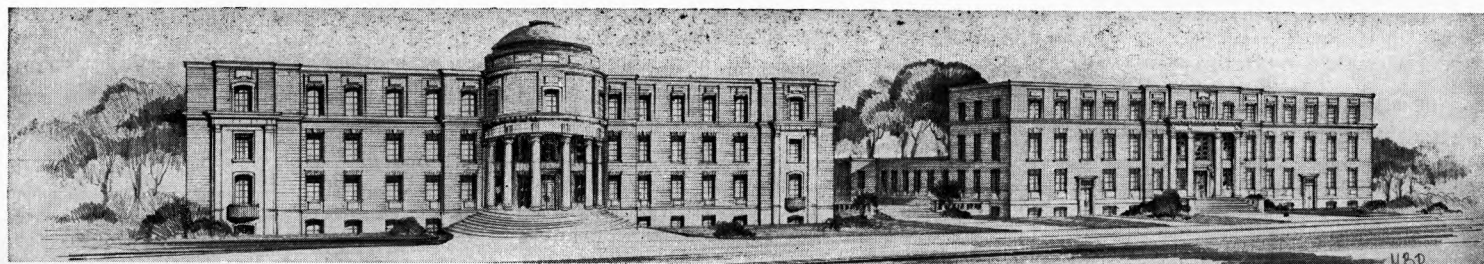


Mineral Industries



College of Mineral Industries, The Pennsylvania State University, University Park, Pennsylvania

VOLUME 31

MAY 1962

NUMBER 8

Beneficiation of Bastnaesite Rare Earth Ore

DAVID R. MANEVAL*

Introduction

The rare earths are neither rare nor unavailable. They are present in trace amounts in much of the earth's crust and in both plant and animal life. Although many individual mineral sources exist, such deposits are, for the most part, small. The over-all crustal abundances follow the odd-even rule closely within the series, with the light lanthanons being the more abundant.^{35, 43, 48}

With the discovery of the Mountain Pass, California, bastnaesite rare earth ore deposit in 1949, the United States found itself with a huge potential source of the rare earths.^{13, 30} It had long been known that the rare earth elements were not "rare"; in reality, they were more abundant than cobalt and chromium, for example. This discovery made a relatively cheap source readily available.

The owners of this deposit, the Molybdenum Corporation of America, have developed processes for the production at the mine of a mixed rare earth fluorocarbonate concentrate product, a mixed rare earth oxide product, and rare earth chlorides. Other products are produced in the other plants of the company and by its customers.

An increased demand for the individual rare earth elements as pure metals or compounds is anticipated due to their many unusual chemical and physical properties.^{6, 9, 10, 27, 35} New uses are being found in optics, metallurgy, vacuum tube manufacture, and atomic energy, as larger quantities of high purity rare earths become available. Also to be considered are the economic factors which show that individual rare earths, because of their unique properties, have a much higher value than mixtures. Therefore, a method for separating the bastnaesite rare earths has been investigated in the Department of Mineral Preparation of the College of Mineral Industries.

In choosing an approach to this problem, several factors were considered. A separation scheme for natural bastnaesite materials was desired that was new and unique and, therefore, unencumbered by patents. A theoretical question of selective complexing alkylphos-

* Research Associate in Mineral Preparation.



DR. DAVID R. MANEVAL

phoric acids with the pure rare earths was also considered. After a thorough literature search, an extraction scheme was chosen, utilizing alkylphosphoric acid digestion of the concentrated ore without prior dissolution in mineral acids, followed by various leaching processes.

The investigation was necessarily limited. The first four elements in the lanthanide series, lanthanum, cerium, praseodymium, and neodymium were chosen for study because they are abundant in bastnaesite, they are consecutive in the lanthanide series, and they are readily available in high purity.³²

It became evident early in this investigation that a rapid and accurate analytical procedure for the analysis of separation products was required. A thorough study of existing analytical methods was made. After consideration of the instrumentation and analytical tools available, the X-ray fluorescence spectrographic method of analysis was chosen as being suitable for the four important elements.

(Continued on page three)

Mineral Industries

Published Monthly
from October to June, inclusive
by

THE PENNSYLVANIA STATE UNIVERSITY

COLLEGE OF MINERAL INDUSTRIES

M. I. CONTINUING EDUCATION

D. C. JONES, *Director*

ROY G. EHMAN, *Editor*

PENNSYLVANIA'S

COLLEGE OF MINERAL INDUSTRIES

Dedicated to

Education and research in all fields of mineral discovery, extraction, and utilization to the end that true conservation — the efficient exploitation of known mineral deposits, the discovery of new deposits, and the development of new techniques for using mineral raw materials not now industrially employed — shall be achieved now and in the future.

DIVISIONS OF SERVICE

EARTH SCIENCES: Geology, Mineralogy, Geography, Geophysics, Geochemistry, and Meteorology.

MINERAL ENGINEERING: Mining Engineering, Mineral Preparation Engineering, Petroleum and Natural Gas Engineering, and Mineral Economics.

MINERAL TECHNOLOGY: Metallurgy, Ceramic Technology, and Fuel Technology.

FIELDS OF WORK

Resident Education

Research

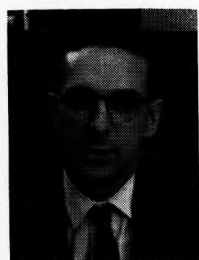
Continuing Education

Correspondence Instruction

Entered as second-class matter at State College, Pa., November 1, 1938, under the Act of August 24, 1912.

MAY 1962

About the Author —



David R. Maneval is a research associate in the College of Mineral Industries. He received his B.S. and M.S. degrees in chemistry from The Pennsylvania State University in 1950 and 1957 respectively, and the Ph.D. degree in mineral preparation from the same University in 1961. He came to Penn State as a research assistant in mineral industries in 1953. From 1953 to 1957, Dr. Maneval was an analytical chemist for various projects in the College of Mineral Industries. From 1957 to the present, he has been doing research in the Department of Mineral Preparation.

His fields of research have included beneficiation and analysis of Pennsylvania manganese ores, Colorado tungsten ore, North Dakota uraniferous lignite, and California bastnaesite rare earth ores. He also is inter-

(Continued on page eight)

COLLEGE ACTIVITIES

EARLE RYBA, assistant professor of metallurgy, recently attended a meeting of the Committee on Alloy Phases, which is a unit of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers in New York City. He also attended a seminar on "Electronic Structure and Alloy Chemistry of Transition Elements," sponsored by the same committee. Dr. Ryba was accompanied by two graduate students from India, P. K. KEJRIWAL and K. S. SREE HARSHA.

JOHN H. HOKE, assistant professor of metallurgy, and CHARLES H. KROPP, instructor in metallurgy, conducted a field trip for members of the junior class in metallurgy during the week of March 19-24. The class visited industrial plants and laboratories in the Pittsburgh district. Part of a program designed to give students in metallurgy an opportunity to observe directly various operations in the metals industry, the trip included visits to the facilities of Jones and Laughlin, United States Steel, United Engineering and Foundry, The Aluminum Company of America, Vanadium Alloy Steel Company, Westinghouse Electric Corp., and St. Joseph Lead Co.

LEONARD G. AUSTIN, associate professor of fuel technology, and R. P. GARDNER, former research assistant in fuel technology, presented two papers entitled "A Radioactive Tracer Technique for the Determination of Breakage Functions" and "Prediction of Weight-Size Distributions from Selection and Breakage Data" at the First European Symposium on Size Reduction in Frankfurt, Germany, April 8-13.

PETER H. GIVEN, associate professor of fuel technology, presented a paper on "Study of Functional Groups in Coals by Means of Radioactive Tracers" to the Fuel Chemistry Division of the American Chemical Society (141st Meeting) at Washington, D. C., on March 27.

The Department of Mining was represented by papers at two national meetings held in May. HOWARD L. HARTMAN, professor and head of the Department, with SATHI TANDANAND, A.P.I. fellow, presented a paper on the results of Mr. Tandanand's doctoral research entitled "Investigation of Dynamic Failure Viewed by High-Speed Photography" at the Fifth Rock Mechanics Symposium at Minneapolis, May 3 to 5. This meeting was jointly sponsored by the Departments of Mining at Penn State, Colorado School Mines, Missouri School of Mines, and the University of Minnesota. B. J. KOCHANOWSKY, professor of mining engineering, spoke at the same meeting on "Progress Made with Angle Drilling in Bench Blasting." Dr. Kochanowsky presented a second paper entitled "Recent Developments in Inclined Drilling and Blasting" at the Coal Convention of the American Mining Congress in Pittsburgh, May 7 to 10. ROBERT STEFANKO, assistant professor of mining engineering, was also on the program of the Coal Convention, speaking on "Practical Rock Mechanics."

B. F. HOWELL, JR., head of the Department of Geophysics and Geochemistry, presented a talk on the Geological Sciences Program at Penn State before the Division of Earth Sciences of the National Research Council in Washington, D. C., on April 2. Dr. Howell also has been re-elected to the board of directors of the Seismological Society of America for the 1962-63 year.

J. C. GRIFFITHS, head of the Department of Mineralogy, was invited to participate in a symposium and short course, March 26-31, on the use of computers in mining (Exploration and Production) given by the Department of Mining at the University of Arizona, Tucson, Arizona. Dr. Griffiths presented a paper entitled "The Uses of Computers and Statistics in Exploration and Production of Natural Resources," which is printed in the Proceedings, Volume 1.

ROBERT W. LINDSAY, head of the Department of Metallurgy, attended a national conference on metallurgical education, April 5-7, at the Massachusetts Institute of Technology. Entitled "Trends in Undergraduate Education in Metallurgical Engineering and Materials Science," the conferences considered several pressing problems in metallurgical education. Among them are the impact of materials science on metallurgy, the current needs of industry, and effective techniques in laboratory instruction. Canadian as well as American educators participated in the conference.

GUY E. RINDONE, associate professor of ceramic technology, recently addressed the Graduate Seminar of the Department of Metallurgy at the Massachusetts Institute of Technology, on the subject, "Some Studies of Glass Properties and Their Structural Interpretation."

RUSSELL R. DUTCHER, research associate in geology, spoke before the Geological Society of Franklin and Marshall College, April 25. Dr. Dutcher also spoke on May 10 to the Four College Geology Conference at the University of Massachusetts at Amherst. His topic for these talks was "Coal and Coal Seams."

A. K. BLACKADAR, R. T. DUQUET, C. L. HOSLER, and H. A. PANOFISKY, all of the department of meteorology, were guests at a meeting of the Atmospheric Science Research Center at Albany, New York, March 20. The group then visited eight campuses of the State University of New York, lecturing on careers and opportunities in meteorology. These tours were part of the Visiting Scientist Program of the American Meteorological Society sponsored by the National Science Foundation.

R. T. DUQUET, assistant professor of meteorology, and H. A. PANOFISKY, professor of meteorology, presented papers entitled "Determination of Stress from Wind and Temperature" and "Circulation Changes Associated with January Warm Spells," at the annual Washington meetings of the American Meteorological Society and American Geophysical Union.

(Continued on page eight)

Beneficiation —

(Continued from page one)

The Mountain Pass Bastnaesite Ore Deposit

In April 1949 an ore body containing a minimum of some 10 billion pounds of recoverable rare earth metals was discovered in the Mountain Pass district of San Bernardino County, California. The mineral, bastnaesite, is a natural rare earth fluorocarbonate of the cerium group that affords an abundant and high grade source of the lighter rare earth elements. The Mountain Pass district is an area about 7 miles long and 3 miles wide, centered near Mountain Pass, 60 miles southwest of Las Vegas on U. S. Highway 91. Following its discovery, the Molybdenum Corporation of America purchased a number of claims at the deposit and a mill on the property which had been constructed to process the district's gold ores. The ore as mined contains, on the average, approximately 10% of rare earth oxides. The balance consists in varying proportions of calcite, barite, silicates, and ferromagnesian minerals. The deposit is the largest known in the world at the present time. The main ore body is about 2,500 feet long, 500 feet wide, and 300 feet deep. Thus, a huge domestic deposit of readily available rare earth ore is on hand. ^{13, 16, 30, 32, 34, 41, 47}

Concentration Process Used at Mountain Pass

The Molybdenum Corporation of America, which acquired the deposit in 1951, uses a combination of flotation, acid leaching, and roasting to make a plus 90% concentrate at its compact mill. Flotation of a heated pulp proved to be the real key to successful low cost concentration. ^{17, 19, 21, 22, 25, 29} Figure 1 illustrates the flow of material through the preparation plant. Numbers in brackets in this section refer to equipment in Figure 1.

Trucks [1] from open pit bring bastnaesite ore to the mill which handles 160 tons per day. Run of the mine ore contains on the average, 9% Re_2O_3 (rare earth oxide). The ore is dumped into the coarse ore bin [2] (150 tons capacity). The feed (minus 15") is carried by a 30" x 13" pan feeder [3] onto a 3' x 5' grizzly screen [4]. The plus 2" ore is fed to a 25 tons per hour 15" x 24" jaw crusher [5] set at 2". The minus 2" material flows to a 40" x 72" vibrating screen [6] which passes minus $\frac{3}{4}$ " material. The oversize goes to a 25 tons per hour capacity Symons cone crusher (2' size) set at $\frac{3}{4}$ " [7]. The combined minus $\frac{3}{4}$ " products flow into a 200 tons capacity fine ore bin [8]. Hardinge feeders [8A], operating under the fine ore bins, draw this feed for transfer to a 4 $\frac{1}{2}$ ' x 8' rod mill [9]. This mill which has a 150 tons per day capacity, discharges a minus 10 mesh product. Water and two to six pounds of soda ash per ton of feed are added just ahead of the rod mill to maintain pH control at about 9.5 [32].

The rod mill product is piped to a 4 $\frac{1}{2}$ ' x 18' size Dorr classifier [10] operating in closed circuit with a Marcy 4' x 5' ball mill [11]. The classifier overflow, containing 52% solids and 96% minus 100 mesh, then flows through a series of three heated tanks [12]. In the first (4' x 4') tank, the pulp temperature is elevated to 140°F by utilizing waste heat from the Diesel-generator sets at the power plant [14]. Temperature is increased to 180°F, then to 200°F in the second (4' x 8') and third (4' x 8') tanks by boiler steam

from a 150-horsepower boiler plant which furnishes steam at 125 pounds per square inch pressure [13]. Holding capacity of the series of tanks is sufficient to provide a total pulp retention time of five minutes in the boil, or third, tank. Sodium silico fluoride (2 pounds per ton) is added before the first tank as a silica depressant and promoter of Re_2O_3 [33]. Sodium silicofluoride (3 pounds per ton), Orzan A (ammonium lignin sulfate, 4-8 pounds per ton) as a barite and lime depressant, and Emersol 300 (oleic-linoleic acid, 1 pound per ton) are added between the second heat tank and the third boil tank [34].

Hot pulp, at a temperature of 130°F, flows to the flotation roughers made up of four 36" Fagergren and eight 24" Agitair machines [15]. The roughers produce a finished tail which goes to a thickener for water recovery. The froth with 35% solids containing 30% Re_2O_3 is cleaned in five stages in Denver 18S flotation cells. The first stage [16] with five cells, produces a froth with 30% solids, containing 35% Re_2O_3 . The underflow tails from the first cleaner report to a Dorrclone classifying cyclone [17]. The cyclone underflow is returned to the ball mill classifier circuit for regrinding, and the overflow reports to the rougher cells. Froth from each cleaner advances to the next stage, and the tail from each cleaner is recycled to the preceding cell. The second stage [18] with three cells produces a froth with 30% solids analyzing 45% Re_2O_3 . The third stage [19] with two cells produces a froth with 30% solids containing 50% Re_2O_3 . The fourth cleaner stage [20] with one cell produces a 25% solids froth with an Re_2O_3 content of 55%. The fifth and final cleaner cell [21] produces a froth with 25% solids containing 63% Re_2O_3 . The Re_2O_3 recovery is 75-80%.

The 63% concentrate may be routed in several ways [22]. Froth can be acid leached [23] to remove lime and raise the grade from 63% Re_2O_3 to 72-75% Re_2O_3 or froth can be sent directly to the filter [25]. The four acid leach tanks are 7' x 8' [23] and operate by counter-current decantation using 10% HCl fed to each tank [35]. The leached slurry is thickened in a 8' x 30' thickener [24] and fed to a 2' x 6' Eimco filter [25]. The filter cake containing 7% moisture can

be sold as rare earth fluorocarbonate or roasted and sold as Re_2O_3 [26]. Concentrate to be calcined is fed into a 4' x 25' Edwards roaster [27]. The final concentrates, then, are the 63% Re_2O_3 product [36], 68 to 74% Re_2O_3 acid leached product [36] or the 92% plus acid leached and calcined product [37].

Tailings from the rougher cells flow to a thickener [28] for water recovery. The underflow goes to the waste tailings pond [31], or to a barite recovery circuit. The tailings thickener overflow and the overflow from the leaching circuit thickener join with make-up water (pumped ten miles to the plant) [29] and go to recirculation [30].

Composition of Bastnaesite Concentrates

There are three grades of bastnaesite concentrates supplied by the Molybdenum Corporation of America. They are referred to as 60%, 72% and 92% concentrates (oxide basis).³⁷ Table 1 shows the proportion of the individual rare earth elements in the bastnaesite concentrates.

TABLE 1. Proportion of the Individual Rare Earth Elements in the Bastnaesite Concentrates.

CONSTITUENT	PERCENT
Cerium	55.8
Lanthanum	28.6
Praseodymium	4.1
Neodymium	10.5
Samarium	0.7
Gadolinium & Europium	0.3
Total	100.0

Chemistry of the Rare Earth Elements

The elements comprising the rare earths have been defined in many ways. The first inner transition series, that is those elements with atomic numbers 58 through 70, are always included in any definition. In this series the $4f^{14}5d^1$ electron configuration contains fewer than its full complement of 15 electrons. If the elements lanthanum ($4f^05d^1$) and lutetium ($4f^{14}5d^1$) at the ends of the inner transition series are included in the designation of rare earths, the group is known as the lanthanons or lanthanide series and occupies the place in the periodic table between barium and hafnium, for which the

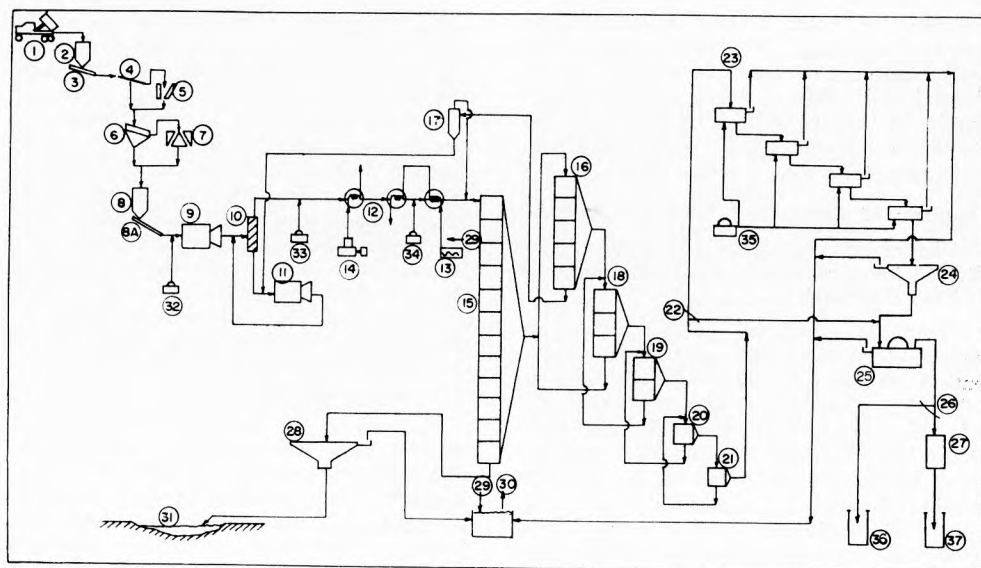


FIGURE 1. Bastnaesite Ore Flow Sheet

periodic law predicted but one element. Older definitions of the rare earths were broader and included several other elements, namely yttrium and scandium, and even hafnium, zirconium and thorium. These elements all have acid insoluble fluorides and other chemical similarities to the lanthanons and often occur with the true rare earths in nature.^{28, 43, 48}

The lanthanons were discovered and isolated in more or less pure form over a period of more than a century, from about 1790 to 1910.⁴⁶ This period is extended to World War II if element 61, promethium, is considered. Promethium was first isolated from uranium fission products and, being unstable under normal conditions, has not been found in nature. The order of discovery of these elements closely follows the order of the difficulty of their separation.

The similarity in properties among the rare earths arises from their similarity in ionic size and electronic configuration. The outermost electronic arrangement is essentially constant and can be represented by $4f^{n-1}5d^16s^2$ or the nearly equivalent $4f^{n+1}6s^2$ with $n=1$ for cerium increasing to $n=13$ for ytterbium. As a more general rule, the lanthanons have no 5d electron in the ground state. The last electron in the 4f shell (or the 5d electron when it exists) is almost as loosely held as the two 6s electrons and acts as a valence electron, thus giving rise to a plus three oxidation state for all the elements in the lanthanide series. Because of the inherent stability of the noble gas configuration (no 4f electrons), the half completed sub-shell (seven 4f electrons) and the fully completed sub-shell (fourteen 4f electrons), other oxidation states arise. Cerium can revert to the La(III) core by losing four electrons and terbium can similarly revert to the gadolinium core, though not as readily. Praseodymium exhibits a plus four oxidation state as an oxide, but the plus five state, which might be expected, has not been proved to exist. Europium(III) and ytterbium(III) are readily reduced to the bivalent state, resulting in the gadolinium and lutetium cores respectively. Samarium can attain a somewhat unstable bivalent state.

In the rare earth series, the ionic radii decreases with increasing atomic number due to the inability of the growing 4f shell to entirely compensate for the increasing positive nuclear charge. This is the well known lanthanide contraction. Separation procedures based on fractionation are based primarily on the exploitation of the small, but significant differences in physical and chemical properties among the rare earths.

Summary of Conventional Separation Methods

All rare earth separation methods can be divided into two classes, the purely chemical and the fractional.

Chemical methods are applied to separate certain elements. These methods are based entirely on the attainment of oxidation states other than plus three. Valence change methods effect good separations with few operations; however, they are not ideal and depend largely upon total and relative amounts of the elements in the mixture to be separated. Generally, the cerium and yttrium groups are separated by solubility differences before applying valence change methods to provide greater selectivity.^{43, 48}

The separation of cerium depends upon its oxidation from Ce(III) to Ce(IV) in nitrate solution and precipitation of basic salts or the insoluble iodate.^{18, 30} The other trivalent earths remain in solution. The valence change Tb(III) to Tb(IV) as a means of separation has been used only in molten alkali systems. Neither praseodymium nor terbium give plus four ions in solution.

The separation of europium and ytterbium is effected by reduction to the bivalent state. Their chloride solutions may be reduced with amalgamated zinc or electrolytically at a mercury cathode. These elements in the bivalent state form insoluble sulfates. Thus 0.5% sodium amalgam, shaken with an acetate solution of the cerium group earths reduces samarium and europium. When this amalgam is shaken with a mixture of acetic and sulfuric acids, a precipitate of samarous and europous sulfates is obtained. Most of the samarous sulfate dissolves as the acetate, and the rest is removed from the precipitate with dilute nitric acid. Repetition of this process affords pure europium and samarium.

All fractionation processes are based upon small differences or trends in properties resulting from the lanthanide contraction. Such properties are basicity, covalent character, stability of complex ions, solubility of various salts in various solvents, and thermal stabilities.

Vickery⁴⁸ covers exhaustively the separation techniques employed through 1953. These include fractional precipitation and crystallization, valency change reactions, thermal reactions, solvent extraction and ion exchange. A complete separational scheme, which makes use of most of these techniques, is outlined in Vickery. Such a combination of techniques is carried out with comparative ease on a laboratory scale, but for commercial production of high purity rare earths the ideal scheme would be a single continuous fractional method. The methods of ion exchange or solvent extraction have been developed to fit these requirements. In all separational schemes developed to date, the percent upgrading per step is only fractional, necessitating repetition of steps until the desired purity is attained.

Summary of Modern Separation Methods

There are two different methods of separating rare earths by elution from resin beds. The first²⁸ was developed at both Oak Ridge National Laboratories and at Iowa State College during World War II for the separation of radioactive tracers. A small quantity of rare earths is adsorbed on the top of a very long ion exchange resin bed in the hydrogen or ammonia form, and the resulting narrow band is eluted with a citric acid solution buffered with ammonia. The rare earth band expands as it moves down the column, and the individual rare earths travel at different rates. Most of the separation is due to the selectivity of the complexing agent for the rare earth ions, as their affinities for the resin are nearly identical.

The second ion exchange method, developed at Iowa State College, is primarily for separation of macro quantities of rare earths.^{38, 39, 40} A mixture of rare earth ions is adsorbed on the top of a resin bed in the hydrogen form if citrate is to be the eluant, or in the copper form if ethylenediaminetetraacetate is used. This band does not expand

appreciably during elution, but the individual rare earth species separate to form individual bands within the main band and can be collected in pure form at the bottom of the column. The most efficient process of this type uses ethylenediaminetetraacetate as the complexing agent rather than citric acid. This technique has recently been applied to bastnaesite by the U. S. Bureau of Mines.²⁴ Ion exchange methods are now used for commercial production of large quantities of high purity rare earths.

Solvent extraction separation of the rare earths has been studied by many workers from the theoretical standpoint.^{5, 7, 14, 15, 23, 31} Practical extraction schemes for the separation of the bastnaesite rare earths have been investigated by Ionics Incorporated^{31, 32} and the U. S. Bureau of Mines at Reno, Nevada.^{1, 2, 12} A five tons per day plant, costing 2.8 million dollars, involving 95 mixer-settler stages using organic phosphorus compounds has been proposed by H. B. Petrow.³³ Such a plant could be designed with a maximum recycling of solvents. Chemical cost, it is estimated, could be held to 30 cents per pound. The rare earth product, with an estimated purity of 90-99% would cost an average of 71 cents per pound. Although not being utilized for production at the present time, some form of solvent extraction holds much promise as the most technically sound and economically feasible continuous separation process.

It is logical to assume that Petrow proposed the use of organic phosphorus compounds due to their selective nature, ready availability, relatively low cost, and other desirable properties. These compounds may also be synthesized in many possible forms.

Organophosphorus Compounds

Organic esters of orthophosphoric acid provide a versatile family of solvent extraction reagents. Some of these compounds have been known for over a century. In the last two decades the organophosphorus compounds have been studied and developed as useful agents for ore processing, analytical, and nuclear uses.^{3, 4, 8, 17, 44}

The alkylphosphoric acids are the partial or complete substitution products by aliphatic or cyclic organic groups for the hydrogen atoms of orthophosphoric acids.

A considerable difference exists between the physical and chemical properties of the monoalkyl and dialkylphosphoric acids compared to the tertiary compound which is neutral in character. The alkylphosphoric acids are relatively unstable to heat, many of them decomposing at temperatures well below 200°C. They are strongly acidic and corrosive to certain metals. They have a tendency toward hydrolysis in water solutions.⁴⁵

Ionization constants show that monoethylphosphate is a stronger acid than phosphoric acid. The single hydrogen of the disubstituted orthophosphoric acid is strongly dissociated, having an ionization constant equivalent to K_1 of orthophosphoric acid.⁴² As the size of the alkyl group is increased, the mono- and dialkylphosphoric acids become slightly weaker acids.⁴²

After considering the wide variety of procedures currently in use and suggested for rare earth separations, a chemical separation process was designed in our laboratories involving digestion of natural bastnaesite

rare earth concentrate with alkylphosphoric acid followed by various leaching operations.

Extraction Procedure Developed in the Department of Mineral Preparation

It should be possible to base a partial and complete separation of the rare earths on the differential solubility of complex organophosphate rare earth compounds in various leaching solutions. The following extraction scheme was designed. The rare earth containing material was digested in alkylphosphoric acid. The treated concentrate was then digested in boiling water, hot alkali, and finally in hot nitric acid. Pure rare earth oxides and carbonates are virtually insoluble in kerosene, water, and alkali, while only ceric oxide is insoluble in acid.^{20, 43} The fact that kerosene, water, and alkali solutions were found to contain rare earth compounds is evidence that various reactions had occurred. The final extraction scheme is illustrated on Figure 2.

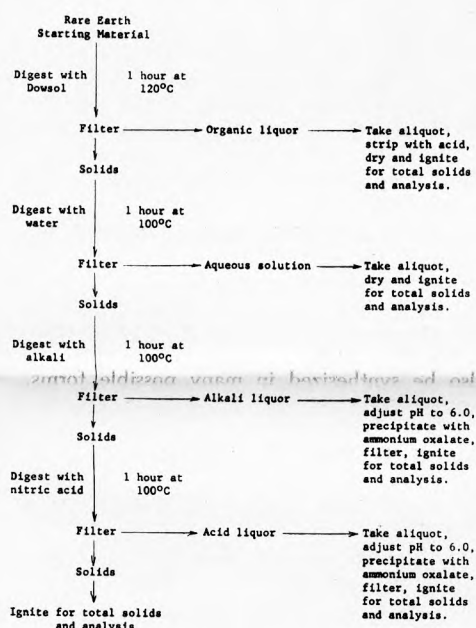


FIGURE 2. General Extraction Scheme

A commercial alkylphosphoric acid solution, Dowsol-12, was secured from Dow Chemical Company, Midland, Michigan. The Dowsol-12, as supplied, contains 25-30% (by volume) dodecylphosphoric acid (frequently referred to as DDPA) in kerosene.

Results

Over the course of a year, several bastnaesite concentrates as well as synthetic mixtures and pure rare earths were tested for the degree of separation which could be achieved by the previously mentioned beneficiation scheme. All products were analyzed by X-ray emission spectrography using methods developed by the author.²⁰

Proposed Scheme for Separation of Natural Rare Earth Material

A consideration of the experimental results indicates that the rare earth carbonate (lot 69) had a larger and more practical degree of mass transfer than the rare earth oxide (lot 19). For this reason it is proposed that the rare earth carbonate is a more logical and practical starting material.

The following scheme is proposed as one possibility for the separation of the natural rare earth carbonate using Dowsol-12. In a single extraction the results illustrated on Figure 3 could be expected.

In an industrial process, the organic solution would be stripped with nitric acid, precipitated with hydroxide, and ignited to form rare earth oxide. The aqueous solution would be precipitated with hydroxide and ignited to the oxide. The alkali and acid solutions would be precipitated with oxalic acid and then ignited to the oxides. The insoluble matter would remain as the carbonate or might be ignited to the oxides. Each oxide residue would then respond in a manner similar to the natural rare earth oxides. It would be difficult to predict what distribution patterns would result from the material which had originally been the various residues. These residues may or may not respond as the original carbonate or as the natural rare earth oxide.

The natural rare earth oxides do not always react as the carbonates. Therefore, the alkali fraction, for example, from the first carbonate digestion cycle would be enriched in lanthanum, cerium and praseodymium, but this fraction, being fed as the rare earth oxide through the same digestion scheme, would find its various components raised in some cases and lowered in others.

Extensive large scale commercial testing would be necessary to fully evaluate the potentialities of the extraction scheme here presented on an industrial scale. It is considered feasible that repeated treatment with successive stages would continue to upgrade or downgrade the rare earth contents with each repetition of this extraction scheme.

Conclusions

Due to the anticipated increased demand for pure rare earths and the availability of major amounts of bastnaesite rare earth ore from the Mountain Pass, California, deposit, a new method was sought to separate the principle rare earth constituents of the ore concentrates.

A method was developed by which the solid bastnaesite rare earth oxide concentrates or carbonate concentrates were successively reacted with a kerosene solution of dodecylphosphoric acid (Dowsol-12), followed by leaching with water, alkali solution, and nitric acid. Following Dowsol treatment, solubility trends for pure cerium and praseodymium oxides and carbonates, and the carbonates of lanthanum and neodymium were determined using the previously mentioned solvents. Mixtures of pure oxides and pure carbonates approximating the composition of the bastnaesite concentrates were also treated in the same manner. The solutes from each step and the insoluble residues were analyzed.

A quantitative X-ray fluorescence spectrographic technique was developed as a part of this work by which lanthanum, cerium, praseodymium, and neodymium could be determined as major components.

Under the conditions of the extraction scheme and the analytical procedures described an evaluation of the results leads to the following conclusions:

1. Solid bastnaesite rare earth material reacts with a kerosene solution of alkylphosphoric acids to yield products which

are, to varying degrees, kerosene, water, alkali, and acid soluble.

2. Rare earth carbonates, with some exceptions, are more reactive than the oxides.

3. There is evidence that the rare earths in the natural materials are in a true solid solution or in mixed crystals, rather than existing as discrete compounds. Synthetic mixtures of the pure oxides and carbonates of the same elemental composition as the natural materials do not respond the same as these natural products to the reaction and extraction treatment.

4. The cerium in bastnaesite ore was found to be, at least in part, in the cerous rather than the ceric state as evidenced by its acid solubility. The acid insolubility of ceric oxide was confirmed.

5. Cerium and praseodymium were found to be very similar in many of their reactions and solubilities. No other combination was found to be so closely related. This similarity of reactivity is related to the formation of a tetravalent rare earth complex in the case of both elements. Lanthanum and neodymium maintained their trivalent status.

6. A separation scheme with industrial potentialities may be feasible based on the

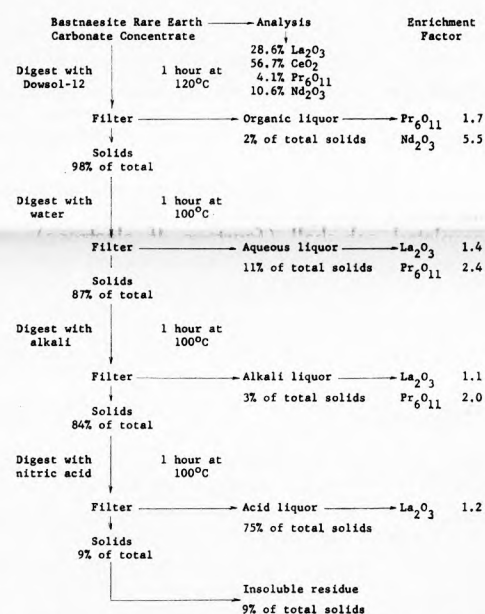


FIGURE 3. First Stage of Proposed Industrial Separation Process

reaction of Dowsol-12 and the natural rare earth carbonate. The proposed digestion scheme is outlined in this paper.

REFERENCES

- Bauer, D. J., Rice, A. C., Berber, J. S., *Liquid-Liquid Extraction of Rare Earth Elements*, U. S. Bureau of Mines, RI-5570 (1960).
- Bauer, D. J., Rice, A. C., Berber, J. S., "Liquid-Liquid Extraction of Rare Earth Elements," paper presented at AIME meeting, San Francisco, Calif. (1959).
- Blake, C. A., Jr., Baes, C. E., Jr., Brown, K. B., "Solvent Extraction With Alkylphosphoric Acids and Related Compounds," paper presented before the ACS Nuclear Technology Symposium, San Francisco, Calif. (1958).
- Blake, C. A., Jr., Baes, C. E., Jr., Brown, K. B., "Solvent Extraction With Alkylphosphoric Compounds," *Ind. and Eng. Chem.* 50(12), 1763-67 (1958).
- Bochinski, V., Smutz, M., Spedding, F. H., "Separation of Individual Rare Earths by Liquid-Liquid Extraction From Multi-Component Monazite Rare Earth Nitrates," *Ames Lab, N.S.A.* 7, 5039, ISC-348 (1953).
- Anonymous, "Rare Earths—Raring to Go," *C. & En. News*, 550-52 (1956).

(Continued on page eight)

GRADUATES RECEIVE ADVANCED DEGREES

June 10, 1961

Major Field	Name	Degree	Thesis
Ceramic Technology	James Floyd Sarver, Jr.	Ph.D.	Polymorphism, Subsolidus Equilibria, and Luminescence Data on Phases in the System $\text{ZnO-MgO-GeO}_2\text{-SiO}_2\text{-TiO}_2$
	Raymond Joseph Bratton	M.S.	Mineral Constitution of Some High-Alumina Clays of Pennsylvania Before and After Heat Treatment, and Their Ceramic Properties
Fuel Technology	Michael Arthur Short	Ph.D.	Some Advances in X-ray Diffractometry and Their Application to the Study of Anthracites and Carbons
	Anthony Michael Cecere	M.S.	The Filtration of Coal Solutions
	Leo Joseph Duffy	M.S.	Concentrated Nitric Acid Oxidation of the Organic Matter of Chattanooga Black Shale
Geochemistry	Jen-Ho Fang	Ph.D.	X-ray Studies of Ca-Cl_2 -Chabazite and Dehydrated Natrolite
	Daniel Ballou Hawkins	Ph.D.	Experimental Hydrothermal Studies Bearing on Rock Weathering and Clay Mineral Formation
	Roslyn Berman	M.S.	Rb-Sr Age Determinations of Lepidolites by X-ray Fluorescent and Isotope Dilution
	Roland Eichler	M.S.	Carbon and Oxygen Isotope Ratios in Marine and Fresh-Water Mollusc Shells
Geography	Dennis Michael Driscoll	M.S.	The Variability of Precipitation in California
	John Paul Roach	M.S.	The Influence of Physical Geography on Naval and Amphibious Warfare in the Pacific in World War II
	Charles Arthur Stansfield	M.S.	A Geographical Analysis of the Cattle Industry of South-eastern United States
	John Viletto, Jr.	M.S.	The Ecological Crop Geography of the Orange in California
Geology	Alexander Rankin Cameron	Ph.D.	Some Petrological Aspects of the Harbour Seam, Sydney Coalfield, Nova Scotia
	Robert Lee Ellison	Ph.D.	Middle Devonian Mahantango Formation in Parts of South-central Pennsylvania
	Alan Davis	M.S.	The Artificial Coalification of Wood Samples of <i>Taxodium distichum</i> (L.) Rich.
	George M. Farlekas	M.S.	The Geology of Part of South Mountain of the Blue Ridge Province North of the Pennsylvania-Maryland Border
	Norman Oliver Frederiksen	M.S.	Sporomorphae of the Brookville Seam Near Brookville, Pennsylvania
	Richard H. Matzke	M.S.	Fracture Trace and Joint Patterns in Western Centre County, Pennsylvania
Geophysics	John Charles Shank	M.S.	A Detailed Magnetic Survey in the Triassic Basin, North Chester County, Pennsylvania
Metallurgy	John William Andrews	M.S.	The Electrolytic Extraction of Manganese from Pregnant Sulfur Dioxide Leach Solutions
	Robert William Dolan	M.S.	Zone Refining of Molybdenum by Electron Beam Bombardment Technique
	George Henry Karchner	M.S.	The Effect of Electroplated Chromium on the Strength and Ductility of Electroplated Nickel
Meteorology	Abraham M. Pavlowitz	M.S.	Dynamical Precipitation Forecasting
	Merlin Wayne Zook	M.S.	The Advancement of General Precipitation Shields Across Pennsylvania
Mineral Economics	Harleigh F. Fatzinger	M.S.	The Effect of Present Depreciation Allowances on the United States Industry
Mineralogy & Petrology	David Narwyn Hinckley	Ph.D.	Mineralogical and Chemical Variations in the Kaolin Deposits of the Coastal Plain of Georgia and South Carolina
	Richard Allen Landy	Ph.D.	Variation in Chemical Composition of Rock Bodies: Metabasalts in the Iron Springs Quadrangle, South Mountain, Pennsylvania
Mineral Preparation Engineering	David Richard Maneval	Ph.D.	Separation and Analysis of Bastnaesite Rare Earths
	James Kelly Kindig	M.S.	Investigations on the Operation of the Circular Concentrator for Cleaning Fine Coal
Mining Engineering	Thomas Victor Falkie	Ph.D.	An Operations Research Approach to Optimization of Mine Haulage
Petroleum & Natural Gas Engineering	Chapman Cronquist	M.S.	Microscopic Behavior of Displacements in a Porous Medium of Oil and Water by Various Alcohols
	Jerry Lee Hamaker	M.S.	Factors Affecting Miscible Displacements in a Horizontal Unconsolidated Porous Medium
	Martin Hersch Harris	M.S.	A Study of Gas-Gas Displacements in Linear Unconsolidated Porous Media

GRADUATES RECEIVE ADVANCED DEGREES — continued*

Major Field	Name	Degree	Thesis
	Raymond Edward McDonald, Jr.	M.S.	The Displacement of Bradford Crude Oil Using Several Modifications of the Alcohol Slug Process
	E. Forest Mintz	M.S.	A Laboratory Method for Determining a Reservoir Rock Water-Sensitivity Index, and Its Application to Some Appalachian Gas Sands
	Ramiro Perez-Palacia	M.S.	A Study of Silica Gel as Water Shut-Off Agent
August 26, 1961			
Major Field	Name	Degree	Thesis
Ceramic Technology	Kee Hyong Kim	Ph.D.	Phase Equilibria in the System $\text{Li}_2\text{O}-\text{B}_2\text{O}_3-\text{Al}_2\text{O}_3-\text{SiO}_2$ and Some of its Subsidiary Systems
	Frederick Welford Perry	Ph.D.	Variability of Mullite as a Function of Conditions of Crystallization and Subsequent Heat Treatment
Fuel Technology	Lewis Grant Lesoine	M.S.	The Reaction of Coke with Hydrogen Sulfide at Carbonization Temperatures
	James Robert Malone	M.S.	The Reactions of Selected Bituminous Coals with Concentrated Sulfuric Acid
	Edward Stephen John Tomezsko	M.S.	Preparation and Properties of Activated Carbons Prepared from Nitric Acid Treatment of Bituminous Coal
Geography	Paul Fredrick Mattingly	Ph.D.	Harrisburg, Pennsylvania: A Geographical Analysis of Elected Aspects of Retail and Wholesale Trade
	Jerome Thomas Kidd	M.A.	No Thesis
Geology	Bruce Donald Middleton	M.S.	A Preliminary Investigation into the Application of Coal Petrography in the Blending of Anthracite and Bituminous Coals for the Production of Metallurgical Coke
	Jan G. Smith	M.S.	The Geology of the Clear Creek Area Montana-Idaho
Geophysics	Ferol Fredric Fish, Jr.	Ph.D.	Effect of Fluid Content on the Absorption of Elastic Waves in Sandstone
	Rahmat Ghaffar-Adly	M.S.	A Detailed Gravity Survey in the Triassic Basin, North Chester County, Pennsylvania
Metallurgy	Kenneth Elmer Pinnow	Ph.D.	The Influence of Cerium on the Hot Workability of an Austenitic Iron-Chromium-Nickel Alloy in the Cast Condition
	William Anton Nystrom	M.S.	The Mechanical Properties of Electrodeposited Brass
Meteorology	Louis Robin Brody	M.S.	Effects of Friction on Pressure Systems
Mineral Economics	James Bruce Carruthers	M.S.	The Changing Political and Economic Climate in the Middle East and Its Effect on the Petroleum Industry
Mineralogy & Petrology	Henry Galt Siegrist, Jr.	Ph.D.	Multivariate Statistical Study of Two Sandstones
Mineral Preparation Engineering	Donald Jean Cook	Ph.D.	The Magnetic Susceptibilities of Copper Minerals and Cassiterite
	James William Fetterman	Ph.D.	Alumina Extraction from a Pennsylvania Diaspore Clay by an Ammonium Sulfate Process
	Geoffrey Purcell	Ph.D.	The Effect of 18-Carbon Unsaturated Fatty Acids on the Electrokinetic and Flotation Properties of Rutile
	Priscilla Catherine Argyle	M.S.	Evaluation of Fatty Acid Containing Industrial Wastes as Collecting Agents
Mining Engineering	Robert Stefanko	Ph.D.	Underground Stress Instrumentation and Support Evaluation
	Ivan Frederick Jackson	M.S.	A Laboratory Study of the Machinability of Slate
Petroleum & Natural Gas Engineering	John Frederic Muirhead, Jr.	M.S.	A Study of Oil Displacement in a Radial System of Porous Medium
December 9, 1961			
Ceramic Technology	Delbert Edwin Day	Ph.D.	The Internal Friction of Soda Aluminosilicate Glasses and its Structural Interpretation
	Gerald Elroy Blair	M.S.	Some Characteristic Features of Lithia as a Constituent of Silicate Glasses
Fuel Technology	James Randall Nichols	Ph.D.	Steady-State Diffusion of Gases through Artificial Graphites
	James Robert Malone	M.S.	The Reactions of Selected Bituminous Coals with Concentrated Sulfuric Acid
Geochemistry	Ranajit Kumar Datta	Ph.D.	Order-Disorder in Spinel
	Robert Wesley Taylor	Ph.D.	An Experimental Study of the System $\text{FeO}-\text{Fe}_2\text{O}_3-\text{TiO}_2$ and its Bearing on Mineralogical Problems
Geophysics	Gordon Daniel Bennett	M.S.	Determination of Specific Capacities in a Multiaquifer Well
Metallurgy	Thomas Stuart Jones	Ph.D.	Reduction of Zinc Oxide by Carbon Monoxide in the Presence of Strontium Oxide
Mineral Economics	Farouk Moustafa Fawzi	M.S.	Iron and Steel Industry in North Africa — An Economic Study for Future Development
	Richard H. Parry	M.S.	An Analysis of the Market for Activated Carbon

* Advanced degrees awarded at December 9, 1961 and March 18, 1962 Commencement will be published next month.

Beneficiation —

(Continued from page six)

- ⁷ Anonymous, "Rare Earths—Switch to Solvents?" C & En. News, 6116 (1956).
- ⁸ Anonymous, "SX Grows More Useful," C & En. News, 56-7 (1958).
- ⁹ Anonymous, "Rare Earths Arrive," Chem. Week 70, 39-40 (1952).
- ¹⁰ Anonymous, "New Role for Rare Earths," Chem. Week 72, 38-9 (1953).
- ¹¹ Dayton, S. H., "How MCA Floats Rare Earths in Heated Circuits," Mining World, 43-5 (1956).
- ¹² Douglass, D. A., Bauer, D. J., *Liquid-Liquid Extraction of Cerium*, U. S. Bureau of Mines, RI-5513 (1959).
- ¹³ Anonymous, "Sulfide Queen Deposit—Southern California's Rare Earth Bonanza," Eng. & Min. Jour. 153(1), 100-2 (1952).
- ¹⁴ Fischer, W., "Procedure for the Separation of Trivalent Lanthanides from Each Other or from Yttrium by Distribution," German Patent Application 12m, 9 F 20841.
- ¹⁵ Fischer, W., "Procedure for the Separation of the Trivalent Rare Earth's Distribution Between Two Solvents," Angew. Chem. 66, 317-25 (1954).
- ¹⁶ Glass, J. J., Smalley, R. G., "Bastnaesite," Am. Mineralogist 30, 601-15 (1945).
- ¹⁷ Higgins, C. E., Baldwin, W. H., Ruth, J. M., *Organophosphorus Compounds for Solvent Extraction*, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL-1388 (1952).
- ¹⁸ Hillebrand, W. F., Lundell, G. E. F., Bright, H. W., Hoffman, I., *Applied Inorganic Analysis*, Chapter 36, John Wiley & Sons, Inc. New York (1953).
- ¹⁹ Hirsch, M., Bacon, R. F., Lucas, E. A., "Method for the Separation of Rare Earths," U. S. Patent 2,722,471.
- ²⁰ Holleck, L., Eckardt, D., Hartinger, L., "Komplex-colorimetric Seltener Erden," Zeitschrift für Analytische Chemie. 146, Band 2, Heft (1955).
- ²¹ Kasey, J. B., "Method of Treating Rare Earth Ores," U. S. Patent 2,735,747.
- ²² Kasey, J. B., "Recovery of Rare Earth Oxides," Australian Patent 222,950; Australian Official Journal of Patents 29(30), 1588-89 (1959).
- ²³ Kirk, R. E., Othmer, D. F., *Encyclopedia of Chemical Technology*, 11, Interscience Encyclopedia, 513 (1953).
- ²⁴ Lindstrom, R. E., *Separation of Rare Earth Elements in Bastnaesite by Ion Exchange*, U. S. Bureau of Mines, RI-5523 (1959).
- ²⁵ Lucas, E. A., Bailey, H. D., "The Mining and Beneficiation of Bastnaesite and Its Industrial Possibilities," Molybdenum Corporation of America, Washington, Pa., 6 pages, presented at AIME meeting, San Francisco, Calif. (1959).
- ²⁶ Maneval, D. R., Lovell, H. L., "Determination of Lanthanum, Cerium, Praseodymium, and Neodymium as Major Components by X-ray Emission Spectroscopy," Anal. Chem. 32, 1289 (1960).
- ²⁷ Miller, J. A., *A Study of the Lanthanum Rare Earth Industry*, unpublished M.S. thesis, Department of Mineral Economics, The Pa. State University, (77 ref.) (1955).
- ²⁸ Anonymous, *Rare Earths in Biochemical and Medical Research*, Oak Ridge Institute of Nuclear Studies, a conference sponsored by the Medical Division, ORINS-12, 1-76 (1955).
- ²⁹ Olson, E., "Bastnaesite Processing," U. S. A. E. C., ISC-1051, 14-16 (1958).
- ³⁰ Olson, J. C., Shaw, D. R., Pray, L. O., Sharp, W. N., "Rare Earth Mineral Deposits of the Mountain Pass District, San Bernardino County, California," U. S. Geological Survey Professional Paper 261 (1954).
- ³¹ Petrow, H. G., Ionics Inc. Private Communication (Nov. 1958).
- ³² Petrow, H. G., Rigoperlos, P. N., Fredrickson, J. B., "Preparation of Pure Cerium Dioxide from Bastnaesite by Solvent Extraction," Ionics Inc., Cambridge, Mass., paper presented at AIME meeting, San Francisco, Calif. (1959).
- ³³ Petrow, H. G., "Separation of Rare Earths by Ion Exchange and Solvent Extraction—A Comparison of Methods," paper presented at the AIME meeting, New York (1960).
- ³⁴ Pray, L. O., "Rare Earth Elements," Mineral Information Service 10(6), California Division of Mines (1957).
- ³⁵ Schanz, J. J., Jr., "The Not-So-Rare Earth Metals," Mineral Industries 29(4), 6 (1960).
- ³⁶ Schoeller, W. R., Powell, A. R., *The Analysis of Minerals and Ores of the Rare Elements*, Chapter XII, 3rd ed., C. Griffin, London (1955).
- ³⁷ Shaw, V. E., *Extraction of Rare Earths from Bastnaesite*, U. S. Department of Interior, Bureau of Mines, Reports of Invest. 5474 (1959).
- ³⁸ Spedding, F. H., "Large Scale Separation of Rare Earth Salts and Preparation of the Pure Metals," Discussions of the Faraday Soc. 7, 214-31 (1949).
- ³⁹ Spedding, F. H., Powell, J. E., "Methods of Separating Rare Earth Elements in Quantity as Developed at Iowa State College," J. of Metals, 1131 (1954).
- ⁴⁰ Spedding, F. H., Wheelwright, and Powell, "Methods of Separating the Rare Earths," Assignors to U. S. Atomic Energy Comm. U. S. Patent 2,798,798.
- ⁴¹ Stamm, H., "Technical Developments in the Field of Rare Earths," abstracted in: Chemical Age 75(1998), 686 (1957).
- ⁴² Van Wazer, J. R., *Phosphorus and Its Compounds*, 1, 584, Interscience Publishers, Inc., New York (1958).
- ⁴³ Vickery, R. O., *Chemistry of the Lanthanons*, Butterworths Scientific Publications, London (1953).
- ⁴⁴ Waggaman, W. H., *Phosphoric Acid, Phosphates and Phosphatic Fertilizers*, Reinhold Publishing Corp., New York, 683 (1952).
- ⁴⁵ Waggaman, W. H., *op. cit.*, 491.
- ⁴⁶ Weeks, M. E., *Discovery of the Elements*, J. Chem. Educ., Chapter 26 (1956).
- ⁴⁷ Wright, L. A., ed., "Rare Earth Deposits in Mountain Pass, California (Bastnaesite, Monazite, Xenotime)," *Mineral Commodities of California*, Division of Mines, State of Calif., 468-72 (1957).
- ⁴⁸ Yost, D. M., *The Rare Earth Elements and Their Compounds*, J. Wiley & Sons, Inc., New York (1947).

Activities —

(Continued from page two)

JAMES P. WIGHTMAN, research associate in fuel technology, gave a Seminar at Lehigh University, Bethlehem, Pennsylvania, on March 16. The title of the Seminar was "Reaction of Carbon with Hydrogen, Oxygen, and Water Microwave Plasmas." Dr. Wightman has been appointed assistant professor of chemistry at Virginia Polytechnic Institute, effective September 1, 1962.

PETER J. WYLLIE, associate professor of petrology, participated in the Visiting Geological Scientist program of the American Geological Institute. During the first week in April, Dr. Wyllie visited the Geology Departments at Wayne State University, Detroit, and at Southern Methodist University, Dallas, Texas. In addition to giving lectures on "Field work with the British North Greenland Expedition, 1952-1954" and "The application of high pressure, high temperature studies to the earth sciences," Dr. Wyllie led several seminars concerned with specific research topics in which phase equilibrium studies have proved to be useful. Informal discussions with faculty and students were included in the program.

RUSTUM ROY, professor of geochemistry, served, by invitation, on a panel of university faculty to advise the Army Research Office on possible directions for materials research on optical lasers. The panel presented up to date reviews of the various possible directions of research in the field to an audience of government and industry representatives. Dr. Roy discussed ultrahomogenization of glass and the effects of high pressure on glass at the meeting held in Durham, North Carolina, May 16-17, 1962.

Dr. Roy has also been invited to give a paper at the Symposium on "The Physics and Chemistry of High Pressures" being held June 26-28, 1962, in London, during the Third Congress of the European Federation of Chemical Engineering. The Symposium is sponsored by The Society of Chemical Industry, The Institution of Chemical Engineers, Institute of Physics and The Physical Society.

RUSTUM ROY, professor of geochemistry, was invited to address a joint colloquium of the Laboratory for Insulation Research under Professor von Hippel and the Solid State Physics group under Professor Slater at the Massachusetts Institute of Technology. Dr. Roy spoke at the April 13th session on "Systematic Ultrahigh Pressure, High Temperature Materials Synthesis," describing recent work in his laboratory in the field of preparative Solid State Chemistry.

JOHN J. SCHANZ, JR., associate professor of mineral economics, has been named chairman of the Student Affairs Committee of the American Institute of Mining, Metallurgical, and Petroleum Engineers for the coming year.

JAMES F. McDIVITT, assistant professor of mineral economics, has been named program chairman for the Committee on Mineral Economics of the Society of Mining Engineers of A.I.M.E. for the coming year.

MINERAL INDUSTRIES, Vol. 31, No. 7

May, 1962

U.Ed. 2-448

About the Author —

(Continued from page two)

ested in complex rare earth salts; extractive metallurgy of columbium, molybdenum, and tungsten; and X-ray emission spectrography.

Dr. Maneval is a member of the American Chemical Society, American Institute of Mining, Metallurgical, and Petroleum Engineers, Sigma Xi, Phi Lambda Upsilon, and Sigma Gamma Epsilon.

HANS NEUBERGER, professor of meteorology, attended the annual meeting of the National Research Council in Washington,

D. C., April 1-3, as representative of the American Meteorological Society.

C. DREW STAHL, head of the Department of Petroleum and Natural Gas, recently delivered a week-long series of lectures at the Denver Research Center of the Ohio Oil Company. The lectures, which dealt with immiscible displacement of fluids from porous media, were presented at a reservoir engineering workshop attended by a group of engineers and physicists of the Ohio Oil Company who are actively engaged in water-flooding projects. The accompanying photo shows the personnel attending the lecture series.