SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, AUGUST 10, 1906.

CONTENTS.

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

THE NATURE AND ORIGIN OF VOLCANIC HEAT.

THE hypothesis of a molten or more or less fluid interior, as possessed by the earth, may now be said to have been abandoned, and along with it the supposition that volcanoes constitute vents for the escape, as a consequence of shrinkage and subsidence, of a portion of the molten content lying everywhere under the solid crust. The hypothesis that the interior of the earth, while in the main solid, has cavities containing melted matter which occasionally is forced out in the form of eruptive outbursts is a kindred one which has found some adherents. But a truly solid interior seems to be demanded by the accepted great rigidity of the body of the earth, and Mallet has put forward the idea that extraordinary pressures exerted to crush the rocks would result in their becoming heated and melted. Evidently, however, mere pressure acting alone, however great, would not suffice for this. Incipient fluidity would substantially put an end to the crushing process and heat generation would stop. The observed high temperatures attained by volcanic products during eruption would not be reached. More recently the thermal effects of volcanoes, and the various results thereof, have been ascribed by one authority to the presence of radium, which, as is known, continuously gives out energy in its breaking up. But volcanic lavas have not been found to be sources of radium or of uranium, the amount of which should be quite large if the supposition is to be given any serious consideration.

The object of this paper is to present a view of the origin of volcanic heat which may possess some elements of novelty and, it is hoped, of rationality. According to this view, much of the heat manifested is due to mechanical work converted into heat, a theory based upon dynamical principles to be later pointed out. Primarily it will be admitted that any substance, gas, liquid or solid, upon which work is done acquires heat in proportion to the energy expended upon it, which heat, if prevented from escaping, at once results in an increase of temperature of the substance. If the mechanical energy so converted be of known amount, we may calculate from the mass and specific heat of the substance or body upon which such energy is expended the rise in temperature. Even if air at ordinary temperature under high pressure escapes through a tortuous or frictional passage surrounded by a good heat non-conductor, it emerges hot. The higher the pressure and the greater the friction met in the passage the greater the increase. The heating is directly related to the work done upon the mass.

If a liquid be substituted for the air the general result is the same, and the liquid may be made to boil upon its escape. If a somewhat plastic solid like hard pitch be subjected to the process, the energy required will be greatly increased, or the pressure required to force it through the tortuous passage of some length will be great. It may emerge hot and melted if the conditions be properly selected.

If now it be assumed that any solid be subjected to a pressure such as to cause it to flow in a tortuous or restricted channel, it will, in so moving, rise in temperature, and continue so to rise until it has reached a degree of fluidity such as to lessen or practically stop the absorption of energy in moving the mass; or until it escapes from the passage through which it is being impelled. The pressure is but one factor of the energy, the other being the distance through which the pressure acts. The pressure required depends upon the resistance to motion, which in turn is greater with more rigid bodies and greater with increase of distance through which friction is met and overcome. The pressure or force required will be at a maximum when the solid mass starts cold or nearly so and will diminish as the temperature is raised and consequent plasticity or fluidity brought about. A rock mass forced to move under great pressure over distances of thousands of feet must soon become melted in the process. It is not necessary to assume that the mass so heated starts cold. It may start at any temperature at which it possesses sufficient rigidity or viscosity to require the exertion of great force to move it in the assumed restricted or tortuous passage or channel. Great velocity of movement in such passage means of course great energy expenditure and rapid heating. The idea thus outlined may now be applied as an explanation of volcanic phenomena. For example, a hot-water spring may be the result of the water having been forced by high pressure to traverse somewhat porous rock, or to pass through narrow but long fissures in which it is churned for a long time before escaping. In like manner any rock mass which, subjected to very high pressure, begins to flow must become heated. If its distance of traverse be great enough in a restricted fissure or channel, it must melt, or even become so heated as to partially vaporize when the pressure is relieved, as when it finally escapes. Let it be admitted that the flexures taking place in the earth's crust or in the outer portions of its mass may bring to bear upon deep-seated and perhaps already heated solid rock masses a sufficient pressure to cause them to readjust their positions, and the condition demanded by the theory is present. Such a condition would mean movement of such masses over considerable distances at high pressures, with the final result of the formation of molten streams ready to escape upward from the pressure exerted upon them. A vent would at last form and the rush of the partially melted rocks towards and out of this vent would become a lava flow. These actions would naturally occur at places of flexure such as would tend to form a ridge, and the loading and sinking of sea bottoms as a consequence of sedimentary deposits would be favorable, as is well known, to such flexure as would tend to heavily compress the rocks along the line of flexure deep down from the earth's surface, while relieving or not increasing pressure near the surface. The compressed rock would in general tend to be shifted or made to flow outward at the line of flexure. This view accords well with the facts. Volcanoes exist along lines more or less parallel to or adjacent to sea coasts or along the weak lines in the earth's surface. It will easily be seen that a single volcanic vent or pipe may serve to relieve or provide a point for outflow for the shifting of material over a great length of flexure deep down under the earth's surface. As the flow and fusion would be a somewhat gradual process it may well be that only when the vent is about to open will there be earthquakes and great subterranean noises, more or less local to the place of outbreak. Very probably eruptions in which melted lava does not appear to have a part, but in which steam and gases, sand, or mud are ejected, are nevertheless dependent upon an upthrust of lava or a subterranean lava stream, which never reaches the surface, but the temperature of which is such that, on its reaching hydrous rock strata, the water is evolved as steam at high pressure, which entering superincumbent layers gives rise to mud eruptions, or escapes from vents or fumaroles.

It would be expected that such rock masses as, under pressure, would yield most readily would be the ones to flow and form lavas. They would also be likely to be the more readily fusible masses, assuming that before the process of compression and extrusion begins they exist at a temperature more or less elevated above that at the surface of the earth. The locus of the rock flow might, therefore, be in deep regions several miles down, so deep indeed that relief of pressure could not occur by folding of upper layers or strata, which would involve the bodily uplift of rocks above, which rocks, exerting an enormous downward pressure, may be of great relative rigidity.

The view of the origin of volcanic heat here advanced makes the paroxysmal nature of volcanic eruptions almost a necessity of the case. The rocks would resist an accumulation of pressure tending to cause them to flow, but finally, under continued increase of force, they would begin to readjust themselves. This would result in heating, softening and fusion. A vent might form and thus on account of the fluidity of the moving mass the accumulated pressure would for the time be relieved. But the original causes might still exist and continue, even after cooling of the heated material in the vents, to result in pressure accumulation, renewed flow and fresh outbreaks at periods more or less remote. The final decay of volcanic action in any region would result from such a permanent readjustment of strains as to entirely relieve the rock masses of any pressures which could become critical and cause flow.

During the cooling of a globe of heated and partly fused matter, such as the earth and moon are believed to have once been, the early volcanic outbursts on them would be without violence, and it seems likely that the materials ejected would have temperatures not greatly above that of the surrounding masses. An eruption at that time would be a welling up of great bodies of rather quiescent lava derived at once from the fluid contents below a but slightly cooled surface. As the further cooling made the body more solid and rigid, especially at the outside surface, the mechanical energy spent in causing an eruption would lead to higher temperatures of erupted matter, which would escape with more violence, explosions of vapor or gas would occur, partly due to vapors evolved from the melted masses upon relief of pressure at the vent, and partly the result of contact of the hot lavas with colder surrounding rocks containing gases or water. Ashes and cinders would become a feature of the eruption. At still later stages eruptions would become less frequent and vents less numerous, but the violence of the outbursts would increase, owing to the very high temperatures reached by the extruded matter during the journey towards expulsion.

It may seem somewhat paradoxical to hold that as a body, such as is the moon, cooled, the temperature of the ejected volcanic matter would rise, but in the present view this would be a consequence of the necessary exertion of greater pressures to cause eruption, owing to the enormous amount of mechanical work or energy expended, as the matter would be forced from greater depths. It happens that upon the earth much of the evidence of volcanic action in archaic or early geological times has been obliterated by erosion and sedimentation, but we have in the moon's surface a record which is not so modified or defaced.

From the whitish streaks surrounding such craters as Tycho Brahe and Copernicus, a type of crater not very numerous on the moon, which streaks are most conspicuous at the time of full moon, it is seen that there have been effects of eruptions of these great craters which extend over hundreds of miles from the craters. These whitish streaks are superimposed upon, and therefore later than, many of the other craters and markings over which they spread. These streaks are probably the depositions from condensed vapors which left the craters in almost radial lines. Inasmuch as the moon has very little atmosphere even at its lower surface and much less at the heights from which these vapors escaped in leaving the craters, the straight line or radial direction taken by them is not surprising; in fact, it is necessary. Vaporous matter escaping into a vacuum moves in precisely that way. Had the earth no atmosphere, the ashes and vapors from a volcanic crater would move away from it in just the same manner, and would be scattered in radial streaks from the notches in the crater walls and to enormous distances. If again the surface of the moon, as seems likely owing to absence of water, be covered with loose masses, or be broken instead of smooth, or be covered with pieces of rock of varying size, it is easy to understand why these whitish streaks should require for visibility a high angle of solar illumination. The condensed deposits would fall in between the boulders or stones on the surface and at low solar elevations would be in the shade or shadow of the broken pieces on the surface. That the surface of the moon, in large part, may be covered with fragments of rock, boulders and stones is probable from the great part that volcanic action has played in giving configuration to its surface, and the absence of any influences which would alter the aspect or general make-up of the surface outside of volcanic disturbances. The markings alluded to as existing around such craters as Tycho and Copernicus, as well as the great depth and other marked characteristics of these and similar craters, declare them to be the more recent of the great volcanic outbursts on the lunar surface. They bear the impress of having been very violent, and the vapors indicate ejections hot up to the point of vaporization. If the view presented is correct, this is entirely natural. On the other hand, contrast these craters with those called Archimedes and Plato, lava plains, surrounding which we see no vapor or fume streaks, and no evidence of great violence, and we are brought to infer that these latter are the results of more ancient action in the nature of more gentle welling up from below of fused matter, not so greatly heated by the energy of expulsion. Such craters are shallow and were probably more in the nature of quiescent pools or lakes of lava than great relief vents from great depths traversed by materials at high velocity and at the high temperatures brought about by the process of superheating while moving against resistance in volcanic pipes. So far then as the moon furnishes evidence on this subject it may well repay further study, and its condition seems to confirm the position taken herein. It has sometimes been claimed that much of the explosive effect of gas and steam from volcanoes may be due to water entering or percolating through heated strata and being converted into steam at enormous pressures. But the possibility of this is doubted. The very pressure of vapor would stop the process at its outset. No water would enter a hot stratum unless forced in by a pressure in excess of that which the steam would acquire upon its generation. A boiler can not be fed with water by a pump which yields less pressure than that carried by the boiler itself.

If, however, the water be already present in a rock stratum which is invaded by hot lava rising in a volcanic fissure, then its conversion into steam and the violent emission thereof may readily take place.

It is conceivable too that considerable movement or shifting under pressure of any moist stratum over considerable distances, especially through a restricted channel, may result in heating it to a temperature sufficient to generate steam. Here again, as in the case of the rock flow before referred to, the work done in moving the particles against great resistance may under proper conditions cause an accumulation of heat energy sufficient to account for explosive effects when the material reaches a vent. Under such conditions also, the expulsion of hot mud or sand with steam may occur without the concurrence of lava flow.

The considerations herein put forward seem to furnish a basis for a dynamical theory of volcanoes. Doubtless the action of heating a flowing rock by energy expended upon it may be, and perhaps is, often supplemented by other causes, such as chemical action brought about by hot contact of substances having affinity for each other. Gaseous products under high pressures may be the consequence of the reactions. Limestone or other carbonate may be decomposed by the contact of hot lava, and carbonic acid gas in great volumes be thus liberated.

We certainly have no need of recourse to an assumption of the existence of large localized bodies and radium minerals to explain volcanic action. To say the least such an assumed store of this rare element is improbable.

The view here advanced, it is thought, presents far less difficulty. It is indeed an extension of Mallet's idea to include other factors of energy besides pressure.

The fact that the heated volcanic masses are in the earth, surrounded by materials of low heat-conducting power, makes the accumulation or retention of heat energy generated by mechanical work possible. The local character, as well as the varied nature of volcanic phenomena, is not difficult to understand. Volcanic outbursts must continue so long as readjustments of the positions of rock masses under a critical condition of pressure occur with the deeper surface layers.

If, as appears probable, the earth's interior is metallic iron, surmounted by a covering of oxidized lighter material, slaglike in character but altered by water and sedimentation, etc., the interior temperature or that of the metallic body is not likely to be very high, and it must be fairly uniform in spite of the gradual increase noted in the surface rocks at increasing depths. Such surface rocks or layers, being of relatively low heat conductivity, serve, so to speak, as a non-conducting blanket in which alone a considerable temperature gradient would be manifested. This condition does not forbid the possibility of the readjustments of masses herein regarded as the initial cause of superheating, even if those masses be quite hot but under such gravitational pressure of superincumbent masses as to forbid fusion.

ELIHU THOMSON.

THE GEOGRAPHICAL DISTRIBUTION OF THE STUDENT BODY AT A NUMBER OF EASTERN AND WESTERN UNIVERSITIES AND EASTERN COLLEGES.

THE accompanying table explains the geographical distribution of the student body of six of the leading universities of the east and of four western institutions, as well as of three New England and two Pennsylvania colleges for the academic year 1905–06, summer session students being in every instance omitted. It was impossible to secure accurate figures for the academic year just closed in the case of the *University of California,* and consequently the figures for 1904–05 were substituted. Comparing the attendance by divisions of the six eastern universities (*Columbia, Cornell, Harvard, Pennsylvania, Princeton, Yale*) with the corresponding figures for the same universities included in a similar table published in SCIENCE, N. S. Vol. XXII., No. 562 (October 6, 1905), pp. 425–6, we note in the first place that there has been a gain for these universities taken as a whole in every division, the largest increase in actual number of students, leaving the north Atlantic division—in which all of these six universities are located—out of consideration, having been recorded in foreign countries, where there has been a gain of eighty-seven students, this being as large as the entire increase of the student clientele of these universities in the United States divisions (exclusive of the north Atlantic). In the south Atlantic states and in the insular possessions these eastern universities have made only a slight gain; in the south central division all of them show an increase with the exception of *Princeton;* in the north central division the chief gains have been made by *Columbia, Princeton* and *Yale,* in the western division by *Columbia, Pennsylvania* and *Yale,* and in foreign countries by *Columbia, Cornell* and *Harvard.* These figures bear out the statement made by the writer in earlier contributions to SCIENCE to the effect that the western and southern clientele of the prominent eastern universities is not suffering any shrinkage. At *Columbia* the attendance from outside