ART. XLII.—*Volcanic Research at Kilauea in the Summer of 1911*; by FRANK A. PERRET. With a Report by Dr. ALBERT BRUN on the Material taken directly from "Old Faithful."

To readers of the six preceding papers of the present series*—devoted specifically to a discussion of the various Kilauean phenomena, products and formations—it will have been evident that, by reason of the necessary concentration upon each particular subject, no detailed reference to the research work, itself, could therein be made. This must be the writer's excuse for venturing upon a seventh paper, which, free from such restrictions, may be devoted to a brief exposition of the origin and aim of the expedition, of some of the research work accomplished and, finally, of data secured and resulting from subsequent investigation of original material collected.

The expedition—and with it the initiation of regular and continuous observations at Kilauea—was due to the initiative of Prof. T. A. Jaggar, Jr., geologist of the Massachusetts Institute of Technology, who, during a previous visit to Hawaii, had become impressed with the opportunity which Kilauea, above all other volcanoes, offers for direct research work, and determined to organize, if possible, a demonstration of its feasibility. To this end, negotiations were entered upon between the Institute and residents of the islands, a promise of coöperation by the Carnegie Geophysical Laboratory was obtained, and a set of cables and electric thermometers, for spanning the crater and for immersion in the liquid lava, were prepared. Nevertheless, for various reasons, years passed without accomplishment and, at the beginning of 1911, the entire project stood to expire of inanition.

At this stage Prof. Jaggar, finding himself unable to assume the charge, made a personal appeal to the writer to head the expedition to Kilauea in the hope of making a demonstration of such practical utility as should result in the establishment of a permanent institution on the spot, and promising to take up the work, himself, at a later date. Although very loath to interrupt, even temporarily, his work in Italy,† the writer considered the foundation of such a work in his own country of foremost importance, and it was thus that, in company with Dr. E. S. Shepherd, of the Carnegie Laboratory, he arrived at the islands in June and commenced those observations and studies

* This Journal, xxxv, 139, 273, 337, 469, 611; xxxvi, 151.

† After having lived through the Etna eruption of 1910, all the phases of which were observed and photographed, the still more important outbreak of 1911 was thus missed, leaving a gap which can never be filled.

which have been briefly considered in the preceding papers of the series.

The project may, therefore, be said to have been founded by the Institute of Technology and the people of Hawaii through the initiative of Prof. Jaggar; with the coöperation of the Carnegie Laboratory, as represented by Dr. Shepherd; and carried into effect by the Volcanic Research Society, in the person of the present writer.

It is but fair to state that the financial means of the expedition were extremely limited and that, had it not been for the hearty disposition of the residents, one and all, to aid and facilitate the work by every means in their power, the results would have been very different. Noted for hospitality and good will, their attitude toward the workers was beyond all

FIG. 1.

praise and the writer takes this opportunity of expressing his grateful appreciation of all that was done.

A difficulty, graver than the financial one, lay in the changed volcanic conditions at this time as compared with Prof. Jaggar's visit in 1909. Then, a complete "black ledge" stood within the walls of Halemaumau forming an accessible platform at no great distance from the lake of lava over which it was proposed to stretch the cables, but, by 1911, this was, for all practical purposes, non-existent, the few remaining sectors being quite unsuitable for supports and anchorages, as will have been evident from a perusal of the paper on "Subsidence Phenomena."* It became necessary, therefore, to work from the top of Halemaumau, and this increased the magnitude and the difficulty of the operations beyond all anticipation.

From figs. 1 and 2 the reader will obtain some idea of the apparatus erected for the purpose of obtaining temperature measurements of the lake lava and for collecting the material, itself, directly from the lava fountains. In the outline sketch

* This Journal, May, 1913.

it was necessary, for the sake of clearness, to greatly exaggerate the size of the trolley and the height of the A-frames constituting the main cable supports, with the unfortunate result of reducing the apparent dimensions of the crater to an almost ludicrous proportion—properly, the size of the trolley should be less than a tenth of the diameter of its smallest wheel, as drawn, and the height of the A-frames, and their distance from the crater's edge, should be reduced in proportion.

FIG. 2.

FIG. 2. Showing cables, trolley, and winch, at eastern edge of the crater.

A $\frac{3}{8}$ -inch Lidgerwood steel cable with hemp core was employed, the total length between anchorages being 530 M. of which nearly 400 M. was clear span between A-frames. This was stretched to a 5 per cent drop according to recommendation of the engineers,* in which condition the center of the span hung some 56 M., at the beginning, above the surface of the lake, the subsequent sinking of which increased this considerably and added greatly to the difficulty of lowering the instruments.

* For others who may undertake similar experiments the writer would advise a greater drop, not only as lessening the strain but as actually facilitating the sending of the trolley to the center of the span.

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The western anchorage was the projecting tongue of an old lava flow around which the cable was bent and secured with clips, while at the eastern end logs were buried crosswise in a cleft of the lava rock.

A team of horses, with appropriate tackle, was employed for the final stretching of the cable to a 5 per cent drop.

The trolley, shown in fig. 2, ran on this main cable and could be brought to any desired position above the lake by means of two smaller guy cables, pulling in either direction by winches, as shown. An insulated electric cable, running over the lower wheels of the trolley and, also, under the control of a winch, served to lower the instruments into the lake and to maintain the electrical connection with the indicating apparatus "on shore." It was found necessary to support the horizontal portion of this cable at intervals by small pulleys running on the main cable in order that its weight should not prevent the lowering of the instrument—an arrangement which could not well be shown on the diagram.

All was thus ready, but an incident, occurring at this stage of the proceedings, has so important a bearing upon the subsequent experiments that it may well be related here. A kink in one of the smaller cables caused it to break and fall into the lake, where it was quickly fused. Now, the temperature of the Kilauean lava has been quite generally considered to be at least equal to the fusing point of wrought iron, for the reason that rods or wires of that metal, immersed in the lava, were rapidly fused. The lava melted the iron—ergo, it had the heat to do it—no deduction could be more simple, more direct, nor more convincing. And yet, to a practised eye, the degree of incandescence—even in the fountains and in spatter-grottoes where the lava was protected from radiation—indicated a much lower temperature. The fusing of the steel cable would mean, let us say, 1300° C., but it was impossible to admit such a degree of heat. How, then, explain the fusion of the steel?

The first glance at the fused cable-end showed the metal to have been converted into the *sulphide*, and it was realized that, not thermal action alone, but *chemical activity*, as well, was here involved. The presence of sulphur—revealed by the abundant evolution of SO₂—had not been considered in planning the experiments, and this incident of the fused cable boded ill for the instruments destined for immersion in the lake.

But another, and broader, consequence results from this demonstration of chemical activity, viz., that all estimates of the temperature of liquid lavas based upon the melting therein of wires or strips of various metals whose fusion points were known, must be considered as having practically no value. As

will be seen later, tubes of nickel, the fusion point of which we may take as being at the least 1450° C., were readily dissolved in this lava, whose temperature could not have approached to within 300° of this.

The first attempts to obtain a temperature measurement were made with resistance coils of fine platinum wire enclosed for protection in concentrically disposed tubes of quartz, nickel and iron, the electrical resistance of the platinum coil varying with its temperature and being read by suitable instruments connected with the shore end of the connecting cable. Needless to say, the metal tubes were several meters in length, and the adjoining portion of the insulated cable was protected by a spiral steel casing.

One of these instruments was successfully lowered into the lake on July 20th, but the electrical connection failed at the moment of immersion and a lava fountain carried away the instrument with all the armored cable. Just before this occurred, however, the spring of the main cable had lifted the instrument, for a moment, quite clear of the lake and it was seen that the metal tube had been fused off at the level of immersion.

Nine days later a second, similar instrument failed, in like manner, to register, and it was evident that this type of thermometer, however useful in the laboratory, was too delicate for the rough conditions of crater activity.*

The third and successful attempt was made on July 31st with a *thermo-electric* couple of platinum and iridio-platinum. This was set up by Dr. Shepherd in a heavy iron tube and the cold end of the element was surrounded by a large iron cylinder filled with water.

It should be said here that, by this time, the conditions at the crater had become exceedingly unfavorable for the continuation of the experiments. The sinking of the lake greatly increased the difficulty of lowering the instruments into contact with the lava, while dense clouds of vapor rendered the lake itself quite invisible from the operating point and made necessary a line of signal-men around each side of the crater for receiving and transmitting previously arranged wig-wag signals from the writer, to whom, alone—perched upon the crag of a sunken ledge, inside the pit—the lake surface and the descending instrument were visible.

In this manner the element was immersed some 30 to 50^{cm} below the surface of the lava, where a thin crust was readily perforated by the descending tube. The shore instrument showed the increasing temperature as the element descended

* The Kilauea lava fountains send tons of heavy liquid to a height of from 6 to 12 meters.

and, when this was immersed, gave, with the correction for the cold-end temperature, 1050°C . The cold-end temperature was taken as being virtually 100°C from the writer's observation of steam issuing strongly from the water jacket (neglecting altitude). The instrument was quickly withdrawn from the lava—its tube already almost gone—and, in a second immersion, was engulfed by a fountain and lost.

The temperature reading thus obtained agrees with the visual estimate of Dr. Shepherd, whose experience in furnace work has given him a special aptitude in this direction. The writer had estimated the fountains at slightly over 1100°C ., and it may be that this difference actually exists between the fountains and the still lava beneath a crust, although it is contrary to all the writer's experience that there should be any very considerable difference of temperature in different parts of a mass of fully liquid lava, even in the case of a long, flowing stream.

It is, at all events, quite obvious that the heat of Kilauean lava has been generally overestimated in the past. "White heat" is a convenient expression, and is a condition easily imagined in contrast with dark surroundings of a warm tint, but a tungsten pocket lamp will quickly dispel the illusion.

Dr. Shepherd, on his second visit to Kilauea, had the privilege of witnessing one of those phenomenal increases of activity which fill the pit from side to side with a lake of boiling lava without a trace of crust, yet the temperature fell short of 1200°C .

A curious observation by the present writer goes far, however, towards explaining the many references to white heat. During the first few nights of his stay at the crater he was, himself, impressed by sudden apparent increases in the temperature of the lava as shown by a change from the golden glow to a whitish incandescence. There being no other indications of greater activity which might account for this phenomenon, he continued to observe the lake and found that, at times, this whiteness appeared in places while the rest of the lava retained its original color. This clearly indicated a cause other than temperature variation, and a little further study resolved the mystery. In the paper on lava fountains reference was made to the gases which, on issuing from the lava, burn in the air with a visible flame and the production of a cloud of the burnt vapors. These vapors, although transparent, have, by reflected daylight, a bluish tint, but when viewed by transmitted light are of a yellowish brown or reddish brown color, according to their density—a color and a quality which is highly absorptive of those orange and yellow rays so abundant in the golden-hued lava. Seen at night through a veil of this transparent vapor, the glowing liquid, although somewhat

less brilliant, appears of a whitish incandescence, giving the impression of higher temperature.

From all the foregoing remarks it should not be inferred that the writer is casting doubt on the many reliable observations of lava at very high temperatures, nor that he finds any difficulty in believing that lava may be brought to the surface at white heat. His contention is that such high temperatures are rare and, at Kilauea, would soon result in a return to the former condition of main-crater activity. At Vesuvius, in 1906, the lava

FIG. 3.

FIG. 3. Pot and chain, filled and covered with lava taken from "Old Faithful." (Photo by H. R. Schulz.)

flowed from a fissure on the southern flank at five meters per second while jets of liquid fragments shot directly from the central conduit a thousand meters into the air; at Etna, in 1910, the lava, at its source, had even greater velocity, with flames of burning gas ten meters in length; Stromboli, in 1907 and 1912, shot the liquid contents of its conduit into view in magnificent fiery spray, and the lava fountains of Kilauea, in 1911, were *tele*-photographed in 1/4 second, at midnight, with a working aperture of F. 10,—none of these conditions involved a temperature approximating white heat.

The expedition not being provided with apparatus for the collection of gases, it was determined to, at least, attempt the taking of lava directly from a fountain by means of the cables.

A plumbers' solder pot, attached by a heavy iron chain to a steel lowering cable, formed the recipient and, by great good fortune, the experiment was immediately successful—"Old Faithful" engulfing the pot and chain—and, although the strain nearly wrecked the entire plant, the very spring of the main cable aided in the immediate withdrawal of the recipient which, brought to shore, presented the appearance shown in fig. 3. The pot and chain—just too hot to be touched—were hung from a beam in the station and, at the expiration of three

FIG. 4.

FIG. 4. Section of contents of pot showing three zones of consolidation.

hours, were still at *virtually the same temperature*, while, during the fourth hour, the entire mass turned cold. This result was unlooked for—and the taking of regular temperature readings neglected—because of the negative result of an experiment on the Etna lava of 1910, when pyrometer readings were taken at one minute intervals, by the writer, on a cooling mass of lava. In that case the temperature fell from 970° C. to 150° C. in an hour, but without any notable abnormality in the regularity of its descent. The probability would seem to be that, in the case of the Etna lava, the first phases of crystallization had already progressed to an extent incompatible with further development in this short time of cooling, while this Kilauean fountain lava is so pure a glass that the beginning

of crystallization may occur even in so small a mass of material, evolving, in the process, a large amount of heat.

On examining the material it was found, as expected, that all the lava upon the chain and that on the outside of the pot was in the condition of glass. That inside the pot showed, in section, three distinct zones (fig. 4), the outer, of the same glass; the next, a layer of gray, semi-crystalline rock, and, finally, a central mass of the same nature but even more vesicular and of a slightly pinkish color. The walls of the gas cavities are of a smoothness indicating a considerable gas tension. It is interesting to note that, in other instances of moderately rapid consolidation, the writer has found the same

FIG. 5.

FIG. 5. Section of sheet pahoehoe showing three zones of consolidation.

division into three zones, as shown in fig. 5, representing a section of sheet pahoehoe, 3^{cm} in thickness, from a drained pool on the floor of the main crater.

As regards this lava from "Old Faithful," if we consider its source, the gaseous nature of fountain mechanism, and the almost instantaneous solidification of the outer layer of the collected mass, it will be difficult to conceive of a more fresh, more original and unaltered material, and its interesting and significant evolution of heat, upon consolidation, was not needed to demonstrate the value of this product for chemical and physical examination. A portion, in section, was sent by the writer to Dr. Albert Brun, whose methods of examining lavas are so well known, and he has most kindly responded with the very interesting note herewith appended and to which the reader's attention is now invited.

Note on the Lava taken from the Halemaumau Pit by Mr. Frank A. Perret in July, 1911, with gas analyses and remarks by ALBERT BRUN.

In the accompanying article, Mr. F. A. Perret shows that he has been able to get, out of "Old Faithful," lava still in a state of fusion. This interesting experiment, carried out with much skill, made it possible to study in the laboratory a lava which was taken when in the midst of the process of evolution. The points which I examine in this note only include a few facts relating to the gases, as well as those relating to the action of steam on the magma. In addition I also examine a special feature in the evolution of crystallization of the melted magma of Kilauea.

Gases.—It is well known that, during the last century, the French astronomer, Jansen, discovered with the spectroscope, that the flames which escaped from the lava lake of Kilauea gave the spectrum rays of sodium, C, and H_2 . The gas analyses published during recent years by myself in my book "*Recherches sur l'Exhalaison volcanique*" (1911, page 115) confirm this composition. The lava in fusion obtained by Mr. Perret in 1911 also gives out gases, the nature of which confirms the above mentioned analyses.

To extract the gases, I heated the glassy lava in a vacuum nearly to the melting point, or to complete fusion. This operation took place in an apparatus already described. It distills quite a quantity of hydrocarbides which are condensed in the form of black bituminous rings which colored P_2O_5 yellowish brown. It also deposited a white ring of $(Na,K)Cl$ and NH_4Cl which can be easily analysed. It is known that the composition of a complicated mixture of gases is influenced by the duration of the time of heating, the temperature, the pressure and the partial pressure of each individual gas, so that the final result is somewhat variable, even with the same materials. But the importance of this slight variation need not be exaggerated.

The lava collected by Mr. F. A. Perret gives off the following gases:

A—Lava heated to complete fusion for a long time; from 1 kilogram of lava.

Solid matters:

Chlorides $(Na,K)Cl$ volatilized, milligrams..... 75

Salmiac (NH_4Cl) id. id. 15

Bitumen very abundant

Gases: Quantity in cubic cent..... 310^{cc}

Contained Cl_2 traces

HCl 4.6

SO_2 14.4

CO_2 67.0

CO 8.

H_2 5.

N_2 1.

100.0

I have explained elsewhere the presence of CO. The examination of the composition of these gases, as well as of the substances volatilized and easily condensed at the ordinary temperature, shows immediately that a great part is combustible. On coming into contact with the atmosphere these substances will burn, owing to the high temperature which they possess on leaving the magma in fusion. Therefore there will also be formed CO₂, and water of *extra magmatic origin*.

This, therefore, easily explains the flames, giving more or less light, which observers have seen rising from Lake Halemaumau. It is also advisable to note that these gases contain very little N₂. The percentage of N₂ will always be a criterium of great general importance, which will denote the purity of the gaseous products collected on the spot, either from a fumarole or from the liquid lava.

Oxidization of the Lava (by water).—The lava collected by Mr. F. A. Perret from "Old Faithful" is not completely oxidized. After having extracted all the gases from it, there remains a melted mass of black silicates, opaque even in thin splinters; this mass is rich in C. Therefore the silicate does not contain enough peroxides in order to oxidize all its C at the temperature of the lake. But if we supply the necessary O₂, either in the form of water or air, we shall be able, at the temperature of the lake, to oxidize all the C easily, and to obtain a great quantity of CO₂ and H₂; therefore this experiment proves that the magma did not contain enough water to oxidize all its C.

This demonstration may be made, in a very elegant way, as follows: Let us take the black silicate residue which during the first heating gives off all its gases, and its volatile substances, and which only contained a residue of carbon. This residuum must be heated in a closed apparatus in the presence of steam and nothing else, and without any traces of atmospheric air. A manometer shows the pressure, at every moment, of the gases formed at the given temperature. In the course of the heating a reaction is developed. The water attacks the lava and its carbon. The pressure in the apparatus which I used reached 500 millimeters of mercury at 1000°.

Under the same conditions the gases of lava *alone, without the action of the water*, only give a pressure of 8–10 millimeters of mercury. The gases collected during this intense reaction have the following composition; B, first exp't; C, second exp't:

Composition of the gases.		
	B	C
SO ₂	26.2	0.25
CO		19.4
CO ₂	5.0	6.4
H ₂	68.0	74.0
N ₂	0.4	traces
	99.6	100.05

The quantity given off from 1 kilogram of lava depends on the quantity of water. I obtained 4000 to 6000 cubic cent.

It is advisable to remark, that the quantity of gases collected is enormously greater than that obtained by the study of the apparent density of the natural vesiculated lava. In our experiment the water oxidizes the lava continually until the chemical equilibrium is reached. This reaction, which we accomplished in the laboratory, does not take place in the magma of the volcano, for the latter contains a residue of carbon. Therefore, if there was any steam, it was in too small a quantity to attack all the C. The proportion reached so low a limit that it is almost nothing.

This enables us to say: that the magma of Kilauea is anhydric, with the exception of the enclaves, and in special cases, (as explained in my *Recherches sur l'Exhalaison volcanique*, p. 264,) it even seems that this proposition may be extended to the ancient magmas, such as granites. For we know that white and black micas are not chemically hydrated minerals, as has hitherto been admitted. For the details concerning this proposition, which seem to be extraordinary, see *Bulletin de la Société minéralogique de France*, Feb., 1913, and *Archives des Sciences*, Genève, xxv, No. 5.

Crystallization.—We wish to draw attention to the interesting point brought to light by Mr. Perret's skilful experiment. The lava was indeed collected at the very time of its volcanic and crystalline evolution; as before explained, a fairly large mass of lava was extracted from the "Old Faithful." When he got the lava in fusion, from the pit, Mr. Perret brought up a glass in which some crystals were floating (labradorite, peridot, and more rarely augite of old formation). Several of these crystals are in the course of digestion. They are corroded and the edges rounded, which shows them to be debris of enclaves. Other crystals have clear cut and sharp angles: they probably are in the course of formation.

The external part of the block, cooled suddenly, was consolidated into a limpid yellowish-green glass. The internal part, cooling more slowly, crystallized. There were no real crystals, but trichitic-centroradiated spherulites. These trichites are generally developed around a preexisting crystal; they form around it a dark-colored hairy setting, opaque in the center and transparent at the edges. The refractive index is greater than that of glass. The fibers are extremely fine, delicate and indistinct in form. It is easy to recognise, with polarized light, the characters of a spherulite, the fibers of which are elongated optically + (positive).

It is impossible to say whether a pure mineral is present. We are in presence of an intermediate state of crystalline evolution. This phenomenon appears in a very short space of time—a few hours. We must be grateful to Mr. Perret for having demonstrated experimentally, *on the volcano itself*, this interesting epoch in the life of the lava.

The present writer had intended commenting at some length on this most interesting report, especially as regards the question of anhydricity, but lack of space absolutely necessitates deferment of the discussion, which, to have any value, would be long. The results obtained by the writer's successors at Kilauea should throw great light upon the exact nature and proportions of the emanations; the field is a fertile one for direct research, and there can be no doubt that the observatory, now established and in charge of Professor Jaggar, will prove itself an institution of the greatest value to the growing science of volcanology.

Some of the more salient points brought out in the present series of papers on Kilauea.

1. Gaseous cause of the mechanism of lava fountains.
2. Three phases of fountain action distinguished.
3. Air oxidation (burning) of gases emanating from the lava.
4. The burnt gases from visible cloud readily photographed.
5. Islands supported by chilling to them of artificial shore and by gas flotation.
6. Formation of gas ducts to top of floating islands.
7. Formation of sub-surface cavity with lava dis-levelling and production of free flowing cascade.
8. Sinking of islands effected by lava overflows due to rapid changes of level.
9. So called "new islands" often due to chilling of lake surface by re-flotation of sunken island.
10. Circulation of lake initiated by gas explosion, and continued by sinking of heavy surface material.
11. Elongated form of lake necessary consequence of this principle of circulation.
12. Variations in height of lava column slightly influenced by atmospheric pressure changes.
13. More strongly by luni-solar gravitational influence.
14. Pronounced sinking of lava after gaseous outburst.
15. Crater ledges may subside so gradually and by so minute a subdivision as to constitute a "slow flow."
16. Evidence of *many* explosive phases in the past of Kilauea.
17. Characteristically tail-less bombs.
18. "Péle's tears."
19. Strong evidence from native tradition as to antiquity, normal origin, explosive, activity, etc. of Kilauea.
20. Monolithic consolidation of stagnant lava.
21. Shell or tubular consolidation of flowing lava.

22. "Pressure casting" of trees.

23. Permanence of crater and conduit walls, floating islands, etc., due to slowly consolidated lava having higher fusing point by reason of crystallization.

24. Temperature of modern lake shown to be from 1050° to 1175° C—possibly from 1000° to 1200° .

25. Appearance of white heat often due to absorption of yellow rays by transparent burnt gases.

26. Thermo-electric element preferable to electric resistance thermometer for field work.

27. Chemical and physical characteristics of fountain lava collected directly.

Posillipo, Naples, August, 1913.