

RESOURCES IN THE PHOSPHORIA FORMATION,
SOUTHEASTERN IDAHO

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INTRODUCTION

In the following presentation I will review the geology of the Phosphoria Formation in southeastern Idaho and the make-up of Idaho's phosphate industry. At the end I will give a progress report on the goals, work methods, and preliminary results for the cooperative program between the U. S. Geological Survey and the Idaho Bureau of Mines and Geology to measure the phosphate resources in a portion of southeastern Idaho.

GEOLOGY OF THE PHOSPHORIA FORMATION

The Meade Peak Phosphatic Shale Member of the Phosphoria Formation underlies several thousand square miles in southeastern Idaho. The most important phosphate deposits are between Soda Springs and the Wyoming border. At the present time phosphate is mined at four open-pit mines in Caribou County--the Conda, Mabie Canyon, Henry, and Wooley Valley mines--and at one--the Gay mine--on the Ft. Hall Indian Reservation in Bingham County. An additional open pit, the Smokey Canyon mine, is planned in Caribou County. Important phosphate production in the past was obtained from underground operations in Bear Lake County, but these have been closed for many years. Additional Idaho phosphate occurrences are known in Bannock, Bonneville, Cassia, Clark, Fremont, Lemhi, Madison, and Teton Counties, but none are mined.

The Phosphoria Formation is Permian in age. It disconformably overlies the dolomitic rocks of the Grandeur Tongue of the Park City Formation which, in turn, lies above the Pennsylvanian and Lower Permian sandstones and limestones of the Wells Formation. The Phosphoria Formation is unconformably overlain by the Lower Triassic shales, siltstones, and limestones of the Dinwoody Formation. Throughout most of the phosphate mining region of southeastern Idaho the Phosphoria Formation consists of three members. The lowest is the Meade Peak Phosphatic Shale Member, a complex interstratified assemblage of phosphorite, phosphatic and carbonaceous mudstone, and minor amounts of limestone ranging from 100 to 250 feet in thickness. Part of this thickness variation results from deformation and weathering.

Phosphate is mined from two zones consisting mainly of phosphorite and with subordinate mudstone and dolomitic limestone in the Meade Peak. These are the upper and lower ore zones; they are separated by the middle waste zone, which consists of phosphatic and carbonaceous mudstones containing local thin phosphorite layers and limestone concretions. The combined thickness that is mined from the upper and lower ore zones generally ranges from 30 to 60 feet in the district.

The Meade Peak is overlain by the Rex Chert Member which ranges from 50 to 150 feet thick and, above this, the Cherty Shale Member, which ranges from 100 to 200 feet thick. Overlying the Cherty Shale Member at the eastern edge of the southeastern Idaho phosphate district, in eastern Caribou and Bear Lake Counties and extending on to the east, is the Retort Tongue consisting of carbonaceous mudstone, dolomite, and

phosphorite. This unit has a maximum thickness of only about 30 feet in southeastern Idaho, and is not mined. It is mined in Montana by Cominco American, Inc., however, at the Warm Springs underground mine.

The phosphorite, phosphatic and carbonaceous mudstones, chert, and carbonate rocks of the Phosphoria Formation were deposited in the shelf and miogeosynclinal portions of the Late Paleozoic-Mesozoic Cordilleran continental margin structural belt. Regional facies studies of the Phosphoria indicate that a thick time-equivalent accumulation of chert and black shale, deposited in a deep-water eugeosynclinal environment, occurs to the west, and time-equivalent sandstones, carbonate rocks, and evaporite deposits deposited in shallow shelf and platform environments exist to the east.

Many geologists who have studied the Phosphoria Formation believe it was deposited in a large embayment from cold marine waters that were saturated in phosphate. The fine-grained clastic material in the Phosphoria Formation came from land areas located generally to the north, east, and south of this embayment, whereas the organic matter probably resulted from a high degree of biological productivity, perhaps brought about by the influx of phosphate saturated waters into the shallow shelf environment. The deposition of phosphate in this Phosphoria Sea may have been similar to phosphorite deposition now occurring along the western margins of arid continental regions, such as North Africa and Mexico. The phosphate is believed to come from the sea water and is precipitated as a result of the decreasing solubility of the PO_4 ion, in response to the rise in water temperature and drop in pressure, as oceanic currents, generated by the Earth's Coriolis force, upwell along the western margins of continents. It is of interest to note that the Phosphoria Formation has been estimated to contain five times as much phosphorus as now is dissolved in all of the Earth's oceans. This implies that a geologically long span of time was required for the deposition of the formation; it may have taken much of the 55-million year long Permian period.

The Meade Peak Phosphatic Shale is poorly exposed in southeastern Idaho because it is a fairly soft rock and not as resistant to erosion as the carbonate rocks of the underlying Grandeur Tongue and the overlying Rex Chert. Details of the stratigraphy of the Meade Peak are obtained primarily from artificial cuts, trenches, and drill holes, inasmuch as the beds are seldom naturally exposed. The mudstones and phosphorite of the member generally are structurally incompetent. In the sloping terrain of southeastern Idaho, this means care must be taken in utilizing the shallow trench data, because near-surface creep rotates the bedding, obscures minor faults and folds, and generally causes thickness and structural attitude measurements to be unreliable. The P_2O_5 content of near-surface samples also is unreliable, due to weathering-induced leaching of carbonate minerals and organic matter and the resulting concentration of the phosphate.

The mineral composition of the average phosphate rock of the Phosphoria Formation is approximately 80 percent apatite, 10 percent quartz, 5 percent muscovite and clay, 2 to 3 percent organic matter,

and 2 to 3 percent of other constituents, including calcite, dolomite, chert, feldspar, pyrite, and iron oxides. The interbedded phosphatic and carbonaceous mudstones have a lower concentration of apatite and a higher content of quartz and other silicate minerals, but about the same content of organic matter. All gradations between phosphorite and carbonaceous shale exist. Locally, thin beds occur that are much richer in carbonaceous material; one at the Mabie Canyon mine that is as much as two feet thick is so rich in carbonaceous matter that it resembles bituminous coal. It is referred to as the "carbon seam" by miners.

Apatite is the principal mineral in phosphorite--it is the fluorine-rich variety with a basic formula of $\text{Ca}_5(\text{PO}_4)_3\text{F}$, but shows significant substitution of Na, Sr, U, Th, Y, and the rare earth elements La, Nd, Yb for Ca, and carbonate and sulfate for the phosphate radical, but only minimal substitution of chlorine or hydroxyl ions for the fluorine. The chemical composition of phosphorite from the Meade Peak Member is somewhat variable, depending on the quantity of carbonaceous material and silicate minerals that it contains. The numerous analyses available in the literature indicate that typically the phosphorite contains 25 to 35 weight percent P_2O_5 , 35 to 50 percent CaO, 2 to 20 percent SiO_2 , up to 4 percent Al_2O_3 , up to a few percent of H_2O , CO_2 , SO_4 and organic matter, and 2.5 to 4 percent fluorine, but generally less than a percent of iron oxides, MgO, or alkalis. The Meade Peak Member contains notably high abundances of a number of metals in close association with the carbonaceous material. These include V, Cr, Ni, Ag, Zn, Cd, Se, and Mo.

As I noted earlier, the phosphate mines are open-pit operations that generally take ore from upper and lower ore zones that are separated by the phosphate-bearing middle waste. This structural configuration leads to the mining of material that varies widely in its content of P_2O_5 . Some has a high enough grade so that beneficiation is not necessary; other material is beneficiated; lower grade material is stockpiled; and other material is placed in dumps, or used as fill in mined-out areas. In general, material containing about 25 percent P_2O_5 is shipped directly to the electric furnace operations for the manufacture of elemental phosphorus, whereas high-grade material with about 30 percent or more P_2O_5 is calcined and sent to the wet acid plants to make phosphate fertilizer. Ore with a P_2O_5 content between about 25 and 30 percent either is blended with lower grade material and used as electric furnace feed for the production of elemental phosphorus, or is upgraded by beneficiation and used for phosphate fertilizer production. Material with less than about 25 percent P_2O_5 and down to as low as about 20 percent P_2O_5 may be beneficiated to furnace grade or acid grade, or stockpiled. In some instances phosphatic shales with lower grades are stockpiled.

The phosphate deposits of southeastern Idaho are structurally complex because of extensive thrust faulting, folding and crumpling, and subsequent normal faulting. In addition, the structurally incompetent nature of the mudstones in the Meade Peak Member has led to their extensive local thinning and thickening, both during tectonic deformation and during

4

geologically recent times as a result of downslope slumping. These structural factors markedly influence how the phosphate is mined at specific locations. In general, the phosphate beds have moderate to steep dips so that mining is limited to elongate zones because of the excessive amount of overburden that would have to be stripped in deeply buried areas. Currently the maximum depth of mining is 300 to 400 feet.

Besides the structural complications, the phosphate beds have undergone variable amounts of weathering alteration. This alteration is due to a supergene enrichment process that has operated over a long period of geological time, and that still is in progress. It affects a zone from the surface down to a few hundred feet deep. The main changes occurring during the alteration are oxidation of the carbonaceous matter and pyrite, leaching of the carbonate minerals, carbonaceous matter and silica, and solution and reprecipitation of the apatite. The net result of the process is that the altered phosphate beds have been naturally beneficiated to a higher P_2O_5 grade. The alteration process is very important because it is almost exclusively altered phosphorite that is mined in the district. Unaltered phosphorite is not as attractive economically because it contains less P_2O_5 and a higher percentage of Mg, S, Al, and other metallurgically deleterious constituents. Clearly, this altered, surface-related resource has a finite availability in the district, and at some future date, probably before the end of the century, unaltered phosphorite will have to be exploited.

IDAHO'S PHOSPHATE INDUSTRY

Phosphate rock mined in southeastern Idaho is used as the basic raw material for two entirely different manufacturing processes: the production of phosphorus in its elemental form in electric furnaces and the production of phosphoric acid by treating phosphate rock with sulfuric acid. The phosphoric acid is used primarily to manufacture various phosphate-based agricultural fertilizers such as diammonium phosphate and triple superphosphate. Except for phosphate rock, the two processes use different raw materials, have different byproducts, and generally are conducted by different companies.

Phosphate rock used in wet acid plants for producing phosphoric acid needs to be acid grade, which is about 30 percent or more P_2O_5 . Most of the phosphate rock mined for fertilizer production has a lower grade, and thus is beneficiated to increase its P_2O_5 content. The beneficiation process involves scrubbing, washing, grinding, screening, and desliming to remove clay and silt. This generally increases the grade by 5 to 6 percent. After beneficiation, the phosphate is calcined at about $1450^{\circ}F$ to remove water and the organic matter by burning it. After calcining, the phosphate rock is reacted with sulfuric acid to produce phosphoric acid, H_3PO_4 , containing 30 to 32 percent P_2O_5 , which is used primarily to manufacture the various types of fertilizer. The principal by-product of the acid process is hydrated calcium sulfate, or gypsum, which is dumped in holding ponds.

5

Two wet acid plants, and the related beneficiation, calcining, and fertilizer manufacturing facilities, are operated in southeastern Idaho. One is J. R. Simplot's acid plant at Pocatello and beneficiation and calcining facilities at Conda, and the other is the complex at Conda belonging to the Conda Partnership, a joint venture of Beker Industries and Western Cooperative Fertilizers, Ltd. Ore for J. R. Simplot's fertilizer plant comes primarily from the Conda mine near Conda, with supplemental production also coming from the Gay mine northeast of Pocatello. The phosphate rock for the Conda Partnership operation comes from the Mable Canyon mine 13 miles east of Conda.

The J. R. Simplot Company currently is developing the Smokey Canyon mine, 25 miles east of Soda Springs near the Wyoming border. Once developed, its production will be used for fertilizer manufacture and will replace production from the Conda mine, when the ore there is depleted.

The J. R. Simplot Company manufactures their own sulfuric acid at Pocatello by burning liquid sulfur in air, oxidizing the resulting SO_2 gas to SO_3 , and then absorbing the SO_3 in water to form H_2SO_4 . The Conda Partnership produces part of their sulfuric acid by a similar process, but purchases some. Until recently about a quarter of their purchases were from the Bunker Hill acid plant at Kellogg.

Phosphate rock used to make elemental phosphorus needs to have a grade of approximately 25 percent P_2O_5 . Part of the furnace grade phosphate rock is suitable as mined, and other material is brought to the correct grade by blending higher and lower grade phosphate rock. Reduction in electric furnaces produces the elemental phosphorus. The charge to the electric furnace consists of phosphate rock in a nodular or briquette form, mixed with quartzite to provide silica, and coke to act as the reductant. Sufficient quartzite is added so that it will combine with the lime in the phosphate rock and form a silicate slag. When the mixture of phosphate rock, coke, and quartzite is melted at 2400° to 2700°F in the electric furnace a silicate liquid is formed that contains the calcium, and minor amounts of Al, K, Na, Mg, and U that were present as impurities in the phosphate rock. Some of this slag has been crushed and used as road metal in southeastern Idaho.

A second more dense liquid, called ferrophosphorus, is formed in the furnace and is tapped off separately from the silicate slag. During the melting process the V, Cr, and Ni are scavenged from the phosphate rock and concentrated in the dense ferrophosphorus liquid. This raises the vanadium content high enough so that it can be economically recovered. Ferrophosphorus typically contains 56 to 60 percent Fe, 24.5 to 27.8 percent P, 3.9 to 5.5 percent V, 3.6 to 4.6 percent Cr, 0.5 to 4.5 percent Si, and about 1 percent Ni.

The water and fluorine in the phosphate rock are driven off by heat prior to processing in the electric furnaces, during the nodulizing or briquetting process. The fluorine is scrubbed by fixing it with lime and is precipitated as CaF_2 . In the electric furnace phosphorus gas,

carbon monoxide, and fine particulate matter, or dust, are produced. The dust, which has a fairly high concentration of volatile elements such as Ag, Zn, Cd, Se, K, and some of the rare earths, is collected by an electrostatic precipitator. The elemental phosphorus is collected in spray towers, and the carbon monoxide is used as fuel for the pre-electric furnace briquetting calciners or rotary kilns.

Two companies operate elemental phosphorus plants in southeastern Idaho. Monsanto Company has a plant at Soda Springs and obtains phosphate rock from their Henry Mine northeast of Soda Springs. The FMC Corporation operates the world's largest elemental phosphorus plant at Pocatello. Phosphate rock supplying the plant is obtained from the Gay mine through a joint mining arrangement with the J. R. Simplot Company; FMC takes most of the production from the Gay Mine.

The other producing phosphate mine in southeastern Idaho is the Wooley Valley mine northeast of Soda Springs, operated by the Stauffer Chemical Company. Phosphate rock from the Wooley Valley mine is shipped to Stauffer's elemental phosphorus plants at Leefe, Wyoming, and Silver Bow, Montana. Stauffer also operates phosphate mines at Vernal, Utah, and, until recently, jointly operated the wet acid plant and fertilizer manufacturing facility at Kellogg with the Bunker Hill Company.

The Kerr-McGee Company operates a vanadium recovery plant at Soda Springs. The vanadium is obtained from ferrophosphorus by a roasting and leaching process, and is marketed as vanadium pentoxide, V_2O_5 . Kerr-McGee recovers on the order of 2.5 to 3.0 million pounds of V_2O_5 a year from ferrophosphorus obtained from Monsanto's elemental phosphorus plant at Soda Springs and from Stauffer Chemical Company's Silver Bow, Montana, plant. The ferrophosphorus produced at FMC's operation at Pocatello is sold to Union Carbide and is shipped to their vanadium plant at Hot Springs, Arkansas. The Cr and Ni, which like V are enriched in ferrophosphorus, are not recovered by the vanadium leaching process.

THE IBMG-USGS COOPERATIVE PHOSPHATE RESOURCE EVALUATION PROGRAM

In October of 1979 the Idaho Bureau of Mines and Geology and the Conservation Division of the U. S. Geological Survey entered into a cost-sharing cooperative agreement to measure in detail the phosphate resources in much of southeastern Idaho's phosphate district. The agreement basically calls for the U. S. Geological Survey to pay about 90 percent of the cost, and the Idaho Bureau of Mines and Geology to supply the personnel, work space, and make the investigations at our Moscow, Idaho offices, under the general direction of the U. S. Geological Survey's Western U. S. Conservation Division in Menlo Park, California. Pamela Derkey is the project geologist for the Idaho Bureau of Mines and Geology, and manages the resource investigation program with the assistance of staff geologist Pamela Palmer, a full-time cartographer, and a variable number of part-time geologists. The U. S. Geological Survey's contract technical officer in charge of overseeing the program is Peter Oberlindacher.

The program calls for evaluating the phosphate resources in 20 7.5-minute quadrangles covering all of the district north and east of Soda Springs in Caribou County where phosphate rock is being mined at the present time, but excluding the deposits in the Ft. Hall Indian Reservation where the Gay mine is located. The older, now inactive, mining district in Bear Lake County is not included. The quadrangles being investigated are: Chesterfield Reservoir, China Hat, Diamond Flat, Dry Valley, Fossil Canyon, Grizzly Creek, Harrington Peak, Henry, Johnson Creek, Lower Valley, Meade Peak, Meadow Creek Mountain, Paradise Valley, Sage Valley, Snowdrift Mountain, Soda Springs, Stewart Flat, Upper Valley, Wayan East, and Wayan West.

A report, accompanied by three maps at a scale of 1:24,000, is to be published for each quadrangle by the U. S. Geological Survey. Except for the final publication step, we expect work for the program to be completed during the summer of 1982. The report and maps for each quadrangle will present information on the structural geology affecting the Phosphoria Formation, and summarize information on the thickness, grade, lateral continuity, phosphate resources, development potential, and ownership of phosphate rock in the Meade Peak Phosphatic Shale Member. We expect the information to be of value primarily for resource management and land use planning purposes.

For each quadrangle, the three 1:24,000-scale maps to be published are: a map showing structural contours on the top of the Meade Peak Member and relevant structural geology affecting the phosphate deposits plotted on a topographic base; a second map showing the areal distribution of the identified phosphate resources with a grade of 16 percent P_2O_5 or greater and subdivided into depth categories of (a) less than 300 feet of overburden (high development potential), (b) between 300 and 600 feet of overburden (moderate development potential), and (c) between 600 and 1500 feet of overburden (low development potential); and a third map showing the areal distribution of phosphate resources in the above depth and development potential categories plotted on a base map showing the current land status and phosphate lease data. Land status for individual land parcels will include information indicating whether the surface title and the phosphate title are federally-owned, state-owned, or privately-owned, and will show the boundaries of Federal Phosphate Leases, Federal Phosphate Right Lease Applications, and State Phosphate Leases.

To date, the total identified phosphate resource containing 16 percent or more P_2O_5 occurring at depths of less than 1500 feet has been measured for nine of the quadrangles, and the results for five are shown in the accompanying table.

Quadrangle	Phosphate Resource		Million Tons at Various Depths			Average	Strike
	Million Tons	Wt. % P_2O_5	0-300 Feet	300-600 Feet	600-1500 Feet	Thickness >16% P_2O_5	Length (Miles)
Upper Valley	661	24.6	171	140	350	51	13
Dry Valley	1104	23.0	363	218	523	52	19
Sage Valley	313	25.8	107	61.4	145	64	4
Diamond Flat	141	22.9	14.9	18.7	107	48	1
Meade Peak	163	24.7	47.8	44	71.4	61	2.5

Table 1. Identified Phosphate Resources in Selected Quadrangles

Details of the procedures used and assumptions made to measure the phosphate resources will be published in the individual quadrangle reports. The basic resource measurement process includes the following steps for each quadrangle:

- (1) The gathering of geologic data from all available published and unpublished sources and the plotting of relevant structural and stratigraphic information on 1:24,000-scale base maps.
- (2) The compilation and selection of information on the grade and thickness of phosphate rock in the Meade Peak Member. This partly comes from drill hole and trench records in the U. S. Geological Survey's confidential files at their Mining Supervisor's office in Pocatello, with the permission of the particular company involved for any piece of data used, and partly from trench data published by the U. S. Geological Survey.
- (3) The construction of cross-sections portraying the geology, grade and thickness data, generally at a spacing of 3 or 4 sections per mile of Phosphoria Formation exposure.
- (4) Construction of structural contours on the top of the Meade Peak Member from the cross-sections and other structural information.
- (5) Overburden thickness isopachs are derived from the difference between the structural contours and the elevation of the earth's surface shown by the contours on USGS topographic maps.
- (6) Resource blocks are outlined according to the 0 to 300, 300 to 600, and 600 to 1500-foot depth categories, and their areas are measured by use of the electronic graphics calculator at the University of Idaho's College of Mines. Each resource block corresponds to one or more drill holes or other data point(s) with a particular grade and thickness of phosphate rock.

(7) For each resource block, the tonnage of phosphate rock is calculated by utilizing the appropriate grade, surface area, and dip information.

(8) The measured phosphate resources are compiled by section and by quadrangle in the various depth categories for tabulation and portrayal on the maps. The section-by-section resource measurements will be kept on file at the USGS offices in Pocatello and Menlo Park. The USGS plans to publish only the quadrangle summaries.

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