A study of the types of clay materials in petroleum-reservoir rocks was continued. X-ray diffraction procedures have been used in studying a number of known reference clay mineral standards, and these have been applied to the identification of clays separated from petroleum-reservoir rocks. A paper is being prepared that describes an improved color test developed for identifying clay-mineral families when x-ray diffraction, thermal analysis, and other more precise but expensive methods are not available.

For the study of interfacial energy relationships at fluid-fluid interfaces, a pendant drop apparatus is being assembled that will permit precise measurements of the interfacial tensions of systems containing surface-active constituents. A convenient cell stage 8/ was developed for measuring liquid-liquid-gas contact angles.

Surface-active and film-forming substances have been isolated from crude oils produced in the Oklahoma City, Okla., and the Rio Bravo, Calif., fields. A report 9/ on the extract from Oklahoma City field crude oil shows that it is composed mostly of normal paraffins of unusually high molecular weight. Further work on identification of the extracts from both the Oklahoma City and Rio Bravo oils indicates that they contain surface-active constituents of unusual structure.

Engineering Research on Secondary-Recovery Problems

Petroleum Field Office, Franklin, Pa. (Bradford, Pa.)

Shooting Oil and Gas Wells with Explosives

Early in 1947 the Bureau of Mines began a study of oil- and gas-well shooting. This research is a cooperative project with the Applied Physics Branch, Eastern Experiment Station, College Park, Md. The preliminary experiments mentioned in the report of last year resulted in two papers. 10/, 11/ The results of the four series of tests in the preliminary experiments demonstrated that the type of instrumentation chosen met the experimental conditions and provided quantitative data from which the generation and propagation characteristics of the explosive wave could be calculated. As a result of the preliminary work, experimental procedures were developed for correlating types of explosives and methods of loading, stemming, and firing the charge with the strains produced in the rock by the explosion and the results of fluid-injection tests made before and after shooting the test holes.

Additional tests were planned to augment the data obtained in the initial work. From these it is expected to obtain data on (1) a rating of types of explosives in

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8/ Fox, William A., A Convenient Cell-Stage for Fluid Profile Measurements: Rev. Sci. Instr., vol. 21, No. 5, May 1950, pp. 499-500.

9/ Denekas, M. O., Carlson, F. T., Moore, J. W., and Dodd, C. G.; Isolation and Analysis of Materials Adsorbed at Crude Petroleum-Water Interfaces, I. Normal Paraffins of High Molecular Weight: Presented before Division of Petroleum Chemistry, 117th Meeting, American Chemical Society, Houston, Tex., Mar. 27-30, 1950.

10/ Grant, Bruce F., Duvall, Wilbur I., Obert, Leonard, Rough, R. L., and Atchison, T. C., Research on Shooting Oil and Gas Wells: Am. Petrol. Inst., Prepr. 826-21-C, pres. at spring meeting, Eastern Dis., Div. of Production, Cleveland, Ohio, Apr. 27, 1950.

11/ Grant, Bruce F., Duvall, Wilbur I., Obert, Leonard, Rough, R. L., and Atchison, T. C., Use of Explosives in Oil and Gas Wells, 1949 Tests: Bureau of Mines Rept. of Investigations 4714, 1950, 29 pp.

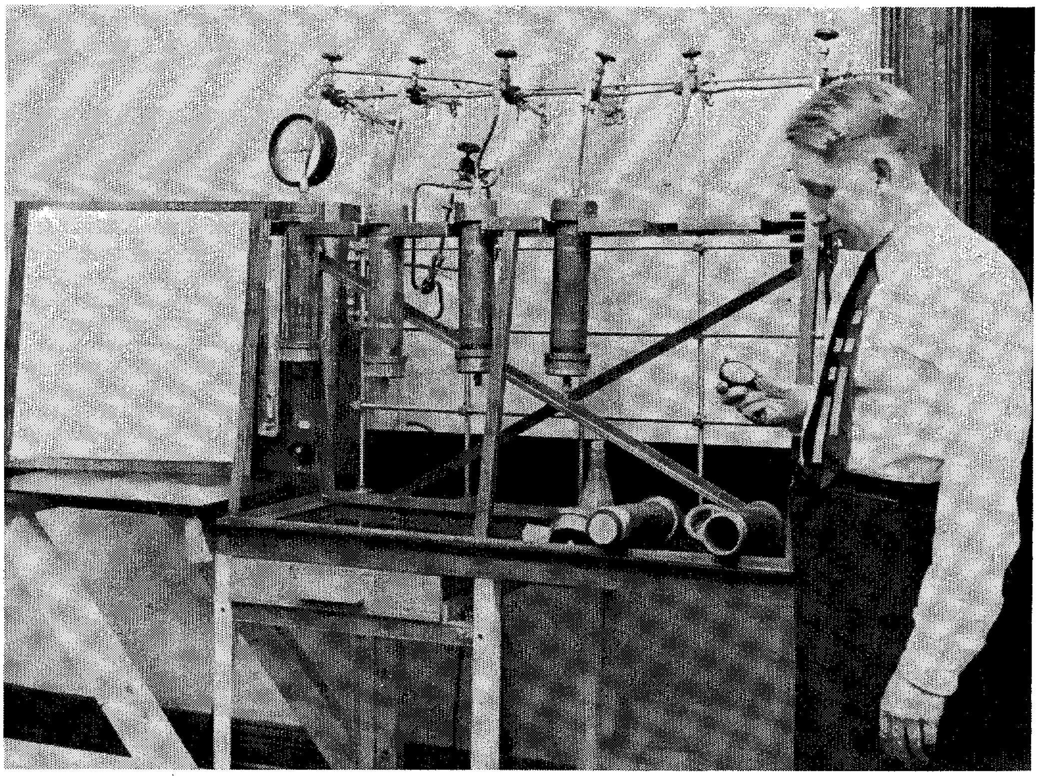

Figure 3. - Apparatus used to study means of selectively plugging more permeable zones of oil-bearing sandstones exposed in gas-injection wells.

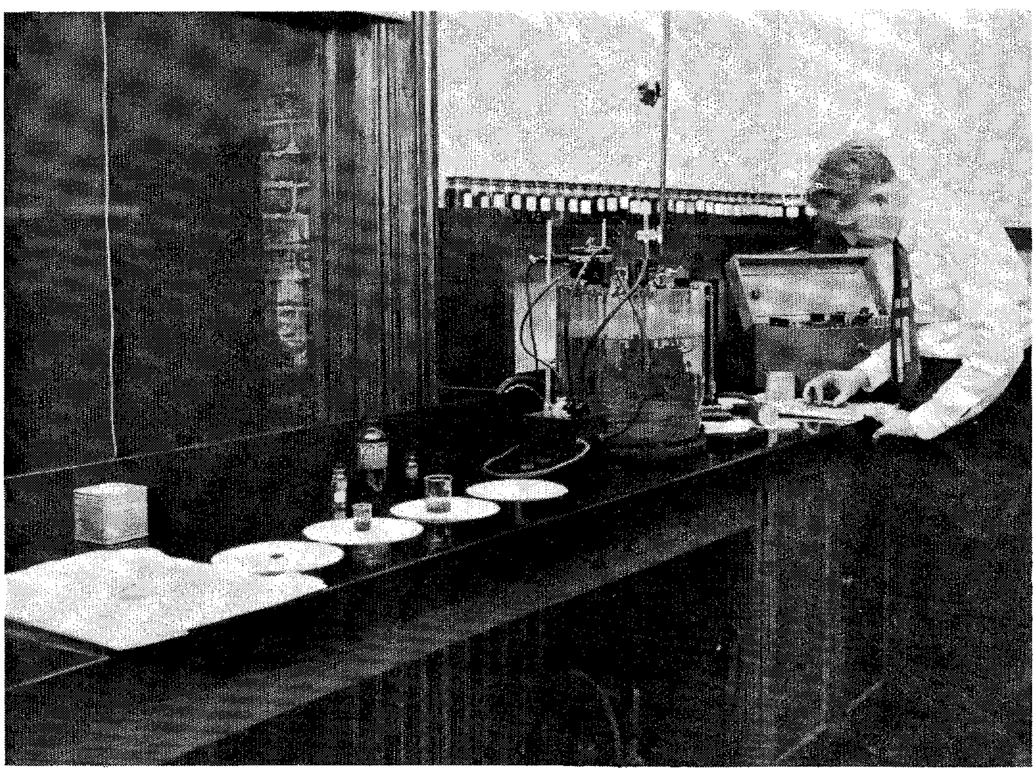

Figure 4. - Impregnating sandstone with plastic containing dye, and preparing thin sections after plastic hardens.

terms of strain waves produced and their generation and propagation characteristics, (2) effect of stemming on performance of different explosives as measured by strain produced, (3) relationships governing the generation and propagation of strain waves from cylindrical charges (also some additional data on spherical charges), (4) time and rate of breakage from an explosion in rock, and (5) correlation of strain data and increase in fluid conductivity of shot wells. For the tests 15 holes 130 to 160 feet deep and 148 holes 20 to 30 feet deep were drilled. Most of the 6,205 feet of hole core-drilled was 2.95 inches (NX size) in diameter. Other diameters ranged from 2.33 (BX size) to 8 inches. Everything was in readiness to begin experimental shooting on June 30, 1950, which was the end of the period covered by this report.

Activity in the second approach to the problem, a survey to determine the physical properties of oil-bearing rocks from representative fields throughout the Nation, resulted in the acquirement of 126 rotary cores (about 15 tons) of reservoir rocks from oil and gas fields in the Appalachian, Mid-Continent, and Rocky Mountain regions. The prompt furnishing of these cores for physical-property testing by a large number of oil and gas companies throughout the Nation is testimony of their desire to cooperate in this important part of the program. Most of the cores were provided within 6 months after the needs were made known to industry.

Physical-property testing of selected specimens from this valuable library of cores accumulated to date was completed, utilizing tests developed by the Applied Physics Branch. These tests permit the determination, on diamond-core samples only, of the following rock properties: Compressive strength, flexural strength, impact toughness, abrasive and scleroscope hardness, modulus of elasticity, modulus of rigidity, specific dampening capacity, and longitudinal bar velocity. In addition, an impact test to determine the breaking strain under high-speed dynamic loading of disks cut from a core sample is being developed, with the expectation that this or a similar laboratory test performed on a core may provide criteria for shot design for the formation of well cores. Although a large number of cores have been furnished by industry, many more will be needed for testing before this phase of the study can be completed.

Selective Plugging of Air-Gas-Injection Wells

Selective plugging of essentially depleted sections of oil sands to prohibit or minimize channeling of injected fluids that otherwise do no useful work in moving oil is one of the most important problems confronting operators of secondary-recovery projects. There have been great accomplishments in developing products that will plug the sand, but placement of the plugging agents in the sand section where needed has not been generally successful. Two products have been used with comparative success in the Bradford (Pa.) field, but one of these products has not proved useful in the more permeable sands of the Mid-Continent, where water flooding is practiced also. In the Appalachian region the most urgent need for work on selective plugging is the development of techniques in applying suspensions of solids in air or liquids in gas-injection wells. Pennsylvania State College and other organizations have done much laboratory work on plugging small sandstone specimens with various smokes and liquids, but none of the products has been applied successfully in the field.

The use of solid particles in suspension in water, or chemically treated water, has been investigated in the laboratory, with the emphasis on considerations of how they could be applied successfully in selectively plugging gas-injection wells. Figure 3 shows the laboratory apparatus used to study means of selectively plugging the more permeable zones of oil-bearing sandstones exposed in gas-injection wells.

Also, field tests are in progress where procedures and information derived from the laboratory study are being applied. An operator of a gas-injection project near Pleasantville, Pa., where gas-oil ratios had increased to a point that the cost of air-gas compression was approaching the net income derived from the sale of the produced oil, set aside a group of wells for testing and the selective plugging of the injection wells. The experiment is being made by Bureau of Mines engineers in cooperation with the oil company and the manufacturer of the plugging agent.

Three injection wells and 14 oil-producing wells were included in the original test area. All 17 wells are equipped with recording orifice meters for measuring the gas injected and produced. The company has provided individual oil tanks for measuring liquid production from each oil well. Injectivity tests on the three injection wells were made before and after selective plugging of the thief strata (which had formerly conducted the bypassing gas) with a solid-water suspension. The changing flow characteristics of the formation have been measured by injectivity tests from time to time after the plugging agent was introduced. Interesting but inconclusive data were obtained. The data indicated that three injection wells adjacent to the original pattern disproportionately influenced the producing wells under observation.

Additional plugging experiments have been conducted, utilizing a different technique than the original, and the wells are still under observation. Three injection wells and one oil-production well have been added to the testing area. Each well is equipped with orifice meters and the oil well with an individual separator tank.

Studies of Earth Temperatures and Reservoir Oil Samples

At the Bureau of Mines Bradford, Pa., Suboffice, which was established in April, 1949, equipment was assembled to record subsurface temperatures and pressures in wells and procure crude oil samples at reservoir conditions. In the laboratory these samples were analyzed to measure solution gas, bubble point, paraffin-precipitation point, wax content, and companion data at the same temperatures measured in the wells. Temperature surveys were made on 42 wells dispersed throughout the Bradford oil field, measurements being taken at 100-foot intervals from wellhead to total depth in each well. Where temperature anomalies occurred, and through the oil-sand section in each well, measurements were made at shorter intervals. In the laboratories, seven bottom-hole crude-oil samples were analyzed. The results of this study are being assembled in a report entitled, "Earth Temperatures and Paraffin-Precipitation Studies in the Bradford Oil Field."

Pore-Pattern Studies

Laboratory experiments utilizing air-drive expulsion of oil and water from "fresh" and laboratory-saturated rotary cores were completed. Rotary cores and crude oils representative of many reservoirs were employed in these experiments. Each of the 34 flow tests was terminated when the produced air:oil ratio reached values comparable to limiting economic operations in practice. The flow tests were made in flood pots operated to simulate air-drive secondary-recovery operations in the field. One objective is to learn if there is a relationship between the volume of oil retained in the sand core following the flood-pot test and the shape, size, and distribution of the sand pores, taking into consideration the velocity and temperature of the fluids used and the rock characteristics.

Microscopy studies of pore patterns were conducted to fit this important characteristic of sandstones into an oil-recovery relationship. A method was developed whereby pieces of sandstone impregnated with a dye-colored plastic and thin sections, 0.001 inch thick, or polished surfaces are prepared for microscopic examination and color photography.

Owing to the wide interest evidenced in this method of preparing specimens for thin sectioning for microscopy, a report[12] was prepared describing the technique developed. Impregnating sandstone with plastic containing dye and preparing thin sections after the plastic hardens are illustrated in figure 4.

Color photomicrographs were completed of 152 thin sections representing the nine radial-sandstone specimens used in the laboratory oil-recovery (oil-retained) tests.

The critical dimensions of the pores exposed in one plane, as depicted in the photomicrographs, are being measured and their significance in relation to the flow experiments sought. The period covered by this report ended with the statistical approach to the problem being initiated.

Flowing of Oil Wells on Gas-Injection Projects

Fundamental characteristics of producing oil through small-diameter, siphon-type flow strings continued to receive attention in relation to the oil production from marginal wells on air-gas injection projects. The initial objective was to determine if the very small quantities of oil accompanying the injected gas to the producing-well bores could be flowed intermittently rather than pumped intermittently. This would allow the energy remaining in the injected gas, after passage through the sand from injection wells to producing wells, to be used to lift the oil by siphon flowing to the surface and into tankage. Following some experimentation in the field, the technique proved feasible in wells 300 to 1,100 feet in depth. Flowing of this type has not been tried in deeper wells. After several years of development through laboratory and applied field research, the flowing of marginal wells in the Oil City, Pa., vicinity is considered an improved oil-production technique and is practiced several places where reservoir conditions allow.

Because flowing permits operating economies not possible with pumping wells, the availability of this technique is of economic importance to operators of gas-injection projects in the Middle district of Pennsylvania and possibly in other oil fields of the Nation.

To make the flowing of small marginal wells on gas-injection projects successful and profitable, operators have found it necessary to improve many operating practices. In some reservoirs, higher gas-injection pressures and higher gas-injection rates under precise control are required to make the wells flow properly.

The factors affecting the design of flow-string siphons of small diameter have been investigated in the laboratory and the results promptly applied in the field.

12/ Lockwood, William N., Impregnating Sandstone Specimens with Thermo-Setting Plastics for Study of Oil-Bearing Formations: Bull. Am. Assoc. Petrol. Geol., vol. 34, 1950, pp. 2061-2067.

On July 1, 1950, there were about 200 flowing oil wells equipped with flow strings designed by Bureau of Mines engineers on 19 leases operated by 5 companies. Of the 200 flowing wells, 150 are being operated on adjacent leases in the Oil City pool, 81 of these wells being operated on 1 lease.

Cable-Tool Coring with Improved Drilling Fluids

Most of the cores procured in the Appalachian region are drilled with cable tools using fresh water as a drilling fluid. Ordinarily laboratory analyses of these cores show lower oil content and higher water content than is considered representative of reservoir conditions, as is often proved later by oil-production operations.

Owing to the vital importance of knowing the true oil and water contents of reservoirs in secondary-recovery developments, Bureau of Mines engineers have conducted field and laboratory investigations in efforts to apply oil-base mud (containing an oil-soluble tracer) to cable-tool coring in the hope that the resulting core-analysis data would more nearly depict reservoir conditions. A specially compounded oil-base mud was procured for the tests in cooperation with oil companies. The eighth well was cored in West Virginia during the period covered by this report. Of the eight wells cored since this investigation was begun, one is in New York, four are in Pennsylvania, and three are in West Virginia. An organic chloride tracer (Aroclor 1254-liquid), more soluble in the oil phase of the oil-base mud than the one used previously (Aroclor 1270-solid), was employed in the last two wells cored.

Petroleum Experiment Station, Bartlesville, Okla.

Locating Abandoned Wells

Army mine detectors and M-scope pipe finders have been used effectively to find the general areas of old abandoned wells. Almost invariably, considerable scrap iron is left around the location of abandoned wells, and this junk may be found with the mine detector. The M-scope pipe finder may be used to follow old pipe lines that were left in place. More recent work by Bureau of Mines engineers has shown that a dip needle is extremely effective in determining the exact location of wells in which some pipe remains, once the general area has been found with the M-scope pipe finder or the mine detector. Pipe that has remained in wells for many years becomes highly magnetized and readily attracts the dip-needle. Attention now is being directed to methods of finding abandoned wells from which all pipe has been removed. Preliminary experiments indicate that old boreholes will reflect a sound wave created by striking the ground and that these reflected sound waves may be picked up with a simple geophone. By moving the position of the geophone and observing the change in the intensity of the reflected sound wave, it may be possible to locate the old wells.

Study of Water-Conditioning Plants

The study of plants conditioning water for subsurface injection to determine the efficiency of different methods of treating various waters to prevent corrosion of metallic equipment and the plugging of the sand by precipitated and suspended solids has been extended to include corrosion tests and chemical analyses at 23 plants in Oklahoma and Kansas. Repeat tests were made on two plants that had changed from closed- to open-type treating systems. Data now are being tabulated and evaluated as a preliminary preparation of the final report on the study. These data show that water treatment in some plants is adequate, although in others the conditioned

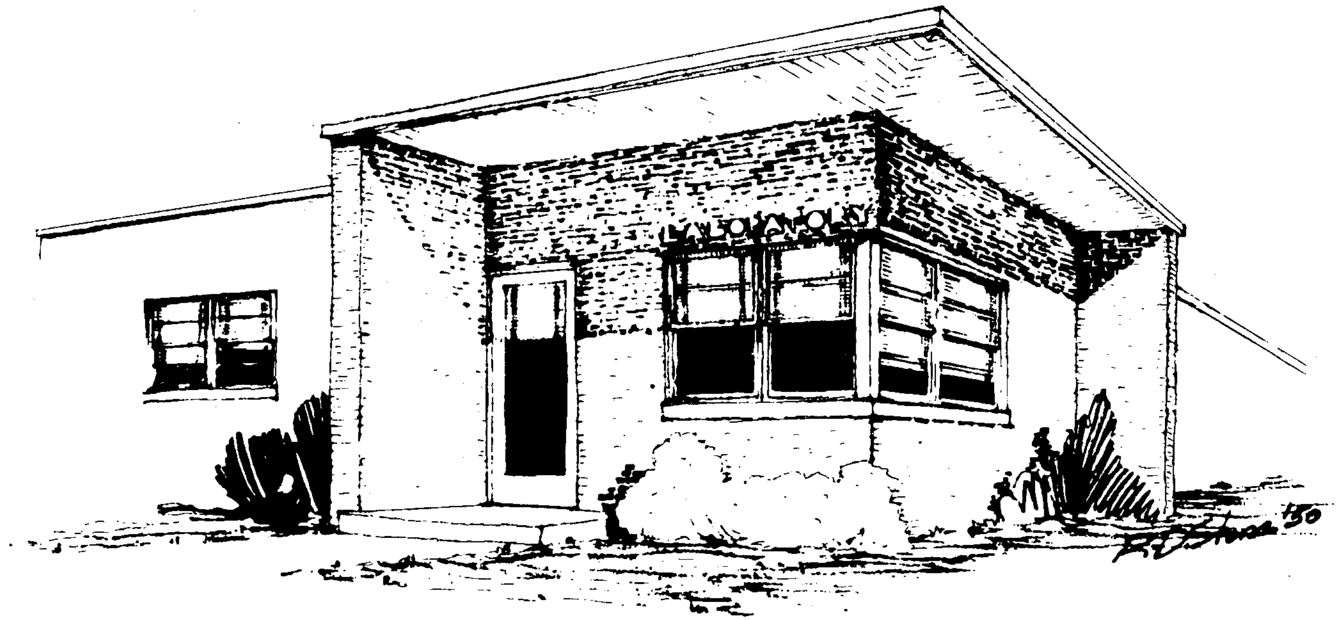

Figure 5. - Architect's sketch of entrance to radiochemical laboratory under construction.

waters are more conducive to corrosion and plugging than the raw waters, indicating need for more careful analysis of waters before treating plants are designed and constructed and for more careful control of treatment by plant operators. A preliminary report[13] on this work was presented at a meeting of the American Chemical Society. Many special chemical tests for the analysis of oil-field brines were developed during this study, and these were made available to the industry in a series of journal articles[14] recently published.

Effects of Dissolved Gases on Corrosion of Metal by Water

Laboratory apparatus was constructed and assembled, and tests were started to determine the corrosivity to metals of the dissolved gases, oxygen, free carbon dioxide, and hydrogen sulfide in water, where all other controllable factors influencing corrosion are maintained constant. Tests have been made using dissolved oxygen in the range of 9 to 0 parts per million in distilled water as the corroding medium, and a significant oxygen-corrosion curve has been obtained. Other tests will be made with varying concentrations of free carbon dioxide and of hydrogen sulfide, and with different ratios of oxygen to free carbon dioxide and of free carbon dioxide to hydrogen sulfide. The procedures followed are similar to those used in field-corrosion tests. The laboratory apparatus is adaptable to and will be used for studies of experimental methods of water conditioning; also, for a study of the effect on corrosion of electric currents caused by bimetallic construction and by changes in fluid velocities.

Tracers in Waters used for Subsurface Injection

Equipment and facilities are being prepared for work on the development of a suitable radioactive tracer for water injected into oil sands during water-flooding operations. Radiation-detection and monitoring instruments have been obtained and a radio-chemical laboratory is under construction. (See fig. 5.) Initial laboratory work is being started on oil-field cores using stable ions as tracers. This work will serve as a guide in the selection of radioisotopes to be used.

Petroleum Field Office, San Francisco, Calif.

Effect of Heat on Oil Recovery

As a part of a study of the gravitational drainage of oil from unconsolidated sands, the effect of heat on the caking of oil sands was explored in a series of experiments in which sands of different texture containing oil of different A.P.I. gravities were used. In these experiments, the temperature at the outlet face of the sand-packed tube, saturated with oil and water, was raised by an electric heating element that was thermostatically controlled.

The results of these experiments indicate that not only does the efficiency of gravity drainage at room temperature depend upon the water content of unconsolidated sands but that, to get enough heat back into sands to reduce materially the viscosity of the low-A.P.I.-gravity residual oils, temperatures at the outlet sand faces must

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13/ Watkins, J. Wade, Arthur, C. E., and Willett, F. R., Jr., Field and Laboratory Studies of Methods of Conditioning Waters for Subsurface Injection: Pres. 117th Meeting, Am. Chem. Soc., Houston, Tex., Mar. 27-30, 1950.

14/ Watkins, J. Wade, Corrosion and Chemical Testing of Waters for Subsurface Injection: Producers Monthly, part I, vol. 14, No. 4, February 1950, pp. 15-19; part II, vol. 14, No. 5, March 1950, pp. 30-31; part III, vol. 14, No. 6, April 1950, pp. 25-31.