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with a 3-inch pile, and strewn with leather cushions cut and dyed with a decorative pattern. Two projecting wings which overlapped at the ends stood out, one on either side, from the open end of the tent, forming a kind of outer court, so as to ensure complete privacy for the inmates. This open space was partly covered during the daytime by an awning, which at night was let down to close the end of the tent.

The dwelling was used as a kind of school for the junior members of the camp. The women, being the more highly educated sex, were the teachers. In one corner of the tent lay a small board covered with Arabic lettering, with which some of the children were being taught to read in that language, after having presumably mastered their own. The Twareg alphabet is, of course, entirely different from the Arab.

Our return journey from Gomar lay, until Shegga was reached again, all across the open desert, and presented few points of interest. There was a caravanserai at the end of each day's journey. At Sif el Menadhi we found one of the so-called "desert mosques," a small enclosure built of stones, measuring about 5 feet square, with a niche at one end to indicate the direction of Mecca. This was used as a place for prayer by the Arabs of the surrounding desert. A journey of four days from Gomar, during the course of which we twice crossed a branch of the Shott Melrir, brought us again to Shegga, from which point our road to Biskra was identical with that of our outward journey.

HOT SPRINGS AND VOLCANIC PHENOMENA.*

By Prof. EDUARD SUESS.

IN immediate proximity to the most remarkable hot spring of the European continent, it seems appropriate to direct your attention to the question of the causes to which such springs are due. The older views set forth in the text-books tell us that hot springs are fed by water percolating down from the surface of the ground, which at a certain depth attains a high temperature, and ascending again at that temperature, brings with it in solution solid substances from the rock. From these conditions it might be possible, knowing the mean gradient of temperature from the surface downwards, to assign approximately a minimum depth reached by the percolating water, and by analysis of the water to learn something of the composition of the rocks through which it has passed.

But in 1880 Franz von Hauer, F. von Hochstetter, and Heinrich Wolf, when consulted with reference to the preservation of the Karlsbad springs, expressed considerable doubts as to the water of the springs coming from the extensive infiltration area, chiefly composed of granite, in the neighbourhood. G. Laube found it impossible to account for either the quantity of water itself or of the carbonate of lime in the deposits, on the hypothesis that they were derived from granite. Ludwig and Mautner had similar difficulty in accounting for the sodium

* Abstract of lecture at the meeting of the Congress of German *Naturforscher und Aerzte*, held this year in Karlsbad. By Prof. Eduard Suess.

present, and suggested that the bulk of the matter in solution must be derived, not from the granite, but from the unknown under-strata of the Earth's crust. Rosiwal was unable to find any correspondence between the yield of the hot springs of Karlsbad and the distribution of rainfall in the region, and concluded further that the carbonic acid must be derived from a heated magma.

It is likely that similar difficulties have been experienced in many regions where hot springs occur. My intention is not to present to you a new theory, but rather to redirect attention to an old one, which, undeservedly as I think, has lately fallen somewhat into the background. But before doing so, I must, for the sake of brevity in what follows, explain the meaning of two expressions. In a well-known paper on metallic veins, published in 1893, Posepny has used the term "vadous" to distinguish infiltrating waters, *i.e.* those of superficial origin, in contradistinction to waters rising up out of the depth. We shall retain this expression, extending it so as to include not merely percolating waters, but all the waters of the hydrosphere—oceans and rivers, clouds and rain. Vadous waters, often impregnated with carbonic acid, penetrate from the surface into the upper strata, where by solution and deposition they form deposits of mineral substances. The waters which, having been warmed, come to the surface in artesian borings are vadous. Thus we may also have vadous carbonic acid, which appears with marsh-gas in coal-beds, and vadous compounds of chlorine, bromine, iodine, and sulphur in the oceans and in salt deposits. The sulphuretted hydrogen separated by the action of bacteria in the depths of the Black sea is also vadous.

The second expression to which I would refer is "pulsation" as applied to springs. There are two kinds of pulsating springs. First, the type of pulsation familiar in the geysers of Iceland. The geyser has a cylindrical tube formed of sinter. Blasts of superheated steam, entering the tube laterally at great depths, are subjected to the pressure due to the column of water in the tube, which raises the boiling-point, let us say, from 100° to 124° C. Successive hot blasts eventually raise the temperature to 124° , and the explosion follows: the upper column of water is blown into the air, water is suddenly discharged from a lower column below the point where the steam entered, the cylindrical tube is emptied, and then slowly refilled from below. We observe that the blasts of steam are hotter than the column of water, the temperature of which rises till the explosion occurs, and then sinks. Pulsating springs of this kind may be specifically termed geysers, or boiling springs.

The Karlsbad springs are also pulsating, but the pulsations are less regular; they occur at short intervals, and are due to a different cause. Over the system of springs lies a mass of deposit, pierced by numerous holes. In this mass carbonic acid gas collects until its pressure is sufficient to force the water out, and since the cavities are irregular, so also is the rhythm of the springs. Springs of this type may be called "bubbling springs" (*Sprudel quellen*). Here we have an important distinction. Boiling springs are not subject to hydrostatic pressure like the waters in artesian wells. The characteristic of hydrostatic pressure is its uniformity; intermissions of long period would be impossible. In the case of the bubbling springs it is difficult to judge from the nature of the movements, but in Karlsbad at least a continuous hydrostatic pressure up to the surface cannot be admitted.

The occurrence of periodic variations in the action of certain volcanoes has long been recognized; these are commonly known as "strombolic" phases of eruptive action, and the quiescent pauses may be anything from a few seconds to several hours. In this connection I may be allowed to describe an experience which made a great impression on me at the time. In January, 1871, Vesuvius

formed a "parasitic" crater at one side of the main crater, and 60 or 70 metres below it. Looked at from a distance, this crater presented the appearance of a jagged protuberance on the side of the main cone of the volcano. On the night of March 31, the weather being clear, as we were standing on the St. Lucia quay in Naples, we distinctly saw rhythmical flashes issuing from the small crater at intervals of six to eight seconds, while similar flashes came from the main crater once in two minutes. The two centres of activity were thus to a certain extent independent of one another, but since they must certainly have been fed from a common deep-seated vent, the separation must have taken place comparatively near the surface, and only the upper part of the vent can have been concerned in the rhythmic movements. The analogy with the geyser was so close that one was forced to the conclusion that Vesuvius is merely a form of boiling spring. On the following day we were able to enter the parasitic crater, and saw the flame bursting out of the vent to the height of about a metre every six or eight seconds; bubbles the size of one's head were blown out of the glowing mass, and blazing pieces of slag hurled into the air; then the flame sank, and a new skin of slag formed over the mouth of the vent, to be blown off in turn by the next explosion. Clouds of steam hovered over the outlet, and hydrochloric acid and acids containing sulphur were present. The general appearance was simply that of a geyser, which ejected melted stone as well as heated gases. Stones were also thrown out by the main crater of Vesuvius. Each of these seemed to draw a tail of steam behind it, and as they fell on the ashes in front of us they were covered with a white crust of sodium chloride. We were confronted again with the old puzzle: the eruptions themselves seemed to be caused by steam, as in the geysers, and the chloride of sodium pointed to the sea beneath us, but how could sea-water percolate into regions of such extraordinarily high temperature? Thirty years separate us from the experience of that day; the same puzzle has presented itself to many investigators in that time, and with a multitude of new observations to help us, we may turn again to seek a solution of the problem.

Silvestri observed the rhythmical action of Etna before the eruption of 1879; Mercalli studied Vesuvius in different years; and Bergeat has made observations on Stromboli. It is obvious that in a natural phenomenon like this one cannot expect the precise regularity of the pulse of a living creature—small lateral passages in the depth, and similar fortuitous circumstances, often cause the periodic outbursts in boiling springs to be preceded by a series of smaller disturbances, which follow no regular period, and the true rhythm of the main explosions is only recognized when the smaller ones are neglected. The great feature of the boiling springs is the irregular entrance of the gases, the explosive power of which increases towards the mouth of the vent.

I believe that the blasts of hot gas in the parasitic crater of the volcano are the source of heat, in precisely the same way as the blasts in the sinter tube of the geyser, and that they are the primary cause of the melting of the lava and of its intermittent outpouring. One is strengthened in this view by the circumstance that sounds like reports of subterranean cannon usually precede great eruptions, the result of the access of superheated vapour to cooler surroundings. These dull reports become gradually more frequent, until at last the first white ball of steam is shot out of the crater; the boiling lava follows later, itself saturated with steam. Be this as it may, it is at least certain that the quantities of steam issuing from the parasitic crater must come from a zone in which the temperature equals or exceeds the melting-point of most rocks, and in which there can be no question of porous or fragmental rocks, and therefore no question of infiltration of vadous water.

Turning now to the gases accompanying the eruptions. After steam, chlorine and gases containing sulphur, are the most important, and carbonic acid gas comes next. Their occurrence follows a definite law. So far as it has been possible to approach them, all fumaroles actually within vents contain steam; but the hottest fumaroles (over 500° C.) on the surface of cooling lava-streams, where approach is easier, are dry. In the emanations from these high-temperature fumaroles are found chlorine compounds, and along with them fluorine, boron, and phosphorus, substances which are the first to disappear as the temperature of the fumarole sinks. Sulphur persists longer, often combined with arsenic. Carbonic acid is given off freely till a much later stage, sometimes till the fumarole is comparatively cool, notwithstanding that it is observed in the hottest dry fumaroles. Fumaroles in different "phases of emanation" may occur quite near one another. The steam of the volcano cannot be derived from vados infiltration, for if it is, whence the carbonic acid? Both must come from the deeper regions of the Earth; they are the outward sign of the process of giving off gases which began when the Earth first solidified, and which to-day, although restricted to certain points and lines, has not yet come to a final end. It is in this manner that the oceans and the whole vados hydrosphere have been separated from the solid crust. Volcanoes are not fed by infiltration of the sea, but the waters of the sea are increased by every eruption.

From volcanoes, we come naturally to the question whether the water of boiling springs is vados or hypogene. The Erzgebirge, which structurally belong to the Karlsbad granite, are traversed by numerous veins, *i.e.* by cracks or fissures, filled up sometimes with quartz or hornstone, sometimes with the ores of different sorts from which the mountains derived their former value and the name they still retain. The mining industry, and the studies of the famous Freiberg school, have made us acquainted with the formation of the Erzgebirge; and one of the most distinguished representatives of the school, whose name cannot be mentioned in an assembly of German naturalists without evoking expressions of enthusiastic admiration, Hermann Müller, recognized more than forty years ago the bearing of these mineral veins on the question we are now discussing. Since the hottest fumaroles of a volcano are dry, the deposits found in them must be the products of sublimation: all later, or *sulphide*, fumaroles contain water, their deposits will be stratified or banded, and in the succession of deposits the greater solubility of the compounds comes into prominence. With reference to this we may quote the following experiments on the nature of mineral veins. Deposits of tin belong to the hottest type, in which the temperature is higher than occurs in thermal springs, and for the most part higher than that of the "sulphide" phase of vein-formation. In contrast to this, the hot springs may be taken as the latest phase of a whole series which led up to the present deposits of ore: such springs occur here and there throughout these deposits. They are for the most part alkaline, and sometimes extraordinarily rich in sodium chloride; the amount of salt in the Karlsbad springs is remarkable, issuing as they do from granite. But the alkalies are not found in the ore deposits, not because they were absent at their formation, but because of their greater solubility. Thus we have at the one extreme the tin layer, at the other the alkaline hot spring with free carbonic acid. In the mine we can recognize the traces of the fumarole above 500° C., as well as of the tepid salt ascending water. Vados influences are not wanting in the upper levels, but they are adventitious, and the alkaline hot springs in the fissures are only the last of a series of events which have their origin deep in the Earth's crust; in spite of their low temperature, and their carbonic acid, they are to be regarded as hypogene waters. Karlsbad is situated on the outcrop of a vein. It now becomes possible

to interpret the observations of the miners. If we could clear away all disguises, and clearly see the system of springs as a whole, we should see that it pierces the granite in two distinct ways: in one part it is covered by its own deposits of lime, but in the depth are deposits of hornstone, binding fragments of the granite into a breccia exactly as the springs of Plombières do in the Vosges, notwithstanding their lack of soluble matter. Veins of hornstone and also of arragonite extend through the surrounding granite, and the observations of Knett leave it an open question whether the deposits of Karlsbad are not intermediate between hornstone and limestone.

The relations of hot springs to mineral veins are further of value in the interpretation of their chemical composition. The efforts of experts have recently been directed afresh to finding an explanation of the filling up of veins by lixiviation from the surrounding rocks, but exact experiments have proved that filling up in this manner, without addition of material from the depth, is inexplicable. The case is similar to that of the Karlsbad springs. At Vesuvius the nearness of the sea made it doubtful at first if the salt were not of marine origin; but here, in the middle of a continent, the salt appears again, both in springs tapped by mining and in the Karlsbad springs. The substances coming from the depth consist of readily soluble compounds, while other more easily separated substances—the metallic compounds—remain behind. To this we must ascribe the quantities of Glauber's salts, soda, and sodium chloride, to which the waters of the Karlsbad springs owe their curative properties. The great quantities of free and loosely combined carbonic acid are undoubtedly of hypogene origin; we know that they correspond to a late phase of volcanic activity, following the basalts. If we look at the elements rather than the compounds which occur in the Karlsbad springs, we find traces of older phases. From the hottest stage we have chlorine, fluorine, boron, and phosphorus, while the metals of this stage—tin, bismuth, molybdenum, etc.—are wanting. Sulphur is present, and with it selenium and thallium, rubidium and cesium, the accompaniments of the sulphide phenomena in many volcanoes; also arsenic and antimony, the ordinary representatives of the sulphide ores, and zinc as a relic of the ores themselves. There remain sodium, potassium, and lithium; calcium, magnesium, and strontium; iron and manganese; aluminium and silicon. Every one of these is met with in mineral veins, and nearly all occur as volcanic products.

To sum up. The temperature of the gases ascending in volcanoes equals or exceeds that of the melting-point of most terrestrial rocks, and these gases cannot be derived from vadous infiltration. The hottest fumaroles are dry; steam and the substances dissolved in hot springs belong to later phases. The covering of tin on the sulphide veins of the Erzgebirge corresponds to the hottest subliming phase of this stage of activity; the other veins—the real sulphide ores—belong to a later stage. The hot springs which burst from the surface at the present day are but a relic of this stage. Along with them we may place the issuing streams of free carbonic acid, noting their close connection with the great basalt zone of northern Bohemia, extending into Silesia.

We may therefore conclude that there are vadous springs and hypogene springs. The term "hypogene" may be applied to springs which are the survivors of volcanic activity, originating in the depths of the Earth's crust, and bringing water to the surface for the first time. As the use of this term, here applied to curative springs, is based on geological considerations, I need hardly guard myself against erroneous therapeutic applications of it. The water of the Karlsbad springs is hypogene water.

All attempts to delimit an infiltration area at the surface for these springs, or to ascertain the depth from which the water rises out of a so-called thermal layer,

are vain. Any attempt to determine the general structure and composition of the granite is equally hopeless; the cavities from which, according to an old estimate, 5,880,000 kilograms of solid material are removed every year, do not exist. Karlsbad stands on a drift of hornstone. If its warm waters still separate the heavy metals in the depths, a mineral vein is in course of formation, and the waters reach the surface impoverished; but it is hardly possible to ascertain whether such action is going on, although it is suggested by the arsenic, antimony, and zinc.

Springs may be easily classified into five groups. First, the ordinary fresh-water spring. Second, springs of vadous water, having the mean temperature of the soil, but characterized by special mineralization, like the iodine waters of Hall and Darkau, and the bitter waters of Saidschütz and Püllna. Third, mineral baths (Wildbäder). Fourth, hypogene springs, not varying in temperature or quantity with the seasons of the year, and having any degree of warmth from the mean temperature of the soil up to over 70° C., sometimes neutral, sometimes weakly mineralized with small quantities of Glauber's salt, common salt, or soda, and sometimes strongly mineralized with the same substances; for example, Marienbad temperature (11°·2 C., from granite) and Karlsbad (73°·8 C., from granite). The fifth group includes the boiling springs, of which no example occurs on the continent of Europe. The free carbonic acid stands, to a certain extent, in an independent position, as is shown by the quantity of it in Karlsbad, and the number of cold acid wells and dry exhalations of carbonic acid gas.

The five groups of springs named do not include every species of spring, and they are not equivalent. Groups one, two, and three are vadous, groups four and five hypogene. As the water flows away from the well, it cools, deposits some of its mineral contents, and mixes with the vadous surface water. Other substances in solution, notably the alkalies, are added to the world's stock of material. The Karlsbad springs bring up more than a million kilogrammes of new salt every year; the sea is not the provider but the consumer of salt, and the many remarkable similarities of composition in the waters of hot springs and of the sea become intelligible; the salts of the sea are now vadous, but they were once hypogene. But the atmosphere as well as the sea is enriched from hypogene sources. All the vast quantities of carbonic acid which issue from the soil at a hundred places, from here along the southern border of the Erzgebirge, and even farther to the east, are hypogene, and they are added to the contents of the atmosphere, except in so far as they are absorbed by vegetation.

We have been brought to the discussion of questions remote from the subject of my lecture. The hottest dry fumaroles, forming deposits of the ore by sublimation, the rain of hydrochloric acid from Vesuvius, and the salt of the Altensalza mines, the hot vapours which recently burned the bodies of the unfortunate victims at Martinique without setting fire to their clothes, and the warm healing waters which rise up here before our eyes, are members of one indivisible series of phenomena. The Earth is still giving off gases in a manner which may be compared to what we observe in the spots on the sun, or on every large mass of cooling steel.

GEOGRAPHY AT THE BRITISH ASSOCIATION, BELFAST, 1902.

THE meetings of Section E of the British Association, under the presidency of Colonel Sir Thomas H. Holdich, R.E., C.B., K.C.I.E., were very successful, although the number of papers and reports, eighteen in all, was smaller than usual. In