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The 1966 Eruption of Izalco Volcano, El Salvador

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During October–November 1966 900,000 m^3 of olivine basalt flowed from the flank of Izalco volcano, El Salvador. The total heat energy was approximately 10^{15} calories. No measurable changes in gravity occurred at stations on the active cone between August 1964 and August 1967. In the summit crater fumaroles have surface temperatures as high as 540°C. The cooling rate of these fumaroles was 18°C/yr before the eruption and 45°C/yr after. Yearly temperature cycles due to wet and dry seasons are superimposed on the general cooling trend. The rate of gas emission at four fumaroles in November 1967 was 86 g/sec. The data from fumaroles and the volume of the flank eruption indicate that the volume of the high-level magma storage beneath the crater was 3.8×10^6 metric tons before the eruption and 1.4×10^6 metric tons after. Four of the larger hot fumaroles contribute at least 10% of the heat loss from the high-level magma storage, whereas heat conduction accounts for more than half the total loss.

Izalco volcano in western El Salvador has exhibited nearly continuous activity since its birth in 1770. A repose period began in 1957 and ended October 1966 with a flank eruption of small magnitude and short duration. This renewed activity occurred while the fumaroles of the crater were being intensively studied. The description of the flank eruption and the study of the fumaroles both before and after the eruption permit calculation of the maximum volume of the high-level magma storage.

Izalco volcano has been studied from March 1963 until February 1968, the date of the latest information incorporated in this account. Attention was concentrated on the fumaroles and the fumarolic products in the summit crater and on observations of the flank eruption during and shortly after its occurrence.

PREVIOUS WORK

Studies of the volcano Izalco and its products prior to 1956 are well summarized by *Meyer-Abich* [1956, pp. 49–62]. Early workers, referred to in the same article, recorded the dates of the eruptive activity and several described the petrography of the lavas and ash. Eruptions were frequent, indeed almost continuous, from 1850 to 1957 (see Figure 1). *Hantke* [1962] indicates that the closing violent eruption of February 1957 was followed by mild activity for the rest of the year and by 1958 the volcano was quiet.

Fumarolic activity has been obscured by the more violent events over the years, and few descriptions of it are available. The earliest description of the fumaroles was made by *Dollfus and de Mont-Serrat* [1868, pp. 395–406], who studied them in April 1866. They reported temperatures in excess of 400°C 15 days before an eruption and after 5 months of relative repose near the end of 1865. The fumaroles in the crater are the subject of a brief abstract by *Stoiber and Dürr* [1963].

PATTERN OF VOLCANIC ACTIVITY

Activity at Izalco began in 1770 on the south slope of Santa Ana volcano, a much older feature. Since that time its activity has consisted mostly of lava effusions from radial fractures at the foot of the cone and tephra eruptions from the summit area. Meyer-Abich [*Mooser et al.*, 1958, pp. 75–81] compiled data summarizing Izalco's activity from written observations which may have been somewhat inaccurate and incomplete, particularly for the early years. Nonetheless, his data represent the most complete survey possible.

From Meyer-Abich's compilation, the repose periods of Izalco are plotted in Figure 2, according to the method of *Wickman* [1966], for statistical analysis. The recent repose period (1957–1966) is also included. Izalco shows

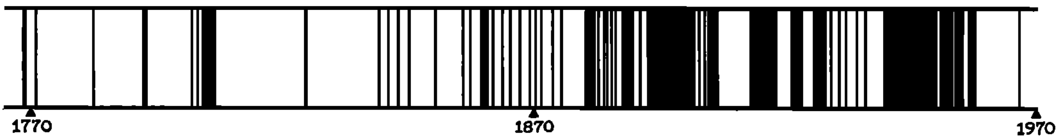

Fig. 1. Eruptions of Izalco volcano since its birth in 1770. Black areas indicate times of recorded eruptions. Data are from Meyer-Abich [*Mooser et al.,* 1956, pp. 49–62].

a dual rate of eruption frequency: an average rate of 0.03 eruption per month for periods during which the repose is less than 3 years, and of 0.02 eruption per month after repose intervals exceeding 3 years. The Izalco eruption frequency pattern is analogous to the Kilauea graph of *Wickman* [1966, p. 343].

Recent Eruption

The recent eruption of Izalco started on October 28, 1966 [*Harrouch,* 1966, p. 9], and lasted for 1 month. The activity occurred on the SSE slope of the cone. Lava was extruded from a vent 550 meters below the summit crater at a site that was also active in 1946. During October–November 1966, two streams of lava, about 10 meters thick, flowed in a southerly direction for approximately 1200 meters. They carried inclusions of old lava, ash, and bombs that continually slumped onto the moving flows from a collapse feature formed above the vent. The inclusions are especially numerous close the vent; over all, they comprise about 10% of the volume. Figure 3 shows aerial views taken in January 1954 and again in December 1966 after the recent eruption. The volume of the 1966 flow is about 900,000 m^3 not including inclusions. The volume of the collapse feature is about 250,000 m^3. By using appropriate estimates, as summarized in Table 1, for magma temperature, heat capacity, heat of fusion, and density, the total heat energy from the lava effusion was determined to be approximately 10^{15} calories.

Petrography

Pre-1966 Izalco lavas are vesicular vitrophyric olivine basalts, usually with bytownite phenocrysts and augite. All have a hypocrystalline groundmass up to 90%. Some variations in feldspar and pyroxene content have been noted. The lavas on the north side of the cone contain labradorite phenocrysts, whereas the phenocrysts in the 1783 and 1793 flows are said to be bytownite [*Weyl,* 1955, p. 17]. Augite is the common pyroxene but hypersthene is reported in the 1793 flow. The olivine content of all lavas is 1–5%. A light colored porphyritic nonvesicular olivine andesite containing andesine and some hypersthene is abundant in blocks in the talus of the north slope.

The October–November 1966 lava is petrographically similar to these older lavas. It is a vesicular porphyritic basalt. Bytownite phenocrysts, average size 1 mm, comprise 30% of the rock, showing albite, carlsbad, and baveno twins and normal zoning. Subhedral olivine phenocrysts comprise 4% and twinned augite phenocrysts 1%. The rock is 65% hypocrystalline groundmass. Previously published analyses and a new analysis of November 1966 lava, together with their norms, are listed in Table 2.

The basalt of the 1966 flow (Table 2, column 3) is a circumoceanic type according to *Chayes* [1964, p. 1580] because it contains less than 1.75% TiO_2. It falls in the high alumina basalt group of *Kuno* [1960, pp. 136–137] because of its Al_2O_3, SiO_2, and $Na_2O + K_2O$ content. It is like that of most other Central American basalts. Analyses compiled by Meyer-Abich and McBirney [*Mooser et al.,* 1958], and those in a more recent compilation of Nicaraguan volcanic rocks [*McBirney and Williams,* 1965] indicate that almost all recent Central American basalts have the chemical characteristic of Cenozoic basalts of circumoceanic areas and of the high alumina group.

Changes Due to Flank Eruption

Several features of the Izalco volcano have been examined in an attempt to detect changes resulting from the flank eruption. They include gravimetry, fractures in the summit crater, temperatures of the crater fumaroles, and chemistry of the condensates of gas issuing from these fumaroles. The velocity of the gas emitted

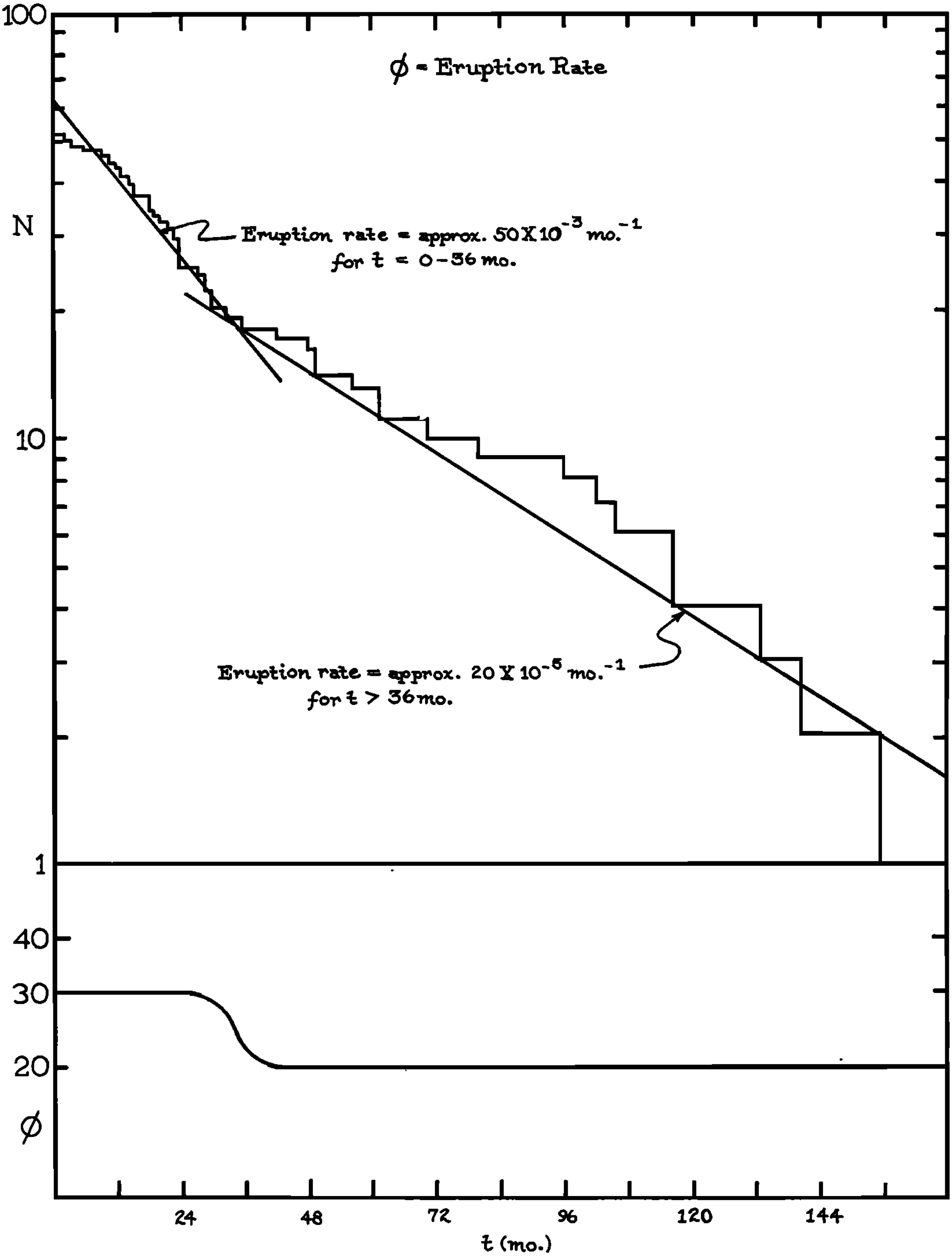

Fig. 2. Logarithmic plot of repose period pattern of Izalco volcano. The step function plotted in the upper part of the figure is the number N of reposes longer than t months. The corresponding age-dependent eruption rate ϕ, measured in 10^{-3} per month is plotted in the lower part of the figure. This form of plot is after the method of *Wickman* [1966]. Data for repose periods are from *Meyer-Abich* [1956, pp. 77–79].

at selected fumaroles was also measured, but only *after* the eruptive period.

Gravity measurements were made with a Worden gravimeter in August 1964 and July 1966 (before the flank eruption), in November 1966 (near the end of the flank eruption), and in August 1967. Three stations were employed at some distance from the crater, three in the crater and one at the base of the cone. The data appear in Table 3. The standard deviations of the measurements taken at stations on the Izalco cone do not differ greatly from the standard deviations of base station measurements. Any gravity changes were less than 0.6 mgal, 2 standard deviations. It is concluded that no measurable changes in gravity occurred during the 1964–1967 period.

The summit crater of Izalco is a circular depression approximately 200 meters in diameter, the floor of which lies from 20 to 40 meters below the rim. In November 1966, during the flank eruption, the only noticeable change in the summit area was the formation of several fractures 10 cm wide and up to 100 meters long. These fractures were not present in August 1966, but were present on November 5, 1966, 2 weeks after the eruption started. They have not widened since. Sublimates are forming in some of these fractures in the same way as they have at the low-temperature fumaroles (100°C) of the crater throughout the period of our observations. One set of fractures striking N 80°E is tangent to the crater rim above the new vent and is apparently associated with the collapse feature. Three other sets of fractures strike N 20°E.

Fig. 3. Vertical aerial views of Izalco volcano taken in January 1954 (*above*) and December 1966 (*opposite page*). North is to the left in both photographs. Both photographs have the same scale; the area shown is approximately 3.5 × 3 km. The October–November 1966 lava flow shows in the photograph opposite at the upper right (see arrows). Explosion of the summit crater and some smaller flows occurred during the period 1954–1957. (Photographs courtesy of Dirección General de Cartografia, San Salvadore.)

TABLE 1. Energy and Mass of 1966 Flow, Izalco Volcano

Density of lava, ρ (measured)	2.6 g/cm^3
Temperature change of magma, ΔT	1150°–24°C
Average heat capacity of basalt, C_s	0.3 cal/g-deg*
Heat of fusion of basalt, f	86.2 cal/g*
Volume of November 1966 flow, V†	1×10^6 m^3 − 10% inclusions
Total volume of new lava	9×10^5 m^3
Total weight of flow, ρV	2.34×10^{12} g
Total heat energy of eruptive products, E‡	1×10^{15} cal

* From values quoted by *Birch* [1942, pp. 235–237].
† Determined from aerial photos and field observations.
‡ $\rho V C_s \Delta T + \rho V f$.

TABLE 2. Analyses of Izalco Rocks

	1	2	3*
Chemical Constituents			
SiO_2	49 80	51.80	51.93
Al_2O_3	21 30	19.30	19 03
Fe_2O_3	3 60	2.78	9 51
FeO	5 80	6.78	...
MgO	4.80	4.40	4.66
CaO	11 60	9.49	9 25
Na_2O	0 90	3 35	3 71
K_2O	0.31	0 76	0.98
H_2O^+	0.44	0.15	...
H_2O^-	0 26	0 07	...
TiO_2	0 98	1.98	0 83
P_2O_5	0 20	0 10	0 39
MnO	0 32	0 36	n.d.
Total	100 31	101 32	100 28
Calculated Norms of Izalco Analyses			
Quartz	9.6	1.9	0.8
Orthoclase	1 8	4.5	5.8
Albite	7 6	28.3	31.3
Anorthite	53.1	35.3	32.4
Diopside: Wo	1.3	4.7	4.6
Diopside: MgDi	0 8	2.7	2 9
Diopside: FeDi	0.4	1.8	1.5
Diopside (sum)	2.5	9.2	8 9
Hypersthene: En	11.2	8.1	8.6
Hypersthene: Fs	6.2	5.7	4.4
Hypersthene (sum)	17.4	13.8	13.0
Apatite	0.5	0.2	0.9
Ilmenite	1 9	3 8	1 6
Magnetite	5 2	4.0	4.9
Total	99.58	101.02	99 61

* All iron calculated as Fe_2O_3; calculated H_2O free. For calculated norms, Fe partitioned in ratio of analysis 1.

[1] *Weyl* [1955, p. 36], basalt of 1783.

[2] *Deger* [1932, p. 52], average of the analyses of four ashes that fell April 24, June 4, 8, 12, 1931.

[3] X-ray spectrochemical analysis (A. K. Baird, analyst, Pomona College, 1967) of lava of November 1966.

On nearly opposite sides of the crater, there are hot fumaroles with temperatures between 300° and 540°C. Temperatures at four of the hot fumaroles have been measured at irregular intervals over a 4-year period. At one of these (Y) we have a series of twenty-nine measurements. Temperature was measured with an iron-constantin thermocouple. The precision is such that ten measurements made at one fumarole at 5-minute intervals were within 2°C.

The temperatures recorded at one fumarole (W) for 1 year are shown in Figure 4. This record is compared with a bar graph of rainfall. There are distinct wet and dry seasons at Izalco; more than 90% of the rain occurs from May through October. It is clear from the figure that temperature variations are related to rainfall. This is supported by data from three other fumaroles. There is a sharp drop in temperature as the rains begin; the temperature remains low during the rainy season and climbs slowly as the dry season progresses. Temperature changes due to long-time cooling are therefore somewhat obscured by monthly or even daily rainfall.

The temperature data for a 4-year period is presented in Figure 5. The yearly temperature cycles appear to be superimposed on a general cooling trend. The best straight lines through the points before and after the November 1966 eruptions have been calculated and plotted to determine the long-term fumarole temperature change during the period of observation. The slopes are negative, 18°C/yr before the 1966 eruption, 45°C/yr afterward. The lines are statistically significant at the 99% level. Statistical analysis shows that the two slopes are significantly different at the 99% level. The same data are available for three other fumaroles, although temperature measurement was somewhat less frequent. For the four fumaroles:

Average temperature during the period of observation ending in November 1966	380°C
Average temperature during the period of observation since November 1966	340°C
Average temperature change through November 1966	-5.7×10^{-7} °C/sec
Average temperature change from November 1966 to present	-14.5×10^{-7} °C/sec

Gas from the hot fumaroles, largely H_2O, has been condensed and collected. Collections have been made from four of the fumaroles at irregular intervals over a 3-year period. Our most complete series from a single fumarole consists of nineteen samples for the period January 1965 to February 1968. The collecting apparatus consists of an aluminum tube that is inserted in the fumarole. The gas passes through glass and tygon tubing into a flask where the condensate is gathered. Suction must be applied to the flask; a simple modification of a battery-driven hand-vacuum clothes cleaner has proved most effective for this purpose.

Condensed gases from each of four fumaroles have been analyzed for several chemical constituents. The series from W is most illustrative (Table 4). Samples taken in the rainy season have lower concentrations of Na, Ca, K, and

TABLE 3. Gravimetric Measurements, Izalco Volcano, El Salvador

Station	Location	Distance from Center of Crater, km	Aug. 14, 1964	Gravity,* mgal July 4, 1966	Nov. 22, 1966	Aug. 15, 1967	Standard Deviation of Gravity Measurements
1	Casa Clark, San Salvador	56		362.80	362.64	362.33	0.24
2	Hotel de la Montaña, Cerro Verde	1.3	48.69	48.61	48.84	48.33	0.21
3	Finca Las Brumas, south flank Santa Ana volcano	2.2	100	100	100	100	
4	Base, north side Izalco volcano	0.6	154.08	154.03	154.25	154.16	0.19
5	North rim of crater	0.1	58.25	58.86	58.85	58.57	0.29
6	Bottom of crater, east side	0.07	61.48	61.25	61.44	61.42	0.10
7	Lowest point in crater	0.04	66.84	66.63	66.83	66.65	0.11

* Relative to station at Finca Las Brumas, taken as 100.

Mg than dry season samples, showing that ground-water dilution is very important. This corroborates our conclusion from the temperature data.

The alkali content of rainwater collected in the crater at Izalco is insignificant, almost undetectable. Thus the results summarized in Table 4 show higher concentrations than rainwater, but much lower concentrations than would be expected in undiluted magmatic water. Data from liquid inclusion studies [*Barnes*, 1967, p. 548] show that normal hydrothermal fluids have concentrations two orders of magnitude higher than our condensates. Calculations indicate that the volume of rain that falls on the 25,000-m^2 area of the summit crater is several hundred times the fumarolic output. Hence, fumarolic water at Izalco, even from the hottest fumaroles, must be considered chiefly meteoric.

Table 4 also shows that the concentrations of chemical constituents in the condensates taken since November 1966 are significantly less (by as much as a factor of 3) than the concentrations in condensates taken in comparable seasons before the eruption.

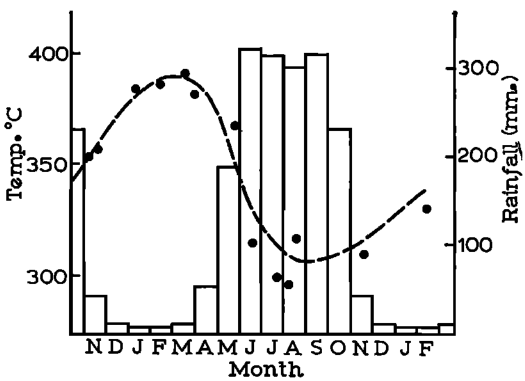

Fig. 4. The effect of seasonal rainfall on temperature of Fumarole *W* at Izalco volcano, November 1966 through February 1968. Fumarole temperature is measured on the scale at left. The trend of the temperature points is shown by the dashed line. The histogram of monthly rainfall is measured on the scale at right. Rainfall data represent a 53-year average of a station at San Salvador [*Servicio Meteorologico Nacional*, 1967].

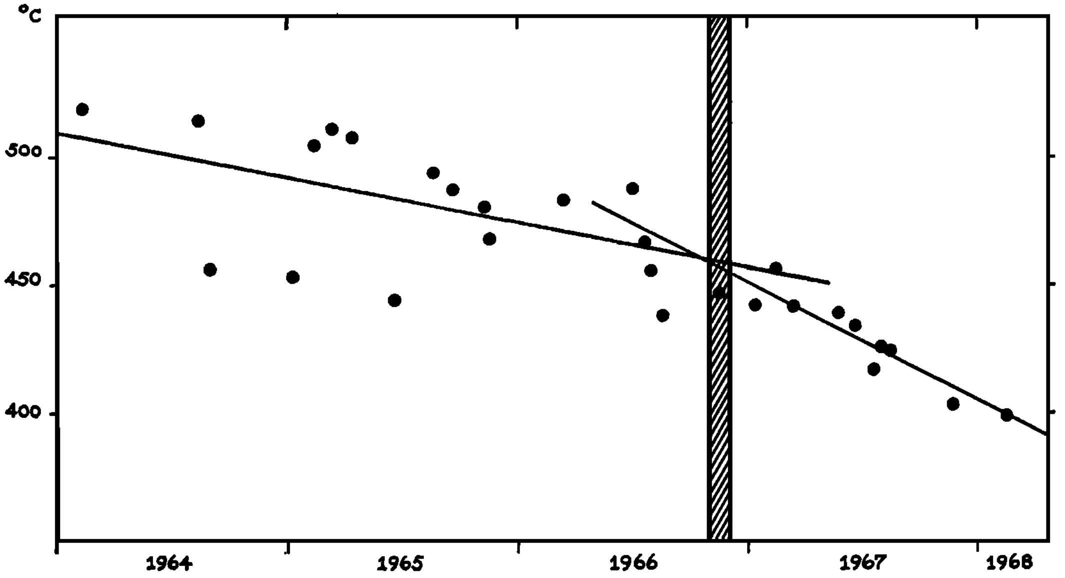

Fig. 5. Temperature change of fumarole *Y* at Izalco volcano during the period 1964–1968. Statistically determined best straight lines for pre- and post-November 1966 measurements, respectively, are plotted. The shaded area represents the flank eruption of October–November 1966.

TABLE 4. Selected Chemical Changes in Condensates from *W* Fumarole, Izalco Volcano, El Salvador
Cl was determined using specific ion electrode. Alkalis were determined by absorption spectrophotometer. All values rounded to nearest part per million.

Date	Temp., °C	*pH*	Cl, ppm	Na + K + Ca + Mg, ppm	Mg, ppm	Ca, ppm	Na, ppm	K, ppm
Jan. 1965	420	1.5	4100	29	6	7	9	7
Sept. 1965	415	1.9	800	16	3	7	4	3
Nov. 1965	342	1.8	1600	48	5	29	9	5
March 1966	399	2.0	3150	138	10	114	10	10
Aug. 1966	346	2.7	800	7	2	2	2	2
Nov. 1966	354	1.9	1650	51	6	35	7	4
	369	1.6	1450	16	3	4	6	4
Feb. 1967	386	1.6	1750	35	3	27	4	2
March 1967	391	1.8	750	39	4	27	6	3
	382	3.1	550	49	9	25	12	4
April 1967	368	4.2	150	4	1	2	2	0
June 1967	315	2.9	210	7	2	2	3	1
July 1967	322	2.7	220	12	1	7	4	1
Aug. 1967	297	2.0	330	3	0	2	1	0
	317	2.5	210	1	0	1	1	0
	±315	2.8	180	6	1	2	4	1
Nov. 1967	310	2.2	240	7	1	4	2	1
	302	2.2	410	6	1	2	2	1
Feb. 1968	331	3.0	150	6	1	3	2	1

Gas velocities issuing from the several hot fumaroles have been measured with an anemometer of the type used in industry (an Alnor Velometer). The discharge rate in feet per minute is measured at many points at the orifice. The area of the orifice and the temperature are also measured. If it is assumed that the gas is 100% H_2O, the weight of H_2O discharged is calculated. Velocity measurements were not made before November 1967, so that we have no data to indicate if the velocity has changed with time or season. The total flow of gases on November 17, 1967, after the eruption, measured at the four fumaroles, averaged 86 g/sec at a temperature of 340°C.

Calculations from Field Data

The rate of cooling of the fumaroles, their temperatures, and the mass of the October–November 1966 lava eruptions have been determined from field observations. These data can be used to calculate the mass of the magmatic heat source before and after the October–November 1966 eruption. The rate of heat loss that would result from such masses can be calculated and compared with the rate of heat loss from the four fumaroles. *Seino* [1959], using fumarole data from Syowa-Sinzan, calculated magma volume from relations similar to those developed below. It is to be emphasized that the results of our calculations are approximate. Several assumptions are made in the considerations that follow: (1) The high-level magma storage was not augmented by additions of new magma from below. (2) The gases of the fumaroles are considered to be entirely water vapor. The error involved here is negligible. (3) The heat flow from the fumaroles is transferred entirely by the emissive gas and represents the total heat flow from the heat source below. This assumption is made for purposes of calculation only. (4) The heat source is assumed to be basalt magma.

There are, of course, fumaroles in the crater other than the four measured; the total is almost a hundred. Only five of these fumaroles have temperatures above 150°C, and the emission rate of these five can be no more than 2 times that of the four measured fumaroles. The cooler (<150°C) fumaroles are relatively very weak emitters, and the emission rate of all these cooler fumaroles is estimated to be less than the total of all the hotter ones. In summary, whether all the fumaroles in Izalco's crater emit 2 or 10 times the gas volume of the four studied is unknown, but the total volume is very probably in this range.

One may construct a series of relationships, using the following notation:

- q, heat content of heat source, calories.
- T, temperatures during the period measured, degrees Celsius.
- Q, quantity per unit time of vapor emitted at fumaroles, grams per second, calculated.
- Qm, quantity per unit time of vapor emitted at four fumaroles measured in November 1967, grams per second.
- M_F, mass of October–November 1966 flow, grams.
- M, mass of heat source, grams.
- L, latent heat of vaporization of H_2O, calories per gram.
- C_v, specific heat, calories per gram of fumarole vapor per degree Celsius.
- C_s, specific heat of basalt, calories per gram-degree Celsius.
- t, time, seconds.

Notations referring to quantities before the October–November 1966 eruption are designated by subscript 1 and for the situation afterward by subscript 2.

The relationships that relate these quantities are

$$dq_1/dt = -C_s M_1 (dT/dt)_1 \quad (1)$$

$$dq_2/dt = -C_s M_2 (dT/dt)_2 \quad (2)$$

$$dq_1/dt = C_v Q_1 (T_1 - 100) + Q_1 (100 - 24) + LQ_1 \quad (3)$$

Surface temperature is 24°C. Caloric output is calculated by steps, 24° to 100° to T_1, + latent heat of vaporization.

$$dq_2/dt = C_v Q_2 (T_2 - 100) + Q_2 (100 - 24) + LQ_2 \quad (4)$$

The mass of the lava of the October–November 1966, M_F, is related to the mass of the heat source before and after the eruption by the expression

$$M_1 - M_2 = M_F \qquad (5)$$

The weight of gas emitted from the fumaroles per unit time before the eruption is not known. Two limiting cases are proposed:

$$Q_1 = 3Q_2 \qquad (6a)$$

$$Q_1 = Q_2 \qquad (6b)$$

In the six equations above the following terms have been measured:

$$(dT/dt)_1 = -5.7 \times 10^{-7}\ ^\circ\mathrm{C/sec}$$

$$T_1 = 380^\circ\mathrm{C}$$

$$(dT/dt)_2 = -14.5 \times 10^{-7}\ ^\circ\mathrm{C/sec}$$

$$T_2 = 340^\circ\mathrm{C}$$

$$M_F = 2.3 \times 10^{12}\ \mathrm{grams}$$

The following data are from *Birch* [1942, pp. 235–241]:

$$C_g = 0.5\ \mathrm{cal/g\text{-}^\circ C}$$

$$C_s = 0.3\ \mathrm{cal/g\text{-}^\circ}C$$

$$L = 540\ \mathrm{cal/g}$$

The following are unknown: dq_1/dt, dq_2/dt, Q_1, Q_2, M_1, and M_2.

The six equations may be solved for the six unknowns. The relationship between Q_1 and Q_2 in equation 6*a* or 6*b* is open to question. Our field observations suggest that the volume of gas emission per unit time from the fumaroles was greater before than after the eruption of October–November 1966; that is, $Q_1 > Q_2$. Our only indication of the amount is the ratio of the alkalis in the condensate, which is 3 to 1, but this datum alone is not helpful. As a possible model of the situation, one assumes (1) that the water from fumaroles is predominately meteoric even in the dry season; (2) that the meteoric component is the same before and after the eruption in comparable seasons; (3) that the condensate concentration change is brought about by a decrease in the magmatic water contribution. From the assumptions it follows that the change in volume per unit time for a given reduction in condensate concentration will depend on the volume of the meteoric component relative to the magmatic component. If, as is mentioned above, the concentration of condensate alkalis is ⅓ as large after the eruption and the magmatic component is assumed to be 75%, then the volume of gas emission per unit will be reduced to ⅓ : $Q_1 = 3Q_2$. Because such a large magmatic component is very unlikely, this relation represents an extreme. The other extreme, probably much closer to the truth, is the assumption that the volume of gas emission has not changed appreciably since the eruption, $Q_1 = Q_2$. Results of calculations for the two cases are given in Table 5.

Table 5 shows that the four observed fumaroles in Izalco crater account for a minimum of 10% of the heat loss from the high-level magma storage. Heat loss by conduction can be calculated by means of the standard spherical steady-state conduction heat loss equation [*Ingersoll et al.*, 1954, p. 36]:

$$H = \frac{4\pi K\ \Delta T\ r_1 r_2}{r_1 - r_2} \qquad (7)$$

where

H, steady-state heat loss by conduction, in calories per second.

TABLE 5. Calculations from Field data, Izalco Volcano

	Measured		
Q_M	Gas evolved per sec at 4 fumaroles after 1966 eruption	8.6×10 g/sec	
M_F	Mass of October–November 1966 flow	2.3×10^{12} grams	
	Calculated	If $Q_1 = Q_2$	If $Q_1 = 3Q_2$
Q_1	Gas evolved per sec at fumaroles before 1966 eruption	8.5×10^2 g/sec	6.0×10^2 g/sec
Q_2	Gas evolved per sec at fumaroles after 1966 eruption	8.5×10^2 g/sec	2.0×10^2 g/sec
M_1	Mass of heat source before 1966 eruption	3.8×10^{12} g	2.6×10^{12} g
M_2	Mass of heat source after 1966 eruption	1.4×10^{12} g	0.34×10^{12} g
	Ratios of Interest, Expressed as %		
$Q_M/Q_2 \times 100$		10 1	43
$M_F/M_1 \times 100$	Ratio of weight of flow to weight of original source	60	88

K, thermal conductivity of basalt, 5×10^{-3} cal/cm sec °C [*Birch et al.*, 1942, p. 253].

ΔT, temperature change between the high-level magma storage and the surface, $1150° - 24° = 1126$ °C.

r_1, distance from center of the high-level magma storage to the surface, 5.5×10^4 cm (the observed difference in elevation between the 1966 lava vent and the summit).

r_2, radius of the high-level magma storage if it is spherical, 5×10^3 cm; value calculated from the equation $4\pi(r_2)^3/3 = M_2/\rho$.

Solution of equation 7 shows $H \cong 4 \times 10^5$ cal/sec. This is equivalent to 6 times the heat loss from the four fumaroles, or 60% of the total heat loss from the high-level magma storage. Field observations make it a reasonable assumption that the other fumaroles in the summit crater account for the remaining 30% of the heat loss.

Although a cylindrical shape for the high-level magma storage is perhaps more reasonable geologically, the dimensions of such a cylinder in this case are difficult to specify for purposes of calculation. If it is arbitrarily assumed that the cylinder has a radius of 2×10^3 cm and height of 4×10^4 cm (thus retaining the calculated mass M_2), and if the cylindrical steady-state conduction heat loss equation is used [*Ingersoll et al.*, 1954, p. 37], H is again $\cong 4 \times 10^5$ cal/sec. Because of the assumption of steady-state conduction heat loss, the H values determined by using both equations must be considered as minimum values.

Summary

The flank eruption of lava from Izalco during October–November 1966 affected the hot fumaroles. Fumaroles in the crater of Izalco have temperatures of 250°–540°C. During the year, the temperature of a fumarole fluctuates as much as 100°C because of the rainy season. The hot fumaroles showed an over-all cooling from year to year. The cooling rate before the eruption was 18°C/yr. After the eruption, the rate increased to 45°C/yr. Calculations based on these cooling rates indicate that four fumaroles account for a minimum of 10% of the heat loss. Heat conduction is responsible for about 60% of the heat loss. The mass of the lava erupted, calculated from field measurements, is 2.3 million metric tons. The mass of magna from which it came, calculated from the temperature change data, is 3.8 million metric tons or less. After the eruption, a mass of 1.4 million metric tons or less remained in the high-level magna storage. Thus, the lava flow represents over ½ of the original high-level magma.

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