ENGINEERING AND SCIENCE

MONTHLY

BY-LINES

CHESTER STOCK

Chester Stock, Chairman of the Geological Sciences Division, tied his fortunes in with the University of California from 1910, when he enrolled as a pre-medical student, to 1925, when he left to become professor of paleontology at the California Institute.

Dr. Stock, who succeeded Dr. J. P. Buwalda as chairman of the Division in June 1947, has been very active in the study of mammalian fossils from western North America, and perhaps is best known for his investigations of the great fossil assemblages from the asphalt deposits in southern California.

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RICHARD H. JAHNS

Shortly after his graduation from CalTech in 1935, Richard H. Jahns joined the staff of the U. S. Geological Survey. His work in subsequent years took him through most of the eastern, Rocky Mountain, and far western states, where he studied and mapped numerous non-metallic deposits. During the war he surveyed deposits of strategic minerals for the Geological Survey.

Since his return to the Institute in 1946, Dr. Jahns has made an extended study of certain pegmatites in southern California, participated in a general investigation of the Ojo Caliente district of northern New Mexico, and spends such time as is left after classes in completing several wartime reports for the Survey.

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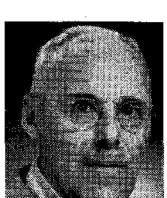
JOHN P. BUWALDA



John P. Buwalda, chairman of the Geology Division from 1926 to 1947, has been with Tech geology from its inception. Called from the University of California in January 1926 to organize the Division, he assembled staff and organized instruction in three main fields—geology, paleontology, and geophysics—to give a breadth of training not surpassed in any institution in America. Dr. Buwalda laid out plans for the two geology buildings, Mudd and Arms, both constructed in 1938, and supervised their equipment.

His recent research interests include the Tehachapi Mountains and faulting in southern California.

ENGINEERING AND SCIENCE *Monthly*

The Truth Shall Make You Free

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ENGINEERING AND SCIENCE MONTHLY

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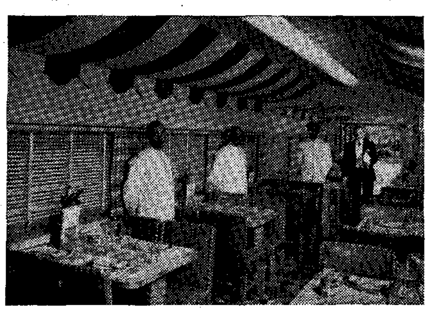
The Main Line

FEBRUARY, 1948

It is popularly supposed that the internal wheels of a railroad, like those of the gods, "grind exceeding slow, but they grind exceeding fine." There may be something to this. Long experience in dealing with the public has shown the folly of snap judgments.

However, unlike the gods' wheels, those of the railroad are capable of sudden bursts of speed. One such burst caught us short last month. Just as we were going to press we got word that the *New Golden State* was about to be born. We managed to squeeze in a few adjectives about it, but we certainly didn't do justice to this smooth-gliding new streamliner. So while it has been linking Los Angeles and Chicago in 45 hours ever since January 4, and *you* may even have ridden it by now, *this* month we're spreading ourselves with not one, but *two* pictures of new cars.



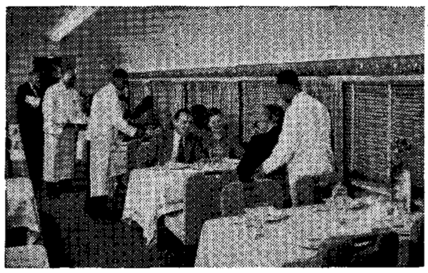
"Fiesta Car"

The gaiety of Mexico awaits you in this informal "Fiesta Car." Designed especially for *Golden State* chair car passengers (Pullman passengers are welcome, too), it serves as a lounge between meals. The bar was inspired by a fountain in a quaint Mexican patio. The tables and comfortably upholstered chairs are made of hand-carved oak. A brightly colored canopy adds to the patio effect.

Five complete trains are required to provide the daily service of the *New Golden State*. One train has the Fiesta Car and the other four trains have coffee shop-lounge cars, too. They don't have the Mexican decoration motif but they're fine cars.

"El Comedor"

Colors from the desert through which it passes were borrowed for the sumptuous dining cars on the *New Golden State*. Varied designs and furnishings distinguish each. In "El Comedor", pictured below, golden yellow seat coverings and linen contrast with tur-



quoise floor and ceiling. Note copper frieze and ancient devil masks. All dining cars on the *New Golden State* are streamlined.

If there is anything to the ancient Chinese proverb about one picture being worth 10,000 words, you now have the equivalent of a short novel on our new, extra fine, extra fast, extra fare streamliner. We invite you to ride it on your next trip east. All Pullmans and chair cars are streamlined and just about the last word in luxurious travel.

Mardi Gras plus

If it's heigh-ho for the Mardi Gras for you, and if you find eating on the train half the fun of traveling, the following letter to Harry Butler, head man in our Dining Car Division, will interest you:

My dear Mr. Butler:

I feel moved to tell you how thoroughly I enjoyed eating in your diner on my recent trip to New Orleans on the *Sunset Limited.*

Your innovation of the full salad bowl, so delightfully made and in such copious quantities, but even more than that, that inexpressively delicious Casserole of lamb is, to my way of thinking, a dish sent from Heaven.

If it was you, or someone in your organization who was responsible for such a treat, I feel that you should know how much it means to someone who travels to have them.

Sincerely yours,

Rudy Vallee

Many thanks, Rudy. We appreciate your appreciation. The *Maine Stein Song* is still our favorite piece.

—R. G. BEAUMONT

S•P The friendly Southern Pacific

Index to Advertisers

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COVER CAPTION

Rainbow Bridge, Utah, carved out of massive sandstone by stream erosion and weathering. A stream flowing in a deeply intrenched meandering course pierced the narrow neck of a meander, and this tunnel-like passage was subsequently enlarged by weathering to give the bridge its present height of 309 feet and span of 278 feet. Photo through the courtesy of Weldon Heald.

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With the Editor--

WE present in this issue a number of articles telling of the work of the Geology Division. We believe this month's **Engineering & Science** will be of unusual interest to our readers because it is the first publication to tell so comprehensively of the various aspects of the Geology Division.

It is the policy of the editors to devote one or more issues per year to telling the story of the Institute's divisions. Last May, with the cooperation of that Division, we presented the story of Institute Biology.

In that issue many readers, including alumni who were graduated before Biology attained its present importance, learned of many accomplishments of Institute men that increased their pride in their alma mater. For example, Tech men who had used plant growth substances such as indole acetic acid in rooting plants and 2-4-D for killing weeds, were astonished and pleased to learn that these substances were developed as the result of work initiated in this country by the Institute.

We believe that readers will find in this present issue stories of accomplishments of Institute men which will be news to them. Alumni may even be pleasantly startled to learn that scientific developments of which they have heard were actually accomplished on the Tech campus. But aside from any surprise which readers might experience, we believe that they will appreciate the opportunity of learning of the achievements of one of the most progressive departments of the Institute.

As we go to press we are in the midst of moving our office to a new location in temporary building T-2. For years our office has been in Throop Hall near the offices of the Placement Secretary and the Association Secretary. This location has had the advantage of giving us convenient access to Association files and to part-time aid of Association employees. But there has been a disadvantage. Our private office (where the M.E., Wes Bunnelle, holds forth) is also used for placement interviews by personnel representatives from various industrial organizations. During the war when nearly all of our undergrads already had jobs with Uncle Sam, there wasn't much interference from this source, but last year there were many days when our M.E. wasn't given a chance at his office. And this year placement interviews have already begun in force, earlier and more frequent than in other years. Judging from this, our use of the office next spring would be nearly nil.

So we are moving away from many of our records, from our Associate and News Editor, Miss Pearl Tolmsoff, who does much of the Association's secretarial work also, and from an office which has frequently been more tantalizing than useful. We move to an office where at least we'll have privacy and of which we'll have full-time use. We rather expect the M.E. to ask for a motor scooter now to get him to and from that part of our staff and records which remained behind.

This move brought to ye editor's attention the severe congestion of Institute space. There is as great a shortage of space in Institute buildings as there is a shortage of homes in Southern California. Many employees are crowded together beyond the point of maximum efficiency, and relief, while being planned, is not expected to be available for some time.

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GEOLOGY AT THE INSTITUTE

By CHESTER STOCK

IN recent discussions conducted by national groups of the geological profession as to the adequateness of today's training of students of geology, much has been said about the importance of a more-than-passing acquaintance with the fundamental sciences. Only of late have the geological faculties of universities come to realize in full measure the significance of a thorough knowledge of physics, chemistry, and mathematics on the undergraduate level as a background for the beginning student in geology. That training in these disciplines is absolutely essential to the student planning to enter the fields of geophysics or seismology has of course been recognized for a long time.

The realization that the beginning student in geology must have a sound preparation in the fundamentals results from the fact that many of the long established subdivisions of geological knowledge have been thoroughly investigated and the techniques customarily used in them are now pretty well standardized. New salients of geology are being discovered and their exploration requires new kinds of instruments as well as a greater and a more exacting dependence upon the basic concepts of physics and chemistry as they apply to the earth.

The value of this background in undergraduate training was long ago appreciated at the California Institute. As a result, provision is made in the geological curriculum to insure thorough indoctrination of the student with physics, chemistry, and mathematics before he becomes too deeply engrossed in geology.

However, of even greater importance are the plans of the Division to enlarge its facilities for graduate students, especially for those who contemplate a completion of their advanced studies toward the doctorate and a future career in research and teaching rather than in applied geology. To accomplish these ends we should enhance the categories of research that call for high competence in physics, chemistry, and mathematics, as well as in geology. That exemplary research of this kind is now being done in geophysics and seismology, there can be no question. That highly important advances can be made in geochemistry, there likewise can be no doubt. A study of the genesis of ore deposits through the medium of geochemistry, of the geochemical changes that arise as a result of igneous emplacements and emanations, of the distribution of chemical elements in the crust of the earth, of X-ray diffractions obtained in particular mineral groups and crystal suites, investigated, however, by mineralogist rather than by chemist, and of the spectroscopic analysis of mineral powders—these represent but a few of the problems wherein geological research benefits from a mutual interest on the part of geology and the fundamental sciences.

Similarly, studies of the physical properties of sediments and of other types of rocks with the electron-microscope and spectroscope, the porosity and permeability of rocks, the investigation of the earth's radioactivity, the distribution of radioactive elements in the crust and its bearing on geologic time—these are representative of a large number of problems that call for a close bond between these sciences. This type of association of interests is in reality an extension of the contact already established at the Institute to enlist the aid of the physical sciences in a solution of problems arising in the several fields of physical geology. Accepting the full implication of these challenges will make the Division of the Geological Sciences a refreshingly unique kind of graduate school for geological research.

The Gem Deposits of Southern California

By RICHARD H. JAHNS

ON a warm June day nearly 76 years ago, Henry Hamilton was picking his way along the brushy southeastern slope of Thomas Mountain in the Coahuila district of southern California's Riverside County. As he crossed a small gullied area, he noticed several rough mineral fragments of attractive pink and green color. Carefuly tracing the occurrence of this loose "float" material to its source higher on the hill, he encountered a ledge of light gray rock in which a few irregular cavities were lined with crystals of quartz and other minerals. Among these others were beautifully transparent pencil-like crystals of red, pink, green, and blue color. These constituted the first California discovery of gem tourmaline, a material that already had been mined in eastern parts of the United States.

A little mining was done at the new locality, and some excellent gems were obtained. As the interest of other men was quickened by Hamilton's success, additional deposits were soon discovered in the same general area, but it was not until nearly 20 years later that any important find was announced. This, in an area 24 miles to the southwest, was an occurrence of tourmaline with large quantities of the lithium-bearing mica, lepidolite. The deposit was exposed on a hill slope immediately north of the little mission town of Pala, on the San Luis Rey River. In addition to large quantities of lithium minerals, it yielded numerous specimens of lilac-colored lepidolite with coarse sprays of deep pink tourmaline. These found favor in museums and collections the world over.

The greatest discovery of all was made still later, in 1898, when several blue, green, and red crystals of tour-

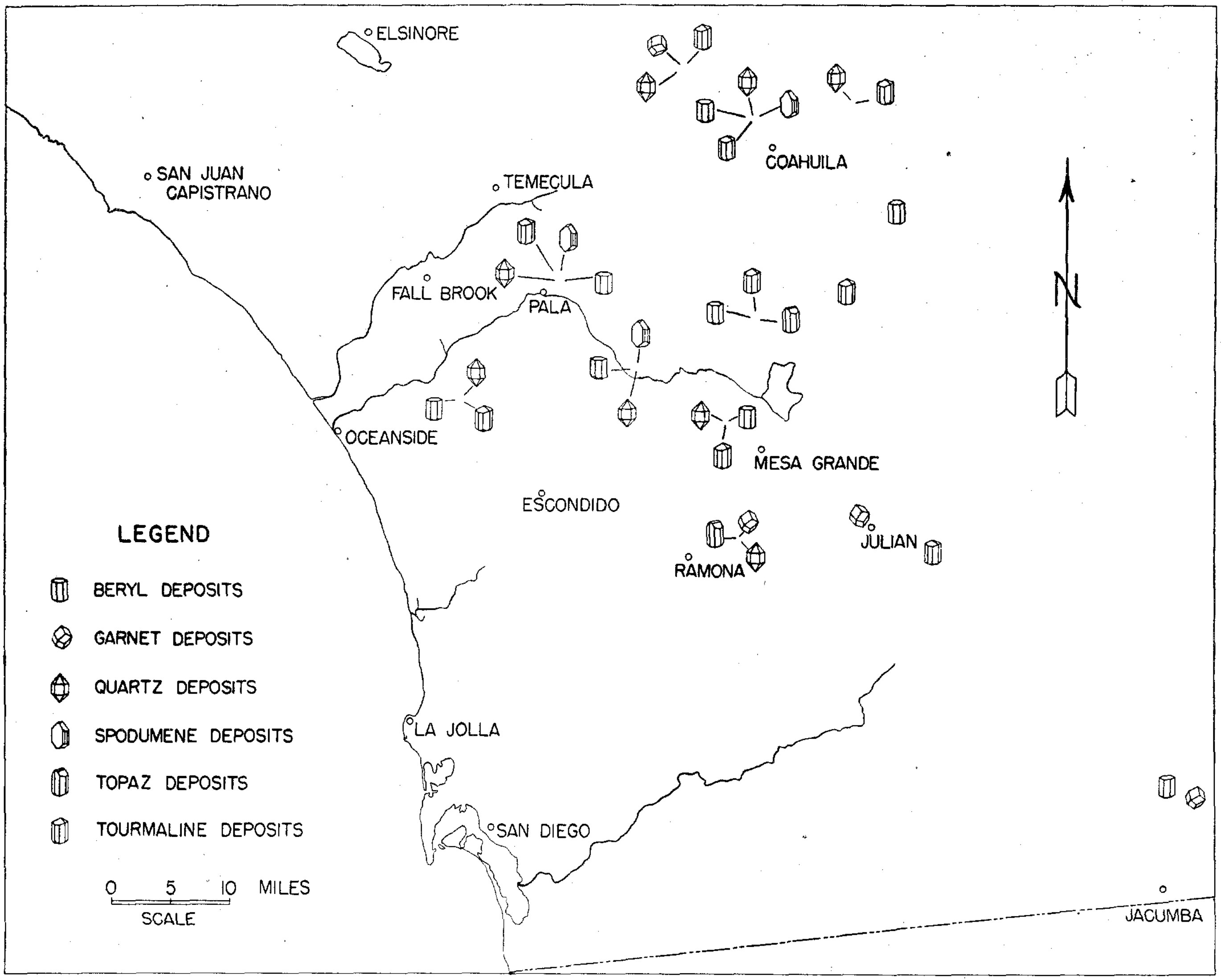


Fig. 1 Map of southwestern California, showing locations of principal gem deposits.

Fig. 2 Typical well-developed "line rock." This garnet-rich rock has been used locally as a decorative stone in fireplaces and garden walls. Hammer at top of boulder is for scale.

maline were shown to cowboys by Indians living near Mesa Grande. The source of this material was found to lie on a high wooded slope south of the San Luis Rey River and about 11 miles south of Palomar Mountain. This ledge became the site of the world-famous Himalaya Mine, the greatest producer of gem tourmaline in North America.

Tourmaline was not the only mineral involved in a series of spectacular discoveries made during the period 1902-1905. Frederick M. Sickler, while working a lepidolite deposit a short distance northeast of Pala, encountered numerous transparent masses of a mineral colored in delicate tints of pink, lavender, lilac, and blue-green. These were subsequently identified as a rare, remarkably clear variety of the lithium-bearing mineral spodumene. The pinkish to lilac-colored types were given the name kunzite, in honor of Dr. G. F. Kunz, who first identified them in his capacity as mineralogist for Tiffany and Company of New York. Kunzite thus is one of California's own minerals.

Additional spodumene deposits soon were discovered in the Pala area, and mining for this mineral, tourmaline, and lepidolite led to recognition and recovery of fine transparent quartz crystals and a beautiful pink to deep peach-colored variety of beryl. The aquamarine and emerald varieties of beryl were well known at the time, but this type was new, and was named morganite in honor of the noted financier. Such beryl also was encountered during mining in the Mesa Grande and Rincon districts.

Tourmaline was found on the slopes of Aguanga Mountain, near Palomar Mountain; at several places in the Mesa Grande area; near the town of Ramona; and at numerous other localities during subsequent years. Colorless to blue topaz, some of it in large, perfect crystals, was discovered at several Aguanga Mountain and Ramona localities, and subsequent mining yielded stones of quality equal to that of the best material obtained from Brazil. In addition the essonite, or hyacinth variety of garnet was found in the Ramona deposits, chiefly as honey-colored to orange-red transparent crystals. It also occurs in the Mesa Grande area; in the vicinity of Jacumba, far to the south near the Mexican boundary; and at several intervening localities.

The locations of the principal gem-producing areas of southern California are shown in Fig. 1. All are in the province of the so-called Peninsular Ranges, a series of ridges and mountains that extends southward from the edge of the Los Angeles Basin. This great highland mass separates the Salton-Imperial depression on the east from the coastal areas on the west, and also forms the "backbone" of much of Baja California. It is characterized by medium- to coarse-grained igneous rocks that range widely in composition.

All the gem materials and minerals occur in pegmatite, a granitic rock characterized by extreme coarseness of grain. The pegmatite ordinarily forms dikes, and these tabular masses range in thickness from less than an inch to 100 feet or more. In most places the pegmatite is surrounded by other, less coarse-grained igneous rocks of more basic composition. In most areas the dikes trend north to north-northeast and dip westerly at gentle to moderate angles. Although they consist chiefly of graphic granite, a peculiarly regular intergrowth of quartz in microcline feldspar, careful examination discloses numerous variations in their composition and internal structure.

Many of the pegmatite masses are very regular in thickness and attitude, and most of them contain little or no gem material. Others are "two-ply" features, with upper parts of graphic granite and lower parts of a strikingly layered, much finer-grained rock that consists mainly of sugary albite feldspar with garnet, black tourmaline, or both minerals. The latter has been termed "line rock," owing to the appearance of its many thin, sub-parallel garnet- or tourmaline-rich layers on most outcrop surfaces (Fig. 2). A little of this material has been used as an ornamental stone, but none of it has yielded gems.

In the central part of some dikes, commonly along or near contacts between "line rock" and overlying graphic granite, is the so-called "pocket zone," "pay streak," "clay layer," or "gem strip" (Fig. 3). Ordinarily this is an irregular series of tabular or pod-like masses that are rich in quartz. Associated with the quartz are albite, microcline, and orthoclase feldspars, muscovite and lepidolite micas, tourmaline of various colors, beryl, and rarer minerals. These masses generally are surrounded by pegmatite rich in muscovite and coarse prisms of black tourmaline.

Some well formed quartz crystals weighing 100 pounds or more have been encountered during mining, although few gem crystals of quartz or other minerals exceed six inches in maximum dimension. The gem material of best quality is found embedded in a pink to pinkish brown clay, which is thus regarded by miners and prospectors as a very favorable indication of "pay stones" (Fig. 4). Some of the gem crystals are loose in the clay, some are attached to other minerals that line the clay-filled "pockets," and a few are wholly or almost wholly embedded in solid pegmatite.

Most of the pegmatites that contain gem tourmaline, topaz, garnet, or beryl are 5 to 20 feet thick, although there is little systematic relation between thickness and gem content. Indeed, the famous Himalaya pegmatite, in the Mesa Grande district, was only 1 to 5 feet thick where richest in gem minerals. There is a definite re-

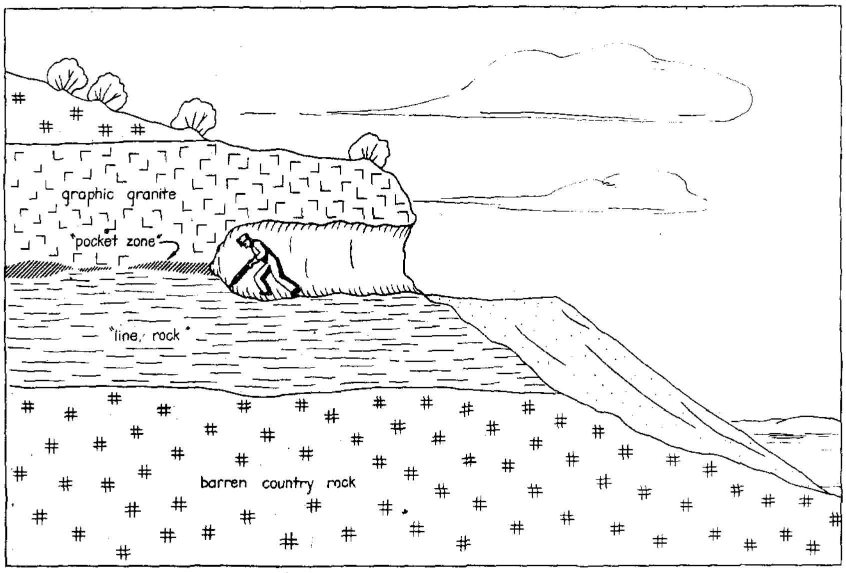


Fig. 3 Diagrammatic cross-section showing distribution of the gem-bearing "pocket zone" and the other rock types characteristic of many southern California pegmatite dikes.

lation, on the other hand, between the occurrence of kunzite and the local thickness of spodumene-bearing pegmatite dikes. Such dikes characteristically thicken and thin, or "pinch" and "swell," as traced along their outcrops. The central part of each bulge or "swelling" is commonly marked by a pod-like mass of quartz or of quartz with long, thin, lath-like crystals of spodumene (Figs. 5 and 6).

The spodumene is opaque and white to pinkish in color, and much has been thoroughly decomposed to a clay-like substance. Inside some of the crystals, however, are fragments of clear kunzite, which appear to represent those parts of the crystals that escaped alteration. The proportion of clear material is rather high in the crystals nearest the centers of the largest pegmatite bulges, and a very few laths are entirely unaltered. Gem crystals of this type are known to reach thicknesses of 2 inches and lengths of nearly a foot, but unfortunately are exceedingly rare.

The mining of pegmatite gems in southern California reached its peak during the decade 1902-1912, when material valued at more than $1,500,000 was marketed. Tourmaline, which represented most of the output, was graded on the basis of size, color, transparency, and freedom from bubbles, inclusions, and other imperfections. Nearly all the gem crystals are shaped like a short lead pencil, with diameters of most ranging from one-eighth inch to four inches or more. They are characteristically hexagonal, with flat or nearly flat terminations. A wide variety of colors has been found, but red, pink, salmon, green, dark blue, and black are most widespread. Many crystals are bi-colored or multi-colored, with sharp or gradual changes from one end to the other or from the interior outward. Some crystals with pink interiors and green rims are known as "watermelon" tourmaline.

Most transparent crystals of high quality were cut into gems, which commanded prices of $2 to $10 per carat. Current prices are somewhat higher than this. Much pink material of slightly inferior grade was sold to Chinese markets, where it was highly prized as carving material. Thousands of crystals, representing a wide range of quality and size, also were marketed as specimens in all parts of the world. So much tourmaline was sold during the "golden decade" of mining, however, that the market collapsed shortly before World War I, and only during recent years has it shown signs of recovery.

During World War II a little tourmaline of deep green and blue color was sold from the Pala district. This represented material left over from previous production, and was used because of its piezoelectric properties. The current demand for such material, as well as for gem stock of highest quality, far exceeds the present available domestic supply.

The rough crystals of kunzite are blade- or lath-shaped, and nearly all are deeply striated and grooved (Fig. 7). Most are small, with lengths of two inches or less, but some nearly a foot long and weighing 24 ounces or more have been recovered during mining. The limiting factor for size of top-quality cut stones is the thickness of the source crystal, as the deepest colors are obtained only when the stones are viewed parallel to the long axis of the crystal. The mineral is a very difficult one to prepare as a gem, owing to its two directions of perfect cleavage and hence its tendency to

Fig. 4 "Pay streak" in Pala Chief mine northeast of Pala. Crystals of spodumene (white) are embedded in a matrix of clay and quartz (dary gray). Some of the spodumene crystals contain material of gem quality.

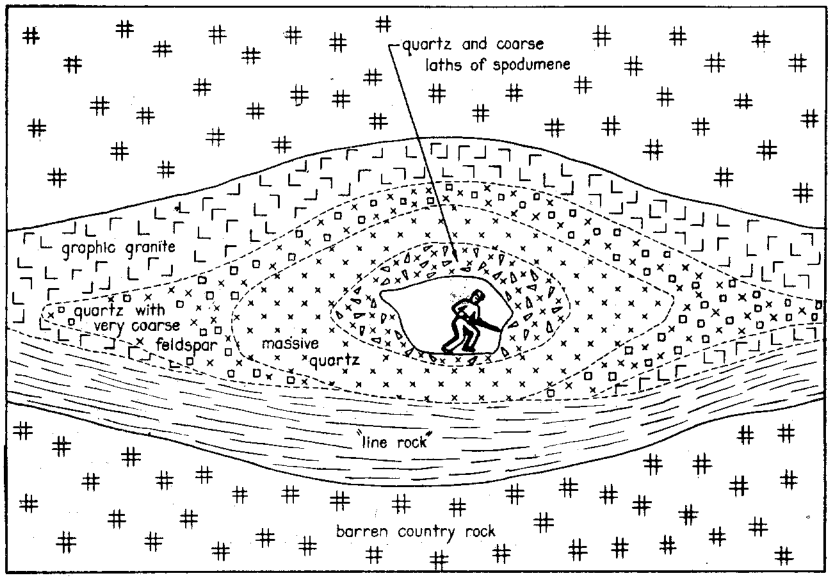


Fig. 5 Idealized cross-section of a typical spodumene-bearing pegmatite in southern California.

break near the edges during cutting. However, it yields stones of exceptional beauty.

Current prices for facet-cut stones of this high quality range from $2 to more than $25 per carat, depending chiefly upon the nature and depth of their color. Kunzite is so rare that it also has considerable value as a specimen material. It has been mined sporadically during recent years in the Pala district, and three mines are being reopened for systematic operation at the present time.

Colorless to blue topaz has been mined chiefly from deposits near Ramona and on Aguanga Mountain (Fig. 1). It has found a ready market, commanding prices of $5 to $15 per carat in the form of facet-cut stones. Much specimen material has been sold as well.

Quartz, garnet, and both aquamarine and pink to salmon-colored varieties of beryl represent only a small proportion of the gem production of southern California, in terms of both bulk and value, but they are widespread in their occurrence and in their distribution in gem and mineral collections. A large pocket of peach-colored beryl crystals was encountered during recent wartime mining for quartz crystals of radio grade in the Pala district, and other crystals of similar form and color have been encountered from time to time in the search for kunzite. Still other occurrences have been reported during recent years from deposits in Riverside County.

The moribund gem mining industry of southern California, with a total recorded production valued at more than $2,000,000, is currently showing signs of revival. Although "bonanza type" operations probably are gone forever, it will be interesting to see whether a gradually rising market and a modern approach to pegmatite geology and mining will sustain activities at somewhat less spectacular levels.

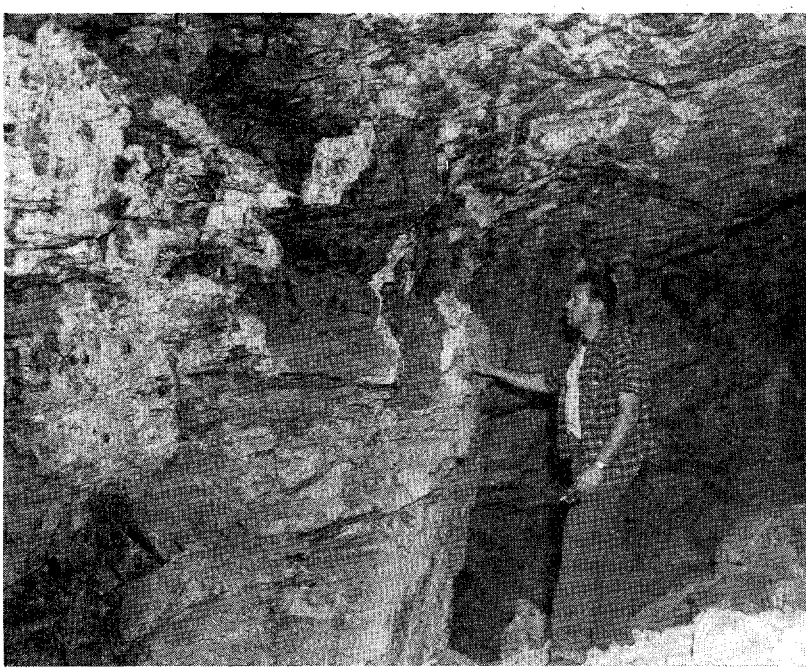


Fig. 6 Don M. George Jr. examines spodumene-bearing pegmatite in the Stewart mine, near Pala. Spodumene crystals (light gray) are abundant in the roof over his head, and lepidolite mica forms most of the rock below his hand.

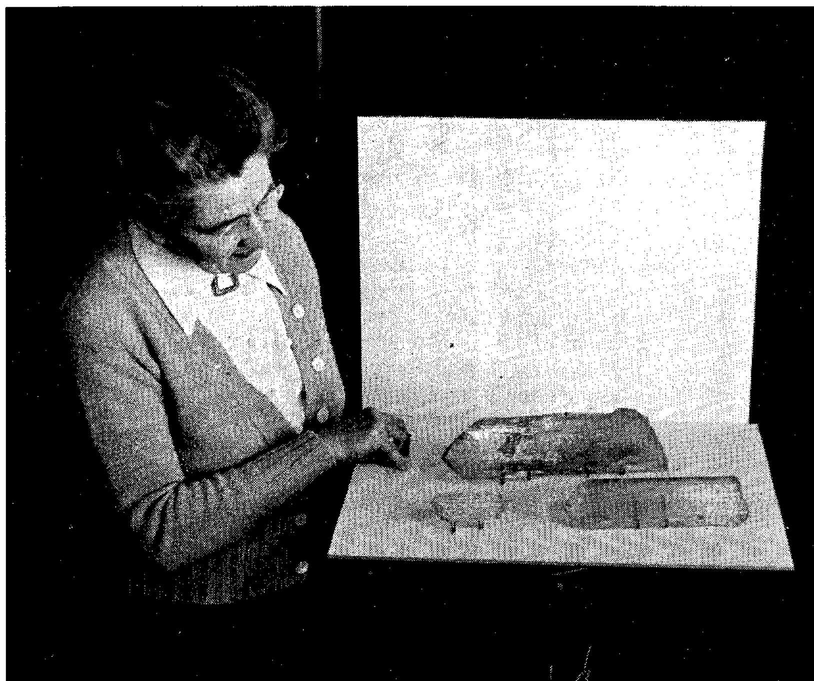


Fig. 7 Leonora S. Reno, secretary of the Division of the Geological Sciences, admires three giant crystal fragments of gem spodumene. The largest ones are two very remarkable specimens from the collection of T. W. Warner, Pasadena.

Seismological Laboratory of the California Institute, located in the San Rafael Hills in the western part of Pasadena, where the piers for seismographs are set in firm granite in cuts and tunnels under the building. Photo by Harold A. Parker Studio.

Unusual Opportunities for Training in Geophysics at the California Institute

By JOHN P. BUWALDA

FORMAL instruction in Geophysics has been given in the institutions of higher learning in this country only in the last decade or two, and even at the present time only a few universities offer extensive courses in this subject. The California Institute has forged ahead in this field. In the number and eminence of staff members giving attention to instruction and research in geophysical branches and in the variety of courses and breadth of curriculum, the Institute probably gives larger opportunity for advanced instruction than any other educational institution in America today.

Geophysics is the investigation of the solid body of the earth, its oceans, and its atmosphere, to determine the arrangement or structure and the physical properties of their parts and ascertain the nature of the changes that are occurring both on the surface of the earth and in its interior. Geologists, oceanographers, and meteorologists also investigate these problems, but the unique feature of Geophysics as a science is its attack on these questions by means of the methods of physics and the use of precise quantitative data. Geophysics is a relatively young science, but has developed very rapidly in the last quarter century.

Distinguished but little in principles and methods but mainly in the kind of information sought, two commonly recognized divisions of this subject are General Geophysics and Applied Geophysics.

General geophysics deals with such fundamental problems as the nature of the materials in the interior of the earth, their composition, temperature, pressure, and physical state; also their arrangement, which is now known to be in concentric spherical shells. Direct, reflected, and refracted earthquake waves, originating at many different localities on the globe and registered by widely-scattered seismographs, are divulging a surprising wealth of information regarding both the outer and the deeper parts of the body of our planet. Other examples of fundamental problems are the structure of the crust beneath mountain ranges and its bearing on the origin of mountains and the cause of volcanism. In the ocean Geophysics attacks such questions as the exact cause of the tides, of so-called tidal waves, and of the vast system of ocean currents. Regarding the atmosphere the geophysicist attempts to determine the constitution and temperature distribution at different levels, the velocity of sound waves, the nature of electrical phenomena, the thermodynamic relations of the different latitudinal zones of the air, and the laws that govern not only the daily vacillations responsible for our weather but the broader circulation over the globe.

Applied Geophysics is concerned with using the principles, knowledge, and techniques of the science in solving a great host of practical problems, many of which cannot be attacked effectively in any other way. Some of the most important of these relate to the finding of new resources for industry, such as oil, gas, and metals. Because of their success and the great value of the resources recovered, new methods have been devised rapidly.

The training in Geophysics at the Institute is almost entirely at the graduate level. The scheme of courses as laid out requires two academic years for its completion. About half of the time in each of six terms is devoted to geophysical courses; the remainder is used largely for additional training in appropriate branches of physics, mathematics and geology. The Institute awards the Masters degree in Geophysics, usualy at the end of the first or second year, the degree of Geophysical Engineer, usually after two or three years, and the Ph.D. degree in Geophysics normally at the end of the fourth year.

It may be stated that at this early stage, when instruction in Geophysics is not yet extensively developed in many institutions in the country, the California Institute is already providing unusual opportunities in this field in terms of staff, physical facilities, and favorable geophysical environment.

The Seismological Laboratory and Earthquake Study

By C. F. RICHTER

THE Seismological Laboratory, which recently completed its twentieth year, is situated off-campus in Pasadena. While its iron gates are open most of the time, its location back of the Annandale golf course on the north side of Colorado Boulevard not far west of the Arroyo Seco is probably seldom noticed by the passer-by.

In 1921, the Carnegie Institution of Washington, on the initiative of Harry O. Wood, set up a program of seismological investigation in his charge. This was to provide a central station in Pasadena and a group of auxiliary stations in Southern California for a study of local earthquakes. Later, with the participation of the California Institute, a site was chosen, the present building was constructed and occupied, and in 1927 the recording of seismological observations commenced. Important features determining the selection of the site were the granitic bedrock and the remoteness from traffic disturbances.

By 1929 six auxiliary stations had been established, and each of these is now operated with the help of an agency other than the California Institute. At Mount Wilson this is the Carnegie Institution of Washington. The remaining stations with the local sponsors are at Riverside (City of Riverside), Santa Barbara (Museum of Natural History), La Jolla (Scripps Institution of Oceanography), and Tinemaha and Haiwee in Owens Valley (Department of Water and Power, City of Los Angeles). In 1939 another station was added, on Palomar Mountain. The auxiliary stations with their instruments are used only for the recording of earthquake data on photographic sheets. The records are sent weekly to the Pasadena office, where they are developed and studied.

In 1937 the entire program and the staff in charge were continued under the auspices of the California Institute. The Laboratory investigations do not include engineering problems that result from motion. The elements of motion resulting from an earthquake, as for example amplitude, velocity, and acceleration, as they affect physical structures are being studied by the Department of Civil Engineering of the Institute.

To lay a ghost, it is worth mentioning that the Laboratory does not predict earthquakes. On the other hand, the average probability of an earthquake in a given period of years can be stated approximately. There is at present no prospect of prediction, in the sense that it can be stated that a strong earthquake will occur at a certain time and place.

The principal research activities of the Laboratory are:

1. The location of earthquakes the world over, including a determination of their depth of origin
2. the accurate location of earthquakes in the Southern California area
3. a study of the seismograms of distant earthquakes recorded at this and other stations over the world, to determine what can be learned as to the interior structure of the earth
4. a similar use of records from the local stations to determine the structure of the upper layers of the earth's crust in the California area.

All these investigations bear on important problems of geology and geophysics. Moreover, the individual characteristics of seismograms give to the specialist limited information about the mechanism of rock fracturing which causes earthquakes. Finally, the earthquake magnitude scale, devised at Pasadena, has led to a completely new interpretation of earthquake statistics.

International seismology rests upon a world-wide exchange of data among the recording stations. Pasadena, having one of the best equipped laboratories, plays a significant part in this exchange. Its published bulletin circulates all over the world, and similar bulletins are received from Bolivia, New Zealand, India, Czechoslovakia, the Soviet Union, and many other countries. The principal center of exchange is the international office at Strasbourg; here data for all stations are collected. These are finally published in the International Seismological Summary, formerly issued from Oxford, but now from Kew Observatory (near London).

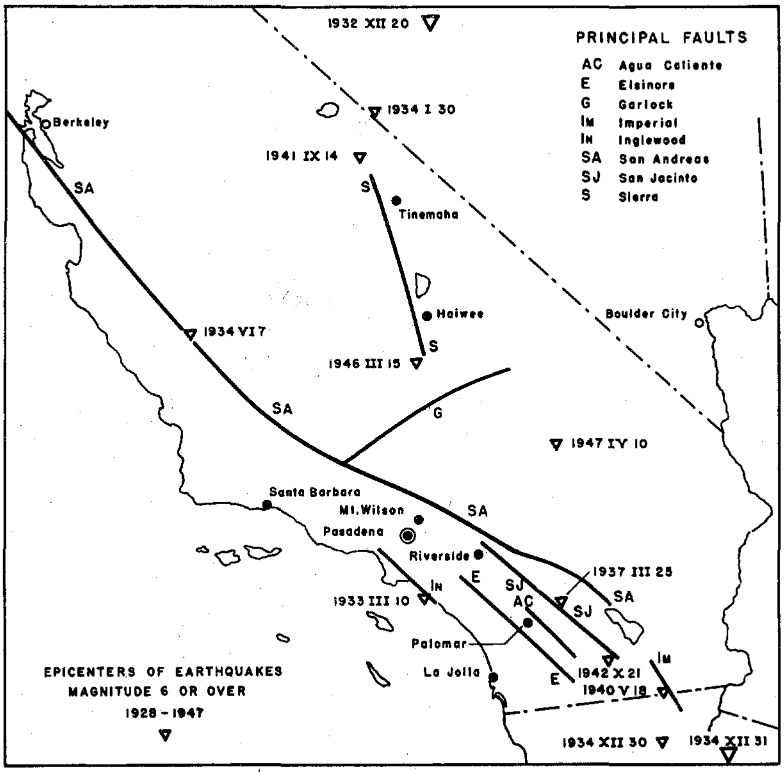
The Pasadena bulletin each year gives data for about 1000 teleseisms—earthquakes distant more than 1000 km. In addition, a report on local shocks is issued in which epicenter, time of occurrence, and magnitude are given for about 300 shocks annually in the area of southern California. For only these local shocks can sufficient data be gathered to permit a location of origin. Hundreds of smaller unlocated disturbances are recorded, some of them undoubtedly artificial, being due to blasting or explosions.

For the study of local shocks data are exchanged with two regional groups of stations. One of these groups centers at the University of California, Berkeley, and deals primarily with earthquakes in central and northern California. The other has headquarters at Boulder City, Nevada, maintaining stations in the Lake

Charles F. Richter has been associated with the Seismological Laboratory since 1927, and has been a member of the Institute staff since 1937. He received his A.B. from Stanford in 1920 and his Ph.D. from C.I.T. in 1928.

Dr. Richter supervises the measuring and cataloging routine at the Laboratory. Data for local and distant earthquakes are preserved in a large and detailed card file. From this file Dr. Richter compiles and edits the Laboratory bulletins.

The Pasadena magnitude scale was set up by Dr. Richter, originally for use in studying local earthquakes. Many of his publications deal wholly or in part with this scale and its applications. Most of them are released in collaboration with Dr. Gutenberg, among them the series on seismic waves and on the seismicity of the earth. Some are studies of particular earthquakes, others are theoretical.



Outline map of the California area, showing stations, principal faults, larger shocks 1932-1947.

Mead area, as well as at Shasta and Grand Coulee Dams. This latter group of stations, fully equipped with sensitive Benioff seismometers, is operated by the U. S. Coast and Geodetic Survey.

The destructive Long Beach earthquake of March 10, 1933, occurred almost in the center of the Pasadena station network. Location and timing for this shock are consequently more accurate than for almost any other earthquake of comparable magnitude. Since the shock was recorded at many distant stations, it provided data for revision of the standard time-distance tables.

An extremely valuable check was provided by the Baker Day atomic bomb test at Bikini on July 24, 1946. The first waves from the resulting shock were recorded at Mount Wilson, Riverside, Palomar, and Tinemaha. Since the explosion was accurately timed, the zero of the time-distance curve is now well established. Similar work has been done on the smaller local scale by timing large quarry blasts at the shot point.

It was at first anticipated that the location of small earthquakes would outline the major active faults and help supplement the geologic data as to the local seismicity. This expectation was disappointed, but in an interesting way. Except for the swarms of small aftershocks which always follow larger disturbances, it is found that small local earthquakes are irregularly peppered over the area. Closer examination shows that they are associated with various small faults that make a mosaic of the regional structure. The occurrence of large shocks appears to be nearly independent of this continuous smaller activity; the time-honored notion, according to which small shocks may serve as a "safety valve" to delay or inhibit the occurrence of larger ones, has had to be abandoned.

Precise seismometrical survey of the desert and mountain portions of Southern California has revealed the occurrence of earthquakes in unexpected areas. Even in settled districts important results of this kind have been reached. Thus, the records establish the activity of the Norwalk fault, which is an important feature bounding the Los Angeles Basin on the north, corresponding to the Inglewood fault on the south (on which the Long Beach shock of 1933 originated). The Norwalk fault is a potential source of serious risk to the metropolitan area.

On April 10, 1947, a large shock took place in the central part of the Mohave Desert, nór far from Manix and Field on the Union Pacific Railroad. Small fault displacements amounting to a few inches were found on a known fault passing near the epicenter located by instrument. The distribution of the small aftershocks, now under investigation, suggests another active line, and indicates unusual complexity in the fracturing which produced this shock.

Study of the direction of first motion as indicated by the seismograms of hundreds of local shocks has confirmed the conclusion of geologists that the parallel northwest-southeast faults of Southern California represent a series of shear fractures, probably conditioned by a north-south compression, along all of which displacement is occurring in the same direction; that is, the southwest side of each fault is being relatively displaced to the northwest. Such displacements, amounting to 15 feet or more, occurred on the San Andreas fault during the earthquake of 1906 and in the Imperial Valley in 1940.

The magnitude scale, previously mentioned, has introduced new precision into the statistical handling of earthquake data. The smallest recorded shocks are of magnitude between 0 and 1; the greatest erthquakes are of magnitude about 8½. This corresponds to a range of about 10^{17} in the energy radiated in the form of elastic waves. The scale, originally devised for California shocks, has been extended to earthquakes over the world and at all depths, using the data of all reporting stations. Among the results is a carefully compiled list of 94 great earthquakes (magnitude 7¾ and over) from 1904 to date. The list of major earthquakes (magnitude 7 to 7.7) is more extensive, there being about 10 such shocks each year. Finally, a critical list of the larger shocks (magnitude 6 and over) in the California area since 1932 has been prepared.

ORE MINERALS UNDER THE MICROSCOPE

By JAMES A. NOBLE

THE student of geology in the course of his training usually passes through three stages of achievement: A first in which he learns to identify the materials with which he works; a second in which he learns to recognize the distribution of these materials in space; and a third in which, from this distribution, he interprets the geologic history of the area of the assemblage of materials. Paraphrasing this generalization into words the student himself might use, he eventualy must answer these three questions: "What is it?," "Where is it?," and "How did it get that way?"

Certainly not all geologic study can be compressed into this simple formula, but the generalization fits several branches of applied geology. In particular, it adapts itself to the study of polished sections of ore minerals as a means of interpreting processes of ore deposition. Though a student may have progressed through the stage of identifying minerals and rocks in hand specimens and with the aid of a microscope, though he may have acquired proficiency in field mapping, and though he may have acquired some skill in the interpretation of the space relations, he is back at the beginning, in so far as the study of ore deposits is concerned, when he sees his first set of polished sections, for he has to learn to identify the minerals all over again.

This change in appearance of even the most familiar minerals when seen on the polished section results from the degree of polish which is needed in the study of opaque minerals. Because most of the ore minerals are essentially opaque in any thickness that can be conveniently handled, it is impossible to study them in the familiar thin section used for the study of rock specimens. As a result, therefore, a smooth surface of the material instead of a thin section is prepared, and all the technique available is utilized to make that surface a true plane devoid of relief. The treatment of the ore sample consists in cutting the specimen and grinding and polishing the cut surface. The grinding and polishing processes call for experimentation with abrasives and for many refinements of method. Accompanying illustrations show the steps used in preparing a specimen for polishing. Current technique by which a surface with a satisfactory high degree of polish is prepared with reasonable expenditure of time and effort is the result of long experimentation by Mr. Rudolf von Huene in the geological laboratories of the Institute.

Although polished sections were first used in the study of opaque minerals in 1864, application of the method was slow in developing, and only within relatively recent years has it come into general use. In consequence, much still remains to be done and the techniques and methods have not outgrown the experimental stage. Parallel with the improved procedures in the study of polished sections has come a specialized technique in the microchemical analysis of ore minerals, made necessary by inherent difficulties in identifying minerals on polished surfaces. Application of this technique and its improvement have progressed in the geological laboratories at the Institute. At present, however, there is need especially for a perfecting of the qualitative chemical analyses, and perhaps of quantitative analyses on a microscopic scale.

In the first step of a microchemical analysis of an ore mineral, a suitable solvent dissolves a tiny grain of mineral scarcely larger than the point of a pin. The single drop of solution is then subjected to chemical manipulations, and the results are observed under the lens of a microscope. These results are for the most part only qualitative, but many of the tests are so sensitive as to afford opportunity to detect traces of impurities in what had been considered to be pure minerals. The frequent occurrence of impurities is of course important. Obviously, it would be still more important to know the exact amount of each constituent, within reasonable limits of error.

However, identifying the minerals is only a means to an end, for eventually the question, "How did it get that way?", must be answered. The second stage of geologic learning, the study of the space relations, moves more rapidly. Long before the student has acquired ability to identify all the minerals, he has noted that they occur in many strange patterns. Interpreting the

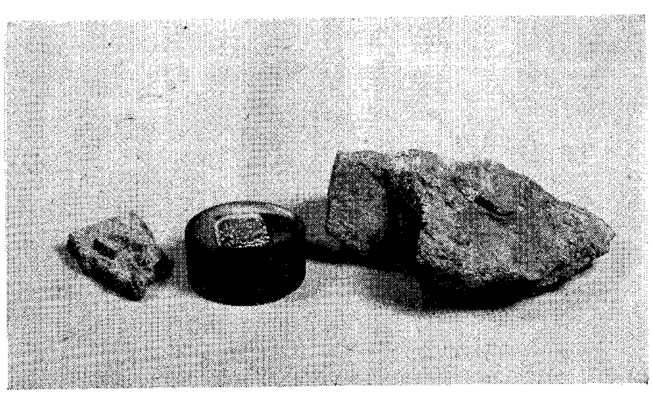


Fig. 1 Successive steps in the preparation of a polished section of an ore specimen. A small chip (on the left)has been cut from the hand specimen (on the right) by the use of a diamond-coated saw. In the center is a finished section of another chip mounted in bakelite and polished.

James A. Noble received his undergraduate and graduate training at Harvard University, stretching four degrees over 19 years. Between A.B. and S.B. degrees in geology and mining engineering in 1920 and 1922, and the M.A. and Ph.D. in geology in 1936 and 1939, Dr. Noble served as mining geologist for zinc mines in Tennessee, copper-zinc-lead-silver mines in Peru, and gold mines in Canada and South Dakota. Before coming to the Institute in 1947 he was for 16 years chief geologist at the Homestake Mine in the Black Hills of South Dakota, one of the large gold mines of the world. Dr. Noble's position at CIT as lecutrer in metalliferous geology represents his first official teaching experience.

During the recent war Dr. Noble did geological work for the Government in a cooperative effort between the Homestake Mining Co. and the U. S. Geological Survey in exploring deposits of vanadium in Idaho and manganese in Baja California.

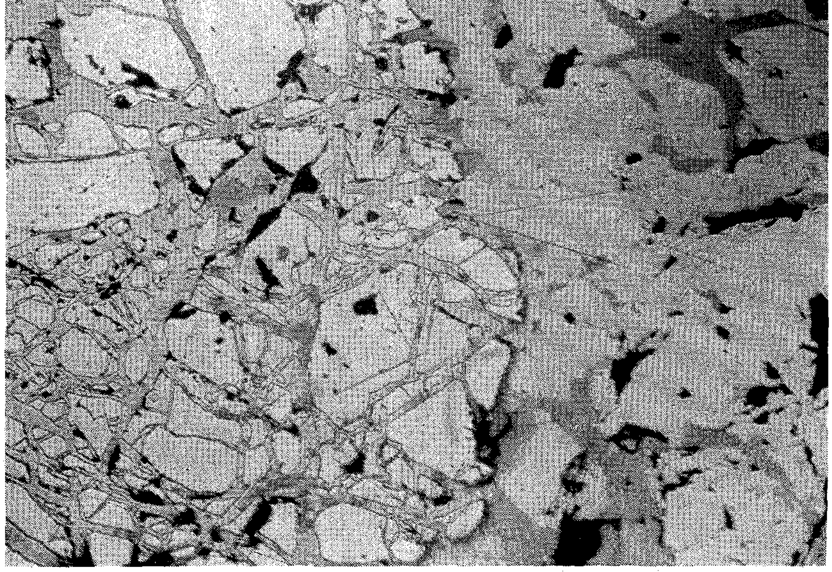


Fig. 2 Photomicrograph of a specimen of copper ore from Magma, Arizona. Light gray areas are pyrite. Intermediate gray areas are chalcopyrite. Dark gray areas are chalcocite. Black spots are holes in the section. Pyrite has been fractured and veined by the other minerals in a pattern sometimes called the "exploded bomb" pattern. There is a suggestion that chalcocite has partly replaced chalcopyrite along cleavage directions. The sequence is pyrite, followed by chalcopyrite, and that probably followed by chalcocite.

space relations is of course handicapped by the fact that in utilizing a plane surface the advantage of the third dimension is lost. Due allowance can be made for this limitation, however, especially if enough material is sectioned to give random sections of all space relations.

As is true for much larger rock units, the identification of the minerals can be made with exactness and their distribution can be shown accurately, but the interpretation of the meaning of these relations is a matter of judgment. The microscope aids in determining the relative ages of the minerals and may likewise afford opportunity to discover something of their mode of deposition. Unfortunately, the relationships are sometimes ambiguous and can be interpreted in various ways by different observers. Other relationships, however, are so obvious in their meaning that they are universally accepted.

The microscopic study of polished sections reveals a vast amount of new information about ore deposits, furnishing as it does not only a means of identifying new minerals present in amounts too small to be seen by the eye or to be detected by analysis, but also a history of deposition of the minerals. An outstanding feature of ore deposits revealed by this study is the extent to which one mineral may be replaced by another. Scarcely a polished section fails to show this process, and in some sections a long succession of replacements can be seen, in which each new mineral in part replaces all the earlier ones. This leads to the disquieting conclusion that still earlier processes of replacement may have occurred of which there is now no evidence, since early minerals may have been entirely destroyed. Such earlier stages in the process of mineralization can only be inferred. The later stages, however, are often indicated in considerable detail and can be accurately discerned if sufficient sampling of the ore deposit is done and the evidence is properly evaluated. Suites of ore specimens like those which comprise the Frederick Leslie Ransome Memorial Collection at the Institute are invaluable in the study of polished sections. It is highly desirable that the Institute collection be enlarged by the addition of specimens obtained from all important ore deposits.

Thus, given a well-chosen suite of ores and rocks, and a set of thin and polished sections cut from these specimens, the mining geologist today can determine the history of mineralization by which a specific ore body has been formed. Since this is an essential step in determining the possibilities of the ore body and in guiding explorations for new ore bodies, it is not surprising that considerable attention is given to the polished section of ore specimens in the geological laboratories of the Institute as a direct approach to an understanding of ore genesis.

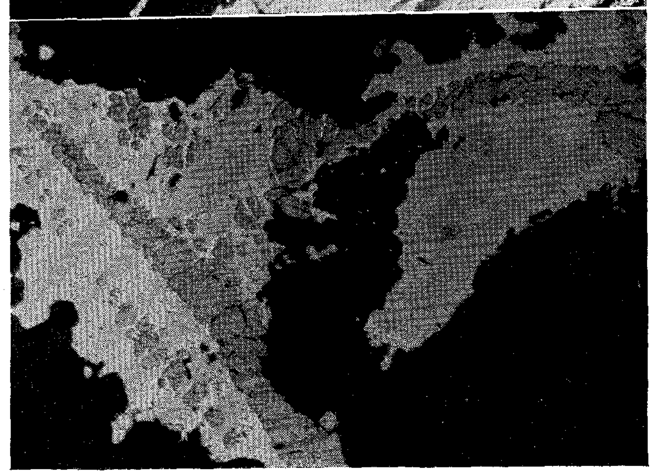


Fig. 3 Photomicrograph of a specimen of gold ore from Randsburg, California. Light areas are mixtures of the sulphide minerals pyrite and arsenopyrite. Dark areas are the non-opaque gangue minerals. Pyrite has pseudomorphously replaced an earlier bladed mineral. None of the bladed mineral remains, but a study of other specimens indicates that it was tremolite. Small rhombic crystals of arsenopyrite are perched on the pyrite areas. The sequence of deposition is, therefore, first tremolite, next pyrite, next arsonopyrite.

Fig. 4 Photomicrograph of a specimen of gold ore from the Homestake Mine, South Dakota. Light gray areas are gold. Dark gray areas are specularite. Black areas are non-opaque gangue minerals, mainly quartz. Gold has surrounded and partly replaced the specularite plates, one of which is represented by a line of separate dots.

Geologic Faulting in Southern California

The Process, Its Effects, and Its Consequences

By JOHN P. BUWALDA

IN regions like southern California where the population occasionally experiences vigorous earthquakes, geological faults are mentioned from time to time in conversation, lectures, and newspaper articles. Since the faults themselves are usually covered with soil or sliderock waste from the slopes above them, they are seldom seen by the general public or even by non-geological but more discriminating observers or engineers. Nevertheless, they are structural features of profound interest and importance not merely to geologists but to all the inhabitants of the regions traversed by them, for they affect the lives of the people in a multitude of ways not immediately suspected.

What are these faults? They are great fractures or breaks extending from the surface down into or through the crust of the earth. The crustal block on one side of the fault has moved horizontally or vertically with reference to the block on the other side. See Fig. 1. Some of these fractures are vertical, others are inclined, and a few are horizontal. In the last type the block or slab of rock above the fault has sometimes moved forward horizontally for distances of miles or even tens of miles over the country ahead of it. Faults range in length from a few yards to hundreds of miles, but the ones in which we are mainly interested in this discussion—the so-called major faults which have blocked out our mountains and valleys— are usually at least some tens of miles in length. The crustal slices between faults are commonly some miles or tens of miles in width. Minor faults usually cut the crustal blocks in various directions, so that there are many more small fractures than major faults. With the use of earthquake data (seismograms) it is found in southern California that the faults on which earthquakes originate extend to depths of at least 12 or 15 miles.

The shift of one side of the fault with reference to the other, vertically or horizontally or obliquely in direction, varies from a few inches or feet on myriads of minor faults to thousands of feet and even a few tens of miles on the more important major ones.

Faulting is of course only one of several processes which bring about the deformation involved in mountain making. In more recent geologic time the western margins of North and South America have been subjected to this process, apparently mainly by the application of east-west compressional forces in the crust, producing the Rocky Mountain and Andean systems. In earlier times the eastern margin of North America was somewhat similarly crumpled to form the Appalachians. At such times, the flexible rocks (sandstones, shales, conglomerates, and limestones) that happen to comprise the crust of the earth in the area of deformation yield to the horizontal forces by bending and form great mountain arches and valley troughs. This process is termed folding. The rocks in the lower part of the crust, at depths of many miles, yield to the horizontal forces by plastic flow, and the crust thickens by bulging both downward into the subcrust and upward, thereby giving the overlying folded part of the crust still greater elevation. Faulting, the third mode of yielding of the crust to the forces applied to it, is common in those areas in which flexible rocks are thin or wanting at the surface and where brittle formations like granite form the upper part of the crust. Naturally the faults developed in the brittle underlying granite frequently cut through overlying flexible sedimentary rocks.

Southern California, from the San Bernardino region to Santa Monica, and from the mountains to the sea, is traversed by a considerable number of major faults. Except that these fractures are somewhat more numerous and are rather active, this territory is not greatly different from others parts of California or from most of the area of the Rocky Mountain states. As a matter of fact, important and active faults occur across the entire width of the continent, as destructive earthquakes in the Mississippi Valley and on the eastern seaboard have indicated several times. Nor should the reader conclude that faulting is the only form of mountain making which is occurring in southern California. Indeed, folding is creating such ranges as the Santa Monica and Santa Susanna Mountains, while downwarping is largely responsible for the Santa Clara and San Fernando Valleys and the Los Angeles Basin.

THE FAULT MOSAIC

The major faults of southern California fall into two sets, not merely on the basis of their trends, but also because of the directions of their movements. See Fig. 1. One set trends roughly northwest-southeast and along these faults the southwest side invariably moves horizontally and northwestward with reference to the northeast side. This direction of movement is demonstrated by fault slips of 15 to 35 feet within historic times, by offset stream channels crossing the faults, by the pattern of subsidiary faults and folds along the margins of the fault blocks, and by the directions of first motion in hundreds of minor earthquakes, as determined by Gutenberg, which indicate the directions of the strains that were relieved by these small shocks.

Well known faults in this set, from northeast to southwest, are the Mission Creek, the San Andreas lying along the southwest base of the San Bernardino Mountains, the Elsinore, the Inglewood, and probably one or two faults off the coast. Our strongest earthquakes have originated on these faults.

The second set comprises roughly east-west faults. They dip or slope toward the north, usually at angles of 45 to 80 degrees measured from the horizontal, and the movement on them is not horizontal but one in which the upper block moves up the fault surface. Thus, they tend to shorten a line drawn on the country at right angles to the length of the faults, and hence are regarded as compression fractures. Like the northwest-

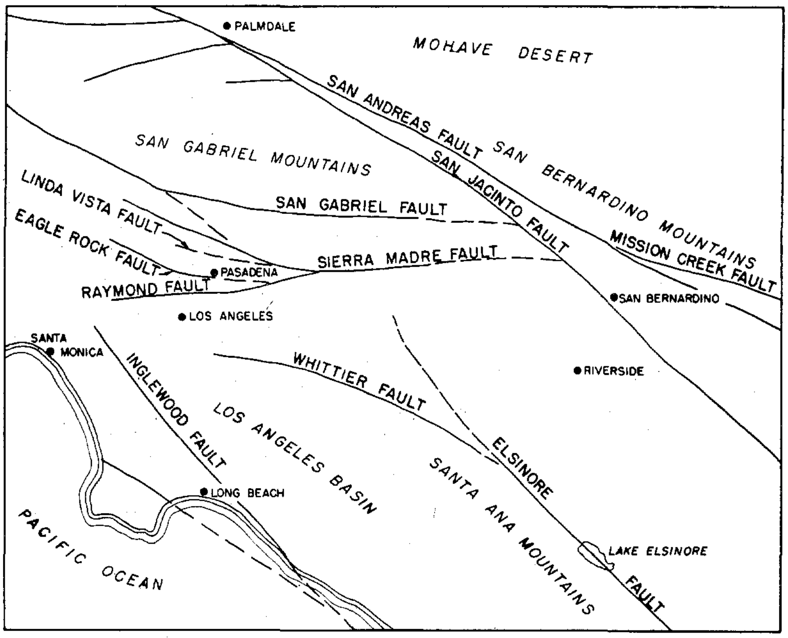


Fig. 1 Sketch fault map of a part of southern California; the northwest-southeast horizontally-slipping faults, and the east-west vertically-slipping faults.

southeast faults they also are active. This is indicated by earthquakes originating on them and by the fact that landscape surfaces situated above them have actually been offset vertically along their trace in recent geologic time. Faults of this category include the San Gabriel within the San Gabriel Mountains, the Sierra Madre along the south base of the same range, the Eagle Rock fault along the south side of the Verdugo Mountains and San Rafael Hills, the Raymond fault forming the escarpment between Pasadena and South Pasadena and south of the Huntington Library, and the Whittier fault following the south base of the Puente Hills. In each case, the north side of the fault has risen with reference to the south side which has been depressed, tilting the block to the north. As the blocks have been lifted progressively higher going north the series forms a gigantic stairway as one proceeds from the northern part of the Los Angeles basin through Pasadena to the crest of the San Gabriel Range. See Fig. 2.

NATURE OF THE FAULTING PROCESS

The displacements on the individual faults range from hundreds to many thousands of feet. But these displacements do not occur in single slips; on each fault the total offset was accomplished by thousands of very small slips, many of them only fractions of an inch. Occurring also is a much smaller number of large slips. Apparently the less frequent larger slips account for the major part of the offset, although even the more important slips seldom involve more than a fraction of the length of the fault.

We infer from the facts given above and from the evidence of the proven drift of triangulation monuments in the Coast Ranges of California, as determined by repeated precise surveys by the U. S. Coast and Geodetic Survey, that at the time of a major slip the entire block on one side of the fault does not suddenly move ahead several or some tens of feet with reference to the block on the other side of the fracture. Apparently, the main portion of a block, usually miles wide and tens of miles long, slowly drifts or is carried along at a more or less constant rate on the more mobile basaltic second shell of the earth for the entire interval between fault slips. But because of frictional resistance to fault slip the adjoining margins of the blocks are strained out of shape, and when slip occurs these margins merely resume their original form by sudden elastic rebound. Therefore only a small marginal fraction of each block on the two sides of the fault moves at the time of the slip. See Fig. 3.

EFFECTS OF THE FAULT SLIPS

The immediate effect of the slip is an earthquake. The energy stored up as elastic strain in the margins of the blocks on the two sides of the fault since the last slip is suddenly released and radiates outward in the form of elastic waves; these constitute the earthquake. About 75 shocks strong enough to be recorded at three or more of the eight stations in the California Institute seismological net (many of them are not intense enough to be felt) originate every month from epicenters within about 200 miles of Pasadena. Some of these arise from minor slips on parts of major faults; the remainder are caused by small dislocations on minor fractures within the blocks. Earthquakes strong enough to be damaging or destructive over a small fraction of the area of southern California occur on the average about once a decade or perhaps somewhat oftener. Major earthquakes that shook violently a large part of southern California occurred in 1769, 1812, and 1857. The history of seismic countries indicates that the areas in which light shocks occur most frequently are in general also those in which damaging quakes can be expected from time to time. Seismic studies indicate that the minor slips on faults only relieve a small fraction of the accumulating strain.

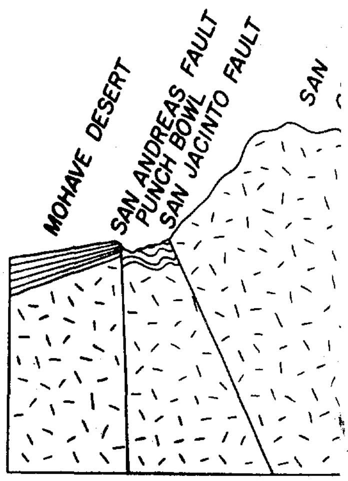


Fig. 2 North - south sketch cross-section through Pasadena showing stair-like fault block structure from the Los Angeles Basin through the San Gabriel Range. Also the water basins formed by tilting of the granitic fault blocks and accumulation of stratified sand and gravels in the resulting depressions.

Fortunately, we are not as helpless against earthquakes as are populations elsewhere in relation to other violent types of natural phenomena. We can now construct buildings at very little added cost that will withstand without damage the kinds of earthquakes reasonably to be expected in California.

A second effect of the faulting is that this region has been broken up into blocks, as above indicated, which have undergone quite different geological histories in recent time. They have acted more or less independently of each other as regards uplift or depression, and the degree of internal deformation in each has differed from that of the others, as has also the nature of that deformation, whether by faulting, or folding, or a combination of the two. The process is still continuing, but is apparently somewhat more active in some areas than in others.

CONSEQUENCES OF THE FAULTING

The consequences of the dislocations on the faults, particularly the vertical slips, have been profound for southern California and have affected nearly every human activity in this region in greater or less degree. It is no exaggeration to say that the region between San Bernardino and Santa Monica and between the mountains and the sea owes most of the unique advantages—topographic, climatic, economic, and indirectly cultural—which have brought a dense population and a vigorous civilization to it, directly or indirectly to vertical movement on the faults. The displacement on the east-west faults has been almost entirely vertical, but the dislocation along some sections of the northwest-southeast faults has also had a large vertical component.

TOPOGRAPHIC CONSEQUENCES

The first topographic result of the faulting is that, in contrast with the boundless flat prairies and plains of the Middle West and the tracts of high rugged mountains forming much of the Rockies, most of southern California consists of low-lying fertile valleys and intervening hill or mountain ranges. Among these valleys are the San Bernardino, San Jacinto, Elsinore, San Gabriel, and other small depressions. Examples of upfaulted mountain blocks are the San Bernardino, San Gabriel, and Santa Ana Mountains, the Puente Hills and the Verdugo Mountains (of which the San Rafael Hills west of Pasadena are a part). The Los Angeles Basin, the Santa Monica and Santa Susanna Mountains, and the San Fernando and Santa Clara valleys are due in part to faulting and in part to warping.

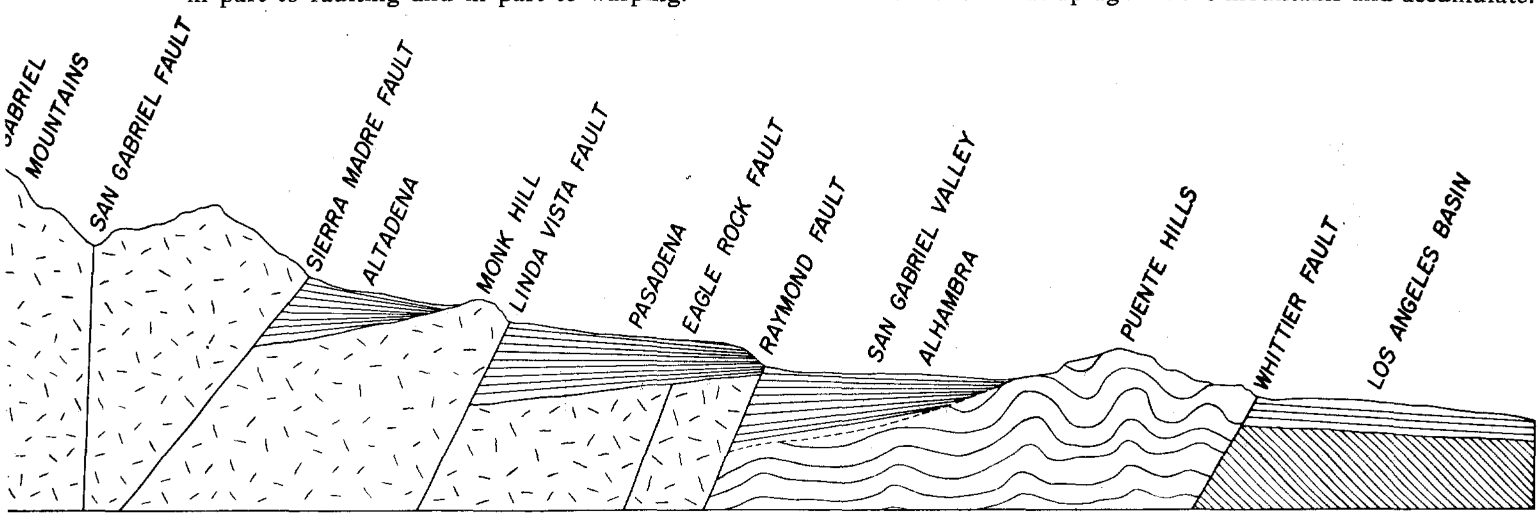
A second topographic result of faulting is that the Los Angeles-San Bernardino region is hemmed in by high mountains on its landward side and forms a protected coastal strip between these mountains and the sea. It is in fact directly connected with the interior country through only four gateways or passes: Tejon Pass (to the San Joaquin Valley), Soledad Pass (to Palmdale and the northern Mojave Desert), Cajon Pass (to the southern Mojave Desert), and San Gorgonio Pass (to Palm Springs and the Imperial Valley). Through these passes flows virtually all the rail, highway, and air transportation. These passes themselves are largely fault features—great fracture zones in the encircling ring of mountains.

CLIMATIC CONSEQUENCES

The fault block mountains with the aid of the folded ranges to the west shelter the Los Angeles region from the extremes of temperature which are more characteristic of the interior and help to give it its vaunted southern California climate. Santa Barbara and San Diego are likewise protected and also enjoy a largely marine climate.

Much of southern California is semi-arid, but the Los Angeles region would receive considerably less rainfall if faulting had not elevated parts of the area. If the lower portion of the territory were all part of a low flat coastal plain, it would probably be nearly as arid as parts of Baja California. The encircling ranges force the northeastward-flowing rain-laden storm air to rise, chill, and drop a large part of its moisture as rain or snow, making available much water to the southland which would otherwise be carried inland to the desert region. This may appear at first sight an injustice levied by Nature in favor of the coastal territory, but climatically it was probably a fortunate happenstance, for the increase or concentration of water in the coastal belt increased its habitability enormously, while the extra water abstracted from the clouds by the mountains would, if allowed to pass, have been spread over such a wide desert area that it would have ameliorated its aridity only slightly.

One unfortunate effect of the encircling mountains relates to the smog. In a plains country slight movement of the atmosphere in any direction will move contaminated air away from a densely settled area. In our region air flowing southward or westward will readily carry smog out to sea, but the movement of seaward-flowing air is somewhat impeded by the mountains. On the other hand, the contaminated air from the cities, when relatively quiet or moving only gently inland, tends to bank up against the mountains and accumulate.



ALLUVIATION OF THE DEPRESSED FAULT BLOCKS

The high-grade high-velocity streams on the uplifted fault blocks cut vigorously and easily carry down their canyons vast quantities of both coarse and fine materials —gravel, sand, and clay. When they cross subsiding fault blocks or the sinking side of tilting fault blocks their grades and velocities are slackened, their capacities to transport erosional waste rapidly decrease, and they deposit a large part or nearly all their load before they reach the ocean. The flat or gently sloping floors of our southern California valleys were built up in this way. Beneath most of these smooth valley surfaces the gravel, sand, and clay are hundreds of feet thick, accumulated in recent geologic time while the blocks were subsiding.

Much of this alluvial fill was deposited, and is now being laid down, in the form of great alluvial fans or cones, the apices of which are at the mouths of the canyons in the mountains from which the material issues. In travelling, for instance, from Pasadena to San Bernardino, the highway rises and falls gently but continuously in passing over fan after fan, lying side by side, each one built outward from the mouth of one of the canyons in the south face of the San Gabriel Mountains.

On these cones or fans, the detrital material is effectively classified, because streams with decreasing velocity and hence diminishing capacity to carry rock waste drop the coarse particles first. Therefore, boulders and gravel are deposited on the upper slopes of the fans, sand on the middle, and clay on the lower slopes. As a consequence the soils near the mountains are commonly rocky; farther down the slopes they are sandy; approaching the coast they are clayey or adobe. The fertile loam areas—mixtures of sand and clay where most of the truck gardening is done, are naturally not near the mountains but well down on the slopes of the fans. The higher parts of the cones can be and are utilized for citrus groves and other crops tolerating loose open soils.

WATER BASINS

A surprising fact, not realized until quite recently, is that on the average very little or none of the rain that falls on an area passes downward through the soil to replenish the groundwater unless the precipitation exceeds about 15 to 20 inches a year, varying somewhat in different localities. This amount of water, or less, arriving in successive storms during perhaps five winter months, is lost, partly by immediate runoff, partly by immediate evaporation, and the remainder by later evaporation from the damp soil and by transpiration by grass, shrubs, and trees. With such scanty winter rainfall the upper few feet of soil become moist, but that moisture generally moves upward, by capillarity to supply evaporation at the surface during the next dry season, rather than downward to join the water table—the zone of water-saturated alluvium usually located some tens of feet below the surface.

Fig. 3 Slickened and grooved fault surface, exposed by removal of the rock on the near side of the fault. Movement was somewhat oblique on a dominantly horizontally slipping fault.

The significance of this fact is that, with southern California so largely dependent on pumped water for its huge and rich agricultural industry, it is most fortunate that high mountains, causing moderately heavy precipitation on the basinward slopes, shed annually large quantities of water to the lowlands. The cubic miles of gravel and sand, porous and pervious, which have accumulated on the subsiding fault blocks serve as excellent underground reservoirs, but in the long run only as much water can be pumped from each basin each year on the average as is contributed to it. The bulk of the water added annually to replace that withdrawn during the previous irrigation season comes from the mountains. It finds its way underground most readily on the upper parts of the fans, where the stream issuing from the bedrock canyon flows usually for some miles over the coarse gravel forming the apical part of the cone. Were it not for the high upfaulted mountain blocks around us and in our midst, the underground water available for agricultural, domestic, and industrial use would be very limited. With a much smaller safe yield of underground water this region would not have been able to develop nearly so rapidly, its wealth would have increased much more slowly, and the cultural development permitted by wealth and leisure would consequently have been greatly retarded.

COASTLINE AND SEA BOTTOM

The present position of the shoreline of the Pacific in southern California, as elsewhere, is determined largely by the present general elevation of the land; for instance, a general uplift of a few hundred feet would drive the strand many miles westward. But the pattern of the coastline—its promontories, points, bays, and other indentations — is largely the result of recent faulting and folding, modified in an important way by wave erosion. In general, the promontories result from anticlinal uplift or rise of fault blocks; the embayments result from depression along the coast or erosion of the less resistant formations which commonly lie in the depressed parts of the shore.

Even though new sediments are supplied plentifully to the waves and currents along the California shore and are used to smooth out the irregularities of the seabottom by filling in the depressions, the sea floor off our coast has a configuration resulting largely from recent deformation by faulting and folding. Great closed depressions occur in it, as yet unfilled by recent waste washed from the land. Long ridges rise above the general level. Islands like San Clemente and probably also Santa Catalina are merely the emerged edges of uplifted fault blocks.

In summary, then, it can be stated that while faulting causes our earthquakes, it has likewise given to southern California the fortunate and attractive characteristics which the land now possesses.

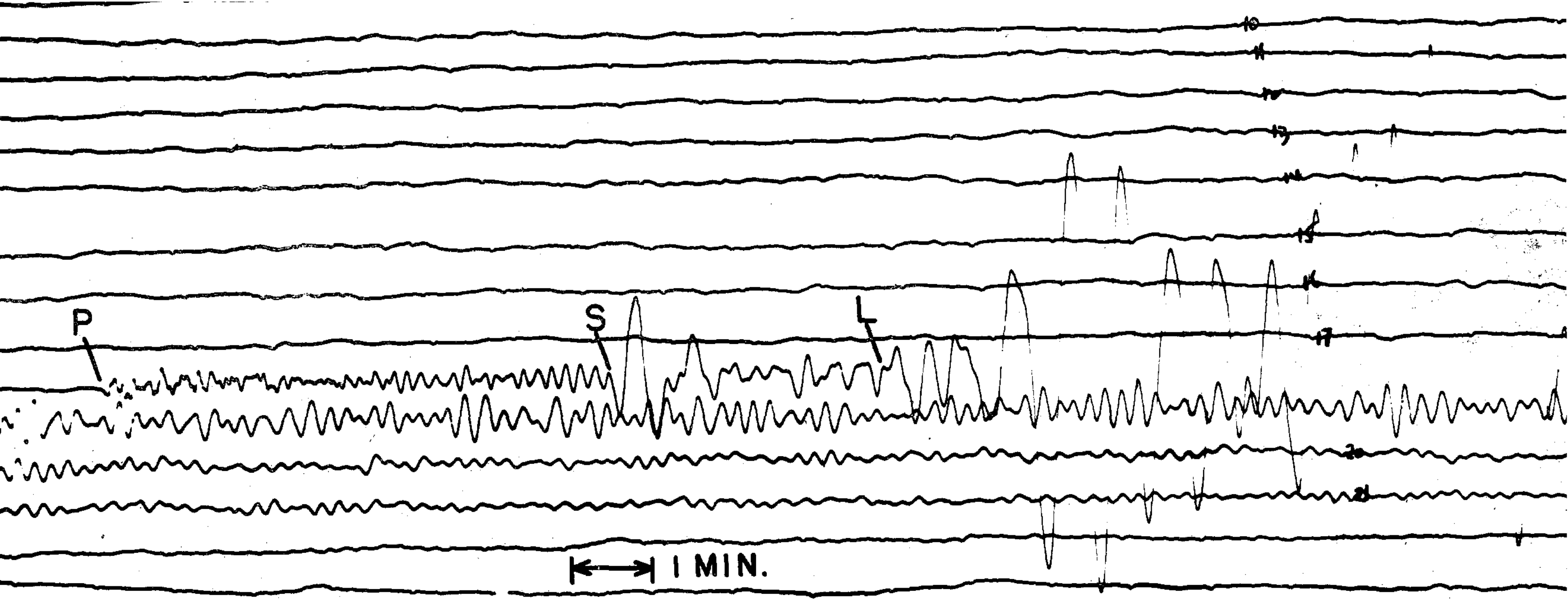


Fig. 1 Record of earthquake July 18, 1934; origin in western Panama; distance from Pasadena about 4600 km; recorded by Benioff strain seismograph.

A Geophysicist X-Rays Mother Earth

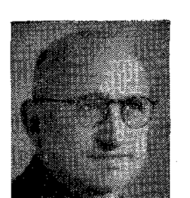
By BENO GUTENBERG

IN much the same way that the X-ray furnishes the physician with data on the internal state of the human body, so the study of seismograms provides the geophysicist with one of the important sources of information concerning the interior of the earth. There, however, the comparison ceases, for seismograms not only give evidence of current happenings within the earth's interior and crust, but likewise offer opportunities to investigate mathematically many theoretical problems relating to their interpretation.

About 50 years ago it was found that seismograms such as the one given in Fig. 1 consist of three major parts: The first impulse (P) from longitudinal waves through the interior of the earth, the second impulse (S) from transverse waves along similar paths, and the main movement (L) resulting from surface waves. Only a few years after these phases had been identified, exact theoretical means were developed to calculate the velocity of P and S waves in the interior of the earth and to construct the rays and the wave fronts. Fig. 2 shows such a picture for longitudinal waves. It indicates the seismic rays arriving at distances 10 degrees of arc apart, and the wave fronts from minute to minute of time. The most striking feature in the figure is the earth's core. Its depth was found about 40 years ago to be 2900 km (approximately 1800 miles) and many later investigations have confirmed this value within about 20 km. At the surface of the core the velocity of longitudinal waves decreases suddenly from about 13¾ km/sec outside the core to approximately 7½ km/sec inside. No transverse waves have been identified thus far inside the core. About 1200 km from the center of the earth the velocity increases again rather rapidly. This causes the rapid change in direction of seismic waves at that depth (Fig. 2). Details regarding this phenomenon are not yet known. The entire picture resembles very much the paths of light in an optical system, including focal points (caustics) at several distances, as well as shadow zones.

There are in addition numerous waves more complicated in character, some of which are indicated in Fig. 3. Waves reflected from the surface of the core have been used for the more accurate determination of its radius. The boundary must be very sharp as waves with a wave length of 10 km, or even less, are reflected. The entire picture is more complicated than in optics because rays arriving at a discontinuity produce not only reflected and refracted waves of the same kind, but also refracted and reflected waves of another kind (S waves if a P wave is incident, and vice versa) so long as the critical angle of incidence is not reached. Waves of the type marked P′P′ in Fig. 3 which completely traverse the earth twice are observed rather frequently; waves P′P′P′ require about an hour to reach a given station Their observation demonstrates that the absorption of energy in seismic waves is rather small.

About 25 years ago the first proof was obtained from seismograms that earthquakes may occur as much as 700 km below the surface of the earth. Earthquakes with deep foci have been studied since that time by use of a variety of phenomena. The deeper the focus of a shock, the earlier do the P-waves arrive near the anticenter of the source. The observed differences exceed one minute. At the same time, stations near the source show a corresponding delay in arrival times. In ac-



Beno Gutenberg, professor of geophysics and director of the Seismological Laboratory, received his Ph.D. at the University of Gottingen in 1911. Since joining the Institute staff in 1930, he has given courses in physics of the solid earth, the oceans and the atmosphere, and in theoretical seismology. At the Laboratory he is working on research concerning the structure of the earth's crust, and jointly with Dr. Richter in determining the seimicity of various parts of the earth. During the war Dr. Gutenberg did research and advisory work which included investigations on the finding and locating of hurricanes by using amplitudes and directions of microseisms recorded by seismographs. Last summer the Navy sent him to the Pacific microseismic center at Guam and then to the Philippines for selection of an additional instrument site, and the Army requested his visiting seismological research centers in Tokyo to advise concerning their future operation.

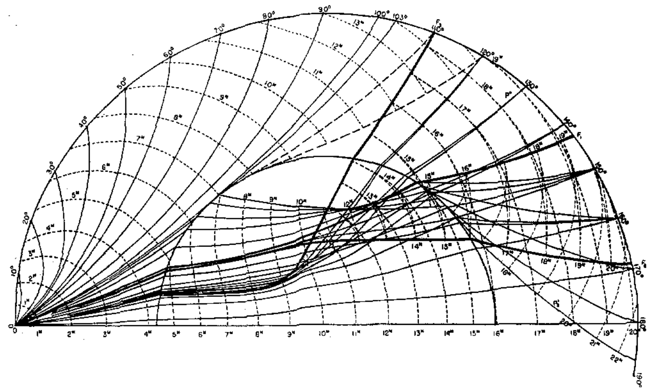


Fig. 2 Cross-section through the earth, showing wave paths of longitudinal rays and wave fronts.

cordance with theory, surface waves become weaker and weaker as the source gets deeper and deeper. In addition, new types of waves become clearer. Not only is there a point of reflection of waves at the surface of the earth approximately half way between the source and the station (resulting in the phases PP and SS), but there is an additional reflection near the focus (pP and sS). These waves follow the direct waves after a time interval which increases with focal depth. Some of them are indicated in Fig. 3. In addition to the reflections mentioned thus far, there are also those due to the transformation from one kind of wave into another (for example, PS, sP, etc.), as mentioned above. Such phases are readily seen in Fig. 3, since longitudinal waves are indicated by full lines and the transverse by barred lines. Thus far the theory has been in excellent agreement with the observations, and a number of phenomena have been found first by the theory and later verified by observations, and in several instances independently.

Observations in various regions agree within a few seconds. However, evidence is clear that the surface layers produce differences within such limits. In addition to variations in the thickness of sediments there are definite local differences in structure down to at least 60 km. Seismograms of near-by shocks furnish information in the investigation of these differences. They show, for example, that at least in some regions, "roots" exist beneath mountains. Certain surface layers in which waves are propagated with low velocity extend to greater depth under mountain chains than under the adjoining plains. The situation is similar to that of an iceberg floating in water.

Shadow zones at distances of about 1000 km from the source, for both the P and S waves, indicate that there is a slight decrease in wave velocity at a depth of approximately 80 to 100 km. This is quite likely due to the increase in temperature, approaching or even surpassing the melting point of the rock at that depth. This also explains the fact determined from gravity observations that most of the earth's crust is in approximate hydrostatic equilibrium. However, regions are known in which gravity observations clearly indicate that the equilibrium is greatly disturbed. In these areas the occurences of earthquakes at various depths are a consequence (and an indication) of such disturbing processes, the details of which are not well understood. It has also been found that a very strong correlation exists between positive gravity anomalies (local excess of mass in the earth's crust), volcanoes, and earthquakes at a depth of 100 to 200 km.

Methods identical with those employed in a study of the earth as a whole are now applied to an investigation of the structures in superficial layers of the earth's crust. These have considerable economic interest. For example, man-made explosions are released and as a consequence the direct as well as the reflected waves (like PcP in Fig. 3) resulting from such a disturbance give information as to the presence of geologic structures below the surface of the earth that may contain oil or other mineral deposits. Finally, the propagation of elastic waves through the ocean and the atmosphere is studied (there is no essential difference between seismic, elastic, and sound waves). This particular type of research is now being rapidly enlarged. It furnishes information on problems concerning the oceans and the structure of the atmosphere. It exemplifies beautifully how a few fundamental equations on elastic waves form the basis for the solution of a large variety of problems concerning the interior of the earth, the oceans, and the atmosphere. These problems were investigated originally for purely scientific reasons. It was determined later that the information thus derived had considerable significance in solving practical economic problems. The mathematical considerations proved to be of fundamental value in bringing success to operations that involved the earth, the seas, and the sky during the past war.

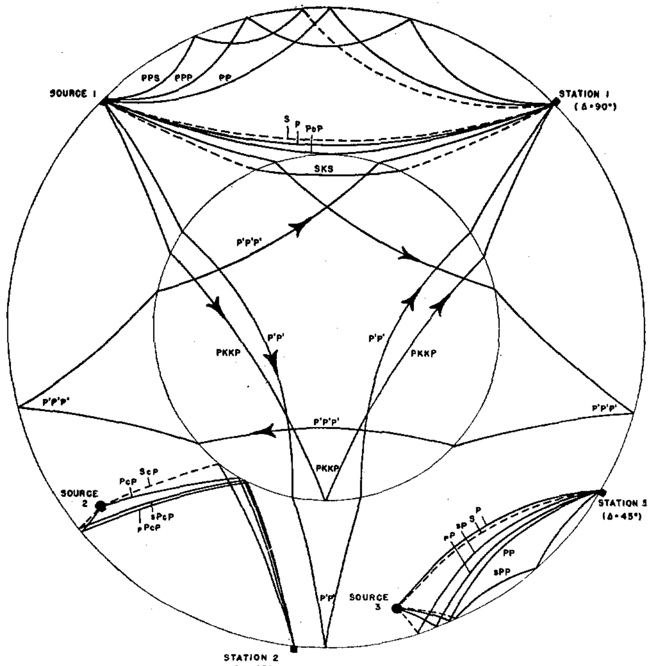


Fig. 3 Sketches of paths of various kinds of waves: Source 1, from a shallow earthquake; Sources 2 and 3, from a deep focus earthquake reflected at the core and at the surface.

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

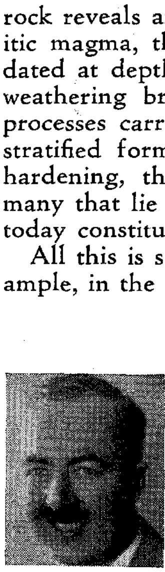
The geologist recognizes, (1) that rocks are made up of one or more minerals—hence training in mineralogy is a necessary first step in petrology; and (2) that rocks constitute the major units that make up our earth. The differences that we find in the earth's "crust," whether these be differences in 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.

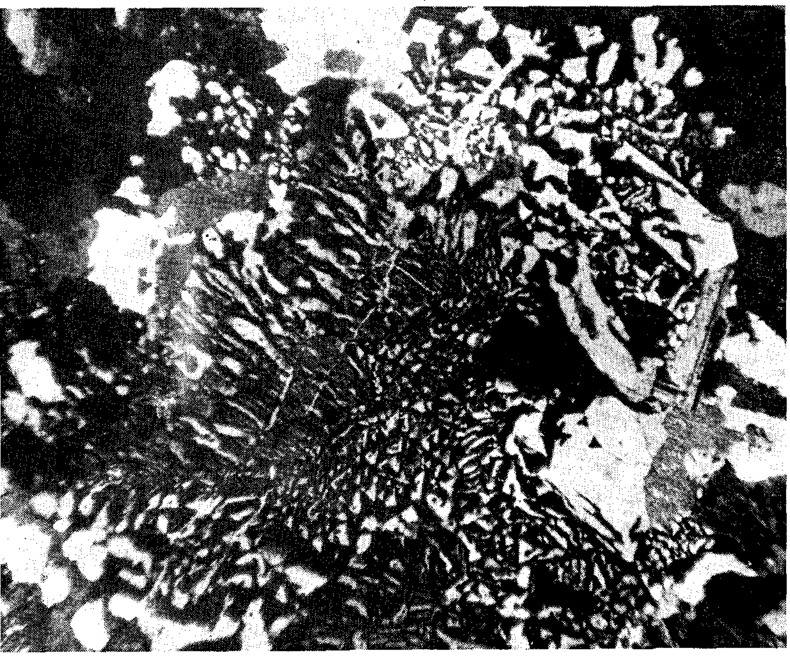
During World War II Campbell was on leave from CIT, and spent two years each in two varied research jobs, with the Geological Survey's strategic Minerals Program, and with UC's Division of War Research, primarily on anti-submarine warfare.

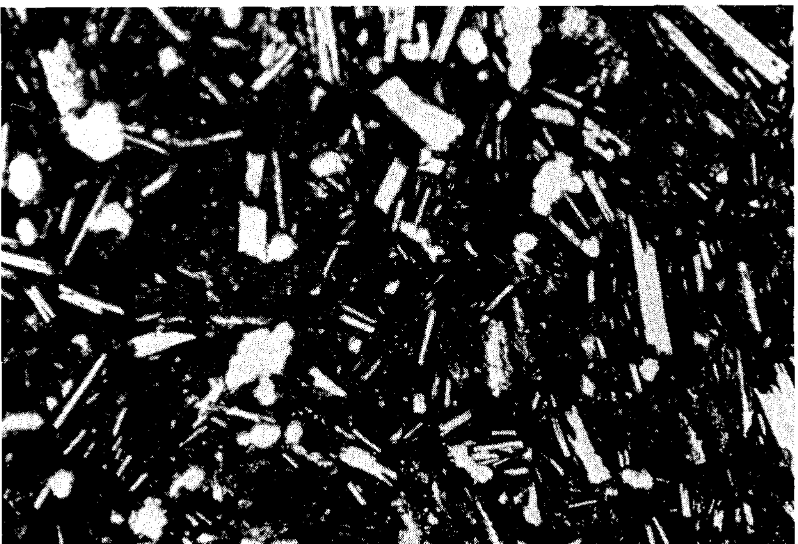
Dr. Campbell's professional activities include service as a committeeman in the AAAS, the Geological Society of America, and in several important AIME posts. He was recently appointed an official delegate of the AIME to the 18th International Geological Congress, which meets in London this summer.

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.

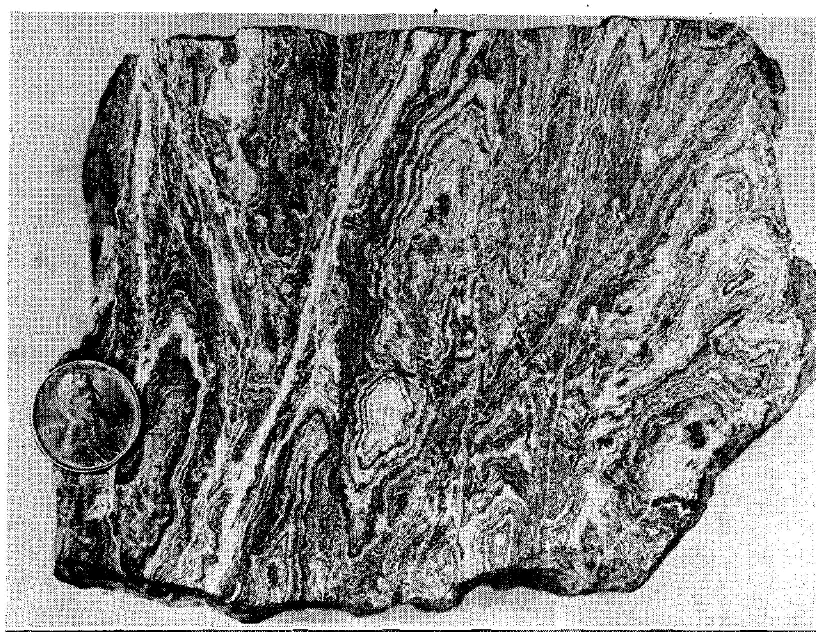


Fig 5 UPPER: "Ribbon rock," Iron Mountain, New Mexico. This is a most unusual variety of the peculiar metamorphic rock type known as tactite. The mineralogy is complex, and in this occurrence is notable for the presence of the rare species HELVITE, a potential low-grade source of beryllium. The district 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.

Seismological Instruments Developed at C. I. T.

By HUGO BENIOFF

INSTRUMENT development has been one of the principal activities of the Seismological Laboratory research program ever since it was started in 1921, under the direction of H. O. Wood, as a minor grant of the Carnegie Institution of Washington. The first instrument to be completed on this program was the torsion seismograph. It was invented by Dr. J. A. Anderson of the Mount Wilson Observatory staff and was developed jointly with H. O. Wood. Essentially, it is a horizontal pendulum in the form of a small mass eccentrically mounted on a taut wire suspension, as shown schematically in Fig. 1. Critical damping of the pendulum motion is provided by a permanent magnet. Horizontal vibration of the ground during the passage of an earthquake wave results in an angular vibration of the pendulum mass. This angular vibration is optically magnified and photographically recorded by means of the mirror attached to the pendulum and the recording drum assembly, as shown in the figure.

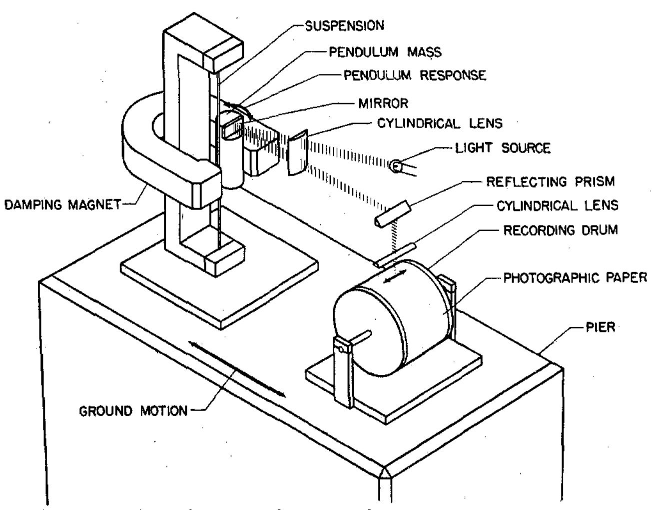


Fig. 1 Wood-Anderson seismograph.

For recording rapid earth movements such as those produced by nearby earthquakes, the pendulum mass is in the form of a small cylinder 2 mm in diameter and 25 mm long. The free period of the pendulum rotating about its suspension is 0.8 sec. With this instrument the magnification, defined as the ratio of light spot displacement to ground displacement, has a maximum value of 2800. For recording the slower wave-movements which are generally produced by distant earthquakes, the pendulum mass is built in the form of a rectangular plate with dimensions approximately 25x8x1 mm. This pendulum has a free period of 6 sec and a maximum magnification of 800. Each station of the California Institute network has two short-period torsion seismographs for recording respectively the north-south and east-west components of the earth movement. In addition, the main station at the Seismological Laboratory has two of the long-period instruments.

Another torsion seismograph in use at the Seismological Laboratory was designed by the late Dr. Sinclair Smith of the Mount Wilson Observatory staff for the purpose of recording strong earthquake movements. The maximum magnification of this device is 4. Instead of one pendulum mass this seismograph has two masses of unequal weight mounted at the ends of a horizontal bar, supported by a torsion suspension through its center.

For many problems the maximum obtainable magnification of the torsion seismograph is too low. Moreover, it was not possible to build a satisfactory torsion instrument for recording the vertical or up-and-down component of the ground motion.

To meet these difficulties a series of instruments was designed in which the pendulum movement generates electric power by means of a variable reluctance transducer. A galvanometer, actuated by this power, records the earth movements. The variable reluctance transducer is in effect an embodiment of the telephone receiver principle. Movement of the seismometer pendulum varies the lengths of a group of four magnetic air-gaps in such a way that two increase in length while the other two decrease in length. The resulting change in magnetic flux through the associated armatures produces an electric potential in the coils surrounding the armatures. The magnetic flux is supplied by a permanent magnet. In order to provide a large electrical output without recourse to amplifiers, the pendulum mass is made rather large, 100 kg (220 lbs). In the vertical component instrument (Fig. 2) the restoring-force is supplied by the supporting spring which is attached at the bottom of the hole in the cyl-

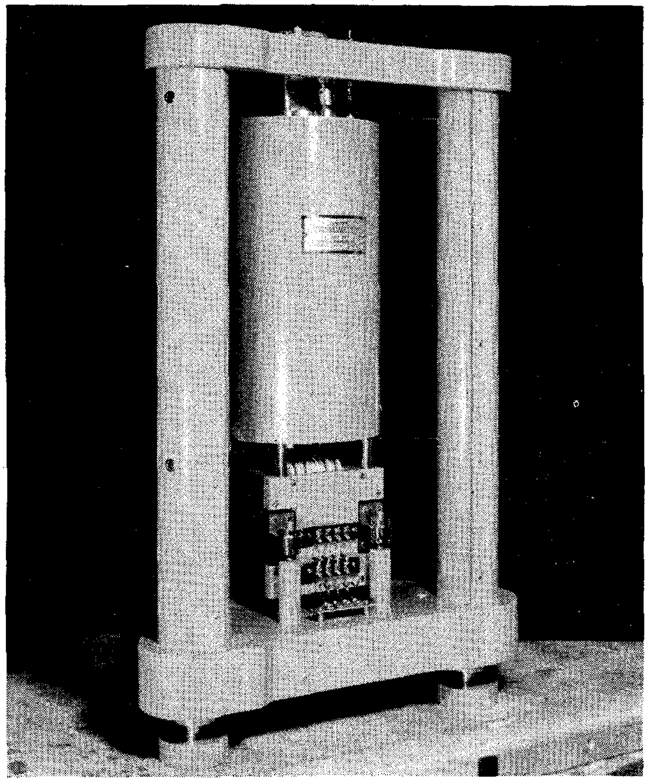
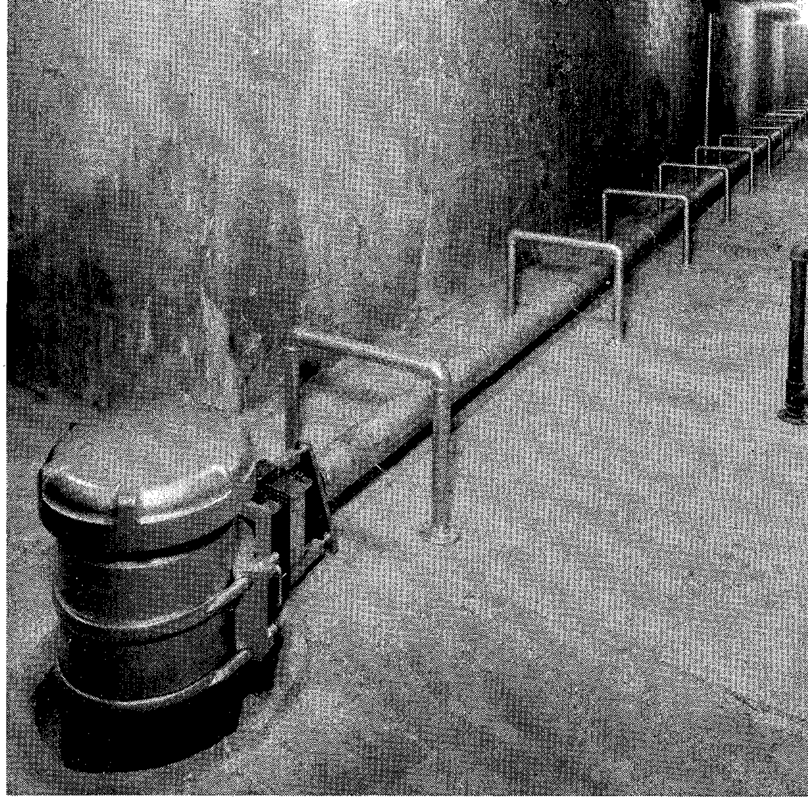


Fig. 2 Vertical component seismometer.

Fig. 4 Electromagnetic linear strain seismograph.



indrical mass. Six steel ribbons are attached to the pendulums in groups of three at each end and to the three supporting posts of the instrument. They serve to confine the pendulum movement to a vertical line. In the horizontal component seismometer, Fig 3, the mass is supported by two of the six constraining ribbons. Restoring force in this unit is provided partly by gravity and partly by the tension of the ribbons. The free period of both the vertical and horizontal component instruments is 1 sec. In practice, each transducer is supplied with two windings for supplying power to two record-

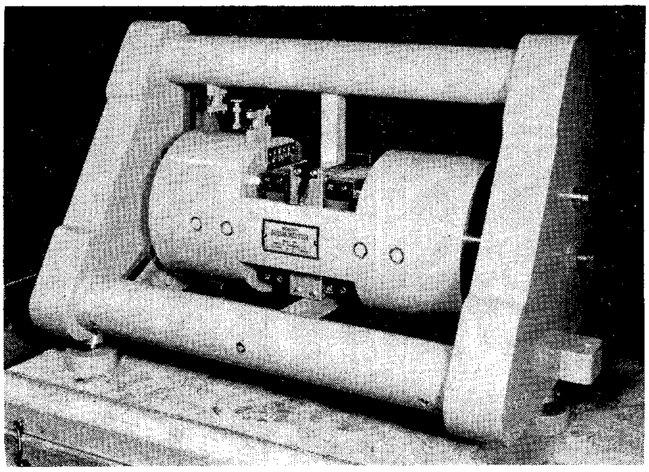


Fig. 3 Horizontal component seismometer.

ing galvanometers operating simultaneously. One galvanometer has a short period (0.25 sec) for covering the high frequency band of the seismic spectrum, whereas the other has a period of from 60 to 90 sec for recording the low frequency portion of the spectrum. With the two galvanometers, each instrument thus covers a frequency range from approximately 5 cycles per sec to 1 cycle in 2 min. The effective magnification of these instruments is limited solely by the ground unrest which is present everywhere on the earth. In regions where the unrest is small, the useful maximum magnification approaches 100,000.

Another new type of seismograph developed at the Seismological Laboratory is the electromagnetic linear strain seismograph. The response of this instrument is derived from strains produced in the ground by seismic waves rather than from the movement of a pendulum as in all other types of seismographs. In effect it consists of two steel piers set into the rock at points 60 feet apart. A 2-in. iron pipe is rigidly fastened to one pier and extends to within a short distance of the other pier. The pipe is supported by 12 wire structures, as shown in Fig. 4, which are longitudinally compliant but quite rigid transversely. When a seismic wave-train traverses the ground in which the instrument is located, the two piers are displaced relative to each other. During a wave compression they approach each other and during a dilatation they recede. This relative movements of the piers produces a motion of the end of the pipe relative to the adjacent pier and serves to actuate a variable reluctance transducer similar to the one previously described. The transducer output power is recorded galvanometrically, as in the seismographs described above. Since the response of this instrument is derived from strains rather than displacements of the ground as is the case with pendulum seismographs, its characteristics differ radically from those of the pendulum instruments. Observations made with this instrument, taken by themselves or in combination with those of pendulum instruments, provide information concerning seismic waves which can not be had from pendulum instruments alone.

The seismograph recording-drums are driven by synchronous motors of special design which operate from impulse currents derived from storage batteries. The impulse frequency is controlled by tuning-forks to a precision of approximately 1 part in 100,000 over a 24-hour interval. The drums rotate once in 15 min. and in a few long-period recorders once in 30 min. The corresponding speed of the paper past the recording light-spot is respectively 1 mm per sec. and 0.5 mm per sec. The storage batteries are charged continuously by rectifiers operating from the power line. The system, therefore, continues to operate for 24 to 48 hours after failure of the line resulting from earthquake or other causes.

Each station of the network is provided with a spring-driven, electrically-wound, marine type of chronometer having electrical contacts which operate once per minute or half minute to actuate time markers on the recorders. In addition, each station has a radio receiver which is automatically turned on seven times daily to record Naval Observatory time signals on the seismograms directly.

(Continued on page 31)

Hugo Benioff, associate professor of seismology, began his scientific work at Mount Wilson Observatory, where he worked summers as an assistant from 1917 until his graduation from Pomona College in 1921. He joined the staff of the Seismological Laboratory, then operated by the Carnegie Institution of Washington, in 1924, after a year at Lick Observatory.

Dr. Benioff's first work at the Laboratory was the development of precise driving systems for seismographic recording drums and a radio timing method for the network of auxiliary stations. Later he developed the variable reluctance electromagnetic pendulum seismograph and the electromagnetic strain seismograph. His seismographs, considered the best available, are operating at stations in all parts of the world.

During the war Dr. Benioff was a research engineer for the Submarine Signal Company of Boston, where he developed numerous sonic, supersonic, and radar devices.

Geomorphology--The Science of Today's Geology

By ROBERT P. SHARP

IN the popular mind geology is a science of antiquity, and the geologist's nonchalant use of millions and billions of years brings only incredulity to the layman. However, geology is not entirely a science of ancient things, for one of its branches, geomorphology, is concerned with matters at the top of the geological time scale.

Geomorphology is defined as the science of landforms dealing particularly with their genesis and evolution. It has a major interest in geologic processes currently acting on the earth's surface and in events of the last 10 to 20 thousand years which, on the geological time scale, correspond to happenings of about 9 or 10 o'clock this morning.

Geology has been criticised by its more exact sister sciences for lack of an experimental approach. Spurred on by such criticism and aided by those sister sciences, geologists have turned to laboratory experimentation with some good results. Unfortunately, the tremendous difference in scale between laboratory experiments and natural phenomena and the impossibility of duplicating the physio-chemical environment attending activities deep within the earth's crust detract from the value of some geological experimentation. Geomorphology is more fortunate in being blessed with the cooperative assistance of an able laboratory technician who daily operates thousands of geological experiments to scale and in proper environment. That experimenter, of course, is nature, and it is largely through observation of natural processes that the geomorphologist unravels the problems of his science. This is not a new approach, nor is it unique to geomorphology, but it finds one of its best developments in that field. Admittedly, some natural processes are too slow to be suited for observation within a man's lifetime, but our newspapers readily attest that this is not a universal handicap. The thorough reader will find mention of an earthquake, volcanic eruption, flood, landslide, or other current geologic activity somewhere in the world almost every day of the year. These recorded events are but a small fraction of the total, for only those of catastrophic nature are reported. Newspapers give ample proof that geology, and more specifically geomorphology, is not wholly a science "of the dead" or, as ungracious critics sometimes remark, "a dead science." Actually, geology is much like a fascinating detective game in which the geologist ferrets out clues of crimes committed oftentimes hundreds of millions of years before. Such ancient clues are naturally obscure, and it is largely by observing similar current crimes that progress is made.

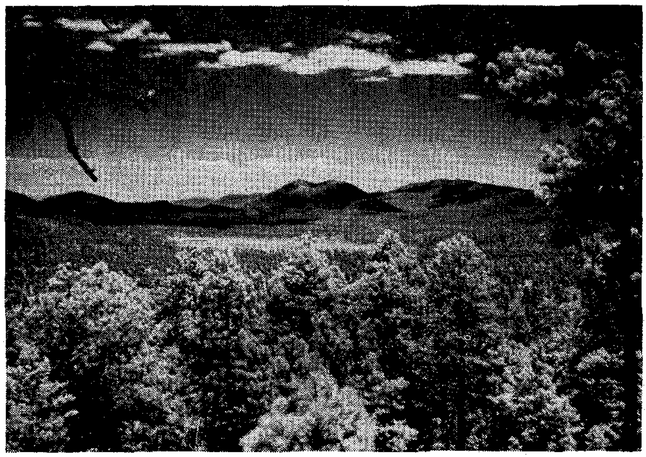


Fig. 2 Sunset Crater and volcanic cones of the San Franciscan volcanic field, Arizona. Features currently under construction at Paricutin can be observed here in a decadent but not too greatly altered state. Latest activity from Sunset Crater was an ash eruption about 1070 A.D.

This is the approach of the geomorphologist. By studying the activities of live glaciers in Alaska (Fig. 4) he is better able to interpret features in canyons of the Sierra Nevada, the Tetons, or the Rockies, which 25,000 years ago were filled with similar streams of ice. For example, high on one wall of a Sierra canyon may be a bedrock bench looking not unlike an abandoned

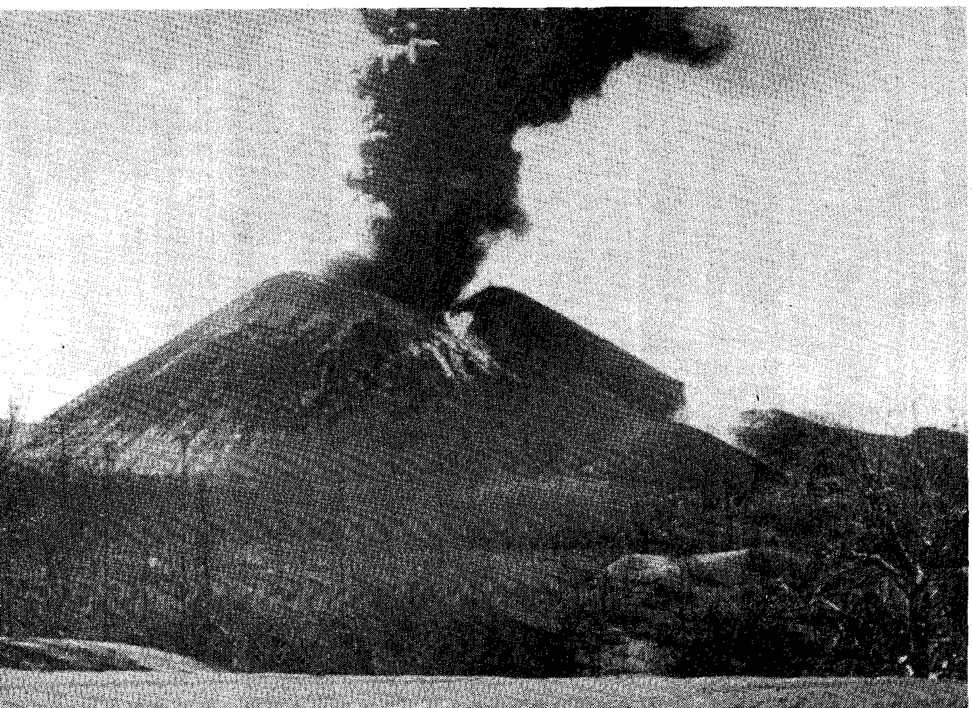
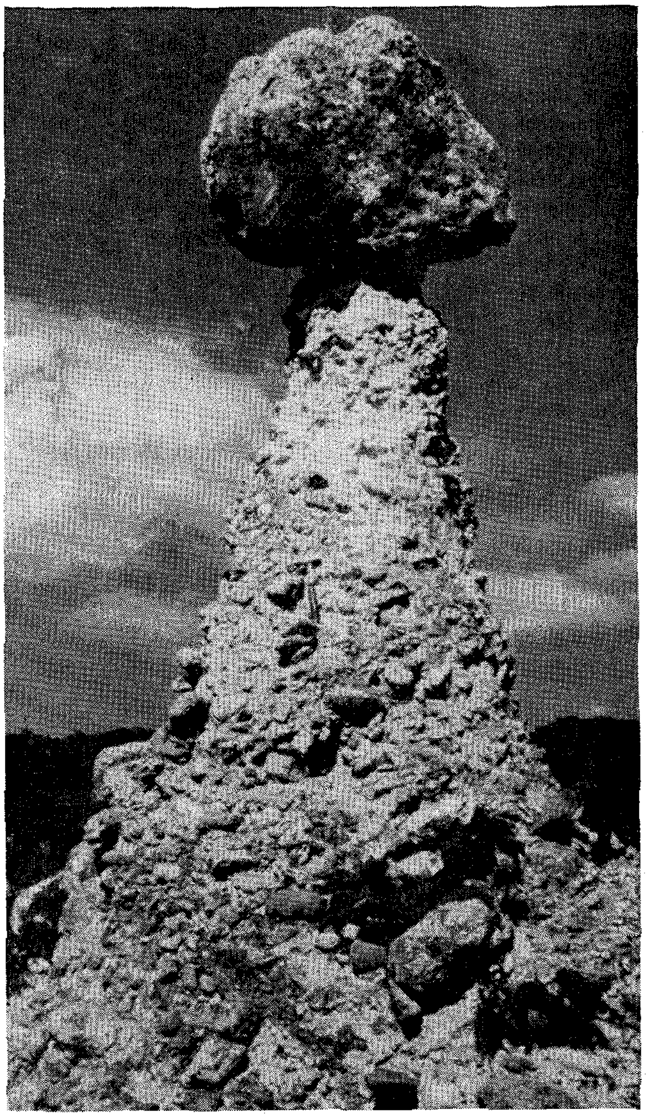


Fig. 1 Paricutin, the currently active volcano in west-central Mexico where nature is busily engaged in operating numerous experiments in volcanism, much to the delight of onlooking geologists. Photo by Donald B. Lawrence.

Fig. 3 **Perched boulder on a pedestal about eight ft. high, *just east of the Big Horn Mountains,* Wyoming. *Similar* features formerly credited to cutting by wind-driven sand are now attributed largely to differential weathering, one of nature's relatively slow processes not too satisfactory for short-time observation.**



highway grade. The genesis of this bench is puzzling until one stands on the edge of a living glacier and sees a powerful stream of melt water rushing down-valley between the valley wall and the edge of the glacier. This stream rapidly carves a narrow channel with the floor and one wall of rock and the other wall of ice. When the glacier shrinks by melting, the ice wall is destroyed and the stream diverted to a lower course, so that its old channel is left as a bedrock bench high on the wall of the main valley. The imaginative scientist may reconstruct this sequence of events in his mind's eye, but it is eminently satisfying to confirm such reconstruction by observing the process in action. Likewise, construction of the imposing lateral moraines near the mouths of glaciated canyons along the east base of the Sierra or in other western mountain ranges is more easily understood when one has camped for a week or two along the margin of a glacier engaged in building such moraines. Signs reading "Slow, Glacier at Work" are not needed, at least in summer, for the constructional activities of the ice are well advertised by the constant sound of falling or sliding debris which piles up along the margin of the glacier to form a sloping apron. This apron becomes a ridge when the ice retreats, and one readily sees that lateral moraines are formed not by the pushing action of a glacier but by accumulation of debris dumped from the ice. Other examples of advantages derived from study of glaciers in action could be cited, but let us turn attention to a warmer subject.

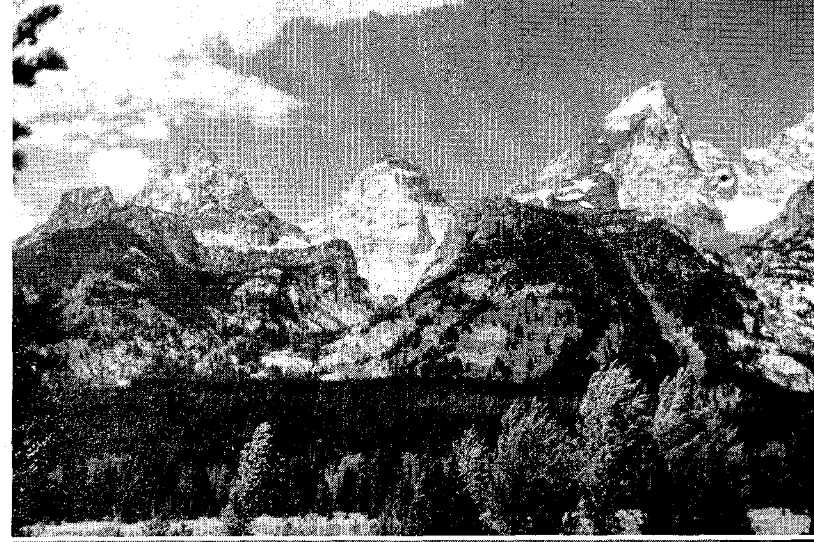
In the province of Michoacan in western Mexico, the volcano Paricutin (Fig. 1) was born on February 20, 1943. In the short space of three months it built a cone 1100 feet high and flows of red-hot lava issued from its base. Geologists of all varieties hastened to this shrine of current geologic activity, and none derived more satisfaction from such a pilgrimage than the geomorphologist. Here he could see in the process of construction many landforms over which he had puzzled in volcanic fields near Flagstaff, Arizona (Fig. 2), the Craters of the Moon in Idaho, or the Lava Beds of northern California. The small "hornitos" or cones built of lava spatter and the curious forms and structures of lava flows are more easily comprehended when one sees them being made. Many persons doubted that the entire side of a large volcanic cone could be floated away on the back of a lava flow until the process was actually observed at Paricutin. The old adage that "seeing is believing" applies to many aspects of volcanic and other geologic activities.

Geomorphology is eminently a pure science. Most of its investigations are motivated by the desire to add to the general fund of human knowledge. A geomorphologist may expend much time and effort in determining why a mountain range has its present form, in proving that perched boulders (Fig. 3) were not "made by the Indians," and in explaining Half-Dome, Yosemite, or Rainbow Bridge, Utah (Cover), to the satisfaction of an itinerant tourist. However, like most pure sciences, geomorphology has many practical applications. For instance, the disasterous Montrose flood of 1934 brought realization to thousands of people that they were living on great alluvial fans built up in large part by floods of the Montrose type. This flood showed that interest in such a mundane scientific matter as the transporting power of running water is powerfully stimulated when a 10-foot boulder is rolled through the living room. The flood control engineer seeking ways to provide protection from fan-building processes finds basic information needed for intelligent solution of this problem in studies made years before by geomorphologists interested only in determining the why, wherefore, and characteristics of alluvial fans.

A California oil company discovered some years ago that it had unfortunately located a number of wells on

Robert P. Sharp describes himself as a "second-phase freshman at the California Institute, having reappeared here in September of 1947, after graduating in 1934." His years between 1934 and 1947 were spent at Harvard, the Universities of Illinois and Minnesota, and in the Army Air Forces. Army activities took him chiefly to Alaska and the Aleutians, included studies of survival procedures and tests of emergency equipment.

Prior to his return to the Institute, Dr. Sharp served as professor of geology at the University of Minnesota, working largely in the fields of geomorphology and glacial geology. In his present capacity of professor of geomorphology he is engaged in setting up research projects which will involve studies of existing glaciers in Alaska and investigations into the products of ancient glaciers in our western mountains.



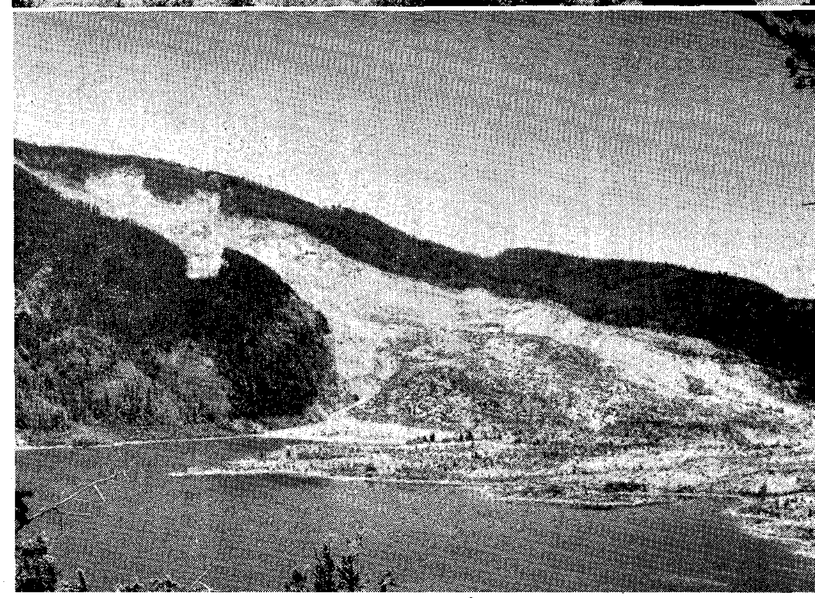


Fig. 5 UPPER: The Grand Tetons, Wyoming. This spectacular bit of American scenery was produced by an uplift on a fault, much in the same manner as the Sierra Nevada or San Gabriel Mountains. Subsequent dissection by streams and glaciers has given the range its present detail and character. Running water and, to a smaller extent, moving ice can still be observed at work in this area.

Fig. 6 LOWER: The Gros Ventre landslide just east of Jackson Hole, Wyoming. Although this slide occurred in 1925, it may be classed as a current geological experiment, for the conditions under which it occurred are known and the products are obvious. The lake formed by damming of Gros Ventre River was three miles long and 200 ft. deep. Part of the dam collapsed in 1927, and the ensuing flood largely demolished the town of Kelly and drowned six or seven people.

a landslide, old but by no means dead. Renewed sliding sheared off well casings, displaced roads, broke pipe lines, tilted derricks, and in general made the oil company unhappy. A student of landslides (Fig. 6) could have foreseen this costly occurrence, and the ultimate means of controlling the slide is to be found in a Ph.D. thesis published simply as a scientific paper dealing with landslides as a natural phenomenon having a hand in shaping many landforms on the earth's surface.

During World War II the U. S. Army was suddenly faced with problems attending operations in Greenland, 85 per cent of which is covered by ice. Glaciologists, a relatively small group of pure scientists operating chiefly within the field of geomorphology, were suddenly at a premium. They were eagerly sought by the armed forces and plied with questions. Can we put weather stations on the Greenland ice cap? What is the bearing strength of ice on rivers, lakes, the ocean? Can we land a large aircraft on a frozen lake near an isolated outpost in order to evacuate a man stricken with appendicitis? Answers to such questions were not always immediately available, but from his purely scientific work the glaciologist had the know-how to get the answers.

When a coastal California city builds a breakwater the natural shoreline processes are disrupted so that the famed bathing beaches of a neighboring city are attacked by waves and currents and partly or wholly destroyed. The neighboring city is unhappy if not distinctly bitter about the entire matter. Solution of this problem is primarily an engineering task, but the basic explanation of what has happened and the key to a proper remedy may be found in an 1890 classic of geomorphological literature dealing with high-level abandoned shorelines of a great lake that once covered much of northwestern Utah.

Thus, the geomorphologist pursues his science by assiduously watching nature perform her everyday geological chores. From these observations he is able to interpret the landforms constituting our present landscape and in so doing provides information fundamental to the solution of problems attending man's constant struggle with his physical environment.

Fig. 4 Muldrow Glacier, Alaska, flowing east from Mt. McKinley, the high skyline peak. Here nature is operating one of her most impressive geological experiments.

The results of similar experimentation performed some 25,000 years ago can be seen in the Sierra and other high western mountain ranges. Photo by Bradford Washburn.

Uncovering the Ancient Life of Mexico

By CHESTER STOCK

ONE of the attractive features of paleontological study is the opportunity it often affords to investigate the geologic history and characteristic life of the past in strange and out-of-the-way places, and on occasion in foreign lands. While thus far it has not been possible for the Division of the Geological Sciences to finance expeditions far afield, the Institute is favorably situated with regard to the exploration of countries near at hand. For the land of Mexico immediately to the south has been until relatively recently a veritable terra incognita in so far as the history of its past vertebrate life is concerned. A little more than a decade ago the Geology Division, with the cordial permission of the Instituto de Geologia in Mexico City, began its paleontological investigations in southern Nuevo Leon, and the discovery of San Josecito cave and its significant and interesting record of life of the Ice Age have been described in these columns (**Engineering and Science Monthly**, September 1943).

More recently the efforts of the Division have expanded in an attempt to penetrate more deeply into the geologic history of Mexico, in the hope that older stages of the fossil record of higher animals (mammals and birds) might be found. In this connection it should be stated that Mexico today, with the exception of its marginal low lands particularly where they border Central America, has many zoogeographic ties with and is closely related to the Sonoran region, as most of the United States is called. This relationship in its animal life existed during the Ice Age, and apparently during the Tertiary as well, although at present only the later stages in the history of life of this period are sufficiently well known to offer testimony that this is actually the case.

For these reasons, it was gratifying that field parties from the California Institute found abundant fossil evidence of an earlier epoch of the Age of Mammals in western Chihuahua. The area is in the drainage basin of the Rio Papigochic near the border of the State of Sonora (see map, Fig. 1). It lies about 175 miles west of Chihuahua City, the principal city and seat of government of the State of Chihuahua. This portion of the State is accessible by a road which traverses the country west from Chihuahua to Cuauhtemoc to Guerrero, thence north to Santo Tomas, through the fossil-bearing area in which are the villages of Matachic, Temosachic, Yepomera, and Rincon. From Rincon the road continues in a general easterly-northeasterly direction to Babicora, Namiquipa to Juarez.

A railroad line over which mixed passenger and freight service is carried about three times a week runs from Chihuahua to Rincon, Madera, Casa Grande to Juarez.

Matachic, Temosachic, Yepomera, and Rincon, all small settlements near which important and productive fossil localities have been discovered, lie in an intermontane basin bordered on the east by the continental divide and on the west by the Sierra Madre Occidental. This is the region traversed by the Rio Papigochic and its tributary, the Rio Boquilla (Fig. 2). The elevation is between 6000 and 7000 feet. The country is largely grass-covered range land with scattered communities and farms where limited tilling of the soil is carried on. No longer is it a region of haciendas, yet the individual landholder sometimes owns a rather large rancho. On the slopes of still higher country grow oak and juniper, with stands of timber (yellow pine) in the mountains. Here, in the more inaccessible parts may still be encountered an occasional group of banditos.

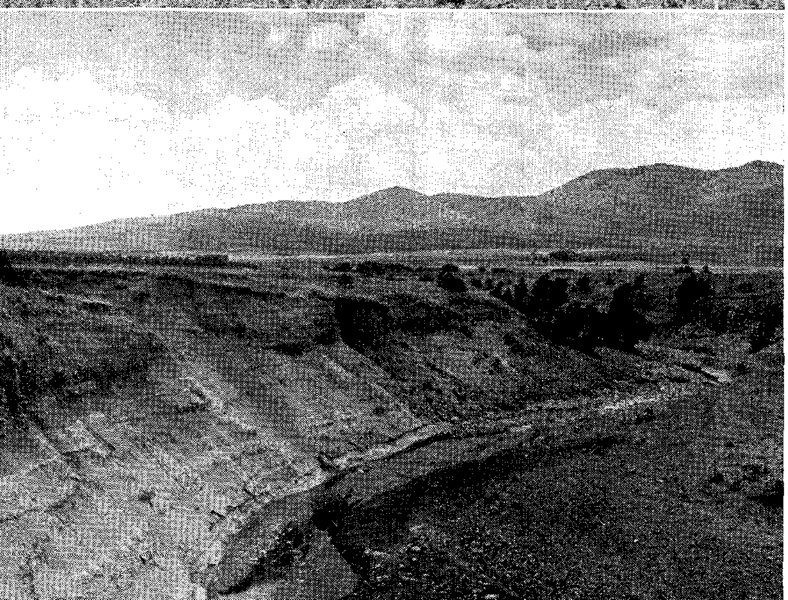
In riding through the valley and mesa area (Fig. 3) from Santa Tomas to Rincon one might readily conclude that the country rock is barren of fossil material, yet a little prospecting of the light-colored outcrops along the arroyos leading down to the Papigochic and the Boquilla tells at once a different story. Figs. 4 and 5 show the succession ot strata and an excavation being worked.

The deposits whence come the vertebrate fossils are several hundred feet thick, and are nearly flat lying. In their upper part they consist of white or light-colored, not well indurated, silts and sands. Interstratified with these sediments are relatively thin limestone strata, the limestone being of fresh-water origin and containing volcanic ash. Lower in this section are greenish clays, thin flows of basalt and sandstone. The fossiliferous strata rest on distinctly older volcanic rocks (flows and tuffs) that are well exposed in the areas bordering the basin of accumulation. In places the the mammal-bearing beds are overlain by gravels laid down at a later time.

The fossil remains consist of bones and teeth. No complete skeletons are found, nor are skulls well preserved. Limb bones that are sturdily constructed are complete, but many are broken. Skulls are shattered and only the hard parts like teeth, and an occasional horn-core, are well preserved. The light-colored sediments particularly have yielded literally thousands of horse teeth, as a rule individually preserved but sometimes forming a series in a fragment of the skull or lower jaw. On the other hand, sufficient is known of some skulls to permit restoration of these types. (Fig. 6). Bird remains are rare.

The assemblage as a whole is a distinctive one, because of the variety of types which comprise it, and because the clear relationships of these animals furnish definite evidence of the geologic age of the formation

Fig. 1 Outline map of Mexico. Cross shows location of fossil-bearing Pliocene deposits in western Chihuahua.



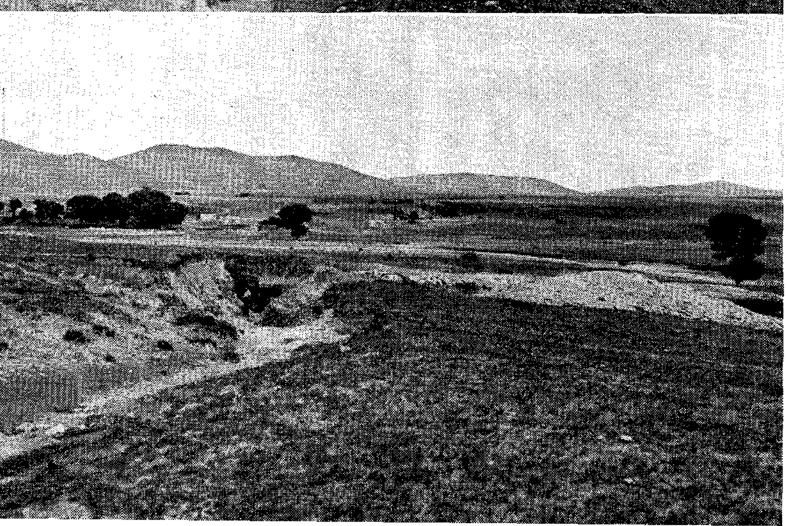


Fig. 2 The Geology Division Dodge Power Wagon crossing the Rio Boquilla north of Yepomera, Chihuahua, Mexico, in the basin of the late Tertiary rocks where fossil mammalian remains were found.

Fig. 3 View looking over the mesa south of Yepomera, Chihuahua, Mexico. Top of Power Wagon was frequently used as a vantage point from which the topography and geology of the region could be sketched. Picture shows graduate student Lloyd Pray, M.S. '43, mapping the fossiliferous deposits.

Fig. 4 View looking south showing exposures of Pliocene deposits along the Arroyo Huschin, western Chihuahua.

Fig. 5 Fossils were frequently found in bank of arroyos cut into the mesa country around Yepomera. Arroyo Los Ponos shown in foreground with excavation made during collecting of fossil material.

in which they occur. As may be surmised, the horses are the most abundant fossil mammals, and they represent at least four kinds. A small horse, measuring slightly more than three feet in height at the withers, possessed teeth in an advanced stage of evolution. It was likewise progressive in the development of its feet, because it appears to have possessed a single functional toe on each foot. With this horse occurred a still smaller form and two larger kinds. Two of these retained the more primitive construction of the foot in which three toes are present. Associated with the horses are rhinoceroses, camels, peccaries, six-horned antelopes, mastodonts, rodents, and rabbits. Along with these herbivorous animals were predatory types like wolves, coyotes, foxes, a great short-faced bear, several kinds of felines, and badgers. A fossil species of flamingo has been described from these deposits.

The assemblage is related in age to a fauna described a few years ago from the Hemphill beds in the Panhandle region of Texas. The latter and similar faunas found elsewhere in Texas and the middle west are regarded as of middle Pliocene age. The Rincon fauna or, as it may be better called, the Yepomera assemblage, on the basis of the stage of evolution of the mammals which comprise it, is later in time than that from the Panhandle, and belongs to a late stage of the middle Pliocene. From the standpoint of the evolution of the horses, the Yepomera species show, for example, an interesting advance beyond the forms known from Texas. The Neohipparion, a horse with many distinctive characters but not on the main line of descent to modern equines, represents definitely a stage in advance of the species from the middle Pliocene of northwestern Nevada, previously described in this journal (**Engineering and Science Monthly**, January 1945).

Perhaps the most remarkable fossil mammal, new to science, found in the Yepomera deposits is an antelope with six horns, three on each side of the top of the skull above the orbits. The restored head of this creature is shown in Fig. 6 in comparison with the head of a modern pronghorn antelope. The horn cores of each side consist of a large prong projecting forward and two prongs in back, arising from a common base, projecting upward and backward.

The history of the region during this stage of the Pliocene, reconstructed from the geologic and paleontologic facts, is that of a lake basin of considerable size with water deep enough to permit in the course of time the deposition of 200 feet or more of clastic sediments, and likewise limestone. During the period of accumulation, volcanic activity in the region gave rise to lava flows and ash showers. Moreover, in the progress of this episode, animal remains were washed into the lake and widely scattered before burial took place. Whether or not the imperfect preservation was due to the oper-

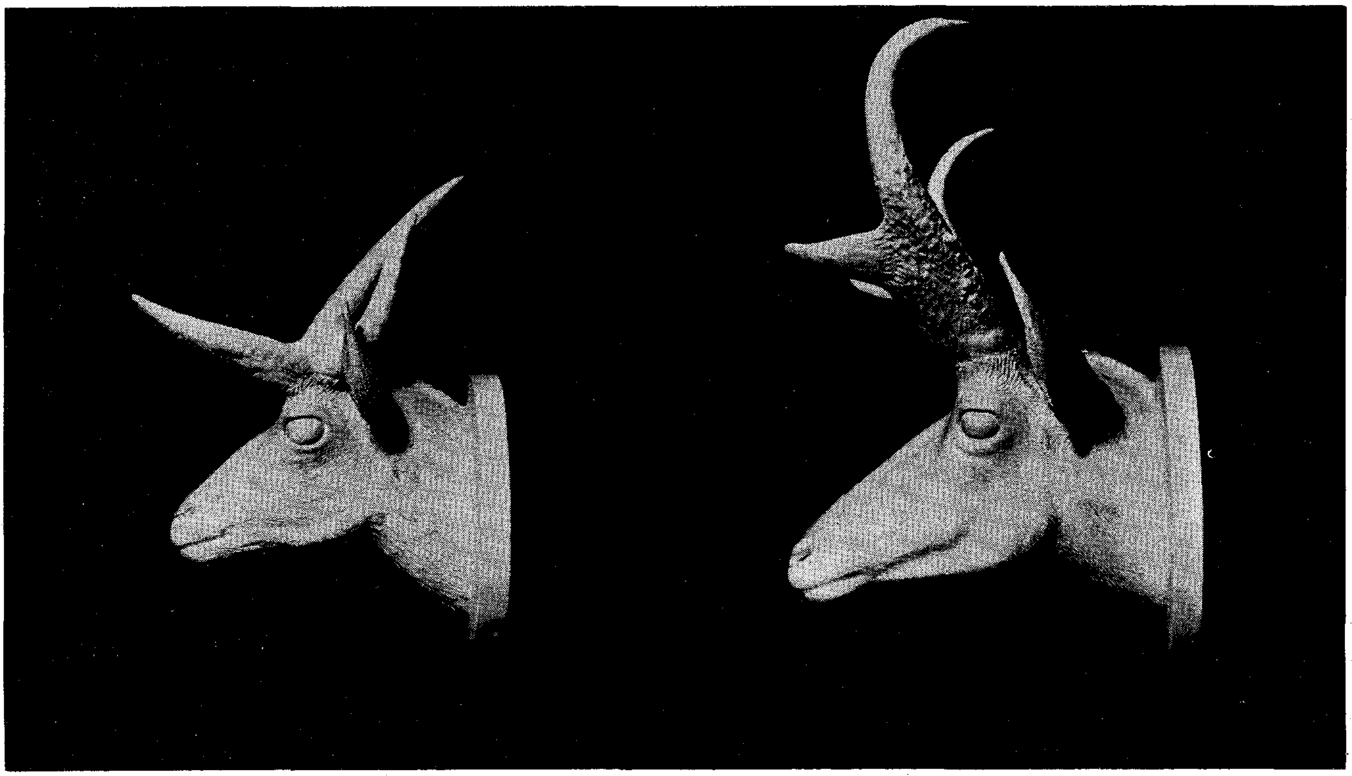


Fig. 6 Restoration of head of extinct 6-horned antelope from the Yepomera Pliocene deposits (on left), and of head of modern pronghorn antelope (on right). Both to the same scale. Restorations by Wm. Otto.

ation of destructive agencies when the organic remains were being transported to their final place of burial, has not yet been determined.

It is apparent from the wealth of material available that the areas immediately adjacent to the lake basin must have been well stocked with animal life. Large herds of horses roamed the country. With these were to be seen on occasion rhinoceroses, the latter representing some of the last of their kind before extinction removed them forever from the native animal world of North America. Smaller herds of camels, antelopes, peccaries, and a few mastodonts give further evidence of the richness of the mammalian assemblage. Large and small carnivores were present, but in fewer numbers, of course, than the herbivores. The hyena-like dogs, known by well-preserved remains at the Panhandle locality, are not so much in evidence in the Mexican assemblage. Small flamingos living in and along the borders of the lake added a picturesque feature to the environment. The remains of flamingos indicate that breeding birds were present at this locality. It is the oldest known occurrence of fossil flamingos in North America.

Only a beginning has been made in the exploration of this part of Chihuahua. The Division of the Geological Sciences plans to continue its geologic and paleontologic studies in the region this year.

Seismological Instruments Developed at C.I.T.

(Continued from page 25)

Thus, under good conditions, the progress of a seismic wave across our network of stations can be measured with a precision of approximately 0.1 sec.

Formerly all seismograms were recorded on 12-x36-in. bromide photographic paper sheets. Since some 30 sheets per day are regularly used in the whole network of stations, the cost for paper is rather high. Moreover, the problem of storage of some 10,000 large sheets per year has been serious. To overcome these difficulties, a film-recorder was developed recently for use with 35 mm motion picture film. The resolving power of film is so much greater than that of paper that a single strip 36-in. long serves for a 24-hour record and actually shows more detail than the large paper sheet. The cost of the film is about one-fifth that of the paper and the storage space required is greatly less than that for paper.

Like the surface of the ocean, the earth's surface is never at rest. It is continuously disturbed by waves, the components of which have varying amplitudes, frequencies, and directions of travel. These minute waves are known as microseisms. Some microseisms are man-made, such as those resulting from traffic and explosions. Others are clearly produced by natural causes. In order to study the possible relation between microseisms and atmospheric pressure variations, a microbarograph was developed. The instrument has a conical diaphragm flexibly sealed in the side of a closed cubical box. A coil attached to the diaphragm is immersed in a permanent magnetic field. Fluctuations in atmospheric pressure move the diaphragm and thus induce electric potentials in the coil. The coil is connected to a galvanometric recorder similar to the ones used with the seismographs previously described. The usable sensitivity of this device is limited solely by the residual atmospheric unrest or noise.

It becomes evident from the description of instruments given above that a modern seismological laboratory requires a miscellany of specialized types of recording and timing devices to obtain the fundamental data on which seismological investigations are based. More than that, the task of planning and building these instruments is never completed. As seismological studies progress, the development continues; not only are better devices evolved, but entirely new instruments are created. The limit of this development seems at present to be defined principally by the ingenuity of the creator.

ALUMNI NEWS

BY-LAW CHANGES OF CONCERN TO CHAPTERS

THE chapters of the Alumni Association form an important part of that organization to carry on activities on behalf of the Institute and to provide a means of maintaining friendships in areas remote from Southern California. The Board of Directors realize that members who live a considerable distance from the home area and who reside in and around cities where there are many Tech men, cannot participate in the activities organized by the home group. In order to stimulate activity and to assist in programs, the Board of Directors has provided, over a period of years, financial assistance to active chapters. The means by which this financial assistance has been given to the chapters has varied from year to year. In the immediate past, it was necessary for the chapters to prepare lists which would be checked in the Alumni Office and then returned for rechecking. In the interest of eliminating much of the red tape, the Board of Directors amended the By-Laws so that it was only necessary for the Chairman and Secretary-Treasurer of a chapter to make a request and certify to the activity of the chapter. Previously it was necessary to make this request before September 1 of any given year. Some of the chapters found that it was difficult to meet this deadline.

In view of these facts, the Board of Directors at its meeting of December 15, 1947, amended two sections of the By-Laws pertaining to the chapters. Section 5.04 now strongly recommends at least four meetings per year, whereas the former By-Law required at least four meetings per year. Section 5.06 gives more time for the chapter officers to request remission of a portion of the dues to the chapter. Stimulation of chapter activities is healthy and it is through these chapters that very great assistance will be given to the Institute in its student candidate selection program and in its fund raising program. The sections as amended are as follows:

Section 5.04—DUTIES OF CHAPTER OFFICERS

Chapter Officers shall cooperate with the Association, its officers and directors, in membership campaigns, fund raising drives, California Institute of Technology student candidate selection efforts, and other association activities as requested by the Board of Directors or its representatives. Said officers shall currently notify the Secretary of the Association of any changes in personnel of chapter officers. They should arrange at least four (4) meetings per year of the chapter members, notifying each chapter member of the time and place of such meetings and shall send notices and reports of such meetings to the Secretary of the Association. The Chairman and Secretary-Treasurer shall submit to the Secretary of the Association such reports and accountings as the Board of Directors may require from any chapter.

Section 5.06—APPORTIONMENT OF DUES TO ACTIVE CHAPTERS

Upon request of the Secretary and Chairman of a Chapter, the Treasurer of the Association shall remit once each fiscal year to each chapter a sum equal to fifteen percent (15%) of the annual dues of an individual member of the Association multiplied by the number of chapter members of said chapter, to assist the chapters in meeting their expenses, including the mailing of notices to members. Such requests shall be honored automatically if made before January 1 of the current fiscal year and may be honored at the discretion of the Board of Directors of the Association, if made subsequent thereto. The amount due shall be computed upon the basis of the chapter membership as shown by the records of the Association as of December 1 of the current fiscal year.

With the Board

DOUG Sellers, director in charge of chapters and membership, reported at the December meeting of the Board that membership had again reached an all-time high, totalling 1978 members. Sixteen hundred were annual members and 378 were life members. This is 131 more than at the corresponding time last year.

Further signs of the vitality and vigor of the Association are indications from several cities that alumni there are about to form new chapters. With three present chapters we may soon have a total of six or seven.

* * * * *

Jim Bradburn announced that the new Alumni Directory would soon be ready and would be sent to Association members as one of the services covered by their dues. The price to non-members will be $1.

It was pointed out that the By-Laws provide that dues for membership on or after February 1 for the remainder of the year shall be only half the annual dues. Thus a non-member alumnus can become a member from February 1 to June 30 and receive the Directory for only $2. This $2-payment will, of course, entitle the alumnus to full membership privileges at the time of the annual seminar.

FINANCIAL STATEMENT OF THE ALUMNI ASSOCIATION

The financial statement of the Alumni Association for the period July 1, 1946 to June 30, 1947 is given below as audited by G. H. McFarlin '25.

BALANCE SHEET -- June 30, 1947

ASSETS

Cash		$ 4,943.08
Accts. Rec.		1,444.10
Investments:		
C. I. T. trust	$19,150.00	
U. S. Treasury Bonds	222.00	19,372.00
Furniture and Fixtures		221.04
Inventory of paper		730.00
Postage deposits		34.46
Total Assets		$26,744.68

LIABILITIES

Accounts payable		$ 2,505.44
Commissions payable:		
R. C. Colling & Associates	$ 50.16	
Agency	111.17	161.33
1947-48 due pd. in adv.		3,201.00
Life membership reserve		
Fully pd. life. mem.	19,150.00	
Partial pymt. life mem.	1,800.69	20,950.69
Total liabilities		$26,818.46
EQUITY		
Equity deficit July 1, '46	(109.66)	
Excess of inc. over exp. yr. ended June 30, '47	35.88	
Equity def. 6-30-47		(73.78)
Total Liabilities And Equity		$26,744.68

STATEMENT OF INCOME ALUMNI ASSOCIATION Year Ended June 30, 1947

INCOME

Dues	$5671.25		
Int. on trust funds	672.60	$6343.85	
Less reserve for subsc to E&S Monthly		3766.00	$2577.85
Gain on trust fund trans.			92.45
Life memberships realized			151.25
Social Committee:			
Adm. to functions		1472.13	
Less expenses of functions		1314.60	157.53
Program Com.:			
Adm. to prog.		1403.25	
Less exp. of programs		1356.19	47.06
Seminar Com.:			
Registration & other fees		777.00	
Less exp. of seminar		636.75	140.25
Miscellaneous			19.09
Total Income			$3185.48

EXPENSES

Administration:			
Directors exp	$ 221.90		
Dues and subscr	25.00		
Services	1280.56		
Sups. & Misc.	385.73		
Postage	470.59		
Printing	195.98	$2579.76	
Chapters		66.00	
Memberships:			
Printing	87.66		
Sups. & Misc.	13.31	100.97	
Placement		250.00	
Undergraduate assistance		130.00	
Total expenses			$3126.73
Exess of inc. over exp. before E &S Monthly			58.75
Net exp. of E &S Monthly			22.87
Excess of inc. over exp.			$ 35.88

STATEMENT OF INCOME ENGINEERING & SCIENCE Year Ended June 30, 1947

Income			
Subscriptions			
Alumni		3766.00	
Student		36.30	
Other		798.50	4600.80
Advertising			4988.50
Miscellaneous			501.65
Total Income			10090.95
Expenses			
Advertising commissions:			
Agency	492.16		
Colling	628.31	1120.47	
Discounts allowed		64.42	
Engraving		766.99	
Managing editor		1885.00	
Mileage		72.05	
Miscellaneous		392.21	
Office Supplies		88.48	
Paper		1206.86	
Postage		96.51	
Printing		4420.63	
Total expenses			10113.82
Net Expense			22.87

Auditor's statement submitted December 15, 1947:

This is to certify that the undersigned has audited the books of the Alumni Association, California Institute of Technology as of June 30, 1947 and to the best of my knowledge found them in order and both balance sheet and operating statement correct.

(signed) Gerald H. McFarlin
Auditor

First 'CANCER MOBILE'

"*TO make the benefits of x-ray available to more and more people...*" That has been the goal of General Electric x-ray specialists since 1913, when the company's energies were first directed into x-ray research by the work of Dr. William D. Coolidge.

Now, with the development of the Cancer Mobile by the combined efforts of the Kentucky division of the American Cancer Society and General Electric, x-ray facilities will be carried into the most remote areas, and to the humblest homes.

The farmer's wife with the lump in her breast, the village store clerk whose voice has dwindled to a hoarse whisper, no longer need live in fear for months wondering whether or not they have cancer. Rural doctors who lack x-ray facilities will use the bus for their private patients. But in addition, those unable to pay will receive free examination.

The Cancer Mobile goes into action along trails of service already marked out by more than fifty mobile tuberculosis-control x-ray buses equipped by General Electric.

You can put your confidence in

GENERAL ELECTRIC