THE AQUEOUS EMANATION FROM PARÍCUTIN VOLCANO[1]

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Abstract

An estimate of the quantity of the water emitted by the crater vent of Parícutin volcano gives 17,000 tons per day, compared to an average daily emission of lava of 100,000 tons from the lava vents. This quantity of water is believed to be larger than the amount of water one could reasonably expect from the magma rising in the eruptive conduit, and suggests a considerable dilution of magma emission by vapors derived from meteoric waters. The apparent differences between crater vent and lava vent emissions bear out this idea. The imposing eruptive column of a volcano would, in such a case, be no measure of the quantity of magmatic water evolved by a crystallizing magma. It is suggested that groundwaters activated by an intrusion into the zone of these waters may play an important role in the hydration and the alteration of wall rock.

One of the problems facing the student of ore deposits is to find a source of water sufficient to account for the huge masses of hydrated and altered rock frequently accompanying certain types of ore deposits. As an example, the propylitization of andesite wall rock accompanying the veins of such a deposit as the Comstock Lode requires the fixation of about 50,000,000 tons of water per cubic kilometer of hydrated rock.[2] In addition to water so fixed, an additional large quantity must be postulated to account for the leaching that evidently occurred during propylitization. Since propylitized or similarly altered rock frequently occupies a number of cubic kilometers, the quantity of water necessary to achieve this alteration must be very large.

Some geologists see an ample source of water for this and similar purposes in the emanations from magmatic bodies and cite the evidently great quantities of steam from a volcanic apparatus as a measure of this tremendous supply. (Kemp: 1906, 1908; Phemister: 1934). Some estimate or measure of the quantity of water vapor emitted, therefore, is desirable, as well as some indication of its probable source.

The eruptive column is, indeed, one of the most impressive features of an active volcano. It consists principally of water vapor, mixed with other gaseous emissions, and is frequently heavily charged with ash. Even when no visible vapor column is apparent because of its superheated condition, the emission of water vapor manifests itself, if atmospheric conditions are propitious, by the development of huge cumulus clouds above the volcano.

Under favorable circumstances an estimate, based on observable factors, of the quantity of water vapor evolved by a volcanic apparatus,

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[2] Based on analyses of andesite and propylite from the Comstock Lode. *U. S. Geol. Exp. 40th Parallel*, **III**, 90 (1870).

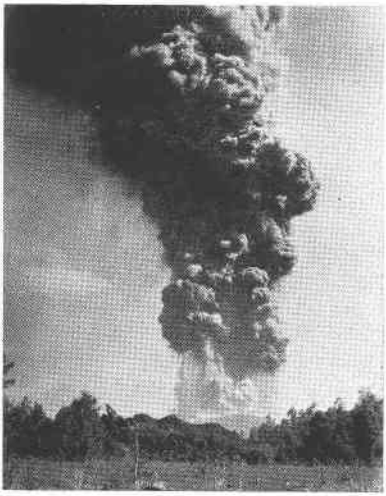

FIG. 1. Heavy eruptive column characteristic of the early Quitzocho period. Parícutin volcano. March 24, 1943.

FIG. 2. Condensation of water vapor to heavy cloud. Zapicho vent, Parícutin volcano. Dec. 6, 1943.

FIG. 3. Eruptive column of steam at time of observations. Parícutin volcano. May 28, 1945.

FIG. 4. Crater vent at time of observations. Parícutin volcano. May 27, 1945.

can sometimes be made. The new Mexican volcano Parícutin has offered such an opportunity.

VOLCANIC PHASES AT PARÍCUTIN

The activity of Parícutin volcano may be divided into three phases. The first, or Quitzocho, period beginning with the original outbreak of the volcano on February 20, 1943, and continuing to October 19 of the same year, involved the building of the volcanic cone. The eruptive activity was characterized by very heavy vapor emission, yielding a majestic eruptive column (Fig. 1), heavy ash fall but with relatively small and erratic lava flows. The second, or Zapicho, period began with the outbreak at the Zapicho vent and the building of the adventitious cone, Zapicho, at the northeast base of the main cone. Zapicho yielded a large lava flow, but very little ash, and invisible eruptive vapors. The vapor emission from Zapicho, however, sometimes manifested itself as huge condensation clouds high above the vent (Fig. 2). During this phase which continued from October 19 to January 8, 1944, the main crater emitted lazy cumulus-like clouds of vapor. The third, or Taqui, period beginning with the outbreak of the Taqui lava vent at the southwest base of the cone on January 8, 1944 was characterized by almost constant but variable activity from the crater (Fig. 3) vent, but with little ash and almost constant emission of lava from one of three lava vents at the base of the cone.

TABLE OF PARÍCUTIN ACTIVITY 1943–1946

Stage	Duration	Ejectamenta Solid Av. per day	Activity
Quitzocho	Feb. 21–Oct. 19, 1943	315,000 tons	Heavy ash laden eruptive column; moderate lava flows.
Zapicho	Oct. 19, 1943–Jan. 8, 1944	350,000 tons	Large lava flow; moderate but constant vapor emission from adventitious vent.
Taqui	Jan. 8, 1944–46	100,000 tons	Large lava flows; slight ash fall; variable vapor emission.

Estimates have been made of the solid ejectamenta, based on the extent of lava and ash cover measured on air photographs and estimates of thickness of lava and ash in the field. The weight per unit volume of ash and lapilli was determined by weighing measured quantities of these products and found to be 1500 kgs/m^3 and 1250 kgs/m^3, respectively. The porosity of the lavas, as estimated from sections exposed in crevasses in the flows, was estimated at 50 per cent. The following table shows the characteristics of the three eruptive phases of Parícutin and the average daily quantity of ejectamenta.

During the Taqui phase it was feasible, at times, to ascend the cone. On one such ascent, on May 27, 1945, at which time the crater was in average eruption for this period, neither unusually violent nor greatly reduced, (Fig. 3) conditions in the crater offered requisites for a satisfactory estimate, based upon directly observable factors, of the quantity of water vapor being emitted by the crater vent. A continuous column of white steam arose from a plainly visible vent near the north edge of the crater with a loud grating roar (Fig. 4). This chimney-like orifice had an estimated diameter of 2 meters. Although the steam emitted was, in general, condensed, there were brief intervals during which it issued as superheated, invisible vapor, but with no evident abatement in force or volume as manifested by the uninterrupted roar accompanying its escape. This condition suggests that the temperature of the escaping vapors had an average temperature of about 100°C. A few scattered bombs were carried out by the rushing vapor column, the highest of which took 10 seconds to fall back to the level of the vent, from which may be calculated, from the relationship of gravity acceleration, a "muzzle velocity" of the bombs, and therefrom the velocity of escape of the vapors of 100 meters per second. These data are, perhaps, as good as can be obtained considering the insurmountable difficulties in making precise measurements. From the density of steam at 100°C. the quantity of water vapor emitted was calculated as 12 tons per minute, or 17,000 tons per day.

In addition to the water escaping from the crater vent, there were additional quantities emitted from the lava vents, the lava flows, and from the slopes of the cone. No satisfactory basis for calculating these amounts is offered, but the quantity apparently was considerably less than that issuing from the crater vent.

With the daily emission of lava during the Taqui phase of about 100,000 tons, the apparent water content of the lava, assuming this emission totally derived from the lava concomittantly extruded, exceeded 17 per cent. This is consideraly more water than is generally believed to be the probable aqueous content in magma. The solubility of water in granite magma has been found to range up to as much as 10 per cent (Goranson, 1931). It is generally supposed that basaltic magma is less hydrous than granitic. At 1200° C., which is the temperature of Parícutin lava as extruded (Zeis, 1946), and 980 bars, corresponding to $3\frac{1}{2}$ kilometers in depth, the maximum solubility of water in granitic magma is 4.8 per cent (Goranson, *loc,. cit.*). Gilluly (1937) concludes that basaltic magma contains upward of 4 per cent, and Phemister (1934) 5 per cent of water. Friedlaender (1926) calculated the emission of water vapor for a 20 hour period beginning on April 8, 1906, at Vesuvius at 1.75 km^3, compared to 0.20 km^3 of primitive solid ejectamenta in the form of lava and ash. Friedlaender's estimate of a crater throat diameter of 500 meters is undoubtedly many times too large and the estimated quantity of aqueous emission correspondingly too high. His figures, however, do indicate that the aqueous emission, compared to the solid ejectamenta, is inordinately high for a magmatic source. Bowen (1928), however, argues for a comparatively anhydrous character of basaltic magma.

The gas discharge from volcanos is frequently cited as evidence of a high water content of magma (Gilluly, *loc. cit.*, Phemister, *loc. cit.*). Kemp (1908) goes so far as to state "Volcanos and all other outbreaks visible to us display vast quantities of steam emitted in such a way as to leave no doubt of its derivation from the molten magma." The high ratio of emitted water to extruded lava arrived at above, however, suggests that, in the case of an imposing eruptive column, the magmatic emanations have been diluted by groundwaters. A further indication of this dilution is the strongly contrasting character of the emanations from these lava and lava vents and of the emissions from the crater vents. Samples of emanations from the lava vents have been collected but have not yet been quantitatively analyzed. Preliminary examinations indicate a high content of hydrochloric acid, with lesser amounts of sulfur dioxide, sulfur trioxide, hydrogen sulfide, carbon dioxide and other minor constituents. The presence of flames in the "hornitos" above the flowing lava indicates the presence of combustible gases, perhaps hydrogen. These emanations are so noxious that it is impossible for one to approach an active lava vent from the leeward side. On the other hand, the emissions from the crater vent, unless the activity is very much reduced, have only a slight, hardly perceptible odor. Perret (1913) has commented upon the mild nature of the volcanic eruptive column. He characterizes it as "sweet and clean as the air itself." Comparative analyses of these two types of emission would give some measure of the degree of dilution but, unfortunately, it has not yet been feasible to collect a satisfactory sample of the crater vent vapors. The qualitative difference in the composition of the two emanations, however, is readily apparent to anyone visiting both vents.

A further indication of the essential independence of the quantity of crater vapors and the lava emission is the total lack of any apparent correlation of lava and crater activity. Day by day, during the period of the Taqui flow, from January 1944 to July 1945, the flow of lava appeared relatively constant, the lava issued constantly and at an apparently uniform rate, with quiet exhalation of gases and vapors. The flows, at their point of extravasation, moved without pause or changes, sometimes for weeks at a time. Yet the crater emission was extremely variable; very heavy eruptive columns alternated with reduced activity or even calm, from hour to hour, in an entirely unpredictable manner.

The close relationship of groundwater to the formation of an eruptive column is suggested by the behavior of Kilauea during the eruption of 1924. At that time the lava column of Halemaumau pit sank to a point below the groundwater level, thereby allowing groundwaters access to the lava conduit, producing violent emissions of gases as an imposing eruptive column, in contrast to the normally quiet Kilauean activity (Jaggar 1947).

An ascending lava column, rising from considerable depths to the surface, must inevitably encounter the water table. If the penetrated rocks are, in part, fractured and vesiculated basalt flows, as is the case of Parícutin volcano, a considerable reservoir of water supply is available. The large gushing springs that issue from the basaltic lavas at Uruapan 20 kilometers to the east, and which initiate the Cupatitzio River, indicate some measure of the amount of water which may be available. Adequate groundwater supplies are, indeed, certainly present.

Studies on slag quenching suggest the possibility that a magma can augment its water content by solution of groundwater, which can later be released at the second boiling point (Sosman 1947). Such a secondary enrichment of water in the rising magma is suggested by the strikingly greater fumarolic activity of the first, or Quitzocho, flow than in the later flows.

It seems reasonably evident, therefore, that a volcanic apparatus can set in motion and activate a large quantity of groundwater, perhaps a much larger quantity than its own magmatic emanation. The activation of groundwaters by a volcanic apparatus or by an intrusive body into the zone of groundwaters would furnish a means of extensive rock alteration. This idea has already been suggested by Lawson (1914*a*, 1914*b*) as a possible explanation for the emplacement of certain types of ore deposits. Lindgren (1935) concedes the probability of commingling of meteoric and magmatic waters in the deposition of ores, but would limit it to the zone of groundwaters, or a maximum depth of 10,000 feet. Activated groundwaters may make some contribution to the metallic content of ore deposits, but this addition is believed to be, in general, small. The mechanism does, however, supply an agency for the hydration of larger bodies of rocks than magmatic emanations seems to offer, and to which much of the altered, but unmineralized wall rock may be ascribed.

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