate rock leads to discolored acid which is difficult to sell.

8. The presence of pyrite in the ore used in a wet acid process will produce lethal H_2S gas and hence is generally prohibitive.

9. If the product is to be used as a fertilizer or feed additive, harmful trace elements include vanadium, arsenic, cadmium, lead, and several of the heavy metals.

Confining parameters in an electric furnace operation are not as restrictive as those listed for chemical processing:

1. For most furnace operations, the grade of phosphate rock need only be greater than 24 percent P_2O_5.

2. Most major problems occur in the preparation of ore for a furnace operation. The major problem in ore "quality" for a furnace operation similar to that of FMC, other than the P_2O_5 content, is moisture. The moisture content of the ore must be in the 9 to 11 percent range. If less than 9 percent, the ore will not briquette properly; if more than 11 percent, the moisture causes problems in calcination; if the moisture is above 13 percent, the ore cannot be totally calcined before entering the

furnaces, and the moisture causes severe problems in the reduction of the fluorapatite and unsafe working conditions.

3. Clay content is another important parameter. A certain amount of clay, in the 65 to 70 percent range, is required to act as a binder for briquetting the ore and supplying some silica, upon reduction, for slag production. If the clay content of the ore becomes too high, the melting point is lowered and causes thermal insulation of pockets resulting in incomplete reduction and complexing of P_4 in the slag.

4. A CaO/P_2O_5 greater than 1.45 increases the melting point, thereby requiring more electricity for complete reduction of the furnace burden. Excess calcium also increases the amount of slag produced, thus increasing the P_4 lost to slag production.

5. Too much sodium in the ore, greater than 0.7 percent, causes a reduction in the melting point with problems similar to those encountered with high clay-mineral content.

6. Too much zinc causes complexing of P_4 which then is lost as waste.

7. Iron present in the ore causes complexes with the P_4 which is subsequently lost as waste in the metal tap.

8. The presence of potassium acts as a catalyst and increases reactivity.

After a region has been appraised, one of three choices must be made:

1. The region has favorable areas that warrant further investigation.

2. The region has favorable areas but is not attractive at the present time. This choice could be due to a change in corporate policy or a change in mineral or product economics.

3. The region is rejected due to a lack of favorable data.

The stratigraphy, paleoenvironment, detailed mapping, and geochemistry of the western phosphate field were nearly completed in the first half of the twentieth century (Mansfield, 1927, 1952; McKelvey, 1956; McKelvey et al., 1959). Most work in the last twenty years has been to clarify certain ambiguous and complex areas. In completing this task, a new regional geologic picture has been developed (Armstrong and Cressman, 1963) and accepted by most geologists. The acceptance of this change in G. R. Mansfield's interpretation of the geology of southeastern Idaho has necessitated geological remapping and reinterpretation of certain portions of that part of the state by the U.S. Geological Survey. This work has all but eliminated a Stage 1 program in any search for new phosphate deposits within the western phosphate field.

Stage 2

Most information on the western phosphate field has been developed and published by government agencies or academic institutions, but such field work is always subject to review, criticism, and reinterpretation. It was on this premise that the work of Stage 2 was based during the "phosphate rush" of the mid-1960's.

The pertinent stratigraphic units used here are listed in Figure 4.

Stage 2 work in the western phosphate field consists mainly of examining maps and reports looking for possible areas of erroneous geologic interpretation or alternative interpretations.

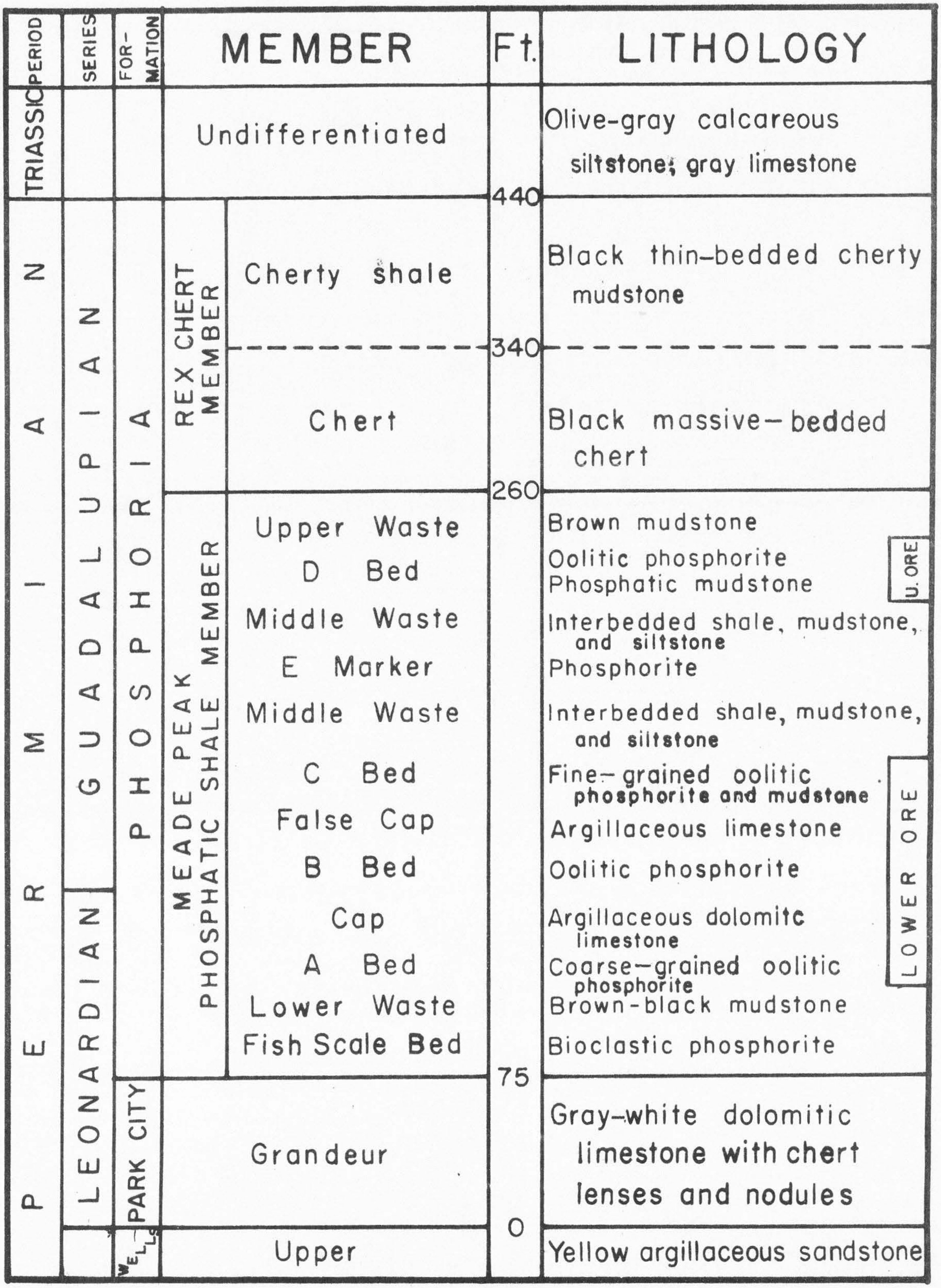


Figure 4. Generalized and abbreviated stratigraphic section, southeastern Idaho.

The areas which are scrutinized most carefully are those in which strata associated with the phosphate-bearing rocks, the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, are faulted together. These fault contacts include Wells Formation against Triassic strata, Wells against Rex, Grandeur against Rex or Triassic strata, Rex against Rex, and Grandeur against Grandeur.

Also, any areas of possible geologic omissions in mapping must be checked carefully. These include areas near the associated strata which show on geologic maps as being covered by regolith. Favorable areas might show as Wells-regolith contacts or areas that show the Meade Peak Member extending under the regolith. Only drilling can determine if the mapped regolith is too deep to permit economic surface extraction of the phosphate rock.

Work in the Stage 2 portion of the search can be completed at any time of the year. Then when field conditions permit, a reconnaissance trip to the area is made to check for any surficial evidence of phosphate rock, float, or incorrect interpretation of the stratigraphy of the area. The lack of supporting evidence from this trip should not discount the property as a possible target area if other evidence is favorable.

One important aspect of this stage is information gleaned from the local populace. Although most of the leads are worthless or already noted, in a few cases the information is useful.

Once the geologist has completed his interpretation of the favorable area, he must make one of two decisions:

1. The favorable area warrants further detailed investigation in the field and is classified a "target" area.

2. The area remains favorable but does not warrant further investigation at present. This choice could result from several factors.

   a. There are minerals or elements present in the ore, the gangue material, or the cementing material which cause serious problems in processing under present technology.
   b. The possible target area is too remote, and present, as well as projected, transportation costs are excessive.
   c. Higher priority of other target areas forces abandonment of field investigations on this property at present.

Even if Stage 2 work is completed during the winter, an application for a phosphate prospecting permit may still be filed on the target area. The permit is for only two years and the cost is $0.25 per acre per year. The permit is an effective and economic land-holding tool. The rental price is presently in the process of being adjusted upward by the United States Government agencies involved.

Once the prospecting permit has been approved, the search can move into Stage 3 at any time within the two-year limitation of the permit. It must be remembered that the permits are issued in the order in which the applications are received. If for logistical or geologic reasons, a sufficient amount of work has not been completed on the property to justify an application for lease within the two-year time period of the permit, an application for a prospecting permit renewal may be filed. This permit renewal, if approved, will extend the life of the original permit land, under the original stipulations, for an additional two years. Two renewals are allowed by law.

Stage 3

If the favorable area has been classified as a target area, the next stage is a detailed appraisal of the area. This surface investigation includes detailed geologic mapping, stratigraphic test holes, radiometric surveys, gravity surveys, and electrical surveys. Old uncemented bore holes and water wells in the area should be logged with both geophysical and electrical well-logging equipment, if appropriate, and water samples from domestic wells should be collected and analyzed (Howard, 1972). The geophysical logs will provide data on which a relatively inexpensive appraisal of the area in three dimensions can be made. Experimentation with new survey techniques should not be ruled out, and computer-drawn trend-analysis maps should be constructed and used.

Before the geologist can propose locations for drill holes, he must have an idea where the phosphate may be located in order to avoid drilling extraneous holes. One of the most obvious aids in locating the Meade Peak Phosphatic Shale Member of the Phosphoria Formation is provided by its morphological characteristics. The Meade Peak Member is less competent than either the Rex Chert

Member of the Phosphoria Formation, which is stratigraphically higher, or the Grandeur Member of the Park City Formation or Wells Formation, which are lower. These differences in competency are exaggerated by weathering processes. The result is a swale which follows the Meade Peak Member along strike. Bounding this swale are knobs of chert in the Rex and the Grandeur. The development of this swale is dependent on the dip of the strata, the severity of weathering, and the amount of alluvial cover emplaced early in the geomorphic history of the area. On many properties the swale has no surface expression at all; on some properties the swale exists as a topographic bench following the strike of the strata or, in extreme cases of vertical bedding, such as the east side of Woodall Peak, northeast of Soda Springs, it may be a valley with as much as 100 feet of surface expression (Figure 5).

The Meade Peak Member, when weathered, is very porous and permeable. This feature sometimes causes a concentration of vegetation along its strike. At times this vegetative expression is only visible upon close examination. It may be that the grass grows thicker or the sagebrush a little taller over the surface trace of the buried Meade Peak Member. In other cases, the Meade Peak Member may show as the only place coniferous trees are growing on the slope. One previously unmapped property that was acquired by FMC was traced out on air photos using conifer trees growing in a quaking aspen forest. This feature is

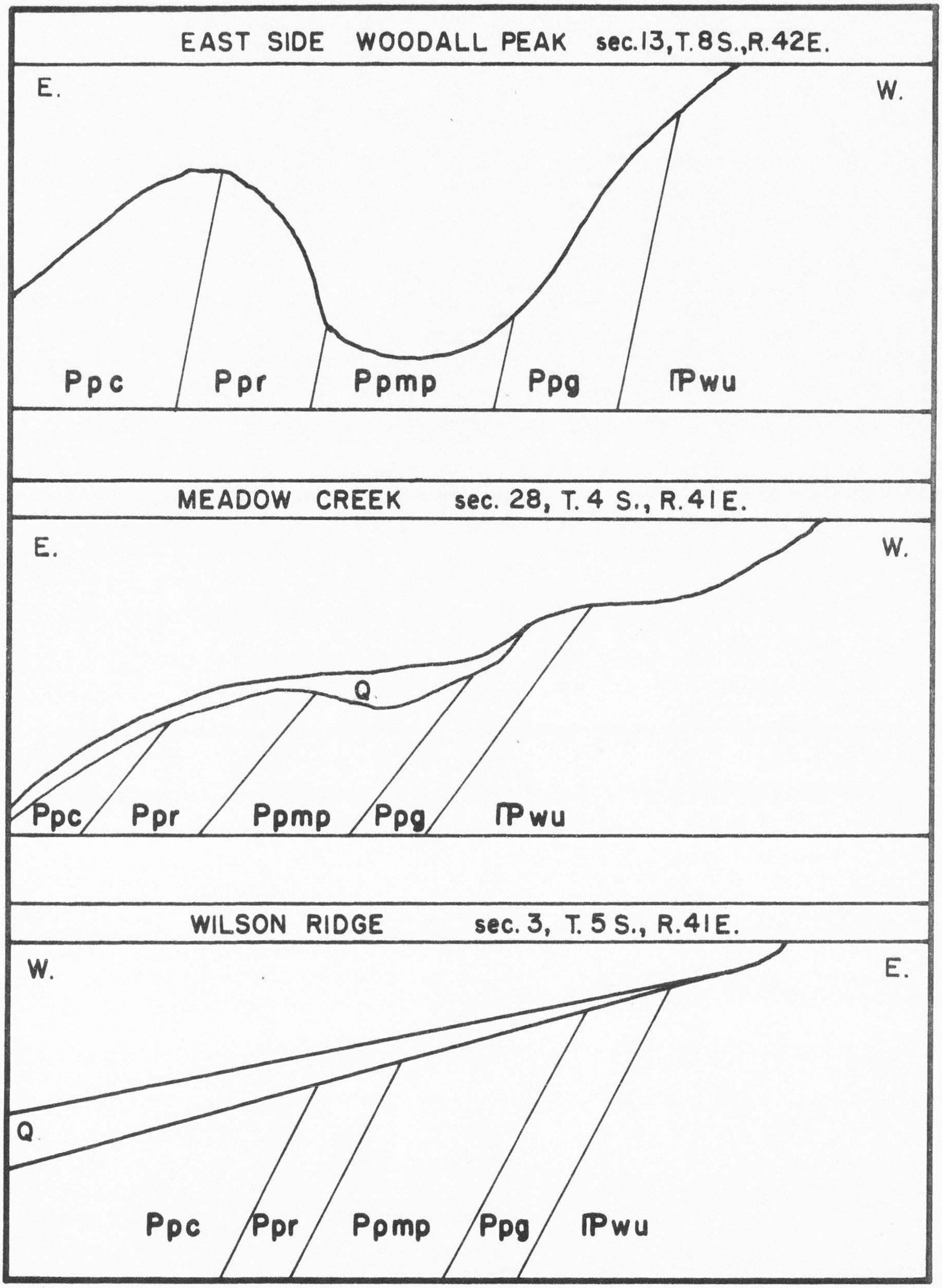


Figure 5. Topographic expressions of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. Refer to Plate 3 for explanation.

located on the east-facing slope of Wilson Ridge, some 40 miles north of Soda Springs. The feature extends over 2 miles along the strike of the strata. This vegetative aid is best expressed on north-facing and east-facing slopes where the snow is present longer in the growing season and gives the ground a more constant moisture content.

Another surface evidence of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation is float. The most commonly observed float from the Meade Peak Member is from the A Bed. This float is light to dark gray, and is coarse grained and oolitic. Locally this float exhibits a light gray cast which is a result of weathering.

In most cases of unmapped properties the alluvial cover is too thick to allow any float to naturally reach the surface. However, float is brought to the surface locally by burrowing animals such as badgers. Such material provides a good cross section of the regolith.

On properties that have been acquired by prospecting permit, because of incorrect mapping of fault contacts, evidence of the Meade Peak Member is sought in the fault gouge or breccia at the contact or in float down the slope. If the breccia contains pieces of the Meade Peak Member, it might mean that part or all of the member exists at depth along the fault contact. If Meade Peak Member float is found down hill and it is not associated with breccia, it may mean that the area was mapped incorrectly and the entire section might be present. If breccia is found and it contains only material from the opposing formations as mapped, it means that the mapping is probably correct. However, if time and money permit, a few holes near the fault contact and in the area where the fault contact disappears under regolith are in order.

Once the surficial trend of the Meade Peak Member has been established or inferred, the design of an exploration program and placement of drill holes follows. The program design depends entirely on the time available, the money that has been allocated for the project, the topography, and the anticipated geologic complexity of the area. Thought must be given to the ownership of the surface rights in the area. Often entire programs must be altered to satisfy the surface owner. A discussion of this aspect will follow later.

When placing drill-hole locations on an unexplored property, one should start in an area that is most favorable for, or exhibits the most evidence of, the presence of the Meade Peak Member. In general, in a Stage 3 program, holes are placed parallel to the projected dip such that one hole completely penetrates the lower ore zone and one penetrates a very few feet of Rex Chert Member and the entire upper ore zone. This design is commonly known as a fence, profile, or panel. These fences are placed approximately 1,200 to 1,500 feet apart along strike in a Stage 3 program. However, severe topographic or complex geologic conditions may cause modifications of the plan. In general, it is good practice to place all fences on 100-foot increments laterally so that the data gathered may be used in proper perspective in future drilling and evaluation programs (Figure 6).

On properties where the geologist has no idea where the Meade Peak Phosphatic Shale Member occurs, he has to design a program wherein all holes are on a fence. The Geologist should ascertain the stratigraphic thickness of the Meade Peak Member in the area. He then must determine the dip of the strata in the drilling area as well as the topographic slope of the area. From these data he must calculate the projected maximum width of the suballuvial trace of the Meade Peak Member, perpendicular to the anticipated strike. The first hole on the fence should be located high enough on the topographic slope so that the geologist is reasonably assured that he will miss the Meade Peak in the desired direction, but close enough to the anticipated location of the Meade Peak so that he expects to hit on his second or third hole. Hole spacing along the fence should be no more than two-thirds of the calculated maximum width of suballuvial formation.

Once a test hole has penetrated the Meade Peak Member on a property that is covered by a regolithic mantle, he has to decide which portion of the member was encountered in order to effectively place the next hole. This decision is greatly aided by the use of down-hole gamma-radiation logging equipment.

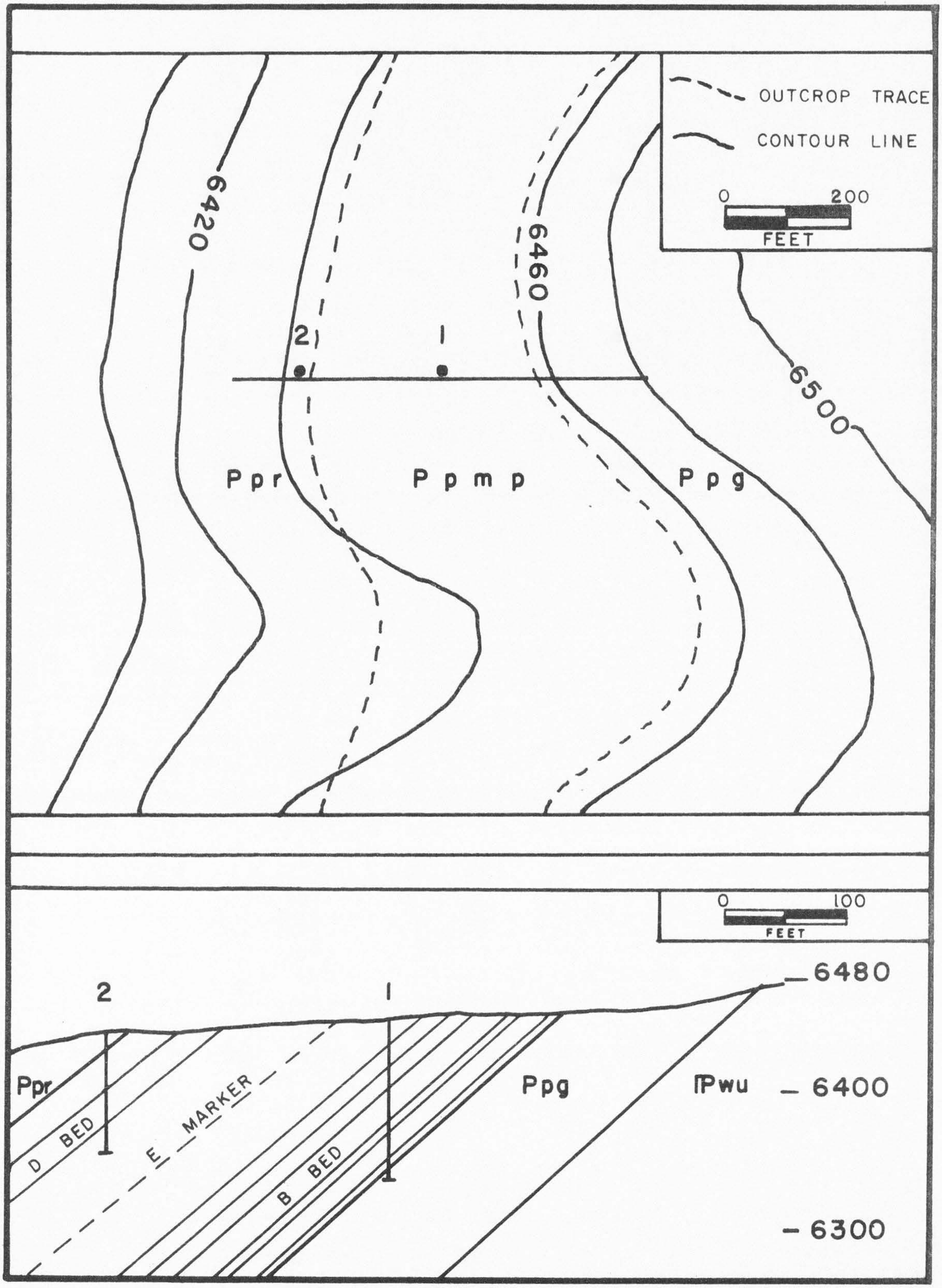


Figure 6. Drill-hole pattern in a Stage 3 program (known outcrop). Refer to Plate 3 for explanation.

Characteristic horizons within the Meade Peak Phosphatic Shale Member of the Phosphoria Formation leave their characteristic trace on the log for the experienced geologist to interpret. The gamma-radiation log alleviates the need for guessing whether the section is overturned as it is on so many properties in southeastern Idaho. The gamma-radiation logging procedure will be discussed in detail later in this work.

Once the geologist has decided which portion of the stratigraphic section the hole has penetrated, he should place his next hole on the fence so that it penetrates the lower ore zone and the Wells Formation or Grandeur Member of the Park City Formation. This decision must be made quickly because the drill and drill crew are waiting. On the initial fence the geologist should place two holes so that they penetrate the Meade Peak Member and Wells or Grandeur at relatively shallow depths, less than 150 feet, to save time and money. His next hole should be placed 100 feet on either side of the fence so that it also penetrates the Wells or Grandeur at a shallow depth. The results from these three holes can be used in a three-point problem to determine the dip and strike of the Meade Peak Member. The reason that the Wells Formation and Grandeur Member of the Park City Formation are preferred over the Rex Chert Member is that most faulting, which affects the results of any three-point problem, occurs between the Wells Formation or Grandeur Member and the Rex Chert Member. In an overturned section the Wells Formation or Grandeur Member is still preferred (Figure 7).

Once the first fence is completed and the dip and strike computed, it is often the best procedure to move only 200 or 300 feet to the next fence to test the results in a similar fence drilling program. If the results of this fence are similar then the 1,200 to 1,500 foot fence spacing may be used for the rest of the property. If not, then a reassessment of the data is in order.

Trenching is another means of exploration that was commonly used in a Stage 3 program in the past but is rarely used today. Trenching is the act of physically baring the entire subcrop of the Meade Peak Member. A bulldozer is used to complete the operation today, but in the past hand trenching was also used. There are very few regions where this method is appropriate in a Stage 3 program. Most notable are areas of very severe topography where an extensive road system must be built in order to drill the property properly. Other than this example, trenching has no place in a Stage 3 program for phosphate, in the writer's opinion. Measurements collected from trenches are too subject to surface creep and give false thicknesses, samples are extremely altered by weathering and are not indicative of the ore grades at depth, faulting and surface creep give false strikes and dips, trenching gives no clue as to structure at depth, trenching creates a scar that takes years to be hidden naturally.

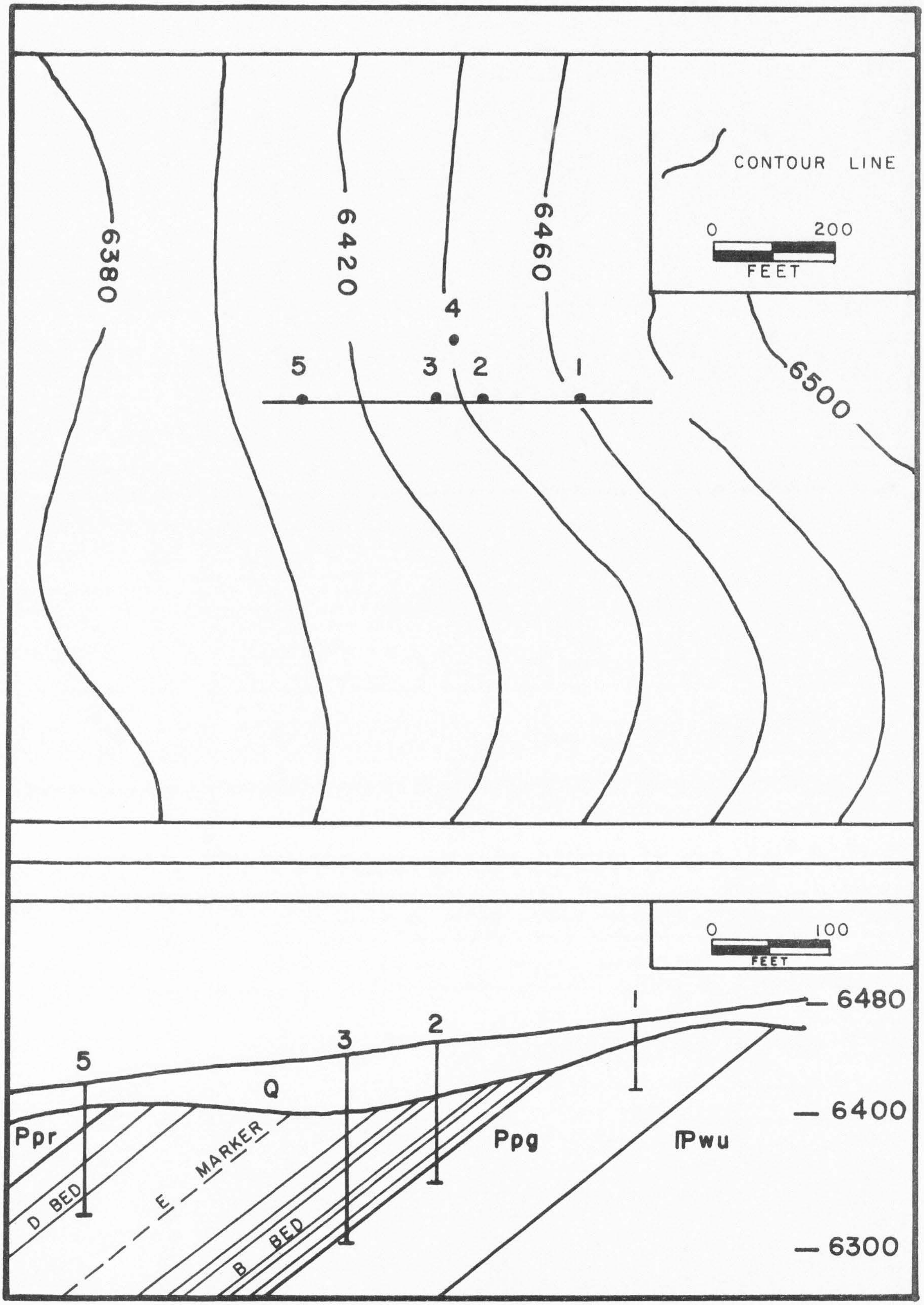


Figure 7. Drill-hole pattern in a Stage 3 program (unknown outcrop). Refer to Plate 3 for explanation.

A geologist must make some of his most crucial decisions during a Stage 3 program. One of these decisions is when to stop looking for the Meade Peak Member on an unmapped property. This, of course, depends upon the size of the property in question and its location. A reasonable rule of thumb on a large, remote property in the western phosphate field, is to drill an exploration fence every 2,500 to 3,000 feet along the strike. If economic phosphate does occur on the property, some evidence of the deposit should be encountered in one of the fences. Some smaller remote properties may warrant only one fence. On properties close to transportation or possible routes of transportation, a more intensive effort may be warranted. The role that transportation plays in the evaluation of a property is important and will be discussed more fully under the heading of property evaluation.

The question of a logical total depth for a hole drilled in searching for the Meade Peak Member must be answered. This question has multiple facets. Although underground mining of phosphate in southeastern Idaho appears uneconomic at present, in the future it may become economic. In general, water and faulting are the major problems in underground mining. In southeastern Idaho, most valleys contain ground water and any property in the valley or on the lower margins of the bounding ridges and dipping into the valley can be ruled out as possible underground properties because of excessive water. To drill these properties deeper than 150 feet in search of the Meade Peak Phosphatic Shale Member would be nonproductive because even in an open-pit operation, an initial stripping of 150 feet would make the property uneconomic at present.

The same philosophy applies to properties farther up slope. If the Meade Peak Member is not encountered above a depth of 150 feet, the property must generally be ruled out as an open-pit phosphate operation. However, the initial question remains unanswered in the question of a possible underground property. In general, the water problem will provide the answer. One should continue drilling until excessive amounts of water are encountered. In one drilling venture, FMC penetrated 250 feet of Wells Formation on an overturned syncline to check for the presence and grade of the Meade Peak Member on a suspected underground mining property, but the drill holes were dry to the bottom.

Upon finishing the Stage 3 program, a preliminary ore reserve estimate must be made for the property assuming the Meade Peak Member has been located. In general, the tonnage and grade at the property, as projected from data gathered in a Stage 3 program, along with its location, will determine when and if the property will be three-dimensionally sampled in a Stage 4 program.

Once the data have been received and analyzed, one of three choices must be made:

1. Enter a Stage 4 program.

2. Reject the target area for the present because of:

a. Inferior tonnage and grade.
b. Elements or minerals present which adversely affect processing under present technology.
c. Transportation costs.

All the choices are related to economics and a decision might change in the future with changing economics.

If it has been decided that the target area warrants three-dimensional sampling and preliminary evaluation, then begins the most expensive and possibly the most important phase of any exploration program.

Stage 4

The initiation of a Stage 4 program may begin at any time in the life of an acquired property. In some cases, a Stage 3 drilling search may, for geologic reasons or management decision, end as a Stage 4, close-order, detailed, three-dimensional sampling program in the same field season. In other cases, particularly on those properties which have been obtained by sealed bid and are thus previously mapped, the property may be drilled through Stage 4 immediately upon acquisition. In other cases, the property may wait as much as twenty years for a Stage 4 program or it may never have one at all. If geologist and management agree that the property has been sufficiently mapped on the surface, the deposit may not be drilled except for mine control just prior to extraction, although this is not a recommended practice.

The aim of a Stage 4 program is always a detailed three-dimensional sampling of the property. The results of the analysis of the data collected during this program will be used in planning the mine, pit design, sequence of mining, and the equipment to be used. All of these parameters will be decided by the geometry and grade of the ore body as disclosed by data from the Stage 4 program. Also included in the program are bulk samples taken for metallurgical testing and pilot plant testing. Whether the ore is amenable existing flow sheets and plant facilities will be determined from these samples. This portion of the program may be called by different names by different companies, from exploration to development drilling, but the aim is the same.

In Stage 4 drilling as in Stage 3 operations, the drill holes should be spaced on fences with at least three holes on each fence. Two holes should penetrate the entire lower ore zone and into the Wells Formation or Grandeur Member. These holes are for grade control and also used to calculate the dip along the fence. The third hole should penetrate a few feet of Rex Chert Member and all of the upper ore zone, plus a few tens of feet into the middle waste section. This hole is used to check the competency of the Rex Member and the presence and grade of the upper ore zone. The portion of the hole below the upper ore zone is to check the depth of weathering, the significance of which will be discussed later. An ideal situation exists when dips are less than 30 degrees. This permits economic penetration of the entire Meade Peak Member and into the Wells Formation or Grandeur Member if no more than 10 to 15 feet of Rex Chert Member and alluvium is encountered at the surface (Figure 8).

The distance between the fences in Stage 4 depends on the geologic complexity of the area, the spacing of Stage 3 fences and the time and money allocated to the project. Generally these Stage 4 fences vary from 200 to 600 feet apart. In Dry Valley, on the northern leases, the initial Stage 3 fences were on 1,000 and 1,500 foot centers. In Stage 4 the centers were dropped to 500 feet and in the area selected for an initial test mine centers were dropped to 250 feet. All Stage 4 drill holes were placed on Stage 3 fence spacing increments. Thus, all the initial drill information gathered in Stage 3 could be incorporated in Stage 4 at the right spacing for equated emphasis on all data with a minimum of superfluous drilling. Drilling may, in this manner, be kept to a minimum, but there must be a flexibility to accommodate any unforeseen and unanticipated problems which can cause the deletion, addition, or the moving of planned drill holes.

After the information from Stage 4 is analyzed, the geologist must categorize the target area into one of three types:

1. Economic mineral deposit.
2. Uneconomic deposit under present circumstances.
3. Not an ore deposit.

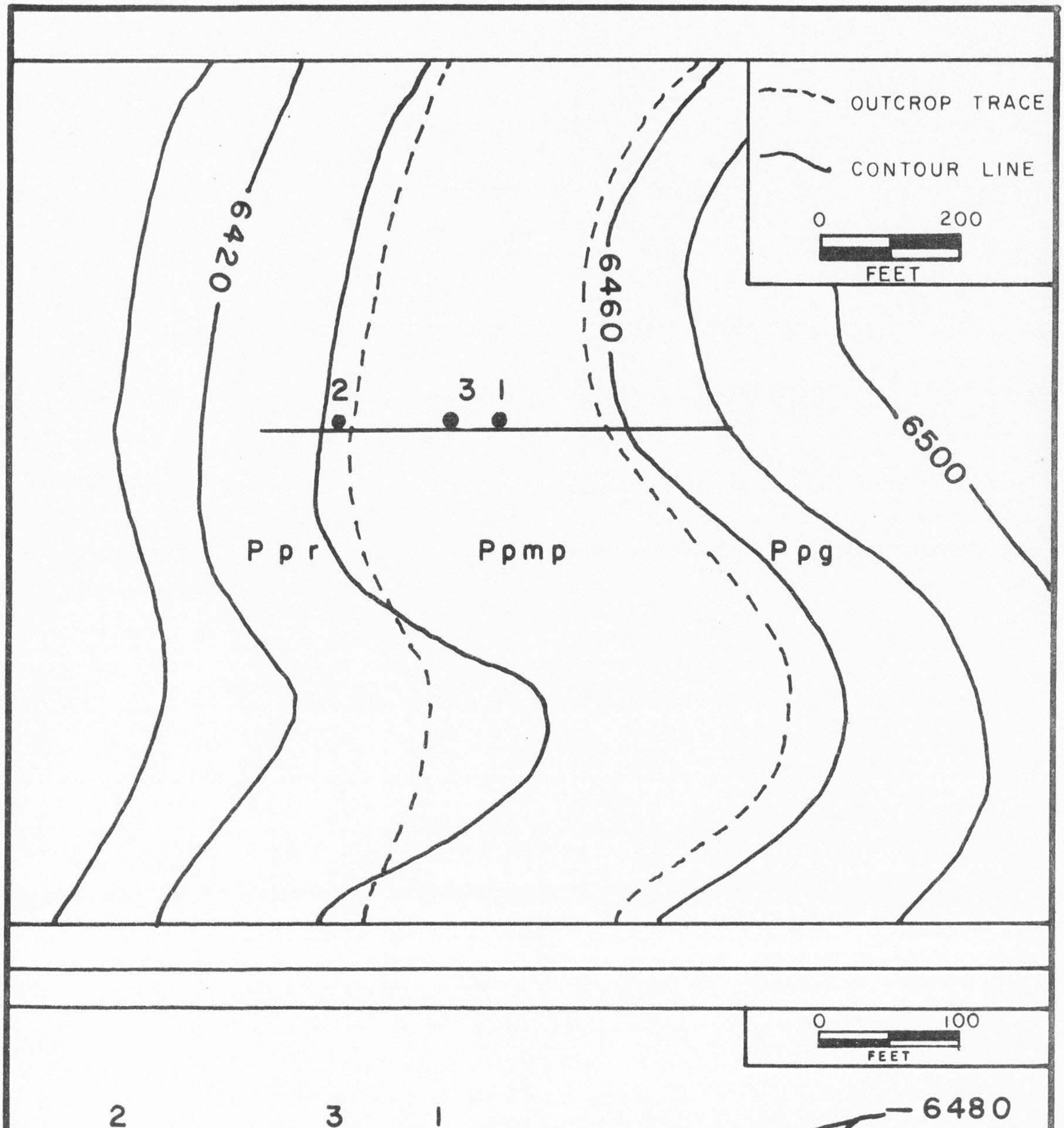


Figure 8. Drill-hole pattern in a Stage 4 program. Refer to Plate 3 for explanation.

After the geologist makes his decision, it is management's decision as to how to further evaluate or develop the property. The deposits are fixed and exhaustible. However, the conditions which make them exploitable are not fixed, and these conditions vary widely within limits set up, by the need for the mineral. Since the basic factor which determines whether or not a particular mineral deposit will be developed is the cost which the user must pay for the mineral at the place of use, economic factors which should be considered are those which affect this cost. Climate and geology are primarily passive factors in this consideration. Market economics, transportation, mining technology and processing techniques are considered active factors. What is unprofitable today may become profitable in the future. All properties which are classified as uneconomic for reasons other than inferior tonnage should be periodically reevaluated for possible economic reclassification.

Having determined the presence of a mineral deposit of sufficient tonnage and grade and the proper chemical and mineralogical characteristics, the evaluation of the property must now be concerned with possible mining methods, costs, and the new, highly important parameter of reclamation and rehabilitation. Among the queries which must be answered are:

1. What is the cost of gaining access to the property?

2. Does the property have potential underground possibilities?

3. How competent are the strata that will comprise the high wall?

4. Can the waste materials be ripped or do they have to be drilled and blasted?

5. Should scrapers or power shovels be used in mining?

6. Should conveyor or truck or scraper be used to transfer the ore to the tipple?

7. Should truck or train haulage to the plant be used?

8. What will be the cost per ton for haulage?

9. Where will the waste and low-grade dumps be situated?

10. How will the property be rehabilitated and what will be the cost?

After all these queries have been answered, the results must be assembled in a manner so as to show the cost of one ton of ore delivered to the plant relative to the value of that ton of ore.

Drilling techniques

There are two basic types of drilling being used in the western phosphate field at the present time with variations in techniques being used in each. These two types are rotary drilling and diamond drilling. The type of drilling equipment chosen is based as much on company philosophy as on the actual equipment needed and results desired.

Although rotary drilling is a relative newcomer to the mineral drilling industry, it has developed into a science in southeastern Idaho. As in every science, the theory might be excellent but the process is only as good as the technicians who implement it. The amount of drilling accomplished and the monies spent are in direct proportion to the experience, capabilities, and knowledge of the driller and, to a lesser extent, his crew. In phosphate drilling where 65 to 70 percent of the direct drilling cost is attributed to drill crew labor, the need for an experienced and capable crew becomes readily apparent from an economic standpoint.

Rotary equipment used in the western phosphate field must be extremely mobile and flexible and yet have the capabilities required to drill a hole several hundred feet deep. Mobility and flexibility are required so that the drilling of several holes and several hundred feet a day can be achieved. These holes can be up to a half mile apart. One may require mud as a circulating medium while the next, only air, and the next, perhaps water injection. The drill becomes more versatile as more equipment is mounted on the drilling rig, and less time is needed to set and prepare the drill over each new hole. When a rig is used in mountainous terrain where roads are generally undesirable, from an ecological point of view, the rig must be able to climb steep grades, turn in a relatively short radius, have enough traction to negotiate extremely muddy and snowy conditions, and have leveling jacks mounted front and rear.

The drilling bit selected greatly influences penetration rate and overall drilling rig efficiency. The selection of a bit type or subtype depends upon the experience and competency of the driller and, although generally technically supported, his preference for a particular brand and/or type. Basically there are two types of bits used in rotary drilling operations in the western phosphate field.

Drag bits have inclined cutting blades mounted on a shank. They are generally preferred in soft altered phosphate rock and alluvium. The drag bit offers the advantages of large-sized cuttings, good penetration rate in soft strata, a long bit life, and low initial cost when compared to tri-cone bits.

Tri-cone bits are composed of three cones with bearings mounted to a shank. Each toothed cone rotates independently of the other. There are a myriad of subtypes available with tooth length, metal hardness, tooth offset, jet-hole size and offset, bearing types, and overall size all being variable. Although some tri-cone bits are constructed specifically for soft formation drilling, the major use of the tri-cone bit in the western field is in the drilling of medium to hard formations. These strata include the Rex Chert Member, unaltered Meade Peak Member, and Grandeur Member and Wells Formation.

The tri-cone bit has the disadvantages of high initial cost which ranges from $90 to $1,400 for 5 5/8 inch size, small cutting-chip size, and short bit life, which is generally less than 600 feet penetration, when compared to drag bits. Generally, the weakest points of the bit are the shank and bearings. When care is taken by the driller and the bit is not ruined, the cutting edges may be retipped for a nominal fee. Retipped bits are generally the most economical in phosphate drilling and may, counting retip footage, run up to 2,000 feet before the bearings fail.

In all drilling operations a circulation medium is required. The drilling fluid serves to cool the bit and rods, remove cuttings from the hole, help control lost circulation, etc. Air is by far the best circulation medium when the strata are dry and care is taken in the sampling program. However, when the strata become too damp to drill with air, or if water is encountered in the drill hole, water or a mixture of water and drilling additives are used. In the western field the drilling additives include bentonite, detergent, soda ash, fuel oil, shredded tree bark and newspaper, and bran. Although the drilling muds have all the beneficial properties mentioned above, they bring with them the following associated problems that are not generally encountered with air:

1. Sample contamination.
2. Lost circulation problems requiring additives to rectify.
3. Decreased penetration rate.

4. Increased site size, trail use from water haulage, and site litter.

Recently, the best of both the air system and the mud system were incorporated. In the new system, water injection, air is used as the circulation medium but the air stream has both water and detergent injected into it. This system is designed as a replacement, in part, for drilling mud systems and has the following advantages over that system:

1. Penetration rate is increased, in some cases even surpassing that of air alone.
2. Better sample recovery than mud due to the lifting capacity of the foam that is formed from the detergent.
3. Less time to change circulation systems.
4. Less site space required.
5. In general, better hole conditioning.

This is not to say that the water injection system solves all drilling problems. There are still many places where the mud system is the only system that can be effectively used. Such areas include those with a high rate of water flow or severe loss of drilling fluids.

A relatively new type of drilling system has been introduced into the western phosphate field in the last five years. This system is reverse-circulation drilling. The reverse-circulation rig was designed to drill in areas where circulation, sample contamination and water are problems. The drill rods used on these rigs are actually two drill pipes, one within the other. The circulation medium, either air or water injection, is forced down between the two pipes. The drilling medium and sample are forced up the inner pipe and collected in cyclone concentrators mounted on the rig. This type of system has several advantages over the conventional rig:

1. No sample contamination.
2. Minimal circulation problems.
3. Very few caving problems in the hole.

However, there are problems associated with the use of the reverse-circulation rig:

1. The drill rod is very susceptible to getting stuck in the hole in extremely fractured or expanding strata because the outside of the rod is nearly flush with the hole wall.
2. It is nearly impossible to tell where water is encountered in the hole.
3. It is difficult, if not impossible, to collect a solid drill core sample when one is desired.

This type of drilling rig, at present, is best suited for mine control drilling in the Meade Peak Member rather than exploration, because of the possibility of getting stuck in the hole while drilling unknown areas. In mine control drilling the competencies of the strata are generally known and information on the water table is generally available from previous drilling data.

Both conventional and wire-line coring with a rotary rig have been attempted in the Meade Peak Phosphatic Shale Member by FMC as well as others. The ventures by FMC met with very limited success at best. Whether it was the crew's inexperience at coring in the western field or the use of the wrong combination of equipment remains a moot point. The advent of gamma-logging equipment use in the field, use of a water injection system which improved sample quality, and anticipation of the high cost of experimenting with coring and of coring itself, if a practical method were found, led to the abandonment of coring attempts by FMC.

Diamond drilling and coring is presently being used by only one company in the western phosphate field, Monsanto Chemical Corporation. Monsanto is using a specially designed and adapted diamond drill. The use of the diamond drill is dictated by corporation philosophy and the need for extremely accurate samples for planning mine production to accommodate complicated plant flow sheet (G. Aland, oral communication, 1972). There are advantages in the use of a diamond drill rig over a rotary rig:

1. Extremely accurate samples, both of ore and of waste.
2. Ability to drill inclined holes perpendicular to the dip and obtain samples at true thickness.
3. Accurate location and attitude determination of faults by visual examination of cores.

There are also several drawbacks to diamond drilling:

1. Loss of rapid mobility.
2. A slower penetration rate.
3. Higher drilling costs.
4. False stratigraphic thicknesses due to inaccurate initial dip estimates.

5. Requires a mud circulating system.

6. Sample handling and storage problems are increased. The diamond drill is best used, in the writer's opinion, in the western field, considering the above advantages and disadvantages, as a mine control rig and only when company policy dictates its use or when special problems arise.

Logging techniques

The primary purpose of exploration drilling is to obtain samples for analytical purposes and lithologic information. This information may be referred to as data points, or meaningful bits of data. Ideally, a continuous semiquantitative grade, lithologic and geophysical log of the drill hole in addition to collected samples, will produce the maximum number of data points.

All geophysical logs do not produce meaningful data in the search for industrial minerals. The mineral being sought must be studied to discover properties which will produce a characteristic trace on a given type of geophysical log. A log which is useful in the search for one mineral may be worthless in the search for another.

The correlation between uranium and P_2O_5 in marine phosphate deposits has been demonstrated. Research on the carbonate-fluorapatite molecule by Altschuler et al. (1954) showed that uranium replaces calcium in the apatite lattice. McKelvey and Carswell (1956:485) report that, with some exceptions, there is a close correlation between uranium and percent P_2O_5. Sheldon (1959:83) indicates that "uranium is positively correlated with ... P_2O_5 ... ." Since gamma-radiation is the principal and most detectable product of uranium atom decay, a device which detects gamma-rays would provide the greatest number of accurate and useful data points in a drill hole through a section of the Meade Peak.

Basically, there are two types of gamma-ray detectors which are useful in down-hole logging operations and produce meaningful results in marine phosphates. These are the scintillator and the Geiger-Müller instruments. The scintillator uses a substance which produces light impulses when struck by a gamma-ray. These light impulses are amplified by a photo-multiplier tube and then converted to electrical currents which are recorded as pulses of radio-activity on a chart. There are several substances which produce this effect, but a thallium-drifted sodium iodide crystal is preferred because of its preciseness and durability.

The Geiger-Müller type of instrument contains a tube that is filled with a gas that ionizes when struck by a gamma-ray. The ionization allows conductance of an electrical current which is recorded as a pulse of radio-activity on a chart. Although the Geiger-Müller detector is a more durable device, the scintillator is generally preferred because of its greater sensitivity.

Conclusions and observations presented herein are based on personal observation, by the author, of about 80,000 feet of gamma-radiation logs of the Meade Peak Member covering 1,500 square miles of southeastern Idaho. The gamma-radiation log is useful in acquiring the following basic information from drill holes in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation (Spalding, 1967; Hale, 1967):

1. Precise location of formational and alluvium-bedrock boundaries.
2. A semi-quantitative check of percentage P_2O_5.
3. Thickness and depth of key zones.
4. Structural discontinuity in the drill hole, or by comparing logs, between drill holes.
5. A rapid check on the location of the zone of alteration.
6. Elimination of confusion created by poor sampling techniques, sampling conditions, and sample lag.
7. An exact determination of which samples should be analyzed.

One must never fall into the trap of forsaking sample collecting and analysis because of the use of gamma-radiation logs in exploration in the western field because the uranium content of the Meade Peak Member is proportional not only to P_2O_5, but also to the degree of weathering. Also, the uranium content of any given bed in the Meade Peak varies laterally when viewed from a regional standpoint, as do all other minor constituents of the Meade Peak. Finally, the logging equipment is subject to malfunction. This malfunction may be minor and may reflect itself only as an amplitude change, which, however, directly affects any grade determinations.

Although never investigated by FMC, it may be possible to use the gamma-radiation logs for grade control in close-order development or mine control drilling in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation when conditions are ideal or constant. In this event, sampling would still be necessary in every third or fourth hole. When conditions are ideal and the logging equipment has been standardized, it may be possible to predict, on a specific property for which the conditions have been stated, the percentage P_2O_5 within one percent. In exploration it is possible to generally predict P_2O_5 content in the high-grade ore zone within 2 percent, medium-grade ore zones within 3 percent and low-grade and subore within 6 percent. However, this is only possible when care is taken with equipment settings and check samples have been analyzed.

It is essential to remember that a gamma-radiation log of a drill hole in the Meade Peak Member measures radioactivity, which is proportional to percentage P_2O_5. The log reveals no quantitative clues to other constituents in the section. If CaO and SiO_2 must be known, then samples have to be taken and chemically analyzed.

Table 1 is a brief summary of the strata generally encountered in exploration for phosphate in the western

Table 1. Summary of strata reaction to gamma-radiation logging techniques in the western phosphate field

Strata	Reaction

Alluvium: generally appears as low intensity. Because alluvium is indicative of the strata upslope, zones of higher than anticipated radioactivity should be used as clues to the presence upslope of the Meade Peak Member. Care should be taken, however, in making this assumption because in certain areas north of Soda Springs volcanic ash beds have been encountered in the alluvium. The ash beds give response to gamma-radiation logging similar to alluvial phosphate.

Triassic (undifferentiated): almost always gives a low trace similar to alluvium, although, in an area northwest of the Blackfoot reservoir, the strata exhibit radiation somewhat higher than anticipated.

Rex Chert Member of the Phosphoria Formation: appears as a dead or flat low trace on gamma-radiation logs. The cherty shale member exhibits some fluctuations approaching the low of alluvium and Triassic strata. However, the chert is radioactively much lower than any of the above mentioned strata. Some 10 to 15 feet above the Rex-Meade Peak interface there is a zone 1 to 2 feet thick of radioactive material which approaches the response of alluvium.

Meade Peak Phosphatic Shale Member of the Phosphoria Formation (Figure 9):

Upper Waste--appears as low to medium intensity. There are two characteristic peaks in this zone, one immediately below the Rex-Meade Peak interface and one immediately above the D Bed.

D Bed--appears as high-medium to high intensity. This is the upper ore zone.

Middle Waste--appears as low to medium intensity. There is a characteristic peak about two-thirds of the way down this zone known as the E Marker Bed. The E Marker Bed may be traced at least from Fort Hall to the Wyoming border. It is in the Middle Waste that the zone of alteration may be traced with some confidence using gamma logs.

Table 1. Continued

Strata	Reaction
	A steady decrease in radiation through this zone indicates the transition zone from altered to unaltered rock.
C Bed--appears as low-medium to high-medium intensity. The extent of alteration determines if this zone is ore.	
False Cap--may cause low to high-medium intensity. The extent of weathering determines if this bed is ore.	
B Bed--generally appears as high-medium to high intensity, generally higher than the D bed. This bed is, from a percentage P_2O_5 aspect, always considered ore and is generally referred to as furnace-grade rock.	
Cap--may appear as low to high intensity. The degree of weathering determines if this bed is ore.	
A Bed--always appears as a high to extremely high intensity. This bed is always ore and is commonly known as the main bed.	
Lower Waste--appears as low to medium intensity.	
Fish Scale Bed--this zone is composed of fish scales and bones high in phosphate. The bed appears as a medium intensity only because of its thinness, not because of low phosphatic content.	
Grandeur Member of the Park City Formation: gives a low intensity. The presence of chert beds may give the same reaction as in the Rex, and results in the strata appearing as an extremely low interval.	
Wells Formation: generally appears as low intensity.	

phosphate field and the effect shown by the strata on gamma-radiation logs taken from drill holes (Spalding and Hurst, 1968). Idealized radiation logs of the Meade Peak Member are presented in Figure 9.

In the above beds where limits were assigned to gamma-radiation log intensity, weathering and consequent alteration are the major governing factors of the logged intensity.

Plate 1 illustrates the correlation of specific zones within the Meade Peak across southeastern Idaho using gamma-radiation logs. The locations of the gamma-radiation logs are shown in Figure 10.

The amount of information that can be interpreted from the gamma-radiation log is largely dependent on the experience of the interpreter. Information on grade can be interpreted only after check samples are collected and analyzed. These are basically visual checks. When interpreting structure from gamma-radiation logs, the only visual check is the actual mining of the drill-hole area. Consequently, the interpreter must be familiar with the structural complexities which occur in the Meade Peak Phosphatic Shale Member before he can accurately interpret the structure from gamma-radiation logs.

The interpreter must look for duplication and/or deletions of the key zones and marker beds. Anomalous thicknesses have structural significance. The interpreter must take into account the dip of the strata when

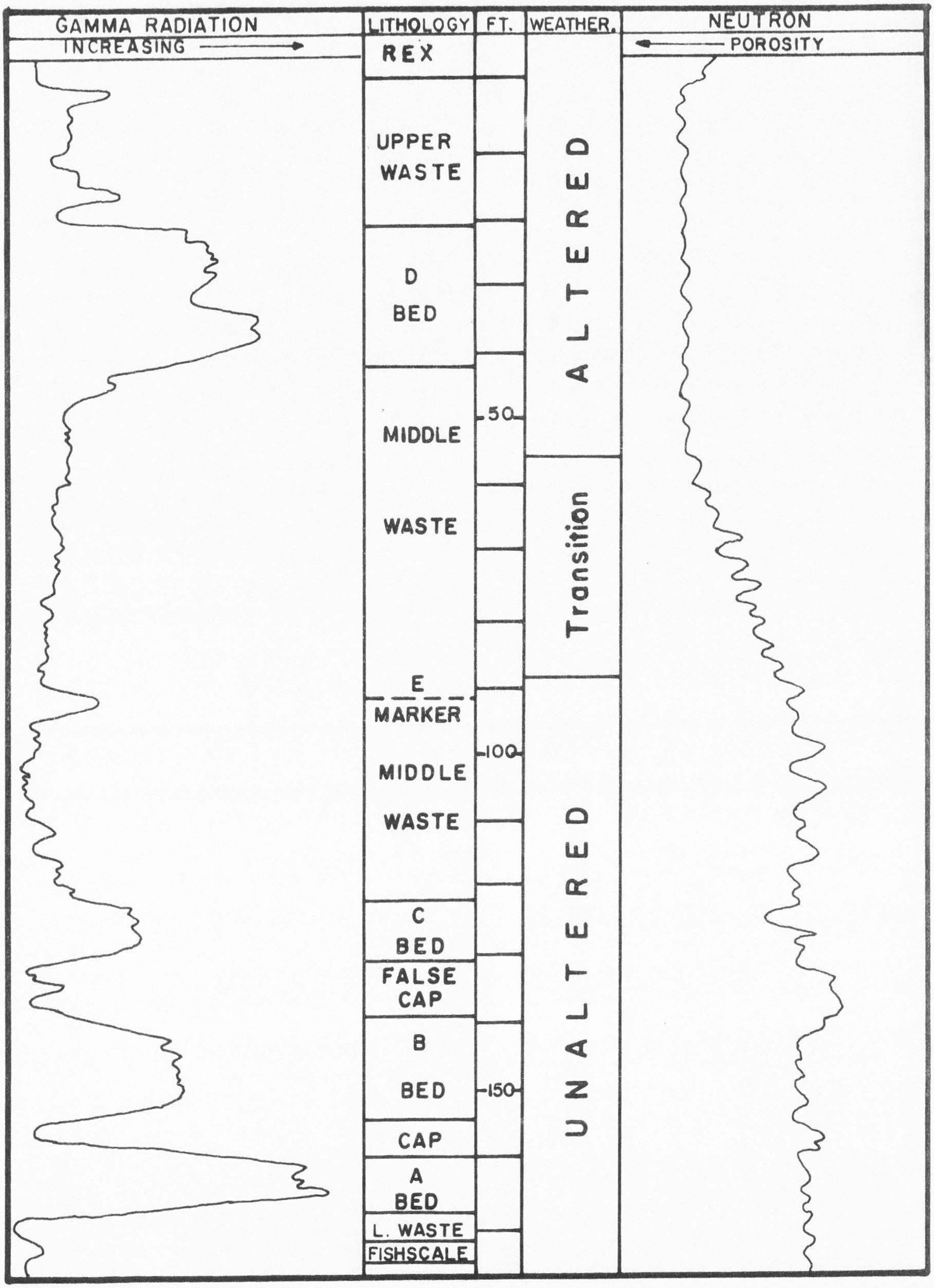


Figure 9. Stratigraphic section and idealized radiation logs of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation.

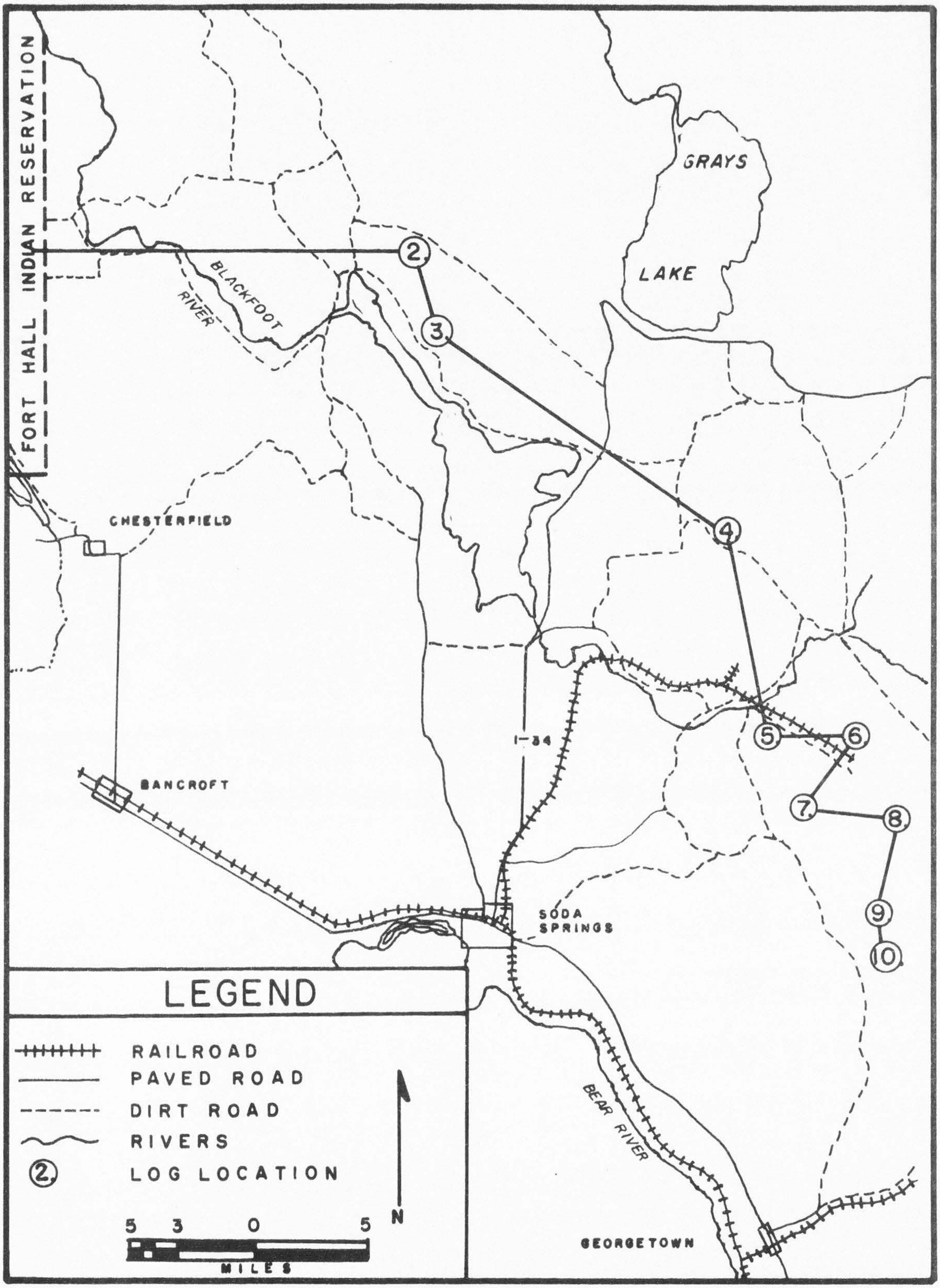


Figure 10. Location of gamma-radiation logs used in Plate 1.

determining thicknesses. The drill-hole thickness is always greater than true stratigraphic thickness unless the strata are perfectly horizontal. Subtleties such as anomalous variation in recorded radiation can only be viewed and presented in accurate perspective by a log analyst experienced in the western phosphate field.

Thus far, only gamma-radiation logs have been mentioned in the discussion of logging techniques in the western phosphate field. There are other log types which should be discussed in conjunction with exploration procedures in the field.

FMC recently purchased neutron logging equipment to add to its logging capabilities. Basically, the neutron logging procedure depends on the detection of neutrons that were emitted by a neutron source attached to the logging tool. Generally speaking, most neutrons are too fast to be detected, thus they must be slowed to a rate that is detectable. One of the most effective substances in slowing the neutrons is hydrogen. Thus, air, water, and hydrocarbons in a drill hole slow the emitted neutrons enough to be detected. The neutron log is thus considered indicative of porosity (Figure 9).

Due to other commitments in logging operations, the neutron tool has been used on less than a dozen holes in phosphate exploration by FMC. To the writer's knowledge, no other company has attempted the use of the neutron tool in phosphate exploration in the western phosphate field.

In the writer's opinion, the tool will prove to be a great aid in the detection of the zone of alteration in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation.

Empirical data indicate that, although most of the Meade Peak Member appears as a shale on the log, showing false porosity, there is enough difference in porosity caused by weathering to be recorded on a log. The porosity difference is partially masked by organic matter which increases in percentage as the effects of weathering and alteration decrease.

The problem of water in mining operations has been alluded to previously. Experience in the Dry Valley area has shown that possible trouble from water cannot always be detected in drilling operations. When drilling with air, a damp spot in the hole is often dried out before it can be detected. When using water injection or mud, damp spots remain undetected. When FMC drilled an area in Dry Valley destined to be a mining test pit, a few damp spots were detected but quickly dried during the drilling operations. However, when the area was mined, springs developed at these damp spots. The pit developed a water problem.

In order to solve the water problem in exploration work, FMC recently purchased down-the-hole temperature logging equipment. Based on the premise that evaporation of water from damp spots causes abrupt but minor changes in the temperature of the bore hole, it is hoped that the delta-temperature tool will locate damp spots in the hole.

With the damp spots located and correlated, areas of possible water problems in future mines can be accurately delineated. Empirical data collected from the few holes logged thus far indicate that this procedure will be practical and applicable.

Efforts to use electrical logging equipment such as spontaneous potential and induction logs in the western field have been futile. This futility is due to the manner of obtaining the logs and the characteristics of the Meade Peak Member. The logs can only be run in holes that are filled with water and it is only rarely that a drill hole in the Meade Peak Member will hold water.

Data based on density variations between the ore and waste zones within the Meade Peak indicate that a tool measuring bulk density may be useful in a quantitative down-the-hole analysis of percentage P_2O_5. Because this type of tool is extremely sensitive to variations in bore-hole diameter, the device must be run in combination with a caliper tool which measures bore-hole diameter. To the author's knowledge, no individual or company has attempted to use this tool in the western field. FMC is currently purchasing this type of equipment for use in phosphate drilling programs as well as other programs. Data collected during the next few years will either prove or disprove its worth in phosphate exploration.

The fact that the types of logging tools mentioned above are gaining acceptance relatively late in the history of the western phosphate field does not reflect a lack of presearch investigation. Only recently have tools been designed to fit the small diameter bore holes used.

Trenching

Some companies working in the western field have relied solely on trenching for information in both Stage 3 and Stage 4 exploration programs. The disadvantages of trenching are as follows:

1. It gives false data on grade as it penetrates only the extremely weathered zone.
2. It gives false stratigraphic thicknesses due to surface creep.
3. It gives false clues to structure because of surface creep, slump and fractures.
4. It gives no clue to structure at depth.
5. It gives no clue to grade at depth.
6. Sample costs are extremely high when compared with drill cuttings.
7. It cannot be used in areas with alluvium over 10 feet thick.
8. Rehabilitation costs are extremely high.

Trenching does have its place in a Stage 4 program when used properly. Trenching should be used as a technique for collecting bulk near-surface samples. Such samples are not necessarily indicative of the ore at depth. There are methods of obtaining slightly deeper samples in a trenching program. Generally, the method used in this deeper sampling program, which adds 5 to 8 feet of sample depth, is to bulldoze a trench twice as wide as normal.

This is followed by using a backhoe to dig a slot down the middle of the trench. This technique, although it may have penetrated the zone of surface creep still has not penetrated the zone of extremely enriched surface ores because the depth of penetration is only 30 to 35 feet.

Underground excavation

Early in the history of the western phosphate field major production was from underground mines. Exploration for those mines consisted of surface mapping, shaft sinking and tunneling. Because rotary drilling was still in the embryonic stages, this type of investigation was never seriously considered for underground mines. The last of the underground phosphate mines in the Idaho-Wyoming-Utah area closed early in 1971 (C. Basham, oral communication, 1971).

Underground phosphate mines still operate in Montana. Exploration in that area consists solely of surface mapping, and development work consists of tunneling. This is not the generally recommended procedure for reserve estimates and mine planning in southeastern Idaho, but it seems to work satisfactorily in the Montana area.

Comparative cost

Sharp, in 1955, described the exploration geologist as follows (in Bailly, 1968:27):

> The diversity of methods and equipment used in mineral exploration today dictate that the exploration geologist needs to be something of a human chameleon

> mentally and superhuman physically. Besides his geological ability, to which I have already referred, he must be tough, tenacious, thorough and endowed with the pioneering spirit and all the attributes of the old-time prospector; he must also have the quality of leadership, the ability to handle men and a rigid subservience to professional ethics.

To this description, I would add that the geologist must also be an accountant, cost forecaster, and salesman. He must be an accountant to keep track of monies spent on any given project. He must be a cost forecaster to accurately budget future programs, and he must be a salesman to sell his ideas, prospects and projects to supervision and management. Each one of these attributes is important, but the following discussion is centered on the geologist's abilities as an accountant, cost forecaster, and economist.

The Act of March 18, 1960, provides that an individual or corporation may obtain a phosphate prospecting permit on lands possibly containing phosphate but unmapped by the U.S. Geological Survey. The tenure of this permit is for two years and the permit may be renewed for an additional four years. There are occasions when a corporation cannot decide whether or not to lease the property, even after holding the ground for six years. Under present circumstances, the corporation should file for the lease because the government agencies reviewing the lease application are now taking three to four years to render an opinion. If during this time period the permittee has decided not to hold the property, he can drop the property simply by not signing the lease when approved. If, on the other hand, the permittee has decided to hold the property, all he has to do is sign the lease when offered. Thus, he has held the ground for nine or ten years while only paying rental fees for six years.

Dealing with the surface owner is also of economic consequence. When the surface owner is a government agency, this is a minor problem because stipulations covering damage to surface are written into the permit or lease. However, when the surface is owned or leased by a private individual, there may be problems caused by a conflict in opinions as to what constitutes permanent damage or monetary loss as a result of drilling operations. Every effort must be made to cooperate with the surface owner because disputes directly affect the rapport with other surface owners in the area as well as the local populace. It is always wise to contact the surface owner prior to budgeting the project to consider projected settlements for possible surface damages.

Drilling projects in the western field should be planned at least six months in advance. Some reasons are:

1. Corporate budgets generally must be completed and approved by January 1.

2. Proposed exploration plans must be completed and submitted to the Regional Mining Supervisor of the U.S. Geological Survey at least 60 days prior to initial drilling for approval. It is good practice to submit these plans at least 90 days in advance of initial operation to allow for any problems in gaining government approval.

3. Time is needed to allow for ample bargaining with a surface-rights owner about possible surface damages.

4. Time is needed to allow for last minute changes in drilling plans.

Forecasting the cost of a drilling project is one of the geologist's more important functions. Forecasting can only be completed with confidence if accurate records were kept of past drilling projects. The records of past drilling should include costs of mobilization, labor, bits, circulation material, fuel and oil, gasoline, maintenance supplies, miscellaneous supplies, food, lodging, supervision labor and expenses, sample analysis cost, rehabilitation, and overhead. The records should be kept in conjunction with and with the aid of the driller or drilling superintendent.

Every company has its own method for the keeping of and categorizing of drilling cost records. The most common method of breakdown is cost per foot drilled. Another method used is to calculate the cost per hour of drilling rig operation.

The primary purpose of exploration drilling is the collection of data. The above cost analysis methods generally ignore the value of the derived data. A new method of cost analysis must be found to fully analyze and evaluate the program in the light of its true purpose. A possible method might be a cost per data point. This information includes lithologic, electrical and geophysical logs, penetration rates, and sample analyses. Using this method, the program could be evaluated on its actual contribution to the search for economic mineral deposits.

There are three types of costs kept for each drilling project. These types are:

1. Direct.
2. Indirect.
3. Total cost.

Indirect costs, as used by FMC, include supervision labor and expenses, mobilization, sample analysis costs, rehabilitation, overhead cost, and, in some cases, report writing. Direct costs are those which are incurred as a direct result of drilling operations and include labor, payroll added costs, bits, circulation material, fuel and oil, gasoline, maintenance supplies, miscellaneous supplies, and drilling crew living expenses. Total cost is the sum of direct and indirect costs.

When considering drilling costs, one should note the type of cost and the items included in that type of cost. Additionally, one should remember that different types of drilling produce different drilling costs. Pit and blast-hole drilling are generally cheaper than exploration drilling because of less down time for moving, and because shallower holes are drilled, rigs in use are specifically designed for local strata and drilling conditions and have a faster penetration rate, and the rigs are generally in use year round and, therefore, maintain experienced crews.

Thus, when considering drilling costs, one should note:

1. Type of cost.
2. Items included in that cost.
3. Type of drilling.

Tables 2, 3, and 4 show FMC's Stage 4 drilling costs on phosphate properties in southeastern Idaho for the years 1970, 1971, and 1972, respectively. The costs in the tables are categorized in cost per foot, rig cost per hour, percentage of direct cost, percentage of indirect costs, and percentage of total costs.

By comparing the direct costs in the following tables, the worth of an experienced crew and geologist becomes obvious, and is appreciated from an economic standpoint. Each property has different drilling costs; some are quite high while others have costs considerably lower. Tables 2 and 3 show direct costs well within the limits experienced by FMC in drilling programs during the last seven field seasons. The direct costs shown in Table 4 are quite high. On only one or two properties explored in the last seven years have the costs been so high. On those properties it was extremely difficult drilling conditions that caused the increase. In 1972, the problem was mainly inexperience both in the crew and field geologist.

If the geologist is armed with the type of data shown in Tables 2, 3, and 4 it is not difficult to forecast figures for any phosphate drilling project. However, many

Table 2. Exploration drilling costs for drill season of 1970*

Item	Cost/ft.	Cost/hr.	Percentage direct costs	Percentage indirect costs	Percentage total costs
Crew labor and payroll-added costs	$0.72	$23.64	66.7		27.9
Living expense	$0.05	$ 1.51	4.3		1.8
Supervision labor and payroll-added costs	$0.08	$ 2.57		5.2	3.0
Living expense	$0.02	$ 0.75		1.5	.9
Bits	$0.04	$ 1.18	3.4		1.4
Fuel and oil	$0.04	$ 1.33	3.8		1.6
Gasoline	$0.02	$ 0.66	1.9		.8
Circulation material	$0.04	$ 1.23	3.5		1.5
Miscellaneous supplies	$0.18	$ 5.85	16.4		6.9
Overhead	$0.68	$22.25		45.3	26.3
Rehabilitation	$0.07	$ 2.37		4.8	2.8
Samples	$0.61	$20.00		40.7	23.7
Moving	$0.04	$ 1.21		2.5	1.4

*Two drill rigs and crews were used. Cost/hr. and drilling rate are the sum of the average of each drill rig. Experienced driller and crew on each rig. Field season llasted five months.

Hours of drilling	858.75	
Footage drilled	28.155	
Drilling rate	32.79 ft./hr.	
Direct cost	$1.08/ft.	$35.40/hr.
Indirect cost	$1.51/ft.	$49.15/hr.
Total cost	$2.59/ft.	$84.56/hr.

Table 3. Exploration drilling costs for drill season of 1971*

Item	Cost/ft.	Cost/hr.	Percentage direct costs	Percentage indirect costs	Percentage total costs
Crew labor and payroll-added costs	$0.78	$13.06	69.0		27.7
Living expense	$0.07	$ 1.11	5.9		2.3
Supervision labor and payroll-added costs	$0.08	$ 1.30		4.6	2.7
Living expense	$0.01	$ 0.19		0.7	0.5
Bits	$0.04	$ 0.72	3.8		1.5
Fuel and oil	$0.06	$ 0.95			2.0
Gasoline	$0.03	$ 0.58			1.2
Circulation material	--	--	--	--	--
Miscellaneous supplies	$0.15	$ 2.48	13.1		5.2
Overhead	$0.89	$14.73		51.8	31.2
Rehabilitation	$0.07	$ 1.14		4.0	2.4
Samples	$0.65	$10.80		38.0	22.8
Moving	$0.02	$ 0.25		0.9	0.5

*Field season lasted five weeks with one rig. Driller and crew relatively inexperienced.

Hours of drilling	263	
Footage drilled	4,375	
Drilling rate	16.64 ft./hr.	
Direct cost	$1.14/ft.	$18.90/hr.
Indirect cost	$171/ft.	$28.41/hr.
Total cost	$2.85/ft.	$47.31/hr.

Table 4. Exploration drilling costs for drill season of 1972*

Item	Cost/ft.	Cost/ft.	Per- centage direct costs	Per- centage indirect costs	Per- centage total costs
Crew labor and payroll-added costs	$0.84	$13.01	67.4		28.1
Living expense	$0.19	$ 2.98	15.4		6.4
Supervision labor and payroll-added costs	$0.25	$ 3.89		14.5	8.4
Living expense	$0.14	$ 2.22		8.3	4.8
Bits	$0.04	$ 0.56	2.9		1.3
Fuel and oil	$0.02	$ 0.32	1.7		.8
Gasoline	$0.04	$ 0.68	3.5		1.4
Circulation material	$0.01	$ 0.09	.6		.2
Miscellaneous supplies	$0.11	$ 1.66	8.5		3.5
Overhead	$0.88	$13.52		50.3	29.8
Rehabilitation	$0.09	$ 1.37		5.0	3.0
Samples	$0.32	$ 4.88		18.2	10.6
Moving	$0.06	$ 1.00		3.7	2.2

*Field season lasted nine weeks with one crew. Driller was experienced geologist and crew were inexperienced.

Hours of drilling	287	
Footage drilled	4,435	
Drilling rate	15.45 ft./hr.	
Direct cost	$1.25/ft.	$19.30/hr.
Indirect cost	$1.74/ft.	$26.88/hr.
Total cost	$2.99/ft.	$46.18/hr.

variables will affect the costs. Some of the variables are:

1. Experience of crew: An inexperienced crew will cause an increase in drilling costs, sometimes as high as 30 percent when compared to an experienced crew.

2. Seasonal drilling: Drilling in the early spring and late fall will show a cost increase up to 25 percent when compared to warmer weather drilling operations. This increase is due to the necessity of winterizing the rig each night and priming the rig each morning, thereby decreasing the number of hours of operating time. Drilling in late spring will increase drilling cost by 15 to 20 percent through loss of mobility because of mud.

3. Down time: All exploration drilling plans should count on at least 30 percent down time due to repairs, moving, logging, and unforeseen occurrences. For this reason, FMC expresses the amount of hole made per hour as "drilling rate" (which accounts for down time) rather than the actual penetration rate achieved.

4. Auxilliary equipment: An auxilliary compressor greatly increases fuel and gasoline costs. An Ingersoll-Rand compressor producing 600 cfm at 130 psi will burn in excess of 10 gallons of diesel fuel per hour. This also increases gasoline consumption because of the necessity of hauling fuel. However, the compressor offsets this cost through greater rig efficiency.

5. Drill-site locations: Properties that are drilled in valleys and lower valley margins will encounter water. Water causes poor sample quality and circulation problems. These water problems produce the need for circulation media aids which must be accounted for in the forecasting. Severe topography increases down time due to moving and road building.

6. Types of strata: Drilling thick alluvial deposits will cause circulation problems. Drilling in certain rock units, for example the Salt Lake Formation, often proves impossible and when possible is extremely expensive.

7. Use of logging equipment: When possible use gamma-radiation logs to determine precisely which

samples to send for analysis. This technique eliminates unnecessary sample analyses.

8. Project duration: Projects of short duration, less than one month, generally have higher unit costs than one lasting an entire field season.

9. Indirect cost analysis: Increased cost of living and inflation must be accounted for in large projects. Up-to-date sample and overhead costs must be used, as these may vary greatly from year to year.

The drilling cost per foot is determined by the drilling rate. However, the geologist must not become so engrossed with keeping the unit cost low that he loses sight of his primary objective, which is to obtain samples and lithologic information. Care must be taken in obtaining the samples, and adequate time must be allowed to sample properly. In an average drill hole in an average section of the Meade Peak Phosphatic Shale Member dipping 20°, sample collection and analysis costs about $17 per sample.

The cost of trenching, depending on strata character, topography and accessibility, ranges from $500 to $1,500 per trench, not counting the logging, sampling, or rehabilitation costs. The average trench in an average section of the Meade Peak Member yields about 25 samples for grade control in the ore zones, so trenching costs from $20 to $60 per sample. Sampling and logging a trench costs about $50 in time and labor or $2.00 per sample. The average analysis for one oxide in a sample costs about $2.50. FMC runs four analyses per sample. Thus, trench samples cost from $32 to $72 each. The undesirability of conducting an exploration project by trenching alone is shown by the above costs. Trenching is for bulk sampling only. When one combines the information on grade and ore performance in pilot tests on the bulk samples, the total amount of data collected somewhat softens the impact of the sample cost.

Exploration in underground phosphate mines consists of tunneling. The phosphate mines in Montana pay on a scale based on the actual amount of work the miner accomplishes in the given pay period. In 1971, the rate was $8.39 per foot of tunnel, for labor only. Although this may seem high for exploration costs, it must be remembered that these tunnels are necessary passages in the underground extraction of ore.

PROPERTY EVALUATION

General Statement

There are different concepts and definitions of property evaluation presently in use. Some define it as involving both the physical processes of acquiring data, and organizing it in a manner to judge its significance in an economic sense. As used in this discussion, it will deal with only the examination of data collected in Stage 4 phosphate exploration programs in the western field.

There are many ways to evaluate the economics of phosphate properties once the data from exploration have been received and analyzed. In an operation such as that of the Mineral Development Department of FMC Corporation, which is basically one of reserve expansion for an existing facility in an already productive area, several of the evaluating criteria are considered nonvariable when considering a single property. The criteria which are considered nonvariable, using a constant production rate, in southeastern Idaho, include power supply, market, regional climate, labor supply, water supply, processing additives and by-products. The criteria which have an economic influence on ore costs and evaluation are considered to be variable. In individual phosphate property evaluation in southeastern Idaho these are geology, mining characteristics, concepts in reserve calculation, transportation, and government regulations. Only those criteria considered variable in southeastern Idaho will be discussed here.

Geologic Factors

Since the basic factor which determines whether a particular phosphate deposit will be developed is the cost which the user must pay at the place of consumption and since geology, except for the weathering phenomenon, does not generally directly affect these costs, it is considered, by most, to be a passive economic factor. Although the grade of ore, the size of the deposit, the attitude and geometry of the deposit are all the result of geologic processes, the significance of these processes is diminished when dealing with a bedded phosphate deposit on an individual property. A phosphate deposit is fixed and exhaustible. Only the economics of mining the ore and the transportation cost incurred by moving the ore are variable. The geologic forces have molded topography and created faults and folds, but it is the topography which affects transportation and complex structures affect mining methods. Both the mining methods and transportation cause the cost of ore to vary at the place of use and are considered to be active factors in the economic evaluation of a property.

The one basic exception to the above concept, that has a very definite bearing on economic evaluation of phosphate properties in southeastern Idaho, is the degree weathering and alteration of the Meade Peak Phosphatic Shale Member. The degree of weathering is determined principally by the water table and its fluctuations, although both the water table and the degree of fluctuation are commonly controlled by faulting and permeability in southeastern Idaho. Hale (1967) suggested that the time of exposure as determined by the progressive erosional retreat of the capping Rex Chert Member greatly influences the degree of alteration. Experiments by FMC indicate that the length of time required to completely alter phosphate rock is of the order of just a few hundred years or less (Peterson and Lehman, 1963). These experiments tend to negate Hale's thesis. Generally, although not always, the portion of the Meade Peak that lies above the highest fluctuation of the water table is totally altered by weathering and leaching; the portion which is in the zone of water-table fluctuation is only partially altered and is called the transition zone; below the lowest point of water-table fluctuation the Meade Peak Member is totally unaltered. Because the above is the most common type of alteration scheme, the several exceptions to this rule exist in southeastern Idaho will not be described here.

Basically, the weathering of the Meade Peak Phosphatic Shale Member is a natural beneficiation process which increases the P_2O_5 content of the Meade Peak Member by the removal of carbonate cement and organic material by oxidation and leaching. Hale (1967) suggests that a portion of the enrichment is due to reprecipitation and secondary growth of phosphatic oolites.

Although the P_2O_5 increase due to weathering in the A Bed sometimes approaches 8 percent to a total P_2O_5 content of 37.5 percent, generally the increase is only 3 to 4 percent. The maximum allowed by chemical formula is 40 percent. The P_2O_5 increase due to weathering in the B Bed averages about 4 percent P_2O_5 to a total content of about 28 percent. Weathering and subsequent alteration have their greatest economic effect in the D and C Beds, the False Cap and the Cap. In these beds the increase of the P_2O_5 content sometimes approaches 15 percent. Only upon weathering and consequent P_2O_5 increase can these beds be considered ore and then only for furnace operations.

In addition to the P_2O_5 increase there are other economic benefits from weathering and alteration processes. The alteration breaks down and removes cementing materials, thereby increasing the porosity and decreasing the degree of consolidation of the strata. This decrease in consolidation allows the use of scrapers as a part of the materials handling system. The use of scrapers for mining is far more economical than the use of power shovels and trucks which would be needed to move the material if the Meade Peak were not weathered. In exploration drilling the penetration rate through altered Meade Peak is as much as 50 percent greater than through unaltered material.

The flow sheet involved in processing phosphate ores is greatly affected by the degree of alteration. In unaltered phosphate rock the CaO/P_2O_5 varies upward from 1.5/1. As mentioned previously, a CaO/P_2O_5 ratio greater than 1.45 increases the power requirements for complete reduction in furnace operations and also increases the amount of elemental phosphorous lost to slag. It is for this reason that the elemental phosphorus plants in the western field rarely use unaltered ore. Organic matter in unaltered phosphate rock amounts to 6 to 7 percent. Organic matter in chemical treatment processes produces discolored phosphoric acids which are difficult to sell.

The economic significance of unaltered phosphate rock is readily apparent in the operations on Monsanto's Henry Mine (Figure 2). In this open-pit mine the pit limits are determined by the depth to the unaltered ore, not by economic mining limits as determined by mine costs. The result is that Monsanto's stripping ratios are about 2.0 cubic yards of waste per one ton of ore at pit bottom rather than the 3.0/1 or 3.5/1 strip ratios which are used as a quick method by FMC of determining economic pit limits in much of southeastern Idaho.

Mining Characteristics

The geometry and depth of an ore body and the topography in the immediate area will determine the type of mining system to be used and the cost of that system. The type, physical characteristics, and amount of waste materials to be moved will affect the configuration and cost of an open pit mine.

The most critical factor in considering mining characteristics and hence the evaluation of phosphate properties in southeastern Idaho is the geologic structure of the deposit. Because of the location of the western phosphate field, in the Idaho-Wyoming thrust belt, and the incompetency of the Meade Peak Phosphatic Shale Member, many deposits which might be considered are badly faulted and fractured. The degree of structural complexity determines in part the mining system to be used on such properties. If the deposit is broken by a small number of normal or high angle reverse faults that are widely spaced, scrapers can be used both for stripping the waste and the mining. If the deposit is extremely faulted and structurally complex, it may be necessary to use a power-shovel and haul-truck mining system or abandon the property completely.

Another factor which must be considered in the evaluation of a property is the competency of the Rex Chert Member and the degree of alteration in the Meade Peak. When the Rex Chert is present as unfractured strata and is poorly weathered, it must be drilled and blasted to be removed. At times the drilling and blasting can add as much as $0.15 per ton of ore to the mining cost. In places where the section is overturned, the Grandeur and/or Wells must be removed by drilling and blasting techniques at a cost similar to Rex removal. When the Meade Peak Member is only partially altered the cost of mining is increased because the greater competency of the material causes decreased equipment efficiency and increased maintenance costs.

In addition to transportation costs which are generally nonvariable for any given property, when viewed from a seasonal aspect, the cost of mining ore material is also nonvariable. The major variable in mining cost estimates is the cost of stripping waste materials to expose the ore-grade rock to mining machinery. It is for this reason that many open-pit mines express their economic limits as strip ratios. In the western phosphate field strip ratios are generally expressed as yards of waste per ton of ore. Depending on the location of the deposit in relation to the extraction plant and the type of extraction used, the economic strip ratios in the field range from 2.5/1 to 5.0/1. In southeastern Idaho, FMC is presently using 3.0/1 to 3.5/1 strip ratios as economic pit limits for property evaluation.

Ore-reserve Calculations

There are many ways to calculate ore reserves. Most are made by an analysis of sample data framed in a polygonal, triangular, cross-sectional or other modified geometric pattern, as shown in Figure 11.

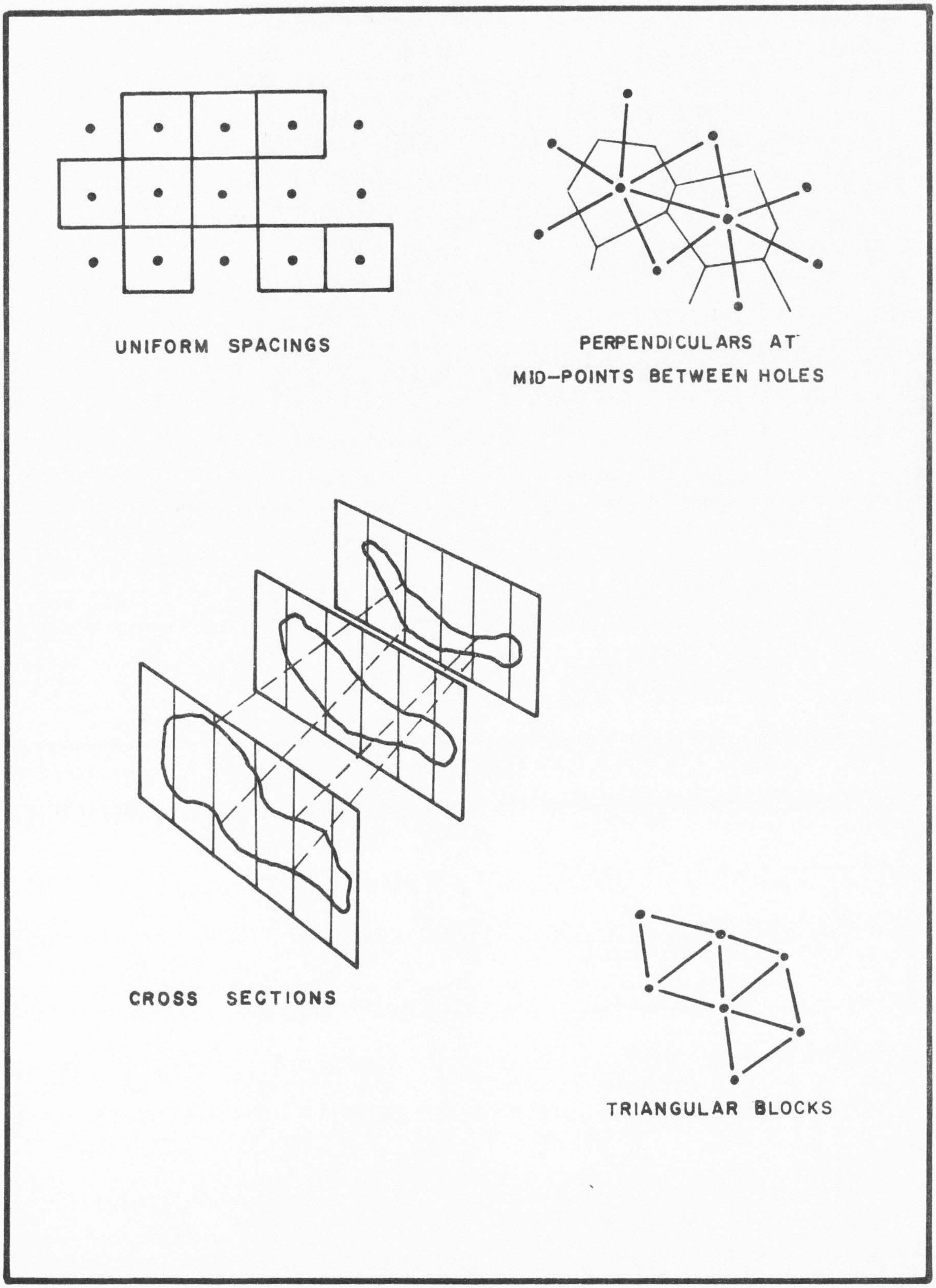


Figure 11. Geometric drill-hole patterns used in ore-reserve calculations.

In deposits other than uniformly bedded deposits, grade estimation presents the greatest problem in ore-reserve calculation. For instance, using a 10-foot radius of influence about each hole in a 100 by 500 foot drill-hole grid, actual positive information covers only 0.1 percent of the total area. In a 100 by 100 foot grid the positive information covers only 3.0 percent of the total area. Thus, ore-reserve calculation is an exercise in taking from 0.1 to 3.0 percent positive information and extrapolating the values to 100 percent. Hazen and Gladfelter (1964), however, statistically demonstrated that sample information in the Phosphoria Formation can be correlated with confidence over a reasonably large area. FMC and others at work in the field have further reduced the error in evaluating sample data by correlating the individual beds within the Meade Peak and thereby reducing the stratigraphic interval over which samples are correlated.

In order to present a picture of a property that is as accurate as possible FMC uses the cross-section method of reserve calculation. That method of reserve calculation will be discussed later.

A major factor in the calculation of ore reserves in the western field is the area of influence assigned to each drill hole. This factor is partially minimized when using cross sections, where the area of influence of each hole is considered to be half the distance to the next hole or to a known or postulated fault whichever occurs first. This method allows the geologist to interpolate and make judgment decisions concerning the construction and use of the cross section for ore-reserve calculation and preliminary mine maps.

Once the cross section has been constructed by the geologist and correlated with and adjusted to fit the adjoining cross sections, he may begin to calculate the reserves under the area of influence of that section. The following is a brief summary of one of the procedures used by FMC:

1. Set the strip ratio or pit depth that will be used in the calculation of reserves.

2. Determine the highwall angle that will be used. This angle is determined by the estimated stability of the material in the highwall. Generally in the western field an angle between 45° and 55° is used.

3. Draw a pit design that fits the criteria outlined in Steps 1 and 2. If stripping ratio is to be used as a limiting factor the pit design may have to be redrawn two or three times after completing Steps 4, 5, and 6 in order to determine a pit with the proper strip ratio.

4. Determine the area of all ore material in the section by using a planimeter. Determine the volume of this material by multiplying the area by the distance of influence for that cross section. Multiply this volume by a density factor and divide by 27 (cubic feet per cubic yard) to arrive at the tonnage for the cross section.

5. Determine the area of all waste material by using a planimeter. Determine the volume of this material by multiplying the area by the distance of influence for the cross section.

6. Determine the strip ratio.

$$SR = \frac{\text{volume of waste (cubic yards)}}{\text{Tons of ore}}$$

7. If the strip ratio is acceptable, then Steps 4 and 5 must be completed for each type of waste and each ore bed.

$$\text{Volume of waste} = \frac{\text{Area x distance}}{27}$$

$$\text{Tonnage} = \frac{\underset{(ft^2)}{\text{Area}} \text{ x } \underset{(ft)}{\text{distance}} \text{ x } \underset{(tons/yd^3)}{\text{density}}}{27}$$

8. Determine average grade P_2O_5 for each individual ore bed.

9. Redetermine strip ratio from information supplied by Step 7.

10. Adjust pit floors and walls to erase sharp angles and redetermine tonnage and strip ratios for entire property.

It is extremely important, when reporting reserves for a property, to list all parameters used in arriving at this figure, for instance, use "18.8 MM tons @ 24.6% P_2O_5 @ 2.95/1 strip ratio; pit floor averages 6,245 feet in elevation and the high wall angle is 55°." Stating the reserve figure in this manner allows one to recompute the reserves and arrive again at the same answer. It also permits properties to be compared on an equated basis.

Proper evaluation of a possible mining prospect involves assessment of numerous variables. Very few variables can be isolated as having no effect on other items once a mine is in operation. Due to this complex interrelationship, a change in one of the variables will generally affect the remainder. Because the true evaluation of a property is the profit margin to the company after sale of the product, the only accurate mine plan is one which is based on the profit to the company and not on the strip ratio.

Computers can be used to plan the mine by accounting for all the variables in mining, transportation, processing, and product price. The major problem associated with the use of computers in this work is the codifying of the information in a form that the computer will accept and use. Once the information has been stored, the computer will draw cross sections, structure and isopach maps, isogrades of ore values, and dollar value. The time saved and accuracy using this method are of great benefit to the geologist, mining engineer, and management.

Transportation

Transportation costs are a major point of consideration in evaluating the economics of phosphate properties in southeastern Idaho. Phosphate ores must be transported within the mine and from the mine to processing plants. The products from the processing plants must be transported to the market. Equipment and supplies must be transported to the mining area. The cost of each stage of transportation, including construction of roads and railroads, must be charged against the phosphate deposit. Transportation cost is considered a variable for southeastern Idaho as a whole, but generally invariable for a given deposit.

It is apparent that the ease of mining and ease of access may play against one another. Accessible deposits which are costly to mine become as desirable as easily mined deposits which can be developed only with high transportation costs. Thus, transportation costs can limit the area in which phosphate mining is economical and the extent as well as the type of extraction.

The full significance of the cost of transportation is readily apparent when one considers that in a recent mining test in Dry Valley by FMC, 46 percent of the cost of a ton of ore delivered to the Pocatello plant, about 80 miles distant, was directly attributed to the transportation of that ore. Although this mining test was only a fraction of a year's ore requirements and a larger operation would reduce both mining and transportation costs, the fact remains that the cost of transportation is a major portion of the total cost of a ton of phosphate ore.

In order to determine the most economic transportation method within a given mine, a full evaluation of available possibly economic transportation systems is required. Such evaluation is beyond the scope of this work and only the rudimentary systems which the explorationist in the western phosphate field uses in his preliminary evaluation of a property will be discussed.

Basically, there are six transportation systems presently in use in the Idaho portion of the western phosphate field:

1. Scraper and railroad.

2. Scraper, haul truck, and railroad.

3. Scraper and rubber-tired train.

4. Shovel, truck and railroad.

5. Shovel and haul truck.

6. Scraper, conveyor and railroad.

Each of these systems has presumably been evaluated economically and designed for the individual deposit where it is used.

The transportation system considered by the explorationist for use on any given property is determined by the geology, the topography, and the location of the deposit. Considering only rudimentary systems of transportation for property evaluation, there are some basic cost factors that should be borne in mind:

1. Truck haulage costs about $0.08 per ton-mile plus $0.02 per ton-mile for each 50 foot mining depth increment. Minimum haul cost is $0.16.

2. Scraper haulage costs about $0.24 per ton-mile.

3. Surge piles cost about $0.06 per ton each time ore is handled.

4. Rail haul from Dry Valley to Conda costs about $0.30 per ton, about $0.016 per ton-mile.

5. Rail haul from Conda to Pocatello costs about $0.90 per ton, about $0.011 per ton-mile.

None of the above mentioned costs include the amortization of haul roads.

Ideally an explorationist, in the evaluation of a property, will use scraper costs within the mine area and up to about 2 miles outside the mine. The 2-mile scraper haulage seems to be the present economic limits, if the haul-road grade is favorable. Beyond this arbitrary 2-mile limit a truck-haulage system is required to transfer the ore either to a rail unit or to the plant directly.

It is important to remember that the role of the explorationist in evaluating the transportation costs of the ore from a property is only to arrive at a general figure. The calculation of specific cost figures for a transportation system especially designed for that property is the role of the mining engineer.

Government Regulations

Factors that will become of increasing importance in future mining operations are the policies and regulations of the United States Government agencies administering government controlled land. In southeastern Idaho, the major surface administrating agency of lands containing phosphate is the U.S. Forest Service and to a lesser extent, the U.S. Bureau of Land Management.

In the past few years the restrictions imposed by the government on the mining industry have increased, government supervision has become greater, and future legislation involving government controlled lands appears ominous when viewed from a mining standpoint. It is obvious that, when considering properties for future mining operations, the ownership of the surface should be weighed rather heavily.

It is not beyond the realm of possibility that the United States Government will at some future date legislate open-pit operations out of existence on the public domain.

Future governmental legislation aimed at controlling or eliminating surface mines could have a great effect on the economics of the western phosphate field. By forcing economically unfeasible demands upon surface operations for ecological control, the government could change the economics of the field enough that underground mines again become competitive with surface mines. Underground phosphate mines in Montana are producing phosphate rock at a cost of about $9.00 per ton in 1971. Thus, it would only require a two to three fold increase in mining cost caused by severe environmental restrictions in the name of ecology to make underground mines competitive in southeastern Idaho again. Hence, each property evaluated must be viewed as a possible future underground reserve.

DRY VALLEY AREA PROPERTY EVALUATION

General Statement

The following section is included in this work as an example of a phosphate exploration venture. The data presented here were collected during an eight-year exploration program by the Mineral Development Department of FMC Corporation in the Dry Valley area. The program was concluded in the fall of 1970.

The geology of the Dry Valley area is relatively simple when compared with other areas within the western phosphate field. However, the principles applied during the exploration of the Dry Valley leases are valid in most areas of southeastern Idaho.

In the Dry Valley area about 500 acres were settled as homesteads prior to the withdrawal of phosphate lands in 1908. Thus, the phosphate mineral rights covered by the homestead lands were preserved in private ownership. In the early 1960's Kerr McGee Corporation obtained mining leases from the owners of these homestead lands. By 1964 Kerr McGee had 320 acres of mineral rights under lease from individuals in the Dry Valley area. In addition to these lands, they had obtained a state phosphate lease and a federal phosphate prospecting permit covering areas of possible unmapped phosphate.

In 1964, FMC submitted a bid on and was awarded a federal phosphate lease covering 720 acres in the Northern Dry Valley area. In 1965, FMC purchased from Kerr McGee all the lands held by them in the Dry Valley area. By the fall of 1965, FMC had under lease or permit about 22,000 feet of strike length covering almost all of the mineable phosphate on the west side of Dry Valley (Figure 12).

Stage 3 operations were first conducted on the leases in 1963 by Kerr McGee. The 13 holes were drilled to check for the presence and quality of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in questionable areas as well as to check the thickness of alluvium. The holes were widely spaced and were drilled for reconnaissance purposes. About 400 samples were taken at 2-foot intervals in the Meade Peak Member. Five of the holes were started in the middle or lower portion of the Meade Peak Member, six were started in areas of thick alluvium and two in the Rex Chert Member. In addition to the 13 holes completed, seven holes were abandoned because of caving and circulation problems or because of the inability to penetrate the Rex Chert. All holes collared in the alluvium used mud as a circulating medium, and because of excessive dampness, mud was used in some of the holes started in the Meade Peak. Because of the contamination of drill cuttings, due to hole caving and mud usage, analytical values were all increased 5 percent by Kerr McGee as a compensating factor. No records exist at FMC of the direct cost

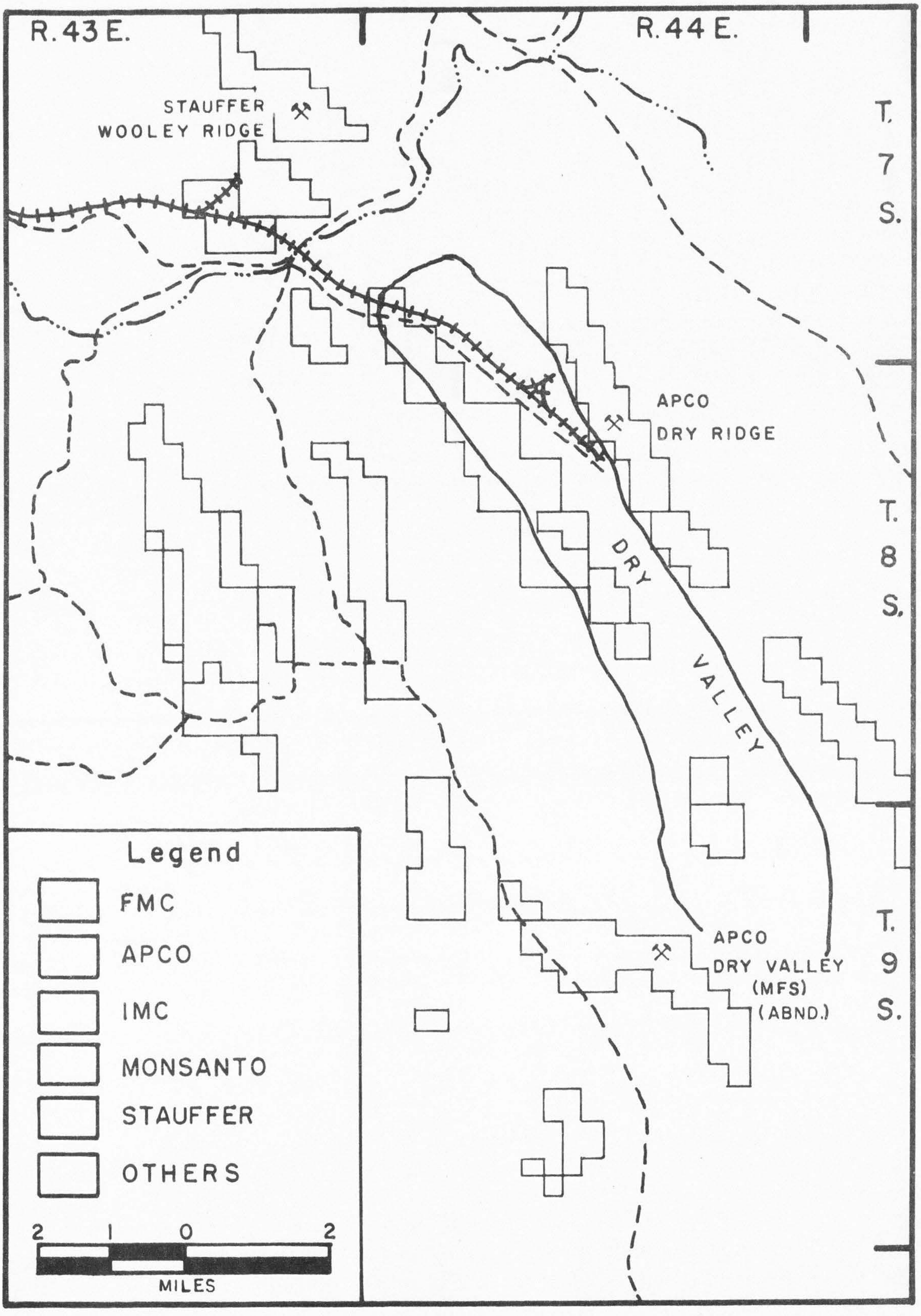


Figure 12. Property index map, Dry Valley, Idaho.

incurred by Kerr McGee on this project. However, by projecting the type of drilling rig used, the season of the year, the number and interval of samples, and contractor experience, a direct cost range of $1.40 to $1.60 per foot is in the realm of probability.

In 1964, FMC initiated Stage 3 operations on the Northern Dry Valley leases. Stage 2 operations had been completed in the preparation of the bonus bid. Stage 3 operations consisted of drilling 42 holes on fences 1,000 feet apart. A total of 1,160 analyses were run on the 290 samples collected. A total of 4,111 feet were drilled or an average of 98 feet per hole. The purpose of the drilling program was to roughly outline the ore body and determine its grade characteristics. When data from this program were assembled and analyzed it was decided that this property warranted a Stage 4 program which was scheduled for 1967. Direct costs for the 1964 program were $1.14 per foot. The cost was somewhat high because of some circulation problems and the small-size rotary drill used at the time.

In 1965, Stage 3 operations were conducted on both the Central Dry Valley leases and the Southern Dry Valley leases. The purpose of the program was to roughly outline the ore body and determine its chemical characteristics. Of particular interest at the time was the extent of erosion caused by Pleistocene stream channels in the area. A total of five holes and 1,282 feet were drilled in the

Central lease area and nine holes and 2,073 feet in the Southern Dry Valley lease area. One hundred sixty-six samples were taken from the two areas. As a result of this program 560 acres were relinquished from the Southern Dry Valley leases because of excessive erosion and alluvial thickness. A continuation of the Stage 3 program was recommended for the remainder of the properties which was completed during 1966. The direct cost for the 1965 program was $1.01 per foot in holes averaging 254 feet in depth.

Efforts in Dry Valley in 1966 centered on defining further the Pleistocene alluvial channels in a Stage 3 program on the Central and Southern leases. A total of 145 samples were collected in 11 holes and 1,855 feet on the Central Dry Valley leases. There were 1,647 feet drilled in six holes and 118 samples were collected on the Southern Dry Valley leases. Samples collected during this program were extremely poor due to hole caving and contamination from the drilling aids used to prevent loss of circulation during drilling operations. The program, however, did achieve its primary purpose of defining the alluvial channels and a Stage 4 program was recommended for the properties. The drill holes in the 1966 program averaged 212 feet in depth and the direct cost was $1.25 per foot. The high cost of the program was due to extremely difficult drilling conditions in the thick alluvium.

The first Stage 4 program initiated by FMC in the Dry Valley area was on the Northern Dry Valley leases in 1967. Data collected during this program provided information on the plant processing characteristics of the ore, actual proven ore reserves, mining costs f.o.b. the Pocatello phosphorous plant, property value for trading or selling purposes, and mine plans to satisfy federal mining regulations. During the program, 105 holes were drilled for a total of 11,654 feet, an average of 111 feet per hole. The direct drilling cost for this program was $1.13 per foot. Drill holes were spaced about 60 feet apart on drilling fences and the fences were placed on 500 foot centers except in the central portion. There, the fences were placed on 250 foot centers because of anticipated mining tests in the area. A total of 938 drill hole samples were taken and 3,752 analyses run. Fifteen trenches were constructed for the purpose of taking bulk samples on which to run pilot tests. A total of 87 individual strata samples were taken and 40 55-gallon drums were filled and delivered to the Pocatello plant for briquetting tests. In addition, waste materials were stripped from 10,000 tons of ore for future plant-run tests.

It was during the 1967 field season that FMC first applied the gamma-radiation logging technique. An instrument was borrowed from El Paso Agricultural Products, the operator of the Dry Ridge Mine, with which to run feasibility tests. A total of 30 holes on the Northern Dry

Valley leases were logged during the tests. Data acquired during the tests were analyzed and a gamma-radiation logging instrument was purchased and used during the 1968 field season.

In 1968, Stage 4 operations were conducted on the southern portion of the Central Dry Valley leases and the northern portion of the Southern Dry Valley leases. The purpose of this program was the same as mentioned above. A total of 10,745 feet were drilled in 64 holes. The direct cost of the holes was $1.10 per foot and they averaged 168 feet in depth. The drill holes were placed on 100 foot centers on fences about 300 feet apart. A total of 402 samples were taken and 1,608 analyses run. No trenches were constructed due to the thickness of the alluvial cover. During 1968, all 10,745 feet drilled in Dry Valley were logged with the gamma-radiation logging device.

In 1969, a total of 36 holes and 4,815 feet were drilled in a Stage 4 program on the northern portion of the Central Dry Valley leases. The holes, which averaged 134 feet in depth, cost $1.49 per foot due to severe drilling conditions, equipment malfunction, and inexperience of the field geologist. There were 781 analyses run on 197 samples. The drill holes were placed on 100-foot centers on fences about 300 feet apart.

During the fall of 1970, a test pit was mined in the central portion of the Northern Dry Valley leases. In conjunction with the test, 15 holes and 1,088 feet were drilled. One hundred twenty samples were taken in the holes, which averaged 73 feet in depth, and a direct drilling cost per foot of $0.96. The 51,000 tons mined and shipped from this pit averaged 28.6 percent P_2O_5 and was used as a plant-scale test of the ores from Dry Valley.

Since 1963, on land now leased by FMC, there have been 320 holes drilled. The total footage in these drill holes was 42,067. Approximately 6,500 analyses have been run on the 2,743 samples taken. In addition, 15 trenches were constructed for bulk samples.

The discussion of geology will center on those strata and structures which are in the immediate vicinity of the phosphate leases held by FMC in the Dry Valley area.

Geologic Factors

Stratigraphy

Stratigraphic units in the part of Dry Valley, Idaho, covered by this report consist of a sequence of marine sedimentary strata of Pennsylvanian, Permian, and Early Triassic age. All units are apparently conformable, although dissolution in the Lower Permian strata creates the illusion of a nonconformity between the Grandeur Member of the Park City Formation and the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. The stratigraphic units exposed are in ascending order (Figure 13): lower unit of the Wells Formation (Pennsylvanian), upper unit of the Wells Formation (Permian), Park City and

PERIOD	UNIT DESCRIPTION	THICKNESS
Quaternary	Alluvium Hillwash	
Triassic	Dinwoody Formation	1700–2000
Permian	Phosphoria Formation	
	cherty shale member	100
	Rex Chert Member	75–135
	Meade Peak Phosphatic Shale Member	180
	Park City Formation	
	Grandeur Member	75
	Wells Formation	
	upper member	1300–1400
Pennsylvanian	Wells Formation	
	lower member	700–750

Figure 13. Stratigraphic section of the Dry Valley area, southeastern Idaho.

Phosphoria Formations (Permian) and Dinwoody Formation (Triassic).

The Pennsylvanian Wells (lower unit) reflects a sublittoral marine environment with shallow-water deposition of sandstone and oolitic limestones. Some of the sandstones are cross-bedded and are light red in color suggesting a nearshore environment (Mansfield, 1927).

The gradation from sandstone to chert with interrelating and interfingering facies changes in the Permian Wells (upper unit) and Permian Grandeur Member of the Park City Formation, which are essentially gradational, suggests a change in depositional environment from a sublittoral environment in the Pennsylvanian to a restricted basinal environment in the Permian (Wells, Grandeur, and Phosphoria). In the Permian Phosphoria sea a restricted reducing environment existed, within which the economic phosphate deposits of the Meade Peak Member were deposited below wave base (McKelvey et al., 1959).

The Meade Peak Phosphatic Shale Member was described by McKelvey et al. (1959) as a regressive-transgressive-regressive sequence with the upper and lower ore zones being part of the regressive phases and the middle siltstone unit marking the transgressive phase. This sequence is clearly shown in the idealized stratigraphic section of Dry Valley (Figure 9) with the strata above and below the E Marker Bed being essentially mirror images of each other.

The genesis and depositional environment of the Meade Peak and Rex Chert are still much in doubt and clouded by conflicting evidence. McKelvey (1967) suggested that divergence upwelling upon a shallow restricted shelf environment is responsible for primary deposition of the phosphates in the Meade Peak and winnowing was one possible mechanism of enrichment. Yet Cook (1969) stated that winnowing was not an important mechanism. Some authors have insisted that a catalyst in the deposition of the Meade Peak Member was the volcanism in the Seven Devils area of western Idaho, yet Cook (1969) collected evidence showing that there is no relationship between volcanism and the formation of phosphorites. There are two items that most authors do agree upon concerning the deposition of the Phosphoria Formation, however:

1. Phosphorites were deposited as a result of cold phosphate-rich waters upwelling on a shallow shelf and deposition resulted from an increase in temperature and pH.

2. The sponge spicules comprising the bulk of the Rex Chert Member were transported to the accumulation area and winnowed by current actions.

The lithology of the Meade Peak Phosphatic Shale Member is consistent throughout southeastern Idaho and individual beds can be recognized almost everywhere. However, the amount of carbonates within the section varies greatly as a result of weathering. As mentioned previously, the Meade Peak Member has been divided into several beds which are recognizable over most of southeastern Idaho.

Table 5 shows a measured stratigraphic section from the SE¼NW¼ sec. 6, T. 8 S., R. 44 E., Dry Valley. Basically, the member is divided into eleven beds which are in ascending stratigraphic order:

1) Fish Scale Bed;
2) Lower Waste;
3) A Bed;
4) Cap;
5) B Bed;
6) False Cap;
7) C Bed;
8) E Marker Bed;
9) Middle Waste;
10) D Bed; and
11) Upper Waste.

Although these divisions are based primarily on economic evaluation of the Meade Peak Member, each bed is correlatable over most of southeastern Idaho as shown in Plate 1.

Cressman and Gulbrandsen (1955) and McKelvey _et al_. (1959) suggested that the uniform size of sponge spicules (Demospongia) and uniform orientation of the spicules are due to transport by current actions from another environment to the area of accumulation of the Rex Chert Member. Winnowing processes during regression and subsequent syngenetic enrichment may explain the deposition of the Rex Chert Member. The siliceous sediments of the cherty

Table 5. Stratigraphic section of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, Dry Valley

(Measured and described on west side of Dry Valley, SE¼NW¼ sec. 6, T. 8 S. R. 44 E., Caribou County, Idaho, by J. S. Spalding, July 28 and August 9, 1971.)

Description	Thickness (ft)	Percentage P_2O_5
Rex Chert Member of Phosphoria Formation		
Chert, hard, medium gray	1.0	
Meade Peak Member of Phosphoria Formation		
Mudstone, medium hard, grayish brown	2.3	
Phosphate rock, medium hard, oolitic, brown	0.7	
Mudstone, soft to medium hard, brownish gray	10.5	
Phosphate rock, medium hard, brown	0.4	
Mudstone, soft to medium hard, thin beds, brownish gray	5.1	
Phosphate rock, soft to medium hard, interbedded black oolitic phosphorite and brown oolitic siltstone (D Bed, upper ore zone)	24.3	26.1
Mudstone, upper 1/3 slightly oolitic, soft to medium hard, tan to brownish gray, thin bedded, thin beds of phosphorite	44.3	
Phosphate rock, medium hard, oolitic, gray (E Marker Bed?)	0.7	14.2
Mudstone, medium hard, yellowish brown to brownish gray, increasing oolites in lower 1/3, thin bedded	48.1	
Mudstone, phosphatic, soft to medium hard, grayish brown, thin bedded (C Bed?)	6.0	17.0
Mudstone, calcareous, soft, brown to grayish brown, thin phosphorite bed near middle of zone (altered False Cap)	4.5	15.1
Phosphate rock and mudstone, slightly calcareous, medium hard, thin bedded, pelletal phosphate (B Bed)	14.0	28.4
Mudstone, calcareous, soft, brown (altered Cap)	3.2	23.6
Phosphate rock, pelletal, slightly calcareous, soft to medium hard, gray to grayish black (A Bed)	7.1	33.1

Table 5. Continued

Description	Thickness (ft)	Percentage P_2O_5
Mudstone, soft to medium hard, light brown	5.5	
Phosphate rock, hard, grayish black, fossils (Fish Scale Bed)	0.4	32.4
Total thickness of Meade Peak Phosphatic Shale Member	177.1	

shale member of the Phosphoria Formation suggest another transgressive phase.

The shales and limestones deposited during Dinwoody time (Early Triassic) suggest a gradual regression to a sublittoral-littoral depositional environment. Ripple marks and linguloid brachiopods suggest possible brackish nearshore environments of deposition (Mansfield, 1952).

Drilling data and surface examination reveal that most of the regolith in Dry Valley is of sand size or smaller. Occasional pockets of small-sized gravel have been encountered. Examination of drill cuttings indicate that the source for the regolith is the immediate surrounding hills and ridges.

Structure

General statement. Southeastern Idaho was part of the Cordilleran miogeosyncline during Paleozoic and much of Mesozoic time (Kay, 1951). Throughout the Laramide disturbance the thick pile of sediments in the geosyncline, about 45,000 feet, was subjected to compressional deformation.

The Laramide orogeny produced compressional forces and formed an arcuate belt of folds and thrust faults tens of miles wide in southeastern Idaho, western Wyoming, and northeastern Utah. The thrusting was originally described as the Bannock overthrust by Richards and Mansfield (1912). They conceived the Bannock overthrust as a single folded thrust plane in some areas, and a thrust zone of several planes in other areas. Their work has been reinterpreted as a west-dipping imbricate thrust zone by Armstrong and Cressman (1963). The same authors attribute the associated folding to compressional and drag forces during the late stage of thrusting. Several east-northeast-trending tear faults are associated with the imbricate thrust zone.

West of the Dry Valley area, northward-trending high-angle faults are superimposed on the Laramide structures. The faults are believed to be of Middle and Late Cenozoic age (Eardley, 1951) and constitute the eastern edge of the Basin and Range structures (Mabey and Oriel, 1970).

Although as many as 20 major thrust faults were named (Eardley, 1967) in the Idaho-Wyoming thrust belt, the Meade thrust fault is the most important in considering the central phosphate region of the western phosphate field. Cressman (1964) described the Meade thrust fault as a large, folded overthrust that underlies a large portion of the southern half of the central phosphate region. The Meade thrust fault is a bedding-plane fault near the base of the Mississippian Madison Limestone. Exposures in the Snowdrift Mountain area, about 12 miles south-southeast of Dry Valley, indicate a horizontal displacement of 18 to 20 miles and a stratigraphic displacement of 12,000 to 15,000 feet. Eardley (1967) applied the Ruby and Hubbert (1959) theory of gravitational gliding as the cause of thrusting in the area.

Some of the major tectonic features in the immediate Dry Valley area deserve quick enumeration as they are closely related to the geology of the phosphate deposits in the area. The Henry thrust fault is exposed in the middle of Dry Ridge about 3 miles east of the study area. This fault places Triassic strata of different dips together at the surface although a greater offset exists at depth as shown in data from a dry oil and gas test hole in the NE¼NE¼ sec. 32, T. 7 S., R. 44 E., Dry Valley (Hite, 1967). This fault can be traced on the surface for about 15 miles to the Henry, Idaho, area although it is offset by the Blackfoot fault and the Rassmussen fault which are tear faults (Mansfield, 1927; Rioux et al., 1966).

The Dry Valley thrust fault was mapped by Mansfield (1927) as a normal contact between Mississippian and Pennsylvanian strata. Remapping in 1958 and 1959 led to the recognition of an obscure west-dipping thrust of unknown magnitude which was named the Dry Valley thrust (Rioux et al., 1966). This feature is located 1½ miles east of the northern Dry Valley area. The geology of the rocks penetrated by the above-mentioned oil and gas test indicates that there is great offset associated with this fault at depth (Hite, 1967). Most structural features that will be discussed in reference to the Dry Valley leases of FMC are probably related to tensional and compressional forces associated with this thrust fault.

The Dry Valley anticline, as mapped by Mansfield (1927) does not exist. The asymmetrical fold that was mapped as the anticline is now interpreted as a drag fold associated with the Dry Valley thrust (Rioux _et al._, 1966).

The Schmid syncline, the axis of which is roughly parallel to the summit of Schmid Ridge, is a simple fold with both the north and south ends plunging toward the center (Cressman and Gulbrandsen, 1955). The one conspicuous feature of the syncline, as shown by Rioux _et al._ in in 1966, is that the axial plane dips to the east, which is somewhat anomalous for southeastern Idaho. This fact might be explained by the eastward movement of the Dry Valley thrust and the lack of a thrust plane close enough above the Dry Valley thrust to cause the type of asymmetry so common in southeastern Idaho (Plate 2).

The following discussion on the structure of FMC's Dry Valley phosphate leases is based on the compilation of data derived from an eight-year exploration program. The ore zones in this discussion are referred to as the upper and lower zones on the Northern Dry Valley leases due to the fact that only a limited number of gamma-radiation logs were run on the properties. Elsewhere, the ore zones are referred to as upper and lower, when speaking collectively, and by individual bed names.

Northern Dry Valley leases. The Northern Dry Valley leases have a total mineable strike length of 12,600 feet which is interrupted in the north portion by an alluvium-filled channel 1,200 feet wide. The deposit strikes generally N. 45° W. and dips from 25° SW. to 48° SW. Economically adverse strike faulting, west side down, and thrusting have cut mineable reserves for these leases some 25 percent when compared to a typical, unfaulted deposit in the Dry Valley area.

Thrusting in the relatively incompetent ore zones is the most common structural element on the Northern Dry Valley leases. Thrusting in ore zones does one of three things:

1. Deletes part or all of the ore.
2. Adds ore to the section.
3. Mixes poor quality phosphate rock with the ore, thereby effectively reducing the P_2O_5 content of the ore zone.

Due to the limited amount of observable data, which covers only an extremely small geographic area, it is often impossible to assign a magnitude of movement to these thrusts although information from past mining indicates the movement is generally less than 500 yards. The thrusting generally follows one or more of four glide planes in the Meade Peak Phosphatic Shale Member, as shown in mine exposures in the area, three of which are in the potential ore zones and thus have a great economic effect on the properties. The most common glide planes for the thrusting in the Meade Peak Member are in the area of the Cap, False Cap, E Marker Bed, and a coarsely oolitic phosphorite zone in the lower third of the D Bed.

No prominent folds were discovered from interpretation of drill hole data although it is inferred that there is some undulation in the bedding as evidenced in the Dry Ridge mine, which belongs to Agricultural Products Company (Figure 12). It is probable that the undulation accounts for some of the differences in dips between individual cross sections. The author does not believe that there are any rotated or tilted fault blocks in this area.

There are two prominent sets of normal faults in the Northern Dry Valley leases. One set follows the strike of the Meade Peak strata and is of short linear extent and small stratigraphic displacement, and one set is made of transverse faults that cross the strike of the Meade Peak. The former set are probably older than the transverse faults and are offset by the transverse faults locally. It should be noted here that many of the features mapped as strike faults on Plate 3 are possibly undulations. Drilling data are not sufficient to distinguish between the two. It is possible that the transverse faults are compliments of the compressional force in the area.

In the north portion of the area under discussion (Plate 3) the dip of the strata generally decreases from 48° SW. in the north to 35° SW. in the south. Thrusting in the north portion is generally restricted to the lower ore zone and is generally destructive, from an economic point of view. The thrusting thin the ore zone and in some cases completely removes the entire zone (Figure 14).

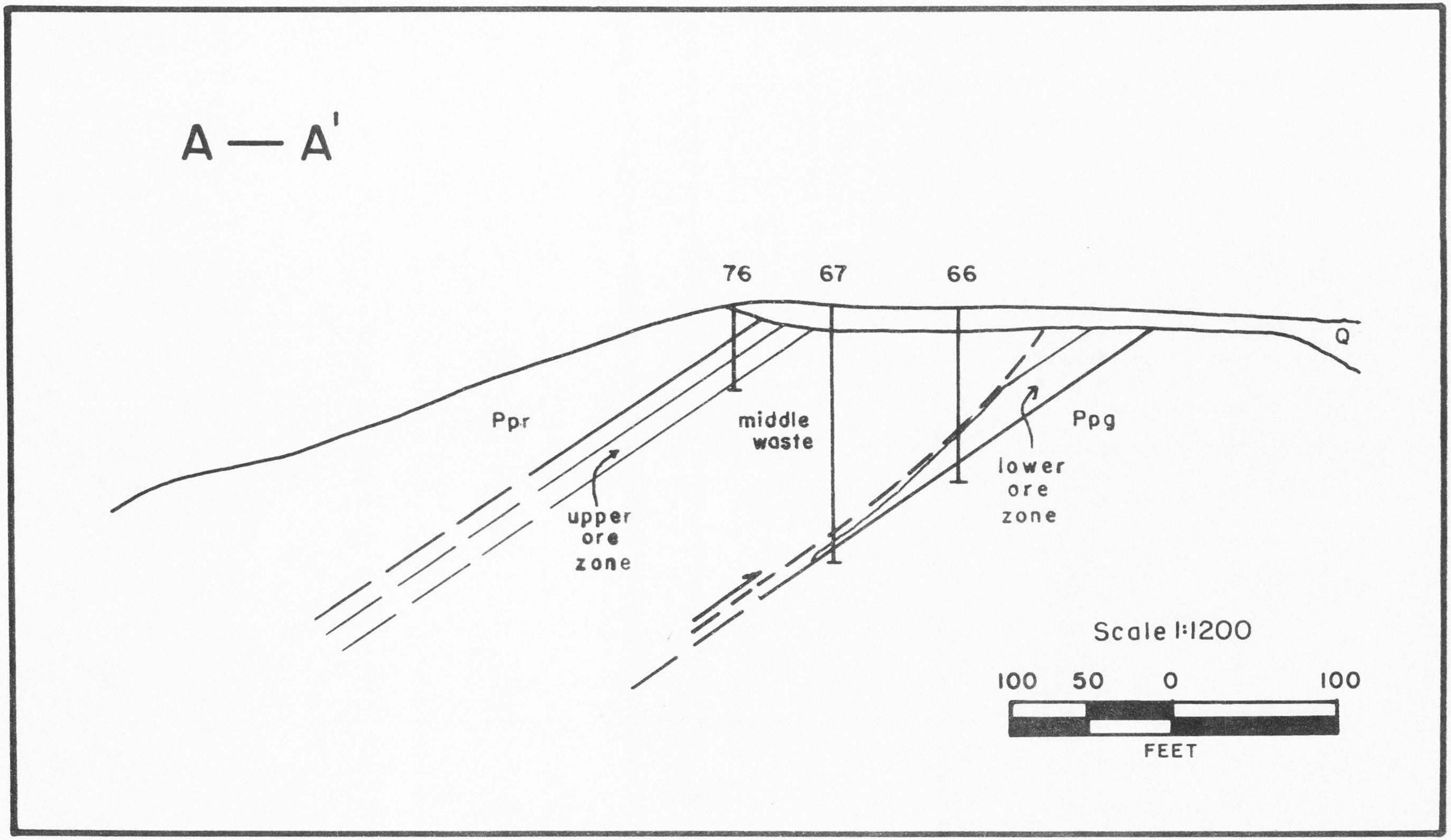


Figure 14. Typical cross section of the northern portion of the Northern Dry Valley leases; view northwest. Refer to Plate 3 for explanation.

The strike faults in the area trend from N. 20° W. to N. 45° W. and have displacements from 10 to 40 feet. All the strike faults appear to be normal with the east-side (valley) down. The transverse faults in this area strike N. 60° E. to N. 70° E. and show both right- and left-lateral strike-slip movement. Dip-slip displacements range from 10 to 50 feet and the strike-slip movement is of the same magnitude. The transverse fault north of where the road passes over the Phosphoria Formation has an unknown dip-slip component, but probably approaches 50 feet. The left-lateral strike-slip component approaches 100 feet. This fault is possibly a western extension of the sliver of the Dry Valley thrust as mapped by Rioux et al. (1966), but no concrete proof is available.

In the central portion of the area under discussion the dip of the strata ranges from 35° SW. in the north to 25° SW. in the middle to 35° SW. in the south. Thrusting in the ore zones in this area of the Northern Dry Valley leases is almost nonexistent as interpreted from the drill-hole data that is available (Figure 15). It is possible that some thrusting occurs in the middle waste zone but no proof is evident.

The strike faults in this portion of the lease are of two types, east side down and west side (ridge) down. The east side down set trends N. 20° W. to N. 35° W. and has displacements of 15 to 45 feet. The other set trends N. 30° W. to N. 35° W. with vertical displacements ranging

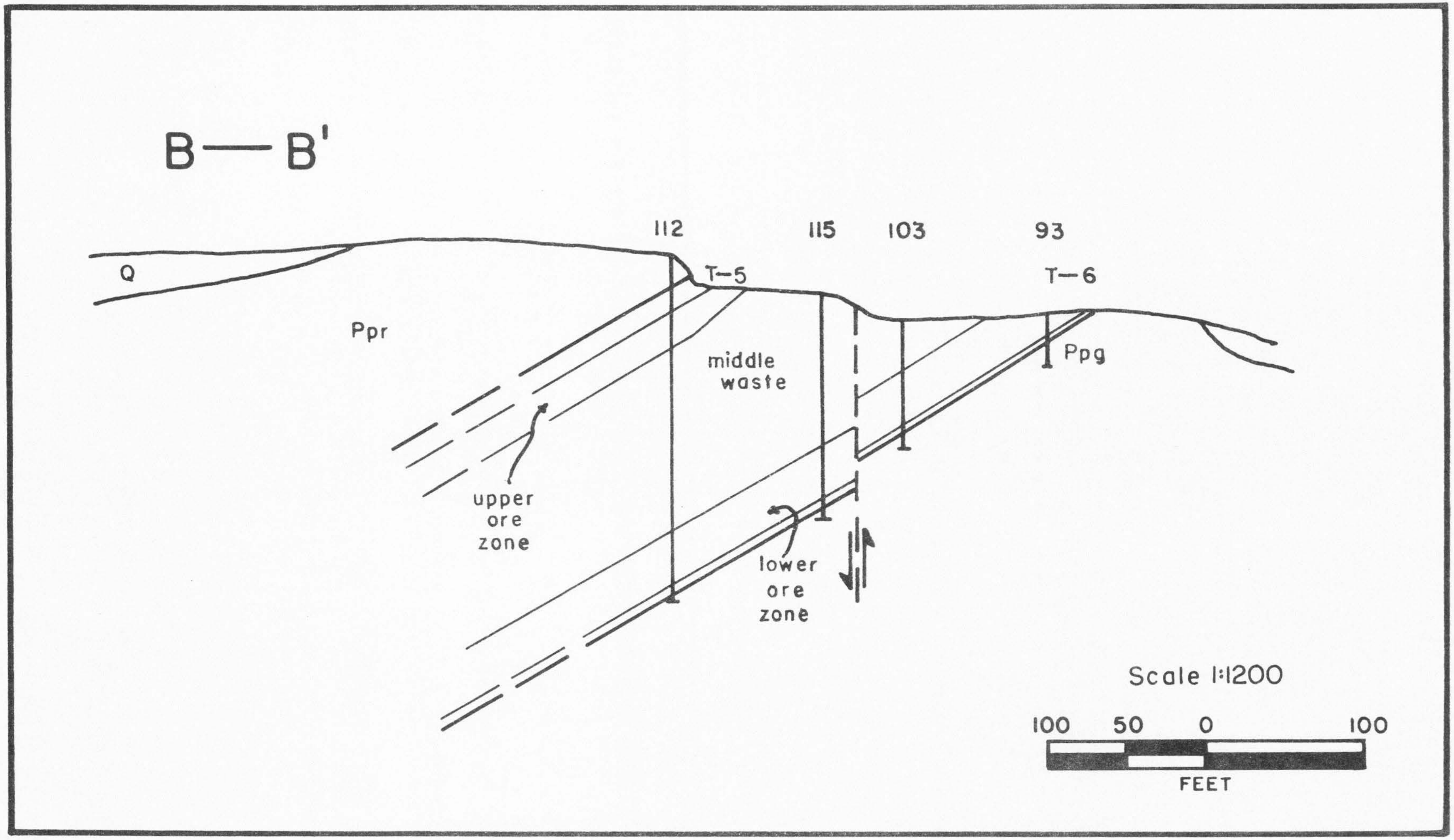


Figure 15. Typical cross section of the central portion of the Northern Dry Valley leases; view northwest. Refer to Plate 3 for explanation.

from 20 to 80 feet. There is a distinct possibility that these two sets can be connected to form a scissors fault of the type that is common in the Fort Hall area but only mining will prove or disprove this theory. There appear to be two sets of transverse faults in this area of the lease. One set trends N. 20° E. to N. 40° E. and the other, N. 60° E. to N. 75° E. and each set shows both right- and left-lateral strike-slip movement. The dip-slip displacements range from 10 to 60 feet and strike-slip movement approaches 100 feet in some cases. Transverse faulting is apparently severe in the central portion of the Northern Dry Valley leases although known fault density is probably directly proportional to the high density of drill-hole information in this area.

The dip of the strata in the southern portion of the Northern Dry Valley leases ranges from 35° SW. in the north to 25° SW. in the south. Thrusting is more severe in this portion than in those thus far discussed. Thrusting here greatly affects both ore zones, generally thinning and mixing the lower ore zone while completely removing the entire upper ore zone over much of the portion of the area (Figure 16).

In Figure 16, a typical cross section of the southern portion of the Northern Dry Valley leases, the strike faults, as shown can be attributed to undulation although they often exist in adjacent cross-sections with greater displacement. As in the central portion there are two

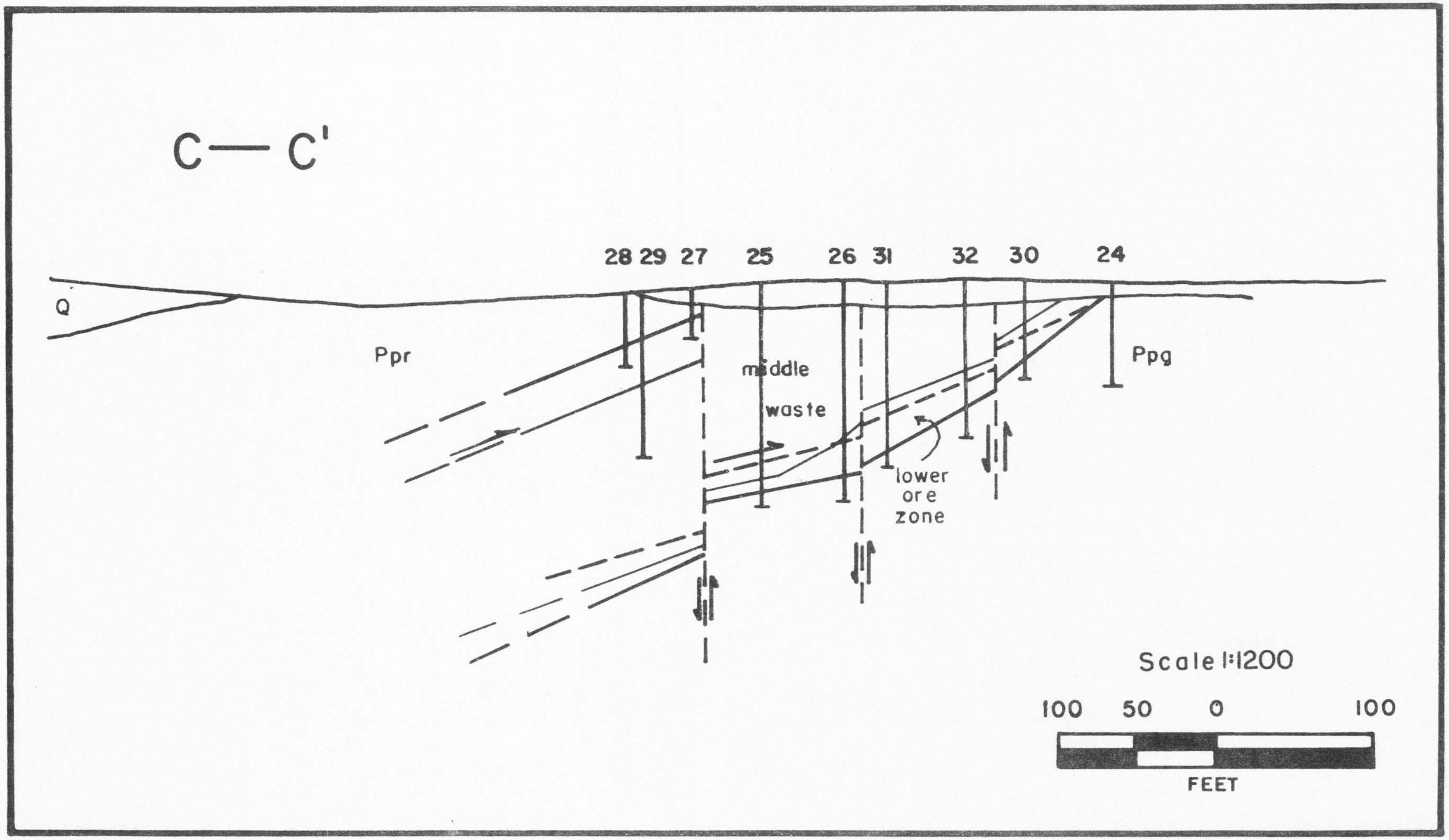


Figure 16. Typical cross section of the southern portion of the Northern Dry Valley leases; view northwest. Refer to Plate 3 for explanation.

types of strike faults. One type with the east side down and the other with the west side down. One set trends from N. 35° W. to N. 50° W. and has displacements ranging from 10 to 25 feet. The other set trends from N. 30° W. to N. 60° W. and has displacements ranging from 30 to 60 feet. There are relatively few transverse faults shown in this portion, probably the result of the relative paucity of data. These faults trend from N. 50° E. to N. 80° E. and show both right-lateral and left-lateral strike-slip movement. The dip-slip displacements range from 10 to 30 feet and the strike-slip movements are on the same order of magnitude.

Central Dry Valley leases. The Central Dry Valley leases have a possible mineable strike length of about 4,200 feet which is interrupted on the north end by an 1,800 foot-long fossil stream channel, probably Pliestocene in age. The deposit here strikes generally N. 48° W. and dips range from 10° SW. to 35° SW. Although economically adverse strike faulting, west side down, and the presence of a fossil stream channel would normally reduce any reserve figure, the magnitude of beneficial strike faulting, east side down, and favorable thrusting offset the other factors enough that there is about 15 percent more mineable reserves present on these properties than on a typical, unfaulted deposit of equal size in the Dry Valley area (Hurst, 1969).

Although the northern portion of the Central Dry Valley leases is bounded on both ends by mineable areas, it is not considered in any reserve figures due to excessive stripping ratios related to the channel fill even when combined with the other areas. Because of the uneconomic nature of this portion, little exploration work was expended here and consequently very little is known about the structural nature of this area (Figure 17).

The deposit is cut by thrust and reverse and normal faults, both strike and transverse in nature. The major fault is near the south-central area of this portion where the effect is beneficial in that ore tonnage is increased over that of a typical, unfaulted deposit. This faulting does, however, disrupt the linearity of the ore zones and will thereby complicate mining (Plate 3). Reverse faults are transverse to the strike of the deposit and are generally oriented in two directions, north and east. Movement along the reverse faults is both dip slip and strike slip. Dips of the faults average 65° SE. The dip-slip component ranges from less than 10 feet to 30 feet. The strike-slip component ranges up to 170 feet. Normal faults are essentially parallel to the strike of the deposit. Dips of these faults also range from 60° to 80° SE. Movement on the normal faults is dip slip. It reaches 80 feet near the southern edge of the area; however, the more common range is 15 to 30 feet.

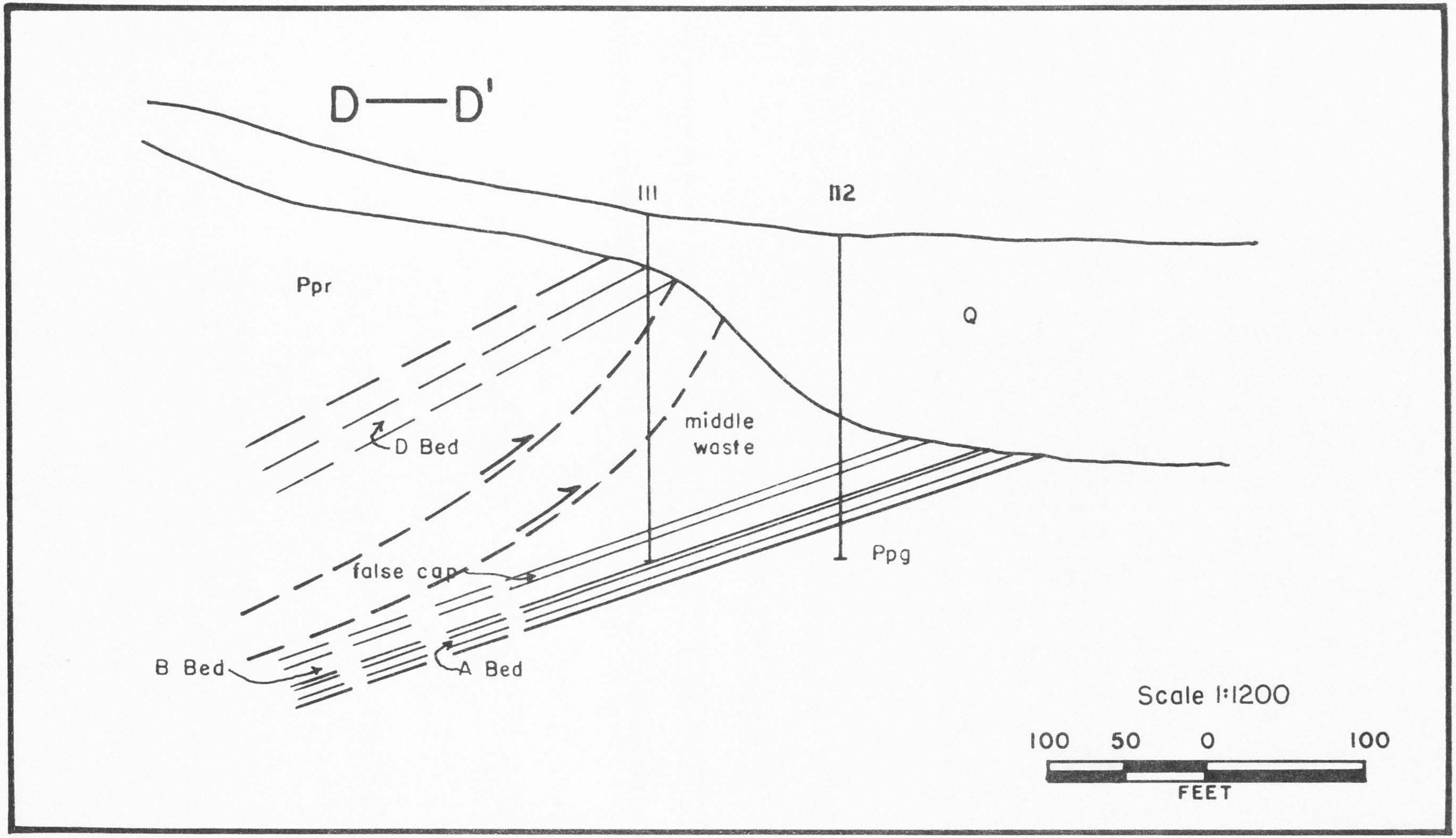


Figure 17. Typical cross section of the northern portion of the Central Dry Valley leases; view northwest. Refer to Plate 3 for explanation.

Thrust faults are generally parallel to the strike of the deposit and the fault dip is nearly parallel to bedding of the strata. There are several areas of complex thrust splitting and thrust zones which intermix waste, C Bed, and B Bed. The important thrusting is confined to the lower ore zone. In the north-central area, all but a small amount of the A Bed has been removed by thrusting for a horizontal distance of 240 feet. Faulting has repeated the entire lower ore zone for 320 feet in dip distance in the central area. The effect of thrusting on the B and C Beds ranges from thinning of the beds to repeating of the sections. Overall thrusting does not appreciably change ore reserves. There are, no doubt, numerous smaller faults within the lease area which were not detected by drilling operations (Spalding, 1970).

The southern portion of the Central Dry Valley leases is structurally different from other areas in Dry Valley under lease to FMC (Hurst, 1969). The typical cross section for this portion of the above mentioned leases is shown in Figure 18. Although illustrated as a series of normal faults, east side down, and one reverse fault, the presence of which is interpreted from the repetition of the B Bed as indicated on a gamma-radiation log, the complex structure in this area could be due to gravity sliding, as the gravity sliding is possibly the result of the dissolution of the Grandeur Member of the Park City Formation, thus removing the support of the Meade Peak Phosphatic

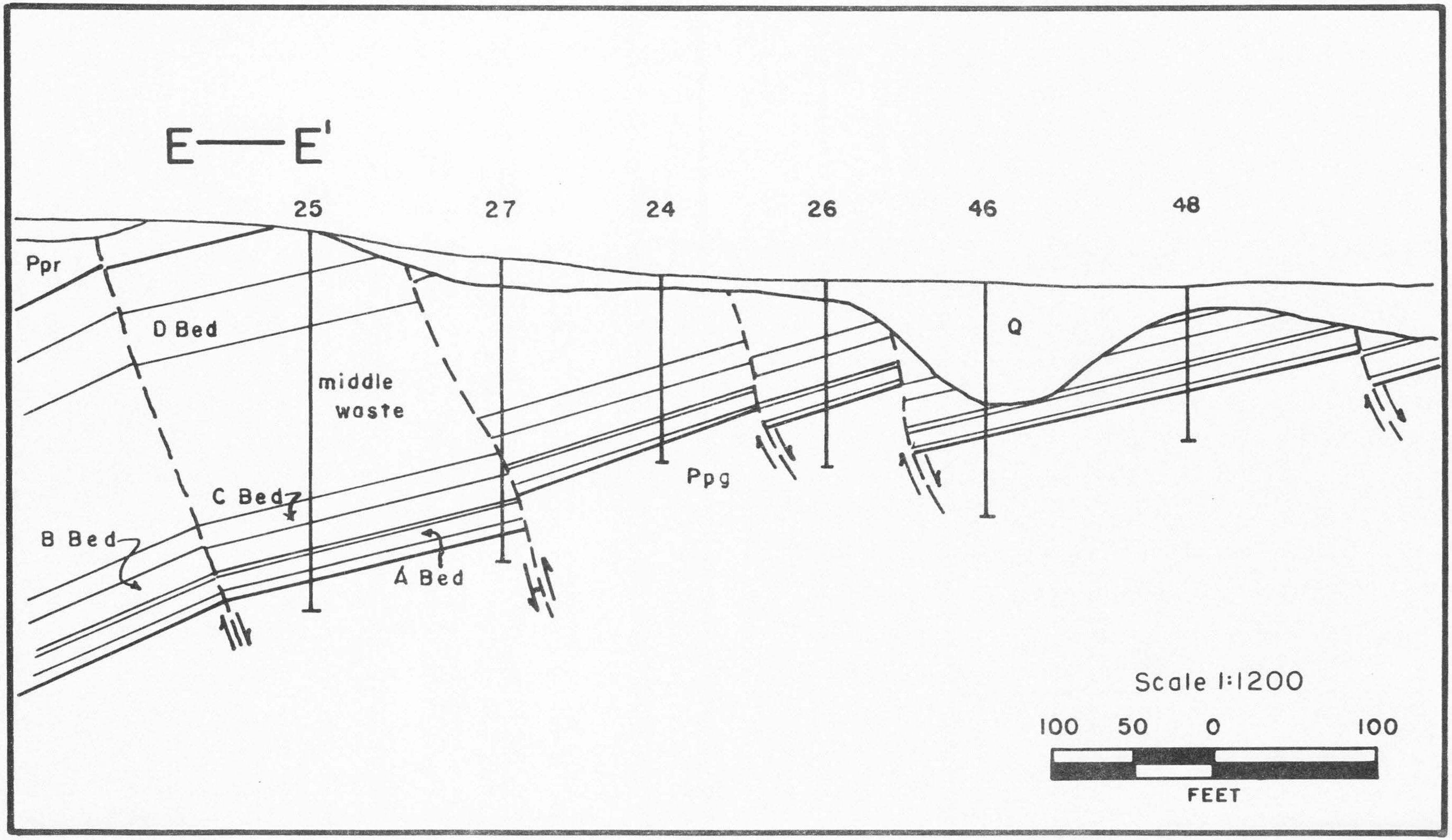


Figure 18. Typical cross section of the southern portion of the Central Dry Valley leases; view northwest. Refer to Plate 3 for explanation.

Shale Member outcrop. The lobate character of this area, as illustrated in Plate 3, is indicative of structures caused by movement of this type. Hale (1967) reports similar features in southern Dry Valley.

<u>Southern Dry Valley leases</u>. The Southern Dry Valley leases have a possible total of 7,500 feet of mineable strike length. The mineable strike length is broken by 6,500 feet of Monsanto's leases and 1,500 feet of strike length covered by regolith too deep to economically extract phosphate ore. Because of the interrupted strike, the lack of detailed information on Monsanto's leases, and the lack of detailed exploration on the leases in the southern portion of this block, only the northern portion of the Southern Dry Valley leases will be discussed here.

The northern portion of the Southern Dry Valley leases has a mineable strike length of about 2,000 feet. The deposit strikes N. 45° W. and dips range from 28° SW. to 40° SW., the most common range is 30° to 35° SW. Major thrusting affects both the upper and lower ore zones. Thrusting in the upper ore zone essentially increases, by about 30 percent, the D Bed ore quantities. The thrust faults are parallel to the strike of the deposit and the bedding planes. The thrust plane is situated in the lower one-third of the D Bed and it repeats the D Bed in the northern part of the area under discussion. In the lower ore zone thrusting is detrimental. In no area has it thickened the A or B Beds. The A Bed has been cut out completely by thrust faults in a large portion of the north-central area. The overall effect of thrust faulting on the northern portion of the Southern Dry Valley leases would be the increase of D Bed and C Bed reserve quantities and decreasing, by about half, the A Bed reserves.

Two sets of reverse faults are present, one trending east and the other trending north. The faults dip from 70° SE. to vertical. Movement is largely dip slip. The displacement ranges from 20 to 50 feet. Strike-slip displacement generally is 20 feet or less except on the fault located in the north-central position where strike slip approaches 50 feet.

The normal faults parallel closely the strike of the Meade Peak Member, about N. 45° W. Most of the displacement is vertical. Dip of the faults is 70° to 80° NE. Dip-slip movement ranges between 10 and 25 feet. As on the southern portion of the Central Dry Valley leases, there are probably numerous smaller faults that were not detected from drill hole data (Figure 19).

Mining Characteristics

The structure and stratigraphy of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation and associated strata have placed the phosphate rock deposits of the Dry Valley area in a long and linear configuration. The linear configuration and the long and essentially

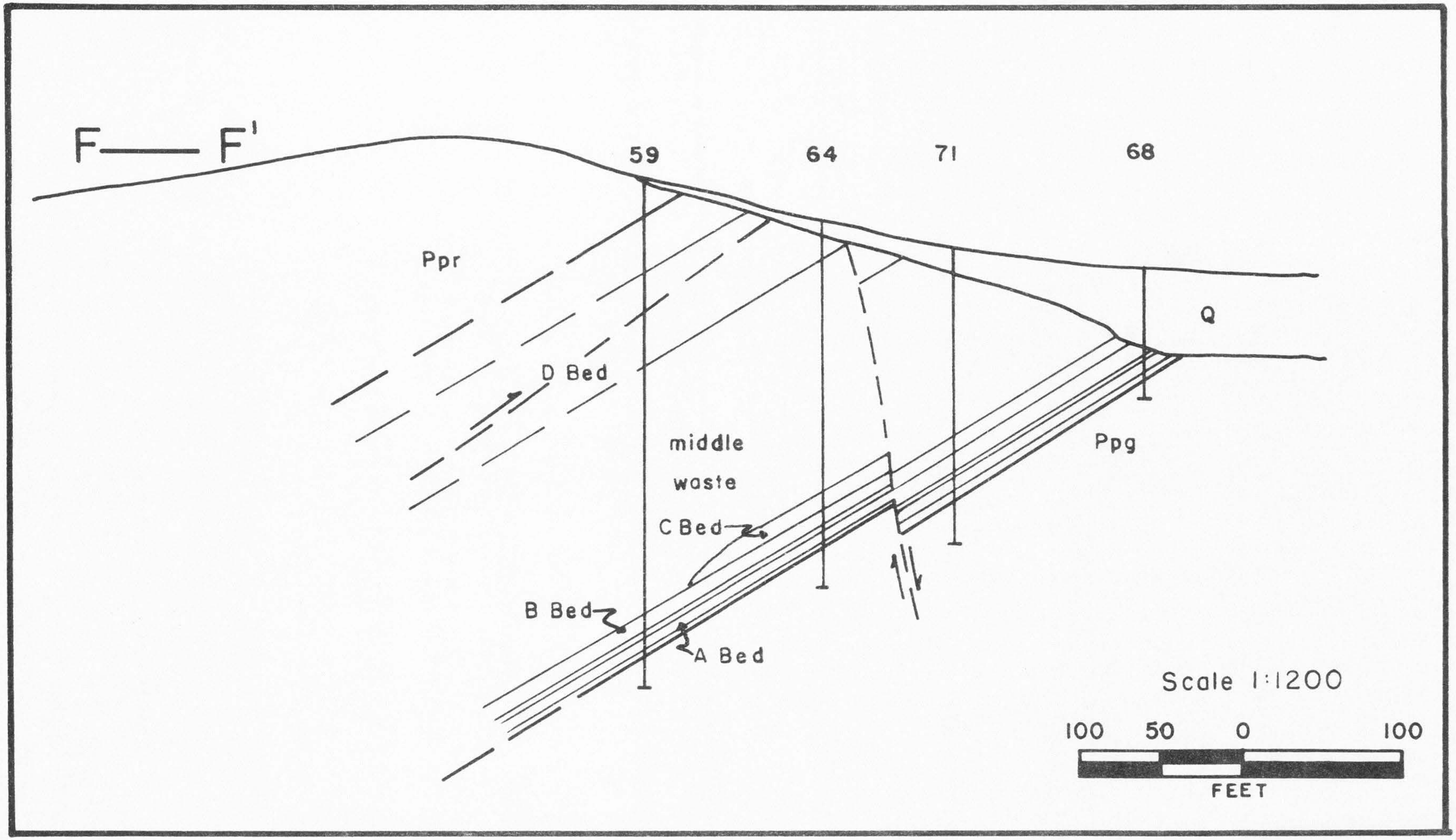


Figure 19. Typical cross section of the northern portion of the Southern Dry Valley leases; view northwest. Refer to Plate 3 for explanation.

uninterrupted mineable strike length are ideal conditions for the use of a scraper-type mining system.

The interruption of the mineable strike by the Pleistocene stream channels dictates the use of at least three pit areas instead of one continuous pit. However, because of the long distance between the channel locations, the interruptions should cause no large economic complications on the mining costs. In ideal scraper operations a minimum pit length of 1,000 feet is required while the maximum economic pit opening is thought to be 1,500 to 2,000 feet in length. Each of the three pit areas will operate well within these parameters.

The southern portion of the Central Dry Valley leases contains an area of relatively complex structure which will disrupt the ideal linear mining concept in that area. Although the structure is not complex enough to force a change of mining systems, it will dictate a careful and complicated scheduling program development for efficient and economic phosphate rock extraction.

Although there are several fault sets which cross the strike of the deposit, the magnitude of displacements is not large enough to force many additional constraints on mining in the area. Prior knowledge of their existence and location will allow for the planning of the necessary alterations in the overall mining scheme.

Thrusting, in general, in the Dry Valley area, serves only to delete, add to, or mix the ore zones. It does not present any complicated structure which would alter the overall mining scheme.

Drilling information indicates that the Rex Chert Member of the Phosphoria Formation is present in all areas and will require removal during mining operations. Drilling data, mining test data, and empirical data indicate that although the Rex outcrop area may be stripped without blasting, the member as a whole will require drilling and blasting prior to removal. The drilling and blasting operations must be accounted for both in scheduling and cost forecasting in mine planning.

In the Dry Valley area the transition zone is generally deep enough that it will not be a prominent factor in mine planning by FMC. Consequently, the proposed mining operations are being planned on essentially an overall strip ratio of 3 to 1.

Ore-reserve Calculations

Because of the confidential nature of the numbers involved, only approximate figures will be used in this discussion. The focus of this section will be on calculations, time involved and grade of the phosphate ore in comparison with FMC's present source of ore on the Fort Hall Indian Reservation.

Calculation techniques

Manual calculation of ore reserves is a long and tedious job in the western phosphate field. Because of the strong role that structure plays in the mining of the phosphate ores, cross-sectional methods have been employed almost exclusively, by the Mineral Development Department, as the desired means of calculating ore reserves.

Two types of economic limits have been used in the calculation of the ore reserves. One is a strip-ratio cutoff of three cubic yards of waste per ton of ore. The other method is a cost cutoff of $3.50 per ton mining cost. At a 3/1 strip-ratio the average mining cost is about $3.40 per ton. For the $3.50 per ton cutoff the average mining cost is about $3.05 per ton of ore. Generally, Mineral Development Department prefers to use the strip-ratio cutoff while the processing departments prefer the $3.50 per ton last-out cutoff. The use of the two types of figures cause little problem in discussions as long as each is annotated correctly.

Using the method outlined in the section on reserve calculation, it is possible to arrive at either type of figure from essentially the same calculation. By using the above method, reserve figures can be stated as x tons at y percent P_2O_5 at a 3/1 strip-ratio; mining to an elevation of 6,225 feet.

The manual calculation of reserves in the above manner is very time consuming. In computing the ore reserves for the Dry Valley leases of FMC, a total of about 2 man years has been used.

Computers offer an economic alternative to the above. By using a computer, all information must be coded and appear in the same form. This codification, in itself, is useful as it alleviates the problem of different people describing the same occurrence in different ways, thus causing some confusion. Once in the computer, the data can be manipulated in such a manner so as to:

1. Draw cross sections.
2. Draw structure, isopach and isograde maps.
3. Calculate ore reserves using as cutoffs:
   a. Strip-ratio.
   b. Mining cost.
   c. Cost of ore f.o.b. extraction plant.
   d. Cost of the finished product.
   e. Profit margin of the product.
4. Calculate the mine plan using the above variables.
5. Design the most economic means and method of extraction of the ore.
6. Design the most economic sequence of mining the deposit.

FMC's program to calculate the above is not completed at this time. When complete, however, it is expected that the program will design a mine, for a deposit similar to Dry Valley, based on the profit margin of the final product, in 5 percent of the time and 30 percent of the cost that was spent in the manual calculation of ore reserves, based on strip-ratio, for Dry Valley.

<u>Ore quantity</u>

In 1952, FMC made a brief survey of the west side of Dry Valley and concluded that there were only 400,000 tons of mineable reserve. On the basis of this report there was no further interest in the area until the early 1960's.

In 1960, FMC acquired a prospecting permit in the Southern Dry Valley lease area. Original tonnage estimates for the permit were about 4,000,000 tons. Later drilling indicated the alluvium too thick to permit economic extraction and 70 percent of the permit was dropped. Tonnage estimates for the remainder of the property were dropped to about 1,000,000 tons.

In 1966, after two years of Stage 3 work, FMC calculated that it had under lease about 15,000,000 tons of mineable phosphate rock in the Dry Valley area. A 1970 estimate showed that there were probably 25,000,000 tons in the Dry Valley lease area. In 1972, a rough re-estimate showed that there might be 28,000,000 tons of furnace grade phosphate (24 percent P_2O_5) on the same ground. Thus, in 20 years, the reserve estimates for essentially the same ground increased eighty fold through exploration and development of the area.

Ore quality

The P_2O_5 content of the ore shipped to Pocatello from the test pit in the central portion of the Northern Dry Valley leases averaged 4 percent higher than the ore being shipped from the mine at Fort Hall. The increase in percentage P_2O_5 was due to two basic differences in mining techniques. First, the high grade rock from Fort Hall is mined and shipped separately to J. R. Simplot Company for the production of fertilizers. In Dry Valley, this rock was mixed with the furnace grade material. Second, the test pit ore was taken from the extremely enriched weathered zone.

The ore quality from Dry Valley, as shown by checks and analyses conducted by plant processing personnel, as compared to Fort Hall ores are as follows:

1. The briquettes made from Dry Valley ore averaged about 9 percent stronger than the Fort Hall ores.

2. Dry Valley ore has more fluorapatite (total of about 70 percent of the material) and less of quartz (total of about 15 percent of the material) than the Fort Hall ores.

3. The illitic clay group comprises about 8 to 10 percent of the Dry Valley ore.

4. Kaolinite comprises about 2 to 4 percent of the material.

5. Other minerals present at less than 1 percent are dolomite, microcline and calcite.

6. The K_2O content of the Dry Valley material is about 65 percent greater than Fort Hall.

The chemical analysis of composite samples taken from one of the train shipments, about 4,700 wet tons, is presented on the following page.

The plant-scale tests run on the ore from Dry Valley proved that the phosphorous facility will operate efficiently on the Dry Valley material. Only minor changes will have to be made in the flow sheet and most of the changes are in the ore handling phase of the operation.

The changes are needed because of relatively high moisture content.

Species	Percent	Species	Percent
SiO_2	16.9	ZnO	0.11
P_2O_5	28.6	Cr_2O_3	0.20
CaO	40.0	V_2O_5	0.31
LOI*	4.2	SrO	0.07
Al_2O_3	4.07	Na_2O	0.70
Fe_2O_3	1.48	F	3.01
MgO	0.33	Total	101.19
K_2O	1.18	H_2O	11.0
MnO	0.03		

*LOI--Loss on ignition

Transportation

As previously mentioned, when considering a region, transportation is a major variable. Prior to 1965, mining in the Dry Valley area appeared uneconomic for FMC because of the heavy burden that transportation costs placed on a ton of ore. The building of a railspur into Dry Valley, by El Paso Agricultural Products Company, in 1965 changed the economics of FMC's Dry Valley deposits. No longer would the cost of building a railroad or a haul road to the deposits have to be amortized against the ore deposit of FMC. The economics of Dry Valley changed again in 1972 when the railspur was designated a common carrier. This change assures that the bulk rate from Dry Valley to Conda will be nearly the same as from Conda to Pocatello.

Possible Developments

Unforeseen circumstances could greatly alter the economics of the western phosphate field either favorably or unfavorably. Present upward trends of world phosphate rock prices indicate that, for the next few years, there will be increased exploration and development activity in southeastern Idaho. Since part of the monies expended on exploration and development of phosphate properties must be charged against the deposit itself, the method and means of exploration and development must be both efficient and economical.

Within a radius of 10 miles of the Dry Valley tipple, there are properties presently under lease to FMC and others, not being mined at the present time, which contain in excess of 200,000,000 tons of phosphate ore mineable at present surface mining economics (Spalding, 1971). In addition, there are unleased mapped occurrences of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation which contain an estimated 60,000,000 tons of phosphate ore mineable at present open pit economics. Deposits which are presently being mined within this radius of 10 miles contain an additional estimated 40,000,000 tons of economically surface extractable ore. The estimated 300,000,000 tons in this circle, 20 miles in diameter is enough to sustain the entire phosphate industry in southeastern Idaho, at 1973 estimated consumption rates, for about 49 years.

Unfortunately, this tremendous reserve is divided among 10 companies or individuals, only four of which are presently operating in the Soda Springs area. Future efforts of exploration and development in the area will probably center on attempts to consolidate a major portion of this reserve into mineable units of 50,000,000 tons or more by two or three companies. Whereas, in the late 1950's and 1960's, the policy of most companies was to lease as much phosphate reserves as possible no matter where the geographic location, the probable policy of the 1970's and 1980's will be the attempted consolidation of as much phosphate reserve as possible into as small a geographic area as possible. This consolidation will take place in the form of trades and/or sale of phosphate properties between the interested companies.

In the Dry Valley area, FMC has under lease nine properties covering some 3,881 acres. On 65 percent of this acreage the surface is privately owned, 26 percent of the surface is controlled by the U.S. Government, and the remaining 9 percent is controlled by the state of Idaho. Of the 8,510 acres in the Dry Valley area under phosphate mineral lease to FMC and others, 73 percent of the surface is privately owned, 16 percent by the U.S. Government and the remaining 11 percent by the state of Idaho. In addition, on 6 percent of the total acreage the mineral rights are retained by the private individual. The Dry Valley area is the only major phosphate reserve area in southeastern Idaho where such a high percentage of private surface ownership is available. Consequently, phosphate acreages in the area are at a premium and are considered quite valuable.

Although the phosphate reserves at the mine on the Fort Hall Indian Reservation are still in eight figures after 25 years of continuous operation, FMC is presently planning its future in the Dry Valley area. The land position held by FMC in Dry Valley is envied by many in the industry because of its access to transportation, the distribution of surface ownership, the tonnage under lease, and the easy transportation access to additional reserves. Within a haul distance of 10 miles to the rail car loading facilities, mostly with a favorable haul grade, there are properties under lease, not presently being mined, with an estimated 120,000,000 tons of economically surface extractable phosphate ore.

The Dry Valley leases offer another feature to FMC, namely, flexibility. Should the primary source of ore at Fort Hall be shut down for any reason, catastrophic or political, FMC could start shipping ore from Dry Valley in three to four weeks. The short time span between shut down and shipping is due to the availability of transportation and the ease with which the deposit can be mined.

There are presently many areas in southeastern Idaho open to prospecting permit and leasing where economically mineable phosphate reserves might occur. Application of the techniques summarized in this work is presently the most efficient, thorough, and economical means of locating these yet unmapped deposits and developing the properties that are presently under lease.

REFERENCES CITED

Altschuler, Z. S., R. S. Clarke, Jr., and E. J. Young. 1954. Occurrence of uranium in phosphate deposits. U.S. Geol. Survey Rept. TEI-440, p. 157-160. Issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Armstrong, Frank C.,aand Earle R. Cressman. 1963. The Bannock thrust zone, southeastern Idaho. U.S. Geol. Survey Prof. Paper 374-J:1-22.

Bailly, Paul A. 1968. Exploration methods and requirements, in Surface Mining. Eugene P. Pfleider, ed., Am. Inst. Mining Metall. Engineers:19-42.

Brinkerhoff, J. L. 1967. Tube furnace reactions of shale components and examination of altered and unaltered ore. FMC Rept. 57, unpublished.

Cook, P. J. 1969. The petrology and geochemistry of the Meade Peak Member of the Phosphoria Formation. Ph.D. thesis, University of Colorado. University films, Inc., Ann Arbor, 1970.

Cressman, Earle R. 1964. Geology of the Georgetown Canyon-Snowdrift Mountain area, southeastern Idaho. U.S. Geol. Survey Bull. 1015-I.

Eardley, A. J. 1951. Structural Geology of North America. 2nd ed.; New York: Harper and Row.

_______. 1967. Idaho-Wyoming fold and thrust belt: Its divisions and an analysis of its origin. In Intermountain Assoc. Geologists Guidebook 15th Ann. Field Conf., Anatomy of the Western Phosphate Field:35-44.

Goldstein, D. 1962a. Extraction of metals from ores and minerals-I. FMC Rept. 4118-R, unpublished.

_______. 1962b. Economics of new vanadium oxide processes. FMC Rept. 4154-R, unpublished.

_______. 1963. Extraction of metals from ores and minerals--II. FMC Rept. 4173-R, unpublished.

Gulbrandsen, R. A., K. P. McLaughlin, F. S. Honkala, and S. E. Clabaugh. 1956. Geology of the Johnson Creek Quadrangle, Caribou County, Idaho. U.S. Geol. Survey Bull. 1042-A.

Hale, Lyle A. 1967. Phosphate exploration using gamma-radiation logs, Dry Valley, Idaho. In Intermountain Assoc. Geologists Guidebook 15th Ann. Field Conf., Anatomy of the Western Phosphate Field:147-160.

Hazen, Scott W., and George W. Gladfelter. 1964. Using unequal sample interval lengths and weighted averages in estimating grade of ore for bedded deposits. U.S. Bur. Mines Rept. Invest. 6406.

Hite, R. J. 1967. Geology of the Standard of California, Dry Valley Unit Well No. 1, Caribou County, Idaho. In Intermountain Assoc. Geologists Guidebook 15th Ann. Field Conf., Anatomy of the Western Phosphate Field:271-273.

Howard, Peter F. 1972. Exploration for phosphorite in Australia--A case history. Econ. Geol. v. 67:1180-1192.

Howard, R. I. 1971. North Dry Valley phosphate plant test. FMC Form. Rept. 71, unpublished.

Hsiao, C. 1966. Phosphate reduction studies. FMC Rept. 51, unpublished.

Hurst, H. N. 1969. Geology and ore reserves of the P. Allen and Bollar phosphate leases, Dry Valley, Idaho. FMC Rept. 5399, unpublished.

Ilardi, J. 1966. Fort Hall shale behavior at temperatures of 1187 to 1524° C. FMC Rept. 4931-R, unpublished.

Kay, Marshall. 1951. North American Geosynclines. Geol. Soc. America Mem. 48.

Lang, F. S. 1965. Effect of shale constituents on phosphorus furnace reactions. FMC Rept. 4659-R, unpublished.

_______. 1966a. Calcination studies on shale and shale constituents. FMC Rept. 4840-R, unpublished.

_______. 1966b. Additional studies on shale calcination. FMC Rept. 4852-R, unpublished.

Mabey, Don R., and Steven S. Oriel. 1970. Gravity and magnetic anomalies in the Soda Springs region, southeastern Idaho. U.S. Geol. Survey Prof. Paper 646-E: 1-15.

Mansfield, George Rogers. 1927. Geography, geology and mineral resources of part of southeastern Idaho. U.S. Geol. Survey Prof. Paper 152.

_______. 1952. Geography, geology, and mineral resources of the Ammon and Paradise Valley Quadrangles, Idaho. U.S. Geol. Survey, Prof. Paper 238.

McKelvey, V. E. 1956. Northwest phosphate. U.S. Geol. Survey Rept. TEI-620. Issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

_______. 1967. Phosphate deposits: U.S. Geol. Survey Bull. 1252-D.

McKelvey, V. E., and L. D. Carswell. 1956. Uranium in the Phosphoria Formation. In Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland: U.S. Geol. Survey Prof. Paper 300:483-487.

McKelvey, V. E. et al. 1959. The Phosphoria, Park City and Shedhorn Formations in the western phosphate field. U.S. Geol. Survey Prof. Paper 313-A.

Montgomery, Kathleen, and T. M. Cheney. 1967. Geology of the Stewart Flat Quadrangle, Caribou County, Idaho. U.S. Geol. Survey Bull. 1217.

Peterson, P. T., and N. Lehman. 1963. Gay mine selected samples--mineral composition. FMC Rept., unpublished.

Richards, R. W., and G. R. Mansfield. 1912. The Bannock overthrust: A major fault in southeastern Idaho and northeastern Utah. Jour. Geology 20:681-707.

Rioux, Robert L., Robert J. Hite, John R. Dyni, and Willard C. Gere. 1966. Preliminary geologic map of the Upper Valley Quadrangle, Caribou County, Idaho. U.S. Geol. Survey Open-File Report.

Rubey, William W., and M. King Hubbert. 1959. Role of fluid pressure in mechanics of overthrusting, II. Overthrust belt in geosynclinal area of western Wyoming in light of fluid-pressure hypothesis. Geol. Soc. America Bull., v. 70:167-206.

Service, A. L., and C. C. Popoff. 1964. An evaluation of the western phosphate industry and its resources. U.S. Bur. Mines, Rept. Invest. 6485.

Sheldon, Richard P. 1959. Geochemistry of uranium in phosphorites and black shales of the Phosphoria Formation. U.S. Geol. Survey Bull. 1084-D.

Spalding, J. S. 1967. Gamma-radiation logging test, Dry Valley, Idaho, and cost analysis of future sampling. FMC Rept., unpublished.

_______. 1970. Geology and ore reserves of phosphate lease I-014184, Dry Valley, Idaho. FMC Rept., unpublished.

_______. 1971. Unitization of phosphate reserves in southeastern Idaho. FMC Rept., unpublished.

Spalding, J. S., and H. N. Hurst. 1968. North Dry Valley phosphate, Soda Springs area, Idaho. FMC Rept., 5237, unpublished.

VITA

James Simon Spalding

Candidate for the Degree of

Master of Science

Thesis: Phosphate Exploration and Property Evaluation In Southeastern Idaho, Illustrated By The Dry Valley Area

Major Field: Geology

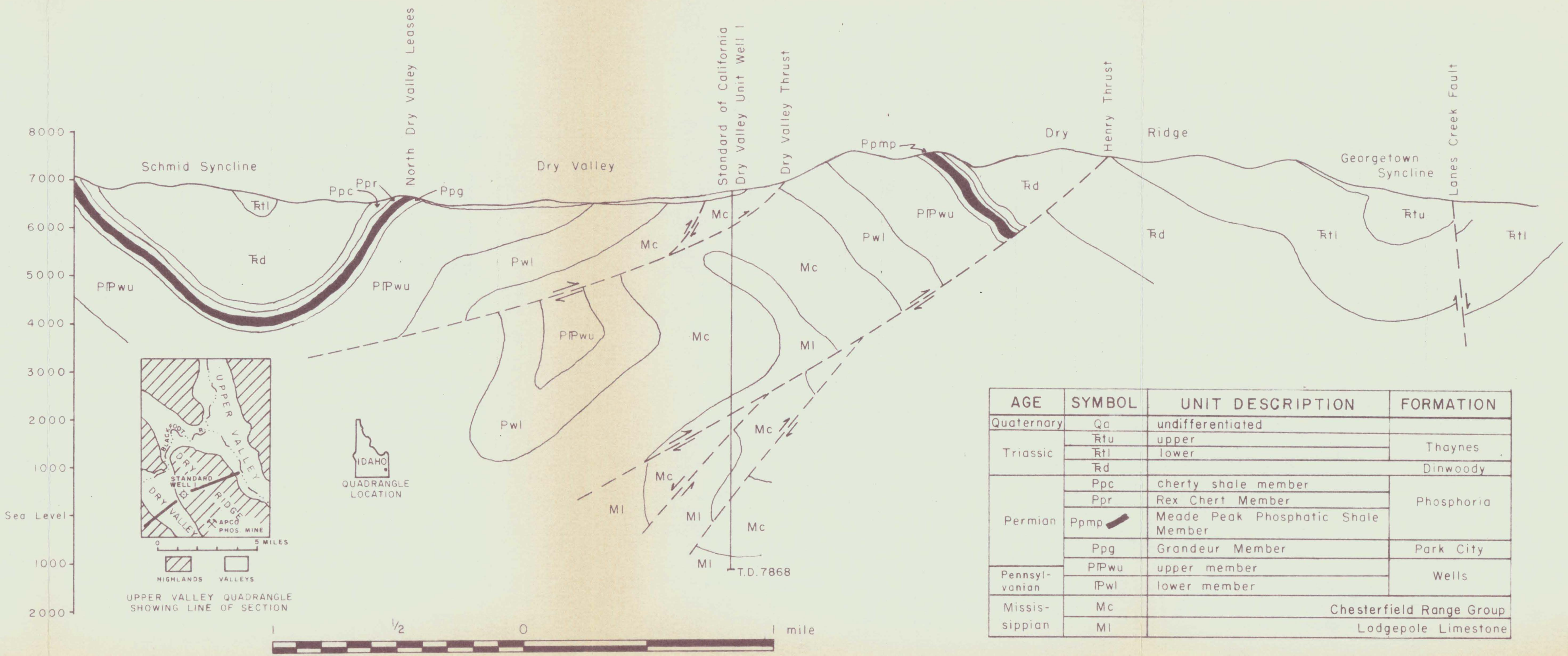
Biographical Information:

Personal Data: Born at Oceanside, California, February 24, 1944, son of D. Ross Spalding and Marjorie Simon Spalding; married Donna Lee Dursteler Spalding July 28, 1968; four children--Deborah Sue, Merek Tal, Tonya Christine, and James David.

Education: Attended elementary schools in Elsemere, Delaware, and Circleville, Ohio; graduated from Circleville High School in 1962; received the Bachelor of Science degree from Ohio University, with a major in geology, in 1966; did graduate work at Utah State University in 1966-67; completed requirements for Master of Science degree, specializing in geology, at Utah State University in 1974.

Professional Experience: 1970 to 1974, project geologist, Mineral Development Department of FMC Corporation; 1968 to 1970, soils scientist, U.S. Army, Mekong Delta, South Vietnam; 1967 to 1968, well site geologist, Mineral Development Department of FMC Corporation; 1966, well site geologist, Mineral Development Department of FMC Corporation; 1965, junior paleontological operator, Cleveland Museum of Natural Science and History.

Gamma-Log Correlation of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, Southeastern Idaho



AGE	SYMBOL	UNIT DESCRIPTION	FORMATION
Quaternary	Qc	undifferentiated	
Triassic	TRtu	upper	Thaynes
	TRtl	lower	
	TRd		Dinwoody
Permian	Ppc	cherty shale member	Phosphoria
	Ppr	Rex Chert Member	
	Ppmp	Meade Peak Phosphatic Shale Member	
	Ppg	Grandeur Member	Park City
Pennsylvanian	PIPwu	upper member	Wells
	IPwl	lower member	
Mississippian	Mc		Chesterfield Range Group
	Ml		Lodgepole Limestone

Southwest—northeast Structure Section Through Standard of California Dry Valley Unit Well No. 1, Northern Part of Dry Valley, Caribou County, Idaho; View Northwest

(modified after Hite, 1967)


PLATE 3
INDEX MAP
R.44 E.
T. 7 S.
T. 8 S.
NORTH
CENTRAL
SOUTH
No.
So.
NORTH
IDAHO
AREA LOCATION
LEGEND
Monsanto Leases
Approximate location of Meade Peak Member
Dry Valley rail spur
0 1 2 miles
NORTH DRY VALLEY
CENTRAL DRY VALLEY
SOUTH DRY VALLEY
EXPLANATION
Lease boundary
Rail spur
Dry Valley access road
A — A' Cross-section
Trench
Drill hole
Ppr Rex Chert Member of the Phosphoria Formation
Ppmp Meade Peak Phosphatic Shale Member of the Phosphoria Formation
Ore zones
Waste zones
Ppg Grandeur Member of the Park City Formation
Transverse faults
Strike faults and outcrop collapse structures
Thrust faults
Ppr Ppmp Ppg
MATCH TO NORTH DRY VALLEY
MATCH TO CENTRAL DRY VALLEY
MATCH TO SOUTH DRY VALLEY
NORTH
CENTRAL
CENTRAL
SOUTH
NORTH
SOUTH
MONSANTO STATE LEASE
MONSANTO FEDERAL LEASE
SCALE 1:4800
400 200 0 400
FEET
Sub alluvial Geologic Map
of
FMC's Dry Valley Leases
Dry Valley
Caribou County, Idaho