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AMERICAN GEOLOGY, 1850–1900[1]

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IN 1850 the knowledge of geology was in an early exploratory stage, especially in America. In England and Europe sufficient progress had been made in the study of the stratified rocks and their contained fossils to contrast markedly with American lack of observations. It could not have been otherwise. The first task of a geologist, entering upon a new field, is to discover and locate the various rock formations. He must have a map, upon which to delineate their distribution. But in 1850 the mapping of America was very crude. Even the eastern country was known only in broad outline and the west was imperfectly explored. Nevertheless, by 1850, material progress had been made in determining the ages and distribution of the sedimentary rocks of the United States east of the Mississippi and of Canada. Logan of Canada, Hall of New York, the Rogers brothers of Pennsylvania and Virginia, Safford of Tennessee, and many others who felt the urge to read the record in the rocks, had identified the strata of certain great periods of geological time, had classified them in order of relative age, and had mapped them with such accuracy as the conditions permitted.

That they had been able to accomplish so much was in part due to the fact that the great leaders in English geology, Sedgewick and Murchison, had established for that country a succession of strata and fossils, which is the same as that of eastern North America.

[1] Abstract of address before the American Philosophical Society, February, 1942.

It may not be assumed that the similarity is a matter of course. Had the Americans been studying the Pacific side of the continent they would have found great dissimilarities. But it is fact, though as yet unexplained, that each ocean basin has been the scene of similar physical changes, contemporaneously, throughout geological history. Thus it happened that the Americans were able to identify in America that succession of strata and fossils which might be designated the North Atlantic sequence. It became the standard and the chronology of world history has since been written in terms of its record.

Among the large number of paleontologists who worked to read this geological record James Hall of New York became the recognized leader, while James D. Dana, through his wide, comprehensive knowledge of the science and his facilities for publication, developed a clearing house for the exposition of geology. His "Manual of Geology" was a compendium of all branches of the science from the first edition in 1866 to the sixth and last in 1897. As a college student in the late eighteen-seventies had I been asked why the globe was cooling and contracting I might have answered: Because Dana says so.

With this too brief reference to the great achievement of establishing the standard geological time scale for America and laying the foundations of a general knowledge of American geology, we must here turn to other branches of the science.

How old is the earth? That was a much discussed question during the latter half of the nineteenth century. At any earlier date the catastrophists could dismiss it with a reference to Genesis. Dana himself in 1863, in comparing the Biblical and geological records of Creation, interpreted the "day" of Genesis as the equivalent of geological eras and maintained that there could be no conflict between the two because both were of the same divine origin. But estimates based on the recession of Niagara Falls and the growth of coral reefs in the Pacific persuaded him that "time is long—even when the earth is hastening toward its last age." In this opinion he agreed with certain early estimates put forward on biological grounds. Darwin thought that evolution had required 200,000,000 years to reach the development of modern forms of life. But Lord Kelvin, estimating the cooling of the earth from a molten state, concluded that not more than 40 nor less than 20 million years had passed since a crust had begun to form. We now know upon much sounder grounds, by the rate of radioactive alterations, that 2,000 million years is a minimum age for the earth in the state we now observe.

Many estimates of geological time were based upon the rates of erosion and deposition of sediments. It was considered possible to approach the one factor by studies of the sediment carried by rivers and to guess approximately how long it had taken to deposit a foot of sandstone or shale or limestone. There was the underlying assumption that the rates had been roughly uniform and that the actual conditions represented those of past ages. Powell and his disciple, William M. Davis, founders of the science of physiography, showed the fallacy of that assumption. When Powell observed the ferocity of erosion in the Grand Canyon of the Colorado, he was almost shocked. Such tremendous gorges, carved in so brief an epoch of geological time! He grasped the concept of recent uplift; he foresaw a slowing down as the height should be worn away; he sensed the inevitable result—that the plateau must be reduced to a low surface, a uniform plain—; and he recognized that erosion must then wait upon renewed activity of lifting forces. Thus he came to recognize what he afterwards always taught: that the processes of erosion follow a cycle, comprising uplift, degradation, and sedimentation; and that such a cycle is but a brief interval between long periods when erosion is almost at a standstill.

Powell had philosophized regarding the processes of erosion. W. M. Davis analyzed them in detail. He dissected landscapes, distinguishing youthful, mature and aged forms, and he thus set up the concepts of youth, maturity and old age as stages that might be recognized in canyons, valleys, hills and plains. He established a purely American branch of geology, physiography. It provides a script by which he who runs may read the record of mountain growth. Mountains had been the symbol of the everlasting. They have come to be regarded as evidences of recent, transitory activity of the earth's internal forces. There have been many epochs of mountain growth. Since the most remote ages great uplifts have been raised and being eroded they have vanished from the scene. The activity is evident to-day. The Alps, the Rockies, the Himalayas are young. The grandest are among the youngest.

It has indeed been inspiring to follow Davis in reading the history of the Appalachians, where we began, and also of the mountains of Europe, Asia, Africa, South America, like an open book, in company with Davis's thought; but one inevitably follows Powell to the sources of that power which is so manifest in them. We get a new point of view. The action is recent, is even now at work. It is on a grand scale, as grand or grander than ever in the past. Can the force then be decadent? Is it running down? Is the earth a dying globe, "hastening on toward its last age" (Dana)? Thus the whole theory of terrestrial dynamics, as it was entertained during the last century, as a deduction from the Laplacian idea of the origin of the solar system, was challenged by a better understanding of the surface features, which had always been open to investigation. That was the contribution of Powell, Gilbert and Davis.

Mountains have long offered another series of problems, those relating to their architectural structures. They are essentially mechanical. Given a force, some force, competent to do the work, how could it act to push up such enormous masses of strata, to force them up out of their original positions in the crust? The ideas involved are those of fracturing and folding on a grand scale. During the latter half of the nineteenth century they developed into that branch of the science that is known as structural geology.

The architecture of the Alps inspired the early students of that branch. The grandly majestic mountains may well seem awesome to many still, as they did to all men in the past; but to the daring few who began two centuries ago to seek to know them more intimately and to the many since, the Alps have revealed secrets which surpassed understanding. To the geologist who knows that normally beds of sandstone and limestone occur as flat sheets, in orderly sequences, they present the phenomenon of strata bent into huge folds without a break, or strangely fractured and forced over one another in apparent confusion. The effects of enormous forces, acting under abnormal conditions, stagger the imagination and long defied analysis. A Swiss, Albert Heim, was the first to reason out the principle, which is now a truism, that any bed of rock, however strong and rigid, may be bent without breaking, provided that it be so loaded that it can not separate. He also saw that solid rock had flowed under adequate pressure, where adequately confined, and that it had recrystallized during such movements. In his beautiful volume, "Das Mechanismus der Gebirgsbildung," 1878, he opened the way to understanding the changes of form and relations that are forced upon masses of rock in the movements of rising mountains.

In America the belt of the Appalachian mountains presents an unusually simple system of long, narrow folds. The folded rocks are bedded sandstone, shales and limestones, which were piled up to thicknesses exceeding twenty thousand feet. They were spread in flat sheets. They are now bent into arches and troughs, in alternation, like wrinkled paper. The brothers, H. D. and W. B. Rogers, executing the geological surveys of Pennsylvania and Virginia during two decades before 1850, observed the folding. The effect is that which would be produced if the belt had been narrowed by compression, but the Rogers brothers thought it impossible that simple compression could have so acted. They conceived a compound action, a combination of vertical and horizontal forces, like rising and falling waves; and they found a not unreasonable cause in the agitation of a thin crust, floating upon a molten interior. Their inferences were consistent with the then ruling ideas of a molten globe and of catastrophic activity of terrestrial forces. They have slowly given way to understanding of the fact that the processes of change are deliberate. The violent earthquake, the volcanic explosion are local, trivial incidents in the creeping operations of terrestrial forces.

Before we can do justice to the ingenuity with which the problems of mountains and their uplift were attacked during the nineteenth century we needs must consider the ideas of terrestrial dynamics that prevailed, and which, indeed, are by no means obsolete to-day.

It was not doubted that the Laplacian theory of the origin of the solar system was essentially correct and its corollary that the earth had cooled from a molten state was a basic assumption. Dana wrote (Manual, 1863, page 739):

> The earth in igneous fusion had no more distinction of parts than a germ. Afterwards the continents, while still beneath the waters, began to take shape. Then as the seas deepened, the first dry land appeared, low, barren, and lifeless. Under slow intestine movements and the concurrent action of the enveloping waters, the dry land expanded, strata formed, and as these processes went on, mountains by degrees rose, each in its appointed place.

Unfortunately for the theory the assumption of a thin crust floating on a fluid interior was mistaken, as was subsequently demonstrated by the geophysicists. Kelvin in 1862 calculated the effect of tidal attractions and showed that the earth must be as rigid as steel to resist them, as it does.

The contraction theory of mountain building, which Dana attributed to Newton, but which he developed, is the hypothesis which was most favorably considered during the half century with which we are dealing; it is still preferred by some geologists. It rests upon the assumption that the globe is cooling and therefore shrinking, bodily; and as the body shrinks it leaves the crust unsupported until the weight of the latter causes it to collapse and push up mountain masses. Dana supported the theory from the date of his first publication on the subject in 1847 to his death in 1897. On the other hand, it was strongly attacked on the ground that any possible contraction of the globe was quite inadequate to account for the observed shortening of the crust. The close of the century found the contraction theory still a subject of debate, with opinion running against it with such students as Dutton, Van Hise and Chamberlin.

Among the contemporaries of the contraction theory was the gravitation theory of James Hall. That paleontologist had observed that the Paleozoic strata of eastern North America had been compressed and folded where they were thick, *i.e.*, in the Appalachian belt, whereas they had remained undisturbed where they were thin, as in the upper Mississippi valley. He reasoned that the folding had been occasioned by the curvature of the strata as they subsided, the result being that the lower beds were stretched, while the upper ones were compressed. Dana combatted the theory on the ground that the curvature could not supply either the pressure or the amount of compression required by the facts. Hall, however, never yielded the point and republished in 1882 his original statement of 1857.

One phase of the gravitation theory remains debatable even to-day, since it involves the unknown factor, the capacity of the earth's crust to bear loading. Where great thicknesses of sediment have accumulated gradually in a trough that has deepened as gradually, did the loading occasion the subsidence? Or did subsidence, due to some other cause, provide depth for the loading? How strong is the crust? What load may it support? Consideration of this problem led Dutton to the idea of balance of the earth's crust. He reasoned that a heavy mass would sink to a lower level than a lighter mass; consequently the surface would exhibit depressions (ocean basins) and elevated areas (continents). But erosion is constantly transferring material from the continents to the oceanic margins and thus disturbs the equilibrium. The unloaded continent should rise and the loaded ocean bed should sink. And there should be a subterranean movement from the latter toward the former. This concept became known as the theory of isostasy which played a very important role in the discussions of the subject. Two schools of thought developed: A weak-crust school represented by J. F. Hayford, Wm. Bowie, and R. A. Daly, assumed a condition of almost perfect balance, a yielding to small differences of load by very slow adjustments. The other school recognized some degree of rigidity in the support of unequal loads and sought to estimate it in terms of the weight of masses, such as mountains, which the crust might carry. G. K. Gilbert was its chief exponent. The weak-crust group has seemed to demonstrate almost perfect equilibrium by numerous observations for the intensity of attraction of gravity, which are evaluated by means of elaborate adjustments; but the mathematics are no stronger than the assumptions, which fail to take account of the elasticity of the foundations. Gilbert, through a searching study of the effect of evaporation of the waters of Lake Bonneville and of commensurate masses which appear to be rigidly supported reached the conclusion that:

> Mountains, mountain ranges, and valleys of magnitude equivalent to mountains exist generally in virtue of the rigidity of the earth's crust; continents, plateaus, and oceanic basins exist in virtue of isostatic equilibrium in a crust heterogeneous as to density.

Subsequent research confirmed this estimate and it is widely accepted as a working hypothesis, as Gilbert put it, although still there are many geologists who accept the conclusion that isostasy is nearly perfect.

These researches in isostasy have been intimately related to the problem of the forces that push up mountain ranges, but it must be said that neither the contraction theory of Dana, nor the gravitation theory of Hall, nor the thermal theory of Millarde Reade, nor the hypothesis of subterranean drag and push in a movement to restore isostatic equilibrium, nor any one of many minor suggestions, has been found satisfactory. American geologists were generally agnostic toward the problem of mountain-making forces toward the end of the nineteenth century—and it may be said still are so.

Mineralogy, the oldest branch of geology, received a great deal of attention in America during the nineteenth century. In this as in broader fields James D. Dana was for sixty years an American authority whose "Manual of Mineralogy" was standard. In successive editions he developed the classification of minerals based upon the fact that minerals are chemical compounds, subject to the laws of chemistry, and capable of reactions to changes of pressure and temperature. Though the change in the point of view was gradual it was very profound, full of significance for the future of mineralogy. What had been a purely descriptive study, of interest chiefly to collectors, became analytical research, directed toward better understanding of the nature of minerals and crystals. Dead minerals came to life.

Crystals had long been examined under the microscope, especially with reference to what could be seen in the thin edges of chips, but it was not until the eighteen-seventies that the art of grinding thin, translucent sections was developed successfully. It became the basis of that study which is now known as petrography. An extremely fertile field, richly sown with facts relating to the characteristics of minerals and their family connections, was opened to examination. The harvest was almost embarrassingly abundant. Hosts of new species appeared. Naming became the fashion. The resulting confusion extended to the description and classification of rocks. Late in the century a group of petrographers, consisting of Whitman Cross, Joseph Iddings, L. V. Pirsson and Henry Washington, undertook to frame a quantitative classification of igneous rocks, based on chemical and quantitative, mineralogic characters. The basic postulate was that the nature of the rock was determined by the chemical composition of the melt from which the minerals had crystallized. The research therefore directed attention toward the study of molten bodies, magmas, beneath the outer crust. It was not published, however, until 1903.

Petrography is a descriptive science; the related study, which investigates the genesis of rocks, is called petrology. Its dynamic nature may be indicated by a quotation from Rosenbusch, founder of petrography, who wrote (1876): "A rock becomes alive to me only when I have grasped its relations to our planet and its history."

He glimpsed a future in which, through study of rocks in the making, we may approach an understanding of the processes that are active in the mass of the earth, under the great pressures, at the high temperatures, through the enormous forces therein existing. In so doing he was at least half a century ahead of others. The recognition of petrology as a promising branch of geology was delayed till about 1890 and its development has been slow. It could not be otherwise. Physics, which must lead in dynamics, was stopped at the atom. It was impossible to penetrate the realm of subterranean forces until that citadel was reduced.

The idea that minerals can adapt themselves to changes of temperature and pressure is expressed in the term metamorphism or its equivalent, alteration. Studies of metamorphosed or altered rocks were purely descriptive, as in other branches of mineralogy, but with the development of optical methods of study and especially of the examination of thin sections under the microscope, the investigation of reconstructed, recrystallized, *i.e.*, metamorphic rocks, was pursued as analytical research, having for its aim an understanding of the effects of heat, confining pressure, and an unbalanced pressure during the process of recrystallization. The microscope confirmed what had long been known on a larger scale, namely, that certain laminated or fibrous rocks, the gneisses and schists, had been forcibly elongated and their minerals rearranged in parallelism, partly by rotation of the original crystals, partly by the growth of new ones. The effects were in part mechanical, in part physicochemical, in varying degrees, and involved shearing of an exceedingly intimate character, and also flow of the solid rock under extreme conditions. Prominent among the many geologists who pursued these difficult studies were the Finnish geologist, Sederholm, and C. R. Van Hise, of Wisconsin. The latter, as a result of investigations begun with R. D. Irving in 1882, in the Lake Superior region, published in 1904 a very comprehensive treatise on metamorphism designed to cover the entire subject of rock alteration. In the then state of knowledge of physics and petrology it was an exhaustive treatise, but in consequence of the revolution in atomic physics and its bearing on problems relating to crystallization from magmas and recrystallization of solid rocks it has now become a reference work, of classical interest chiefly. In that respect it has shared the fate of nearly all the compendiums of geological learning of the last century.

In the study of historical geology a knowledge of metamorphism has made it possible to read the records of that remoter past, which is represented by the so-called Archean rocks. The vast areas of these crystallines in North America and Europe, which were known to Dana, were described by him as continental nuclei, as masses formed at that stage of the earth's development when continents began to grow, possibly before there were any sedimentary rocks. But through researches in metamorphism it became possible to distinguish metamorphosed sediments from rocks of igneous origin and to determine the sequence of their relations. Gradually the ancient record has been read, not only in America, but in all continents, and much is now known of the geography and terrestrial activities of those long past eras. The imaginary stages of earth history, the creation of lands and seas, the catastrophies from which they sprang or in which they, Atlantis-like, disappeared were found to be mythical as the gods of Scandinavia and have been replaced by the normal events of terrestrial change.

Thus the study of the metamorphic rocks widens our understanding in two directions. It throws a beam of light into vistas of the past of which we never dreamed and it uncovers the processes of gradual change in the realms of force far beneath our feet.

The nineteenth century bequeathed to geology a rich inheritance of facts. In every branch, in historical, paleontological, structural, mineralogical, economic, in every subject, the mass of observations was so great that no scholar could embrace it all. Leaders emerged as specialists, not like Dana as all-round geologists. Special societies were contemplated and eventually organized in order that students of one branch or another might have opportunity to discuss with fellows who would understand, rather than to talk to experts in other fields who could not be expected to. And yet an individual advancing in his preferred line of research often found need of support from a colleague or from a group of colleagues proceeding on other lines and mutual exchange of ideas characterized the relations of the truly broad-minded. The open mind was encouraged by such outstanding scientists as Chamberlin and Gilbert, authors of the method of multiple hypotheses, and cooperation was vigorously promoted by the Geological Society of America, the U. S. Geological Survey and the geological faculties of Harvard, Yale, Wisconsin, Chicago and other leading universities. American geology entered the twentieth century strongly manned and rich in material for study. The condition was an exceedingly healthy one, in marked contrast to that which had prevailed when paucity of information and tenacity of individual opinion retarded progress.

Nevertheless, the science was very weak in theory. Chamberlin when asked on one occasion what occupied his thought replied in miner's phrase: "Prospecting old drifts to see what, if anything, of value is left in them." He referred specifically to the Laplacian hypothesis of the genesis of the solar system (which he and Moulton proved fallacious) and its consequences in geology, the once molten, cooling globe; the once steaming, now congenial atmosphere, the once potent, now dying earth. These ideas had become suspect. Advanced students entertained the thought that the planet was much older than had been estimated, that its vast energies were still very effective, and that the changes they had wrought in its crust during the later geological periods were so great that they could not have been worked by gravity and residual heat. Yet no other forces were known and the framing of new hypotheses to replace the old proceeded doubtfully. In this day, 1942, it is known that those doubts were fully justified; however, thanks to Madame Curie the inexhaustible energies of the atoms of the globe, that is to say the energies of its entire mass, are potentially available to geological speculation. It is no longer a question of power, but one of its distribution and of the mechanisms through which heat, gravity and atomic forces work.

PHYSICS IN INDUSTRY[1]

By Dr. E. U. CONDON

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TO-DAY the nation's industries are working together as never before to do their part in the battle for freedom. It is fitting at such a time that we look over that part of civilized life for whose cultivation we as physicists are responsible, that we try to see how our science has been developing and in what direction we may cause it to grow in the future. We want to see clearly the job ahead so we can set about doing it earnestly and cheerfully; for we believe that, with effort, we can determine the future in peace as in war.

Although we can trace contributions to physics in America as far back as, say, Benjamin Franklin and his kite, the reasonably wide-spread organized research in physics that is now such an important feature of American academic and industrial life is a product of the last twenty-five years. Our professional group, the American Physical Society, is not yet fifty years old. For the first twenty years or so of its existence, very little was reported by its members which has affected the later development of our science in a basic way. The period was one of thoroughly sound beginnings marked by a few really outstanding contributions: Rowland discovered the magnetic effect of moving electric charge, and he perfected the diffraction grating for spectroscopy. Hall discovered the Hall effect, which is to-day a valuable tool in studying electrical conduction in metals and crystals. Michelson and Morley discovered the phenomena which laid the groundwork for the theory of relativity. Somewhat later Millikan measured the charge on the electron and the Planck constant.

It was a period in which very few of our physicists had the opportunity to contribute much to the advancement of science. Most of them were concerned with teaching, and the great industrial laboratories as we know them to-day simply did not exist.

A great change set in just after the first World War, although it is hard to see that that had much to do with it directly. Indirectly it did, for war acts as a stimulus to cooperative effort. The National Research Council was organized and soon after the war the Rockefeller Foundation established the National Research Council fellowships in physics, chemistry and mathematics. By this means some fifty young doctors of philosophy were each year enabled to continue their development as research men to such a degree of self-reliance that most of them could shoulder other burdens without losing their ability to carry on in research. I believe that these fellowships alone, supported at a cost that was absolutely trifling, have done more for the development of American research science than any other single thing. The fellowships reacted not only on the fellows but on the institutions and the faculties at the universities where the fellows worked.

In the 1920's research in fundamental physics expanded by leaps and bounds. The momentum carried by x-ray quanta was demonstrated by Arthur Compton. Davisson and Germer discovered electron diffraction; investigation of cosmic rays was inaugurated; atomic and molecular spectra were analyzed; and a group of young American theoretical physicists participated vigorously in the development of quantum mechanics.

It was also a period of rapid expansion of industrial physics in the electronic industries. From the birth

[1] Essential substance of an address delivered at the opening of the Charles Benedict Stuart Laboratory of Applied Physics, Purdue University.