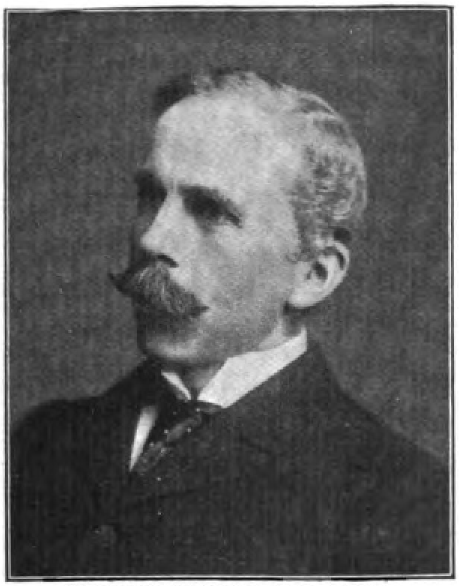
The Flow of Rocks.

AN IMPORTANT SCIENTIFIC THEORY PROVED TRUE.

BY FREDERICK T. C. LANGDON.

IT is a well-known scientific theory, and one of great and far-reaching importance, that the solid rocks of which the earth consists become, under the enormous heat and pressure of the interior, semi-liquid and mobile, so that they may be said to flow like treacle. This astounding fact, long suspected, but never before demonstrated, has been proved at last by Professor Frank Dawson Adams, M.Sc.Ph.D., F.G.S., Logan Professor in Geology at McGill University, Montreal. With machinery especially constructed for applying tremendous pressures, even up to ninety tons per square inch, during periods varying from fifteen minutes to 128 days, Professor Adams has squeezed columns of marble until the molecules have slipped and twisted, separated and re-united, changing entirely the granular appearance of the structure, while weakening it but comparatively little.



PROFESSOR FRANK DAWSON ADAMS.
From a Photograph.

These experiments have clearly shown why the rocky strata of the earth are so irregular, why they are rent asunder by earthquakes, why mountains have taken shape, why some of the greatest of geographical changes have occurred. It is a far cry from the flow of liquids to the flow of rocks, but Professor Adams's experiments have demonstrated that the one resembles the other; that rock-structure under extreme pressure seeks relief along the lines of least resistance and flows in those lines, just as it is known that liquids flow.

A drop of rain-water on a window-pane moves downward through a zig-zag course, the deviations being due to tiny causes in the shape of bits of dust, imperfections in the glass, etc. That drop of water follows the line of least resistance. A mass of rock deep in the world-crust, pressed down upon by countless tons of like material, seeks to get away from the overpowering force and moves—infinitely slow though the motion be—along paths of the smallest opposition. The cases are parallel. Immense masses of rock strata are thus moved during inconceivable periods of time, being slowly forced along beneath the surface of the globe, or projected outside in the form of mountains or hills. When the "overhang" weight of the hard-pressed strata becomes too great for the cohesive force of the molecular structure there is a toppling, a settling towards the centre of gravity, a rupture at the "fulcrum," and then an earthquake.

Although these complicated bendings and twistings have long been recognised by geologists, there has been much discussion as to the way in which this "flow" has taken place and a wide divergence of opinion. In some quarters the process has been considered as purely mechanical; in others the possibilities of solution and redeposition of material were taken into the equation. With so much opportunity for doubt the problem was one which might be elucidated by experiments upon rock movements—if movements could be induced in rocks under known conditions. And if the results thus artificially obtained corresponded with the structures of deformed rocks found in Nature, a great deal might be learned not only about the character of the movements, but also about the conditions necessary to produce those movements.

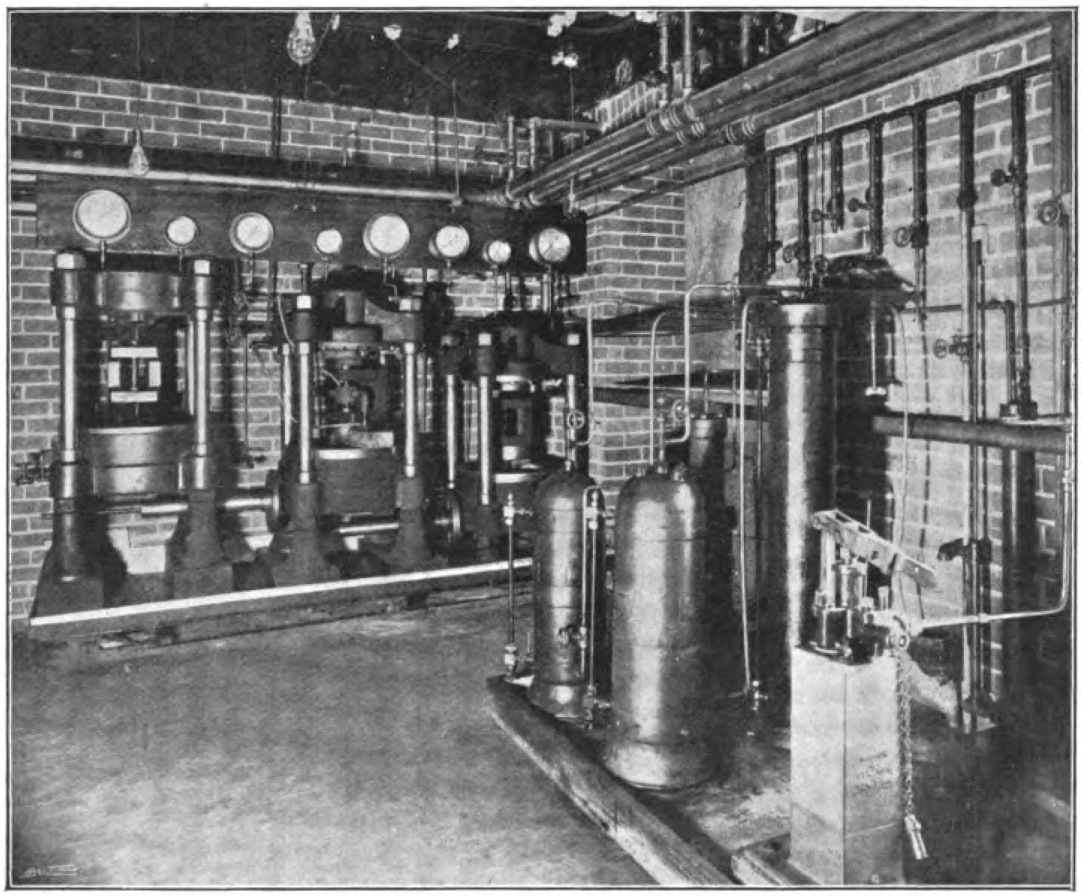
It is almost universally agreed among geologists that there are three principal factors needful to bring about those conditions to which, in the deep parts of the earth, rock structure is subjected, and that these conditions are: First, tremendous pressure; second, high temperature; third, percolating waters.

As regards the question of pressure, let it be said that mere cubic compression does not result in a flowing motion, although it may effect a change in the molecular structure of the rock. That the mass may have movement, a differential pressure is necessary; and to obtain this differential pressure under the conditions prescribed, inventive genius must needs get to work. In the evolution of a proper machine for his experiments Professor Adams was aided by Professor John T. Nicholson, D.Sc., M.Inst.C.E. The studies were conducted in the Mining Building at McGill University.

That the interesting way in which the experiments were carried on may be clearly explained for readers of THE STRAND it will be advisable to begin with a description of the preparation of the blocks of pure Carrara marble used in the tests, and gradually to lead up to the machinery with which the squeezing is accomplished. To subject the marble to a differential pressure it was sought to inclose it in some metal with a greater elasticity than the marble, but at the same time ductile to a considerable degree. Heavy tubes of wrought-iron were adopted. These were formed after the plan used in making big guns, by wrapping thin strips of Low Moor iron about a soft iron bar, welding each strip in succession, and finally boring out the core. The consequent tube of Low Moor iron was one-fourth of an inch thick, with the fibres of the metal running around the tube instead of parallel to its long axis.

Small columns of marble, varying in diameter from eight-hundredths of an inch to one inch, and about one and five-hundredths of an inch long, were accurately fashioned and polished on a lathe. Then the Low Moor tube was fitted about the marble, both the column itself and the interior of the tube being tapered very slightly, and so contrived that the marble would pass only half-way into the tube when cool. The tube, being subjected to expansion through the agency of heat, increased in diameter enough to allow the marble to pass completely into it, leaving at either end about an inch and a quarter of the tube free. When the tube cooled a uniform contact between the metal and the rock was obtained.

The subject was then in readiness for the next step. Into either end of the tube containing the marble column was inserted an accurately fitting plug or piston of steel, and



PLANT AT MCGILL UNIVERSITY, WHERE THE FLOW OF ROCK WAS DEMONSTRATED.
The machine on the extreme left of the photograph is ready to make a "cold dry crush"; the machine in the middle is ready to make a "hot dry crush" (the asbestos packing which would be wrapped about it to keep in the heat being removed); and the machine on the right is prepared for a "hot wet crush."

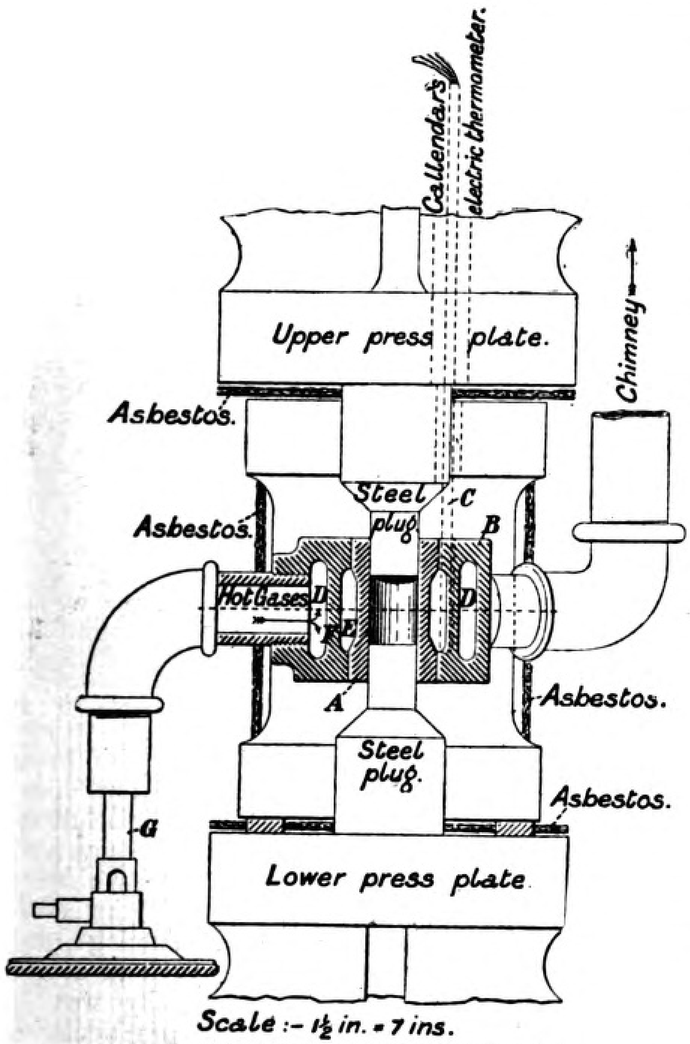
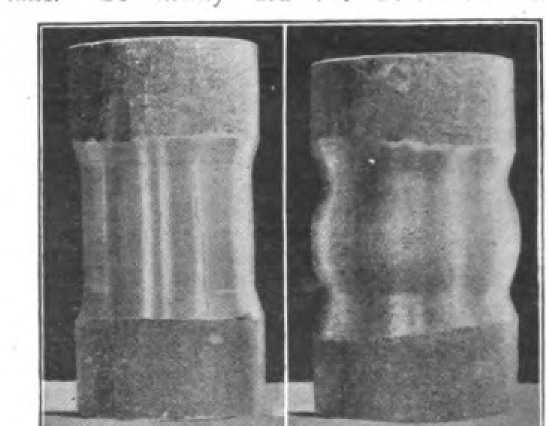


DIAGRAM OF THE "HOT DRY" CRUSHING PRESS.
A. Tube inclosing column of Carrara marble. B. Cast-iron jacket bored to **receive tube. C.** Place for insertion of a Callendar's platinum resistance **thermometer. D.** Channel for circulation of hot gases. E. Air space, into **which thermometer** bulb projects. F. Wall separating gas space from air space. G. Gas pipe.

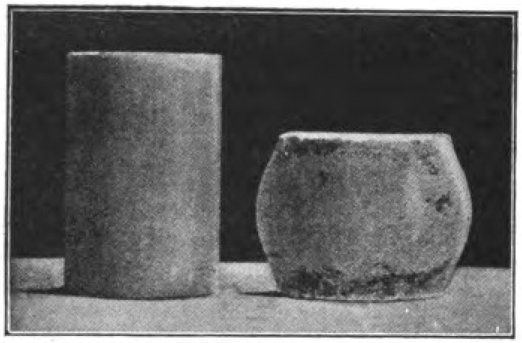
pressure was applied by means of these. This pressure — and a most extraordinary pressure, too — was brought about by a powerful double hydraulic "intensifier" press, by means of which (in earlier experiments when water from the city mains was used) forces as high as 13,000 atmospheres were exerted on the marble, which forces were easily regulated and maintained at a constant value for months at a time, if needed.

Having learned that columns of marble, 1in. in diameter and 1½in. high, were crushed at from 11,430lb. to 12,026lb. to the square inch, the column in its wrought-iron casing was placed in the squeezing machine and pressure applied gradually, the extreme diameter of the tube being accurately measured at frequent intervals. Until a pressure of 18,000lb. to the square inch was reached (varying slightly with the thickness of the tube) no effect was noticeable, but at that pressure the tube was found to bulge slowly and symmetrically, the bulge being confined solely to that part of the jacket surrounding the marble plug. The distension was permitted to continue until the tube showed signs of rupture, when the pressure was removed. The marble was submitted to pressure under the following four conditions: (*a*) At the ordinary temperature in the absence of moisture (cold dry crush). (*b*) At 300deg. Centigrade in the absence of moisture (hot dry crush). (*c*) At 400deg. Centigrade in the absence of moisture (hot dry crush). (*d*) At 300deg. Centigrade in the presence of moisture (hot wet crush).

On columns of marble at the ordinary temperature eight experiments were made in the absence of moisture, the rate at which pressure was applied varying in different cases, and the consequent malformation being in some cases extremely slow and in others more rapid, the extremes being ten minutes and sixty-four days in those particular cases. On the completion of the experiments a narrow cutter in a milling machine was used to slit the tube longitudinally along two opposite lines. The marble was found to be still firm and compact, and so to cling to the two now distinct sides of the jacket that mechanical aid in the shape of wedges was necessary to tear them asunder, and even then the marble was split through the vertical axis. So firmly did the deformed half-



At the left is shown the Low Moor iron tube inclosing a column of Carrara marble ready to be placed in the machine. On the right is the same tube after having been slowly deformed during a period of sixty-four days.

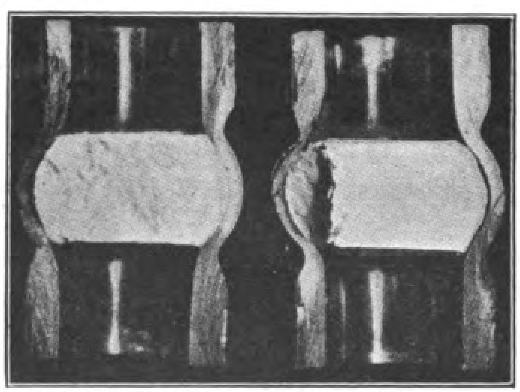


On the right is the piece of deformed marble after removal from its jacket. On the left is a column of marble of the dimensions its partner originally possessed.

columns then cling to the halves of the jacket that a vice had to be used to set them free.

While compact and firm, the squeezed marble differs from the original in possessing a dead-white, chalky hue, the glistening cleavage surfaces of the calcite being no longer visible. This difference is extremely well shown in certain cases where some parts of the original marble remain unaltered by the pressure.

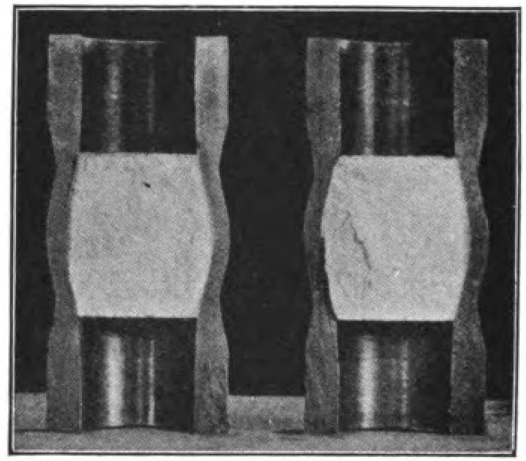
That the strength of the rock might be tested, three of the half-columns obtained in different experiments after the manner described above were selected. The first of these, which had undergone a slow deformation extending through a period of sixty-four days, gave way under a load of 5,350lb. per square inch; the second, compressed for one and a half hours, broke down under a pressure of two tons per square inch; and the third, which had been squeezed but fifteen



Tube containing the deformed marble, milled open, and the marble split in two as described. In this particular case the marble column was reduced one-half its original height in four hours.

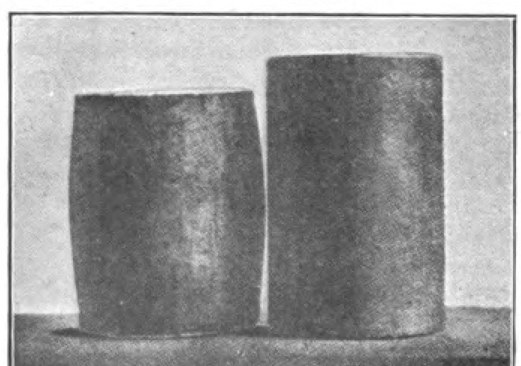
minutes, crushed under 2,776lb. So that, in spite of allowances made for variance in shape of specimens tested, the marble after deformation is weaker than the original rock, for it has been previously mentioned that columns of marble such as were tested in the way described above exhibited originally a crushing weight of between 11,430lb. and 12,026lb. to the square inch. Hence when deformation is conducted slowly the resultant rock is stronger than when deformation is rapid.

As has been said, some portions of the tested marble columns were found unaltered.



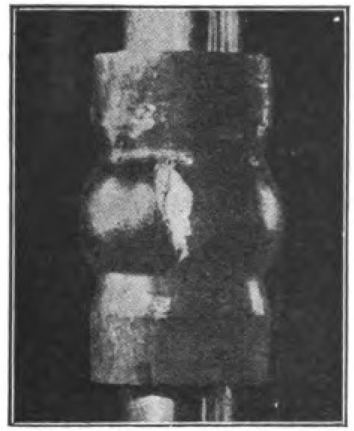
The result of seventeen days' pressure; deformation only slightly marked.

It was, therefore, possible to get thin proximal sections of changed and unchanged material and to examine them beneath the microscope, when the nature of the movement which had taken place was clearly discernible. The deformed part was distinguished by its turbid appearance, differing most markedly from the clear, transparent mosaic of the original. This turbidity was of greatest strength along a series of reticulating lines running through the sections, which lines, when highly magnified, are seen to consist of bands of tiny calcite granules. The calcite individuals along these lines—the "lines of shearing"—have broken down, moved past one another, and come to be compactly massed after the movement ceased. The resultant structure is identical with that seen in the felspar of many gneisses.



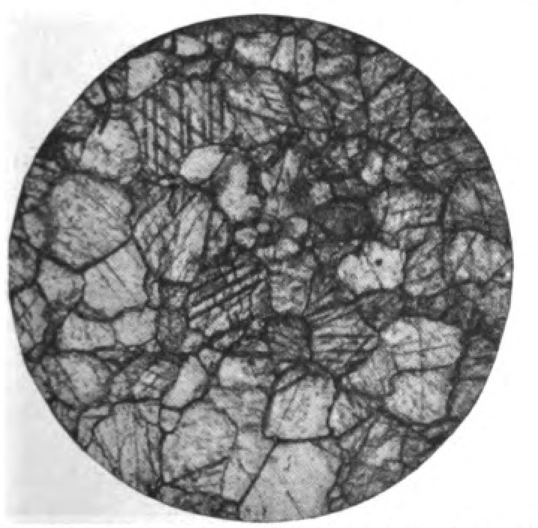
At the left is a column of marble whose deformation occupied 124 days, during which a temperature of 300deg. Centigrade was maintained. The column at the right represents the original size of the other.

Professor Adams next experimented with the effects of heat, and after putting the marble into the machine (supplied with suitable apparatus for the generation of heat) he learned that the crushing load of the column deformed under those conditions was equal to 10,652lb. per square inch. So that, while marble deformed under the influence of great heat is not quite as strong as the original rock, it is, to say the least, very strong.

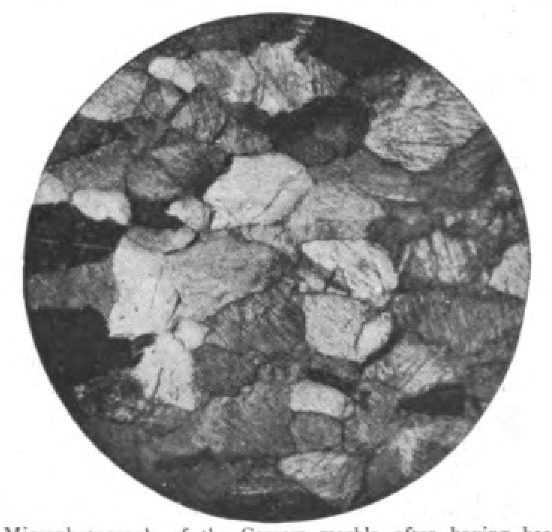


In this case the pressure on the marble was continued so long and the deformation carried so far that the moving marble within rent asunder the metal jacket inclosing it.

The third factor which it was believed might have an influence on rock formation —moisture—was next considered, and yet another modification of the machine was needful. For sixty-four days water was forced through the marble column at a pressure of 460lb. to the square inch. The column was heated to 300deg. Centigrade. Under these conditions the marble yielded by molecular slipping, but the deformed column was found actually to be slightly stronger than an unchanged bit of the original rock. The structure was identical with that developed at 300deg. Centigrade without the presence of moisture. Water therefore did not affect the character of the deformation. The remarkable strength of the modified rock may have been due, however, to an infinitesimal deposition of calcium carbonate along very minute cracks or fissures.



Microphotograph of the Carrara marble used in the experiments. The rock as found in Nature. The individual grains have very nearly the same diameter in every direction, although differing somewhat in size among themselves.



Microphotograph of the Carrara marble after having been slowly deformed during 124 days at a temperature of 300deg. Centigrade. The individual grains can be seen to be flattened in a horizontal direction.

All of which leads up to a most interesting and, at the same time, a most astonishing fact; namely, that an examination of marble deformed at a temperature of 300deg. Centigrade, or better at 460deg., indicated an internal molecular motion precisely identical with that observed in metals changed by impact or compression. The agreement between the two is so close that the term "flow" is as correctly applied to the movements of marble under the conditions of pressure, previously described, as it is to the movement which takes place in a button of gold, for example, when squeezed in a vice, or in a rod of iron when jammed between rollers.

That it might be known definitely whether the structures shown by artificially malformed marbles were to be found in Nature's contorted crust, a series of forty-two specimens of marbles and limestones from various portions of the globe were chosen and examined with the minutest care. Of these, sixteen showed structures like those in the artificially deformed rock, and the movements of the granules had been absolutely identical with those superinduced in the Carrara marble. In six other cases there was a greater or less resemblance, and in the remaining twenty specimens the structure was different.

It is believed from the results of other experiments now being carried out, but not yet completed, that similar movements can be induced in granite and other harder crystalline rocks.