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JOSEPH A. HOLMES MEMORIAL, AT THE PITTSBURGH STATION OF THE BUREAU OF MINES.
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EXPERIMENT STATIONS OF THE BUREAU OF MINES.

By Van. H. Manning.

FOREWORD.

During the nine years that have elapsed since the Bureau of Mines was established in 1910, the work of the bureau has included many investigations that have proved of high value to the Nation. Eleven mining experiment stations established by act of Congress have greatly increased the bureau’s usefulness; being situated in the mining fields, these stations are closely in touch with industrial needs, and the results of their research and educational work are more directly available to those engaged in the mining, metallurgical, and mineral industries.

In the United States mining is second in importance to agriculture only. The Federal Government annually appropriates large sums in the interest of agriculture, whereas the appropriations for mining are relatively small. But the nation-wide popularity of Government assistance to agriculture should not overshadow the need of Federal assistance to the mineral industry. With scientific management farms can be made to produce indefinitely without any depletion of the potential resources of the soil, but the mineral wealth of a country is a fixed quantity, and every year’s production brings nearer its ultimate exhaustion.

As the deposits of the richer or more readily available ores, especially those in the West, have been depleted, development of methods for mining and treating the leaner or more inaccessible ores has lagged, so that meeting the increasing demands for certain metals is becoming more and more difficult. In some branches of mining the small independent operator is greatly handicapped. He has to rely on custom mills and smelters for the profit or loss of his product, and because of relatively inefficient methods of milling or smelting he may receive no return for much of the ore he mines. Even though the small operator thinks he knows of improved methods of obtaining the metals from the ores, he can not afford to install the necessary machinery or to carry on experiments that may or may not prove successful.

In view of the increasing need of metals and the impossibility of renewing the ore supplies, efforts should be directed toward develop-
ing the most economical and efficient methods in mining and metallurgy. The great mining companies carry on independent research work, some of them on a large scale; but as such work is usually undertaken for gainful purposes, these companies do not feel under any obligation to give the results of their investigations to the world. Clearly the solution of the difficulty is to place in the mining districts trained mining and metallurgical engineers who will investigate and solve the problems for the benefit of the whole industry. It is with this purpose in view that experiment stations of the Bureau of Mines have been established to investigate economy, efficiency, and safety in mining, and to make public the results of the investigations.

The Federal Government can be of most help in developing the mineral resources of the country when its forces are brought in direct contact with these resources. Mining is as old as civilization, but only within a generation has this country busied itself with any other problem of mining than the amount of mineral products that could be put upon the market. Little concern was felt if much of the metal in an ore was wasted, if the miner lived in unsanitary surroundings and died of preventable disease, or if accidents occurred frequently and from causes that could easily be controlled. Now we realize that the waste of any resource is inexcusable. The mineral wealth of the country can be mined but once. The task before the Nation is to recover as much metal as possible from the ore in the ground, and to do this in the most economical way without waste of human life. This task is of such magnitude as to warrant aid from the Government through experiment stations. In its efforts to make the work of these stations of most benefit to the mineral industry the Bureau of Mines seeks the cooperation of State authorities, of mine operators, of miners' organizations, and of every person interested.

These experiment stations also serve an educational purpose. Generally speaking, mining is not a preferred occupation. The miner should have reason to take greater interest in his work; he should feel that the experiments the Government is making affect him vitally by enabling him to increase his production and by making his work safer. The mine operator should realize that the Government stands ready to aid him, and he should know that he can bring his own problems to a Government organization that is trained and equipped to solve them. The surest method of accomplishing these results is to carry the work of the Bureau of Mines into the mining regions through the establishment of experiment stations easily accessible both to the mine operator and to the miner.

Many miners in this country do not read English, but they can understand motion pictures of mining methods; they can learn how lives can be saved in case of accident; and they can appreciate the larger results gained by modern methods and equipment. In every
mining region there should be some agency for the disseminating of knowledge that will increase the efficiency of the miner and safeguard his life. Such work has been started in certain districts now served by experiment stations of the Bureau of Mines. The aim is ultimately to cover all mining areas, and Congress has authorized the opening of additional mining experiment stations from time to time.

The war has emphasized the need for governmental research into all matters that in any way concern the common welfare. The Federal Government has the funds and the power to conduct investigations in the most efficient way. It can avoid the duplication of effort that is apt to occur if such work is carried on by the States alone. By working in conjunction with the State authorities the Government can include the special phases of research work necessary in any particular State. The stations of the Bureau of Mines already established have demonstrated their value in solving unusual problems.

It is difficult to measure and appreciate the contribution of these stations to the winning of the war. They helped to find more economical and efficient methods of production and to stimulate the production of minerals necessary to the proper equipment of our Army and Navy. The successful results of their work can be traced in almost every branch of the Army, from certain steels needed for the big guns of the Ordnance Department to the hundreds of soldiers trained in the use of oxygen breathing apparatus in the mining and sapping regiments of the Engineer Corps.

The experiment station at the American University on the outskirts of Washington, D. C., solved new problems in the testing and manufacture of war gases so efficiently that long before the end of the war the production of poison gas was far ahead of the supply of shells. This station also helped to develop highly efficient gas masks, smoke screens, and other defensive devices.

Although the work at this station was taken over by the War Department on July 1, 1918, in accordance with the program of uniting the gas investigations under the Chemical Warfare Service, work is still being carried on there, and the valuable equipment and laboratories form a nucleus around which a great mining experiment, station system could be developed.

The station at Columbus, Ohio, situated at a clay-working center is employed mostly on ceramic problems. In this country there are about 4,000 firms manufacturing clay products, including brick, tile, sewer pipe, conduits, hollow blocks, architectural terra cotta, porcelain, earthenware, china, and art pottery. The amount invested in these industries is approximately $375,000,000 and the value of the products exceeds $208,000,000 annually.
The station at Bartlesville, Okla., is investigating problems that arise in the proper utilization of oil and gas resources, such as elimination of waste of oil and natural gas, improvements in drilling and casing wells, prevention of water troubles at wells, and of waste in storing and refining petroleum, and the recovery of gasoline from natural gas.

What the Bureau of Mines has done for the great coal-mining industry, chiefly through investigations at the experiment station at Pittsburgh, Pa., has been published in numerous reports issued by the bureau. Some of the more important accomplishments have been the development and introduction of permissible explosives for use in gaseous mines, the training of thousands of coal miners in mine-rescue and first-aid work, and the conducting of combustion investigations, aimed at increased efficiency in the burning of coal and the effective utilization of our vast deposits of lignite and low-grade coal.

How vast are the deposits of low-grade ores being made available through the experiment stations is shown by the work assigned to the station at Minneapolis, Minn. The primary purpose of this station is to devise methods of utilizing low-grade iron ores. It has been estimated that the reserves of low-grade magnetic iron ores in the State of Minnesota alone amounts to some forty billion tons, but until recently these ores have been untouched because no process of treating them profitably had been devised. Even now only one company is attempting to utilize them. The Minneapolis station has already demonstrated that one process for utilizing the great deposits of manganiferous iron ore on the Cuyuna Range is metallurgically possible.

Work such as this not only stimulates mineral production and helps to make available tremendous resources that are now unused, but it increases the total wealth of the Nation and ultimately benefits every citizen.

The mining industry is so related to commerce and manufacture that the importance of publishing the results of technical investigations of mining problems is becoming more and more evident. The miner and the mine operator are integral parts of the industrial system of the country, and each needs to keep in close touch with what the Government is doing through the mining experiment stations of the Bureau of Mines.

In the West vast quantities of low-grade complex ores will become available as soon as commercially feasible processes are devised. Many of the problems involved, which are being attacked at the Golden, Colo., station, the Salt Lake City, Utah, station, the Seattle, Wash., station, the Tucson, Ariz., station, and the Berkeley, Calif., station, are of such a nature that the small operator can not afford to attack them, and the large operator finds them outside his field.
Yet the solution of any one of them may add greatly to the available resources of the country and may result in establishing a new industry that will build up the district in which it is situated. Already these stations, although young, have witnessed such results.

To-day, through the efforts of men at the Golden station, there is an American radium industry. Formerly the low-grade radium-bearing ore was wasted, the best of the ore was bought by foreign concerns at ruinously low prices, and the radium was shipped back to this country at excessively high prices.

The Salt Lake City station has devised novel methods of treating certain low-grade and complex ores of lead and zinc. These methods show a large saving of metal over methods hitherto employed, and have made available ores that other methods could not treat profitably.

The Seattle station is busy with the beneficiation of the low-grade ores of the Northwest, and the mining and utilization of the coals of the Pacific States; the Tucson station is working on the beneficiation of low-grade copper ores; and the Berkeley station has shown how losses may be reduced at quicksilver plants and how methods at those plants can be improved.

In the conduct of these investigations the bureau seeks and is obtaining the cooperation of the mine operators. At more than a dozen mills in the West engineers from the stations are working directly with the mill men on various problems, and the results they already have obtained more than warrant the existence of the stations. Success in solving one problem may easily be worth millions to the country. Mining men are using these stations more and more freely as they realize that the Government maintains these stations to help them, and that the difficulties of the operators, both large and small, will receive sympathetic consideration and such aid as the stations can give.

ACKNOWLEDGEMENTS.

Dorsey A. Lyon, supervisor of stations, H. E. Tufft, of the editorial staff of the bureau, and Prof. W. C. Thayer, of Lehigh University, temporarily detailed for service with the Bureau of Mines, assisted in the preparation of this bulletin. Also, acknowledgement is due H. Foster Bain, formerly assistant director of the bureau, for criticism and correction of the manuscript.

COOPERATIVE WORKING AGREEMENTS WITH STATE INSTITUTIONS.

In order to insure the most effective action with State agencies working along similar lines to the bureau, to harmonize activities and avoid needless duplication of effort, and to have the advantage of the use of the facilities provided by such institutions, the Bureau
of Mines endeavor to cooperate with State organizations and with State universities and mining schools. The wisdom of this policy has been amply demonstrated and the number of such institutions cooperating with the bureau is constantly being added to each year.

As has been stated, a number of the mining experiment stations of the bureau are established at or housed in buildings provided by State universities or mining schools.

Thus the station at Urbana, Ill., situated at the engineering experiment station of the University of Illinois, works in close cooperation with that institution and with the Illinois Geological Survey. The station at Tucson, Ariz., is housed in a building on the campus of the University of Arizona; the station at Berkeley, Calif., occupies a building of the University of California, and works in cooperation with that institution; the station at Moscow, Idaho, is situated at the University of Idaho; the station at Golden, Colo., is at the Colorado School of Mines; the station at Minneapolis, Minn., is at the University of Minnesota; the station at Columbus, Ohio, at Ohio State University; the station at Salt Lake City, Utah, at the University of Utah; and the station at Seattle, Wash., at the University of Washington. In addition to cooperating with the institutions mentioned, the bureau also does cooperative work with the Industrial Accidents Commission of California, the Oregon Bureau of Mines and Geology, the University of North Dakota, and Cornell University.

SAFETY AND RESCUE STATIONS.

The mine-rescue and safety work is under the supervision of George S. Rice, chief mining engineer of the Bureau of Mines, and is in charge of D. J. Parker, mine safety engineer, with headquarters at Pittsburgh, Pa.

For the purpose of facilitating the mine-rescue and safety work of the bureau the country is divided into districts, the safety and training stations and the headquarters for mine rescue cars being selected with regard to convenience and effective effort. The seven safety stations are at Pittsburgh, Pa.; Norton, Va.; McAlester, Okla.; Birmingham, Ala.; Jellico, Tenn.; Seattle, Wash.; and Vincennes, Ind. The eight mine rescue cars, three of which are specially designed all-steel cars, have headquarters at Pittsburgh, Pa.; Huntington, W. Va.; Ironwood, Mich.; Evansville, Ind.; Pittsburg, Kans.; Raton, N. Mex.; Butte, Mont.; and Reno, Nev. In addition to these eight cars, three all-steel cars similar to those now in use are under construction and will be put in service as soon as completed. These new steel cars will probably replace three of the five wooden cars now in use. Also three rescue trucks for general training work are maintained, one each at the Pittsburgh, Birmingham, and Seattle stations. An
additional rescue truck is now under construction for the Vincennes station.

Each station is in charge of a foreman miner, who gives both mine-
rescue and first-aid training. The stations are equipped with
emergency sets of rescue apparatus and first-aid supplies for rendering
assistance at near-by mines in the event of a disaster. The mine-
rescue cars are completely equipped for giving aid at such disasters
and for training work, and have accommodations for about 12
persons. Each car when fully manned has a foreman miner who
trains men in safety and rescue methods, a first-aid miner who gives
training in first aid, a mining engineer, and a surgeon. Plate II
shows a mine-rescue car. The interior of such a car is shown in
Plate III.

WORK OF THE CARS AND STATIONS.

In 1917 and 1918 a special feature of the work of the cars and
stations, in addition to the rendering of aid at mine disasters, the
training of miners in first-aid and mine rescue work and the organizing
of field contests in first aid and mine rescue, has been the training of
soldiers at military camps in rescue and safety methods and in the
use of breathing apparatus in poisonous or irrespirable gases.

An important duty of the men engaged in this work is inspecting
rescue apparatus for mining companies and giving advice as to its
condition and the repairs needed.

During the fiscal year ending June 30, 1918, fully 8,851 miners
were trained in mine rescue and first aid at more than 70 towns in
the 19 States where such training was given; the lectures and safety
demonstrations were attended by more than 33,000 miners. Since
its establishment the bureau has given first aid or rescue training, or
both, to more than 55,000 miners.

An important feature in stimulating the interest of miners in
rescue and safety work is the holding of mine-rescue and first-aid
contests at which teams from the different mines compete. During
the fiscal year 1918 Bureau of Mines employees participated in 13
field contests. Some of these were company affairs, others were
intercompany or interstate. The bureau's men helped to arrange
and supervise some of the contests and gave competing teams
special instruction and training. Handbooks on rescue and first-
aid methods, published by the bureau in 1916 and 1917 have proved
of especial value in training men at mines.

RESCUE WORK AT MINE DISASTERS.

Members of the Bureau of Mines investigated 38 mine accidents
during the fiscal year ended June 30, 1918. Thirty of these were in
coal mines and eight in metal mines.
The value of oxygen breathing apparatus in exploring mines after fires and explosions has been demonstrated many times. As the possibilities and limitations in the use of breathing apparatus are becoming better understood, and as recovery work at mines is being placed on a more systematic basis, success in the employment of such apparatus is more assured, and the possibility of the wearer coming to grief through lack of proper knowledge of the device becomes increasingly small. A technical paper describing the principal types of breathing apparatus and the proper precautions in their care and use was published by the bureau in 1917.

INVESTIGATIONS OF MINE SANITATION AND HYGIENE.

Through a cooperative agreement with the United States Public Health Service, experienced surgeons are detailed for service with the Bureau of Mines rescue cars. These surgeons investigate sanitary conditions at the mines and camps visited by the cars, and give illustrated lectures on how to keep the home and the mine sanitary, and how to prevent the spread of communicable diseases. Health hazards and conditions tending to favor occupational diseases in mines, mills, and industrial plants are studied and methods of improving or alleviating such conditions are suggested. Nearly always this work has received hearty cooperation from the mine operators, and the workers and their families show keen interest in the lectures. The surgeons also examine applicants for rescue training to determine whether they are physically qualified for mine rescue work.

Special investigations relative to silicosis, or miners' consumption, and the general health of miners in the Butte, Mont., district are being made by a mining engineer of the Bureau of Mines and a surgeon of the Public Health Service. These investigations will show whether the disease is prevalent in Montana mines and the precautionary measures that will have to be taken where working conditions tend to injure the miners' health.

The complete results of a similar investigation in the Joplin district, which had been underway for some years, was published as Bulletin 117 of the bureau.

THE MINING EXPERIMENT STATIONS.

The work of the Bureau of Mines in connection with the 11 mining experiment stations that have been established since 1908, the needs that led to the establishment of each station, and the problems that confront the bureau are discussed in the following pages. There were general reasons for placing each of these stations in the territory where it is situated, as well as such local reasons as position near mining fields and convenience of transportation.
BUREAU OF MINES RESCUE CAR AND CREW.
General oversight of all the mining experiment stations is intrusted to Dorsey A. Lyon, supervisor of stations, with headquarters at Washington, D. C.

The superintendents of the stations are selected because of their having broad technical knowledge, as well as skill in handling economic problems. Solution of a mining or milling problem is often complicated by the fact that the mine or plant under consideration may be situated in a new or undeveloped district, so that the availability of fuel or supplies and the transportation facilities must be taken into account in devising methods of extracting or treating the ore. Each station looks after the interests of a diversified mining population with its many problems of safety and health. Without police powers or other means of enforcing its views, each station must depend upon the good will of the region that it is established to serve. It must consider problems of transportation and supply, study markets, and devise feasible methods of production and treatment.

The list of stations, with the dates of their establishment and the general character of the minerals or industries that they are to study, is as follows:

<table>
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<tr>
<th>Experiment stations of the Bureau of Mines.</th>
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<tr>
<td>Station</td>
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<tr>
<td>Station at Pittsburgh, Pa.</td>
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<td>Station at Urbana, Ill.</td>
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<td>Station at Salt Lake City, Utah</td>
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<td>Station at Golden, Colo.</td>
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<td>Station at Berkeley, Calif.</td>
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<td>Station at Tucson, Ariz.</td>
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<td>Station at Seattle, Wash</td>
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<td>Station at Fairbanks, Alaska</td>
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<td>Station at Columbus, Ohio</td>
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<td>Station at Minneapolis, Minn.</td>
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<td>Station at Bartlesville, Okla.</td>
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</table>

Each station makes a monthly report to the director of the Bureau of Mines, through the supervisor of stations, on the progress of the investigations that are being conducted. Also, suggestions and
requests for the maintenance and extension of the work are made to the director, through the supervisor, who determines what problems call for immediate solution. Thus the work of the stations is coordinated; each station pursues its own specific duties; the director and his assistants decide the broader questions of relative importance; and the supervisor sees that the work at each place is kept steadily advancing in accord with the general plan. Each station acts independently, but interests and investigations are closely coordinated; an earnest purpose to regulate official action in the correlated interests of science and of industrial progress, with due regard to public happiness and prosperity, is the end sought.
THE PITTSBURGH STATION.

ORIGIN OF THE WORK ON FUELS.

The work now being done by the Bureau of Mines had its beginning in the testing and analyzing of fuels, as authorized by Congress, at the Louisiana Purchase Exposition in St. Louis, Mo., in 1904—a duty then under the supervision of the United States Geological Survey. Early in 1905 the work at St. Louis was placed under the direction of Joseph A. Holmes, as expert in charge. Analyses of coals, steaming and coking tests, and various related tests were made, and after 1905, under appropriation made by Congress, the testing of structural materials was added. By order of the Secretary of the Interior, in April, 1907, these two allied groups of investigation—testing of fuels and testing of structural materials—were made a separate branch of the United States Geological Survey, with Dr. Holmes, as chief technologist, in charge. Early in the same year all the fuel-testing equipment, except that for coking and washing tests, was moved to the Jamestown Exposition at Norfolk, Va., where tests of coals used in the Navy were made during the years 1907 and 1908.

ESTABLISHMENT OF THE PITTSBURGH STATION.

In 1908, before the Federal Bureau of Mines was established, a beginning of Government investigations relating to coal mining was made at Pittsburgh, Pa. By a temporary arrangement with the War Department, part of the grounds of the old Arsenal on Butler Street was leased to the Department of the Interior. There material and equipment were assembled, the nucleus being formed from exhibits and machinery used in the investigative work at the St. Louis and Jamestown expositions. The chief motive for the establishment of this station was the desire to help and guard the miner, to prevent mining accidents, to rescue the victims of mine disasters, and to experiment on different means of meeting and eliminating the ordinary risks of the miner's life.

The first efforts at this station related to the testing of explosives for use in coal mines and to gas-producer, briquetting, and steaming tests of coal. Large-scale tests to determine the explosibility of coal dust and the best methods of preventing dust explosions began in 1910 at the experimental mine established at Bruceton, about 13 miles south of Pittsburgh. In 1911 Dr. Holmes issued his first annual report as director of the new bureau. This report presents not only the practical results achieved, but also the patience and
foresight of the director, every page showing his earnest purpose to make the station immediately useful to the region in which it is placed, and ultimately to the entire country.

Investigating, first, coal-mining problems and fuels, the station soon obtained results of great value; for hand in hand with scientific investigations went the endeavor to meet the problems of mine accidents, first aid, safety, and accident prevention—to safeguard the life of the miner and improve his working conditions. At the time of the passage of the act establishing the bureau in 1910 the factor most effective in calling attention to the need of Government action was a series of frightful disasters in coal mines in December, 1907, and a growing realization of the preventable waste of life and resources in mining and metallurgical industries. The work at Pittsburgh suggested similar efforts at other places and gradually established standards for a safety campaign that soon became nation wide.

**REMOVAL FROM THE OLD SITE.**

Early recognizing the need of a permanent home for the station and one that would be adapted to the work being carried on, Dr. Holmes finally succeeded in obtaining the Forbes Street site now occupied by the Pittsburgh experiment station and also succeeded in getting from Congress an appropriation to erect the building now occupied. This building was completed and ready for occupancy in September, 1917. However, it was not possible to move the station in its entirety at one time and the moving was gradual; but in the spring of 1919 the bureau had practically vacated the old arsenal grounds. The formal dedication of the new building will be on September 29, 1919.

One phase of the work at the old site was the testing of explosives, but the proximity of public buildings and residences made it imperative that the explosives work be moved to a locality where the lives of the public would not be endangered nor damage done to property. Accordingly the large-scale tests of explosives are now made at the experimental mine of the bureau at Bruceton, Pa.

**THE NEW BUILDING.**

The new building of the Bureau of Mines is in the residential part of Pittsburgh, in the Schenley Park district. The commercial development of Pittsburgh, its rapid growth, and its stirring business life are matters of common knowledge; everyone has heard of its coal and iron interests, its mines and furnaces and mills. The city is known far and wide for the activities of its industrial leaders; and to the general public Pittsburgh represents little else than coal, iron, and steel. But in the group of buildings seen within a circle of a half-mile radius from the Bureau of Mines Building a higher note is
struck—the intellectual as well as the material interests of the people of a great city. Across a ravine to the south rise the impressive buildings of the Carnegie Institute of Technology; across a broader ravine to the west, through which run the tracks of the Baltimore & Ohio Railroad, lies the Carnegie Museum with its all varied appeal to learning and intelligence and taste. On the northern, western, and southeastern horizon tower the largest buildings in the city, churches, the Mellon Institute, the new buildings of the University of Pittsburgh, the Masonic Temple, Pittsburgh Athletic Club, the Soldiers’ Memorial, Schenley Hotel, and Schenley High School. Among these are many beautiful and tasteful houses and gardens that mark the favorite residential section of the city.

Fronting on the north on Forbes Street stands the new building of the Pittsburgh station. It is plain and unpretentious, yet massive, dignified, and attractive, and adequate to the present needs of the mining experiment station. The main building, shown in Plate IV, is three stories high, with a frontage of 332 feet, and it is flanked at each end with two-story wings, running back from the street 211 feet. Each wing projects a few feet beyond the front line of the main building, and is 48 feet wide. The central part of the building is 210 by 56 feet. An impressive feature of the central building is the massive archway that forms the entrance, a monolith in concrete; eagle, decorations, and all details forming one great stone, to which a special treatment has given a surface accurately imitating granite. It is said by competent architects to be the finest piece of work of its kind in the United States. A view of the west end of the corridor is shown in Plate V.

Opposite the entrance, on the south wall of the corridor is a medallion portrait (see frontispiece, Pl. I) in bronze of Dr. Joseph A. Holmes, organizer and first director of the bureau, with an appropriate inscription. Behind that wall, with entrances from each side of the central panel, is an auditorium that seats 240 people. It is fitted with camera and apparatus for motion pictures and for illustrated lectures.

On the first floor of this central building are the administration offices. Here are rooms for the director, connecting with a large conference room; offices for the supervisor of stations, who represents the director at this station and has supervision of the work. There are also office rooms for the chief clerk of the station, and for the mails, files, purchase, and supply divisions. A plan of the first floor is shown in figure 1.

On the second floor of the central building are offices for the coal-mining engineer, the mine-safety engineer, the superintendent of the experimental mine, and the explosives engineer, also the library and
reading room. The top floor accommodates the division of technical service, with rooms for computing, drafting, photographic, and motion-picture work, with dark rooms and appliances for printing and development, and storerooms where thousands of negatives are kept. On this floor there is also a kitchen and a large room adjoining which is used as a cafeteria for the employees of the station.
NEW BUILDING OF THE PITTSBURGH EXPERIMENT STATION.
The ground floor holds the instrument shop, a supply and store-room, a smoke room for testing oxygen rescue-apparatus and for training men in their use, rooms for rescue apparatus, for shower baths and toilets. The entire east wing is occupied by the offices, workrooms, and laboratories of the chemical division. The west wing houses the engineering interests and the investigations of fuels. The mechanical engineering laboratory on the ground floor runs the whole depth of the wing and is two floors high.

**THE POWER HOUSE.**

At the old site, as already noted, the power plant has been dismantled. The new power house on the Forbes Street site has been completed, and the machinery is installed. Advantage has been taken of the slope to place the power house on a lower level, behind the main building and out of sight from the front. (See Pl. VI.) The structure is 55 by 220 feet, built of reinforced concrete, and divided into three parts. A short spur from the railroad tracks enters the grounds at the southwest corner. Coal is lifted from the cars by means of an electric hoist to a large pocket, from which, on the inside, fuel may be taken into the boiler house. This is at the west end of the building, where three boilers are installed—two water-tube boilers of the Babcock-Wilcox type, formerly in the Capitol at Washington, and one Parker boiler. The center space in the building is occupied by the engine room. There are now installed three simple engines of the Nordberg type, connected with 200 k. v. a. three-phase, 440-volt generators. The engines can be run independently or any two can be run in parallel. The motor-generator set will furnish direct current at 110 and 220 volts.

The space at the east end of the building is intended for several kinds of apparatus. The apparatus for the study of heat transmission through boiler tubes is being set up here; also special furnaces for the study of the combustion process within the fuel bed. House-heating boilers, four in number—perhaps six if there is room enough—will aid in the study of problems of efficiency in heating houses by both steam and hot-water systems.

A De Laval turbine has been brought over from the old arsenal site and set up in the engine room for the use of the electrical laboratory in special testing.

**PROPOSED SHOP.**

Among the buildings projected there may be a structure known as the service building, to be between the main building and the power house, running lengthwise from east to west, for storing tools and supplies, and available for the manifold needs of a large plant employing many men. It should be a long and narrow building, two stories in height, with the probable dimensions of 200 by 40 feet,
of an architectural style to conform to the general appearance of
the main building.

As grading and filling goes on the property will be developed on
an orderly and well-conceived general plan, making this site a digni-
fi ed and acceptable home for the Pittsburgh station.

DIVISIONS OF THE BUREAU REPRESENTED AT PITTSBURGH
STATION.

The following divisions of the bureau are represented at the Pitts-
burgh station: Mining, fuels and mechanical equipment, explosives,
petroleum, metallurgy, chemical, administrative.

Below is given a summation of the character of the work of each of
these divisions:

MINING DIVISION.

The principal work of the mining division at Pittsburgh has to
do with coal mining. Two phases of this work are emphasized—
(1) Mine rescue and first-aid work; and (2) the prevention of mineral
waste.

MINE RESCUE SECTION.

The mine rescue section of this division is engaged in mine rescue
and first-aid work, chiefly the rendering of aid at mine disasters,
the training of miners in first-aid and mine rescue, and the conducting
of first-aid and mine rescue contests.

A mine safety motor truck fully equipped with mine rescue appa-
ratus and mechanical resuscitating devices, inhalator, safety lamps,
ox ygen cylinders, life-line reel, stretchers, and first-aid cabinets,
complete with sterilized bandages, compresses, bandages, etc., is
held in readiness to be dispatched to the scene of disaster on short
notice. The truck is in charge of a crew expert in mine rescue
and first-aid work, and is sent to all mine fires, explosions, and disas-
ters in the Pittsburgh district.

All work relating to the testing of rescue apparatus and of mechani-
cal resuscitating devices is in charge of this section. Both the
Gibbs and the Flueuss machines are being tested for efficiency. All
apparatus sent to the mine rescue cars and field stations is tested at
Pittsburgh before being shipped.

A schedule of tests has been prepared for establishing a list of
permissible mine rescue breathing apparatus, giving fees, character
of tests, and conditions under which apparatus will be tested.

Names of men trained by the bureau between July 1, 1914, and
June 30, 1916, were published in Technical Paper 167,a and those of

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a Parker, D. J., Men who received Bureau of Mines certificates of mine rescue training, July 1, 1914, to
REAR VIEW OF PITTSBURGH STATION, SHOWING POWER HOUSE.
men trained between July 1, 1916, and June 30, 1918, are printed in Technical Paper 226. This list will supplement that published as Technical Paper 167, which gives the men trained by the bureau during the period July 1, 1914, to June 30, 1916. The publication of the names and addresses of men so trained enables State and mine officials to obtain with minimum delay the services of the nearest available trained men in the event of a mine disaster.

THE EXPERIMENTAL MINE.

The primary purpose of the bureau's experimental mine at Bruce ton, Pa., 13 miles south of Pittsburgh, is to enable explosions of coal dust and gas to be made on a scale comparable with ordinary mine explosions. The walls, roof, and timbering of a mine present conditions that can not be duplicated in a gallery of wood, steel, or concrete. Hence preventive measures that are quite successful under artificial conditions in a surface gallery are not necessarily successful in a mine. Arrangements of the experimental mine make possible the duplication of any kind of explosion that may occur in a coal mine. In this mine, moreover, other investigations relating to safety can be made, such as tests of gasoline locomotives, of mining or cutting machinery, of electrical equipment, and of ventilation methods. Gas-producer tests and physical and chemical tests of explosives can well be associated with a plant of this sort.

COAL-DUST EXPLOSIBILITY TESTS.

Dusts of various coals have been tested for explosibility in the experimental mine. The coals tested range from anthracite, containing 5 or 6 per cent volatile matter, to subbituminous coals containing more than 40 per cent. Four of the coals tested by the standard method are: One from Clearfield County, Pa.; one from near Benham, Ky.; one from the Crows Nest Pass field, British Columbia; and one from Vancouver Island, British Columbia. Each coal was tested for explosibility in sizes corresponding to the average fineness of road dusts obtained from the mine in which the sample was taken, and also in a size of standard fineness for comparison with other coals.

Also, tests of various sizes of dust of Pittsburgh coal from the experimental mine have been made. This series, when completed, gave the explosibility of four sizes of coal dust under three conditions—without gas, with 1 per cent, and with 2 per cent of gas in the ventilating current.

A series of tests was made to determine the effect of free moisture, when mixed with coal dust and with rock dust, upon the explosibility of the four standard sizes of Pittsburgh coal dust.

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All of these tests were made in the standard test zone in the experimental mine, which is lined with "gunnite," or blown concrete. From these tests three charts or sets of curves, have been prepared, which show how the composition of the coal, the size of the dust particles, and the moisture content effect the explosibility of the dust. These charts have been found useful in interpreting the results of explosion tests and in determining what dust mixture is necessary at any particular mine to render the coal dust inert.

A view of a manometer, for measuring the pressures developed by an explosion, is shown in Plate VIII, B (p. 30).

EXPLOSION BARRIERS.

In this mine, explosion tests of barriers containing rock dust in shelves and troughs which tip with the force of the initial explosion, have been repeatedly made. Rock-dust barriers of various types which have been devised by bureau engineers and successfully applied in commercial mines are described in detail in Technical Paper 84.\textsuperscript{a} Recently much success has been had with troughs that discharge a thin sheet of water in fine spray through a $\frac{1}{4}$-inch aperture. In tests made no explosion has penetrated this barrier.

EFFECTS OF MINE STOPPINGS ON EXPLOSIONS.

A series of explosion tests was made in the two butt entries in the experimental mine to determine the effect of mine stoppings in checking or propagating explosions. Explosive limits for two sizes of coal dust were determined in one of the butts, with heavy stoppings placed in the cut-throughs and with no stoppings. A similar series of tests was made in the other butt, from which five rooms have been turned. These tests show that while the rooms did not change the explosive limits much, they did cause lower pressures and velocities. The series indicates that the danger of explosions being propagated is practically no greater with strong stoppings than with light stoppings or no stoppings at all. Resistance and confinement, however, within certain limits increase the dynamic thrust of the explosion. The effect of an explosion on a concrete stopping, which was completely destroyed, is illustrated in Bulletin 141.\textsuperscript{b}

A series of tests was made to determine how near the mouth of the entry an explosion could be started that would travel inby and through the mine. It was found that a blown-out shot of 2 pounds of black blasting powder would propagate an explosion through pure coal dust when the source of ignition was 180 feet from the mine mouth. When the point of ignition was moved to within 112 feet


of the mine mouth, propagation was not obtained even when the igniting charge was increased to 4 pounds of powder. In all of these tests the flame traveled outby to the mouth of the entry.

STENCHES FOR WARNING MINERS OF DANGER.

A novel method of warning miners of danger by turning a foul-smelling gas into compressed-air lines has been developed at the experimental mine. One of the most promising stenches tried is a preparation of butylmercaptan or isomercaptan; its pungent and disagreeable odor gives timely warning of an unsafe condition and allows the miner time to escape. Its manufacture involves the replacement of the oxygen of alcohols by sulphur, compounds known as hydrosulphides or mercaptans being formed. Thus butyl alcohol \( \text{C}_4\text{H}_9\text{OH} \) is converted to butylmercaptan \( \text{C}_6\text{H}_{13}\text{SH} \).

In the event of sudden danger, such as a fire on the surface near the mouth of the mine, or in one of the upper levels with a large number of men in the next level below, or any condition necessitating hasty escape of the men, the engineer at the surface can at once, by means of a simple device, introduce this pungent substance into the compressed-air pipes. Its odor is unmistakable, and is instantly detected by the miner, who has been told to regard the odor as a danger signal. The odor reaches him through the drill that he is using, the hoists where he is working, the pump that he is controlling, and through all forms of machinery using compressed air. The method is simple and direct; it replaces expensive telephone equipment, and is more dependable than electric bells and signals.

COAL-MINE ENGINEERING.

One of the chief efforts of the mining engineering division is to increase the output of coal by advising the use of mining methods that insure the recovery of a larger proportion of the coal mined and a general saving in expenses. A progressive operator using improved methods and fewer men will mine an acre thoroughly, whereas a non-progressive competitor will mine two acres with less production, greater cost, and more discomfort to the miner. A bigger production per acre decreases the expense for mine props, for haulage, for pipes, and for electric systems. Thus, the small mine, intensively developed, may prove a far better venture than a larger one poorly worked.

Better light is an immediate benefit, as a miner working by good light can do more work with greater safety and comfort, and will give more willing and efficient service than one working in a dimly lighted place. It is obvious that in a mine worked intensively much better lighting facilities can be had for less cost than in a poorly worked mine covering a much larger area.
Waste in the Anthracite Fields.

The shortage of fuel during the winter of 1917–18 brought before the country the need of avoiding waste in mining and preparing coal. In general, there are three sources of waste at the mines: Coal left in the ground, coal lost by poor methods in mining, and coal wasted after it is brought to the surface.

In some anthracite mines more than half of the coal in an area mined has been left in the ground. That this is unnecessary is shown by the fact that there are mines working seams 4 to 6 feet thick in the Lackawanna Valley region, about 300 feet below the surface, from which 90 per cent of the total content is recovered. The end of the anthracite supply, at present rates of production, is only a matter of years. Hence the more progressive operators use the greatest care in mining, and the sources of waste, so heavy a drain upon the expense account in the earlier years of the industry, are now sedulously curtailed. More coal is mined from the beds, better methods are introduced for handling coal, improvements are investigated and adopted, and better machinery for cleaning the coal is put in use. The successful coal-mining engineer of to-day is the man who can cause the seam to yield the greatest proportion of marketable coal with a minimum waste.

Waste can be curtailed by using improved machinery and the sizes of coal once rejected. From 1820 to 1870, after deducting the percentage of loss due to impurities and waste, only one-fourth of the anthracite coal actually mined was sent to market; by 1882 improved methods and the use of smaller sizes brought the yield up to nearly one-half. To-day, under ordinary conditions, three-fourths goes to market and only one-fourth to waste, but this is still too much.

As regards machinery, the greatest improvement is in the breaker. The old and badly-gearied cast-iron rolls, moving at slow speed, had blunt teeth that crushed much of the coal and ground it to dust. The modern steel rolls, revolving at high speed, have sharp teeth which cut the coal without crushing it. In breakers fitted with modern machinery, long shaking screens are used to separate prepared coal into different sizes. At some plants the dust, waste, and culm are briquetted.

Through the efforts of the Bureau of Mines, and of State and commercial organizations, practices almost universal a few years ago have been largely abolished; the mining public has recognized the folly of waste, and a general regard for conservation, both of mineral wealth and of human life, has been established. We are learning to prize and to estimate at their full value the wealth of this country in metals and in fuel. The appointment of State fuel engineers in the chief coal-using States, and the establishment of an organization to discover how far steam boiler plants are following economic methods of burning coal would greatly aid conservation of fuel.
DIVISION OF FUELS AND MECHANICAL EQUIPMENT.

The fuel efficiency section of this division at the Pittsburgh station has charge of the investigations relating to the increase of safety and efficiency in the use of fuels throughout the country and in the mechanical equipment of mines. It renders large service to other Government bureaus in matters pertaining to fuel economy. Investigations of the processes of combustion have resulted in the publishing of reports of great usefulness and of fundamental importance.

Coals purchased for the use of the Government are inspected and tested, in order to determine those best suited for the heating requirements of any particular power plant or boiler installation.

Tests have been made of the so-called "fuel-saving powders" that are flooding the market. Almost every one of these has been found to be absolutely worthless for the purpose intended. A bulletin is to be published covering this phase of the bureau's work.

GIBBS OXYGEN MINE RESCUE APPARATUS.

The Gibbs oxygen mine rescue apparatus had its development in this division, and is fully described in the Yearbook for 1916 (pp. 12–16). As this apparatus is superior to any other similar device, known to the bureau, for entering poisonous or irrespirable atmospheres, the attention of the War Department was called to its value for use in mining and sapping work. As a result, experiments were begun in cooperation with the War Department and the apparatus was brought into form for manufacture. Through contracts entered into by the Engineer Corps of the Army with a commercial firm, the apparatus was manufactured in quantity and shipped overseas for military use. The apparatus is light, its parts are well protected against injury, and recent tests show it to be a distinct advance as regards simplicity, lightness, reliability, capacity, and efficiency of regeneration. It furnishes air that is cooler and easier to breathe than any other available apparatus tested.

In two mine fires and in one disaster the Gibbs apparatus met all requirements. Fifteen tests were made; eight of these were during a period of more than two hours of strenuous work, to determine the functioning and the tightness of the apparatus; the other seven tests were for determining the efficiency of the regenerative cartridge. All results were satisfactory. Only a little carbon dioxide, usually less than 1 per cent, was present in the air supplied to the wearer.

Sixty-five sets of this apparatus have been received by the Bureau of Mines. These, after being tested for tightness and proper functioning, and after their record is taken, are being distributed to the mine rescue cars and safety stations.
ELECTRICITY IN MINES.

The work of the electrical section of this division at the Pittsburgh station has largely to do with the testing of electric mining equipment submitted by manufacturers to determine its safety for use in gaseous coal mines. The danger of an explosion being started by an electrical machine, lamp, or installation sparking or becoming overheated when gas is present is so obvious that the importance of this work is evident to the most casual observer. Equipment that passes the tests prescribed by the bureau is approved by the bureau, this approval being attested by a plate bearing the seal of the Department of the Interior. As a result of this work, mining has been made immeasurably safer and the use of equipment approved by the bureau is being rapidly extended.

Apparatus is tested under schedules issued by the bureau from time to time, as the need for a particular class of apparatus develops. The types of apparatus for which schedules have been issued to date include the following: Permissible electric motors for mines, permissible portable electric mine lamps, permissible miners' safety lamps, permissible gas detectors for mines, permissible mine-locomotive headlights, permissible electric lamps for mine rescue service, permissible flash lamps for use in explosive mixtures of methane and air, permissible single-shot blasting units, and permissible self-contained oxygen breathing apparatus.

These schedules are becoming widely known throughout the mining industry, and a large proportion of the mines are using apparatus approved by the bureau.

Besides extending the approval system manufacturers are encouraged to develop safe apparatus, and the bureau is constantly seeking to improve laws and rules covering the installation and maintenance of electrical equipment in mines.

TESTING OF MINE MOTORS.

The coal-mine operator requires a motor that can be used in a mine where fire damp may occur. In the bureau's tests of explosion-proof apparatus, assumption is made that such explosive mixtures are present. The motor or other explosion-proof piece of apparatus to be tested is placed in a gallery (Pl. VII, A), where it is not only surrounded by an explosive mixture of gas but the motor casing is filled with it. Plate VII, B, shows a motor piped so that an explosive mixture of gas can be placed within the casing. The gas within the motor is ignited by a spark plug or from the commutator. If no explosion of the gas outside the motor occurs after repeated tests of this kind, the motor passes the permissibility tests and is given the bureau's approval for use in gaseous mines.
A. MOTOR TESTER.

B. MOTOR PLACED IN GALLERY FOR TESTING IN EXPLOSIVE GAS.
EXPLOSIVES DIVISION.

PHYSICAL TESTS OF EXPLOSIVES.

As previously stated in this bulletin, all work relating to the physical testing of explosives is now conducted at the experimental mine. Congress appropriated $17,000 for moving the equipment, and for building foundations, instrument shelters, and service lines (water, gas, steam, electric, sewerage, and drainage). The equipment, including two galleries each 100 feet long, the ballistic pendulum, the Mettegang recorder, small impact machine, large impact machine, pendulum friction machine, flame-testing apparatus, Bichel gages, calorimeter, and a variety of lead-block expansion and compression-test equipment, were moved. These apparatus and the methods of using them have all been described in Bulletin 66 a of the bureau.

The moving was planned and so conducted as to interfere the minimum length of time with any given test, so that there was practically no interruption of the testing work during the time of moving. This was accomplished by preparing the foundations for a given apparatus and then dismantling, moving, and setting up promptly. The moving began in July, 1917, and continued intermittently for two months.

The new installation (Pl. VIII, A) includes four instrument shelters 20 by 30 feet, and one story high, of hollow-tile construction and concrete floors; three “bomb-proofs”—one very large, within which several pounds of explosive may be detonated, one within which an hydraulic press is installed, and one for apparatus for mixing explosives; separate magazines for the storage of high explosives, including permissible explosives, black blasting powder, and other easily ignited powders, detonators, electric detonators, and samples sent to the station to be tested. Especially heavy foundations were required for the ballistic pendulum, the galleries (Pl. IX, A), and the large bomb-proof (see Pl. IX, B.) Several hundred feet of concrete walks and concrete steps were built in order that explosives and dangerous blasting supplies could be transferred with safety. The magazine for high explosives is built in accordance with the principles laid down in Bureau of Mines Technical Paper 18, "Magazines and Thaw Houses for Explosives."

The work of this division consists of studying the physical characteristics of the various classes and grades of explosives used in mining and also the physical characteristics of different kinds of blasting supplies; the character and quantity of poisonous and inflammable gases produced by the explosives used in close or inadequately ventilated places are also studied, the purpose being to classify explosives

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on this basis so that the user may have information on one of the dangers attending the use of explosives in mines. Exhaustive tests are also made of coal-mining explosives to determine their permissibility for use in dusty or gaseous coal mines.

CHEMICAL TESTS OF EXPLOSIVES.

In the explosives chemical laboratory of the bureau at Pittsburgh examinations are made of samples of explosives submitted to the bureau for test, to determine the permissibility of the explosives for use in dusty or gaseous coal mines or the suitability of the explosives for use in metal mines, tunnels, and quarries. Under this head is included the examination of samples of permissible explosives collected in the field from time to time in order to determine whether the permissible explosives on the market maintain the composition of the samples originally tested by the bureau.

In addition to the chemical examinations of mining explosives to determine their permissibility for use in dusty and gaseous coal mines, and for other industrial purposes, much work in connection with the analysis and inspection of explosives has been conducted for the War Department and other departments of the Government, including the inspection of dynamite and detonators for the Panama Canal. The cooperative work for the War Department included tests of grenade fillers, shell fillers, and gun greases. On account of the excellent facilities possessed by the bureau for research work in explosives, the cooperative work with the War Department on explosives and explosive materials for use in munitions developed rapidly during 1917 and 1918.

An investigation is being made of different methods of analyzing and of testing explosives, and of the standardization of all methods with a view to preparing a manual describing the best methods of procedure to follow in such work. Also a study was made of the preparation, properties, and uses of explosives. A technical paper describing the methods used in the explosives laboratory has been published by the bureau.

Work on a propylene glycol dinitrate, to be used as a commercial explosive, has been completed. The process involved the nitration of propylene glycol, the determination of propylene glycol nitrate thus made, and the preparation, analysis, and tests of different types of commercial explosives in which this material is to be substituted for the nitroglycerin now commonly in use.

Further work has been done on the determination of explosive materials or their products of combustion in coal samples from boreholes or blown-out shots. A paper on this subject is in course of publication.
A. THREE OF THE NEW INSTRUMENT SHELTERS, EXPERIMENTAL MINE.

B. MANOMETER FOR MEASURING THE PRESSURES DEVELOPED BY AN EXPLOSION.
A. GAS-AND-DUST GALLERY, EXPERIMENTAL MINE.

B. THE "BOMB-PROOF," AT EXPERIMENTAL MINE, FOR TESTING RATE OF DETONATION OF EXPLOSIONS.
Representatives of this laboratory assisted in the investigation of explosions at places where explosives were being made for military use.

Experiments have been made to determine the suitability of flax and the down of the milk weed, cat-tail, and white smoke-root as substitutes for cotton in the manufacture of nitrocellulose for nitroglycerin.

As nitro substitution compounds are used in all classes of explosives, a knowledge of the nitrogen content of such compounds is useful in identifying them and determining their purity. The bureau has issued a technical paper describing the various methods used for the determination of nitrogen in substances used in explosives.

"Sand Test" for Detonators.

The sand test for detonators, devised by the bureau, has been modified to give results more nearly proportional to the quantities of priming employed. The sand test has been thoroughly described in former publications of the bureau. The detonator whose strength is to be determined is fired by electricity in the center of a definite quantity of standard 30-mesh quartz sand contained in a block of steel with cylindrical bore. Then the sand is sifted and the amount of crushing of the sand measures the strength of the priming. A set of such tests soon leads to a general standard for the detonating force of all explosives so tested. It is also possible with this device to determine whether the detonation of the explosive was partial or complete. This test has proved to be a distinct aid to manufacturers and users of detonators.

Petroleum Division.

The routine work of the petroleum laboratory of the Pittsburgh station consists largely of the inspection of fuel oil purchased for the Government. Other work has included the analysis of samples of crude oil, tests of lubricating oils, tests of fuels for airplane motors, and various products of cracking processes, so-called "gasoline improvers," gun greases, and coal-tar derivatives. Practically all of this work was of military nature and is mentioned in Bulletin 178.

Pitch Formation in the Intake Manifolds of Engines.

The formation of pitch sometimes occurs when gasoline is carbureted. Physical conditions controlling this phenomenon have been determined and the chemical factors involved are to be studied.

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DETERMINATION OF UNSATURATED HYDROCARBONS IN GASOLINE.

The results of a study of methods of determining the unsaturated hydrocarbons in gasoline has been published as Technical Paper 181. In the manufacture of motor fuel from heavy petroleum products by cracking processes, and in the testing of such fuel, a knowledge of the percentage of olefins or unsaturated hydrocarbons in the gasoline is desirable. The various methods for making such determinations were studied and experiments made to determine their relative value and develop them to a maximum of convenience for laboratory use.

MISCELLANEOUS WORK.

Apparatus for the making of dynamometer tests of gasoline engines is now being set up and a series of experiments is to be started at an early date.

Much work has been done in developing and perfecting laboratory apparatus used in testing petroleum. Particular attention has been given to the problem of determining the calorific value of liquid fuels.

METALLURGICAL DIVISION.

The technical staff of this division at the Pittsburgh station has recently been doing research work on nickel, tungsten, and molybdenum steel, especially as regards their use for military purposes.

METALLOGRAPHIC LABORATORY.

The work of this laboratory is devoted entirely to the examination of iron and steel for industrial and other purposes. Since May, 1918, when this laboratory was organized, something like 1,500 samples of metal have been prepared, studied, and photographed for the Ordnance Department.

CHEMICAL DIVISION.

WORK OF THE FUEL-ANALYSIS LABORATORY.

The analysis of fuels belonging to or for the use of the United States Government is one of the chief duties of the analytical laboratory and the large number of determinations involved occupy most of its time. In addition, there are analyzed in this laboratory samples of coal, coke, ores, and various materials collected in the course of investigations being made by the Bureau of Mines and other branches of the Federal Government and by State geological surveys and experiment stations. These include the War Department, Navy Department, Panama Canal, United States Geological Survey, Indian Office, and the Illinois State Geological Survey.

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Sample of coal, mine-road, mine-rib, stone, and coke dusts taken by mining engineers of the bureau during investigations of explosions and fires in coal mines are analyzed in this laboratory. From these analyses and the information obtained in the examination of the mine, it is sometimes possible to form conclusions as to the general nature and causes of the explosion, which can be applied in making recommendations for the prevention of future explosions or fires.

Problems of military importance included the analysis of samples of pyrite taken in connection with the investigation of sources of pyrite for manufacturing sulphuric acid; analyses, for the fuels and mechanical division, of samples of coal, ash, clinker, and residual fuel taken in connection with steaming tests; and examination of materials collected in connection with chemical warfare investigations at the American University.

**FUSIBILITY AND CLINKERING OF COAL ASH.**

During 1918 the investigations of the fusibility of coal ash from the coals of Pennsylvania, Virginia, West Virginia, Indiana, Illinois, and Maryland were practically completed. The method employed was developed by the bureau and is described in Bulletin 129 a. In the laboratory furnace used for fusing the ash a reducing atmosphere is maintained by using much more gas than is needed for complete combustion.

This investigation is of value because the fusibility or softening temperature of the ash of a coal is an indication of the liability of that coal to form clinkers. For most uses the more easily a coal clinkers the less valuable it is for fuel. When the data obtained from these tests has been classified and arranged, every fuel user will be able to judge better the type of coal best adapted to his plant, and to guard against the purchase of coal that may give excessive trouble from clinkering.

**PHYSICAL LABORATORY.**

The physical laboratory at the Pittsburgh station is equipped for testing and calibrating physical apparatus and measuring instruments used in the work of the bureau and for making a number of tests that require apparatus not usually found in an ordinary laboratory. The calibrations and tests made include the calibration of potentiometers, millivoltmeters, sling meters, and mercury thermometers.

**THE GAS LABORATORY.**

Immediately after this country entered the war the splendid facilities of the gas laboratory at the Pittsburgh station and the services of the bureau’s experienced chemists were offered to the War Depart-

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ment for experimental work in connection with gas warfare. This offer was cordially accepted. Many of the testing methods used in grading and inspecting gas masks and absorbents for gas masks were developed here. This testing work and considerable research work was carried on until October, 1917, when most of the war work was transferred to the American University experiment station at Washington, D. C.

On account of the pressing importance of the military investigations, only the more urgent and necessary routine mine-gas investigations, such as are required in the investigations of fires and explosions in mines, were conducted during 1918.

A new method and a portable apparatus have been developed for the determining of small percentages of sulphur dioxide in the air of metal mines. By this method mining engineers can make tests quickly and easily in the mines where the samples of mine air are taken. The apparatus is cheap and all broken parts are easily replaced.

The work on the employment of stenches in compressed air lines as a danger warning to miners, described on page 25, was largely done in this laboratory.

MICROSCOPIC INVESTIGATIONS OF COAL AND OTHER MATERIALS.

A bulletin entitled "Structures in Paleozoic Coals" is in course of publication. The purpose of this report is to clear up some of the confusion that exists as to the character of the components of coal. Conceptions as to the origin, composition, and general nature of the coal substance vary widely, so that it has been difficult for the chemist to attack many coal problems intelligently, and the engineer has not had a broad chemical basis for studies of combustion and other processes relating to the use of coal. Hence the efficient utilization of coal in industrial plants has suffered from this lack of knowledge as to the composition of coal itself. The bulletin now being published contains the result of a microscopic study of coals from different parts of the United States.

The work of this laboratory includes microscopic examinations of coal dust, rock dust, charcoal, and of miscellaneous materials submitted by the various divisions of the bureau. A microscopic study was also made of the structure of charcoal to determine the relation of its structure (both physical and gross) to its efficiency as an absorbent for use in gas masks.

GLASS BLOWER.

The extensive research carried on by this division demands many special scientific instruments of a degree of accuracy not procurable in the open market. All such requirements are taken care of by an expert glass blower.
ADMINISTRATIVE DIVISION.

The administrative division of the Pittsburgh station comprises six sections, as follows: Technical service, clerical, purchases and supplies, library and translations, shops and power plant, care of buildings and grounds.

The chief clerk of the station has general supervision of all clerical work, purchasing, accounting, receiving, shipping, and the supply room. Supervision of shops and power plant is in charge of a mechanical superintendent. The custodian of the buildings and grounds has general supervision of the labor force, the janitors, and the watchmen.

THE LIBRARY OF THE PITTSBURGH STATION.

The largest of the seven branch libraries of the bureau—parts of the main library at Washington—is at the Pittsburgh station. Although these branches will ultimately be duplicates of one another, they differ greatly at present in equipment. The Pittsburgh branch has some 6,600 books and received about 190 periodicals. The books are chiefly technical works on physics, chemistry, geology, and mechanical and electrical engineering, mining, metallurgy, chemical technology, industrial safety and hygiene for miners and metal workers, and miners' diseases.

TECHNICAL SERVICE SECTION.

In order to eliminate as far as possible the doing of routine work by engineers, chemists, and other investigators, the station has a corps of draftsmen, photographers, computers, and clerks who cooperate in designing and drafting special apparatus; in reducing laboratory and test observations; and in preparing data and illustrations for reports, and frequently assist in making test observations.

An important phase of the work from April, 1917, to July, 1918, was the computing, plotting, drawing, and the making of large numbers of blue prints of photographic reproductions of the results of observations relating to the work on war gases at the Pittsburgh station and the American University experiment station.

MOTION PICTURES.

Taking, developing, and exhibiting moving pictures has become an important feature of the bureau's educational campaign for promoting safety and health among miners. The large set of records at the Pittsburgh station representing various subjects is constantly being increased. The bureau has a complete equipment of camera and electric lamps for taking films either on the surface or underground. Usually the taking of pictures has been done in cooperation with the owners of the mine or plant to be pictured, the bureau
furnishing the photographer, films, and camera, the operator supplying the workmen, making all electric connections, and sometimes paying the expenses of the bureau’s representative.

The films are stored in fire-proof safes which have a large flue connecting directly with the outside of the building. When needed for use these films are placed in special metallic shipping cases holding four to six rolls each.

By a recent arrangement a large film corporation cooperates with the bureau in obtaining motion pictures of mining events of interest to the general public, these pictures are shown at theaters throughout the country in connection with the weekly news items supplied by the corporation.
THE URBANA STATION.

ESTABLISHMENT.

The first mine rescue station west of Pittsburgh was established by the technological branch of the United States Geological Survey, at Urbana, Ill., in 1908, in cooperation with the State geological survey. Later a more direct connection with the University of Illinois led to an investigation of the coals of the interior field of Illinois and Indiana, with reference to methods of mining and utilization. At first limited in scope to mine-safety work, the Urbana station soon became extremely useful in the investigation of certain special problems whose solution has been of general interest and wide application.

On July 1, 1911, the Federal Bureau of Mines, the University of Illinois, and the State geological survey entered into a formal cooperative agreement jointly to investigate methods of mining coal in Illinois, particularly with reference to safety measures and appliances for preventing accidents, to improvement of working conditions, to the use of explosives and electricity in mining, and other inquiries pertinent to the mining and utilization of coal. On July 1, 1917, a new agreement was entered into whereby the scope of the cooperative investigations was broadened to include, besides coal mining, quarrying, metallurgical and other mineral industries. The Bureau of Mines agreed to maintain a mining experiment station at the university, to be devoted to the purposes mentioned and to such other investigations as should be assigned to the station by the director. The university agreed to furnish free of charge to the bureau a laboratory, offices, and the use of its library. In addition the State geological survey and the university set aside certain funds to be used in connection with the cooperative work.

The results of this work in Illinois are contained in 28 bulletins. Of these the University of Illinois, through its engineering experiment station, has issued 12 bulletins dealing principally with coal-mining practices and with coal preparation. The Illinois geological survey has issued 10 bulletins covering the coal resources of the State, a chemical study of Illinois coal, clay materials in coal mines, and surface subsidence resulting from coal mining. The Federal Bureau of Mines has issued seven bulletins, which deal particularly with Illinois mining conditions, as follows: Bulletin 72, "Occurrence of Explosive Gases in Coal Mines"; Bulletin 83, "The Humidity of

**SCOPE OF THE STATION.**

Under the new cooperative agreement the Urbana station became a full-fledged mining experiment station of the bureau. Thus it has been possible not only to continue the cooperative investigations in Illinois, but also to extend the work of the station over the contiguous coal-mining fields in Indiana, western Kentucky, Iowa, and Missouri.

Illinois, with more than 36,000 square miles underlain by coal, is the center of the coal-mining industry of the interior coal basin. In 1917 there were mined in Illinois more than 80,000,000 tons of bituminous coal, and the industry employed more than 80,000 men. Of the adjacent States, in Indiana there were mined about 22,000,000 tons; in west Kentucky, 13,000,000 tons; in Iowa, 9,000,000 tons; and in Missouri, 5,000,000 tons—a total for the district of more than 129,000,000 tons, or nearly one-fourth of the entire bituminous production of the United States.

Within the district served by the station are large cement mines and quarries, perhaps the largest limestone quarries in the country, the lead and zinc mines of Missouri, Oklahoma, Kansas, and southern Wisconsin, and practically all the fluor spar mines of the country. In addition Illinois is third among the petroleum-producing States of the Union. About 5,000 underground metal miners are employed in the district.

As regards metallurgical industries the State of Illinois alone contains nearly 40 per cent of all the zinc retorts of the country. Chicago has become a center of iron and steel manufacture second only to Pittsburgh.

To this tremendous mining and metallurgical activity the station at Urbana is centrally situated, as it is midway between Chicago and St. Louis, and nearly every mining district in the interior coal basin lies within a radius of 200 miles. Railroad facilities are convenient in every direction.

**THE STATION QUARTERS.**

The station occupies five offices on the third floor of the north wing of the ceramics building of the university. Plate X is a view of the building, the position of the offices being indicated by the flag. The rest of the third floor is occupied by the State geological survey.

Directly in the rear of the ceramics building are the mining laboratories (Pl. XI), which are thoroughly equipped for coal washing and
BUILDING HOUSING THE OFFICES OF THE URBANA EXPERIMENT STATION OF THE BUREAU OF MINES.
MINING LABORATORY BUILDING, URBANA STATION.
general coal preparation. Plates XII and XIII are interior views of the laboratories. The analysis laboratory is completely equipped for coal sampling and analysis, mine gas analysis, and investigational work. All these laboratories are being used by the bureau representatives. The work at the station has been in charge of E. A. Holbrook, superintendent. Bureau of Mines rescue car 3, with headquarters at Evansville, Ind., is under general charge of the mining engineer of the station.

WORK OF THE STATION.

RECOVERY OF PYRITE FROM COAL.

Much of the work of the station during 1918 was in connection with the recovery of pyrite from the coals of the central basin, for use in making sulphuric acid. Field trips and extensive concentration experiments carried out in the mining laboratory on machinery of commercial size lead to the conclusion that from many coal-mining districts in the central basin, pyrite now mined with the coal and rejected as worthless, can under most market conditions be sent to a central concentrating plant and there converted into commercially pure pyrite, and usually the coal accompanying the pyrite can be recovered as a by-product. A report describing the results of the tests has been prepared.

The station has cooperated with the geological surveys of the States of West Virginia, Pennsylvania, Ohio, Indiana, Tennessee, Illinois, Iowa, and Missouri in investigating the possible recovery of pyrite from coal mines in these States. Tests and analyses of methods of treatments have been worked out at the station and indicated that a large quantity of commercial pyrite could be obtained from these sources.

MINE ACCIDENTS AND ACCIDENT PREVENTION.

Many of the fatal accidents in the central coal field result from local explosions of gas being propagated by coal dust. During the year a number of such explosions in Indiana and Illinois have been investigated, and at one mine a thorough study of the explosion hazards was made.

On July 1, 1917, the various State agencies in Illinois charged with the inspection and supervision of mines were consolidated as a single State department of mines and minerals under the directorship of Evan D. John. This department has lent its assistance freely in promoting the special work of the station in the Illinois field. On its part the station was able to assist the State department in the recovery of a large coal mine in southern Illinois, after an explosion disaster. Later the mining engineer of the station sampled the air in a number
of mines under investigation in southern Illinois by a State mining commission, and the results of the analyses were submitted to the commission. The station also cooperates with the State department in training mine rescue and first-aid teams throughout the State.

SURFACE SUBLINENCE AT MINES.

Three years ago the Bureau of Mines, as a part of its cooperative agreement, established a series of permanent surface monuments above four coal mines in different parts of Illinois where mining was conducted under different systems and conditions. As mining has progressed beneath these monuments, careful surveys have been made both inside and outside the mine, to determine the effect on the surface of such mining. The question of surface movement or subsidence at mines has become of great importance, especially in Illinois, where much of the coal underlies valuable farm land or building property.

COOKING AND CARBONIZING ILLINOIS COALS.

The work on the coking of coal and on the carbonization of coal in inclined gas retorts has aroused interest in the commercial possibilities of the central-district coals for these uses. The wastefulness of present methods of using coal is well known. When coal is burned in furnaces to generate steam, the possible by-products that might be obtained are lost, and only the heat generated by the fuel is utilized. The volatile matter, containing tar and hydrocarbon gases, is hard to burn completely, and the result is often a heavy black smoke issuing from the stacks which, in many cities, constitutes a nuisance. When coked in a by-product oven this coal gives not only a valuable coke, but may be made a source of benzol, toluol, gas, tar, ammonia, and cyanogen, which are all valuable by-products. The modern economic methods of coking the bituminous coals of Illinois and Indiana have been a source of considerable revenue.

The Urbana station has investigated and published the results of past efforts to coke Illinois coal and has cooperated in by-product coke-oven tests in an effort to produce a successful metallurgical coke from this coal.

Considerable headway has been made in the substitution of Illinois coal for eastern gas coal in coal-gas retorts and in substitution of Illinois coal for eastern coke in the water-gas sets used in the manufacture of illuminating gas. This work is being carried on by the Illinois cooperation with the added cooperation of the Illinois gas association. The solution of these problems would give an added demand of considerable commercial importance for Illinois coal.
INTERIOR OF MINING LABORATORIES, URBANA STATION.
COAL JIGS, URBANA STATION.
FUTURE WORK.

Great interest is being manifested by mine operators and others in new methods of mining that will permit the recovery of a greater proportion of the coal. At no time has the subject of proper ventilation and the overcoming of dangers from gas and dust in the mines been of so great interest to the practical mining engineer as at present. The campaign of education, among such a multitude of mines and miners, to be effective, must be practical, continuous, and personal. The Urbana station should take, in cooperation with the State and other agencies, a leading part in this work.

A wide field open to the station deals with the technical problems in mining, on which little information is available. Among these are studies of mine layouts, mine haulage, mine hoisting, and mine fires.

The cooperative work with the State geological survey, the university, and the gas association should be vigorously prosecuted. The State survey has appointed a gas engineer to act with the bureau's engineer, and through the other agencies a bench of gas retorts has been secured at Pontiac, Ill., where large-scale tests of the central basin coals can be conducted and operating difficulties overcome. These investigations are being extended to the use of Illinois coal and coke in water-gas sets and in gas producers.

The State agencies of the gas investigation can work in Illinois only, but the bureau's representatives may act in an advisory capacity to the plants in the surrounding States in which Illinois coal can be used.

The investigations of methods in the preparation of coal, of which the saving of pyrite from coal is one phase, are to be continued. Washing and other means of removal of impurities and preparing coal for the market have not received the same technical recognition in the United States as in France, England, and Germany, on account of the great quantity of clean coal here and the low price of the prepared product. Under the present fuel conditions an awakening of interest is taking place along the general line of preparation of coals for the market. The Urbana station, because of its location and unexcelled laboratory facilities for washing and other treatment of coal, should be able to do much work in this general technical field and be prepared to be of real assistance through testing work in specific cases.

Due to the Illinois cooperative agreement and to the relative importance of the Illinois coal field, the station has confined much of its coal investigation work in the central west to mining problems in Illinois. This work should be broadened so as to include the contiguous coal fields of adjacent States, with particular regard to their local conditions. In Illinois the various State agencies have made
more progress than the other States in this field in the study of mining conditions and in maintaining a centralized agency for the State functions connected with mining. The direct effect of such agencies must always necessarily be limited by the State boundaries. It should be a particular function of this station, by reason of its ability to work independently of State boundaries, to disseminate information on improved safety practices and more efficient technical methods and be of direct aid in time of mine fires or other unusual occurrences. On the other hand, the bureau's engineers engaged in this work should be able to receive and compile the kind of information that has been of such value to the Illinois mining industry. All this work implies a closer cooperation between the station and the agencies having supervision of mine inspection in the various States of the district.

In sum, the chief work of this station must always relate to the mining, preparation, and utilization of the central basin coals. Each of these divisions offers fields for research that hardly have been entered.
THE SALT LAKE CITY STATION.

ESTABLISHMENT.

Utah's standing as a mining State is due to large bodies of low-grade ore, such as the mammoth deposits at Bingham. Successful treatment of these ores presents a problem not yet fully solved. This was the reason for the establishment of a department of metallurgical research at the State School of Mines. As stated in the act (Laws of Utah, 1913) the purposes of this department were to conduct experiments and research "with a view to finding ways and means of treating profitably low-grade ores, and of obtaining other information for the benefit of mining industry and the utilization and conservation of the mineral resources of the State." During the latter part of 1913 this research work was directed by the head of the department of metallurgy of the University of Utah.

In January, 1914, an agreement was entered into with the Federal Bureau of Mines under which the work of this research department was to be under the direction of metallurgists of the Bureau of Mines assigned to this station, the university to provide quarters and assist in the investigations. Other State institutions and mining and metallurgical companies have freely cooperated in this work.

PRELIMINARY SURVEY OF UTAH ORES.

One of the first steps undertaken was to determine the location and extent of the various low-grade and complex ores in the State. The principal mining districts were visited to determine whether any considerable tonnage of ore had been, or could be, developed which was not amenable to profitable treatment by present day milling and metallurgical processes. The results of this preliminary survey were published in 1915 by the bureau as Technical Paper 90. Since then other districts in the State have been visited and examined from time to time, and these investigations are being continued.

Samples of complex and low-grade ores were collected, especially those offering distinct metallurgical problems, such as oxidized ores of copper, lead, zinc, silver, or gold that were too lean to be smelted direct. These ores were analyzed and the results for ores which up to that time could not be treated economically were tabulated. Immediate need of metallurgical experiment and research for the handling of all such ores was made apparent.

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NEED OF METALLURGICAL RESEARCH.

Mechanical concentrating processes have proved to be unsuited to the treatment of low-grade oxidized ores; therefore attention had to be given to the development of new processes for the treatment of such ores. Research work carried on by the principal copper companies has developed flotation processes for the treatment of low-grade copper ores, but the flotation plants do not save all the copper in these ores, because a large part of the ore treated is a mixture of sulphides and oxides of copper. The problem presenting itself in some places was the recovery of mineral which escaped the concentrators and went into the tailings, with the added problem of finding a suitable process for recovering the copper from the capping of oxidized ore overlying the ores being treated. It was not possible to erect such plants and operate them with any prospect of success until much research and experimental work had been done. A little later much attention was given to hydrometallurgical treatment of zinc ores, especially by the process of roasting the ore, leaching the zinc with sulphuric acid, and then precipitating the zinc. Such work did not solve the zinc problem as a whole, nor was it undertaken for that purpose, but to solve the special problem of each particular ore. It was soon found that there were five distinct metallurgical problems confronting the metal workers of Utah. These five problems were as follows: Treatment of (1) low-grade zinc ores, (2) complex lead-zinc ores, (3) oxidized lead ores, (4) low-grade copper ores, (5) ores carrying gold and silver.

THE ZINC PROBLEM.

The chemistry of zinc is so different from that of other metals that the retort process, until the recent introduction of the electrolytic process, was the only one used to produce the metal commercially. The losses occurring in the zinc industry in mining, milling, and smelting are very great; probably less than 50 per cent of the zinc mined actually reaches the form of spelter. Losses of zinc at the mine amount to a large tonnage. In the average western lead mine zinc generally occurs as a shell in the stopes from which oxidized ores have been taken. To fill the stopes with waste makes these shells an absolute loss. In indiscriminate dumping of low-grade ore and waste on the surface much zinc is also lost. A vast tonnage is tied up in low-grade zinc ores; most of this is oxidized zinc.

The retort process, the method generally used for recovering zinc from its ore, has seemed until recently the only one suited to the requirements of this metal. However, zinc losses in retort smelting are large, and only those ores which have a high zinc content can be treated at a profit. Research work at the station has shown that
other methods, such as igneous concentration or volatilization and leaching, have great promise for the successful treatment of low-grade ores of zinc.

**THE LEAD-ZINC ORE PROBLEM.**

As with zinc, a great deal of lead is lost in mining lead ores from leaving in the mine ores of too low a grade to be treated, and from indiscriminate dumping and waste on the surface. The problem in Utah was twofold. Lead smelters naturally prefer ores containing a high percentage of lead and a minimum of zinc; a point is therefore reached where the zinc present prohibits profitable smelting of the lead. Lead blast furnaces have to accept ores containing more or less zinc until the problem of removing the zinc from the ore before smelting it for lead can be solved. If a cheap and efficient method for separating lead and zinc and saving both could be devised, the miner would receive pay for both metals, whereas now he is penalized for whatever excess of either lead or zinc his ore contains above a specified percentage. The principle involved is that in smelting ores containing lead and zinc the latter volatilizes at a much lower temperature than the lead, makes heavy fumes, and clogs the passages, and also forms accretions on the sides of the furnace. Hence ore containing more than 5 per cent of zinc is penalized, and if it carries as high as 15 per cent is rejected. The saving of both the lead and the zinc would be a distinct advancement in economic conservation of our mineral wealth.

**THE OXIDIZED LEAD ORE PROBLEM.**

Utah has large bodies of low-grade lead ore which had been oxidized by contact with the air, for the level of ground water in Utah is so low that often the mines will be entirely dry and the lead ores weathered to a condition not permitting concentration by mechanical methods. Some of the ores also are contaminated with zinc, making them complex. The problem in all these ores is one of concentration. The amount of such ores available is hard to estimate, yet hardly a county in Utah fails to have deposits.

**THE COPPER PROBLEM.**

The problem of treating low-grade copper ores, like many others, is twofold—to concentrate to a point justifying smelting at a profit and to remove copper from ores of lead and zinc by some process other than smelting. The copper ores of Utah were generally treated by the former process. From ore which is a mixture of sulphides and oxides of copper a poor saving is made, oxides not being recovered by ordinary processes of concentration and escaping with the tailings.
The problem is to find a suitable process for the treatment of oxidized ores. Distance from railroads and lack of water complicate the problem.

THE PRECIOUS METALS PROBLEM.

Utah has in the past produced some free gold ores, but seldom very rich and never in large quantities. Some gravels yielded placer gold for a time, and some mines yielded finely disseminated free gold ore rich enough to pay handsomely when reduced by the cyanide process. Mercure gave by far the greatest returns as a strictly gold camp. Its ore was of low grade and could not have been treated but for the advent of the cyanide process just when old processes had failed.

Utah seems destined to produce and handle only low-grade ores. Silver ore rich in the metal was common in most of the early camps. Later developments showed increased tonnage but distinctly lower grade. From the first mining in Utah the State has stood high in silver production; it still awaits some cheap method of treating plenty of "ore in sight" carrying silver only in small quantities. The problem of treating this ore has always been due to the presence of some other metal, generally copper, preventing treatment by the cyanide process, or some other method equally applicable.

Distance from railroads, or lack of water, has made treatment by ordinary metallurgical methods impracticable; in many places even impossible. In connection with these researches the station at Salt Lake City has become an extremely important center for mining and metallurgy.

WORK OF THE STATION.

Under the cooperative agreement with the University of Utah, the university furnishes the offices and part of the funds for the station. Five or six "fellows," graduate students in either mining or metallurgy and candidates for a master's degree, work under the direction of the Bureau of Mines staff on mining or metallurgical problems. The university has recently constructed additions to the metallurgical building for the purpose of accommodating the bureau in this cooperative work. These additions, with their equipment, cost $32,000.

The building housing the offices is shown in Plate XIV.

Laboratory work is for the most part carried on in the metallurgy building, therefore the station is in close touch with the mining and metallurgical staff of the university. Without their help and the untiring efforts of the director of the State School of Mines, this station could not have accomplished the work it has done. Also, outside cooperating agencies are spending much money for specific work carried on by them at the station. The station is at present in charge of Thomas Varley, superintendent, assisted by F. G. Moses and J. C. Morgan.
BUILDING HOUSING OFFICES OF SALT LAKE CITY STATION.
PROBLEMS ATTACKED.

The station has succeeded in working out several processes having to do with some of the important problems connected with the mining industry of the State, and has, it is believed, succeeded in making possible the treatment of ores that could not otherwise be handled at a profit. One of the most important lines of work has been that of assisting the popularizing of the flotation process in the intermountain region.

A great deal of research work dealing with brine leaching of oxidized lead ores a was done at this station with results so favorable that it was taken up by various mining companies and worked out on a much larger scale than had been possible for the Bureau of Mines. The advent of flotation retarded the progress of the process as a means of treating lead-sulphide mill slimes, for which it was originally developed, but the large tonnage of oxidized ores in different parts of the intermountain region leaves the method a large and fertile field for development.

The chloride volatilization process for oxidized and sulphide complex ores, described in Bulletin 157, b was worked out in this station. The process promises to have a wide application and to become one of the most important factors in lead metallurgy. At first the opinion was held that this process could be applied only to the oxide ores of lead and possibly of silver, but later developments have proved that it can be applied to the complex lead sulphide ores as well, and it seems to be admirably suited to the treatment of certain classes of copper ores.

One company has constructed and is operating a plant to treat oxide lead ores by this process; another plant is to be built to treat complex lead-silver sulphide ores by the volatilization process; and another to treat copper ores. All of these plants are the direct results of experimental research at the Salt Lake City station.

The results of the work on lead ores have been incorporated in Bulletin 157, "Innovations in the Metallurgy of Lead," previously mentioned. The results of the experiments in the concentration and hydremetallurgy of zinc ores has recently been published as Bulletin 168, "Recovery of Zinc from Low-Grade and Complex Ores."

COOPERATIVE WORK WITH MINING COMPANIES.

Close cooperation between the Bureau of Mines and the mining interests of the State is made possible by an arrangement through which mining men or companies may enter into cooperative agreements with the department of metallurgical research of the Uni-

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a For further details regarding this work the reader is referred to Bureau of Mines Bull. 157, Innovations in the metallurgy of lead, by D. A. Lyon and O. C. Ralston, 1918, pp. 58-74.


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versity of Utah (with which the bureau is cooperating), and have its aid and the use of its equipment for their special problems. Any such person or company pays the university a certain fee for the use of the equipment and the power and supplies that they actually use. The bureau's engineers assist in directing the work and keep fully informed of the progress made. When the work is terminated a complete report is made to the university and to the bureau. If so desired these reports are considered confidential for a period not to exceed two years, after which time the bureau or the university has the right to publish them. To take out patents on any discoveries made in connection with this work is not permitted.

On the other hand, the university and the bureau agree to assist cooperating parties in every way possible, to allow them the full use of the university's and the bureau's equipment, and to give them the benefit of the technical knowledge of the university and of the bureau.

This arrangement has made it possible for the station to be of effective service to the mining people of the State, and has also brought to the files of the station a mass of valuable data. Several cooperative agreements have been made and some companies have been able to work out problems of interest to them in a way that would have been impossible except by such an arrangement. Among the companies that have taken advantage of this agreement have been the General Engineering Co., of Salt Lake City; the Mineral Products Co., of Marysvale, Utah; the Combined Metals Co., of Pioche, Nev.; the Utah-Apex Mining Co., of Bingham Canyon, Utah; and the Emma Consolidated Mines Co., of Alta, Utah. Successful results were obtained in most instances, and commercial mills have been or will be built as a result of these cooperative agreements.

VOLATILIZATION AND ROASTING PLANTS.

Some of the most important advances made at the station were in the volatilization of metal chlorides from ores. The results of the small-scale tests were so successful that a plant which could handle 100-pound samples was built.

This was replaced by a new volatilization plant at the pyrometallurgical laboratory, which consists of a rotary kiln with a maximum capacity of 300 pounds per hour and an electrical precipitator with a capacity of 3,000 cubic feet of gas per minute.

The kiln has a length of 20 feet with an inside diameter for 15 feet of 13 inches, the remaining 5 feet having a diameter of 20 inches. It is driven by an electric motor through a series of cone pulleys so that the speed may be varied. The kiln is heated with a Hauck high-pressure oil burner, burning a gas oil of 25° Baumé gravity.
The material is fed into the kiln through a screw feed with a water-cooling jacket on the outside. This feeder is arranged with variable speed pulleys so that the material can be fed at various rates from 100 to 300 pounds per hour. The gases from the kiln first enter a dust chamber where the heaviest material being carried is settled out. From the dust chamber they are carried through 15-inch diameter pipe up through vertical stacks to the top of the treaters. In these vertical stacks more of the solid material is settled out from the gases and collected in a dust box at the bottom.

The treaters have a capacity of 1,500 cubic feet in each unit, there being two units in the installation. Each unit consists of twenty 6-inch pipes 8 feet long. The gases enter the top of the treaters, go down through the treater tubes, leave the bottom hopper of the treaters, and are exhausted through a fan to the stack.

The electrical equipment for the treaters consists of a 5 k. v. a., 80,000-volt precipitator transformer, and a rectifier driven by a three-horsepower synchronous motor and a controlled switchboard. The switchboard contains switches for the main control, motor control, and transformer control. The regulation of the primary voltage of the transformer is obtained by means of an auto transformer and a theater dimmer. Meters are mounted on the board for the measurement of the voltage, current, and wattage. A milliammeter is placed in the treater circuit for measurement of the high-tension direct current.

The supply circuit for the equipment is over a separate line from that used for the other motors in the building. This gives a more even operation of the equipment than could be otherwise obtained, as the voltage does not fluctuate with the change of load on the other motors.

Under normal operation the treaters usually take about 65,000 volts, this voltage varying somewhat with the atmospheric conditions and with the nature of the fume being precipitated.

Many tests have been made in this plant with the most gratifying results. The tests have proved conclusively that it is possible to treat many types of oxide and sulphide ores, and that the electrical precipitator is a successful device for recovering the valuable metal constituents; also, enough fume has been recovered from the operation of this plant to show that the problems of fume treatment can be solved successfully.

The equipment in this laboratory also comprises a 2-foot revolving-hearth roaster of the Wedge type. With certain types of high-sulphur ores part of the sulphur must be removed from the ore before further treatment. For this purpose the Wedge type of furnace has proved satisfactory.
VOLATILIZATION OF LEAD AND SILVER FROM COMPLEX SULPHIDE ORES.

The most important of the major problems investigated at the station was the recovery of lead and silver from complex sulphide ores containing lead and silver. Utah has an enormous amount of this class of ore. Heretofore, it has been impossible to treat such ore successfully, owing to its physical makeup, by any known method except direct smelting, and the lead and silver content of much of the ore is so low that smelting yields little or no profit. Exceptionally gratifying results were obtained in experiments with this class of ores, and a cheap and satisfactory method of treatment devised. By adding the correct amount of sodium chloride or calcium chloride to the ore and heating the mixture to between 850° and 950° C. in a revolving cement kiln, 95 to 99 per cent of the lead and 80 to 85 per cent of the silver can be easily driven from the ore in the fumes. This fume can then be easily recovered from the furnace gases with an electrical precipitator. The precipitated fume is mixed with a small amount of coal, say 15 per cent, and the equivalent proportion of limestone, and fused. The resulting products are lead-silver bullion and calcium chloride slag. The slag can be used in the first roast to replace the sodium chloride that was used in the previous operation.

This process can be used for either oxide or sulphide ores of lead and silver, even those containing zinc, as the zinc is difficult to volatilize and a good separation of the lead and zinc is obtained. Such separation has always been difficult under the older methods. Enough work has been done on the process to prove that it will be a commercial success and will make possible the treatment of great quantities of ore that up to the present time has been difficult or impossible to handle. It is expected that in the near future a large mining company of Utah will build a plant to test further the possibilities of the process.

COMPLEX LEAD-ZINC ORES.

One of the most important of the problems attacked to date has been the treatment of the lead-zinc sulphide ores. As is well known, lead in a zinc ore is not paid for by the zinc smelter, while zinc in lead ore is always penalized by the lead smelter. Thus if the two metals are not separated before they are shipped, one of them is a total loss. Metallurgists of the Bureau of Mines have suggested several schemes for the treatment of such ore, some of which have proved very promising. The most encouraging method tried to date is light roasting of the ore with a small amount of common salt. The sodium chloride converts nearly all of the lead into lead compounds that are soluble in a saturated brine solution, by which the lead can be leached from the ores and recovered, leaving the zinc unaffected.
and in a condition for recovery by gravity concentration or flotation. This process can be applied to all ores in which the lead and zinc are not so closely combined that they can not be separated by crushing.

**OXIDIZED ORES.**

Another important problem attacked by the station is the treatment of oxidized ores that carry both lead and zinc. These ores are difficult to sell because the zinc causes trouble in lead smelters and the lead gives trouble in zinc smelters. A satisfactory method of handling this type of ore has been evolved. This depends on the fact that the chloride of lead can be driven from the ore by heating, leaving the zinc in suitable condition for leaching with sulphuric or sulphurous acid solution. The process has proved satisfactory for the types of ores that are adapted to it. Fortunately many of the oxidized ores are of this type.

**OXIDIZED LEAD-ARSENIC ORES.**

Treatment of oxidized lead-arsenic ores, of which there are large tonnages in Utah and adjoining States, was one of the minor problems taken up at the station. At first the intent was to make, if possible, a salable product of both the lead and arsenic in the ore, but a study of the arsenic situation revealed that this source of arsenic was not important enough to justify further experiment. It was found, however, that high recoveries of the lead by leaching with saturated brine were possible, and that volatilization would recover the lead and more than half of the arsenic.

**MANUFACTURE OF AMMONIUM PHOSPHATE.**

Nearly all of the ammonium phosphate consumed in the manufacture of fertilizer has been made in the southeastern part of the United States near supplies of phosphate rock. The present method is to ship ammonium sulphate from the by-product coke plants, the producers of most of the ammonia, to the phosphate fields. The sulphuric acid necessary for the manufacture of the ammonium sulphate is bought in the open market.

A vast quantity of sulphuric acid can be made from waste gases at western smelters. Near these smelters are large supplies of phosphate rock. It was thought that possibly this phosphate could be treated in the West to make phosphoric acid, which could then be shipped to the ammonia makers, who could use it to make the ammonium phosphate direct from the phosphoric acid.

Work at the Salt Lake City station to determine whether it would be feasible to put the idea into commercial practice, without too much change in the existing plants, showed that chemically the method was feasible, but that the mechanical difficulties at present would make the venture unattractive.
OIL-SHALE INVESTIGATIONS.

Utah is, geographically, the center of the large oil shale deposits of the Inter-Mountain region, and on account of its position with respect to these deposits the Salt Lake City experiment station is at present the center of the oil-shale investigations. The station has begun a series of investigations to determine the best methods of treating shales with a view to determining their present economic status. Undoubtedly these shales will be an important source of hydrocarbon oils, perhaps in the near future.

FLOTATION WORK.

Experiments made at the Salt Lake City station to determine the possibility of floating the lead or zinc from some of the oxidized ores of Utah have shown that some of the lead ores could be sulphidized and good recoveries obtained, but the zinc ores could not be handled satisfactorily in this way.

In connection with flotation work, some important results were obtained in cooperative tests of wood oils for the Forest Service. That bureau wished to have some of the wood-oil products from its laboratories tested for their possible value as flotation oils. Samples of these different products were sent to the station at Salt Lake City, where they were thoroughly tested to determine their efficiency. Many of them proved to be efficient and could be used to good advantage in commercial flotation plants.

POTASH INVESTIGATIONS.

As is well known, potash salts are important constituents of the commercial fertilizers that are vital to our agricultural welfare. Before the war practically all of the potash used in this country was imported from Germany. This foreign potash was so cheap that no attempt was made to obtain potash from local sources. Hence, when the German supply was cut off, the situation became serious, and an investigation of potash resources and possible sources of supply was immediately begun.

Potash salts exist in nature in enormous quantities, but unfortunately in such a condition as to be useless until converted to soluble form. The principal natural source of potash is the silicates of potassium, and the development of a cheap method of recovering the potash from such silicates would solve the problem. The mill dumps of the Cripple Creek district in Colorado, those of the Utah Copper Co. at Garfield, Utah, and of the Inspiration Consolidated Copper Co. at Miami, Ariz., all contain large quantities of potash salts. The recovery of the potash from the materials named is attractive, as they have been mined and are already fine enough for direct treatment.
During the past few years many schemes have been suggested for the recovery of potash from silicates, hence experiments were begun at the station to discover whether any of the suggested methods could be applied commercially to the mill tailings mentioned.

The numerous methods tried fall naturally under three heads: (1) Decomposition with sulphuric acid, (2) treatment with phosphoric acid and calcium hydroxide, (3) chloridizing roasting and precipitation. The first and second were found to be impracticable, but the third might be applied where gold or some other valuable material is present in addition to the potash. Although the tests can not be considered a success in demonstrating a means of recovering potash from mill tailings on a commercial scale, there are indications that under more favorable conditions the tailings might easily be the source of much American potash.

MICROSCOPIC EXAMINATIONS OF ORES AND METALS.

The microscopic laboratory of the Salt Lake City station has a broad field of usefulness. This laboratory is equipped with everything necessary to make microscopical studies of ores, metallic substances, alloys, or other materials. Each year hundreds of specimens of ores and minerals submitted by mine operators, prospectors, and others are examined, and reports rendered as to the character of the samples and the probable value of the deposits.

GRAPHITE MILLING TESTS.

In an investigation of methods of purifying graphite concentrates, two methods of concentration were worked out with satisfactory results. The first, a combination treatment in an electrostatic machine and a finishing treatment in a burr mill, gives a finished product containing about 90 per cent carbon, with a recovery of 85 per cent. The other method is a combination treatment in a ball mill, flotation machine, and burr mill. The finished product contains about 90 per cent carbon and the recovery is about 80 per cent.
THE GOLDEN STATION.

The station in Colorado was the second of the two established in 1910, its special province being the investigation of rare metals. At first this station was at Denver, but about two years ago much of the equipment was transferred to Golden, where the station is now housed in one of the buildings of the State School of Mines. A view of this building is shown in Plate XV.

The work of this station has, so far, related chiefly to investigations of uranium, radium, molybdenum, tungsten, vanadium, and the methods of saving rare metals occurring in minute quantities in commercially valuable ores.

WORK AT DENVER.

Shortly after Congress made its first metal-mining appropriation for the Bureau of Mines, the director felt that a part of this money could be used to no better advantage than in investigating the rare metal resources of the United States, with a view to increased production, higher efficiency, and the elimination of waste. It was known that there were in the United States deposits of carnotite, pitchblende, molybdenum ore, vanadium ore, etc., from which a small output was obtained, but that there was room for considerable improvement in methods of concentration and in the treatment of the concentrates. It was, therefore, decided to establish a branch of the Bureau of Mines in Denver, Colo., to investigate rare metals, including the mining and concentration of the low-grade ores, their metallurgy, and any chemical problems of commercial or scientific interest.

The minerals that have been of particular interest to the Colorado station of the Bureau of Mines are those containing radium and uranium, thorium, vanadium, molybdenum, nickel, tungsten, and manganese.

COOPERATION WITH NATIONAL RADIIUM INSTITUTE.

When the Colorado station was established, large quantities of radium-bearing ores from Colorado were being exported for treatment in foreign countries, and excessive prices were being paid for that part of the manufactured product returned to this country. In addition, much of the low-grade ore was being thrown on the dump and lost, owing to the lack of satisfactory concentration methods. As the carnotite deposits of Colorado and Utah represent the largest
BUILDING HOUSING THE OFFICES AND LABORATORIES OF THE GOLDEN STATION.
source of radium-bearing ores of the world, the need of investigation was obvious. Under a cooperative arrangement between the Bureau of Mines and the National Radium Institute, founded by Dr. Howard A. Kelly and Dr. James Douglas, the institute was to furnish the necessary funds for experimental work and receive most of the radium produced. The problems studied were the methods of recovering radium from carnotite, purification of the radium salts, methods of concentrating the low-grade ores, and the recovery of uranium and vanadium at the same time as the radium. Another agreement, made between the National Radium Institute and the Crucible Steel Co. of America, provided for leasing 16 carnotite claims in Montrose County, Colo., thus insuring a supply of ore.

An experimental plant was built in Denver and subsequently enlarged. This plant was operated for about two years, and during this time produced 8,543 milligrams of radium element at a cost of a little over $40,000 per gram. A considerable quantity of uranium oxide and vanadate of iron was recovered at the same time.

As methods of radium determinations ordinarily used in scientific work were not applicable to plant conditions, it was necessary to develop new methods for plant control. The electrosopes developed during the course of the work are now more or less standard in this country.

At that time practically nothing had been published on the fractionation of radium salts, and this work had to be developed from the start. Full details were worked out, showing the best conditions for fractionating radium from barium salts, and the losses that are likely to be met. The results of this work have been published and have been of great use to others who have contemplated going into the business.

Incidentally, a new method of converting sodium uranate cheaply and efficiently into a high-grade uranium oxide product was developed. A concentrating mill was built at Long Park, near the leased mines. Here, concentrating methods were studied and ultimately more than 300 tons of concentrates were produced from low-grade ore that otherwise would have been left on the dump.

OTHER WORK ON RARE METALS.

An investigation of the ratio of radium to uranium in carnotite ore was also made and the results published in Technical Paper 88 of the bureau. It was ascertained that whereas in some secondary uranium minerals of recent origin the ratio was low, this was not true of large bodies of carnotite ore. In all places where 1 ton or more of the ore was thoroughly sampled, the ratio was practically

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the same as that of pitchblende, although in some small samples of carnotite the ratio was below the normal.

The molybdenum deposits of the country were investigated, and the possibilities of the molybdenum industry in this country were thoroughly studied. A considerable amount of preliminary work was also done on both molybdenite and wulfenite, as well as on methods of separating copper minerals from molybdenite.

A preliminary investigation of some of the complex lead and zinc ores of Colorado, particularly those of Leadville, was started. It was known that in many ores the minerals could not be separated by concentration processes. The reasons for this were determined, and valuable information was obtained as to the physical composition of these ores.

REMOVAL TO GOLDEN.

The station was moved from Denver to Golden in July, 1916, under a cooperative arrangement with the Colorado School of Mines. This arrangement aimed at the promotion of close relations and general cooperation in mining, ore dressing, and metallurgical research.

The school of mines transferred its Physics Building (see pl. XV) for the use of the station. This building is of brick, has two stories and a full basement, and is equipped with high-pressure steam, compressed air, and other facilities. The upper story is mainly occupied by two chemical laboratories, each of which can accommodate about six men. The first story contains offices and the station's library. In the basement are the ore-grinding equipment, laboratory for the treatment of rare-metal ores, two other small laboratories, tool shop, and storerooms. The station has full use of the experimental ore-dressing and metallurgical plant of the School of Mines. This plant is about one-half mile from the main buildings and is completely equipped for large scale experiments in sampling, mechanical concentration, cyanidation, magnetic and electrostatic concentration, and flotation. Views in the metallurgical laboratory are shown in Plates XVI and XVII. The station is in charge of Richard B. Moore, superintendent.

EQUIPMENT.

The laboratories of the station are equipped with all the chemical apparatus necessary for analytical and research work in connection with the rare metals. A special room is reserved for electrosopes for radium determinations. A Hilger constant deviation type of spectroscope is available for ordinary spectroscopic work, and a Hilger spectrograph for special research work in which great accuracy is desired.
METALLURGICAL LABORATORY, COLORADO SCHOOL OF MINES, USED BY GOLDEN STATION.
ANOTHER VIEW IN METALLURGICAL LABORATORY, GOLDEN STATION.
One room is used for work in connection with large quantities of radium emanation. Three hundred milligrams of radium element in the form of bromide is held constantly in solution, and to this is adapted a Duane apparatus (Pl. XVIII) for pumping off and purifying the emanation from the solution. In this manner a supply of purified emanation can be obtained at any time for experimental work.

The room in the basement for grinding ores is equipped with a crusher, ball mill, coffee mill, disk grinder, Newaygo screen, and Rotap sizer, all power driven. An adjoining room is completely fitted up with apparatus for experimental work in the treatment of rare-metal ores on a semicommercial scale. The equipment was installed with the idea of making it as flexible as possible; and any rare-metal ore can be given any kind of an acid leach, alkali leach, roast, reduction, or fusion; also any combination of the above treatments can be readily effected. Ores can be handled in quantities of 10 to 500 pounds at a run.

RECENT WORK OF THE STATION.

RARE METALS.

SOLUBILITY OF PURE RADIMUM SULPHATE.

The solubility of pure radium sulphate in water and in aqueous solutions of sulphuric acid of various concentrations was determined at 25°, 35°, and 45° C. The results showed that radium sulphate has a low solubility, the solubility increasing somewhat at the higher temperatures and with concentrations of acid in excess of 50 per cent. The industrial recovery of radium as sulphate depends, fortunately, not on its own solubility, but on the sulphate being precipitated with barium in much greater proportion than alone. Were it not for this circumstance the practical recovery of radium would be almost impossible. Further investigation is being made of the action of mixtures of radium and barium, for the purpose of enabling one to predict how much barium should be added to a given radium ore in order to obtain a maximum recovery of radium.

RECOVERY OF MESOTHORIUM IN THE MANUFACTURE OF THORIUM NITRATE FROM MONAZITE SAND.

Although the carnottite deposits in Colorado and Utah constitute the largest source of radium-bearing ores in the world, most of this carnottite will be mined within five or six years at present rates of production. As most of the radium produced is being disseminated, through its wide use in luminous paint, the finding of a substitute for radium is important. Such an element is mesothorium, found in all thorium ores. The life of mesothorium is not nearly as long as
that of radium, but is long enough for use in luminous paint and for some of the uses of radium in therapeutic work. In the past no attempt has been made to recover mesothorium in this country, all of the material having gone on the dump.

The Bureau of Mines made a cooperative arrangement with the Welsbach Co. to investigate the best methods of recovering mesothorium in the manufacture of thorium nitrate from monazite sand. This work involved making a number of plant runs on approximately 5 tons of ore, and tracing the losses and final recovery throughout the whole process. It also involved methods of quantitative determinations of mesothorium to find what the losses were, as well as methods of fractionation and purification of the mesothorium salts. Satisfactory results were obtained which will be applied in the plant of the Welsbach Co., Gloucester, N. J., and ultimately published.

**EFFECT OF RADIIUM EMANATION ON MIXTURES OF HYDROGEN AND OXYGEN.**

Part of the radium that has been reserved by the Bureau of Mines for scientific use has been put into solution for the purpose of collecting the gas, radium emanation, by means of the Duane apparatus (see Pl. XVIII). The emanation thus collected has been used for studying the laws governing the combination of hydrogen and oxygen gases under the influence of the alpha rays when these gases are mixed with radium emanation. These investigations, to be extended to other gases, may throw some light on the chemical reactions that take place during electrical discharges in gases. Some of these reactions are of considerable industrial importance.

**TREATMENT OF PITCHBLENDE FOR THE RECOVERY OF RADIIUM AND URANIUM.**

Under a cooperative arrangement with Mr. Alfred I. Du Pont and Mr. William Wright, of the Colorado-Gilpin Gold & Radium Mining Co., about 100 tons of low-grade pitchblende ore and 6 tons of high-grade ore were furnished the Bureau of Mines for experimental treatment. Work on this ore was begun in 1917 and completed in 1918. Methods of concentrating the low-grade ore were worked out and applied. The high-grade ore and the concentrates, after a thorough investigation of the most efficient methods that might be used, were treated in the plant of the National Radium Institute, and the radium recovered was returned to the company. It was found that the original ore could be treated much more easily than the concentrate, which consisted almost entirely of pyrite. However, methods were developed that could be applied to either product. One of the results of this work was that the plant of the institute was finally equipped for the treatment of both pitchblende and carnitite.
APPARATUS FOR PURIFICATION OF RADIUM EMANATION.
FRACTIONATION OF RADIUM SALTS.

In connection with its cooperative work with the National Radium Institute, the Bureau of Mines has fractionated about 9 grams of radium element, starting with barium chloride containing only one part per million of radium chloride. After seven or eight fractionations in aqueous solutions containing hydrochloric acid, the radium reached a concentration of about 25 parts per million, at which point it is converted into bromide and fractionation continued in aqueous solutions containing hydrobromic acid until the concentration of radium bromide reaches about 1 per cent. At this stage the salt is collected until several hundred milligrams of radium element are obtained. Fractionation is then continued on a small scale to any desired degree, and on two occasions the bromide has been brought to 100 per cent purity, as verified by gamma ray measurements of the Bureau of Standards.

When large quantities of salt are being handled in a continuous system it is not difficult to crystallize radium to 100 per cent purity at an expense nearly as small as for the 1 per cent material; but in treating a small quantity of radium, crystallization to a high degree of purity becomes much more difficult, requiring many repetitions of the fractionation.

RATIO OF RADIUM TO URANIUM.

The determination of the ratio of radium to uranium in primary minerals has been made by several competent observers. Rutherford obtained the figure \(3.4 \times 10^{-7}\), but afterwards found that his radium was impure. Correcting for this impurity, his final figure was \(3.2 \times 10^{-7}\). Hyman and Marckwald obtained the figure \(3.328 \times 10^{-7}\); while Becker and Jannasch found \(3.415 \times 10^{-7}\) when the emanation was obtained by melting the radium salt, and \(3.383 \times 10^{-7}\) when the emanation was obtained from a solution.

A knowledge of the exact ratio bears directly upon the question of radium recovery in commercial work, besides having pertinent scientific value. This ratio must be used in determining the recovery of radium from the original ore in a commercial plant; and as the figures given vary as much as 6 per cent, it is important that the true ratio be determined beyond question. The radium obtained by the Bureau of Mines in its cooperative work with the National Radium Institute has given an opportunity to purify some radium bromide up to 100 per cent; and with this as a standard, a start has been made on the redetermination of the ratio of radium to uranium.

RADIIUM LUMINOUS PAINT.

Some work was done to determine the best methods of producing phosphorescent zinc sulphide, which is mixed with radium salts in
making radium luminous paint, and to determine the effects of certain physical and chemical factors on luminosity. This investigation had a decided bearing on war work, as the luminous paint is used on all of the instruments carried by airplanes, such as clocks, manometers, and compasses, and is also used to a considerable extent for gun-sights and other military equipment.

**ACTINIUM AND IONIUM.**

Two other elements associated with radium in all of the uranium ores are actinium and ionium. These elements are long-lived and active enough to be useful as substitutes for radium in the manufacture of luminous paint. An investigation was made of the best methods of recovering these elements from radium-bearing ores during the manufacture of thorium. A considerable quantity of concentrates was obtained during the operations of the National Radium Institute, and these concentrates with other material were used for this work.

**POLONIUM.**

Some work has been started on the recovery of polonium from lead residues and also from some old glass tubes that contained radium. Some of this recovered material has already been purified and used for experimental purposes in making luminous paint.

**TUNGSTEN, NICKEL, MOLYBDENUM, AND VANADIUM.**

The conditions under which tungstic acid may be efficiently reduced to metallic tungsten have been studied. Metallic tungsten is a commercial product almost always obtained when low-grade and medium-grade tungsten ores are treated chemically with a formation of tungstic acid. It is largely used in place of ferrotungsten in making tungsten steel.

Some work has been done on the metallurgy of wulfenite or lead molybdate with the object of recovering not only the lead, but also the molybdenum in a convenient concentrate free from arsenic and sulphur. Some experiments have been undertaken on the separation of wulfenite from vanadinite, as the two minerals frequently occur together.

Experimental work was started on the metallurgy of several vanadium minerals, particularly vanadinite, or lead vanadate, and cuprodescloisite, as these minerals offered an additional supply of vanadium for war purposes. The metallurgy of two nickel ores has been studied in detail, namely, a garnerite from North Carolina and an ore consisting mostly of sulphides from Alaska. Some success has been obtained and the work is being continued.
COOPERATIVE INVESTIGATION OF THE CARON PROCESS FOR THE TREATMENT OF MANGANESE SILVER ORES.

M. H. Caron, of the Netherlands East Indies Bureau of Mines, is the inventor of a process for recovering silver from oxidized manganiferous ores. This process was investigated and developed at the Colorado station at Golden under a cooperative agreement between the Netherlands East Indies Bureau of Mines, the United States Bureau of Mines, and the Research Corporation. Each of these interests furnished engineers and funds for the work.

For a long time the recovery of silver from many oxidized manganiferous ores has proved a difficult metallurgical problem. Such ores can not be treated directly by hydrometallurgical methods, and many of them are too low grade for profitable smelting. The Netherlands Government is particularly interested in the process on account of the large deposits of such ore in certain government-owned lands in Sumatra. Also, the mining industry of the United States would be benefitted through the development of a satisfactory process for treating refractory silver ores. Mr. Caron has assigned his original patent to the Research Corporation of New York, which is acting as an administrative agency for handling the original patent, as well as such other patents as may develop in the course of the work.

Briefly, the process consists of heating the ore to approximately 800° or 900° C., and bringing the heated ore into intimate contact with reducing gases, such, for example, as producer gas. The manganese dioxide is reduced to manganese monoxide, and simultaneously with this reaction the silver is converted into such a form as to be readily recovered by cyanidation.

Although the process appears to be simple, considerable investigation has been required to establish its limitations and the best conditions for its operation. Among the many points covered might be mentioned the problem of preventing reoxidation. If the hot reduced ore comes in contact with air, reoxidation takes place and refractory silver compounds are formed; therefore, methods of cooling under reducing conditions must be developed. Also, if cooling is not done under the proper conditions, this reoxidation may even take place slowly with a corresponding loss during the subsequent cyanide treatment. The problems that arose in this connection have now been definitely solved. To effect satisfactory reduction on a commercial scale a specially modified direct-fired furnace had to be developed. This furnace does away entirely with the disadvantage of having to work in closed tubes or retorts. Lots of 500 to 1,000 pounds of ore have been put through the experimental equipment with entire satisfaction. Development of the process has now proceeded to the point where it can be introduced commercially with assurance of its success.
Similar manganese-silver ores from widely separated localities are amenable to treatment by the process. The value of the process is shown by a few of the results obtained. The recovery of silver from some Sumatra ores has been raised from 11 to 96 per cent. Ore from a deposit in Colorado gives only 30 per cent by ordinary cyanidation but readily yields more than 90 per cent when treated by this process. A sample from Arizona containing 62 per cent of manganese dioxide yields only 6.9 per cent by direct cyanidation and 93.1 per cent by the new method. A Mexican silver ore yielding 40 to 50 per cent by ordinary cyanidation gives over 90 per cent extraction by the Caron process.

An interesting feature of the process is that the manganous oxide resulting after reduction is readily soluble in acids, hence the manganese can be recovered as a by-product. The possibility of recovering marketable manganese product from the residue by simple mechanical means is being investigated.
THE ITHACA BRANCH OFFICE.

For some years past the Bureau of Mines has maintained a branch office at Cornell University, Ithaca, N. Y. The Bureau of Mines, in cooperation with the American Institute of Metals and Cornell University, undertook a study of brass and nonferrous alloys manufacture, and has maintained a small staff of alloy chemists, who have worked in cooperation with the university staff and used its laboratories in their experiments. This work is in charge of H. W. Gillett, alloy chemist.

The work has had especial reference to the relative efficiencies of different types of furnaces and the improvement or development of furnaces with a view to reducing metal losses.

A bulletin on "Brass Furnace Practice in the United States" was published by the bureau in 1914, and another bulletin on "Melting Aluminum Chips," which discusses the loss of aluminum in melting scrap and suggests improved methods, was published in 1916. More recently, Dr. Gillett and his associates, working in cooperation with brass companies of Detroit, Mich., have evolved a new type of rocking electric brass furnace that has many superior features and is now in commercial use by a number of firms. During 1917 and 1918 most of the work at this laboratory was on alloys used in steel making, including ferrotungsten and ferro-uranium, this work being in cooperation with the Bureau of Ordnance of the War Department. A special study was made of the possible value of zirconium for alloying steel, and a series of samples of zirconium steels was prepared. These samples are to be tested by the Bureau of Standards.
THE BERKELEY STATION.

In 1911 the Bureau of Mines established an office in San Francisco, Calif., for conducting investigations of smelter-fume problems and various problems relating to petroleum. Later, when the mining experiment station at Berkeley was established, the metallurgical work was transferred to that station, the office at San Francisco being maintained for the study of petroleum problems.

In 1914, at the Panama-Pacific Exposition in San Francisco, the Government board allotted to the Bureau of Mines $7,000 and the space for an exhibit. By a cooperative arrangement between the director and various representatives of the mining and metallurgical industries, exhibits were made of devices to increase safety and efficiency in mineral industries of typical mining machinery, of experiments in metallurgy, and of petroleum machinery and methods. Much machinery and equipment thus assembled was given to the Bureau of Mines at the close of the exposition and was transferred to the station at Berkeley.

EQUIPMENT.

The station is housed in the Mining Building (Pl. XIX) of the University of California. The laboratory and offices are on the second floor; a well-equipped machine shop and storerooms are in the basement. One section of the laboratory is equipped for assaying and analytical work. Another section is devoted to research work on the chemical problems of metallurgy. The equipment includes special apparatus for studying chemical changes at high temperature, and for the determination of fundamental physical and chemical constants involved in metallurgical operations. As the chemical department of the university is large and active and the scientific library is extensive, the station is particularly well situated for conducting highly specialized research work on problems of the mineral industry.

SCOPE OF THE STATION'S WORK.

The importance of San Francisco as a mining center, the facilities for scientific research in its technical schools, and the two great universities near it, were strong reasons but not the chief reason for establishing an experiment station at Berkeley. The territory tributary to this station, which includes California, western Nevada, and the Klamath region of southern Oregon, is remarkable for the
BUILDING HOUSING THE OFFICES AND LABORATORIES OF THE BERKELEY EXPERIMENT STATION.
A CALIFORNIA GOLD DREDGE.
extent and variety of its mineral resources. The mineral production of California alone in 1916 was worth, roughly, $130,000,000, and included the following materials, the production of which was valued at $100,000 or more: Borax, brick, tile, cement, chromite, pottery clay, copper, gold, lead, lime, limestone, magnetite, manganese ore, mineral water, natural gas, petroleum, potash salts, pyrite, quicksilver, salt, silver, soda, building stone, gravel and road materials, tungsten concentrates, and zinc.

The mining industry in California employs over 13,000 men, which places the State among the first seven as regards the number of men employed in mineral industries.

FIELD OF RESEARCH WORK.

As the list of minerals shows, the mining industry of this region has a considerable future. Moreover, some parts of California—notably the desert areas—have not been thoroughly prospected, and discovery of other mineral deposits is to be expected. The rate at which the mineral deposits of California and adjoining territory can be developed is limited by certain economic factors, chiefly transportation and market. At present, and probably for many years to come, the principal points of consumption for the mineral products of California must be at a considerable distance, either in the central and eastern States of this country, or in foreign countries bordering the Pacific. Hence, these products must have some advantage, such as exceptionally high quality or low cost of production, to offset the high freight charges.

Fortunately the disadvantages mentioned are in a measure offset by certain natural advantages, such as undeveloped water power and abundant oil fuel. The further development of these mineral resources, especially the complex and low-grade ores, will involve a variety of problems. In such a field as this, it is believed, the station can be particularly helpful.

GOLD.

One can not mention the gold output of California without recalling the early placer mining. The picturesque side of gold mining in the State has largely disappeared, but production on a large scale continues, and California still leads the Union in this respect. The annual yield is roughly one-fourth of the total amount produced by the United States and Alaska together, and almost 5 per cent of the world's production.

In recent years the growing scarcity of high-grade ore has brought into the foreground the problem of treating the low-grade and refractory ores. Many unsolved metallurgical problems in this field demand early attention. The claim of the gold-mining industry is
particularly strong because of the unique position of gold as a monetary standard. The price of gold is fixed, and the rising cost of labor and supplies can not be met, as in all other industries, by an increase in the price of the product. The alternative is to improve recovery methods and to reduce the cost as much as possible. Thus there is a big field for investigation in the gold industry of California and the adjoining region.

MANGANESE, CHROME, AND QUICKSILVER.

The war markedly stimulated the production of manganese, chrome, and quicksilver in California, as is illustrated by the following figures:

| Production of manganese and chrome ores and of quicksilver in California. |
|--------------------------------------------------|---|---|
| Manganese ore...........................................tons.. | 150 | 15,500 |
| Chrome ore...............................................do.. | 1,500 | 52,400 |
| Quicksilver...........................................flasks.. | 11,373 | 24,201 |

MANGANESE.

The endeavor to stimulate production of the so-called war minerals brought up for immediate solution several important metallurgical problems. Manganese may be taken as an example. Nearly all of the manganese ore in California and the adjoining region is high in silica, and much of it is so low-grade that concentration is necessary before shipment to the smelters. Moreover, in some of these siliceous ores the manganese and silica minerals are so finely divided and intimately mixed that separation is extremely difficult. In attacking this problem the station cooperated with the State Council of Defense for California and with the mining department of the University of California.

CHROME.

The chrome situation is somewhat similar to manganese, except that the low-grade ores are in general more amenable to concentration. The important tonnage of chrome ore produced in California in 1917, amounting to about one-third of our domestic requirements, was obtained from a large number of deposits. Chromite in California occurs chiefly in small pockets scattered over a considerable area, many of them on ranch land which had not been thought to contain valuable minerals. These scattered deposits attracted the attention of many people unfamiliar with prospecting or mining but who had heard that minerals previously unsalable were now necessary for war purposes and could be mined to advantage. Soon there arose an active demand for information in regard to these
minerals and for assistance in classifying them and determining their value. The Berkeley station has been able to assist many people thus interested.

QUICKSILVER.

Quicksilver production was stimulated by the war, but the history of quicksilver in California goes back to the Spanish régime. Reminders of that period are found in the names of some of the mines, the technical terms still current, and the numerous Spanish and Mexican workers in the industry. Some 40 years ago the output of quicksilver in California was greater than that from any other quicksilver district in the world. One of the old mine records contains an illuminating comment of a mine foreman to the effect that the mine was evidently failing, as it had been necessary to drop the grade of ore from 30 to 28 per cent. The change that the industry has undergone since then is illustrated by the fact that the average grade of ore treated in California in 1917 contained probably not far from one-half of 1 per cent of mercury. In fact, before the war, quicksilver mining in California and in other sections of the West was on the decline. The greatly increased demand for this metal for military purposes gave the industry a new lease of life.

In treating such lean ores as those containing one-half of 1 per cent, low mining and reduction costs and a high recovery are essential. In the early days, with high-grade ore, an inefficient process yielded a handsome return. To-day 40 to 60 tons of ore and frequently more have to be treated in order to obtain the amount of quicksilver yielded by 1 ton of the ore mined at New Almaden in the old days.

WORK OF THE STATION.

INVESTIGATIONS OF LOSSES IN QUICKSILVER PLANTS.

Having the military importance of quicksilver in view, and realizing the difficult problems before the industry, the Bureau of Mines, early in 1917, through its station at Berkeley, entered into a cooperative agreement with several California quicksilver operators for the purpose of studying the metallurgy of mercury. Little technical or scientific work had been done in this field for many years, and such data as were available were neither accurate nor capable of direct application to present conditions. Although the methods of treatment in common use differed little from those in vogue many years ago, it was necessary to consider whether some of the new processes or appliances for ores of other metals might not be applied to advantage in the treatment of quicksilver.

The furnace in common use for reducing quicksilver ore is known as the Huttner-Scott, or more commonly the Scott, furnace (Pl. XXI, A). In this type of furnace the ore passes slowly over a series of inclined tiles in direct contact with the hot gases from the combustion of fuel.
The mercury distilled from the ore is taken up by the stream of gas. With the low-grade ores treated, the volume of the mercury vapor is vanishingly small as compared with the volume of gas into which it passes, being frequently less than 0.1 to 0.2 per cent. It is obviously not an easy matter to recover the quicksilver from such dilute gases, and the problem has received much attention from quicksilver operators.

The efficiency of existing methods of recovery was, therefore, one of the first questions taken up by the station in its study of the metallurgy of quicksilver. The conventional condenser system for the recovery of quicksilver from furnace gases consists of a series of brick or stone chambers, followed frequently by some wooden chambers, and then a side-hill flue leading to a short stack. In view of the large volume of gas through which the quicksilver vapor was disseminated, it was thought that important amounts might be carried through the condenser system and escape from the stack. No direct determination of the magnitude of such losses had ever been made. In studying this point it was found that the method developed for sampling other smelter gases could not be applied to quicksilver plants, owing to the low temperature and large water content of the condenser gases. After several trials a suitable type of apparatus was developed (Pl. XXI, B). Several determinations at two different plants showed that the stack losses are extremely small, not exceeding 1 to 2 per cent of the quicksilver output.

Several other possible sources of loss in condensers were also investigated. As a result of this work, the conditions for efficient condensation of quicksilver vapor have been determined and several modifications in present condenser practice have been suggested. Some of these undoubtedly will be tested soon on a practical scale at commercial plants.

The application of new types of furnaces to the treatment of quicksilver ore and of various concentrating procedures to the treatment of low-grade ores is being studied.

Another investigation dealt with the methods used in assaying quicksilver ores and furnace products. Some of these were not accurate and others were too tedious. Moreover, certain types of ore, high in sulphur or bituminous matter, were found exceedingly difficult to assay by any known method. As a result a method that is both rapid and accurate has been devised.

In studying the changes taking place within the quicksilver furnace information was needed with regard to the volatility of cinnabar, the common quicksilver mineral in California ores. As the boiling point of metallic mercury is 357° C., it has been commonly supposed that heating quicksilver ore to this temperature will expel the mercury. The experiments showed that cinnabar sublimes at about 500° C., and that when cinnabar ore is heated in the absence
A. TYPICAL SCOTT QUICKSILVER FURNACE. PHOTO BY W. W. BRADLEY, CALIFORNIA STATE MINING BUREAU.

B. FUME-SAMPLING APPARATUS FOR QUICKSILVER DETERMINATIONS.
of air it does not give up all its quicksilver until the temperature is somewhat higher. The information obtained from this study has proved to be of value in interpreting the process taking place within quicksilver furnaces and retorts.

POTASH.

The station at Berkeley has cooperated with the scientific research committee of the State Council of Defense for California in several chemical and metallurgical matters. The demand for a domestic supply of potash brought about by the war, has stimulated activity at the various saline deposits in the West, among others, Searles Lake in southern California.

The bittern from the manufacture of salt from sea water is also a possible source of potassium chloride, magnesium chloride, and bromine, for all of which there was strong demand. In devising processes for the recovery of these valuable materials, considerable saving of time, money, and effort can be effected through cooperation between various private individuals and Government institutions having information bearing on the question at hand. Through the Federal Bureau of Mines and the State Council of Defense some developments in the recovery of saline products were made immediately available to those engaged in the industry, and at the same time information desired by the Federal Government for military purposes was obtained.

PROSPECTING FOR WAR MINERALS.

The war stimulated many people to search for new sources of material for military purposes and to develop new processes for the winning of these materials. Many projects have originated in the territory tributary to the station at Berkeley, and it has been important to investigate them rapidly and thoroughly in order that nothing of value might be overlooked. The station was asked to make a number of investigations of this sort and among the many propositions of doubtful merit some have appeared to be of real value. In this work the advantage of a local station representing the scientific and technical activities of one of the branches of the Government has been particularly evident.

FULLER’S EARTH.

The possible use of California fuller's earth for purifying lubricating and edible oils offered a problem calling for immediate solution. At present all fuller's earth used by California oil refiners is shipped from Georgia and Florida, although there are thousands of tons of fuller's earth in the State. An investigation to determine whether California earths can be used for filtering purposes has been completed.
SAN FRANCISCO FIELD OFFICE.

The field office at San Francisco, Calif., is on the fifth floor of the United States Customhouse, its laboratories being in the Treasury Building close by. Until the establishment of the Bartlesville station, the work on petroleum technology was centered at San Francisco. From this office field investigations of various problems relating to petroleum engineering and technology are conducted throughout the United States. The chemical and technological laboratories of the station are well equipped.

PROBLEMS UNDER INVESTIGATION.

PROTECTING OIL SANDS AGAINST WATER.

Many oil fields in the United States have had their potential yield much reduced by water entering the oil sands. In California great advance has been made in methods of excluding underground waters, and the Bureau of Mines through its investigations in that State has demonstrated how such methods can be applied in other fields. The principal method advocated is the use of cement.

INCREASING THE ULTIMATE PRODUCTION OF WELLS.

Investigations have disclosed that in many fields far more of the oil originally in the oil sand is not recovered than is brought to the surface by the wells. Investigations have been conducted throughout the United States to ascertain the quantity of oil remaining in the oil sands, and methods are being devised for increasing this recovery by the use of compressed air and other means.

STUDY OF THE MIGRATION AND ACCUMULATION OF OIL AND WATER.

The relation between the accumulation of oil and of water in oil-bearing formations is of great importance to the oil industry. Experiments are being conducted in the San Francisco office to ascertain the underlying causes and effects of the migration of oil and of water through oil sands. Plate XXII shows apparatus used in such pl. XXII experiments.

VALUATION OF OIL PROPERTIES.

Although the proper valuation of oil properties is a matter of fundamental importance to the industry, rational engineering principles have not been applied to it in the past. Recently methods for
APPARATUS FOR STUDYING CAUSES AND EFFECTS OF MIGRATION OF OIL AND WATER THROUGH OIL SANDS.
estimating future production and thus determining a just basis for
the appraisal of oil properties have been devised. These methods
are being employed by the Bureau of Internal Revenue in making
valuation allowances under the taxation acts passed by Congress.
The San Francisco office has been asked to appraise Government oil
lands in California and elsewhere, and to advise on the royalties
involved in leasing oil and gas lands.

**DRILLING METHODS.**

The bureau has begun a study of well-drilling methods in the
United States. Various factors that have determined the methods
used in different fields have been investigated and many problems
that call for the use of special methods have been solved.

**FISHING PROBLEMS.**

Troubles encountered in placing and in carrying casing through
caving formations are being investigated. Methods of overcoming
some of the troubles encountered are being demonstrated.

**PUMPING OF OIL WELLS.**

Investigations have been made with reference to the effect of
methods of perforating casing and screen pipe in oil wells on the pro-
duction of oil. The deposition in an oil sand of minerals that tend
to exclude oil from a well and to decrease the total amount of oil
recovered from the sands has also been investigated.

**SUPERVISION OF GOVERNMENT OIL LANDS.**

The San Francisco office of the Bureau of Mines has been called
on to advise with the Land Office on the operation of certain oil
lands in the California oil fields.

**TRANSPORTATION OF HEAVY OIL THROUGH PIPE LINES.**

Some of the heavy viscous oils in the California oil fields move
through pipe lines with difficulty. Investigations of the engineering
features involved in the transportation of these oils, and the crack-
ing of such heavy oils, in order to reduce their viscosity and increase
their fluidity, are under way.

**A STUDY OF TOPPING PLANTS.**

Plants for the continuous distillation of the lighter fractions of
crude oil, known as topping plants, are much used in California fields
and to a less extent in the Gulf coast fields and in the fields of Okla-
ahoma. These plants have been investigated.
STORAGE OF OIL.

Investigations throughout the United States have dealt with the different types of storage tanks and reservoirs for crude oil—their cost, construction, maintenance, the evaporation losses, and the other factors that have to be considered in the storage of petroleum.

Investigations are now being made to determine the actual evaporation losses as related to climate, type of tank, and character of oil.

OIL AND GAS WELL FIRES.

The causes, means of prevention, and methods of quenching fires at oil and gas wells and of oil in storage have been investigated.

OIL-CAMP SANITATION.

Most oil and gas fields are developed rapidly under boom conditions that lead to highly insanitary conditions surrounding the living quarters of the men and their families. The bureau has investigated oil-town sanitation, with special regard to the peculiar conditions that menace health and life.

BIBLIOGRAPHY OF PETROLEUM.

A bibliography of petroleum, containing thousands of entries, is maintained at the San Francisco office. Although primarily for the use of the members of the petroleum division, it is available for the benefit of the petroleum industry.
STATIONS ESTABLISHED IN 1916.

The act of Congress approved March 3, 1916 (40 Stat. 969), authorized 10 new mining experiment stations to be under the Bureau of Mines, not more than 3 of which were to be established in any one year. The three stations established in 1916 were placed at Fairbanks, Alaska, at Tucson, Ariz., and at Seattle, Wash. Each of these had its particular field of service. The station at Tucson is to study problems connected with the mining, concentration, and metallurgical treatment of low-grade copper, gold, and silver ores; the station at Seattle is to investigate similar problems in connection with the coal and ore deposits of the Northwest and of the coast of Alaska; and the station at Fairbanks will take up the problems connected with the development of the mineral resources of Alaska.

THE SEATTLE STATION.

The station at Seattle was established specifically to investigate the problems connected with the mining and treatment of coal and other mineral deposits of the Northwest. Its first task was to make a thorough survey of the needs of the territory it was intended to serve and to get into close touch with local mining and metallurgical interests, in order to learn how it could be of most help.

In 1916 the division of metallurgy was created in the bureau, and the Seattle station was one of the first stations to profit by the change. The work of the station thus includes mining and metallurgy. Chief accomplishments to date have been in the study of scientific methods in connection with those subjects and in suggesting the best means of applying such methods to commercial conditions. Also careful attention has been given to some of the more theoretical questions involved. The station is housed in a building (Pl. XXIII) provided by the University of Washington. The work of the station is in charge of F. K. Ovitz, superintendent.

EQUIPMENT OF ORE-DRESSING LABORATORY.

The laboratories at the University of Washington are well equipped for ore-dressing tests. The equipment includes jaw and gyratory crushers, rolls, disk crushers, ball mills, tube mills, concentration tables, and almost every kind of flotation machine, both mechanical and pneumatic. The laboratory contains also a Dings electromagnetic separator, which was lent jointly to the Bureau and the College of Mines by the American Smelting and Refining Co.
ELECTROMETALLURGICAL LABORATORIES.

The Seattle station has two electrometallurgical laboratories, electrolytic and thermoelectric, situated in the south end of the College of Mines building. The electrolytic laboratory, of dust-proof construction, is fitted with a motor-generator set and other equipment.

The thermoelectric laboratory is separated from the rest of the building by cement partitions. The transformers and switchboards are separated from the furnace room proper by cement partitions, fitted with large glass panels. At the top of the transformer room are the voltage regulators, the regulator platform serving also as a charging floor for the electric furnaces. The furnace room is of fire-proof construction throughout. Fumes from the furnaces are carried through a hood and flue to a 90-foot brick stack at the end of the building. The electrical equipment includes two 140 k. v. a. transformers; two 77.4 k. v. a. d.plex induction regulators, complete with motor and necessary shafting and gears for coupling them. Bus bars convey the current from the switchboard to the furnaces.

WORK AT THE SEATTLE STATION.

The work of the station may be grouped as follows: Studies of methods of mining and preparing western coals, research work in flotation, mining and concentration of ores of metals, especially those that were needed during the war, and electrometallurgical investigations. Much work was done in cooperation with the University of Idaho at Moscow in obtaining data for a report on the mining districts of that State. Other work having a military bearing included investigations of the tin deposits of the Black Hills; concentration tests of quicksilver and chrome ores, in cooperation with the station of the bureau at Berkeley, and investigations of manganese and other ores in cooperation with the Oregon Bureau of Mines and Geology.

COAL INVESTIGATIONS.

MINING METHODS IN WASHINGTON.

The station is making a detailed study of coal-mining methods in the State of Washington, taking into account the thickness and dip of the beds; the characters of the walls; systems of mining, and methods of loading, haulage, hoisting, and ventilation.

Some of the important problems are a study of roof pressures under great depths, the control of roofs at varying depths with different systems of mining, and the gases produced at the various mines, with particular reference to the outbursts of gas in the mines of the Pierce County coal field.

WASHING TESTS OF WASHINGTON COALS.

A study is being made of the specific gravities of the various coals of the State and the impurities that may accompany the coal from the working face to the cleaning plant.
BUILDING HOUSING THE OFFICES OF THE SEATTLE STATION.
During the field season of 1918 a detailed study was begun of the coal-washing plants in the State. Efficiency tests were made of the various types of washeries, and representative samples of the various products were analyzed. It is expected that these results will show the efficiencies of the different plants and also show the grades of coal produced.

Studies will be made of the lignitic coals of Washington in the attempt to find more efficient ways and means of utilizing them. Also fuel tests of powdered coal will be made with the coals of this State, either independently of the bureau or in cooperation with the companies that are now experimenting with the utilization of powdered coal.

**IDAHO COALS.**

The coal-mining engineer of the station at Seattle made a preliminary examination of the Teton Basin coal field in Idaho. A report of the results of this investigation was included in the bulletin on the mining districts of that State.

**OREGON COALS.**

Two visits have been made to the Coos Bay coal field of Oregon for the purpose of examining the mining conditions and for investigating the possibility of finding improved methods of using this coal. These two phases of work are still under consideration. Also the coal field east of Medford, Oreg., was visited.

**GOVERNMENT MINES IN ALASKA.**

The coal-mining engineer of the northwest station, acting as consulting mining engineer to the Alaskan Engineering Commission in the development of coal mines in Alaska, made a field examination of two coal mines being opened by the Government in the Matanuska field, and suggested plans for the development of the mines.

**WASHING AND COKING TESTS OF ALASKA COAL.**

At the close of the season of 1917, 40 tons of coal were shipped to Seattle, for the purpose of making a washing test of two of the coals and a blacksmithing and coking test of the other. The 40 tons comprised approximately 20 tons of Chickaloon coal and 20 tons of Eska Creek coal. Although both coals could be improved by washing, a great loss of combustible material results when a suitable product is made of the Eska Creek coal, which had a large inherent ash content. The washed Chickaloon coal makes a satisfactory blacksmith coal and will also make satisfactory coke.

Float-and-sink determinations were made on a thousand-pound sample of coal from the Baxter prospect on Upper Moose Creek.
CONCENTRATION AND FLOTATION OF ALASKA NICKEL ORES.

Some work was done, in cooperation with the station at Golden, on the concentration of a low-grade nickel ore from Alaska. This ore is massive sulphide and is composed of sulphides, chiefly of pyrrhotite; the copper content by assay is a little less than 2 per cent and the nickel content about 4 per cent. Tests were made with a view to removing the copper as a high-grade copper concentrate and then separating the nickel as a high-grade commercial concentrate. The ore-dressing tests were followed by hydrometallurgical treatment. Possibly the electrometallurgy of the nickel products will be investigated.

CONCENTRATION TESTS OF TIN ORES.

Past methods of concentrating the tin ore in the Black Hills district of South Dakota were investigated and typical samples of the ores were sent to Seattle for concentration tests. These tests showed what could be expected in the recovery of tin from the low-grade ores of that district and the tin content of the products.

CONCENTRATION TESTS OF QUICKSILVER ORES.

In cooperation with the station at Berkeley, some concentration tests of typical samples of quicksilver ores from California were made to determine what recovery could be effected by concentration, and whether the method would have any advantages over direct smelting.

CONCENTRATION TESTS OF CHROME ORES.

Concentration tests of chrome ores from beach sands of southern Oregon were made in cooperation with the Oregon Bureau of Mines and Geology, in order to determine what could be expected in the way of recoveries under commercial practice. These tests were by wet concentration and electromagnetic separation of the concentrates. Concentration tests have also been made of chrome ores from different parts of California and Oregon, with the purpose of ascertaining how the chrome content of low-grade deposits could be made to yield commercial products. So far the results have been encouraging.

CONCENTRATION TESTS OF MANGANESE ORES.

Metallurgical analyses of the ore and concentrates at a concentrating mill near Lakecreek, Jackson County, Oreg., showed poor recoveries of the manganese. Tests were made in an attempt to help the operators in recovering mineral that is now being wasted.

ELECTROMETALLURGICAL INVESTIGATIONS.

Field investigations include a review of the present status of electrometallurgical plants in the Northwest, showing the general character of the work, equipment, and operating conditions. Particular attention has been paid to plants engaged in the production of ferro-
alloys, on account of the importance of these alloys for special steels for military uses. It was found that such plants need much encouragement and attention. In the past there has been a tendency to start electric furnaces without much regard to basic technical considerations. With the intent of supplying some of this much-needed information, the station at Seattle has endeavored to collect such data as is needed by those concerns engaged or embarking in such work. Frequent personal visits have been made to the plants of the district.

INVESTIGATION OF HYDROELECTRIC POWER IN NORTHWEST.

Data have been compiled on hydroelectric power in the Pacific Northwest and Southeastern Alaska with reference to the potential power available and the situation of proposed sites. Data have also been tabulated, as far as possible, showing the power now available at existing plants, the maximum power available with present equipment, details of installations, and operating costs.

UTILIZATION OF METALS FROM WASTE TIN CANS.

An investigation was made of the probable metal waste of tin and iron in the Northwest and some experimental work was carried on having for its object the elimination of this waste. However, the work had to be stopped because of the lack or nonarrival of apparatus that had been ordered for trying out the small-scale experiments on a semicommercial scale.

FERROMANGANESE.

Pending the receipt of thermoelectric apparatus, a study was made of the manganese situation with reference to plants operating on the Pacific coast and in the Pacific northwest. Some of the data has been gathered directly, some was supplied by field engineers of the bureau.

FERROCHROME.

Small-scale experiments have been made in the electric reduction of chrome-bearing beach-sand concentrates to ferrochrome. Concentrates from low-grade chrome ores will be given similar treatment.

OTHER FERROALLOYS.

From the inquiries and samples submitted there seem to be numerous tungsten and molybdenum prospects in the Northwest, and it is planned to do some electric furnace work on these ores in order to determine their suitability for the production of ferromolybdenum and ferrotungsten.

SMELTING OF TIN CONCENTRATES.

Because of the natural advantages of the ports of Puget Sound and their proximity to large salmon canneries, one of these ports is probably the logical place for a tin smelter for smelting tin concen-
trates from Alaska and Bolivia, as well as the by-product tin oxide which, it is found, may be obtained from detinning old tin cans. This problem will receive early attention.

**ELECTROLYTIC TREATMENT OF COMPLEX LEAD-ZINC ORES.**

The proposed treatment of the complex lead-zinc ores suggest a combined thermoelectric and electrolytic process. In the Couer d’Alene district, Idaho, some large-scale experiments have been conducted for the recovery of lead by roasting the ores to lead sulphate, leaching with brine solution, and then electrolyzing. To date, the drawback has been the lack of coherent deposition. This problem, together with the recovery of lead and lead-chloride fume, obtained by volatilization of lead as lead chloride after a chloridizing roast with sodium chloride, will receive early attention in the electrolytic laboratory.

**ANTIMONY.**

More antimony ore (from Alaska) passes through Seattle than any other one place in the United States except New York City, when imports from Bolivia are particularly large. In addition, antimony prospects in all three northwestern States might possibly become commercial mines if there should be an outlet nearby. For these reasons, the station has taken a more than passing interest in antimony. The metallurgical treatment has already been pretty well worked out.

**AMMONIUM NITRATE.**

It is proposed to do some work at this station along the lines of making ammonium nitrate compound by electrolyzing nitric acid. The results of some small-scale experiments seem to indicate that it may be possible to devise such a process that would be commercially feasible.

**MANUFACTURE OF METALLURGICAL CHEMICALS.**

The use of the electric furnace in the manufacture of chemicals, such as hydrochloric acid and phosphoric acid has been advocated and it is proposed to try out some of these suggestions at an early date.

**THERMOELECTRIC SMELTING OF COPPER ORES.**

Some of the deposits of low-grade copper ore in southeastern Alaska seems to be situated so as to favor the development of thermoelectric plants for smelting. Ample power is available, and when the problem of a supply of charcoal or coke is solved much interest should be manifested in the development of such a process.

**PHYSICAL PRINCIPLES OF FLOTATION.**

The development of the flotation process has been rapid, and practical knowledge of the process is in many ways in advance of the science. Although many details of methods of operation, the
use of oils, and other phases of mill work have been worked out, adequate explanation of the underlying theories has been lacking.

The results of studies made at the Seattle station of the physical principles of flotation have been illuminating. Surface tension, the angle of contact between liquid surfaces and solids, the spreading of oils on water, the flotability of different shaped particles, and the effects of colloids on flotation have received special attention.

The modifying effects of oil on the surface tension of water proved to be less than had been supposed. An apparatus (see Pl. XXIV, A) for the measurement of surface tension was developed, based on the drop-weight method. A mathematical formula expressing the relation of the angle of contact between liquids and solids to flotability was worked out. In studying the flotability of various shapes of particles, a surface was designed that illustrates film suspension remarkably. Plate XXIII, B, shows a piece of window glass cut in this design floating on pure water by film suspension. The interfering effects of colloids on flotation were clearly demonstrated.

The results of these tests were published in Technical Papers 182, "Flotation of Chalcopyrite in Chalcopyrite-Pyrrohotite Ores of Southern Oregon," and Technical Paper 200, "Colloids and Flotation."

COOPERATIVE WORK IN IDAHO.

In cooperation with the University of Idaho, at Moscow, an examination of the mining districts of Idaho was begun late in May, 1917, and continued during the summer. E. K. Soper, then dean of the mining department of the University of Idaho, visited the mining districts in the central and southwestern parts of the State and also some of the districts in the northern part. D. C. Livingston, professor of geology at the University of Idaho, visited some of the mining districts in central Idaho during the summer, and prepared maps covering the State. Thomas Varley, then superintendent of the station at Seattle, spent a short time in the field, principally in the mining districts in central and northern Idaho, and made a brief visit to the southwestern districts with Mr. Soper. The metallurgical engineer of the station spent most of his time in the Cœur d'Alene region, where he visited nearly all of the mining districts and devoted most of his time to examining milling methods.

The results of these field investigations have been published by the bureau as Bulletin 166. This bulletin aims to give the location of the various mining districts and the nature of the present operations as well as of those that have been carried on. Field work is to be continued and the results are to be published in more detail, with greater emphasis on the metallurgical treatment of the ores.
The experimental work done at the University of Idaho under the direction of the Bureau of Mines has been chiefly on the flotation of mill feeds and tailings of lead and zinc ores from mills of the Cœur d'Alene district. The purpose of these flotation tests was to find the most suitable flotation mixture, for separating the lead minerals from the zinc minerals, what proportions of the different reagents are needed, and what operating conditions give the highest recovery of both minerals.

All of the tests have been conducted in a Varley mechanical type flotation cell. Air at low pressure can be used with all the machines.

In general, the reagents that have been given the highest differential selection of galena from sphalerite are common salt (NaCl) sodium carbonate (Na₂CO₃), coal-tar creosote oils, and a few heavy coal-tar oils. Special laboratory distillates from mixtures of different coal-tar creosotes and alcohol and coal-tar creosotes dissolved in alcohol offer promise for these ores. Seemingly, the coal-tar creosotes and distillates with alcohol used in an alkaline solution give the best results.

As regards recovery it has not been difficult to obtain a high selection of the metallic sulphides from the gangue, in fact 95 per cent recovery has easily been made. The problem is to make a high recovery of each metallic sulphide from the first differential separation. Some of the tests will be applied on a large scale in mills of the Cœur d’Alene district, as soon as the laboratory results warrant such trial.

THE TUCSON STATION.

FIELD OF THE STATION.

The territory served by the station at Tucson, Ariz., includes Arizona, southwestern New Mexico, southwestern Texas, and that part of southeastern California which borders on the Colorado River. The special task of this station is the investigation of methods of recovering copper and associated metals from low-grade ores, and in this respect its activities are not limited to the area named. Although the principal metal produced in this area is copper, there is an important production of lead and zinc, of the precious metals, and of some of the rare metals such as molybdenum, tungsten, and manganese. Views at manganese mines are shown in Plate XXV, A and XXV, B. Promising deposits of quicksilver, of vanadium, and of nickel have been found, but are only partly developed. On account of the importance of these metals, the station has an important duty to fulfill in studying the problems that arise in connection with their mining and treatment.
A. DROP-WEIGHT APPARATUS FOR DETERMINING SURFACE AND INTERFACIAL TENSION.

Left, apparatus as arranged for surface-tension test; middle, interfacial tension, dropping downward; right, interfacial tension, dropping upward.

B. GROOVED GLASS PLATE LOADED WITH SAND AND RAFTED ON WATER BY FILM SUSPENSION.
A. MINING AND SORTING MANGANESE ORE AT A MINE IN ARIZONA.

B. WINCH AND SORTING BOX AT A MANGANESE MINE IN ARIZONA.
The mineral production of the area tributary to the station is large and increasing. In 1917 the output was in excess of a quarter of a billion dollars. The value of the output of copper, lead, zinc, gold, and silver in Arizona for 1917 was roughly $214,000,000, and that of New Mexico, $33,700,000, as follows:

Approximate output and estimated value of principal metals produced in Arizona and New Mexico in 1917.

<table>
<thead>
<tr>
<th></th>
<th>Arizona</th>
<th>New Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>633,000,000</td>
<td>$209,000,000</td>
</tr>
<tr>
<td>Lead</td>
<td>18,000,000</td>
<td>1,865,000</td>
</tr>
<tr>
<td>Zinc</td>
<td>20,700,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Gold</td>
<td>192,880</td>
<td>3,386,000</td>
</tr>
<tr>
<td>Silver</td>
<td>6,354,000</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

a Troy ounces.

The number of men employed in mining in Arizona during 1917 was approximately 23,000; employment statistics for New Mexico are not available. Among the largest employers in the metal-mining field are the Chino Copper Co., with mines at Santa Rita, N. Mex., and mills and smelter at Hurley, N. Mex.; the Copper Queen Mining Co. and the Calumet & Arizona Mining Co., at Bisbee, Ariz.; and the Burro Mountain Copper Co., at Tyrone, N. Mex.

PROBLEMS CONNECTED WITH THE MINING OF LOW-GRADE COPPER ORES.

On account of the large scale on which mining of the porphyry copper ores is conducted, the tonnages ranging from 5,000 to 20,000 tons a day for a single property, problems of development, mining, transportation, ventilation, and the prevention of mine fires and their control are more than ordinarily difficult. As the low grade of much of the ore compels careful attention to economy in mining, the method of mining is of great importance. Many experiments have been made with different variations of underhand stoping. Two large mines have resorted to open-pit mining with steam shovels. One mine after many years of underground mining contemplates changing to open-pit methods.

MILLING AND LIxiviation PROBLEMS.

On account of the large tonnages involved, the location of concentration and leaching plants must be carefully studied with reference to water supply and to tailings storage, because of possible re-treatment and of pollution of streams. The mine and the mill are usually
connected by a broad-gage railroad, and the ore trains are hauled by steam.

Milling of porphyry copper ores is in a transition stage. The ores may be roughly classified as follows:

1. Sulphide ores containing some oxidized copper, where table concentration followed by flotation—or flotation alone—recovers most of the sulphide copper and some of the oxidized copper, leaving for re-treatment a tailing of relatively high grade which contains a high percentage of the oxidized copper. A large proportion of the Chino, Ray, Miami, Inspiration, and Utah Copper ores is of this character.

2. Clearly defined bodies of oxidized ore with sulphide content low enough to warrant leaching with sulphuric acid and wasting the sulphides. Such bodies occur at the Utah Copper and the New Cornelia properties.

3. Mixed oxidized and sulphide ore for which straight leaching or straight concentration would be too wasteful. Ore bodies of this class are found at all of the properties.

4. Accumulations of mixed oxidized and sulphide tailings which offer much the same problem as the ores of class 3.

TREATMENT OF SULPHIDE ORES CONTAINING SOME OXIDIZED COPPER.

A brief description of the Miami and Inspiration mills will suffice to illustrate the treatment of sulphide ores containing some oxidized copper.

MIA MI MILL.

The Miami mill was originally designed to treat, by gravity concentration only, some 6,000 tons daily of ore having an assay value of 2.25 to 2.5 per cent copper, and containing perhaps 0.5 per cent of copper in oxidized form. The mill began work early in 1911 and was in full operation the latter part of the year. Since then the original design has been modified in many details. The ore is crushed with gyratory crushers and rolls, separated on Callow screens, ground in Chilean mills, which are fast being replaced by Hardinge mills, and concentrated on Deister tables and Deister slime tables, with the necessary intermediate apparatus. In 1914 flotation of tailings was tried and a flotation system installed. The mill is now treating 10,000 tons daily of ore averaging about 2.25 per cent copper content, and is making concentrates that average around 24 per cent copper. The mill recovers 90 per cent of the sulphide copper and less than 25 per cent of the oxidized copper.

IN SI R I PA RI ON MILL.

The Inspiration mill as first designed was based largely on experience gained at the Miami, as the same engineer designed both plants. When the Inspiration mill was developed the flotation process was
developing rapidly in the United States, so that opportunity favored the testing and comparison of gravity concentration and flotation.

Flotation was first considered for the treatment of tailings from gravity concentration. The results obtained from experimental work, however, soon led to the conclusion that flotation would play a much more important part. In January, 1914, a 600-ton experimental plant was built in which flotation was the principal method. This plant solved many questions and led to the final adoption of the simple flowsheet of the new mill of the Inspiration Company, which includes Marcy mills with Dorr classifiers, Callow or Inspiration flotation cells, followed by classification and secondary flotation treatment, with final table concentration of the tails from secondary flotation. It is to be noted that this latter concentration could be effected as well by additional flotation equipment, but the cost would be greater, because of the special oil needed to save this particular product.

The Inspiration mill treats 20,000 tons daily, making a 29.5 per cent concentrate from a mill feed carrying about 1.4 per cent copper, of which 0.3 per cent is oxidized. The mill recovery of sulphides is 90 per cent; the cost of crushing and concentration is about 63 cents a ton, including royalty on flotation patents.

Thus it happens that within a short distance of each other are two magnificent plants, one representing the highest development of the old practice, the other representing the highest development of the new practice.

It would seem that the flotation practice developed at the Inspiration mill, with such modifications and betterments as will naturally result from constant experiment, has solved the sulphide recovery problem.

**TREATMENT OF OXIDIZED ORE LOW IN SULPHIDE COPPER.**

The New Cornelia Copper Co., at Ajo, has standardized a sulphuric acid leaching practice for ores of the second class. The Ajo deposit comprises a low-grade sulphide ore, which must be mined by open-pit methods, overlain by a capping which may be regarded as a well-defined body of 12,000,000 tons, of oxidized ore, containing 1.65 per cent oxidized copper and a negligible quantity of sulphide copper.

The ore is crushed in tandem gyratory crushers to 3-inch size, then in tandem Symons horizontal disk crushers to ½-inch size. This product goes to the leaching vats.

The leaching plant consists of eight lead-lined concrete vats, with a 15-foot ore column, and 1,500,000 gallons of leaching solution in circulation, having a rate of flow of 1,000 gallons per minute. The solution contains 3 per cent sulphuric acid, 2.5 per cent copper, and 2 per cent iron as sulphate. It is introduced at the bottom of the last vat.
which is receiving its final (eighth day) treatment, percolates upward through this charge and then through the charge that is receiving its seventh-day treatment, and so on successively to the first vat, whence it emerges as a practically neutral solution containing 3 per cent copper and ferric sulphate. The latter is reduced to ferrous sulphate because ferric sulphate redissolves copper precipitated by electrolysis. This reduction is accomplished by passing the solutions through absorption towers against ascending gas, containing 7 per cent sulphur dioxide. The resulting 3 per cent copper solution passes to the electrolytic tanks where one-sixth of the copper is removed. The leaching solution, with the wash solutions from the charges, is then built up for refuse. Besides dissolving the copper the leaching solutions take up various constituents from the ore, such as alumina, iron, etc., which would accumulate in succeeding cycles, and the copper after each cycle if reduced to 2.5 per cent. Therefore, after each cycle one-fourth of the solution is run to waste and is replaced with fresh acid and water. The copper in the wasted solution is precipitated as cement copper on scrap iron.

Sulphuric acid for leaching is made at the new acid plant recently put in operation at the Calumet & Arizona smelter. The output of this plant is 210 tons of 60° B. acid, most of which is consumed at the New Cornelia plant. Sulphur dioxide gas is obtained by roasting a high-grade copper-bearing pyrite produced in the Warren district. The calcined ore is returned to Douglas to be smelted. Experiments are now under way looking to metallizing the calcined iron by heating with coal in a closed rotating kiln, thereby making sponge iron for the precipitation of cement copper.

In all its mechanical details the new Cornelia plant is a model of construction; it operates smoothly and satisfactorily. It is treating daily 5,000 tons of oxidized ores containing 1.65 per cent copper and is making an 80 per cent extraction.

TREATMENT OF MIXED OXIDIZED AND SULPHIDE ORES AND TAILINGS.

Mining operations in the various districts, in so far as possible, are confined to ores of the first and second classes. On account of the larger demand and increased price of copper in recent years, many of the mills have worked far above their rated capacity, with resultant imperfect crushing and high sulphide tailings that carry varying, but always important, percentages of oxidized copper. At all of the large plants the treatment of such tailings and of the mixed oxidized-sulphide ores is a most important problem. In some of the older camps, where selective mining is no longer possible, and where ores containing a large proportion of oxidized copper must be milled, the situation is acute. This problem is being attacked vigorously from different sides and all the companies are working at it.
That the outstanding problem in the copper industry of the Southwest was the recovery of copper from mixed oxidized-sulphide ores became evident some time ago. Several properties have distinct bodies of mixed ore high in oxidized copper, these bodies ranging from a couple of million to perhaps ten million tons.

An examination of the various large tailings dumps showed that sulphide losses in tailings are due to the following causes: Insufficient crushing; deliberate overloading of mills to obtain a large output of copper, and an oxidized coating of film on sulphide particles, which must be removed in order to insure efficient recovery of the remaining sulphide by flotation.

There is very little sulphide ore that does not contain enough oxidized copper to warrant retreatment of mill tailings. Therefore, practically the entire tonnage milled and to be milled involves the retreatment of this mixed oxidized and sulphide material.

**General Conclusions as to Copper-Ore Problems.**

A general survey of the situation by the technical staff of the bureau’s station at Tucson has led to the following conclusions:

Flotation would make satisfactory recoveries of clean sulphides. Sulphuric acid leaching seemed to offer a satisfactory process for oxidized copper ores containing negligible quantities of sulphides.

Certain operators felt that the solution of the problem of mixed oxidized and sulphide ores, as regards their particular ore, lay in sulphidizing or “filming” the oxidized mineral and subsequently floating it with the sulphides in one operation. Other operators felt that their ores were more amenable to an adaption of sulphuric acid leaching, followed by precipitation of the dissolved copper on metallic iron and recovery of both sulphide and cement copper by flotation, thus doing away with some rather objectionable steps in the recovery of copper from sulphate solutions. It seemed at first that the field had been rather completely covered by the well-organized experiment staffs of the large copper companies, but further investigation developed the fact that the companies were somewhat disappointed with the net results of their large-scale experimental work; also that a very promising field—leaching and sulphur dioxide gas—had been left entirely untouched.

It was evident that the first requisite to solving the mixed ore problem was a dependable analytical method for determining the exact proportions of sulphide and nonsulphide, or oxidized, copper present. The known methods were faulty and the one generally in use (the sulphuric acid method) gave erroneous results, part of the sulphide copper in the tails being reported as oxidized copper on account of the solubility of chalcocite in cold dilute sulphuric acid.
Therefore, the station gave attention first to the development of a reliable analytical method for the selective determination of oxidized and sulphide copper.

**SMELTING PROBLEMS.**

There are many important smelting plants in the area served by the station at Tucson, and all of them do a custom business. The larger plants are at El Paso, Tex.; Hurley, N. Mex.; Clifton, Morenci, Douglas, Miami, Globe, Ray, Jerome, and Humboldt, Ariz. Among the problems of smelter practice are those mentioned below.

The mining public regards the sampling of mill products and mine ore at the smelter with undisguised suspicion. Standardization of the practice and a description written in nontechnical language for the information of the public would be a benefit.

The basis of smelter schedules is not understood. The producers do not appreciate the fact that most of the smelters were built to furnish an outlet for the ores of one or more groups of mines, nor do they comprehend the difficulties under which the smelters are laboring. Neither do the smelters appear to be always solicitous of the problems of producers. Many misunderstandings that arise through the producer not knowing the difficulties and losses encountered in smelting practice could be cleared away. Similarly the attitude of smelting corporations toward the producer and his problems might be improved.

A study and correlation of practice in the following departments of the smelters might be helpful: Dust losses; preparation of fine material destined for the blast furnace; converter practice; and utilization of waste products, such as gases and slags.

**BUILDINGS AND EQUIPMENT.**

The station at Tucson, Ariz., was established in the summer of 1916, and active work was begun in January, 1917. The first six months were devoted to a general survey of the area to be served by the station; the second half of the year to the ordering and installation of equipment.

The station is housed in buildings of the University of Arizona and works under a cooperative agreement with the Arizona State Bureau of Mines and with the college of mines and engineering of the State University. The State Bureau of Mines furnishes the funds for two or more metallurgical fellowships, and recipients of these fellowships do research work in the laboratories of the station. The station is in charge of Charles E. Van Barneveld, superintendent.

**EQUIPMENT.**

During 1917 the station occupied temporary office and laboratory quarters on the university campus pending the construction of the new mines and engineering building. Provision was made in the
new building for offices, for a chemical laboratory, an electrical laboratory, an assay-furnace room, a general metallurgical laboratory, and an overflow laboratory. The equipment selected includes metallurgical apparatus to handle roasting, leaching, and concentration tests of ores in lots of 100 pounds to several tons. Much of this equipment was temporarily erected and in use several months before it was installed in the new building.

INVESTIGATIONS.

SELECTIVE DETERMINATION OF COPPER MINERALS IN PARTLY OXIDIZED ORES.

The first problem undertaken was the development of a dependable analytical method for the selective-determination of the sulphide and nonsulphide copper minerals in partly oxidized copper ores. A satisfactory method was worked out, the details of which have been published in Technical Paper 198.²

SULPHUR DIOXIDE METHOD FOR COPPER ORES.

In connection with this work a careful study was made of the action of sulphur dioxide gas on copper minerals, and an apparatus was constructed for the use of hot sulphur dioxide gas, direct from the roasting furnace, as a solvent for nonsulphide copper in any form. Small-scale laboratory tests gave most encouraging results on materials of the mixed oxidized-sulphide class, and as a result a plant was constructed to test ores and tailings in quantity ranging from 1 ton upward with a maximum capacity on tailings of 10 tons per 8-hour day.

The work undertaken requires experimentation in different processes, as follows: Crushing, gravity concentration, flotation, leaching, and precipitation of ores and tailings from the five principal districts in the territory. The field is broad and the tonnage involved is enormous.

THE FAIRBANKS STATION.

The station at Fairbanks, Alaska, was established primarily to aid in solving problems arising in connection with the development of the gold, copper, and other mineral resources of the Territory, and expressly those that relate to the prevention of waste in the mining and milling of low-grade ores and the application of hydroelectric power in the mineral industries. This station is housed in temporary quarters (Pl. XXVI) furnished by the Commercial Club of Fairbanks. The equipment of the station includes an ore-testing laboratory, where milling and concentrating tests on a small scale can be made, and a laboratory for chemical analyses, assaying, and microscopic examinations of ores and minerals.

Fairbanks is on the Tenana River, a tributary of the Yukon, and has many of the conveniences of a modern city, including an electric light plant, a telegraph system connecting it with the mining camps in the vicinity, and a wireless station. Transportation from points on the Pacific coast is chiefly by way of Dawson and the Yukon River. A railroad up the Tenana Valley makes travel in the area immediately tributary to Fairbanks comparatively easy, but outside that area travel is difficult. The new Government railroad, in course of construction, will undoubtedly prove a powerful stimulus to mining and to commercial ventures.

In Alaskan mining the cost of power is a factor of growing importance. As the shallower deposits are worked out and the mines become deeper, more elaborate pumping and hoisting equipment must be used. Power for running machinery at mines and mills is now chiefly obtained from wood and gasoline. Timber near the mines is scarce and is being rapidly cut off; gasoline is brought from the Pacific States, and its cost is accordingly high. Utilization of Alaska coal and development of hydroelectric power would be of advantage. A study of the possible application of hydroelectric power to mining, milling, and smelting will be a special feature of the work of the station.

Another feature of the work is the supplying of information to prospectors and others regarding economic minerals submitted for identification. In connection with this work a collection of minerals is being formed and information is being compiled on the appearance, mode of occurrence, value, and uses of economic minerals found in Alaska.

In the metallurgical laboratory studies are made of the best methods of treating low-grade ores. Samples of ores submitted by parties desirous of the bureau’s help and ores selected as typical of certain districts are studied under the microscope and by screen analyses and by laboratory methods. Then test runs are made on lots of 1 to 5 tons to determine the type of concentrating machinery or the process best suited to the ore studied.

Crushing and milling tests have been made on a few ores from certain properties and recommendations made to the owners.
STATIONS ESTABLISHED IN 1917.

The three mining experiment stations established in 1917 are at Columbus, Ohio, Minneapolis, Minn., and Bartlesville, Okla. The chief function of the station at Columbus is the study of problems of the ceramic industries; that of the station at Minneapolis, the beneficiation and utilization of low-grade iron ores, including hematites, magnetites, titaniferous magnetites, and manganiferous ores; and that of the station at Bartlesville, investigations relating to petroleum and natural gas.

THE COLUMBUS STATION.

As the mining and manufacture of clay products is one of the chief industries in the United States, one of the stations established in 1917 deals with ceramic problems exclusively. The main reasons for selecting Columbus, Ohio, as the site of this station were that Columbus is the center of important clay-working industries, Ohio being the leading State in manufacture of clay products, and that the University of Ohio, which has a school of ceramics, offered to provide quarters for the station and, as soon as possible, furnish funds for active cooperative research work. The specific purposes of the station are to conduct research work and carry on investigations on problems arising in connection with the ceramic industry, to encourage the development of ceramic raw materials, and to devise improved methods for the refining, manufacture, and utilization of domestic clays, with especial regard to the prevention of waste and the improvement of the quality of the products.

IMPORTANCE OF CERAMIC INDUSTRIES IN THE UNITED STATES.

Ceramic industries in the United States are many and varied. They include the mining, refining, and utilization of the nonmetallic minerals used in the manufacture of products that require baking, hardening, or fusing in kilns and furnaces.

In the manufacture of clay products the three materials used in greatest quantities are clay, sand, and limestone. These are widely distributed and exist in vast quantities.

The most important ceramic industries are those utilizing clays. Plants for making clays are in operation in every State and Territory of the Union. The most important products made are brick, tile, sewer pipe, flue lining, conduits, hollow blocks, fireproofing, architectural terra cotta, stoneware, porcelain, earthenware, china, and art pottery.

The number of firms manufacturing clay products in the United States is about 4,000, representing an investment of approximately
$375,000,000. The value of the Nation’s clay products exceeds $200,000,000 per annum. Approximately 75 per cent of this sum represents brick, tile, and other structural material, and the remainder higher grade material classed as pottery.

The six leading States in order of production of clay products are Ohio, Pennsylvania, New Jersey, Illinois, New York, and Indiana. The value of their production exceeds $135,000,000, or is about 68 per cent of the total domestic production. Ohio, the leading State, produces annually clay products valued at more than $45,000,000, or approximately 22 per cent of the Nation’s output. More than 600 plants in the State are engaged in clay-working operations representing an investment of approximately $50,000,000.

In the manufacture of structural materials—such as brick, terra cotta, tile, and sewer pipe—a wide variety of clays is utilized.

The principal materials used in the manufacture of pottery are kaolin, ball clay, potter’s flint, whiting, and feldspar. In the manufacture of glazes, enamels, and colors for decorative purposes over 250 different minerals and chemically prepared materials are required.

Refactories for furnace linings are of the greatest importance to the metallurgical industries, for without suitable refractories most of the metallurgical processes would be impossible. Where the best quality of clay fire brick will not withstand the severe furnace treatment often necessary, it is necessary to use fire brick made from other mineral substances, such as ganister, magnesite, chromite, and zirconia. Graphite is important in the manufacture of graphite crucibles used in making crucible steel, brasses, and other alloys.

In the manufacture of Portland cement, large quantities of clay, shale, slag, limestone, and marl are needed. In the manufacture of quicklime, used in mortars and plasters and for certain chemical purposes, a pure grade of limestone is required. Gypsum is a mineral of considerable importance. From it wall plaster, plaster of Paris, fireproofing and Keen cement are made. Common window and plate glass, bottle glass, optical glass, tableware and cut glass, chemical glassware, and special glasses for scientific purposes utilize large quantities of high-grade sand as well as pure limestone.

Industries manufacturing grinding wheels and other abrasive products from natural corundum, as well as from the electric furnace products, such as silicon carbide and fused bauxite, are important ceramic industries.

In the sheet-metal and cast-iron enameling industries, feldspar, fluorspar, cryolite, kaolin, silica, borax, boric acid, red lead, white lead, whiting, tin oxide, and antimony oxide are used as ingredients of the enamel for such products as bathtubs, lavatories, kitchen sinks, laundry tubs, chemical ware, stove parts, granite ware, automobile tags, signs, and enameled jewelry.
NEED OF SCIENTIFIC RESEARCH IN CERAMICS.

Although clay working was one of the first arts toward which savage man turned his attention, the ceramic industries are among the last to receive much scientific attention. The scientific study of ceramics began in Europe about 1869. In the United States the first degree in ceramic engineering was conferred in 1900, and only four universities and one college now offer instruction in ceramic chemistry and ceramic engineering.

Technical assistance is needed especially in the clay industries. Clay plants are widely distributed and, in general, comparatively small, representing an average capitalization of less than $100,000 per plant. In the bottle-glass industry over $500,000 was spent in the development of the modern automatic bottle-blowing machine, but no clay-working firm feels that it can afford to spend a fiftieth part of that sum for experimental purposes. The general methods employed in the manufacture of clay products are substantially the same as those employed half a century ago. Advance has been made in kilns and machinery, but has not kept pace with that made in many other industries.

A more thorough acquaintance with the raw materials, a more extended development and improvement in automatic machinery for molding and handling the products, and a wider adoption and further improvement of the continuous kiln and the tunnel kiln are needed in order to reduce losses and to conserve both labor and fuel.

EQUIPMENT OF THE STATION.

The laboratories and offices of the station are housed in Lord Hall (see Pl. XXVII), a building containing the mining engineering, metallurgical, and ceramic laboratories of the University of Ohio. A two-story addition and a kiln house have been erected for the use of the station (see fig. 2). The first floor contains two general laboratories, a machine shop, and a pottery laboratory. On the second floor are offices, a drafting room, an optical and chemical laboratory, and an electric furnace laboratory.

In the laboratory in the west basement are a dry pan, pug mill, and molding machine, bins for storing crude and screened clay, a screen and two bucket elevators for conveying the crushed clay from the dry pan to the screen and the screened clay from the bin to the pug mill. Provision has been made for driving this machinery with two 30-horsepower motors. One drives the dry pan, elevators, and pug mill, and the other is connected to the molding machine. This arrangement gives flexibility and permits tests being made on the molding machine independently, as, for example, in determining the power required for molding stiff mud clay products, a subject on which no reliable data exist. This machinery, with the tunnel
FIGURE 2.—Addition to Lord Hall, Ohio University, for the ceramics station of the Bureau of Mines.
driers and large kiln, also permits tests of clays on a scale comparable to that of small commercial plants.

The two large laboratories of the new addition have been equipped for general experiment work. The machine shop contains a turning lathe, drill press, shaper, double grinder, and workbench. In ceramic experiment work it is sometimes necessary to make apparatus that can not be purchased in open market.

The pottery laboratory contains a blunger, filter press, vertical pug mill, potter’s jolly, a battery of six porcelain-lined ball mills, and a disk grinder. This equipment is used for the preparation of clays for casting and jiggering, for pressing test pieces, and for preparing glazes and enamels.

The optical laboratory is equipped for the study of optical properties of ceramic materials and for making refined physical measurements.

The electrical furnace laboratory contains two carbon-resistance furnaces, two nichrome-resistance furnaces, a platinum-resistance furnace, and a small arc furnace.

WORK OF THE STATION.
KAOLIN INVESTIGATIONS.

During the war an unusual demand for chemical stoneware arose from the manufacture of dyestuffs, of ingredients for poisonous gases and explosives, and of other chemicals. A study of the properties of stoneware clays of Ohio and Pennsylvania was begun, chiefly to call attention to valuable stoneware clays not widely used and to show how their qualities could be improved by inexpensive physical and chemical treatment. Over 50 per cent of the china clay or kaolin used in the pottery, paper, and oilcloth industries in normal times has been imported from England. Although there are large quantities of high-grade kaolin in the United States, consumers of this commodity claim that the kaolin miners are unable to deliver a product that is comparable to the English.

In the manufacture of the better grades of pottery, the domestic kaolins either do not give ware of good color or else cause high bisque losses. The principal objections to the use of domestic kaolins as fillers in the paper and oilcloth industries are that the domestic kaolins do not give good spreading qualities and wear out the machinery rapidly.

The workable kaolin deposits east of the Mississippi River are being investigated by engineers of the bureau. At each deposit data have been collected on its extent and structure, its location and accessibility, and the methods of mining and refining used. Samples have been collected and sent to the Columbus station, where experiments in refining and blending will be conducted with the object of producing a clay equal to imported varieties.
In connection with the work on kaolins, two investigations are underway. These are the use of sulphuric acid and the sedimentation of clays, and the use of American clays as fillers for oilcloth.

REFRACTORIES.

The station is investigating a number of problems in refractories. Some of these problems are: The use of domestic magnesite as a substitute for imported varieties for the manufacture of refractories; the use of dolomite for furnace linings; the use of American graphite in the manufacture of crucibles; and the utilization of American clays for bond clay in the manufacture of graphite crucibles.

OTHER PROBLEMS.

Other problems in connection with the clay industries are the improvement of methods of handling and burning clays so as to obtain greater efficiency and less waste of fuel, and a study of the effects of dust on the lungs of workers in mines and shops.

THE MINNEAPOLIS STATION.

The Lake Superior iron district, which includes the iron ranges in Minnesota, Wisconsin, and Michigan, produces about 88 per cent of the total iron ore mined in the United States. Much of this production comes from ore of good grade, but the district has vast deposits of low-grade ore. The supply of high-grade ore may be exhausted in 30 years, or even less, and the problem of the beneficiation and utilization of the leaner ores is of great importance. As Minnesota ranks first in production of iron ore, and the State university had offered to cooperate with the Federal Bureau of Mines in furnishing quarters for the station and the use of its laboratories, the station was established at Minneapolis. In a city as large as Minneapolis supplies and material can be promptly obtained, and the numerous foundries and shops offer excellent facilities for the construction of special apparatus and machinery. Because of railroad connection, large samples of ores for testing can readily be assembled from the ranges of the Lake Superior district, and also from the West and Southwest. The problems to be investigated at this station include the concentration of sandy and cherty hematites, of lean magnetites and titaniferous magnetites, and the concentration of manganiferous ores; a study is also to be made of new processes for the reduction of iron ores.

PRODUCTION OF IRON ORES IN THE LAKE SUPERIOR DISTRICT.

The preeminence of the Lake Superior district in production of iron ores is shown by the following table, which gives the production of Minnesota, Michigan, Wisconsin, New York, Alabama, and the other States for the years 1908 to 1917.
Iron ore mined in the United States during the 10 years 1908 to 1917.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Year</th>
<th>Minnesota</th>
<th>Michigan</th>
<th>Alabama</th>
<th>New York</th>
<th>Wisconsin</th>
<th>Other States</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1908</td>
<td>18,652,200</td>
<td>8,839,199</td>
<td>3,734,438</td>
<td>697,473</td>
<td>733,993</td>
<td>3,325,013</td>
<td>35,983,356</td>
</tr>
<tr>
<td>1909</td>
<td>28,975,149</td>
<td>11,900,384</td>
<td>4,321,252</td>
<td>1,015,333</td>
<td>1,067,436</td>
<td>3,875,883</td>
<td>61,156,437</td>
</tr>
<tr>
<td>1910</td>
<td>31,956,769</td>
<td>15,383,938</td>
<td>4,871,273</td>
<td>1,287,209</td>
<td>1,149,553</td>
<td>4,381,024</td>
<td>66,889,734</td>
</tr>
<tr>
<td>1911</td>
<td>34,645,105</td>
<td>10,329,039</td>
<td>5,827,791</td>
<td>1,081,270</td>
<td>698,660</td>
<td>3,314,678</td>
<td>45,876,502</td>
</tr>
<tr>
<td>1912</td>
<td>34,431,768</td>
<td>11,191,439</td>
<td>4,565,603</td>
<td>1,215,672</td>
<td>800,600</td>
<td>2,886,074</td>
<td>55,150,137</td>
</tr>
<tr>
<td>1913</td>
<td>38,658,793</td>
<td>12,541,083</td>
<td>5,215,740</td>
<td>4,459,625</td>
<td>1,018,272</td>
<td>2,786,911</td>
<td>61,980,467</td>
</tr>
<tr>
<td>1914</td>
<td>21,946,901</td>
<td>10,796,700</td>
<td>4,838,969</td>
<td>785,277</td>
<td>886,512</td>
<td>2,185,812</td>
<td>41,439,761</td>
</tr>
<tr>
<td>1915</td>
<td>35,464,660</td>
<td>12,514,516</td>
<td>5,309,354</td>
<td>998,846</td>
<td>1,095,389</td>
<td>2,143,727</td>
<td>55,596,400</td>
</tr>
<tr>
<td>1916</td>
<td>44,589,422</td>
<td>18,071,016</td>
<td>6,747,901</td>
<td>1,342,907</td>
<td>1,304,518</td>
<td>3,116,308</td>
<td>75,167,672</td>
</tr>
<tr>
<td>1917</td>
<td>45,033,000</td>
<td>17,709,000</td>
<td>6,707,000</td>
<td>1,965,000</td>
<td>1,202,000</td>
<td>3,285,000</td>
<td>75,324,000</td>
</tr>
</tbody>
</table>

\textsuperscript{a} From annual volumes of Mineral Resources of the United States, U. S. Geol. Survey.\textsuperscript{b} From estimate in “The Iron Trade Review” of Jan. 24, 1918.

**Beneficiation of Lake Superior Iron Ores.**

Since iron mining began in the Lake Superior district efforts have been made to improve the quality of the ore shipped to the furnaces. Selective mining, hand picking, screening, crushing, washing, jigging, magnetic separation, and other methods have been practiced more or less. Heating and drying the ore to drive off moisture and sulphur have also been tried. The chief impurity in most of the low-grade ore is silica; other impurities are phosphorus, sulphur, titanium, alumina, and water, the last either combined or in a free state. Success in attempts at beneficiation depend directly on the cost of treatment, the degree of concentration effected, and the purity of the product.

There is a large field for experimental research in the iron-ore problems of the Lake Superior district. Mine operators are showing an increasing interest in the concentration of the leaner ores, for the ore of higher grade is being rapidly depleted by the enormous tonnage mined annually, and the grade of ore produced is gradually decreasing. The table below shows that poorer and poorer ores are being mined and treated, in contrast to the “60 per cent” ore of earlier days.

*Average iron analysis of Lake Superior ores.*

<table>
<thead>
<tr>
<th>Year</th>
<th>Iron content (natural)</th>
<th>Per cent.</th>
<th>Year</th>
<th>Iron content (natural)</th>
<th>Per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1902</td>
<td>55.3917</td>
<td>1909</td>
<td>51.8691</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1903</td>
<td>54.8018</td>
<td>1910</td>
<td>51.8596</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1904</td>
<td>55.0155</td>
<td>1911</td>
<td>51.5148</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1905</td>
<td>54.1069</td>
<td>1912</td>
<td>51.6734</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1906</td>
<td>53.3901</td>
<td>1913</td>
<td>51.3578</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1907</td>
<td>53.0113</td>
<td>1914</td>
<td>51.2908</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1908</td>
<td>52.9987</td>
<td>1915</td>
<td>51.4740</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Many operators are experimenting in regard to the treatment of their ores, frequently repeating the same mistakes and arriving at results the same as those obtained by other operators. To be effective, the data from this work should be assembled and coordinated, sup-
plemented by special investigations, and then published so that it will be available to all. As the Minneapolis station works in cooperation with the mine operators, and with the State School of Mines, which maintains a mining experiment station for the study of Minnesota ores, it is expected that this station will offer unusual facilities for research and be able to assist the industry by coordinating and disseminating data bearing on the efficient utilization of iron ores.

**WORK OF THE STATION.**

The Minneapolis station is housed in temporary quarters in the old laboratory of the Minnesota School of Mines, and in an adjacent office (Pl. XXVIII) built for the use of the station. The experiment station of the School of Mines is elaborately equipped for experiments in ore dressing and metallurgy, and the Federal station will have the advantage of using the laboratories and equipment. An apparatus for magnetic concentration tests is shown in Plate XXIX.

As the steel industry during the war needed large amounts of manganese, and as imports of foreign manganese ore were curtailed by the necessity of transporting troops and supplies to Europe, the obtaining of enough domestic ore to meet the needs of our blast furnaces became an imperative necessity. Therefore, it was decided that as long as should be necessary the station should devote its energies to manganese, and the first work of the station was a survey of the manganese situation.

During the first year the work of the station was in charge of Edmond Newton, superintendent, who was succeeded by C. E. Julihn, the present superintendent.

During the summer of 1918, in cooperation with the State School of Mines, a comprehensive examination was made of the manganiferous mines of the Cuyuna Range, and manganiferous deposits on the other ranges, including the Mesabi, were examined.

Extensive research work was conducted on the use of manganese alloys in open-hearth steel practice, and the extent to which low-grade manganiferous domestic ores could be utilized. A study was made of the production of ferromanganese in blast furnaces, every furnace in blast on manganese alloys being visited. A similar investigation was made of the production of spiegeleisen in blast furnaces.

At the station a large amount of experimental work was conducted on the concentration and beneficiation of low-grade ores of manganese. These tests were conducted in the ore-dressing laboratories of the State mining experiment station.

Two processes for the direct reduction of manganese from its ores, known as the Jones process and the Bourcoud process, were investigated.

Reports prepared on all of the manganese investigations mentioned will be assembled and published as a bulletin of the bureau.
THE STATION AT BARTLESVILLE.

The petroleum experiment station, established in 1917, was placed at Bartlesville, Okla., because of that city being in the Mid-Continent field of Kansas and Oklahoma, which is the center of the petroleum industry in the United States and produces more than one-third of the country's output.

Authorities estimate that there are in the United States 300 refineries, valued at approximately $430,000,000. The total value of the output of crude petroleum and natural gas in 1916 amounted to $450,000,000; the copper output had a value of $474,000,000, and gold not more than $193,000,000, but these prices are for mine metal.

The Mid-Continent field, being connected by pipe line with the Atlantic and Gulf coasts, supplies oil to some of the largest refineries in the world, which are on the Atlantic seaboard. Moreover, many large refineries in the Mid-West, which supply the consumers of the Mississippi and Missouri valleys, depend entirely on Oklahoma and Kansas for supplies of crude oil.

BUILDINGS AND EQUIPMENT.

The Chamber of Commerce of Bartlesville donated $50,000 for the station and four acres of land as a site were given by Mr. G. B. Keeler. This sum was used to construct buildings and purchase equipment. The contract for two buildings, one for offices and one for a laboratory, was let June 3, 1917. Pending the construction and equipping of these buildings, work was conducted from temporary quarters supplied by the chamber of commerce.

PETROLEUM PROBLEMS.

The tremendous development of the oil industry in Oklahoma, Texas, and adjoining States makes this station a natural center for investigation, experiment, and report, as well as for helpful practical suggestions to operators. Situated in the oil fields, its position insures close cooperation with the producer and investor.

Petroleum engineers of the bureau, working from this station as a center, will conduct field investigations aimed to prevent waste in the production of oil and natural gas. Studies will be made in the improvement of methods of drilling and casing wells, the causes of water troubles and their abatement, prevention of waste at refinery plants, and the saving of valuable by-products, such as gasoline present in natural gas or in "casing head" gas.

The station endeavors to cooperate in every way with producers and refiners and aid them in solving their problems. Conferences and correspondence with various oil company officials about definite
problems have awakened much interest among operators and have shown that they stand ready to aid the station to the fullest extent. For example, a request for the aid of certain officials in a campaign to shut off water from oil wells and prevent damage by infiltration has evoked a hearty response.

In the laboratory of the station research work on practical problems in the recovery of gasoline, the refining of petroleum, and similar work will be conducted. The investigations will not be confined to any one branch of the industry, nor to any one part of the country, but will extend to all districts having interests that are similar. The problems studied will be followed from the preliminary stages in the laboratory to final adjustment to practical conditions in the field.

Among the development and production problems suggested are the dehydration of emulsified oil and the prevention of its formation in oil wells. Experience has shown that probably all emulsions in wells are formed after the oil has left the sand, and their formation can often be prevented. Studies of methods for excluding water from oil and gas wells, of the effect of water on the production of oil wells, and of casing and tubing problems, would be of value. Work on the use of safety devices in the oil fields, the possible substitution of explosives safer than nitroglycerin for shooting oil wells, and the effects of shooting on oil wells, would be of interest. Investigations for determining the capacities and characteristics of oil and gas sands, the proportions of oil not being recovered by present methods of production, and the laws governing the expulsion of oil from the oil sands will be started at the station. There is little information on this subject, and it will not be possible to interpret data and to judge the value of various methods of producing until the underlying scientific laws are better understood. Methods for stimulating production and increasing the recoveries of oil from the sands, including the effects of vacuum pumping, use of compressed air or gas, and use of water flooding, present a fertile field for research. In this connection, pumping problems and equipment, including the use of automatic air and gas pumps, electrical equipment, and air lifts would receive attention.

Storage and transportation problems include losses of oil in storage, prevention of fires at tanks and wells, the flow of oils in pipe lines, and the construction of storage tanks and reservoirs.

At refineries the problems are many and varied. The efficiencies of condensers and heat exchangers, reduction of wastes and losses of the lighter fractions, methods for effecting a cleaner separation of gasoline from the heavier cuts, recovery of acid, especially in small refineries, and utilization of sludge and acid tar are some phases demanding attention. Collection and dissemination of data on
properties of petroleum for refinery engineering, such as latent and specific heats of oils and various fractions and other properties that will influence designs of stills, heat interchangers, condensers, would be of value to refinery engineers.

Investigations on the construction and operation of compression, refrigeration, and absorption plants for recovering gasoline from natural gas, with regard to the recoveries being made, and improvements in the plants or methods employed are being conducted by bureau engineers. It is believed that many of the existing plants are not recovering all the gasoline, and that gasoline plants could be profitably installed for the treatment of much gas now going to waste at oil wells or being turned into pipe lines untreated.
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