

Ulloa's observations of the glory, fogbow, and an unidentified phenomenon

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Ulloa's complete print of the glories and fogbows on Mt. Pambamarca in Peru (now Ecuador) is presented. It shows two other phenomena, an erupting volcano and an as yet unidentified optical effect. The glories and fogbow are analyzed to obtain the drop size of the fog, and the unidentified features are discussed.

Introduction

The first written description of the glory and fogbow was made by Ulloa^{1,2} with Juan. King Philip V (Duke of Anjou) of Spain commissioned them to lead an expedition to the equator to determine the shape and dimensions of the earth. The men set sail in 1735 to South America and ultimately reached the Paramos regions of Peru, in what is now Ecuador. Paramo refers to an environmental zone in northern Peru and Ecuador, often called the puna, which is a high, wet grassland. Near Quito from Mt. Pambamarca (from the quechua pampa marca or flat place where there is a settlement) the explorers observed several atmospheric phenomena recorded in an exquisite print (Fig. 1). In the style of the day, three separate and unrelated events were depicted in a single picture; a volcanic eruption, the glory and fogbow, and a third, heretofore unknown optical phenomena. Exact dates were recorded for only a few of the phenomena shown in Fig. 1. It is known, however, that the events in and around Mt. Pambamarca, including the sightings of the glories and fogbow, took place between Aug. 1737 and July 1739 and not, as some authors have claimed,^{3,4} in 1735. In this paper we discuss the optical phenomena presented by Juan and Ulloa.

Glories and Fogbow

Ulloa's description of the glories and fogbow (Fig. 2), translated from the French in which the book was published in 1752, reads as follows:

"At the beginning, the Phenomena to which we were witnesses on these Paramos incited boundless astonishment in us, but through the process of viewing them, we accustomed ourselves to them. The first we saw one of these was on Pambamarca, the first time that we climbed this Mountain. It consisted of a whole triple Rainbow formed in the following manner."

"It was morning at a point of the day at which the whole Mountain found itself enveloped in the clouds, which, dissipated by the first rays of the Sun, left only slight mists that the eyes could scarcely discern: our images became visible [in the mists], from the side opposite that from which the Sun was rising, and around 10 fathoms from our location, like a mirror where the reflections of each of us were represented, and in which the uppermost extremity was surrounded by three Rainbows, all three of which had the same center, and the outermost colors or the outside colors of the innermost one touched the inside color of the following, and beyond those Rainbows, one saw at some distance a fourth Arch of a whitish hue."

"All four were perpendicular to the horizon; when one of us went from one side to the other, the Phenomenon followed him entirely without alteration or distortion. This was the most impressive, it is thus that we found six or seven people in a group, each of whom saw his own Phenomenon and did not notice the others. The width of the diameter of these Arches varied in proportion to the extent to which the Sun had risen further above the horizon, at the same time the colors disappeared, and the image of each layer little by little became imperceptible, until the Phenomenon vanished entirely. The diameter of the inside Arch, taken at the outermost band of color, was at first estimate 5.5

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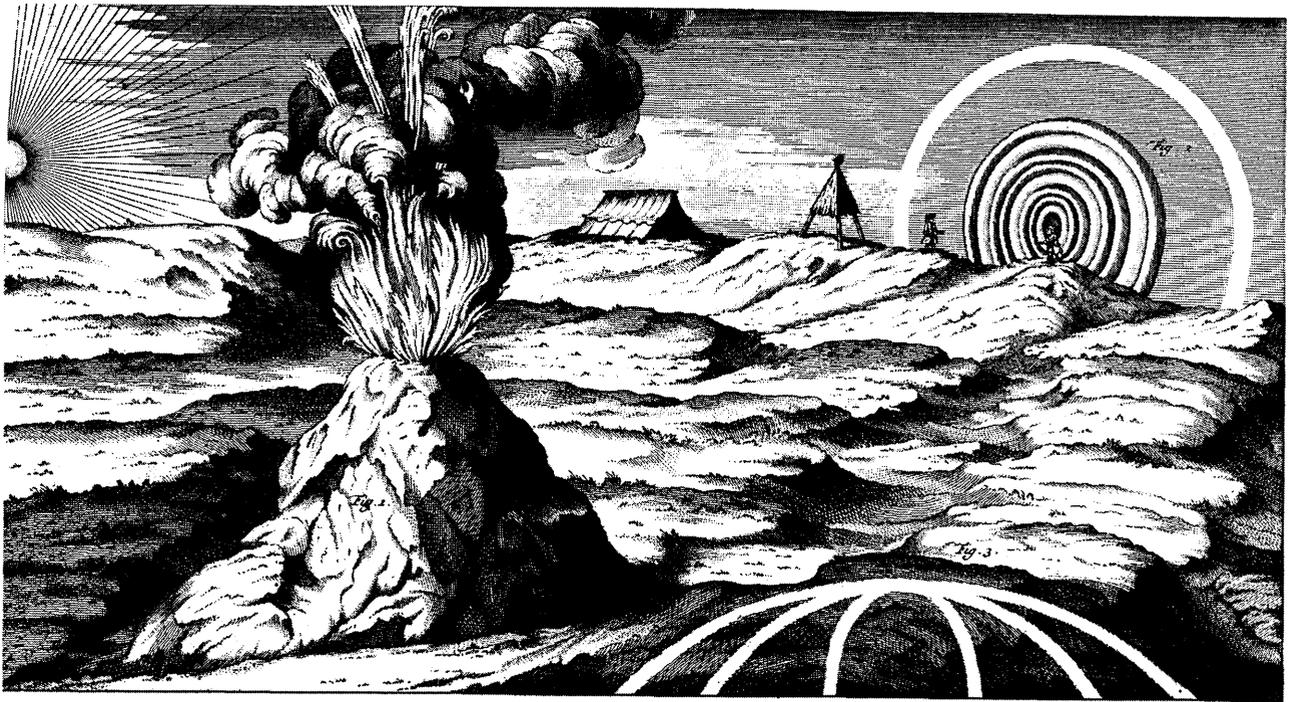


Fig. 1. Original figure from Juan and Ulloa (1752). Note that three scenes are depicted: (1) an erupting volcano (left), (2) the glories and fogbows (upper right), and (3) the unidentified arcs (lower right).

degrees or thereabouts, and that of the outermost Arch separated from the others, was 67 degrees. When the Phenomenon began, the Arches seemed to be oval in shape or elliptical like the disk of the Sun, but then they little by little became perfectly circular. Each little Arch was red or rose, but this color faded and the color orange succeeded it, followed by yellow, then by jonquil [pale yellow], and finally by green; the outermost color always stayed red. All that can be better understood by the engraving herein."

Ulloa's graphic and detailed account of the glories and fogbow is somewhat at variance with the print. The divergence of words and pictures should not be interpreted perjoratively because it results from a practice that was common in old treatises. Without photographic technology, the figures were artistic renditions. Furthermore, in an effort to minimize the expense and difficulties of prints and their reproduction, a number of unrelated scenes were merged into a single print.

With these variances in mind, let us examine Ulloa's observations of the fogbow. Ulloa claims that the bows were perpendicular to the horizon, suggesting that the sun was also near the horizon. Indeed, the sun can be seen at this location near the left edge of the picture, and shadowing on the hills is consistent with the sun being low and to the left. Figure 2 also shows the bows to be somewhat oblique to the horizon in such a manner as to reveal slightly more than half of a circle. Such an observation can only be made from the summit of a promontory while looking downward, and from the figure such a situation is indeed presented.

The mirrored image (right) of the observer (left) is an obvious fabrication, since what would be seen would be the observer's shadow. Curiously, the glory rings are drawn as though being solid with deep concentric channels separating the colors. They are shaded as though casting shadows from a sun to the left. The shading technique was probably used to indicate color: diagonal hatching was blue, stippling was green, and vertical hatching was red. This interpretation would seem to agree with the written descriptions. It also places a bluish glare around the shadow of the observer's head, again as expected from visual and photographic observations of glories in the modern age.

Ulloa and Juan were in Peru to survey the earth and it is not surprising that they took some care in measuring the angular sizes of the phenomena. Ulloa states "The diameter of the inside arch [glories], taken at the outermost band of color [third order red], was at first estimate 5.5 degrees or thereabouts." From simple diffraction, $2a \sin \phi = n\lambda$, where a is the drop radius, ϕ is the scattering angle of 2.25° , n is the order, and λ is the wavelength taken as $0.65 \mu\text{m}$, we find $a = 24.8 \mu\text{m}$. A more accurate formalism by Tricker⁵ predicts $a = 26.3 \mu\text{m}$. The fogbow, too, can provide some particle size information. Ulloa claimed that the diameter of the fogbow was 67° . This corresponds to a radius of 33.5° or a scattering angle of $180 - 33.5 = 146.5^\circ$. If this scattering angle is interpreted as the outermost part of the fogbow, then according to Lynch's tables,⁶ $a = 8 \mu\text{m}$, a factor of 3 less than the value obtained from the glory calculations. On the other hand, a fogbow formed in drops with $a = 25 \mu\text{m}$ (determined above



Fig. 2. Enlargement of the glories and fogbows from Fig. 1.

from the glory) would have an outer scattering angle of $\sim 140.3^\circ$, some 6° smaller than was reported. We have some difficulty in viewing this discrepancy as an error in measuring the diameter of the fogbow, even though such large angles are more difficult to measure than are smaller angles (glory). Both Ulloa and Juan were capable observers and their measurements should be taken at face value. Rainbows formed in either size droplets would indeed be colorless. Secondary fogbows would be faint and may not be expected to be visible; Ulloa makes no mention of them.

Ulloa's Unidentified Arcs

Figure 3 shows an enlarged portion of Juan and Ulloa's print showing the unidentified arcs. The translation reads as follows:

"On several occasions we noticed that in these Mountains the Arches were formed by the light of the Moon. I saw a quite singular one the fourth of April 1738, in the Plain of Turubamba at 8 o'clock in the evening; but the most extraordinary of all was observed by Don George Juan on the Mountain of Qui-

noa-Loma on the 22 of May, 1739 at eight o'clock in the evening. These Arches were composed of no other color than white, and formed themselves in the slope at the top of a Mountain. The one which we saw was composed of three Arches meeting at a single point. The diameter of that in the middle was 60 degrees, and the thickness of the color white occupied a space of five degrees. The two other Arches were similar to that one."

A nighttime display illuminated by moonlight would surely preclude any possibility of detecting color in the arcs and we cannot, therefore, conclude that color was not intrinsically present. The authors give no real clues as to the elevation of the phenomenon (other than it was below the horizon) nor do they divulge their vantage point relative to the arcs and the moon. We know, however, that the arcs were big, but the authors' words are ambiguous. "The diameter of that [arc] in the middle was 60° ." Apart from the difficulty in assigning a diameter to any of the arcs shown in Fig. 3, because they do not appear circular and therefore do not have a constant radius, it is unclear which arc is



Fig. 3. Enlargement of the unidentified arcs from Fig. 1.

being metered. The term middle could refer to the smallest radius arc because it is in the middle of the display, or the arc lying between the inner and outer arcs, i.e., between the smallest radius and largest radius arcs.

Morphologically, the display reported above (Fig. 3) would seem to be more like an ice crystal halo⁷⁻⁹ display than any other type of phenomena because it contained multiple intersecting arcs. Yet the form is unlike any halos known to these authors. Without information as to its angular size and shape and in what part of the celestial sphere the display appeared, it is probably impossible to identify it. Having multiple, intersecting arcs (the exact geometry of which is uncertain) and being below the horizon when the moon was up suggests that it may have been some kind of antisolar arc display, like those photographed by Eberhard.⁷ We note that the display was observed at night near an elevation of 3500 m in the Andes where the temperature regularly dropped below freezing. Thus the possibility that the cloud in which it was seen was made of ice crystals is consistent with the general circumstances of observations.

On the other hand, Ulloa claims that the width of the arcs was 5° and the precision with which he measured the glories and fogbow leaves little room to interpret this number. No arc with a 5° breadth is known to us except, perhaps coincidentally, the fogbow itself formed by drops with a radius of $\sim 12 \mu\text{m}$. The morphology of such a bow does not, however, match that of the bows in Fig. 3.

Summary and Conclusions

The complete print by Ulloa of the glories and fogbow on Mt. Pambamarca has been presented and analyzed.

The drop size of the cloud based on Ulloa's measurements was $\sim 25\text{-}\mu\text{m}$ radius. The authentic figure shows an additional optical phenomenon that remains unidentified.

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