Petrology at the California Institute

By IAN CAMPBELL

TO the layman, "petrology" is a word with an obviously petroliferous connotation; but to many a geologist any connection between this word and an oil pool is little more than coincidental. Have the Greeks, then, led us astray? Not so. The Greek word **petra,** meaning "stone" or "rock," appears as a root in many well-known English words. Thus we have **petrify,** meaning to "turn into stone," and **petroleum,** meaning "the oil that comes from rock." Similarly **petrology** means "the science of rocks." Unfortunately, relatively few rocks contain oil; hence the observation above that most petrologists are not necessarily oil experts.

Having defined the term, we might logically inquire (since all who read this journal will know what **science** is), what is a rock? No doubt anyone who, essaying his first steps, has stubbed his toe on a rock, feels that thenceforth he knows what a rock is! Yet the late Dr. Frederick Leslie Ransome, until his death in 1935 Professor of Economic Geology at the California Institute, published a learned article on the subject, "What is Rock?", his conclusion being that neither lexicographers, geologists, nor lawyers are in any agreement on the answer to this seemingly simple question. Indeed, extensive court battles have been waged on this very question, and without reaching even a legal settlement on the matter. Is sand a rock? Is salt a rock? Is ice a rock? Some persons quite logically would answer yes to each of these questions; others would disagree. Rock, then, is perhaps best left undefined; but by this very token rocks offer a fertile field for investigation and research.

THE NATURE OF PETROLOGY

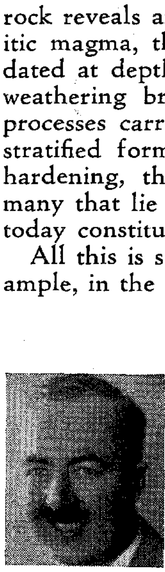
The geologist recognizes, (1) that rocks are made up of one or more minerals—hence training in mineralogy is a necessary first step in petrology; and (2) that rocks constitute the major units that make up our earth. The differences that we find in the earth's "crust," whether these be differences in surface expression or differences in internal behavior, result largely from differences in rock types. Therefore training in petrology is basic to any real understanding of geology.

To a budding petrologist, faced with the statement that rocks are made up of different combinations of minerals, and knowing that in the earth there are some 1200 well-recognized species of minerals, the possible diversity of rocks may assume alarming proportions. Fortunately for the science, however, the quantitatively important rock-forming minerals are relatively few in number, and complexity is further reduced, on the one hand, by certain interesting associations, and, on the other, by incompatabilities between important minerals. Thus the white mica, muscovite, almost invariably heralds the presence of quartz in a rock; whereas the mineral olivine (known as peridot in its gem occurrences) is an almost equally certain indicator of the absence of quartz in the rock in which the olivine occurs. Reasons for these compatabilities and incompatabilities between minerals, so important to the petrologist, lie in the domain of physical chemistry, a related science which has contributed much to petrology.

A petrologist commonly is concerned with much more than identification of the mineral components of a rock. He is equally concerned with **texture** of the rock, that is, the pattern formed by the mineral components, which depends on the size and shape and arrangement of the mineral grains. See Fig. 1. To the geologist a rock is a record of earth history, and the specific characters of a rock result, somewhat indeed as in the organic world, from the controls exercised by heredity and environment. Thus minerals indicate the (chemical) parentage of a rock; texture reflects the environmental conditions under which it has formed. To interpret from the "petrified record," **i.e.,** the rock, the details of ancestry and environment that will be of importance to the geologist, is the job of the petrologist.

By way of illustrating the effect of environment, or of interpreting the features of texture with specific respect to the formation of rocks, we might take three specimens, each of which on testing yields exactly the same chemical analysis, and each of which on mineralogical examination proves to be formed of quartz, feldspar, and small amounts of mica. To the chemist and to the mineralogist these rocks might thus appear to be identical; but not to a petrologist. The petrologist will recognize the identical ancestry (heredity) of the three rocks, in that they all stemmed ultimately from acidic (silicic) magma; but attention to texture would reveal that one rock was a granite, that is, a rock probably solidified from magma at considerable depth within the crust; therefore under conditions of slow cooling which give rise to a distinctive, relatively coarse-grained pattern such as may be seen in the granite so well exposed in the Yosemite region. The second rock the petrologist might recognize as pumice, also a consolidation of magma, but in this case, a consolidation that took place after the liquid was ejected from a volcano, with the result of such rapid cooling that the rock is now extremely fine-grained and in part even glassy, like the flows found in the Mono Basin region. The third rock reveals an even longer history: Originally a granitic magma, the rock from which the magma consolidated at depth was subsequently exhumed by erosion; weathering broke it into fragments and sedimentary processes carried these to the sea, depositing them in stratified form as a sand; later still, with burial and hardening, the sand became a sandstone, similar to many that lie beneath the Los Angeles Basin, and that today constitute important reservoirs of oil.

All this is still but a small part of petrology. For example, in the last illustration the petrologist is not nec-



Ian Campbell, professor of petrology and associate chairman of the Geology Division, has been on the Institute staff since 1931. After taking A.B. and M.A. degrees at the University of Oregon in 1922 and 1924, he served as a teaching fellow at Northwestern and Harvard, and as assistant professor of geology at LSU, before returning to Harvard for his Ph.D., which he received in 1931.

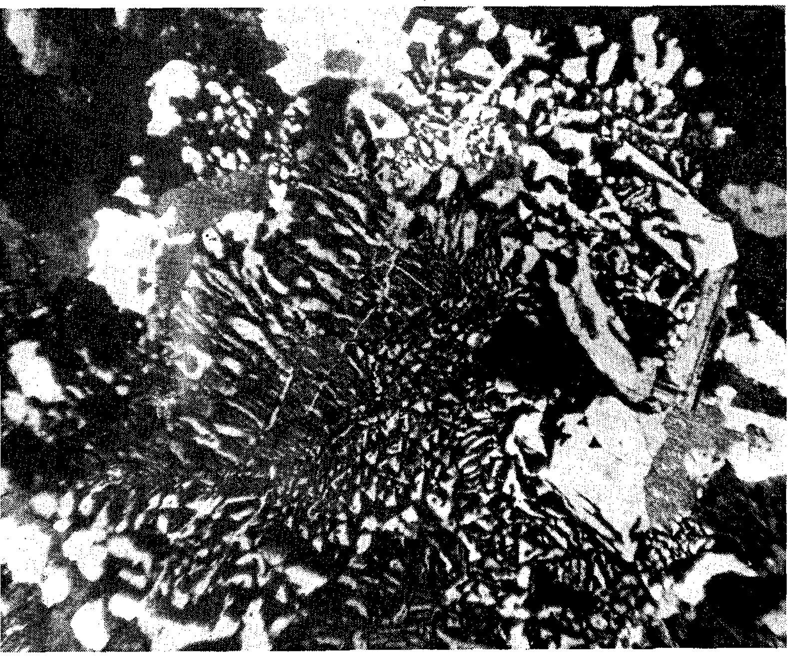
During World War II Campbell was on leave from CIT, and spent two years each in two varied research jobs, with the Geological Survey's strategic Minerals Program, and with UC's Division of War Research, primarily on anti-submarine warfare.

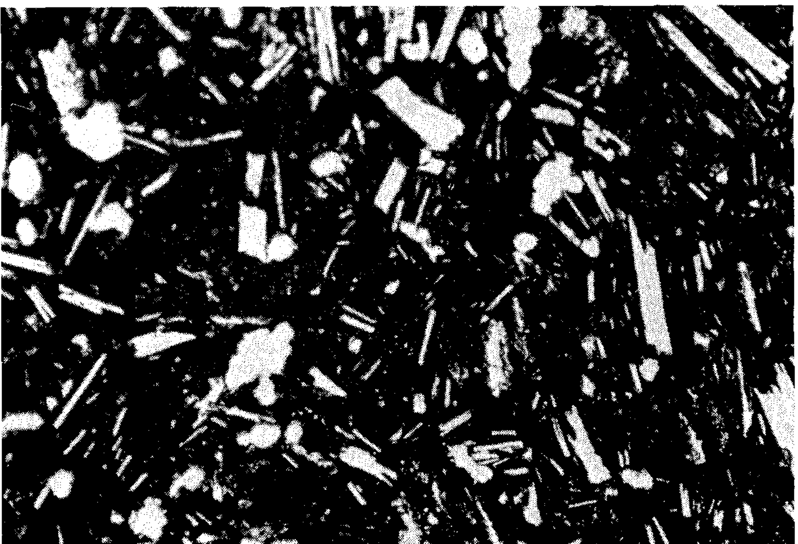
Dr. Campbell's professional activities include service as a committeeman in the AAAS, the Geological Society of America, and in several important AIME posts. He was recently appointed an official delegate of the AIME to the 18th International Geological Congress, which meets in London this summer.

essarily content to have learned that the rock is a sandstone, or that it is an oil reservoir. He will want to know how thick it is, and in which direction it swells, and in which direction it pinches out. He will want to know its porosity and its permeability, which are functions of its mineralogy and of its texture; he will want to know the direction in which the currents flowed that deposited this ancient sand, and many other things.

Examples could be multiplied, but suffice that the domain of petrology is almost as broad as the domain of geology itself. However much a petrologist may think to specialize in a certain type of rock, he soon finds that research has led him into seemingly far corners of the field. In the illustration given above, it was pointed out that a sandstone had been derived—as indeed it very commonly is—from granite. Evidence is accumulating that a reverse development may also occur; namely, that a granite may be derived from a sandstone. No concept could have been more shocking to the petrologist of a generation ago, but today it is a burning question: What is the origin of granite? Fifteen years ago Dr. George H. Anderson* began to find evidence in the White Mountains of California and Nevada that part of the granite there did not result from a consolidation of magma, but from extreme metamorphism of pre-existing sediments. Other investigators, here and elsewhere throughout the world, have examined and re-examined the problem of the origin of granite, but much research yet remains to be done before all the answers become known.

*Now vice-president of the Lone Star Steel Company, then a graduate student at the California Institute.





The importance of texture (environment) in rocks has been briefly emphasized, but time does not permit discussion of the many provocative problems that are related to the variations in magmas (heredity). Why, for example, are certain important elements, such as chromium and nickel, associated almost exclusively with rocks of ferromagnesian ancestry (the so-called basic magmas)? Why are tin and tungsten found only with siliceous (acidic) magmas? These are important questions, particularly to a country whose mineral resources have suffered wartime depletion, but only recently have we begun to grasp at the answers.

INVESTIGATIVE TOOLS

What methods does the petrologist use in an investigation; what research tools are available to him? First and foremost, of course, is the field occurrence itself. The petrologist may spend much time in the laboratory, but only to study specialized phases of his problem. Many of the most significant features of rocks are too big to be studied anywhere but in the field. In this respect students at the California Institute are more fortunate than the majority of their fellows the country over. The relatively arid climate and rugged topography of this general region have combined to yield rock exposures on a grand scale rarely available elsewhere.

But if some features of rocks are too large for observation anywhere except in the field, others are too small to study anywhere except in the laboratory. In the laboratory various procedures are possible: Physical measurements of crushing strength, of porosity, of permeability, etc., are often important. Chemical and/or X-ray analysis may throw more light on the nature of a rock. The training in engineering and chemical practice that all students in the Institute receive furnishes an excellent background for the man wanting to specialize in petrology. However, much the favorite tool of the petrologist is the microscope. Procedures to adapt microscopic technique to the study of rocks have been carried to a high degree of refinement at the California Institute. Most important is the process of sawing a rock chip and then lapping this down to a thickness of 0.03 mm (1/1000 in.). See Fig. 3. Reduced to this thickness, many seemingly opaque rocks become transparent and the minerals and textures involved can be studied in transmitted light under a microscope, known as a polarizing or petrographic microscope, especially developed for rock study. In such a microscope, besides the usual lens system for production of a magnified image, light-polarizing prisms and a rotatable stage permit an analysis of crystal patterns in the minerals, similar in some respects to the information that an

Fig. 1 UPPER: Photomicrograph (x35) of a curious texture (known as "micrographic") developed by quartz (light) and feldspar (dark) in a rock from the famous Darwin, California, mining district, an area studied some years ago by V. C. Kelley '32, Ph.D. '37, now professor of geology at the University of New Mexico. The pattern exhibits a striking resemblance to that which characterizes eutectics between metals, thus suggesting that similar physico-chemical laws have governed the development of this mineral association.

Fig. 2 LOWER: Photomicrograph (x50) of basalt from Paricutin volcano, Mexico. This represents some of the earliest lava erupted, as the specimen was obtained by W. E. Snow, geologist for the Pachuca mines and formerly graduate assistant in geology at the Institute, in March 1943, less than a month from the time the first smoke appeared in Dionisio Pulido's cornfield. The section shows feldspar (lath-like light gray crystals) and olivine (equant white crystals) in a matrix of basaltic glass (black). The irregular flow patterns which developed in the viscous lava as it congealed, are well shown in some areas of the section by local subparallelism of the feldspar laths.

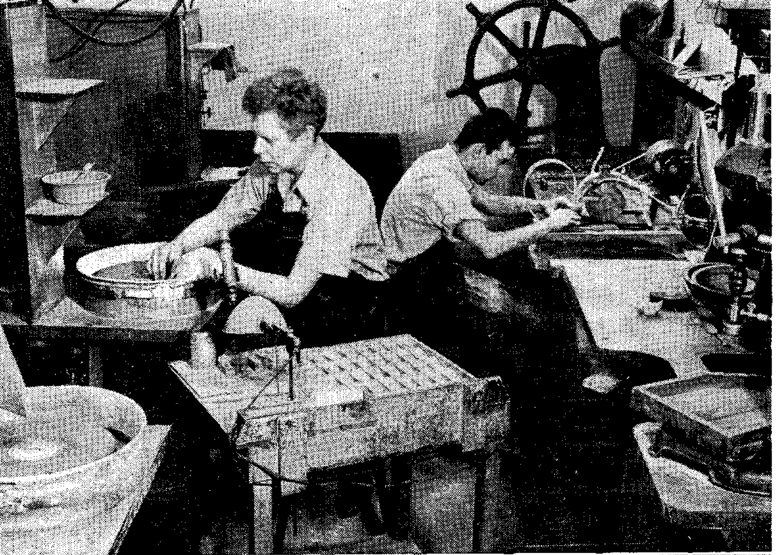


Fig. 3 UPPER: Part of the thin-sectioning laboratory in the Charles Arms Building. At the left Rudolf von Huene '34, research assistant, is cutting down a section on an intermediate-grind lap; at the right, R. J. Smith '45, graduate student, is slicing a specimen on the diamond saw. In the right foreground is a new device for taking small cores; in the right background is a large rock trimmer.

Fig. 4 LOWER: Part of the petrographic laboratory in the Arms building. In the foreground R. C. White, M.S. '47, graduate assistant, is using a Leitz six-spindle integrating stage for micrometric research. In the background, from left to right, are C. W. Allen '47, graduate student, E. C. Buffington, M.S. '47, graduate assistant, Lloyd Pray, M.S. '43, National Research Council pre-doctoral fellow, G. P. Rigsby '48, and Ian Campbell, professor of petrology.

X-ray would reveal. Moreover, in thin-section the arrangement of grains in the original rock is preserved undisturbed, thus permitting a simultaneous study of a rock's two most fundamental variables, composition and texture. The thin-section laboratory is in charge of Mr. Rudolf von Huene, division technician, who has pioneered many devices and procedures so that our thin-section laboratory is today probably unsurpassed by any in this country, and is equalled (if at all) by only a very few.

By means of suitable devices, such as the integrating stage, shown in Fig. 4, quantitative measurements of the mineral components in a rock section become possible, following a theorem developed by DeLesse in France and Rosiwal in Holland. This permits much more accurate analysis and comparison of rocks, an important matter since the amount of variation that may exist within a single rock body is something about which we still do not know as much as we should.

RESEARCH IN PETROLOGY

Research in petrology at the California Institute has ranged all the way from studies of granitic rocks in southern California, Nevada, Montana, and British Columbia, to studies of basalts in the Hollywood Hills and in the Oregon Cascades and of rhyolitic volcanoes in the Mono Basin; and from sedimentary formations in the San Joaquin Valley and in the Los Angeles Basin to complex metamorphic rocks at Iron Mountain, New Mexico (see Fig. 5), and in the Grand Canyon of Arizona (see Fig. 6). Each study throws a little more light on the question with which we began, what is a rock? Much more remains to be done before the question can be answered to the satisfaction of everyone.

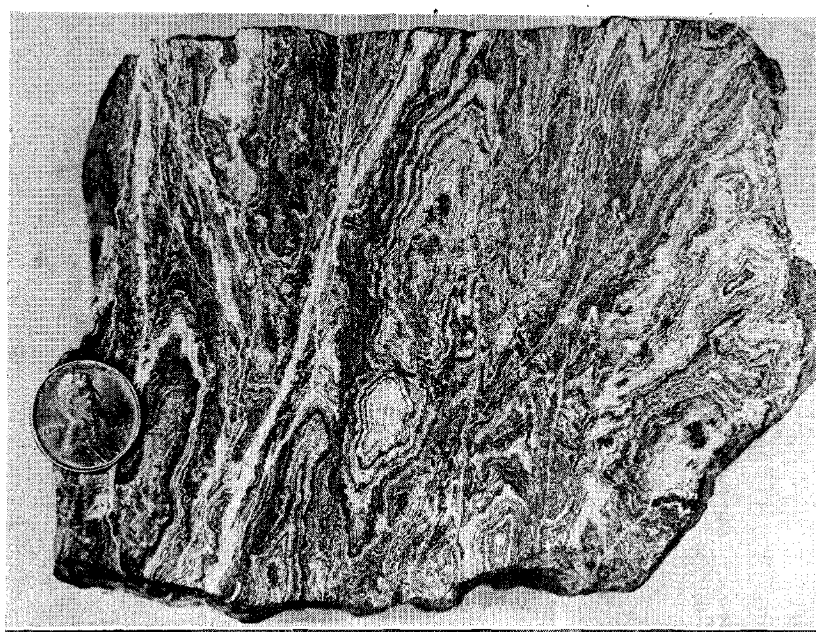


Fig 5 UPPER: "Ribbon rock," Iron Mountain, New Mexico. This is a most unusual variety of the peculiar metamorphic rock type known as tactite. The mineralogy is complex, and in this occurrence is notable for the presence of the rare species HELVITE, a potential low-grade source of beryllium. The district was investigated during the war for the U. S. Geological Survey by R. H. Jahns '35, Ph.D. '43, now associate professor of geology at the California Institute.

Fig. 6 LOWER: Characteristic metamorphic patterns of some of the Archean rocks of the Inner Gorge of the Grand Canyon. In this rock, an amphibolite (ancient lava flow), the "ptygmatic folding" seen near the center of the figure evidences the severe mechanical distortions to which the rock has been subjected; the "porphyroblasts" of feldspar (white spots) represent chemical changes induced long subsequent to the original crystallization of the rock.