

PROGRESS in RESEARCH  
MINERAL INDUSTRIES  
EXPERIMENT STATION



BULLETIN No. 53  
BIENNIUM 1947-1949

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as of July 1, 1949

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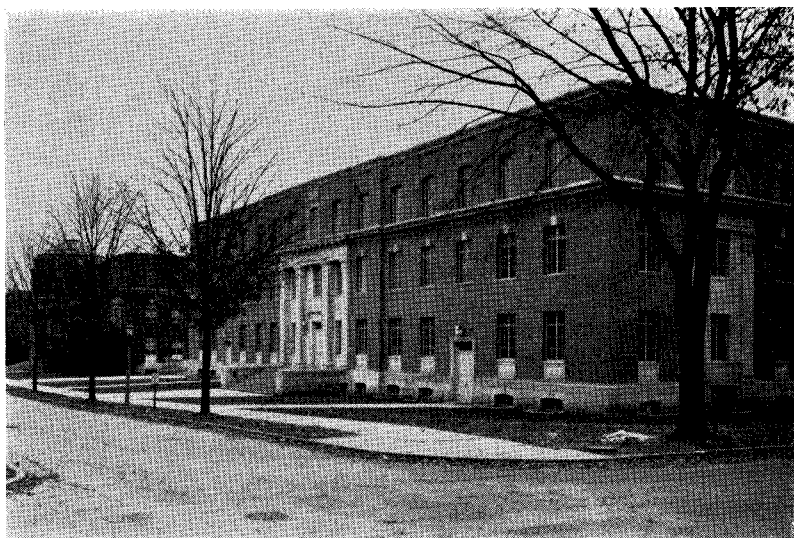
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## FOREWORD

THE accomplishments of research during World War II have brought about general recognition by the public of the importance of this phase of human endeavor. Originally nurtured in the colleges and universities, research was embraced by industry after the turn of the century and rapidly demonstrated its merit. As a result the amount of research done by industry soon far surpassed that carried out by educational institutions. Furthermore, research has been accepted as a responsibility of the government, and federal activities along many lines have expanded enormously during the past decade.

However, much of the industry research is applied in character and there remains a very great need for fundamental studies which explore the unknown and whose sole objective is the search for truth. Such studies can best be conducted in the atmosphere of institutions of higher education. Conditions in such institutions are not only conducive to research of a fundamental and long range character, but such activity is a necessary part of the educational process. The very fact that most industries and government agencies have large research programs has created a demand for men with graduate training which includes creative effort. An active research program not only presents opportunity for gaining experience in research, but—what is more important—it enlivens the rest of the teaching program as well. In fact no satisfactory graduate work is possible without the inclusion of an active research program.

In addition to this obligation of relating research to advanced education, a land-grant college has a second obligation, that of rendering research service in the interest of the State and the Nation. While recognizing the fact that research flourishes best in an atmosphere of freedom, it should nevertheless be possible to satisfy both obligations in a large measure by some integration of the research program. This requires at least a modicum of organization. It has been said that you “can organize for research but you can’t organize research.” In order, therefore, to foster rather than hamper the research activities of the School, the Mineral Industries Experiment Station has been set up as the organized research spirit which has in the last analysis been responsible for the growth of these activities. All members of the faculty who are engaged in research are members of the Experiment Station staff.



MINERAL SCIENCES BUILDING, ERECTED IN 1948. BEYOND IT TO THE LEFT IS THE  
MINERAL INDUSTRIES BUILDING

The Experiment Station receives its funds from three general sources; namely, (1) appropriations from the General Assembly of the Commonwealth, (2) the Federal Government and other public agencies, and (3) grants from industries. During the past biennium the distribution of funds among these general sources has been as follows:

State Funds .....	\$297,304.91
Federal Funds .....	\$336,228.00
Industrial Grants .....	\$540,318.94

The results obtained in all research projects supported by State Funds are published from time to time. Research supported by Federal Funds and Industrial Grants is carried out under agreements between the College and the sponsoring agencies. Some of the results obtained from research projects in these two categories are of such nature that publication may be delayed for a period of not more than two years after completion of the project.

Specific provision was made of part of the State Funds by the General Assembly of 1947 as follows: for the support of research and investigation of long-range basic problems affecting the mineral industries, \$40,000; for the purpose of matching money contributed by industry to the School of Mineral Industries for research and investigation, \$50,000; for research in petroleum production, \$25,000; for the study of problems affecting the slate industry, \$35,000; for expenditures by the School of Mineral Industries under the supervision of the State Department of Mines for the purpose of carrying on research and investigation on anthracite and bituminous coal, provided the anthracite and bituminous coal industries match this appropriation with a contribution of \$35,000, the sum of \$70,000. This was matched by contributions from the Anthracite Institute, Central Pennsylvania Coal Producers' Association, and Western Pennsylvania Coal Operators' Association.

#### Scope of This Report

This report summarizes the progress made during the biennium 1947-1949. Much of the information has been published in greater detail in other bulletins, technical papers, and circulars. A list of such publications during the biennium is included at the end of this bulletin.

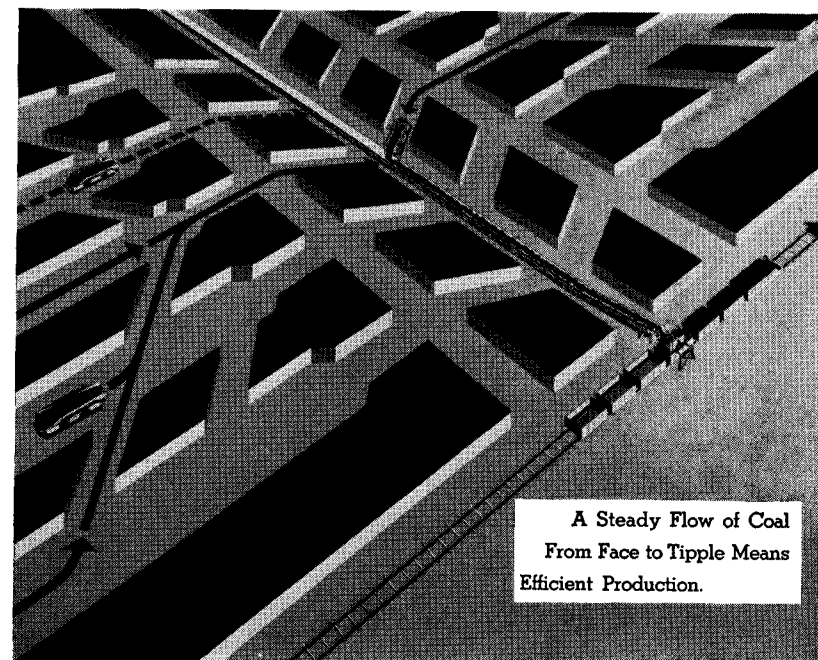
A. W. Gauger

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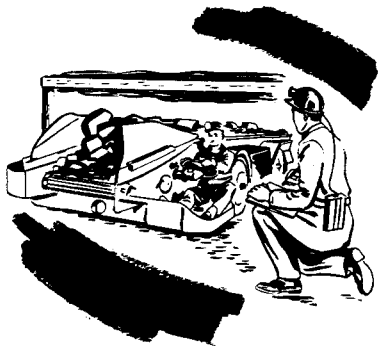


A Steady Flow of Coal  
From Face to Tipple Means  
Efficient Production.

## New Method for Evaluating Mine Performance

MECHANIZATION has brought mass production methods into the mines. It has also brought problems of integration of muscle and machine to insure efficiency and low cost. Research in the Mining Division was concentrated on projects concerned with increasing the efficiency of mechanical mining equipment and methods of operation. An important result has been the development of a new method for rating men, machines, and production units in mines, which, if used, should lead to lower costs and increased production in mining.

Bulletin 50 of the Mineral Industries Experiment Station, titled *More Profit in Mechanical Mining* gives a detailed description of the method. A brief outline is presented on the following pages.

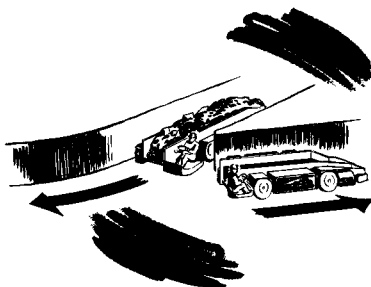


### 1. Time Studies

One observer is stationed at the loader; another at the discharge station. Both keep a time record and note all loading and gathering activities within their scope of observation. The chief object of this study is the determination of productive time and delays with the cause of such delays.

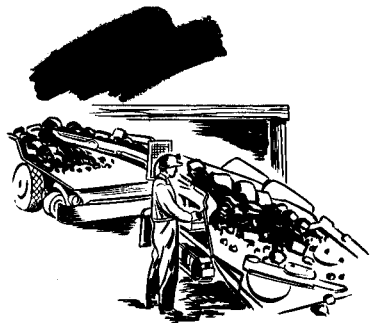
### 2. Method Studies

A map of the section is obtained and all the travel routes, producing faces, standby points, and locations of stationary section equipment are noted. Careful study of the section diagram may reveal defects such as these: complicated travel routes that can be simplified; cable interference, especially at ventilation doors; and track layouts inadequate to provide empties as needed.



### 3. Production Studies

In the final step the results of the other two studies are combined with section production statistics to determine key performance ratings. These ratings help to make section performance an open book. When compared with similar data, they indicate relative productivity of the men and machines in the section.

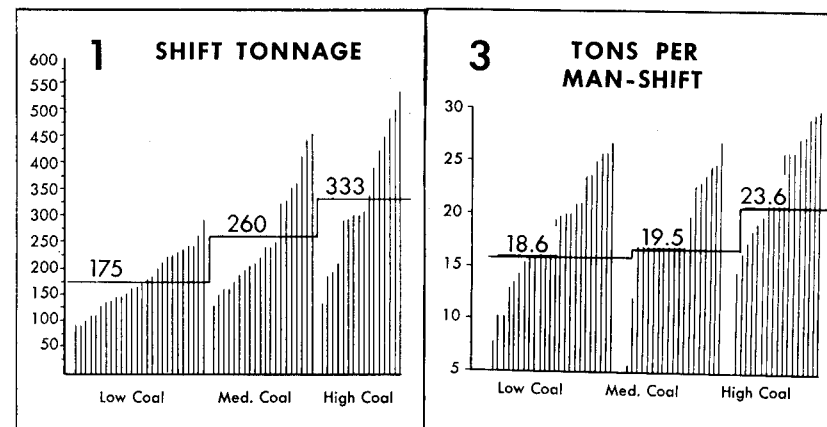


By making these studies the following information can be obtained:

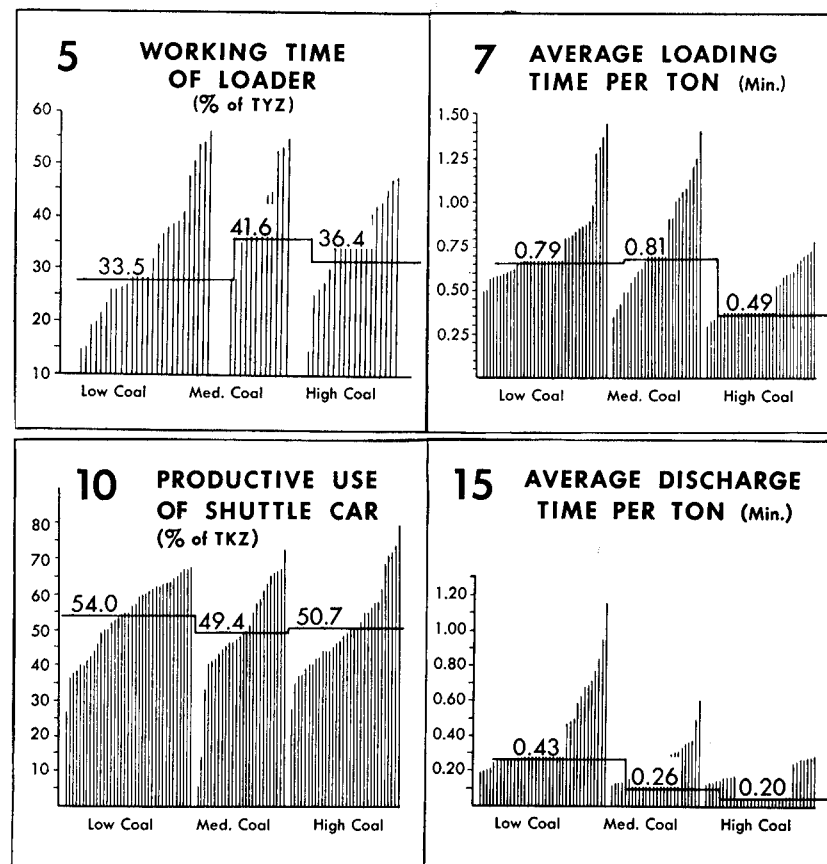
Time spent in production.

Time lost due to delays and the cause of such delays.

Working time of loader; average loading time per ton; working time of shuttle car; average discharge time per ton. Individual rat-



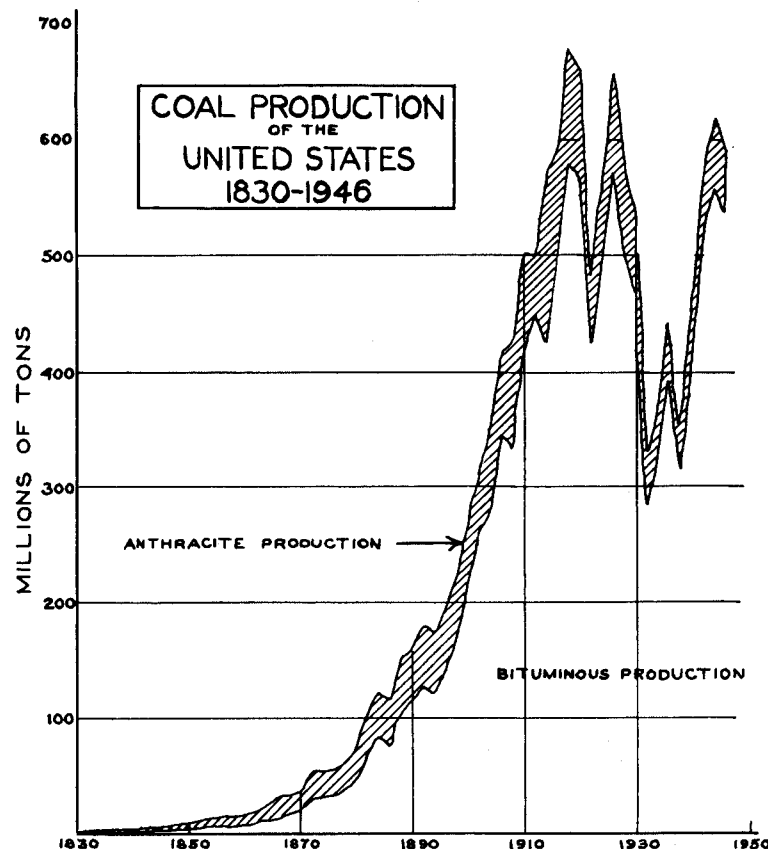
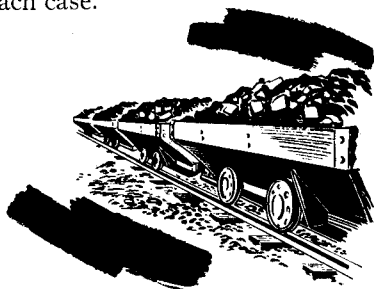
ings can then be compared with results obtained in a survey conducted in connection with this project. Key operating data are presented in 18 charts, which depict the results of detailed studies made in approximately 100 mines. Six of the charts are reproduced herein to illustrate the



type of information available. The horizontal lines give the average performance of the mines studied in each case.

This method has been used with considerable success by a number of companies. It has indicated weak spots, aided in increasing efficiency, and provided management with a basis of comparing its production units and machines. At one mine where these studies were made management corrected its operation thereby saving 40 cents per ton production cost.

In the conduct of this project, the services of at least 25 graduate and undergraduate students were used, thus affording them an opportunity for contact with mining operations. The value of this supplement to classroom training in the case of these students is obvious.



THIS GRAPH SHOWS THE EFFECT OF TWO WORLD WARS ON THE DEMAND FOR COAL. A SIMILAR SITUATION EXISTS IN THE CASE OF MANY OTHER STRATEGIC MINERALS.

## The Mineral Industries in World War II

TOTAL war involves the mobilization of all of the resources of the nation; among the most important of these are the mineral resources. The importance of this fact under present-day world conditions led to a critical study by a graduate student of the mobilization and functioning of the mineral industry during World War II. The resulting thesis was published by the National Security Resources Board and distributed to representatives of the mineral industries throughout the country for review, comment, and suggestions. The record of World War II demonstrates that the problem of domestic mineral production and distribution was never solved in a satisfactory manner, and it is hoped by study of this report current and future planning will not repeat the mistakes of past experience.

Tracing the history of the growing importance of mineral power in waging war it is apparent that the basic factor underlying a nation's ability to wage warfare on the pattern of World Wars I and II is a functioning mineral industry.

It is extremely important this economic base be secure before the mobilization and training of an army in order that the soldier may be given a fighting chance.

The study is thoroughly illustrated with charts, maps, diagrams, and other graphic material as aids in understanding basic data such as location, production, and use of virtually every mined product required in peace or war.

The study highlights the weak points in our domestic mineral policies and the possible bottlenecks in our production that could be affected by relatively few strategic bombing missions.

In a summary of previous experience it is pointed out that the nation's mineral policies prior to, during, and following World War II left much to be desired. In addition to assisting our enemies before Pearl Harbor in obtaining minerals needed for their war effort, we had little organized intelligence concerned with mineral matters.

In the United States in 1948, only three years after cessation of hostilities, no precautions are taken to deny technical information to any potential enemy.

There is no doubt that if our present policies continue, information concerning any technical improvements released to our domestic industry or changes in our mineral potential will spend little time arriving in the hands of any nation friendly or otherwise.

Eleven conclusions are presented in this report among which are quoted the following:

1. Assuming that Government regulation will be required in the event of another war, a well-defined chain of command, including Federal and State agencies, through which regulation is accomplished must be established well in advance of hostilities.

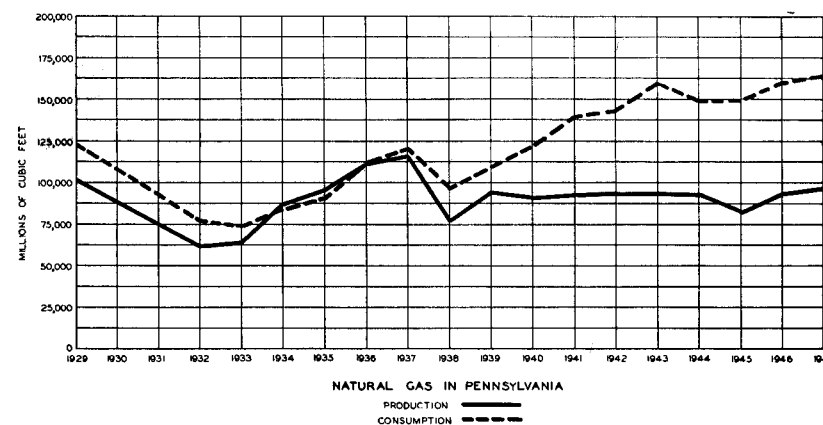
2. A definite program should be developed with a view to obtaining almost all needed materials within the Western Hemisphere, even at a greater dollar cost in some cases, plus arrangements for air transportation of high-value, small-volume, Latin-American products, thus overcoming a possible submarine menace.

3. Stockpiling of essential materials in advance of war should provide for the accumulation of materials as nearly as possible in the semi-finished state, thus saving transportation facilities, power, labor, and time when the materials are put to final use in an emergency.

## Trends in Natural Gas Production and Consumption in Pennsylvania

MINERAL ECONOMICS has been called "the record of a battle between the growing difficulties of nature on the one hand, and discovery, transport and technology on the other." The importance of research in this field is illustrated by a statistical study of the natural gas industry made during the biennium. Natural gas is an important raw material in many of Pennsylvania's industries. The glass industry, for example, is dependent upon natural gas for its existence, and tends to locate in areas where natural gas is available cheaply. Of late years there has been some migration of this industry from Pennsylvania to the southwest with its attractive gas reserves.

Studies of the natural gas industry reveal an interesting story. In 1929 the consumption of natural gas was somewhat larger than its production. Imports from outside sources were necessary. The amount imported declined slowly, and in 1934 domestic production within the State was ample to supply the consumers. In fact, from 1932 to 1937 the production as well as consumption indicated little or no divergence between supply and demand. Since 1937, however, consumption has exceeded production within the Commonwealth, and the self-sufficiency of Pennsylvania in natural gas becomes a matter of history. The future of the industries dependent upon natural gas will depend upon our ingenuity in applying discovery, transport, and technology.



The problem ceases to be one in dusty statistics and becomes one of practical importance to the survival of industry, jobs, and prosperity within our State. We must either find new sources of gas or rehabilitate old wells to increase the supply, bring increasing amounts of gas in from other fields, or make substitute fuels from our resources of coal.

In other words, researches in mineral economics are important in defining the problems before us and suggesting possible lines of research endeavor.



# Mineral Beneficiation

THE POSTWAR years have seen continued high demand for minerals coupled with rising costs of production. As a result of the demands of the War and the aftermath thereof, Pennsylvania has suffered an accelerated depletion of its mineral resources. This has brought us face to face with many problems, two of which are of paramount importance. These are rising costs resulting in part from the fact that the more easily moveable resources are gone and in part from the high wages; an example has already been presented of the researches of the Experiment Station seeking to lower costs of producing minerals.

The second problem results from the fact that many of the highest quality resources are exhausted. We must turn our attention to second-quality deposits and devise economical methods of beneficiation which will convert these into useful raw materials.

Among the more important problems of this character are the approaching shortage of coal suitable for the steel industry and the rapid depletion of high-grade clay. Unfortunately the funds available to the Experiment Station are wholly inadequate for the studies required in this field. Nevertheless researches are under way, particularly in the field of coal preparation. Details of several of these projects follow:

## *Efficiency of Coal Washing*

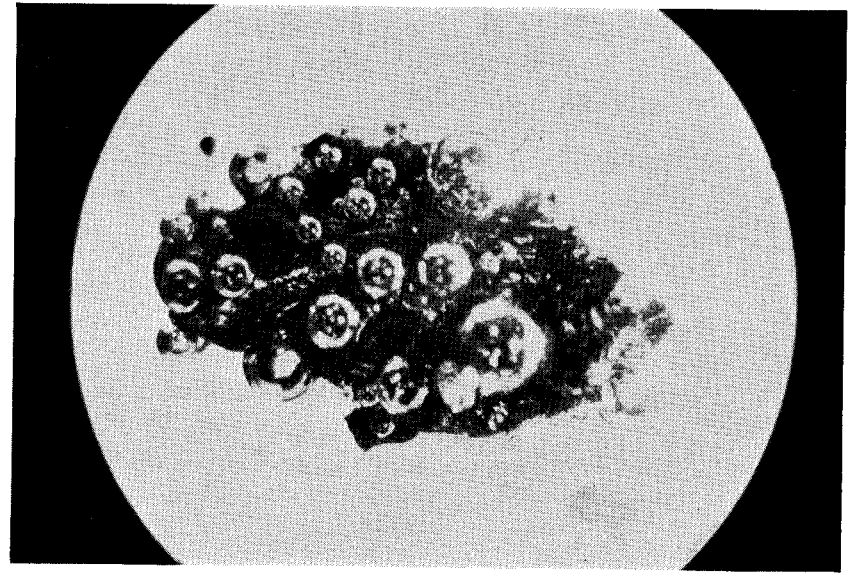
The loss of recoverable coal by many coal preparation plants has been a subject of pertinent interest to coal producers for many years. As the conservation of our natural resources becomes increasingly important, it is urgent that steps be taken to find improved processes for recovery of usable coal. In recognition of this, studies are being undertaken currently to learn the extent of this loss and to devise ways and means of correcting it.

A study at a bituminous coal plant showed that pickers at the picking tables were rejecting as high as 240 tons per day in two shifts, of which 40.6% was found to be recoverable coal at the normal washing specific gravity. Further, if these pickings, which were plus six-inch lump, had been crushed to minus two-inch and sent through the washing process, the recovery could have been increased to 60.3%.

## *Flotation of Coarse Particles*

Heretofore the separation of minerals by flotation has been successful only in fine sizes. There has been no clear-cut explanation for this limitation. In the case of coal it is desirable to float particles that are larger than the upper limit of current practice. In order to arrive at methods of achieving this result, it is advantageous to know the me-

chanism of the process. As a result of this investigation a new hypothesis termed "eruptive multi-bubble" is offered as a mechanism of the process. The study involves flotation of samples followed by examination of air bubbles in the concentrates and tailings under the microscope, visual observation of particle-bubble attachment in a frothmeter, and motion photography at a speed of 1,080 frames per second.



THIS PICTURE SHOWS A COAL PARTICLE MAGNIFIED 8 TIMES. NOTE THE MANY BUBBLES ATTACHED TO THE SURFACE. THESE BUBBLES CAUSE THE PARTICLE TO FLOAT.

## *Beneficiation of Fine Anthracite*

The cleaning and recovery of the anthracite fines that were once permitted to enter the rivers and streams but are now being recovered is one of the major problems facing the industry. Much of this fine-size coal is contaminated with appreciable quantities of mineral matter which must be removed before the product can be successfully used as a fuel. Considerable research has been conducted on the various proposed and current methods used for cleaning such fine-sized fuel, and comparative efficiency and recovery studies have been made on several different processes operating under different conditions in order to determine the advantages and limitations of each. The studies are as yet incomplete, but already show that some processes are more efficient for cleaning silt in certain size ranges, while others are more efficient for other size ranges. This suggests the desirability of applying the various cleaning processes only to the fuel size range for which each is best suited and thus increasing over-all recovery of the marketable product and improved efficiency of operation.

# Petroleum and Natural Gas Research

SINCE August 27, 1859, when the Drake well was completed, Pennsylvania has been a leader in the development of new and better methods of oil finding, production, transportation, and processing. Many of these developments originated in the field through the alertness of workers and their skill in improvising new methods as new problems were encountered. To them we owe improved drilling techniques, pipeline transportation and secondary recovery, as well as hundreds of small contributions necessary to the conduct of the oil business. Even more assistance in the nature of technological advances will be needed in the future since the oil which is easy to find and recover has been taken from the ground and consumed. More science must be applied, and it is the function of research to discover and apply those scientific truths by which the future of oil production in Pennsylvania may be encouraged and prolonged. The importance of extending the life of this industry for as long as possible is recognized. In order to aid in doing this the Experiment Station is using the talents of its staff in many fields, especially in geology, mineralogy, geophysics, and petroleum and natural gas engineering.

Thus improvements are sought in methods of oil finding to aid in exploration and further possible discovery as well as in methods of recovery which seek to extract the last drop of this valuable resource from the reservoir rock.

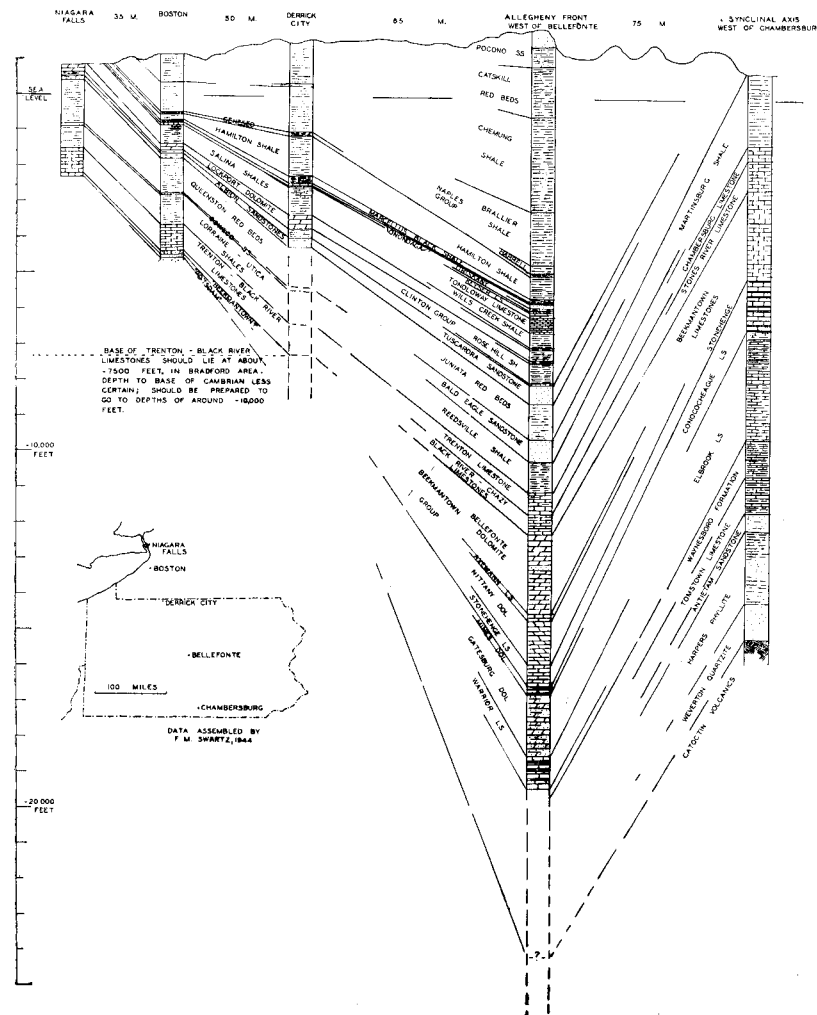
The work was expanded considerably during the biennium through grants from oil companies, which is indicative of the confidence that industry has in the research being carried on in this institution. The program is being used as a model for similar setups in other states that realize the need for such work in their own areas. Numerous visitors have inspected the general facilities and specialized equipment designed and constructed here, and they are being duplicated in the new laboratories. The Director of the Experiment Station discussed the program at a Petroleum Recovery Conference sponsored by Texas Petroleum Research Committee at A. and M. College of Texas and also conferred with this Committee on details of administration.

The annual technical conference which is held in State College, and at which formal reports are presented on the progress of the work, has been drawing increasing attendance from representatives of the oil industry, both from Pennsylvania and other oil-producing areas of the United States. The papers which are presented are published in a College bulletin and in some of the leading petroleum journals. In addition to the above methods of disseminating the research findings, periodic

progress reports are sent to the oil companies, and direct contact is made in cases where special information is requested or field tests are being made.

The work is carried on with the assistance of many graduate and undergraduate students, thus giving them training which will be of immeasurable use to them in later life.

For many years, discoveries of oil and gas have furnished only small additions to known reserves in the Pennsylvania region; continuation of production has resulted instead from improvements in techniques of secondary and tertiary recovery. Growing interest in the oil and gas possibilities of geologically deep horizons has stimulated studies of the ancient sediments deeply buried in Western Pennsylvania but outcrop-



ping in other areas in Pennsylvania, in Maryland, and in New York. Studies of the characteristics of these rocks where they appear at the surface are being used as a basis for preliminary interpretations of the oil and gas possibilities of the more northwesterly subsurface extensions. Charts and maps graphically illustrate the regional changes in thickness and rock characters that affect possibilities of the sediments both as parent sources of oil and gas materials and as reservoirs for accumulation. Further revisions of these charts and maps are in progress. Several test wells have reached the Trenton and Sub-Trenton in westernmost Pennsylvania in past years, and two wells are now being drilled to test them near Bedford in the southcentral part of the State.

These geologic studies have been accompanied by mineralogical and petrographic work on the nature of the rock in two formations seeking to determine whether they are potential oil reservoirs.

Most of the oil in Pennsylvania is produced from sandstone, but a very large volume of limestones and dolomites, which produce enormous amounts of oil in the Mid-Continent and West Texas regions, have not been exploited or even explored in Pennsylvania as yet. The possibility of obtaining oil from these limestones and dolomites exists, and studies have begun on the Lower Ordovician Nittany dolomite formation to discover what are the most favorable portions of these rocks, at what depth they may occur, how oil may be stored in them, and in what part of the Commonwealth they may be found.

#### *Petroleum Production*

In the early days of flush or "primary" production, the petroleum in the ground had its own source of energy in the form of dissolved gas which forced it to the surface when the drill hole reached the reservoir rock. This has for the most part been exhausted and the sand with the oil. Most of the Pennsylvania production is now accomplished by driving the oil to the producing wells with artificially injected water or compressed air or gas. This procedure is known as "secondary recovery." Even after both primary and secondary methods have produced all the oil that can be obtained with present techniques, there still remains nearly a third of the original oil in place. While most of this could probably be recovered by mining or by extraction with liquified gases, such operations are at present prohibited by their cost. A large part of the current research in petroleum production is directed toward finding improvements in methods which will not only reduce the costs of production, but increase the recoverable fraction of the oil originally in the ground.

Petroleum is contained in underground reservoirs consisting of porous rock. Associated with it are also found water which contains more or less dissolved salts (called "connate" water or "oil field brine"), and dissolved natural gas hydrocarbons. The problem of recovering the

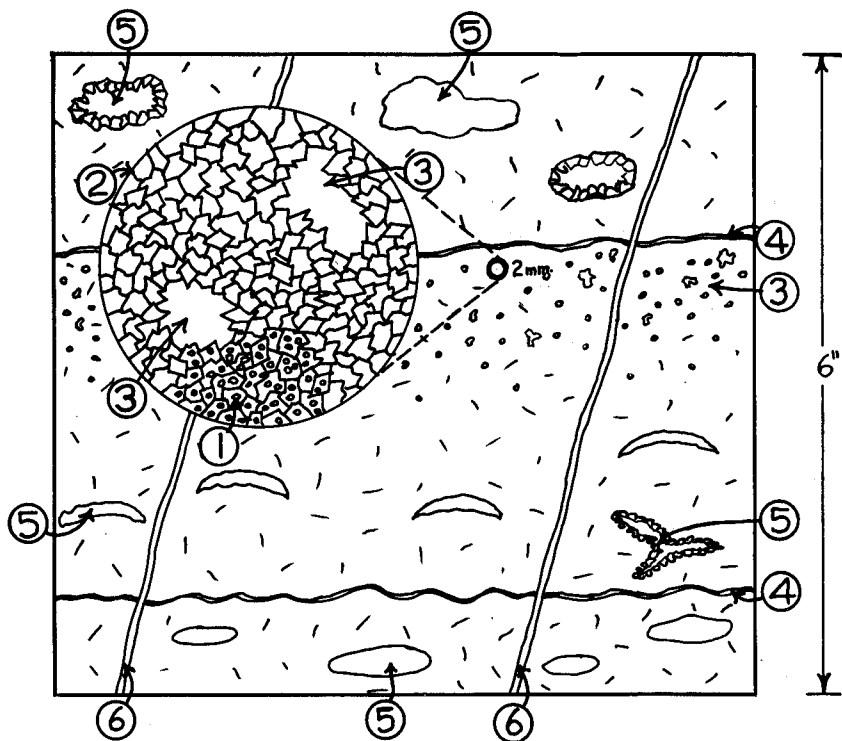
maximum possible amount of the petroleum underground involves a complete understanding of the mechanism by which fluids move through porous rock. This sounds simple but is in reality very complex, and it is only by time-consuming studies in many laboratories, applying all of the research tools and techniques at our disposal, that it will be solved. The Experiment Station has continued to make some very significant contributions to the understanding of the mechanism of the movement of oil through rock and to the improvement of the efficiency of recovery. A few of these advances are described briefly in the following pages.

*Porosity and Permeability.* Petroleum is contained in rock formations by virtue of the porosity. It is moved through the rock as a result of the permeability.

The problem of determining why certain rocks in Pennsylvania can store oil whereas others cannot, and of differentiating quickly between these during prospecting and drilling, has been the subject of fundamental petrographic research. In this work a very detailed study has been made of the so-called "pore pattern," meaning the description, origin, and relations of the holes or pores in the rock which act as miniature natural storage tanks for oil. A mathematical treatment has been made to relate the type of pore structure in a rock to standard physical measurements which are normally made by petroleum engineers, such as measurements of porosity and permeability. The development of these fundamental concepts into a practical industrial methodology is in progress.

A much discussed, and little understood, factor in secondary recovery efficiency has been the pore size distribution in reservoir rocks. A simplified mercury injection technique has been used to study the pore distribution character of producing horizons in Pennsylvania. In addition to the general information so obtained, a correlation between permeability and distribution is in evidence. There is also promise of a useful correlation between field flooding efficiencies for various sand samples, and the laboratory results of mercury injection tests.

The ability of a natural petroleum reservoir to conduct fluids into and from a well (permeability) is an important quality to the oil producer. The standard fluid which has been used to measure permeability in the laboratory has been air. As useful as these results have been, they have been open to question for some time, since they assume the equivalence of liquid and gaseous flow. Work in these laboratories has shown that in the case of producing formations in Pennsylvania, the permeability determination using air may be in error by as much as one hundred per cent if used as a value applied to a reservoir liquid.



This sketch illustrates diagrammatically the types of pores in Nittany Dolomite. The block is limited by long narrow cracks at (4) and (6) along which fluids flow toward the well.

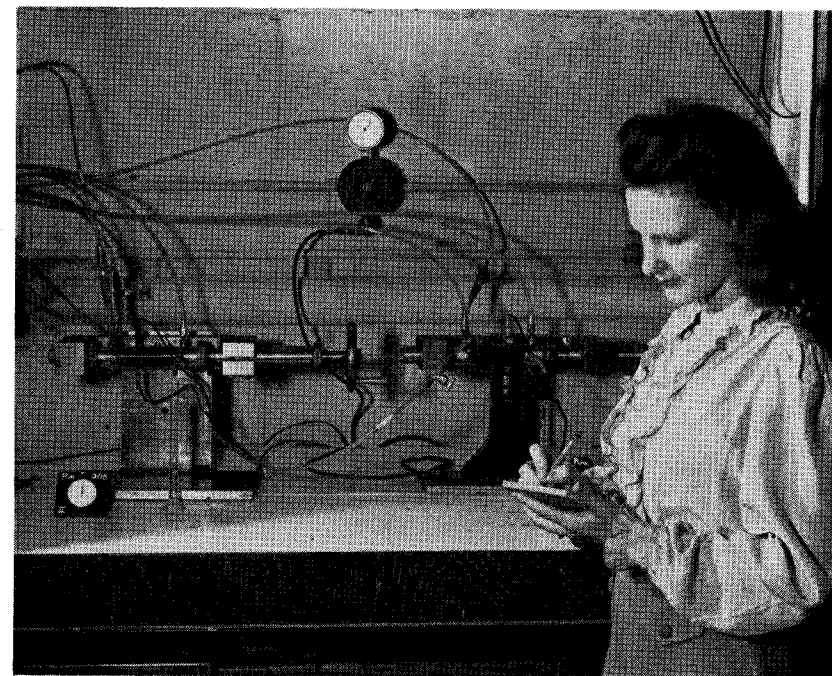
The fluids are stored in pores from which they can flow slowly into the cracks if the pores are interconnected.

These pores may be fairly large as shown at (5) or much smaller ones. The smaller pores are the most important for storing oil or water. The large circle is a magnification of the smaller circle, which is really two millimeters or 1/12 of an inch in diameter. Within this small circle there are three types of pores, those within mineral grains (1) intergranular pores (2) and disseminated pores (3) which may or may not be interconnected. These three types of porosity may exceed 10% of the rock.

In recognition of the pioneer work done in this institution on permeability, the American Petroleum Institute sponsored a project on a comparison of gaseous and liquid permeabilities. The work to date indicates that the findings will have far-reaching significance both from a practical and a theoretical standpoint.

In addition to the above work on the flow of a single fluid in reservoir rocks, investigations are under way on multiple fluid flow. A maximum of three fluid phases (oil, water, and gas) may be present in an oil sand, and all three may be flowing simultaneously. It is necessary to know the laws governing such flow so that predictions can be made of field behavior. Heretofore no simple and rapid technique has been

available for making such measurements. During the past two years this laboratory has devised equipment and technique permitting the simple, rapid, and accurate measurement of multiphase flow behavior on small core samples. This relative permeability test has been adapted, with slight variation, by many of the production research laboratories of the country. The test technique has opened a new phase of fluid-flow study, and is pointing toward a more thorough understanding of both primary and secondary recovery mechanisms.



APPARATUS DESIGNED AND BUILT IN THE EXPERIMENT STATION FOR THE STUDY OF THE SIMULTANEOUS FLOW OF OIL, GAS AND WATER IN OIL SANDS.

The determination of properties such as porosity, permeability, oil saturation, connate water, etc., requires the taking of cores which are later examined in a laboratory. This procedure is slow, and the producer frequently wants such information in order to follow the progress of the drill. In order to obtain useful information while the drilling process is going on, various techniques have been resorted to. One of these is known as electrologging. At the present time many wells in the Bradford field, Pennsylvania, drilled for the development of secondary recovery oil production are subjected to the electrical measurements of this process. Certain reservoir characteristics of the oil-bearing rock are reflected in these measurements, supplementing the information

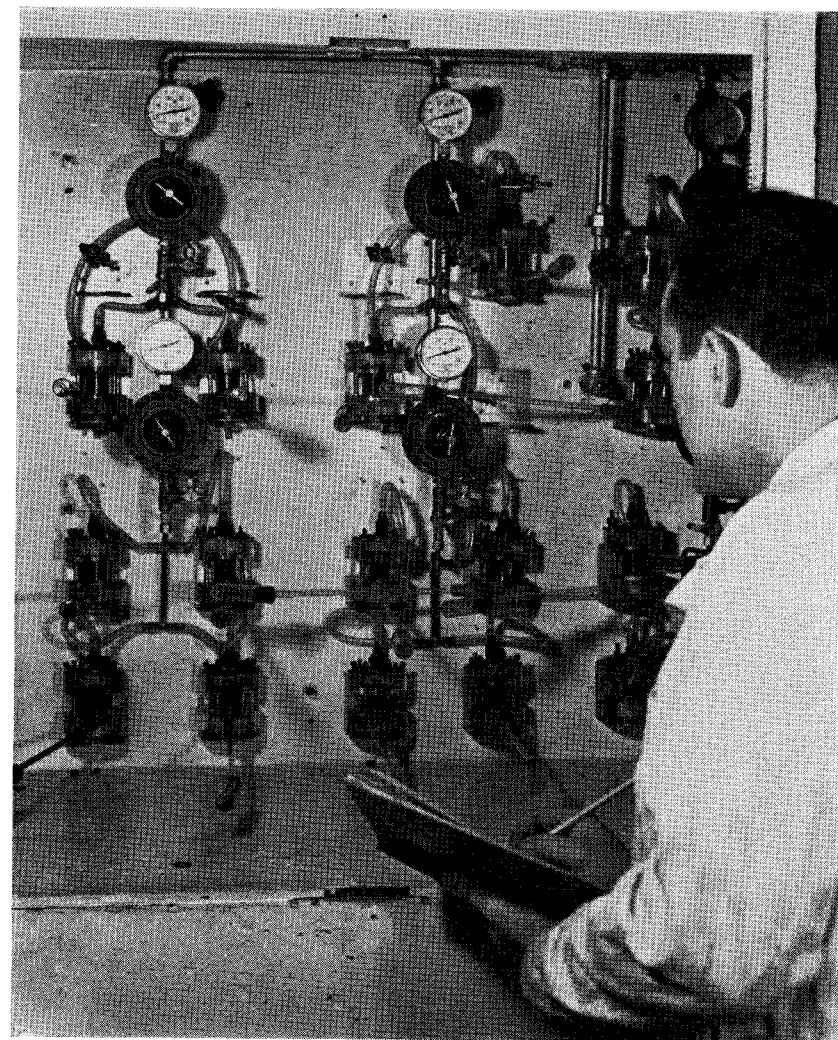
obtained from an examination of well cores. However, the interpretation of such measurements is very difficult. For this reason a research program on electric-logging techniques and on the interpretation and significance of the measurements was started. At the present time it is possible to obtain connate water saturation with a fair degree of accuracy, and promising approaches for the calculation of natural flood water, porosity, and permeability are in the process of being explored.

*Well Spacing and Well Shooting.* Well spacing in secondary recovery has been based chiefly on trial and error which in many cases has involved costly mistakes. Calculations made in the Experiment Station have led to the development of a method for determining the most desirable spacing under different operating conditions based upon permeability, sand depth, shot responsiveness of the formation, and the expected recovery. The study also indicated the desirability of resorting to flowing production in water flooding, particularly during the late stages of the flood when the lowering in development and operating cost should result in increased profits. Furthermore, it will permit the development of marginal areas, thereby increasing the reserves of oil.

In order to make a secondary recovery operation more profitable and also to increase the amount of oil ultimately recoverable from the ground, it is necessary to "shoot" the wells with a charge of nitroglycerine. In addition, a properly designed shot will tend to correct for permeability variations in the different producing strata and cause the production to proceed more uniformly. As widespread as shooting is, it has not been placed on a quantitative basis; and a large part of it has been on a rule-of-thumb basis. In order to correct this a study was made of shooting involving both field data and theoretical calculations. Based upon these studies a method is now available for calculating the shot size and shot distribution for a well using the permeability, well spacing, and shot responsiveness of the formation.

*Gas Injection Prior to Water Flooding.* As a result of some early work carried on in the petroleum production research laboratories and recent research by one of the oil companies, it has been found that the injection of gas prior to water flooding has decidedly beneficial effects. Laboratory and theoretical studies have shown that increased recoveries approaching twenty per cent above that presently obtained in our most efficient floods are possible. The effect of different types of gases and changes in operating conditions on the recovery are under study at the present time in an effort to determine just why pre-injection of a gas phase should so increase the effectiveness of a subsequent water flood. When this question is adequately answered, a more intelligent application of gas injection under field conditions will be feasible. The method is one of the most promising to be investigated for improving recoveries.

*Chemical Flooding.* It has long been known that certain chemicals, in particular those having a detergent action, increase the percentage of recoverable oil. Due to the amount of chemical required, it has not been found profitable to employ such chemicals in water flooding. In the investigations conducted during this biennium, emphasis has, therefore, been placed on reagents that may react with some constituent in the oil itself and, therefore, produce the detergent chemical in the reservoir rock. While some increase in oil recovery has been noted, probably the greatest beneficial effect has been in increasing the effective permeability



DETERMINING THE AMOUNT OF OIL HELD IN CORES OF OIL BEARING SAND BY CAPILLARY FORCES AT VARIOUS STAGES OF DEPLETION.



of the formation to the flood. This may make it possible to increase the rate of oil recovery and perhaps bring certain low permeability sands into the range of economic operation.

*Selective Plugging.* One of the major problems in secondary recovery operations arises from the great variation in permeability between various underground strata. Thus, after the more permeable streaks have been depleted of recoverable oil, the larger part of the injected water or gas continues to pass through these streaks to no avail. This difficulty has been overcome to a large extent in the case of water flooding by a selective plugging technique previously developed in the School of Min-



A FIELD TEST OF SMOKES DEVELOPED IN THE LABORATORY FOR PLUGGING LOOSE STREAKS IN RECOVERY OF OIL BY AIR-DRIVE.

eral Industries. In view of the importance of selective plugging, research work has continued on it during this biennium with emphasis on applications to gas drive recovery. Field and laboratory tests are under way at the present time on air-gas drive projects using agents similar to those employed with such success in water flooding.

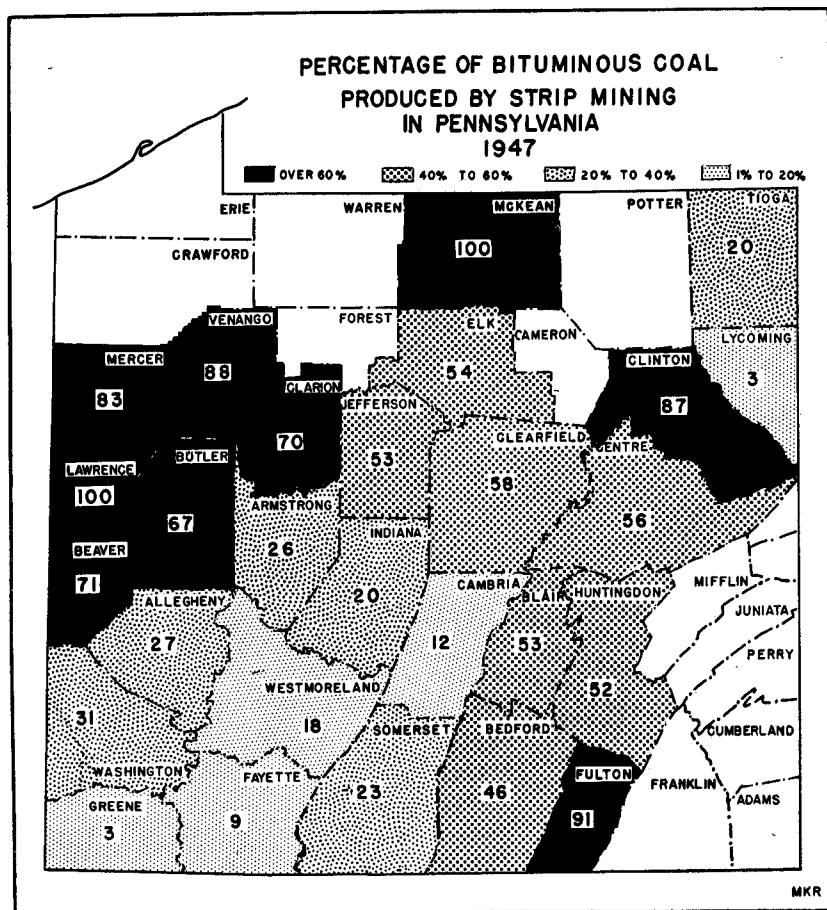
*Water Injection in Air-Gas Drive Operations.* Laboratory work has shown that remarkable increases in the efficiency of recovery by air-gas drive have been obtained by the injection of alternate slugs of water. Not only is the ultimate recovery of oil increased, but in addition it is accomplished with less air or gas in a shorter period of time and at a lower cost. Several field tests are under way at the present time applying this method of operation.

## Earth Sciences

NO sharp line can be drawn between research in Earth Sciences and research in the related fields of Mineral Engineering and Mineral Technology. In all three fields consideration has to be given to the origin of minerals and other natural phenomena as well as to the possibilities and methods of extraction and utilization of minerals. And so, although research in Earth Sciences is concerned primarily with field and laboratory investigations which will lead to a better understanding of the origin and history of our planet, much information obtained is of direct use to Mineral Engineering and Technology. Results of high temperature research to learn more of the origin of igneous rocks, for example, are directly applicable to many high temperature industrial mineral processes such as glass, refractory, and steel making. Or again, studies of the conditions under which petroleum forms and accumulates lead to the discovery of oil and gas fields.

### *Strip-Mining*

Bituminous coal strip-mining in Pennsylvania has risen from 2,792,000 tons in 1939 to 35,964,000 in 1947 and in certain counties it represents the major portion of the coal mining operations. The spoil piles of rocky waste left by this method are unsightly, are not easily returned to productive use, and in some cases give rise to acid waters. Improvements of methods of spoil bank reforestation are being studied by the Department of Forestry of The Pennsylvania State College, and request was made for geologic assistance in investigating the features of spoil banks that affect revegetation. Geologic studies have been in progress during the past two years investigating spoil bank characters in the vicinity of Brookville and Somerset. Spoil bank characters are affected primarily by (a) the nature and proportions of the shale and sandstone layers stripped from the coal overburden and dumped in the spoil pits; (b) the amount of pyrite in these shales and sandstones, and in the bony refuse of the coal that is thrown on the spoil piles. The pyrite or "fool's gold" oxidizes to iron sulphates, iron oxides, and sulphuric acid, producing the well-known sulphur waters or acid waters of mine drainage. Variations in amount of pyrite cause wide differences in acidity of the ground water of the spoil banks and also in the drainage waters, so that revegetation and drainage problems vary markedly in spoil banks from differing coals, and in some cases in spoil banks of the same coal in differing areas. In westernmost Pennsylvania, some coal overburdens contain thin, limy layers that help to sweeten the spoil banks. The geologic studies are directed to investigation of the characters and proportions of the shales and sandstones of overburdens of



THE IMPORTANCE OF STRIP MINING IN SEVERAL COUNTIES OF PENNSYLVANIA IS OBVIOUS ON THIS MAP.

various coals, and to the distribution of pyrite in the overburden. Characters of the coals exposed in the strip mines and information about the underclays that may prove to have ceramic uses, are also being recorded and studied.

Geographic studies are directed towards recommendations for effective land utilization of areas where strip-mining has been or is being practiced.

#### *Ores for Metallurgical Industries*

The zinc industry of Eastern Pennsylvania at present derives its ores from New Jersey and Virginia, although bodies of zinc ore are now being developed in Pennsylvania. Field and laboratory studies have been inaugurated to give information about mineral content and mineral



THESE TWO PHOTOGRAPHS SHOW WHAT IS POSSIBLE IN STRIPPING OPERATIONS. THE UPPER FIGURE IS A PHOTOGRAPH OF A STRIP MINING OPERATION NEAR HOUTZDALE, PA. THE LOWER SHOWS A RECLAIMED SPOIL BANK AREA IN GROVE CITY, PA. WITH ITS PONDS, PICNIC AREAS, PLAYGROUNDS, TRAILS AND SWIMMING FACILITIES, IT IS NOW THE MOST ATTRACTIVE COMMUNITY PARK IN WESTERN PENNSYLVANIA. THE STRIPPING OPERATION TOOK PLACE DURING WORLD WAR I; THE BANKS MATURED AND THE PLANTING WAS DONE IN THE EARLY 1930's.



relations of the zinc ores that will aid metallurgical treatment as well as discovery and development of reserves. Thin-sections and polished sections are being prepared from ore specimens carefully located in mine workings. The sections provide information about the composition of the ore minerals, the size of the grains and relations of grains of differing materials. Such data are helpful in improvement of milling and smelting practices. They also help to show directions of movement of the solutions that deposited the ore, and give evidence about the downward extension of ore deposits and location of areas most favorable for future prospecting.

Ores used by the metallurgical industries represent special, local concentrations of metallic compounds, deposited from solution. The basic nature of the chemical reactions concerned in development of certain types of ores is being considered with special reference to volume-for-volume replacements. Any knowledge of the conditions of ore deposition will aid in finding new areas of ore and in extension of known areas of ore.

### *Geological Field Mapping*

The areal geology of the Bedford quadrangle in Southern Pennsylvania is being studied, and a report discussing the stratigraphy, structural geology, and economic geology will be completed in the near future. Interest in the quadrangle has been renewed because of the wells now being drilled to test oil and gas possibilities of the Silurian and Ordovician rocks of the area.

### *Pennsylvania Clays*

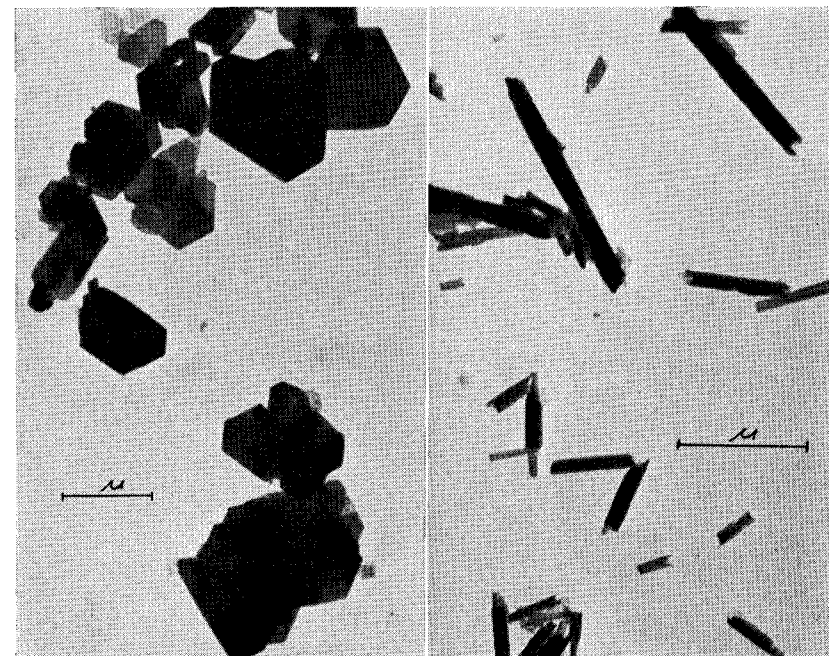
An inventory of the clays and shales of the State of Pennsylvania is being compiled. The inventory comprises accurate mineral composition, and textural characteristics of these materials as revealed by x-ray diffraction, electron and petrographic microscope studies, differential thermal analysis, and grain size distribution patterns.

This information will form the basis of reference for important industrial developments in the fields of ceramics and petroleum technology.

### *Electron Microscope and High Magnification Research*

Mineralogical research in the High Magnification Laboratory has proceeded along three lines: investigation of the clay minerals, a study of crystals and bubbles in opal glass, and an exploration of the application of the electron microscope to geological problems.

Studies of the kaolin group of clay minerals have yielded a new and important picture of the atomic structure of the mineral halloysite.



TWO OF THE PRINCIPAL MINERALS IN CLAY ARE SHOWN AS THEY APPEAR UNDER THE ELECTRON MICROSCOPE. THE HEXAGONAL PLATES IN A ARE TYPICAL OF KAOLINITE WHEN MAGNIFIED 19,000 TIMES. HALLOYSITE IS SHOWN IN HOLLOW TUBES REPRESENTING CURLED-UP CRYSTALS, MAGNIFIED 27,500 TIMES IN B. THE YARDSTICK ON BOTH PICTURES IS ONE MICRON, I.E., ONE THOUSANDTH OF A MILLIMETER OR 1/25,000 OF AN INCH.

Magnifications up to 30,000 times show that this mineral consists of exceedingly fine tubes 2,000 times thinner than a human hair. This is in striking contrast to the six-sided plates characteristic of the more common clays of this group.

Electron microscope pictures of opal glass show in detail the crystals and bubbles which scatter the light and make the glass opalescent. The particle size, shape, and distribution have been observed and measured for a representative group of samples manufactured by companies in Pennsylvania. Since similar work is impossible with the light microscope, this research represents a major advance in the study of the nature and cause of opalescence. It also indicates the important role of this powerful instrument in scientific research on mechanism of the crystal growth.

Many problems in the field of geology remain unsolved because the light microscope is not powerful enough to bring out extremely minute details of texture and morphology of minerals found in rocks. Work in progress reveals the significance of high magnification studies of oil sands, fossils, metalliferous ore bodies, and other geological subjects.



### *Seismograph Station*

The important aims of seismological research include the increase of: (1) knowledge about the interior of the earth, that is, the depth to and materials composing the core and the various layers; (2) information on the deep structure of the various continents and ocean basins; and (3) knowledge about the nature and causes of destructive earthquakes.

To accomplish these objectives, accurate data on every earthquake are required. The Seismograph Station is one of a national network of some sixty continuously recording stations. Detailed reports of teleseisms recorded here are sent to the U. S. Coast and Geodetic Survey at Washington, D. C., and to the Jesuit Seismological Association at Saint Louis, Missouri, for co-ordination with data from other stations of the network. During the past year, 30 earthquakes originating in all parts of the world have been so reported.

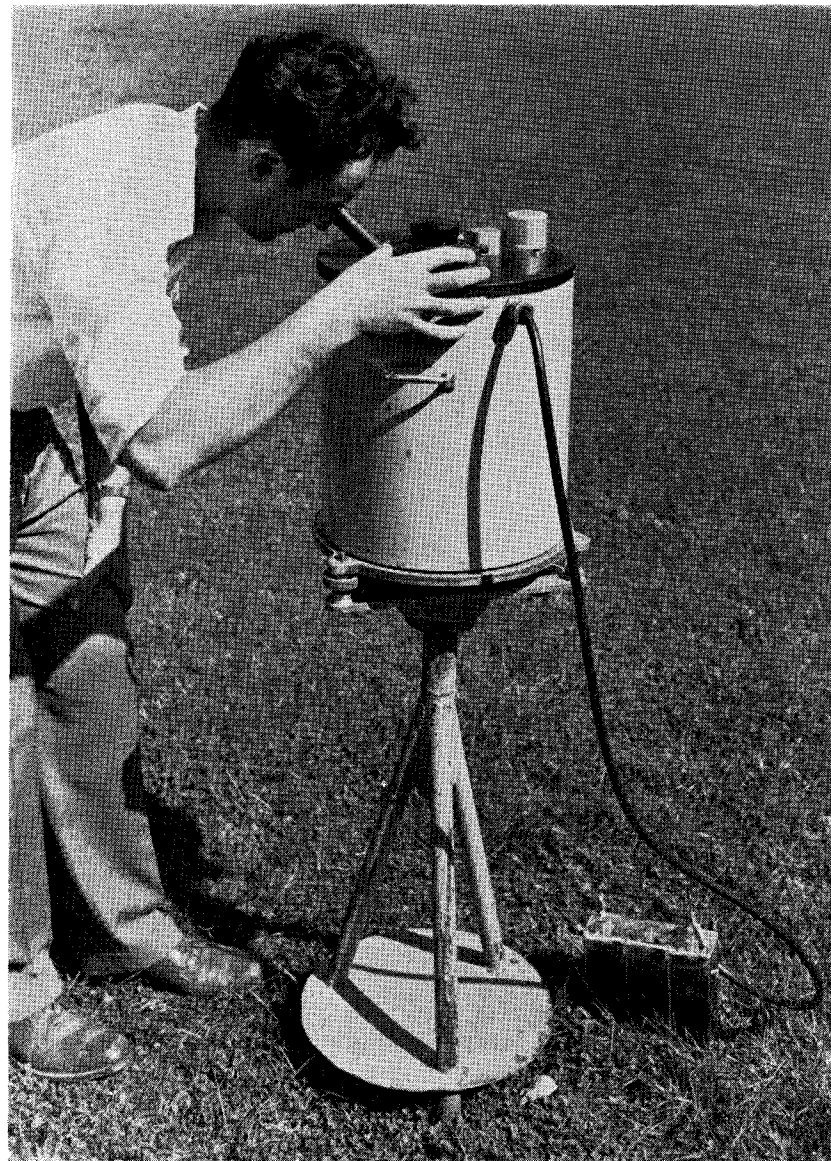
A program of construction and improvement of the station was begun in May, 1948. In addition to the two horizontal-component Galitzin-type instruments with photographic recording, the station now has a vertical-component instrument of original design, built in the Geophysical Laboratory. These instruments enable station personnel to determine the direction from which an earthquake shock came. The new instrument also displays an earthquake immediately upon arrival, since it records with ink in the Division office. It is planned to attach an automatic earthquake-alarm to attract the attention of the operator.

### *Gravimetric Survey of Pennsylvania*

The structural features of the Appalachian Mountains are well known at the surface, but little is known of the structure at great depth. A regional survey of the gravitational field within Pennsylvania has been initiated in an attempt to obtain physical information which will assist in the interpretation of the deep structures of the Appalachian Mountains.

Preliminary measurements have been made across the Allegheny front to determine the relationship which exists between the relatively gentle folding of the Allegheny plateau and the stronger folding which occurs to the southeast of the Allegheny front. Nearly four hundred gravity stations have been occupied in four traverses. The data are now in the process of reduction and interpretation. The gravitational data in conjunction with magnetic measurements will give some idea of the general subsurface structure within the Commonwealth.

Studies of the regional structural features of the Allegheny plateau as interpreted from geophysical data will be of value in the location of favorable structures for the accumulation of oil and gas.



AN INSTRUMENT CALLED A GRAVITY METER MEASURES SMALL VARIATIONS IN THE EARTH'S GRAVITATIONAL FIELD. FROM SUCH INFORMATION IT IS POSSIBLE TO OBTAIN PRELIMINARY KNOWLEDGE OF WHAT IS BENEATH THE EARTH'S SURFACE.

### *Geochemical Prospecting for Minerals*

Within the last few years interest has been aroused in this country in geochemical prospecting for ore. The basic idea upon which this method of prospecting is based is that there exists around most ore

bodies a small amount of the ore and associated substances disseminated in the rock. In many cases the ore material is not disseminated far from the ore body, but other constituents, characteristic of the ore, may be widely spread. In such cases analyses for the significant material traveling farthest are made. Thus by systematic soil analysis of a promising area, certain localities may be found to be exceptionally interesting.

Analyses of plants and water have been investigated in Centre County and abroad with rather promising results. As yet sufficient material has not been accumulated to make definite statements as to the usefulness of the method.

Work is being carried on to find new methods of soil and water analysis. Existing methods of analysis are also being used to build up a supply of data from which to draw conclusions regarding the efficiency and usefulness of the method.

### *High-Temperature Geochemistry*

It is a well-known fact that both temperature and pressure increase from the surface of the earth downward toward the center. Many of the minerals now exposed by erosion and available to man, such as sillimanite, olivine, and diamond, formed at great depth within the earth's crust, and therefore under conditions of high temperature and pressure. Studies are under way using apparatus which can simulate the temperature and pressure conditions existing at various depths within the earth's crust, in order to find out how these minerals formed.

In one type of apparatus, pressure vessels are used in which experiments are run up to a maximum temperature of about 800°C with an accompanying maximum pressure of 30,000 pounds per square inch, laboratory conditions simulating those at a depth of about five miles. The alumina-silica minerals and their hydrates are now being studied. In other apparatus, high temperature studies at atmospheric pressure are being made of minerals composed of CaO, MgO,  $Al_2O_3$ , and  $SiO_2$ , and of fluoride compounds composed of  $BeF_2$ , LiF, NaF, and  $MgF_2$ .

### *A Simple Method for Shallow Meteorological Soundings*

Information on the vertical distribution of atmospheric temperature and humidity is usually obtained by means of instruments which are connected to miniature radio transmitters and carried aloft by free balloons. For detailed exploration of the lowermost few thousand feet of the atmosphere, which is important in studies of air pollution, frost protection, etc., this method is not only costly but also inadequate because of the too rapid ascent of free balloons and their horizontal drift.

A new method was designed whereby instruments suspended from captive balloons transmit their signals in the form of elastic vibrations

through an electrically nonconducting mooring string. The signals can then be picked up by the observer on the ground either aurally with the aid of a mechanical phonograph reproducer or automatically by means of a crystal pick-up, amplifier, and tape recorder.

### *Studies in Atmospheric Condensation and Precipitation*

When the water vapor in the air condenses, clouds thus formed generally consist of minute water droplets even at temperatures as low as 40°F below zero and lower. On the other hand, some clouds are known to be composed entirely of ice crystals or of a mixture of liquid droplets and ice particles. These facts raised the question as to the conditions that lead to the freezing of the undercooled water droplets and to the crystallization of water vapor into ice crystals.

Experimental studies carried out in the meteorological laboratory revealed that the spontaneous freezing point of droplets ranging from 0.04 inch to 0.016 inch in diameter is practically constant at about 3°F, whereas for smaller droplets the freezing point becomes rapidly lower. Thus, for example, a droplet of 0.002 inch diameter will not freeze until it reaches a temperature of 27°F below zero. It was also found that a transformation of water vapor into snow crystals occurs only when the cloud forms at or below a temperature of 18°F below zero.

These results throw new light on the formation of rain, sleet, and snow from undercooled clouds. However, the process of growth of the minute cloud droplets into rain drops at temperatures above 32°F is still problematic. Experimental investigations are now under way into the various factors that affect the coalescence of small drops.

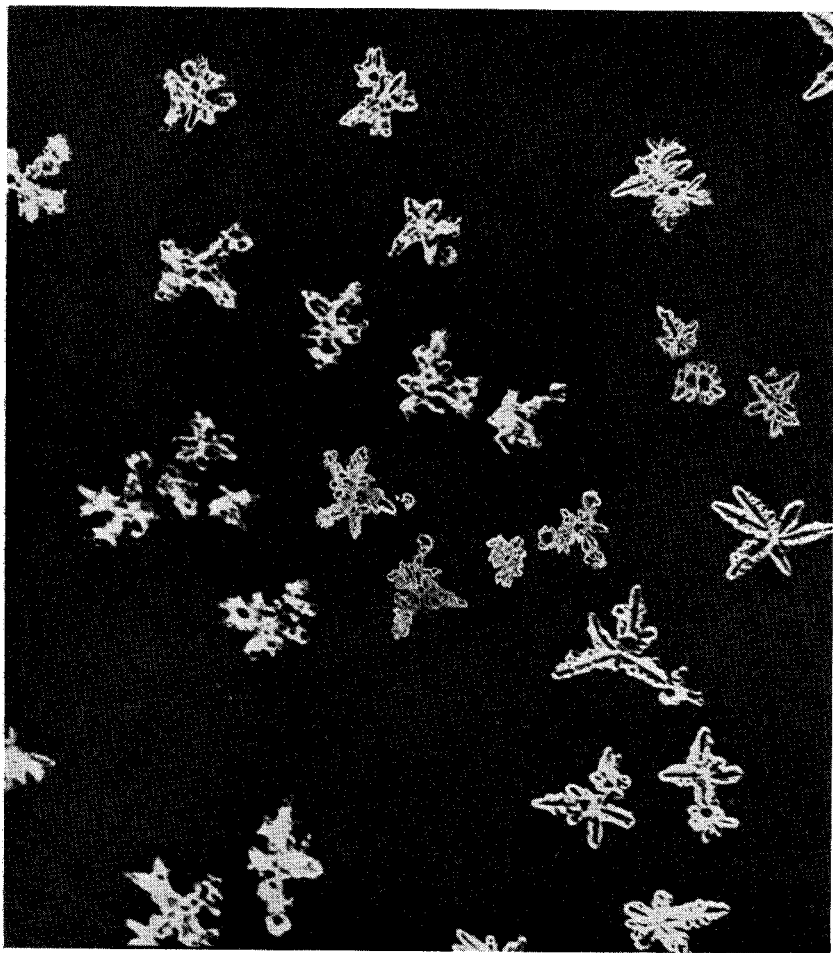
### *Studies in Air Pollution*

The effect of man's industrial activities on the pollution of the air has been noticed for the past several hundred years, but it is only for the last few decades that scientists have paid attention to this problem. How serious this problem can become was forcefully demonstrated by the fatal "smog" that settled over the town of Donora, Pennsylvania, late in October 1948. At the site of the Brookhaven National Laboratory careful micrometeorological investigations are being conducted in order to determine the weather conditions under which the radioactive waste gases from a nuclear chain-reaction pile will be harmlessly dissipated, a consideration of utmost importance from the viewpoint of public health.

The problem of air pollution is being studied from various angles. Laboratory investigations are conducted into the effect of condensation

nuclei, those invisibly small dust particles produced by combustion processes, on the persistence of fog in industrial areas. Another project deals with the relationship between pollution and the visibility through, that is the transparency of, the air. Preliminary studies have revealed that while visibility has no one-to-one relation to air pollution, a pollution index composed of visibility and relative humidity shows considerable promise. This phase of research is being further pursued at this time.

A more direct approach is also being attempted by designing a method by which the relative size distribution of the nuclei can be mea-



SNOW PRODUCED IN THE LABORATORY AT  $-36^{\circ}\text{F}$  SHOWS EXQUISITE CRYSTALLINE SHAPES WHEN OBSERVED UNDER THE MICROSCOPE.

sured. This investigation is being made in cooperation with the Division of Mineralogy.

#### *Effect of Weather on Electric Power Consumption*

The effect of weather on the operation of power plants has long been considered, and extensive use is made of weather forecasts in anticipating significant deviations from normal loads in the various branches of an electric power network.

The power plant of The Pennsylvania State College presents a unique opportunity for studying in detail the effects of individual weather elements on the power consumption, because of the restricted use made of electricity on the campus and because of the fact that records not only of the various scheduled campus activities are available, but also of the various weather elements including solar and sky radiation. A thorough analysis of the different factors affecting electric load is under way.

#### *Expanded Use of Pyrheliometric Records*

Pyrheliometers are intended for recording the intensity of solar and sky radiation on a horizontal surface. The previous Biennial Report recorded that pyrheliometric records can also be used for the determination of the duration of sunshine. Recently a method has been developed whereby such records can be employed in the objective forecasting of summer showers. The analysis of seven summers showed that the relative radiation intensity received between the hours of 8 and 9 a. m. enables a forecaster to make hits 19% better than chance, without involving any skill whatever.

An additional study is being made at present in order to determine whether the type of clouds and the state of the sky can be deduced from pyrheliometer records. This study will be based on simultaneous observations of the type and amount of clouds and the solar and sky radiation intensity.

#### *Environmental Studies of the North American Arctic*

A project sponsored by the Quartermaster General of the United States Army to study the environmental conditions in selected areas of the North American Arctic is being pursued. Maps are being prepared on slope, drainage, seasonal temperature, freeze and thaw conditions, precipitation, surface ground conditions and vegetation covering. These maps are being prepared from field observation, aerial photograph interpretation, and other source materials.

### *Revival of Iron Mining at Scotia, Centre County, Pennsylvania*

Greatly expanded demand on Lake Superior iron ore reserves during World War II resulted in reestablishment of small-scale iron-ore mining operations in Centre County, and has stimulated interest in possibilities of iron-ore operations in other parts of Pennsylvania. An analysis of physical and economic factors underlying such operations is in progress, in an effort to determine the extent of probable current and future production.

### *Landform Regions of Northeastern China (Manchuria)*

Current American-Soviet relations suggest the desirability of initiating studies of the physical geography of Soviet dominated or occupied territories, should American forces be called upon to operate in such regions. A refinement of earlier studies on the terrain of Northeastern China is currently in progress. Delimitation of landform regions, their characteristics and military implications, constitute the essence of the study.

## Mineral Technology

Research in the technologies is directed toward the better utilization and conservation of the raw mineral materials of our Commonwealth.

### METALLIC MINERALS

#### *Ductility of Steel at High Strength Levels*

The decrease in ductility of steels which accompanies heat treatment to high hardness and strength levels has long been of concern to users of steel. At the request of the United States Navy, Bureau of Ships, a study of the causes of this loss in ductility was undertaken, with the hope that some recommendations could be made as to how it might be improved. The effect of nitrogen removal by means of a moist hydrogen treatment was studied first, but it was found that no improvement in ductility resulted from such a treatment. Other factors investigated were the effect of nonmetallic inclusions and banding. It was learned that the ductility of exceptionally clean steels varied less with respect to rolling direction than did steels of normal cleanliness. This indicated that nonmetallic inclusions do result in a loss in ductility. The effects of banding were studied by measuring the ductility in tensile specimens cut perpendicular to the plane of a highly banded, high manganese steel. It was found that at comparable strength levels, the ductility of specimens subjected to a homogenization heat treatment was much greater than for steels of the same composition which had not been so treated.

### *Cleavage Failure of Ship Plate*

During the past war one of the major problems faced by the armed services was the problem of supply. To meet this problem it was necessary to construct merchant vessels by all-welding techniques. When such vessels were placed in service, however, it was found that they were highly susceptible to brittle failure. It has been found that many factors induced brittleness in ship plate as used in the Liberty Ship design, and among these was steel quality.

A project was completed under the sponsorship of the United States Navy, Bureau of Ships, the purpose of which was the study of steel quality as indicated by the tendency of ship plate to brittle fracture. The results have been reported in numerous government reports and in two recent technical publications. Briefly, these results have consisted in the development and evaluation of a specifications test applicable to specimens of small size, and the study of the fundamental flow and fracture properties of selected ship plate steels.

### *Temper Brittleness in Alloy Steels*

Certain alloy steels which have been slowly cooled from the tempering temperature fail in a brittle manner when subjected to a shock type of loading. The same steels when cooled rapidly from the tempering temperature behave in a more ductile manner. It has been shown that steels when subjected to a standard impact test exhibit a transition from ductile to brittle failure depending upon the temperature at which the test is being conducted. The transition proceeds from ductile to brittle fracture with decreasing temperature. It is apparent, therefore, that in the case of steels susceptible to temper brittleness, slow cooling from the tempering temperature has the effect of elevating the temperature at which this transition takes place. This has been confirmed by laboratory tests. The phenomenon has an effect directly opposite to what would be imagined if one were to consider that cooling slowly meant additional time at tempering temperatures, thereby further softening the material, which would in turn be expected to further increase the ductility.

Under the sponsorship of the United States Army, Bureau of Ordnance, an investigation into the causes of temper brittleness is in progress. The establishment of a small-scale tensile test as a device for demonstrating the effect of temper brittleness is the present objective. Subsequent effort will be directed at chemical alteration of the test specimens, followed by appropriate heat treatment, to afford opportunity for a study of the effect of various elements on the susceptibility of steels to this phenomenon. The investigation will be extended to a general study

of the mechanism of fracture of metals. Once this mechanism is better understood, it is hoped eventually to increase the ductility and fracture stress properties of heat-treated alloy steels.

#### *Alloys for Extremely High Temperature Applications*

The development of jet and rocket motors has emphasized the problem of obtaining materials with improved strengths at temperatures above 1500°F. A literature search was made for the Navy Bureau of Aeronautics to discover whether there has been proposed any means of predicting the mechanical properties of alloys at elevated temperatures. It was found that no experimental or theoretical bases for such predictions are available.

Several promising empirical methods of developing alloys with improved high temperature strength were suggested by the survey, and a research program was set up to study one of these, the use of inter-metallic compounds. A very considerable amount of new equipment was designed and constructed for this program. Since January 1, 1949, the work has been continued under an Atomic Energy Commission Pre-doctoral Fellowship.

#### *Flow and Fracture of Single Crystals of Binary Iron Alloys*

A fundamental research problem on the mechanical behavior of high purity iron binary alloys is being carried out under an International Nickel Company Fellowship. Because of the profound effect of minor impurities on the mechanical behavior of single crystals only those materials of highest purity are being used in the preparation of the binary alloys. The effect of alloying elements and prior treatment on the flow and fracture characteristics of a number of iron binary single crystals will be investigated.

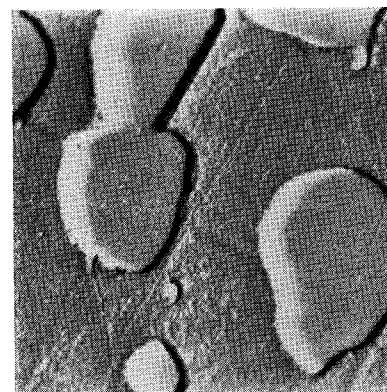
#### *Measurement of Thickness of Electrodeposited Coatings*

A project sponsored by the American Electroplaters' Society has as its objective a study of the methods which have been proposed for the determination of the thickness of electroplated coatings on both ferrous and nonferrous basis metals. Since the most important single item in metal finishing specifications is the thickness of the coating, it is highly desirable to know more about the accuracy of the methods which are available for measuring this factor. Early in the investigation it was found that the microscopic method, which has been widely accepted as the most accurate method, is subject to surprisingly large errors. It was also shown that the methods which depend upon the rate of a chemical reaction, of which there are several, are strongly influenced by factors such as internal stress and grain size of the deposit which in turn are

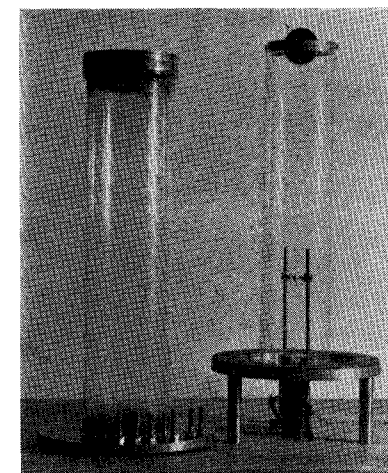
determined by the plating variables. It is evident, therefore, that procedures should be available for readily calibrating a given method against standards prepared under the same conditions as the commercial deposits to be measured. A study of such procedures is the present objective of the project.

#### *Radiation Laboratory*

Foreseeing the usefulness of the radioactive-tracer technique in metallurgical research, staff members of the Division of Metallurgy studied the availability at radioactive artificial isotopes, acquainted themselves with the regulations of the Atomic Energy Commission governing the sale and use of such isotopes, visited other metallurgical laboratories in which tracer-guided investigations were already in progress, and ultimately, through the enthusiastic action of the Dean of the School and the co-operation of other interested groups on the campus, stimulated the formation of an all-College committee of scientists to serve as the central agency of the College in all requests submitted to the Atomic Energy Commission for radioactive materials. Meanwhile, the Division's own laboratory was equipped and experiments were begun on what is expected to be an extended investigation of equilibrium and rate processes in heterogeneous metallurgical systems.



THE REPLICA SHADOWED WITH CHROMIUM IS EXAMINED UNDER THE ELECTRON MICROSCOPE AT A MAGNIFICATION OF 30,000 TIMES. THIS PHOTOGRAPH SHOWS WHAT AN ETCHED SPECIMEN OF SPHEROIDIZED 1.2% PLAIN CARBON STEEL LOOKS LIKE.



EVAPORATING UNIT IN WHICH CHROMIUM IS HEATED IN A VACUUM UNDER THE REPLICA WHICH IS FASTENED TO A TILTED DISC.

### *Electron Microscopy of Metals*

As an adjunct to the R.C.A. electron microscope, an instrument has been constructed for shadowing with chromium the collodion replicas which are used in the study of metal surfaces. The shadowing of the replica with chromium not only protects it from the heat of the electron beam in the microscope, but also adds contrast to the final photograph. The electron microscope is being used in a study of the structures observed in embrittled alloy steels, and is providing information on the structure of certain electroplated bright nickel coatings whose grain structure is beyond the limit of resolution of the ordinary light microscope. The present development of bright nickel coatings has been attained on a wholly empirical basis, and it is hoped that a knowledge of the structure of such coatings may lead to a more rational approach to the problem of improving the processes by which they are obtained.

## NONMETALLIC MINERALS

### *Slate Research*

Supplementing work carried on during the preceding biennium, emphasis during the 1947-1949 period has been placed on completing the study of the use of waste slate in six products which have progressed beyond the laboratory stage; other products which had been studied were discarded because of the apparent impracticability of attempting to produce them commercially or because the economics of operation were not favorable in competition with other products. Three of the products on which study has been completed have been processed under commercial conditions and have demonstrated that the techniques and compositions developed in the laboratory were reproducible on a large scale. Lightweight aggregate, slate-lime brick, pressed slate boards, ceramic ware, acoustical tile, and mineral wool show indications of being the most promising outlets for waste slate.

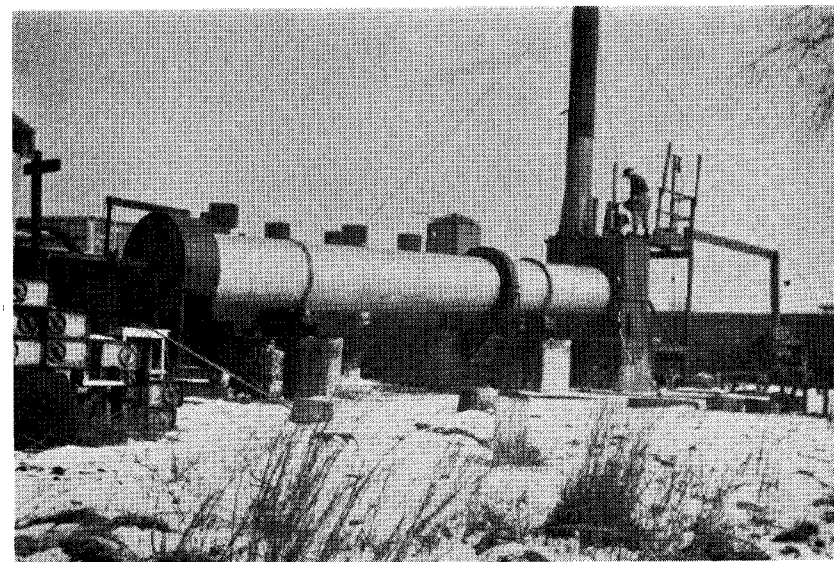
In addition to the above, considerable study was made of the problems of coloring slate roofing panels, of the possible use of waste slate in Portland cement, of the problem of cleaning school blackboards effectively, and of the essential differences between gray bed and blue bed stock.

### *Lightweight Aggregate for Concrete*

Another plant-scale trial of lightweight aggregate was completed during this period. Physical tests made on concrete utilizing this aggregate indicate that it possesses a unit weight considerably below average and a strength above that normally required for construction. Pro-

duction costs are estimated to be sufficiently below average retail prices to justify production in competition with commercial grades of aggregate.

Firing in a rotary kiln similar to that employed in the cement industry appeared to be an economical and practical method of preparing this product. Three cooperating companies—one in Ohio, one in Pennsylvania, and another in New Jersey—have permitted the College to use their rotary kilns for testing purposes. The accompanying illustration shows one of the rotary kilns which was used to produce expanded slate aggregate under commercial conditions.



FOLLOWING TESTS IN THE LABORATORY THIS PILOT PLANT ROTARY KILN WAS USED TO MAKE LARGER QUANTITIES OF EXPANDED SLATE FOR FURTHER TESTING.

### *Slate-Lime Brick*

A quantity of standard size brick was fabricated in a commercial plant. These brick were tested in the College laboratories to determine the merits for structural purposes. Compressive strength, modulus of rupture, porosity, resistance to abrasion, resistance to heat shock, and resistance to freezing and thawing were among the properties investigated, and standard weathering tests were made. After two years of exposed weathering, the brick still pass specifications which would permit their being used for normal structural purposes. No further laboratory or pilot plant study of this product is considered necessary; it is apparently ready for consideration as a production item.



### *Pressed Slate Boards*

Laboratory tests conducted on additional samples fabricated by custom molding companies in Maine and in Pennsylvania have indicated that a slate panel made by compression, molding a mixture of slate flour and an organic binder possesses properties which could be considered for use as bulletin board slate, electrical insulating panels, and perhaps roofing shingles.

### *Ceramic Ware*

The chemical and mineral composition of slate suggested the possibility of its being used as a raw material in ceramic products. Exploratory trails indicated that pulverized slate could be dry-pressed satisfactorily and could be shaped in soft-mud or stiff-mud forming operations without excessive difficulty. A slurry made from slate flour and water was easily deflocculated for use in slip casting of artware and earthenware shapes. Upon proper firing treatment, with control of the firing schedule to permit evolution of the gases liberated during the thermal decomposition of some of the minerals contained in slate, it was found that a vitrified bond can be formed with many of the characteristics inherent in low-fired ceramic ware. A pleasing shade of fawn can be produced without the use of body stains. Higher temperatures produced better vitrification and greater strength, but a chocolate-brown color resulted which limits market appeal.

### *Acoustical Tile*

Sound absorption qualities of laboratory-fabricated sets of tile were evaluated in a commercial testing laboratory recommended by the American Acoustical Materials Association. The sound absorbing properties at 500 cycles were found to be considerably lower than desired. This would indicate that more work may be necessary before commercial application is found practicable.

### *Mineral Wool*

Laboratory work on this product has been advanced to a stage preparatory to plant-scale production in one of several cooperating commercial plants whenever normal production can be interrupted to permit such tests.

### *Colored Roofing*

Slate is admittedly one of the most durable roofing materials on the market but serious inroads have been made upon its sales by materials

less durable but which are colorful enough to appeal to an increasingly color-conscious public. Although colored roofing may not be in the category of new products from waste slate, it would assist in creating new markets for natural slate. Chemical treatment, cementing agents, accentuation of some of the coloring material in slate, and the uses of various combinations of primer and cover paints have resulted in some surface colorations which have stood up remarkably well under severe weathering tests. A study of the fundamental character of the surface of slate revealed that it is predominantly a sheet of illite with unsatisfied potassium ions on the surface. Ionic transfer methods, particularly one procedure which deposits elemental copper on slate from a copper tartrate and formaldehyde solution using silver ions as a catalyst, show promise of providing a tightly adhering coat which may be the answer to the problem of producing a satisfactory ground coat or bond for paint.

### *Use of Waste Slate in Portland Cement*

The proximity of the slate belt to the Lehigh cement region, in conjunction with the known composition of slate, suggested the use of slate as a constituent in the manufacture of Portland cement. Preliminary trials were not conclusive evidence, but it is believed that there is justification for considering waste slate as a raw material constituent of Portland cement if and when present raw material supplies become depleted or submarginal.

### *Blackboard Cleaning Study*

One of the current problems in the slate industry stems from the complaints of present users of slate boards that slate does not stand up with constant use in the classroom. It was determined that the major factor involved was negligence or improper cleaning methods. Specific recommendations were made toward prolonging the life of slate blackboards and in improving their writing characteristics.

### *Study of Blue Bed and Gray Bed Slate*

There apparently have been little data to explain the inherent differences between gray bed and blue bed stock which account for the former being more durable than the latter. It was determined in the laboratory that there was a significant difference in composition which would explain the difference in physical properties. Chemical and x-ray analyses revealed that the gray bed contained appreciably more silica, less lime, less magnesia, less iron, less carbon, and less volatiles than the blue material.

## RESEARCH IN GLASS TECHNOLOGY

### *Fields of Glass Formation*

The fundamental problems of the conditions for a substance to form a glass and the possibilities to extend the fields of glass formation are being examined. Most glasses consist of a three-dimensional network of  $\text{XO}_4$  tetrahedra. According to their random arrangement these tetrahedra are slightly distorted in glasses. Deviation from the regular tetrahedron in bond angle and X-O distances is an essential condition of glass formation. By introducing ions of various field strength, such as a combination of  $\text{Li}^+$  and  $\text{K}^+$ , the environment of the  $\text{XO}_4$  groups becomes less symmetrical and crystallization becomes less probable. The field of alkali borate glasses can be increased greatly by the use of dissimilar alkali ions. Potassium metaphosphate can be obtained as a glass only with difficulty, but addition of  $\text{Li}_2\text{O}$  produces glass.

### *Adhesion Phenomena*

The field of glass technology deals with many problems involving the adhesion of a vitreous phase to metals. In order to shed light upon the problem of adhesion, studies were made with simple systems such as alkali halides and metals. A strange phenomenon has been uncovered. Potassium and sodium chloride, or the bromides and iodides of the alkali metals adhere to the glass or platinum crucible in which they were melted. However, if small amounts of a chloride are added to an iodide or vice versa, nonadhesion results. An explanation is offered for this phenomenon based on the formation of capillary-active groups which form in the surface of the melt in such a way that the forces directed towards the walls of the crucible are at a minimum. Nonadhesion can also be accomplished by adding traces of heavy metal chlorides ( $\text{PbCl}_2$ ) to a fused alkali halide.

The formation of capillary-active groups in fused salts and glasses led to studies of the surface tension. For several glass compositions, the surface tension was determined as a function of the temperature. It can be shown that many oxides undergo a change in oxidation when present in a glass surface. The shift in the oxidation equilibrium, not only affects the surface tension of the glass, but also makes this property a function of the furnace atmosphere.

### *Hygroscopicity of the Glass Surface*

Studies on the deformation of heavy metal ions such as  $\text{Pb}^{++}$  and others, reveal that these ions are in a state of strong polarization when present in a glass-air interface. Strong ionic forces are directed from the deformed metal ions towards the glass whereas the forces towards

the gaseous phase are very weak. As a result a glass surface treated with certain heavy metal salts becomes less hygroscopic, has a lower friction coefficient, and is less likely to assume an electrostatic charge on rubbing.

### *Methods to Determine Surface Forces Emanating From Solids*

Many problems in glass technology require a better understanding of the forces emanating from the surface of a glass. Two methods have been developed to gain better insight into these forces. One method is based on the migration speed of gold atoms at a glass surface. The rate of migration of gold atoms is affected by the forces acting between the gold atoms and the surface of the carrier. These can be measured by the time and temperature necessary to cause the gold atoms (colorless) to form crystals of colloidal size (pink-purple).

Another method of studying surface forces is based on the release of gas bubbles from water supersaturated with carbon dioxide. Solids which extend strong forces to the liquid make high supersaturation possible (clean glass surface). Solids having a basically different structure than water (graphite, diamond, silicon carbide) cannot extend strong forces towards the liquid and provide weak spots in the system where gas bubbles are readily released at their surface.

### *Striking of Glass*

The formation of crystals from a glass by heat treatment is widely used to produce opalescence and color. A basic study is in progress for determining the factors which influence the precipitation of fluoride and apatite crystals in opal glasses. Similar work is being done with glasses containing the sulfides and selenides of heavy metals. By means of x-rays and the electron microscope, the nature and the size of the crystals are determined as functions of the glass composition and heat treatment. Another method which is now being applied for determining ionic rearrangements in glasses on heat treatment is the thermal analysis by means of a differential thermocouple.

### *Apparent Molar Refraction of Glasses*

As a first approximation soda-lime glasses can be considered ionic substances. Lead glasses or glasses containing large and deformable cations, such as barium or thallium, however, can no longer be treated as ionic substances; their binding forces are somewhere between the ionic and the covalent type. The degree of covalency of glass can be determined by means of the molar refraction. Covalency is indicated by a strong deviation of the molar refraction from additivity of the values of the gaseous ions.



### *Color and Fluorescence of Natural and Synthetic Minerals*

The Geophysics Branch of the Office of Naval Research is sponsoring a project on the color and fluorescence of minerals. In spite of the interest in this property, very little is known about its relation to the atomic structure of crystals. Minerals are synthesized containing different coloring ions, and the influence of the environment upon these ions is studied. If an ion of a transition element is surrounded by anions in a highly symmetrical way, only weak light absorption results. Decreasing the symmetry of the environment produces stronger absorption.

### *Asymmetrical Groups in Glasses*

Two other projects sponsored by the Office of Naval Research deal with the formation of asymmetrical groups in glasses. In connection with these projects, glasses are being examined with the aid of catalysts. It has been found that certain ions, such as mercury and lead ions, catalyze a certain reaction only when absorbed at a glass surface, but not when in solution. These ions may poison the catalytic activity of platinum on the same reaction (decomposition of hydrogen peroxide). The role of the carrier of the catalytic ions is explained on the basis of Fajan's theory of the deformation of ions.

### **General Research Fellowships**

#### *Structural Clay Products Research Fellowship*

The Structural Clay Products Manufacturers Association of Pennsylvania established a Fellowship in the Division of Ceramics for research on problems of importance in the production of structural clay wares. The association requested that work be done first in studying the value of adding various chemicals, as reported frequently in technical literature, in order to improve the control of the manufacturing procedures. It was found necessary to determine first the minerals present in representative brick clays of Pennsylvania, and then to determine the effect of chemicals on these minerals. In continuation of this study, a graduate student is now making careful measurements of the colloidal properties of the mineral illite, which seems to be the chief mineral of many of these clays. Very little information is available as to the effect of chemicals on the behavior of this mineral.

#### *American Refractories Institute Fellowships*

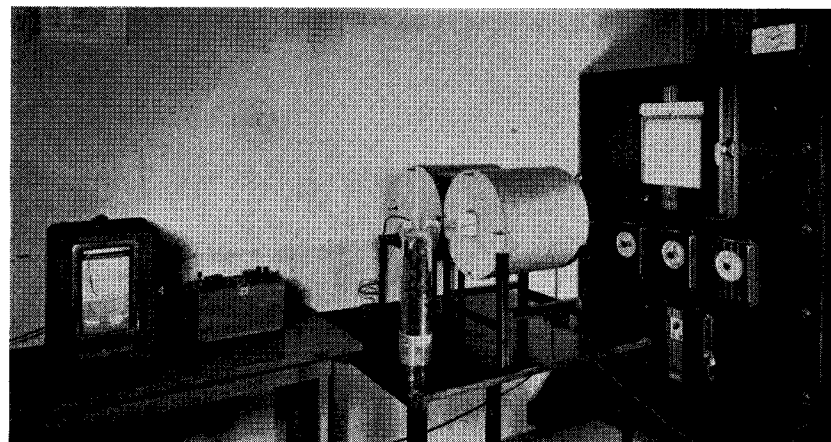
The American Refractories Institute sponsored two fellowships in the Division of Ceramics during the period of this report. One gradu-

ate student has built an electric furnace, with unusual composition of resistor bars, capable of being heated to about 3650°F. In this he will measure the change in electrical conductivity of rods of commercial refractories and of specimens prepared in the laboratory, as the temperature is gradually increased to the limits of the furnace. This information will be of considerable practical value as well as adding to the knowledge of the internal structure of the materials studied.

Another graduate student has recently completed an investigation of various phase relations in the system  $\text{BeO-Al}_2\text{O}_3\text{-SiO}_2$ . Bodies with compositions in this system have properties of interest to mineralogist and ceramist. Studies were made of the synthesis of compounds known to exist in this system, and some of their properties were determined. Results of this work are now being prepared for publication.

#### *Orton Foundation Fellowship*

Sponsored by the Edward Orton, Jr., Ceramic Foundation, studies have been made of the decrease in porosity of ceramic bodies on being fired to progressively higher temperatures and on various time schedules. Particular attention was given to the effect of the composition and physical properties of the fluxes used in developing low porosity, essential in the production of many important ceramic wares such as vitrified china and electrical porcelain.



DIFFERENTIAL THERMAL ANALYSIS APPARATUS USED TO MEASURE DIFFERENCES IN THE TEMPERATURE OF A SAMPLE, DUE TO HEAT EFFECTS ACCOMPANYING CHEMICAL OR PHYSICAL CHANGES, WHILE THE MATERIAL IS HEATED FROM ROOM TEMPERATURE TO 1000-1500°C IS AN EFFECTIVE AID IN IDENTIFYING CLAY MINERALS.

### *Miscellaneous Fundamental Research*

The research programs of graduate students yield important information of value to the ceramic industries of the State. Considerable attention is being given at present in the Division to the synthesis of pure ceramic compounds and determination of their properties and behavior. This involves a study of rates of reaction and the identification of the reaction product in various fields of chemical compositions, measurement of the stability of the compounds formed (their decomposition temperatures, for example), and observation of the physical properties of these compounds over wide ranges of temperature.

### *Industrial Research Programs*

Specific ceramic problems have been attacked during the past two years for a manufacturer of glass containers, a producer of refractories, a steel company, and a manufacturer of materials for porcelain enamels.

During the past three years the Air Materiel Command of the Army Air Forces has sponsored a research project devoted to the examination of ceramic materials for application to aircraft power plants. Ceramic bodies must be developed for service as rocket liners, thrust nozzles, turbine rotor and stator blades, and other jet engine components, where the temperatures exceed the useful limits for metals.

The program of investigation comprises a systematic study of the properties of refractory oxides and silicates, including crystal structure, thermal expansion, polymorphism, and decompositions and melting. In addition, measurements of the strength and resistance to heat shock at selected temperatures contribute data relative to performance under service conditions. Research is under way also in the field of refractory carbides, nitrides, and borides, and their inter-reaction products with constituent metals as oxides. A continuing effort is made to correlate observed data with known principles of the physical chemistry of solids, and to contribute wherever possible to the growing body of theory in this field.

## MINERAL FUELS

### RESEARCH ON ANTHRACITE

#### *Gasification*

The conversion of coal into carbon-monoxide and hydrogen has been one of the major phases of research for the past several years. This gaseous mixture, commonly called synthesis gas, is the starting material from which synthetic natural gas, liquid fuels, or chemicals can be manufactured. During the past two years, laboratory studies have been completed on the mechanism and the speed of one of the major

gasification reactions (steam-carbon) in order to supply additional fundamental data upon which equipment can be designed for the synthesis gas process. Laboratory studies are also in progress on a high speed gasification process in which incandescent fuel is blasted with air or oxygen at velocities up to 10,000 feet per minute. These studies are yielding information on the speed at which carbon can react with oxygen and are providing basic data upon which gasification equipment design can be based. Data secured in full-scale plant tests at Trail, British Columbia, on the production of synthesis gas from rice and barley anthracite and from coke by reaction with oxygen and steam, and on the utilization of this synthesis gas in the synthetic ammonia process have been calculated and reported in terms of the application of this process to synthetic liquid fuels manufacture. The results of these tests indicate the advantages to be gained by using relatively pure oxygen instead of air for the gasification process, and the suitability of anthracite and anthracite synthesis gas.

#### *Utilization of Fines*

Studies on the cleaning of fine anthracite have been reported elsewhere in the Bulletin. The utilization of these fines presents a problem which is being attacked in two ways. One is by means of further investigations on "pelletization." This process consists of forcing wet fines under pressure through a die. The fines are thus extruded in spaghetti-like rods an inch or more in length and up to an inch in diameter. After drying, these short rods or pellets have reasonably good strength characteristics, and make a satisfactory sized fuel for certain purposes. Because of their relatively high combustibility and their ease of ignition, they are especially satisfactory for specialized uses as household fuel and may have application in gasification processes. Tests on mixtures of anthracite and bituminous coal silt show that such mixtures can be pelletized satisfactorily, thus permitting the preparation of a "tailored" fuel having distinctive properties. One possible application of the blend pellets might be the manufactured gas industry where the added volatile matter from the bituminous coal would increase the heating value of the gas produced and thus permit the use of less oil for enrichment. One gas utility plant is interested in this possibility and has agreed to make plant-scale tests in the near future. A 10-ton-per hour pilot extrusion machine is now in operation producing pelletized anthracite. The second attack on the problem is by blending small percentages of anthracite fines with the bituminous coals used for the manufacture of by-product coke. This practice, studies on which were initiated during the war as a means of increasing the available fuel supply and improving coke quality, has now been in commercial application for several years. Additional research, however, has added new knowledge of interest to

the coal suppliers and the carbonization industry. Specifications for the anthracite fines most suitable for use in this process have been developed, and studies have been completed which indicate the usefulness of the anthrafines in controlling the swelling pressure which is developed when certain bituminous coal blends are carbonized. Detailed blending practices and experience records from a number of by-product plants using anthrafines have been accumulated and reported in order to assist new users.



THIS VIEW OF CUPOLA, MIXING LADLE AND OPERATOR POURING METAL INTO A MOLD WAS TAKEN AT A COMMERCIAL FOUNDRY WHERE TESTS WERE CONDUCTED BY THE FUEL TECHNOLOGY DIVISION USING ANTHRACITE AS A FUEL.

### *Anthracite as Cupola Fuel*

Because of the scarcity of quality foundry coke, interest in the use of anthracite as cupola fuel has increased, and an extensive research program has been undertaken to determine the best conditions for its use in modern high-speed iron melting operations, and to evaluate the characteristics of the various anthracites available for this use. It was found that because anthracite tends to pack into a denser bed than does coke of equivalent size, the resistance to the flow of gases through a cupola was increased when using anthracite. It is necessary, therefore, to have available a blower that will operate at a pressure sufficient to drive the same quantity of air through the anthracite. Where such blower capacity is available, high-speed melting can be readily attained with anthracite-coke mixtures and in some cases with anthracite alone. Plant-scale tests in cupolas ranging in size from 24-60-inch diameter have been made and melting rates as high as or higher than normal rating obtained. Metal temperature, metal fluidity, metal composition

and fuel consumption compared favorably with normal practice when using coke, although the flexibility of the operations were generally less satisfactory because of the higher pressures. Data from a number of plants also suggest the desirability of using small tuyere ports when employing anthracite, as this appears to permit the incoming air to penetrate the burning bed more satisfactorily.

### *Miscellaneous Studies*

Studies on the flow of gases through deep beds of fuel have been extended in order to secure information on how much of the gas admitted to the bottom of a fuel bed actually passes through the fuel and how much passes up along the walls and has little contact with the fuel. The investigations were made over a range of fuel size from No. 5 buckwheat to pea anthracite in containers from  $\frac{1}{2}$  inch to 24 inches in diameter. A relationship was found to exist between the ratio of the diameter of the container to that of the fuel, and the percentage of gas by-passing the bed. Only when the ratio attained a value of 100 did the by-passing become negligible. Theoretical studies on the effect of the stationary gas film surrounding each particle upon the pressure drop through the bed were also completed and have proved of value in interpreting the mechanism of gas flow through beds of broken solids.

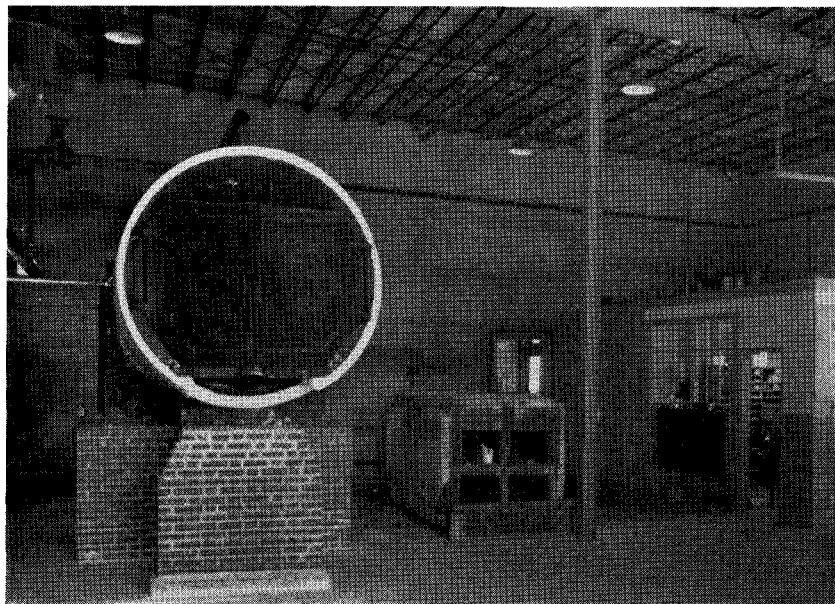
Work on the compilation of data on the physical properties of anthracite and bituminous coal such as electrical and thermal conductivity, specific heat, thermal diffusivity, thermal expansion, specific resistance, and di-electric constant has been continued and the results have been published. The information has proved of value to organizations engaged in engineering calculations on design of drying, bulk flow, and gasification equipment.

### **RESEARCH ON BITUMINOUS COAL**

#### *Comfort Heating*

Limited field trials on an automatic ash-removal-type and on a clinking-type Pennsylvania stoker have been continued in order to secure additional data on mechanical defects that might arise from continuous operation over a period of years. Detailed tests were also performed on the year-round use of the ash-removal-type for service hot water production. These tests showed that this stoker is capable of furnishing trouble-free semiautomatic operation the year around, with considerable saving in fuel over hand-firing methods, with no noticeable overheating of the home during the summer months, and with a lower cost than any other fuel or method of home heating plus service water production. One of the leading stoker manufacturers has been licensed to manufacturer stokers incorporating the improvements developed at

the College. After a period of design and development work, it is hoped that this manufacturer will have on the market an improved domestic stoker capable of furnishing automatic comfort heating with Pennsylvania bituminous coals.



EXPERIMENTAL BOILER UNIT IS AVAILABLE FOR LARGE-SCALE EXPERIMENTS ON THE COMBUSTION OF PENNSYLVANIA BITUMINOUS COAL.

### *Commercial and Industrial Stokers*

Work on the development of single retort underfeed stokers in the size range from 100 to 1,200 pounds per hour burning rate has been continued. Extensive test work on a variety of bituminous coals has indicated that the lack of satisfactory combustion performance with most coals could be traced directly to the distribution of sizes in the fuels as actually delivered to the burning zone of the stoker rather than to the generally blamed coking, caking, swelling, and plastic properties of the coals. With test coals in which the distribution of sizes was modified to produce that found most suitable for use on this class of stoker, combustion performance was good in all cases. Because it is not economically feasible to produce and sell coals having the ideal size consist, research has been continued on means by which the stoker or furnace could be modified to improve the burning performance. This has led to studies on stoker retort design and on the use of various designs of arches and baffles to improve combustion. A satisfactory baffle (sus-

pending arch) design has been developed and installed in a 178 HP heating boiler fired with a standard underfeed stoker. Performance of the baffled stoker has been excellent. Burning rates have been nearly doubled, over-all efficiency has been improved, manual attention has been decreased materially, and smoke production has been reduced to negligible proportions. In the three months of test to date, no evidence has appeared of increased wear on the grates or fire-box lining, or of deterioration of the refractory baffle. Additional work is in progress on improved baffle designs for installation in other types of boilers.

A new combustion engineering laboratory, jointly financed by the College and the coal industry of Pennsylvania, has been built and placed in service. This new unit of the Mineral Industries Experiment Station is the most completely equipped research laboratory in the country for work on stokers. Boilers and stokers in size ranges from domestic units to the 178 HP boiler fired with a 6' x 6' underfeed stoker are so interconnected that any one may be operated under special test conditions or under the normal operating conditions of supplying steam for use in the College heating system. Facilities are also available in this laboratory for work on domestic stokers.

### *Non-Fuel Uses*

Investigations on the development of chemical uses for bituminous coal, especially the finer sizes for which less commercial demand exists, have been continued on a laboratory scale with emphasis on the production and uses of humic acids, the chemical nature of these acids and the coals from which they were prepared.

### *Coal Fertilizers*

Bituminous coal itself is not a fertilizer, but as shown in the report for the last biennium it can be converted by the action of nitric acid into "nitro humic acids" which do have fertilizer value. By treatment with nitric acid, the coal is oxidized and nitrated and a product results which contains about 5 per cent organic nitrogen in a form which is slowly made available to plants. Greenhouse and field tests established its suitability for use as an organic fertilizer. Emphasis during the past year has been upon the development of a commercial process for the production of these acids. Significant progress has been made in reducing the amount of nitric acid required and in shortening the processing operations. Employing catalysts during the nitration stage permits acid consumption to be reduced to about one-third of that previously required. Processing techniques have been developed which suggest that a continuous gas phase treatment involving very little handling of the product may be feasible. Work is continuing on both lines of attack.

## Organic Chemicals

"Nitro humic acids" are an intermediate product between coal and relatively simple organic compounds of known structure. From a study of the chemical properties and structure of this intermediate product it is hoped that fundamental information will be developed which will shed light on the constitution of coal itself as well as lead to chemical uses for the product. Solvent extraction studies on the nitro-humic acids have yielded interesting information on the apparent molecular and equivalent weights of the acids and have led to a method, using a dioxane-water mixture as solvent, for the separation of the acids into two major components with markedly different properties. Detailed information on the solvent powers of about a hundred different solvents and solvent mixtures has been reported during the past year.

## Hydrogenation

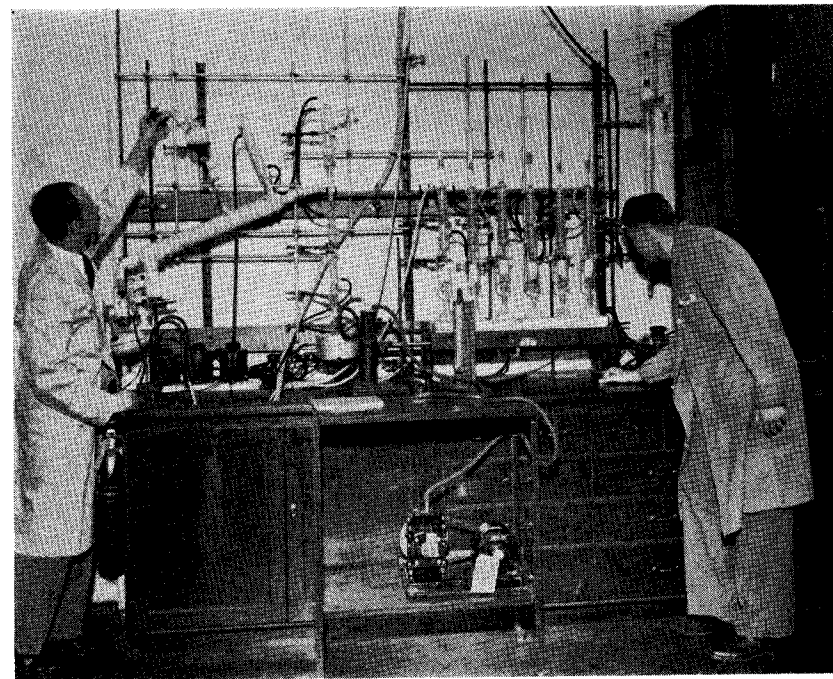
Another possible means of producing organic chemicals directly from coal is by hydrogenation at high temperatures and pressures. This process, used in Germany and England during the war for the production of synthetic liquid fuels, is being studied intensively in America at the present time. Despite the commercial use of this process, little is known about the chemical mechanism of the reactions involved. Considerable work on the coal hydrogenation process has been done at the College over the past 15 years, with the effort during the past biennium directed principally toward studies on the chemistry of the process. The attack has been through the hydrogenation—or better expressed, hydrogenolysis—of known organic compounds believed to be related in chemical structure to the coal molecule. Studies have recently been completed on two organic compounds, pyrene and carbazole. With the former compound, the hydrogenation was found to proceed through a series of hydrogen addition and cracking reactions to yield lower boiling gasoline-like material similar to that obtained by coal hydrogenation. With the latter compound which contains the element nitrogen, the mechanism of hydrogenation and cracking was similar, but the nitrogen linkage was found to be more stable than the rest of the structure. The small percentage of nitrogen which was released, appeared in the products as ammonia suggesting almost complete break-down of the structure to gaseous products.

## RESEARCH ON TARS AND OILS

### Tar Characterization

Although tars produced from manufactured gas operations, known as water gas tar, are related in some ways to the tars from coking

processes, no satisfactory method has ever been developed for their characterization. The increased demand for tar chemicals by the plastics and synthetic resin industries has resulted in a desire for standard methods of separation and analysis whereby an indication of the use-properties of different water gas tars could be compared and evaluated. Studies on the development of a characterization method were begun over a year ago under the sponsorship of the American Gas Association and have resulted in the development of a tentative characterization method which appears to be very satisfactory. Tests are now in progress using this method to characterize a variety of tars from different sources in order to establish the merits and limitations of the standard method.



LABORATORY EQUIPMENT USED IN STUDY OF TARS.

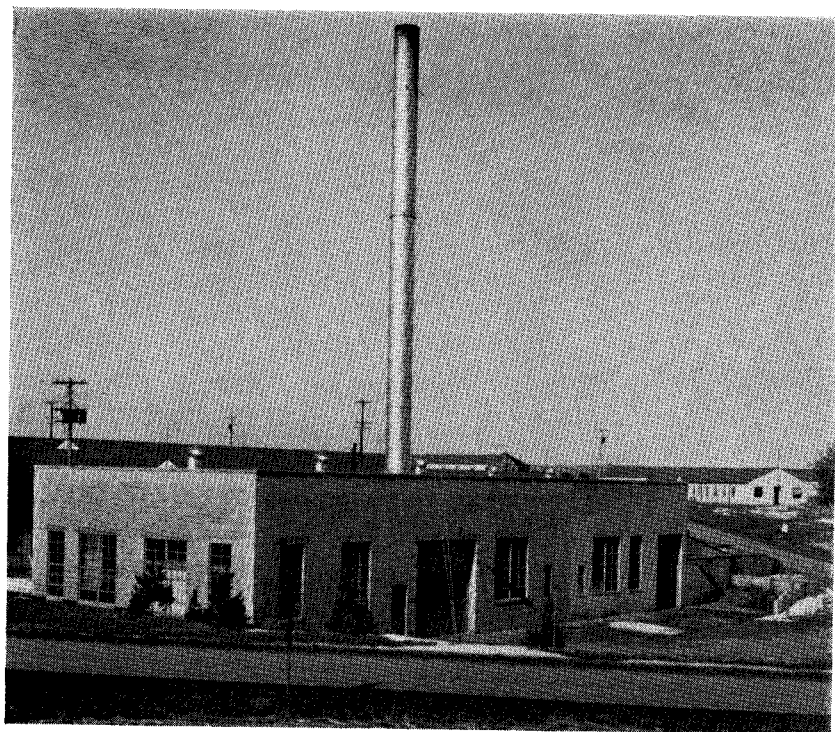
### Vacuum Distillation

In dealing with high-boiling heat-sensitive mixtures of compounds such as are found in tars, the use of distillation at greatly reduced pressures is frequently employed. Unfortunately fundamental data on the efficiency of various types of fractionation column packings is not available for low pressure operation. In order to furnish needed data in this field, an investigation has been made on the efficiency and general operat-

ing characteristics of a variety of packings at pressures from 10 mm. to 760 mm. of mercury. The results of this investigation showed that the separating efficiencies of different column packings did not fall off at reduced pressures as had been anticipated, although the through-put was reduced because of the reduction of weight of vapor present in the column at the lower pressures.

#### *Tar Constituents*

Studies on the isolation and identification of the chemical compounds present in water gas tar have been continued. The inadequacy of the physical data, normally used for product identification, on the complex organic compounds found in tars has necessitated employing the more tedious and time-consuming chemical methods of identification. A number of what are believed to be pure compounds have been isolated, however, and B methyl styrene has been definitely identified in addition to a number of more easily identified compounds which were known to be present.



VIEW OF NITTANY POWER PLANT AND NEW COAL COMBUSTION LABORATORY.

## PUBLICATIONS OF THE MINERAL INDUSTRIES EXPERIMENT STATION

Research results of the Experiment Station are disseminated through the following publications: (1) bulletins which present the proceedings of technical conferences, and the detailed results of experimental studies of a comprehensive problem; (2) information circulars which present in nontechnical language the results of studies which are given in greater detail in other publications, and statistical data or pertinent information gathered from other sources; (3) technical papers consisting of copies of papers published in scientific journals, of progress reports, and of results of experimental studies representing isolated phases of research later to be published in bulletin form.

Publications released during the biennium are listed below. These may be obtained from the Director of the Mineral Industries Experiment Station, The Pennsylvania State College, State College, Pa., at the price quoted.

#### *Bulletins*

- Bulletin 48 Eleventh Technical Conference in Petroleum Production. 1947. *Price \$2.*
- Bulletin 49 Petrographic Characteristics, Plastic and Carbonizing Properties of Chilean Coals by A. W. Gauger and Americo Albala. 1948. *Price \$2.*
- Bulletin 50 More Profit in Mechanical Mining Through Studies of Loading and Gathering Performance by A. W. Bitner and D. R. Mitchell. 1948. *Price \$3.*
- Bulletin 51 The Domestic Mining Industry of the United States in World War II by John Davis Morgan, Jr. 1949. *Price \$3.*
- Bulletin 52 Twelfth Technical Conference on Petroleum Production. 1948. *Price \$3.*
- Bulletin 53 Progress in Research for Biennium 1947-1949. *Free.*

#### *Circulars*

- \*Circular 28 Mineral Industries Correspondence and Extension-Class Instruction. 1947. *Free.*
- Circular 29 The School of Mineral Industries of The Pennsylvania State College. 1948. *Free.*
- \*Circular 30 Mineral Industries Extension and Correspondence Instruction. 1948. *Free.*
- Circular 31 Roots of Human Progress by Edward Steidle. 1948. *Free.*
- Circular 32 Analysis of Mineral Industries Education in the Western Hemisphere by Edward Steidle. 1948. *Free.*

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- Circular 33 Philosophy for Conservation by Edward Steidle. 1949. *Free.*
- Circular 34 Mineral Industries Extension and Correspondence Instruction. 1949. *Free.*

#### *Technical Papers*

- T. P. 121 The Source of Acetic Acid Obtained by Oxidation of Coal by Corliss R. Kinney. 1947. *Price 25 cents.*
- T. P. 122 The Oxygen Gasification of Anthracite in the Wellman-Galusha Producer by C. C. Wright and L. L. Newman. 1947. *Price 50 cents.*
- \*T. P. 123 The Alteration of Feldspar and Its Products as Studied in the Laboratory by Robert L. Folk. 1947. *Free.*
- T. P. 124 Relative Permeability Measurements on Small Core Samples by R. A. Morse, P. L. Terwilliger and S. T. Yuster. 1947. *Price 25 cents.*
- T. P. 125 Precision Determination of Stress-Strain Curves in the Plastic Range by John R. Low, Jr., and Frank Garofalo. 1947. *Free.*
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- T. P. 132 Small Coal Fired Central Heating Plant Pays Dividends by T. S. Spicer. 1948. *Price 25 cents.*
- T. P. 133 Evaluation of Underground Loading and Haulage Machines by David R. Mitchell and Staff of the Division of Mining. 1948. *Price 50 cents.*
- T. P. 134 Solvent Extraction of Indene and Coumarone from Coal Tar Light Oils by A. W. Gauger and J. N. Breston. 1948. *Price 50 cents.*
- T. P. 135 The Effect of Variation in Notch Severity on the Transition Temperature of Ship Plate Steel in the Notched Bar Impact Test by R. S. Zeno and J. R. Low, Jr. 1948. *Price 25 cents.*

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- T. P. 136 The Blending of Anthrafines in Coke Production by J. D. Clendenin and Joseph Kohlberg. 1948. *Price 75 cents.*
- T. P. 137 Cupola Operations with Anthracite by C. C. Wright and W. J. Reagan. 1948. *Price 50 cents.*
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