whose marble edges are rounded off, forming hollows and basins such as one sometimes sees in mountain streams. The bridge is of marble, and is about 4 meters long, 3 meters broad and some 3 meters thick. The canyon under it is 4 or 5 meters deep. Both in formation and appearance the bridge is entirely different from the one in the Shenandoah Valley or the little one on Cranberry Island, Me., the only others I have seen. Natural bridges at best are rare phenomena, and the one at North Adams is unique, as far as I know, in being formed of a true marble.

Stated Meeting, held Wednesday, December 12, 1900.

SUBTERRANEAN WATERS.

BY CHARLES MORRIS.

The crust of the earth is only in a general sense a solid mass. In many localities it might be compared to a sponge, full of cavities and ramifying passages, and freely permeable to liquids. While in many places it is composed of dense rock or firm clay, through which water cannot make its way, in others it is rent and splintered, and large cavities here and there exist. Again, much of the material of the crust is porous, water passing somewhat freely through it, and in other localities water makes its way by a process of solution, dissolving and carrying off certain constituents of the rocks. As a result of this permeable condition much of the water which falls upon the earth's surface makes its way into the interior, penetrating the pores and cavities of the crust, which seems to be fully saturated with water.

What may be the actual quantity of water thus held in the earth's crust it is far beyond the present power of science to decide. It must be very great, since, in addition to the free liquid, water exists as a constituent of the hardest rocks. If restored to the surface it would doubtless be sufficient to raise considerably the ocean level, and perhaps to flood all the lower portions of the dry land. In that

remote period when the heated condition of the crust prevented the inflow of water, and the whole of earth's liquid element swelled the ocean, such a condition very probably existed. For ages, as the crust cooled, the waters made their way into the interior, until they reached a considerable depth, and the depression of the ocean level permitted a large section of the surface to emerge as dry land. One important result of this cooling of the surface and narrowing of the oceanic basins has been a decrease in evaporation and rainfall and a localization in the distribution of atmospheric waters, so that large regions of the surface have become deserts. This process of desiccation will doubtless continue in the future, but with great slowness, since the cooling of the earth's crust has become a very deliberate operation.

The quantity and distribution of the liquid contents of the crust are very imperfectly known. We can become aware of their distribution only by the upflow of water through springs and the piercing of the surface with wells. It is of interest to find that water exists at some level in almost every locality where such a well has been sunk, and that it is abundant at some of the greatest depths that have been reached, frequently under sufficient pressure to rise to the surface. There are, of course, vast reaches of strata destitute of water in a free state, but these dense strata have failed to check the downflow of the liquid element. Pierce them, and water is found below; pierce still lower strata, and water again outflows, often in large volume. Like the rocks themselves, the liquid contents of the crust seem to exist in successive strata, growing warmer as they lie at greater depths, and usually bearing mineral matter in solution, the product of the rocks through which they have made their way.

An interesting analogy may be shown to exist between the crust of the earth and the human body. The latter, solid exteriorly, is everywhere permeated with streams of flowing liquid, which pours forth wherever the surface is pierced. In the same manner, if we pierce the earth, its life blood gushes out, now flowing quietly, as from a vein, now spirt-

ing freely, as from an artery. Wherever we break through the skin of the great body of the earth the same results appear. In some of the most unpromising localities an abundance of subterranean water seems to exist. Even under the arid surface of the Sahara, the most extended of the earth's deserts, there appears to be an abundant supply of water at a moderate depth, which oozes forth freely at almost every point where an artesian well is sunk. The arid region of Southern California is partly irrigated from a similar subterranean stratum, and like conditions exist in other desert regions of the earth's surface, natural springs oozing up where artificial ones have not been made.

From this we may deduce that, so far as subterranean water is concerned, there is no marked difference between regions of abundant rainfall and those of great aridity. Dry as the soil may be in one locality, moist as it may be in another, the boring-rod of the well-driver reveals a strikingly homogeneous condition in the depths of the crust, and an oasis is formed in the desert wherever there is a passage upward for the underground waters.

There is nothing surprising in this. Such a distribution of the subterranean waters is what we might naturally expect to find. Once penetrate to the sub-surface and we reach a region in which the diverse influences of aridity and precipitation fail to assert themselves. Though the surface distribution of water may be localized, the movement beneath the surface is likely to be general, the water following every channel and making its way by multitudinous avenues to regions far removed from its place of origin. While the surface water may flow through river channels to desert regions, the underground distribution is likely to be more general, since, while the surface represents but a single stratum, there are many underground strata, each affording special opportunities for distribution. While the arid regions of the surface are those of small rainfall, those of the interior are due to impermeable rock strata, and the two conditions are not likely to coincide. It is quite conceivable, indeed, that there may be a far more abundant supply of water beneath a desert than beneath a well-watered

region, if the strata in the former case are more permeable than in the latter. The movements of subterranean waters have been going on for ages, and their existing distribution is dependent far more upon freedom of underground flow than upon variation in surface rainfall.

If, now, we come to consider the conditions under which the interior water exists, it is impossible to accept a widespread popular conclusion to the effect that flowing streams and rivers of water exist in the depths of the earth's crust. Streams of this character are found in great caverns, and this has doubtless led to the conception that the underground waters exist largely as rivulets or rivers, flowing through interior channels as the blood flows through our veins.

The fact is, however, that, apart from the streams found in the cavities in limestone strata, which must somewhere find a passage to the surface, such conditions do not and cannot exist. There are no such deep-lying streams, no great rivers flowing within the earth's crust; the subterranean waters being either at rest, or moving sluggishly as they are drawn off.

The interior of the crust was, in all probability, saturated with water in far remote times, and it is impossible for this water to move except to the extent that it finds a surface vent. It is probably contained almost wholly in porous rocks, and but to a small extent in channels and cavities. For the same reason the inflow is limited, being dependent upon the outflow. A saturated sponge can take in no more water, even if plunged into a full vessel. And there can be no movement of water into its interior, except to the extent that water escapes from its surface. In like manner, if the earth's crust be once saturated, all its pores and cavities filled, no more water can enter, and there can be no movement of the water within except to the extent that the contained liquid has an opportunity to escape.

The most evident channels of escape are those of springs, yielding cold, warm or hot water as they come from varied depths. These are rarely sufficient in number or volume to create any active interior movement, and most generally have to do with superficial strata. They are not confined

to the land surface, but frequently open under water, occasionally forming the sole supply of lakes. As one example of this may be instanced Lake Bombon, in the island of Luzon, which has no visible inflow, but has a considerable river for its outflow.

The well may be regarded as an artificial spring, which taps water strata of varied depths, occasionally, no doubt, reaching very ancient accumulations, which have lain undisturbed for ages. If irrigation wells increase very largely in number, as they seem likely to do in the future, they may give rise to a somewhat active movement of the interior waters. The artesian outflow is, of course, limited in quantity, since the sources from which it draws need to be renewed from the surface, and the seepage downward is a deliberate process and not calculated to yield a rapid new supply. The quantity of water to be obtained from the earth's crust is, therefore, far from inexhaustible, and represents a supply that has been gathering for ages. It may be said further that this water cannot reach the surface except through the influence of pressure, this being usually, perhaps solely, a hydrostatic pressure operating from some supply of water at a higher level, and indicating that the interior waters are to a large extent in continuous contact. It may be, indeed, that the pressure of natural gas has its share in the upflow of water, as it probably has in that of petroleum.

As regards the depth to which water can descend in the earth's crust, it is to a large extent an open question. Professor King, in his able study of this subject, considers that water may reach to a depth of more than 10,000 feet, —how much more he does not venture to suggest. If the crust were permeable to an indefinite distance downward, and water could descend unchecked, a vast volume would be necessary to produce saturation, but there can be no doubt that the rocks grow denser and less permeable as depth increases. The elevation of mountain ranges and the deposition of thick strata of new rock material have undoubtedly greatly compressed the underlying rocks, decreased their porosity, and forced out much of their more

ancient water contents, and it is possible that in this way a limiting layer may eventually be formed through which no water can penetrate. Yet at any time the rending action of earthquakes seems capable of opening vast rents in the deeper rock layers, producing cavities sufficient to contain large bodies of water, and to permit the descent of this liquid element to much greater depths.

There appears to be a limiting agent different from this, and one not subject to the action of chance or accident, or to the possible existence of porous rocks at a much lower level than has been estimated. This is a stratum of heat, not of dense rock, and one that seems likely to constitute an effectual limit to the descent of water, its action being to reverse the descending tendency of the liquid substance and convert it into an ascending tendency. In other words, the heat at a certain depth must be sufficient to convert the water into steam, which seeks to force itself upward with an energy greater than that with which the superincumbent water seeks to descend. The pressure of water at great depths, it is true, considerably raises the evaporating point, but there is a limit of temperature at which no amount of pressure can overcome the tendency to vaporize, and where this degree of heat is reached the possible descent of water comes to an end.

There are facts which seem to indicate that this limiting layer of temperature varies in depth to a large extent in different regions of the earth. In the Yellowstone Valley, for instance, the phenomena might be held to prove that the inflowing water is converted into steam at a very moderate depth. The multitude of hot springs, the leaping geysers, the whole phenomena of the valley, appear to indicate a high degree of heat at no great distance beneath the surface, a temperature sufficient to vaporize the descending water and hurl it up again in boiling fountains. And the same might be held to be the case in the various other geyser regions of the earth.

This is only one of the phenomena supposed to be due to the conflict between water and heat in the earth's crust. There is another and a far more important one, that of

volcanic eruptions, which are by many held to be results of the conditions here considered. In the geyser, the steam and water have open vents and are free to escape. In the volcano the vents are closed and the imprisoned giant of steam has to force its way to the surface. The boiling lava, which here replaces the hot water of the geysers, is saturated with the water to which its force of uplift is due, and this, as it reaches the surface, flashes again into steam and rends the lava into dust, or so-called ashes. The earthquake, which so often accompanies the eruption, is a result of the same cause, and testifies to the throes of the imprisoned giant in its mighty effort to break its bonds. The whole phenomenon is a striking example of the limitation of the descent of water through the influence of internal heat. This view, of course, is hypothetical, but as an instance in its favor I may refer to the remarkable eruption of Krakatoa in 1883. The suddenness and extreme violence of this eruption suggest the probability that some new opened crevice or cavity admitted the ocean waters in great volume to the heated strata of the mountain depths, and that these waters were converted explosively into steam, which expanded with a force sufficient to blow the mountain into fragments and hurl its debris miles into the air.

While it is possible that the existence of geysers and volcanoes indicates marked differences in the depth of the superheated rock layer, this is by no means necessarily the case. It may simply indicate that they occur in the localities in which the crust is specially permeable to water, and that such results are likely to occur wherever water is able to make its way downward to a sufficient depth. It may be suggested that unbroken strata of dense rock check the deep descent of water throughout the greater part of the earth's crust, and that it is able to reach the superheated strata only in the limited localities to which the phenomena in question are confined, and also that some of the effects named are likely to appear wherever and whenever the subterranean water does penetrate to this depth.

These considerations lead to the interesting conclusion that the most vigorous activities of the earth's crust—the

volcanic eruption, the earthquake and the geyser—may be largely or wholly due to the action of subterranean water. The same may be said of other activities of the crust. The slipping of strata, to which some earthquakes are credited, may be caused by the solvent action of water, and the lateral pressure to which mountain elevation is due is held to be a result of surface denudation and the heaping up of new strata beneath the ocean waters.

There is a second very important service rendered by water, that of the cooling of the earth's crust. In the primeval period the surface waters were constantly rising as vapor and conveying the superficial heat upwards, to be radiated from the atmosphere into space. In the succeeding period the subterranean water became engaged in similar service. Heated in the lower strata, it rose as the hot spring or the geyser, and in the form of explosive steam it hurled great masses of molten rock to the surface, there to yield its heat to the air. The volume of heat thus conveyed in a century to the surface is very considerable, and in former times was probably much more so. It may much exceed that which reaches the surface by the slow process of conduction.

Subterranean water would thus appear to have long been an agent of the utmost service to the earth, giving rise to the great activities of the crust and aiding essentially in cooling its interior. What will be the future record of this useful agent it is difficult to say. As the crust continues to cool, the waters may make their way to lower depths, unless checked by a general layer of impermeable rock. The cooling of the rocks will also tend to make them more capable of water absorption, and it has been suggested that the ocean waters may all eventually be swallowed up in this way, and the earth become a dry and dead planet like the moon.

This at least we can be sure of, that if such an event takes place it will be at some very remote period in the future. The seepage of water into the earth has long been decreasing with the decrease in the area of rainfall. If the oceans should grow narrower by the partial absorption of

their water, the rainless area will grow still more extensive and the area of seepage become more contracted. Civilization is adding to this effect by the removal of the forests. The water once held in their mold and gradually penetrating the surface now hastens downward to the streams and adds much less than formerly to the subterranean supply. As desiccation increases nature will continue what man has begun, the forest area narrowing and the waters rushing with less resistance to the sea. These influences must greatly check the possible future disappearance of the ocean waters within the crust, and whatever the final result may be, many millions of years must pass before the earth can become, from this cause, unfitted for the habitation of man.

DISCUSSION.

PROF. F. L. GARRISON suggested that some of the effects which Mr. Morris attributed to underground action might more probably be due to atmospheric conditions, such as aridity, etc.

MR. J. C. TRAUTWINE, JR.:—In connection with the water supply of Philadelphia, suggestions have been received from time to time looking to the utilization of subterranean supplies by means of artesian wells.

From what I know of the geology of Philadelphia, and of the gneiss and mica schist upon which it appears to rest, I have always been skeptical as to the existence, under the city, of strata favorable to the formation of true artesian wells, which, I have supposed, could hardly be looked for below the relatively ancient rocks which immediately underlie the Philadelphia clays and gravels. I should be glad if any light could be thrown upon this branch of the subject.

DR. HENRY LEFFMANN:—Whatever may be the nature of the waters under the earth in this region, it is a matter of experience that deep wells generally yield a supply, but that the quality and quantity are often unsatisfactory. In many cases the water contains so large an amount of iron compounds as to be unsuitable for ordinary uses. Several wells in the business section of the city have been aban-

done for this reason. Chlorides, principally, of course, sodium chloride, and calcium compounds, are also apt to be present in large amounts. A well of about 533 feet deep near the mouth of the Schuylkill River yields water containing considerable sodium chloride, but little of other substances, and this water has been used for some time both by human beings and farm animals for drinking without apparent injury. A well at Ninth and Mifflin and one near Hestonville also yield good waters. On the other hand, a well over 2,000 feet deep, near Broad and Green Streets, yields but little water, and, judging from my analysis, this is derived from the subsoil and not from a deep water-bearing stratum.

MR. JAMES CHRISTIE mentioned artesian wells in and near the northern portion of the city, especially in the neighborhood of Pencoyd, which yielded fairly, but the water of which was highly impregnated with magnesia, so much so that the employes of the Pencoyd Iron Works complained of intestinal troubles as a result of using it.

MR. TRAUTWINE sketched upon the blackboard a geological cross-section of Southern New Jersey between Philadelphia and Atlantic City, as given on a map prepared by the New Jersey State Geological Survey, showing alternating strata of sand and marl sloping gently from the Delaware River to the Atlantic Ocean, and underlaid, at least in the vicinity of Philadelphia, by the older rocks already mentioned. It will be seen that, according to this section, the deep artesian wells sunk near the seashore really tap the outflow from the vast natural sand filter bed formed by the sandy plains of Southern New Jersey, those nearest the coast intercepting the greatest number of these water-bearing strata, while near the Delaware River only the lower most of these strata are met with.

During recent years a company proposed to make a large excavation close by the Delaware River on the New Jersey side at Palmyra, opposite the Lardner's Point or Frankford Pumping Station of the Philadelphia Water Works. This excavation, it was argued, would be filled with pure water which could then be led in pipes laid under the river to the Lardner's Point Station, and thence pumped to reservoirs or into the distribution instead of using the unpurified Delaware River water as at present.

In correspondence had in connection with this scheme, the promoters expressed the view that the excavation would be filled by water drawn from the State of New Jersey in the near vicinity, but it has always seemed to me that if reliance can be placed upon the cross-section here shown, we should expect rather that the excavation would be filled by water filtering into it from the Delaware River through the intervening mass of sand and silt.

DR. LEFFMANN:—I do not know what data Mr. Trautwine's correspondent has that should lead him to reject the view that the water-bearing strata in New Jersey are inclined so that they are deepest at the seashore, but I should require a thorough exposition of his argument before I would abandon the views that have been so carefully worked out in connection with the geology of New Jersey, especially by Mr. Lewis Woolman.

I have found the water yielded by the new artesian wells at Camden analogous, in composition, with filtered Delaware River water. At Atlantic City, the artesian wells at Haddon Hall, and other wells of about 800 to 900 feet depth, gave a very satisfactory water, low in total solids, while both the deeper and the shallower wells gave much less satisfactory water, and wells sunk midway between Atlantic City and Philadelphia gave water heavily charged with iron. The water of the artesian well at Asbury Park is heavily charged with iron in solution, which, by the action of the air injected into it by the Pohlé air-lift pump, becomes further oxidized and reaches the surface carried in suspension, and is filtered out.

Geyser waters are very rich in silicic acid. In this

respect they differ from most deep waters, and it is probable that a powerful dissociation action takes place when very hot water under pressure comes in contact with the ordinary rock silicates.

Apropos to this, I may mention a laboratory experiment in which I was obliged to immerse a glass vessel for some time in hot water under high pressure. The glass in this case showed evidence of having been attacked and partially dissolved by the water.

MR. CHRISTIE mentioned a fresh-water well near the seashore, the level of which rose and fell with the tide.

MR. TRAUTWINE:—The rise and fall of the level of the water corresponding to the rise and fall of the level of the tide may readily be explained by the accompanying sketch illustrating the flow of water from a higher to a lower reser-

voir through a pipe provided with piezometers, or tubes indicating the pressure.

As the water flows from the higher reservoir, through the pipe, to the lower reservoir, the levels of the columns in the piezometers gradually become lower as we proceed from the upper to the lower reservoir; for, in each portion of the pipe, a part of the pressure existing at the upper end of such portion is expended in overcoming resistances in such portion.

If now, by any cause, as by the fall of the tide in the ocean, the level of the lower reservoir be lowered, that in the upper reservoir remaining constant, the hydraulic grade (or line joining the tops of the columns in the piezometers) will be correspondingly lowered.

The lowering of the level in the lower reservoir, of course,

increases the total head under which the water is flowing, and which is equal to the difference between the water levels in the two reservoirs. This increase in the total head causes an increase in velocity throughout the pipe, with a consequent diminution in the pressure at each point.

This seems to be in general analogous to the case of wells supplied from a higher district further inland, each well being in fact a piezometer standing upon the water-bearing stratum through which the flow is proceeding outward to the ocean, and it is therefore only reasonable to expect that the levels in these wells, especially those near the sea, would show a correspondence with the levels in the ocean.

DR. LEFFMANN :—I think it would be a great mistake to limit the term artesian to wells that furnish water that rises above the surface level; the true distinction is that the water is obtained from a stratum that is separated from the subsoil by one or more impervious layers, and is, therefore, not derived from the rain, surface or subsoil waters of the immediate district.

CHEMICAL SECTION.

Stated Meeting, Thursday, January 24, 1901.

A BRIEF SKETCH OF THE ESSENTIAL REQUISITES OF "POWDER" AS DISTINGUISHED FROM "EXPLOSIVES."

BY DR. W. J. WILLIAMS.

(Being the Address of the Retiring President.)

In many minds, probably, the question arises, "What is the difference between a 'powder' and an 'explosive?' Are they not 'almost synonymous,' or at any rate are not all powders also 'explosives?'" In the ordinary acceptance of the terms the reply would be "yes," and yet in the military technical use of the words the difference is great.

"Powder" is a means of propulsion for projectiles. "Explosive" is a means for production of powerful shattering effects.