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# FORO



# A NEW TYPE OF MAAR VOLCANO FROM THE STATE OF DURANGO—THE EL JAGüEY-LA BREÑA COMPLEX REINTERPRETED; A REPLY

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## INTRODUCTION

The major point of the paper under discussion (Swanson, 1989) is that the El Jagüey-La Breña complex, located in Durango's Guadiana valley (Figure 1), is a previously unrecognized type of maar volcano, in which a caldera (La Breña) formed following eruption of supporting material through an adjacent maar (El Jagüey). The paper proposed a simple developmental history (Figure 2), consistent with the geology and location of the volcanic complex. The complex started as a scoria cone, like 100 others in the valley; it evolved into a breach scoria cone, as most scoria cones do; then water encroachment briefly and dramatically converted the eruption style from magmatic to phreatomagmatic, creating El Jagüey maar and the adjoining La Breña caldera. The objections presented by Aranda-Gómez and coworkers (1990), termed conclusive and supportive, can be categorized as: (1) questioning the one-maar interpretation; (2) questioning details of the developmental model for the El Jagüey-La Breña complex; or as (3) supportive of their own two-maar interpretation. I welcome the opportunity to answer to their objections and elaborate on this distinctive type of maar volcano.

## SIMILAR GEOLOGY BUT CONTRASTING MODELS

The two studies have a great deal in common. Both conclude that prior to maar formation, the site was the location of a small cluster of scoria cones and associated lava flows. Both studies show that maar formation (one or two depending on the model) was followed by purely magmatic volcanism; both acknowledge that this volcanism was recorded first by scoria-fall beds interlayered with surge deposits and ultimately by scoria and lava from a vent in La Breña caldera.

I also agree that not all pieces of the puzzle are available. The area surrounding the complex is under cultivation, nearly to the rim of both major structures, and rocks important to both models along the western rim of La Breña caldera are not exposed. My assertion that the complex contains only one maar constitutes the most important difference in interpretations. With puzzle pieces missing, which interpretation explains best the geology and setting of the El Jagüey-La Breña complex? This reply will critically examine the evidence presented against the one-maar interpretation, arguments against details of the developmental model for the complex, and evidence presented in support of the existence of two maars.

## ON EVIDENCE AGAINST ONE-MAAR

### *SURGE TRANSPORT DIRECTIONS*

Inferred surge transport directions for the upper 5–10 m of the surge sequence constitute one of only two lines of evidence raised by Aranda-Gómez and coworkers (1990, fig. 2, b) directly against the one-maar model. At two locations, the southern sides of El Jagüey and La Breña, they believe they have "conclusive evidence" that La Breña was the source of the eruption.

It must be remembered that my model has material withdrawn from beneath a scoria cone centered on La Breña and ejected from El Jagüey as somewhat northeastward directed blasts. The northeastward directed flow directions along El Jagüey, therefore, are entirely consistent with this model. They are, in fact, required by the asymmetry of El Jagüey's crater, with its vent offset to the southwest. My model also specifies that a pre-maar scoria cone foundering into La Breña caldera only after phreatomagmatic activity ceased. It should be emphasized that post-eruption collapse adjacent to a maar is not a matter of speculation, but it is based upon the observed 1957 eruption of a maar on the Pacific island of Iwo Jima (Corwin and Foster, 1959). My model described how the scoria cone deflected material ejected southwestward from El Jagüey. The transport directions noted along the southeastern rim of La Breña are entirely consistent with deflection by this pre-collapse scoria cone.

It would have been interesting to have transport direction from the flat-lying surge beds exposed where the two structures join. These must have come from either El Jagüey, to the northeast, or from La Breña, in the opposite direction, yet no flow direction measurements are reported from this critical spot. It should also be questioned why no transport directions are reported from lower in the surge sequence to see if they differ from those stratigraphically higher, as their model would suggest.

### *SCORIA-FALL MARKER BED*

Aranda-Gómez and coworkers (1990) note a scoria bed interlayered and exposed with surge deposits in the walls of El Jagüey. They use the decreasing thickness of this marker bed with distance for La Breña to indicate a source there, but this is not an issue. I also noted the scoria bed and similar thickness variations. I agree it indicates a La Breña source, the pre-maar scoria cone.

The entire eruptive sequence began and ended as a purely magmatic event at La Breña. The surge sequence is the result of the introduction of water, and the surge sequence records that interaction. It may be viewed as a "battle" dominated for a time by water but ultimately won by La Breña magma. That magma also managed a few minor "victories" during the interval dominated by pyroclastic surge eruptions.

## ON EVIDENCE AGAINST DETAILS OF THE ONE-MAAR MODEL

The necessity for an unusually large pre-maar scoria cone, the profile of that cone, the lack of rafted cone material, the stratigraphic position of scoria beds west of the complex, surge beds west of the complex, and the nature of the water supply which triggered maar formation, all were called into question to challenge details of the one-maar model.

### *THE PRE-COLLAPSE SCORIA CONE*

Among a number of unfounded criticisms directed toward my concept of the pre-maar scoria cone, was the idea that it had to be unusually large. The gently dipping scoria beds found in the

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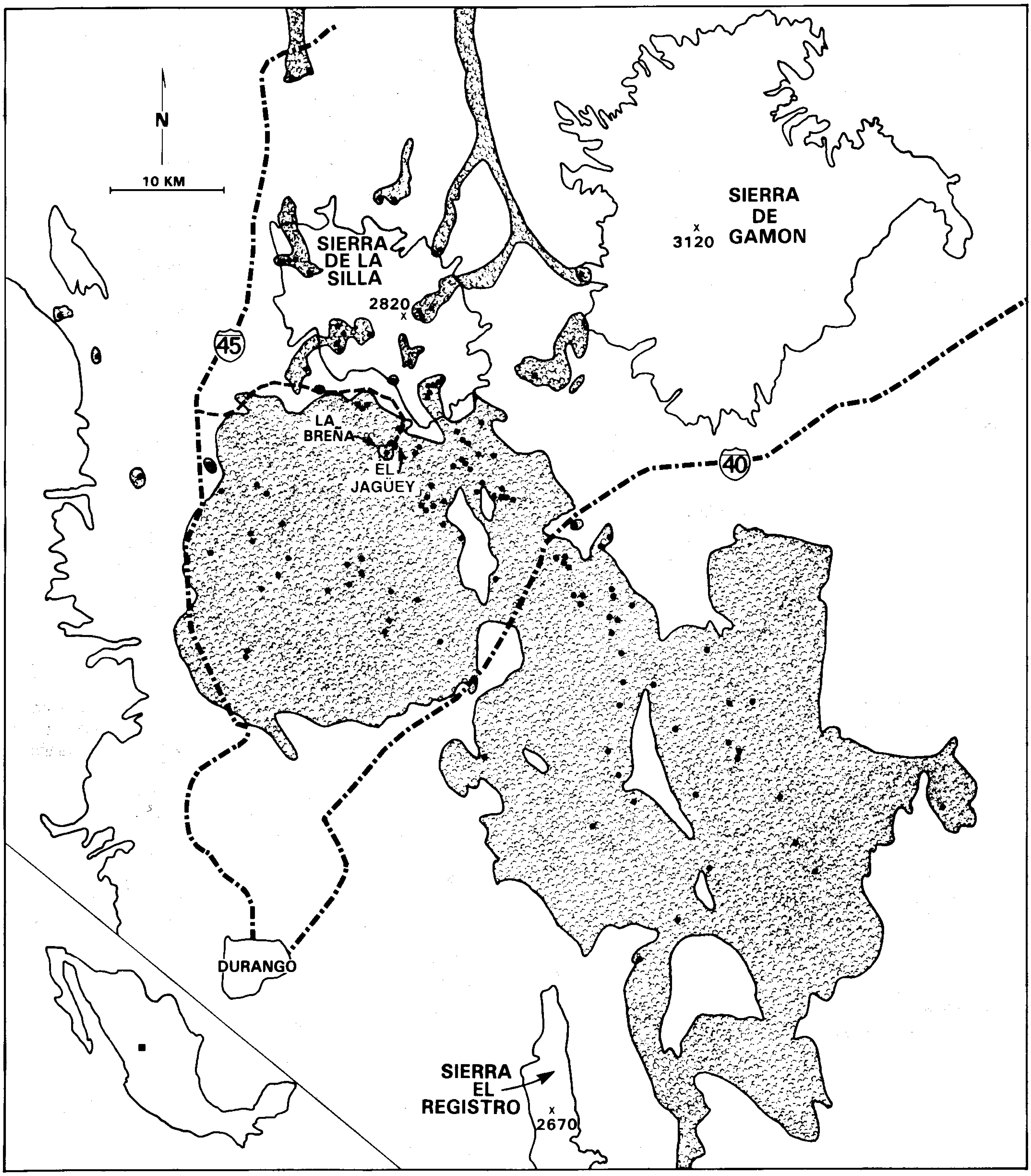


Figure 1.- The Guadiana Valley volcanic field. The distribution of Quaternary basalt is indicated by the shaded areas; mountain ranges are shown using the 2,100 m contour line, and dots indicate volcanic centers. All data are taken from DETENAL (1977a, 1977b, 1977c, 1978a, 1978b).

quarry west of La Breña are considered to be from the old scoria cone, but "proximal deposits" are the words of Aranda-Gómez and coworkers (1990), not mine. I consider them to be distal flank deposits, and I do not conceive of the pre-maar scoria cone as being any larger than nearby Cerro Pelón or Cerro Cazuela (Aranda-Gómez *et al., op. cit.,* figs. 4, a and 4, c). A simple tracing of the profile of either Cerro Pelón or Cerro Cazuela placed on a light table over the profile of the El Jagüey-La Breña complex is most revealing. The gentle outer slope and the abrupt break in slope inward match La Breña's slope beautifully. In addition, this

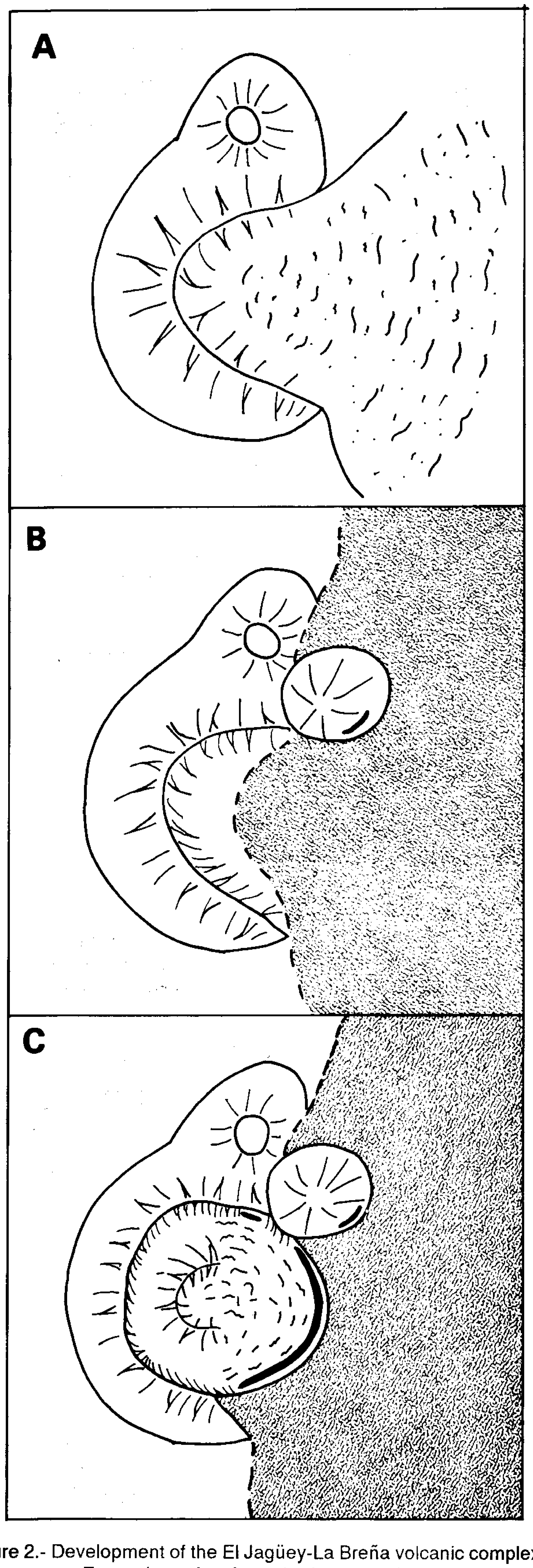


Figure 2.- Development of the El Jagüey-La Breña volcanic complex. (A) Formation of a breached composite scoria cone; (B) eruption of El Jagüey maar; (C) formation of La Breña caldera and eruption of lava from an intracaldera spatter cone complex (taken from Swanson, 1989).

comparison places the craters of these volcanoes directly over La Breña's crater, the probable vent area for both pre- and post-collapse magma.

Like most scoria cones (Wood, 1980), the pre-maar cone is believed to have been breached when magma injected along its base and rafted part of it away. Cerro Pelón may be among any number of examples of cones where rafted material is found nearby, but I am unimpressed by the argument that the rafted parts must be found. The complete disintegration of the cone material is also common, and there is no way to know what lies buried under soil, alluvium, lava, and scoriae to the west. Still, the small exposure of the pre-maar scoria cone in the northwest wall of El Jagüey (Aranda-Gómez *et al., op. cit.*, fig. 2) has probably been rafted. The exposure consists of altered pre-maar agglomerate which actually occupies a larger area than shown on their fig. 2. It overlies a fresh, horizontal layer of basalt, but the contact between these two units is not exposed. My interpretation of this exposure is that it is vent agglomerate from the pre-maar scoria cone intruded by the underlying basalt and rafted a short distance northeast of the original vent site.

Although we agree that a pre-maar scoria cone is exposed along the walls of the El Jagüey-La Breña complex, they consider the western rim of La Breña to be composed of post-collapse scoriae completely covering pyroclastic surge beds. They point out that maars like La Joyuela and Cráter Elegante have collapsed to cut and expose the bedded internal structure of pre-maar scoria cones. I have not been in La Joyuela, but Cráter Elegante and La Breña caldera are vastly different in terms of size, depth of collapse, climate, and post-collapse volcanism. Conditions at Cráter Elegante are excellent for exposing a small flanking scoria cone (Gutmann, 1976), which in addition to the factors already listed, receives support from an intruding dike. Conditions at La Breña caldera are much less revealing. One could just as well ask why the surge beds postulated by their two-maar model are not exposed. Why, one might well ask, would exposure of pre-maar scoria beds be expected when the proposed overlying maar surge deposits are not?

The crux of the problem is that no stratigraphic sequence can be determined with confidence along the western side of La Breña. The scoriae and bombs littering the western rim could be either pre-maar or post-maar in origin. The only certainty is that there are no surge beds exposed. The visible evidence suggests that the western rim of La Breña consists of pre-maar scoriae with a thin mantling layer of ejecta from the intracaldera lava cone.

## STRATIGRAPHIC POSITION OF SCORIA BEDS AND SURGE BEDS WEST OF LA BREÑA

Aranda-Gómez and coworkers (1990) report finding scoriae over the surge sequence outside the El Jagüey-La Breña complex. Scoriae that could have come from the post-collapse vent in the complex or any one of several nearby sources. I agree that post-collapse scoriae could have been vented from La Breña, certainly lava and bombs were, but I see no evidence for any great volume of scoriae. If scoriae overlie the surge sequence outside the El Jagüey-La Breña complex, why are there no scoria beds over the surge deposits exposed along the rim of the two structures? Why especially are scoria beds not found where they should be thickest, inside the complex?

These authors located "several small outcrops of surge beds" south and west of the complex (Aranda-Gómez *et al., op cit.*, fig. 1). My model calls for a mature but breached scoria cone preventing the southwestward dispersal of pyroclastic surges, and it seems to have been very effective at doing that. I note that they found no surge beds southwest of the complex, and that there is no reason why pyroclastic surges skirting the flanks of the scoria cone could not have reached the locations shown on their fig. 1.

*WATER SUPPLY*

I agree that there is probably an extensive aquifer underlying in the valley, but the assertion that El Jagüey's lake is unchanging is not true. It changes gradually with annual and multi-year variations, as does, I presume, the local water table. I have found the lake at very different levels during visits that span nearly 20 years, and local farmers talk about times when the lake dries completely. All this, however, has absolutely nothing to do with my developmental model.

Water encroachment was specifically mentioned as the triggering mechanism. I speculated that the maar formed during the short summer rainy season, and my next sentence read "The runoff from the nearby mountains infiltrated basin-fill sediment lying between the older welded tuff and the recently emplaced lava flows of an actively developing scoria cone to cause the phreatic explosions". I find it difficult to understand how this concept would led to the conclusion that one-fourth of the 100 vents in the valley should be maars. I think my paper was very clear in suggesting that it was runoff, not rainfall; a point source of surface discharge ("arroyos draining the mountains"), not general aquifer rise; and that these combined with a favorable geographic location to cause maar formation. There may be a "maar-forming season", but it would only affect active vents near mountain drainages, and then only during runoff events. I am not puzzled, as they are, that under these conditions only one maar formed from 100 potential valley vents or that other vents at the base of ranges are scoria cones. I am puzzled by their explanation that only one location in 100 allowed magma to rise at a rate conducive to maar formation, if indeed rate of rise was any factor in the Guadiana Valley at all.

ON EVIDENCE SUPPORTIVE OF THE TWO-MAAR MODEL

Vent asymmetry of El Jagüey, thickness and grain-size variations in the pyroclastic surge deposits, surge deposit stratigraphic sections, and chemical variation diagrams used by Aranda-Gómez and coworkers (1990) to support a two-maar model.

*VENT ASYMMETRY*

The authors explain El Jagüey's asymmetric, inclined funnel shape as a result of the deposition of more material when decelerating surges struggled to climb the crater's northeastern wall. This explanation ignores the fact that the surge deposits are far thicker on the southeast side of El Jagüey. The crater has the shape of an inclined funnel simply because a blast inclined away from La Breña produced a vent in the shape of an inclined funnel. Its shape has not been modified at all by surge beds from another source.

*THICKNESS AND GRAIN SIZE VARIATIONS*

Aranda-Gómez and coworkers (1990) are mistaken when they state that Swanson "...notes that the thickest part of the pyroclastic sequence is likely to be at the northwestern and southwestern ends of the low saddle that divides the crater". My words were: "The pyroclastic sequence exposed along the east rim of La Breña caldera thins rapidly from a maximum thickness of 60 m at El Jagüey's southern rim to 10 m at La Breña's southern rim". I did not find surge deposits above the northwestern end of the divide but rather pre-maar lava and overlying agglomerate (Swanson, 1989, fig. 2). We agree that the thickest surge deposits are at the southeastern end of the divide, between the two structures where, to me at least, a 60 m thick section is readily apparent. We also agree that the surge sequence thins rapidly north along El Jagüey and south along La Breña, but only the one-maar model with its directed blast offers a reasonable explanation for this.

Aranda-Gómez and coworkers (1990) report that the size and abundance of ballistic fragments in the upper 5 m of the surge sequence decrease in a northeastern direction along El Jagüey's rim. This is probably a natural consequence of the crater's asymmetry, which makes the northeastern rim distinctly more distant from the vent than the southeastern rim. I also note a decrease in the size of ballistically ejected fragments throughout the surge sequence southward along the rim of La Breña, with distance from El Jagüey.

*SURGE STRATIGRAPHY*

Aranda-Gómez and coworkers used a scoria marker bed, 52 cm thick, exposed in the northeastern wall of La Breña, 16 m below the crater rim and correlate it with a thinner (34–2 cm) layer only 1–5 m from the top of the crater rim along El Jagüey. They interpreted this layer as dividing surge deposits from the two sources. I measured sections at approximately the same two locations and found a scoria bed, 46 cm thick, 19 m below the rim of La Breña and 2 m above the basal explosion breccia of the surge sequence. I found a correlative scoria bed at El Jagüey, 20 cm thick, and maintaining its position 2 to 3 m above the basal explosion breccia. I suggest that missing this scoria bed caused the authors to mistakenly correlated scoriae at two different stratigraphic levels. They go on to use this "marker bed" and call upon complex facies variations in order to explain the stratigraphic section in terms of two-maar eruptions.

The surge stratigraphy in and surrounding El Jagüey is very clear. It is the product of a major vent-clearing phreatomagmatic eruption with only one volcanic breccia at its base. This was followed by numerous, closely spaced phreatomagmatic explosions alternating with an occasional purely magmatic event. Surge deposit thickness and the size of ballistic fragments show a direct decrease with distance from El Jagüey. This one, simple, completely conformable sequence, can be traced continuously to El Jagüey's rim and down into its crater. There is no evidence of two surge sequences whatever. Two surge sequences, if present, would be readily apparent in the stratigraphic section in a repetition of the prominent basal explosion breccia and locally conspicuous unconformities. If surge beds had actually been erupted from La Breña, the expected result would be the near filling of El Jagüey's crater, rather than the 1 to 5 m thick surge bed attributed to it.

*CHEMICAL COMPOSITION*

The chemical composition of collected samples is used in support of their stratigraphic interpretations, and to conclude that "when these data are interpreted according to Swanson's model (I989), they appear chaotic". I seriously question the concept of using chemical data to support stratigraphic conclusions, especially someone else's stratigraphic conclusions. I had no role in selecting the samples in question. I might, for example, be in full agreement that their samples DGO 114, 116, and 120 are post-maar scoria. Even so, there seems to be a problem. Although their fig. 8 shows a clear difference in chemistry between pre- and post-maar lavas (units for there is no disagreement on stratigraphic position), it is unclear to me how it shows that post-maar scoria is more chemically evolved than maar-related scoria. If these two scoria units can't be distinguished, on what basis can pre-maar scoria be distinguished? One logical conclusion of fig. 8 is that lava episodes can be distinguished clearly, but that scoria events can not. If DGO 114, 110, and 120 are pre-maar scoria, does that really make the data much more chaotic?

## DISCUSSION

Our field descriptions of the El Jagüey-La Breña complex agree to a high degree, but our interpretations do not. Like several other geologists, I undertook the study of the complex assuming that there were two adjacent maars, one of which collapsed to form a caldera while the other did not. I wondered, however, why two maars at approximately the same location would exhibit such different, post-eruption behavior. I hoped my knowledge of the local geology (Swanson and McDowell, 1984), and a study of the composition of the maar surge deposits, would tell me something about the dynamics of the underlying explosion chamber and why one maar collapsed while the other did not. The constant ratio of lithic fragments from overlying Quaternary basalt and an underlying Tertiary ignimbrite suggested an explosion chamber that grew laterally in sediment between these two layers. The explosion chamber finally collapsed to form only one caldera because there is only one maar.

Like others, I came to the complex with a dogmatic belief that two holes in the ground meant two maars, but the lack of two surge sequences forced me to consider alternatives. I wondered if La Breña could have collapsed as a result of an eruption from El Jagüey, but the distribution of the surge beds was puzzling until I remembered a photograph, from a volcanology book (Macdonald, 1972, p. 290), of the Iwo Jima maar, a smaller, modern analogy.

The one-maar interpretation is different, but the fact that I had to break away from preconceptions and volcanologic dogma makes me all the more confident of my conclusions. A philosophically analogous example is the 1912 ignimbrite eruption that formed the Valley of Ten Thousand Smokes, Alaska. For decades, it was assumed that adjacent Mount Katmai caldera had experienced an eruption (Fenner, 1920). A closer look revealed it had erupted nothing and its collapse was due only to the withdrawal of magmatic support (Curtis, 1955, 1968; Hildreth, 1987).

I have shown that arguments against the one-maar model are consistent with it, that evidence challenging details of the proposed sequence of events, in fact, support that sequence, and that evidence proposed in support of the two-maars is better explained by the one-maar model. There is one final point. The Guadiana Valley is a monogenetic volcanic field containing 100 vents (Figure 2). Monogenetic volcanic fields typically contain numerous scoria cones, associated lava flows, and a few maar volcanoes if conditions are right. Maars in such fields appear to be the surface expression of "scoria cones gone bad", to borrow a phrase from Charles Wood. That is, there would have been scoria cones, had not surface or near surface hydrologic conditions interfered. As the name monogenetic implies, these vents have short, simple volcanic histories and then become extinct. One interpretation of the volcanic history of the complex involves a scoria cone complex, lava flows, two overlapping maar volcanoes, then still more volcanic activity; certainly, a polygenetic site in a monogenetic volcanic field. I have interpreted the history of the complex in terms of a monogenetic volcano. The complex is a "scoria cone gone bad", and it shows a continuous evolution from scoria cone, to breached scoria cone, to maar volcano, before returning to purely magmatic volcanism. My model for the evolution of the El Jagüey-La Breña complex is simple, it is consistent with the geology of the complex, and consistent with the nature of monogenetic volcanic fields.

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