FORO

Univ. Nal. Autón. México, Inst. Geología,
Revista, vol. 9, núm. 2, 1990 (1992), p. 204-210

A NEW TYPE OF MAAR VOLCANO FROM THE STATE OF DURANGO—THE EL JAGÜEY-LA BREÑA COMPLEX REINTERPRETED; A DISCUSSION

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INTRODUCTION: CONTRASTING MODELS

In the past four years, we have been studying the geology and petrology of the Durango volcanic field (DVF) (Aranda-Gómez *et al.*, 1988, 1989, 1991; Smith *et al.*, 1989; Pier *et al.*, 1991). We paid special attention to the La Breña-El Jagüey volcanic complex (LBEJVC), because it is one of the few places in the DVF in which the detailed evolution of a volcanic center can be unraveled, and where a collection of volcanic rocks, whose relative ages could be inferred, can be obtained. According to our interpretation, the LBEJVC consists of two intersecting maars—La Breña (LB) and El Jagüey (EJ)—at least two pre-maar scoria cones and associated lavas, and a series of nested post-maar lava and scoria cones that erupted within LB and flooded its floor with lava (Figures 1 and 2, a). A completely different model for the evolution of LBEJVC was recently proposed by Swanson (1989). In this communication, we will briefly summarize the two models and then review key field and laboratory observations that, we believe, support our model and contradict the model of Swanson (1989). Our field observations led us to propose a model for the geological evolution of the complex (Aranda-Gómez *et al.*, 1988, in press), which forms the basis of our petrogenetic model (Pier *et al.*, 1991).

Prior to the formation of the maars, the place now occupied by the LBEJVC was the site of a small cluster of scoria cones and associated lava flows. One of these volcanoes was partially destroyed during the phreatomagmatic eruptions that formed the craters of LB and EJ. Its remains are now exposed in a small outcrop in the northwestern wall of EJ (pre-maar scoriae in Figure 2, a). The other cone is completely buried under the pyroclastic blanket that surrounds the maars. Its geomorphic form is still discernible 450 m north of LB crater (Figures 1 and 2, a). We view LB as a maar formed after EJ maar, and we regard the upper part of the pyroclastic deposit, now prominently exposed along the northeastern rim of EJ, as a surge sequence accumulated during the formation of LB. Part of this well-layered surge sequence crops out in the lower wall of EJ, near the bottom of the crater (Figure 2, a). It seems that some of the surge clouds from LB travelled down the southwestern wall of EJ, fanned out across its floor, and climbed the opposite walls before emerging onto the surrounding lava plain. During this process, the surge clouds formed a pyroclastic blanket around LB and deposited tuff and tuff-breccia in and around the EJ crater. The phreatomagmatic phase was gradually succeeded by a series of strombolian eruptions from vents within LB. Some of the earliest strombolian events are registered in the LB surge sequence as scoria-fall beds, interlayered with the surge beds (Figure 2, a). Finally, the phreatomagmatic activity completely gave way to strombolian eruptions and lava effusion, and a series of at least three scoria and lava cones formed in LB crater (Figure 2, a). At many places around the craters, the rims and inner walls of the maars are covered by post-maar tephra. Therefore, in these places the surge sequences related to the formation of the maars are now buried under a thick blanket of post-maar scoriae and ash. This phenomenon is specially pronounced in the northern, western, and southwestern parts of LB crater.

According to the model recently proposed by Swanson (1989), LB is a collapse crater (caldera) developed immediately after, and as a result of, the formation of EJ maar. Swanson's model implies the former existence of a large scoria cone over the site of LB caldera. Prior to the formation of the collapse structure, the eastern part of this LB scoria cone is thought to have been rafted away by the lava flows now exposed in several places in the crater walls. A sudden influx of groundwater from the north shifted the volcanic activity to the site of EJ, triggered the formation of EJ maar through a series of phreatomagmatic explosions, and removed the support from beneath the LB scoria cone, causing its collapse.

It is important to establish which of the proposed evolutionary models for LBEJVC conforms best to the field data, because the petrological interpretation of the samples collected depends on the inferred ages of the rocks. The two models lead to strikingly different interpretations; we consider some of the scoria samples collected (DGO 114, 116 and 120 *in* Pier *et al.*, 1991) as post-maar and the lava samples collected in the crater's walls (DGO 101 and 117 in Pier *et al.*, *op. cit.*) to be pre-maar. If Swanson's model is correct, all of these rocks are related to LB scoria cone and are older than the EJ maar.

We are very grateful to Swanson for the fact that his paper (1989) prompted us to revisit the LBEJVC, to verify the basic field information that could support either model. As it is common in many geologic problems, not all pieces of the puzzle are available, but in our opinion, the field evidence strongly supports our interpretation. This evidence is summarized in the following section. Some of the arguments are considered conclusive, such as the orientations of sedimentary structures in the surge sequence (channels and dune-like structures; Figure 2, b), the thickness variations in a scoria-fall marker bed (Figure 2, a), the inferred transport directions determined from ballistic trajectories (Figure 2, b), the nature of the scoria deposits in the western part of the complex (Figure 3), and the slope of the remnant LB scoria cone (Figure 4). Other lines of evidence are regarded as supportive of our model, but not conclusive, such as the size of the hypothetical LB scoria cone (Figure 5), the absence of a reworked (rafted) scoria deposit (Figure 6), the facies variations in the pyroclastic sequence (Figure 7), and the chemical composition of the rocks (Figure 8).

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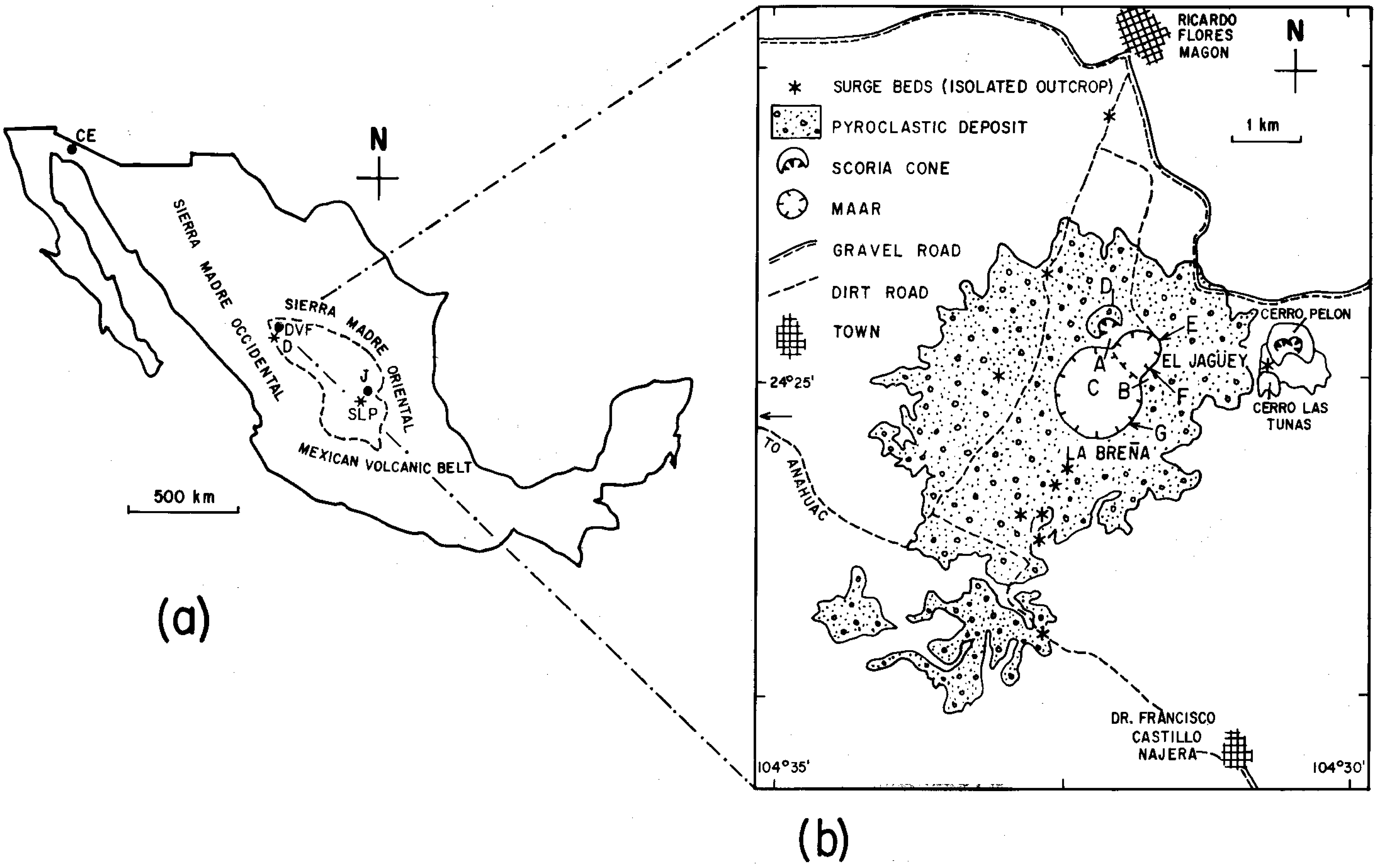

Figure 1.- (a) Generalized map of Mexico showing the location of the Durango Volcanic Field (DVF), just northeast of Durango city (D). The locations of other maars mentioned in the text are also indicated: Cráter Elegante (CE) and La Joyuela (J), north of San Luis Potosí city (SLP). (b) Vicinity of La Breña-El Jagüey volcanic complex. The patterned distribution of post-maar ashes (pyroclastic deposit) was taken from the 1:50,000 DETENAL geologic map (G13D72). Points A and B are localities mentioned in the text. C, D and E show the locations of the measured stratigraphic sections.

DISCUSSION

CONCLUSIVE EVIDENCE

Inferred transport directions using bed forms, channels, and ballistic clasts in the surge sequence

Transport directions in surge beds can be inferred from sedimentary structures (Fisher and Schmincke, 1984; Wohletz and Sheridan, 1979). We studied the upper 5–10 m of the surge sequence along the southern, eastern, and northern rims of EJ, and along the southeastern rim of LB. We determined transport directions using the geometry of impact pits produced in the water-saturated surge beds by ballistic clasts (Aranda-Gómez *et al.*, in press), and to a minor extent, the orientation of channels and dune-like structures. The results are summarized in Figure 2, b. Transport directions in the southern and eastern wall of LB spread radially from the center of the crater. Inferred transport directions in the upper walls of EJ also point toward LB, and not toward the center of EJ. We realize that only the transport directions determined in the southeastern portions of the maars are diagnostic of LB as the source for this portion of the surge sequence. Those vectors determined in the northeastern part of EJ are consistent with either LB or EJ as the source of the beds, because the center of both craters aligns along a SW-NE direction, which is the overall transport direction in that area. Excellent three dimensional exposures of the upper surge sequence exist in the shaded area in Figure 2, b. We determined 12 transport directions in that small area using bedding sags. The rose diagram in Figure 2, b shows that even in the best outcrops, transport direction can only be determined with a precision of ± 20°. However, the uncertainties in the measurement of the vectors do not invalidate our basic conclusion: the upper part of the surge sequence originated at LB maar.

Scoria-fall marker bed interlayered in the surge deposit

We found a scoria-fall bed that can be traced continuously around the southern, eastern and northeastern walls of EJ (Figure 2, a). This marker bed is interlayered with the well-bedded pyroclastic sequence dominated by sandwave and plane-parallel surge beds exposed within the upper 5 m of the walls of EJ. The marker bed shows a gradual decrease in total thickness from 34 cm in the southern rim of EJ to 2 cm in the northeastern wall of the same crater (Figure 2, a). This systematic change in thickness is consistent with the increasing distance from the source. Therefore, we conclude that the eruption vent for the scoriae had to be located to the south or to the southwest of EJ. LB is the only likely candidate.

Nature of the scoria deposits in the western part of LBEJVC and the slope of the remnant of LB scoria cone

Several maars have been documented that have developed in areas formerly occupied by cinder cones (Figures 1 and 3),

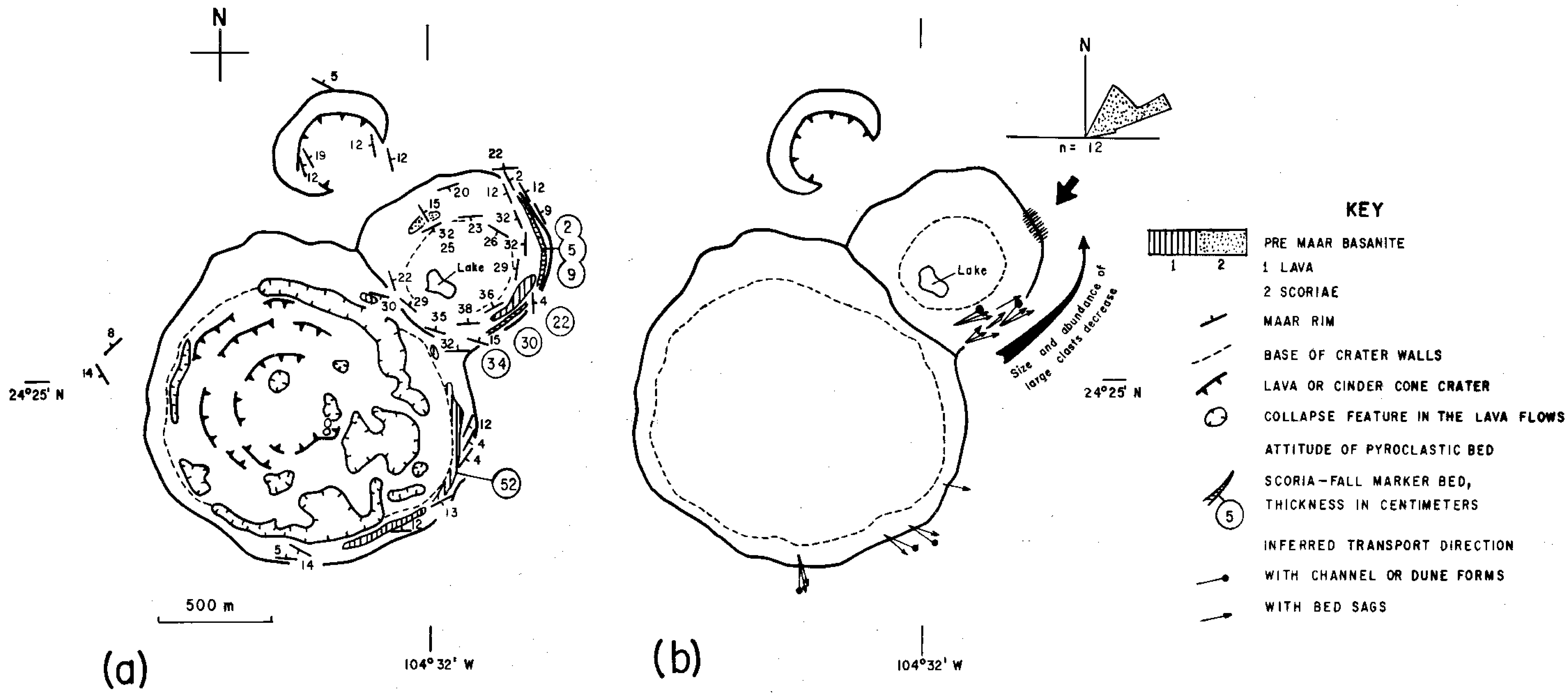

Figure 2.- (a) Structural map of the La Breña-El Jagüey volcanic complex, showing the attitude of the surge beds and post-maar ashes, and the thickness variation along the scoria-fall marker bed. Note the steep inward dips of the maar-related pyroclastic layers within EJ maar. (b) Vectors for transport direction measured in the upper 10 m of the surge sequence from impact pits and bedding sags formed by ballistic clasts and from channel axes and dune structures. The curved arrow shows the decrease in abundance and size of large ballistic clasts in the eastern rim of EJ. See text for discussion.

including Cráter Elegante, in Sonora (Gutmann, 1976), and La Joyuela, in San Luis Potosí (Aranda-Gómez, 1982). At these maars, the internal structures of the pre-maar cinder cones are clearly exposed in the walls of the craters (Gutmann, 1976, fig. 3; Figure 3). If the hypothesized LB scoria cone was partially destroyed by the formation of LB and EJ craters, either by caldera-like subsidence (Swanson, 1989) or by phreatomagmatic eruptions, and if the southwestern, western, and northern walls of LB and the southwestern portion of EJ are part of the former LB scoria cone, one would expect to see in these walls the internal structure of the cone, with its well-defined, steeply dipping bedding. Such is not the case at LBEJVC. The scoria outcrops along the maar rims and inner walls of the craters do not show any signs of bedding. Rather, the deposits consist of loose scoriae and ash that drape the maar rims in a manner consistent with our interpretation of these as post-maar deposits.

The quarry mentioned by Swanson (*op. cit.*, p. 243) indeed shows a well-bedded sequence of relatively well-sorted, lapilli-sized scoriae. However, the beds dip gently (~ 8–14°) away from La Breña (Figure 2, a). These gentle dips are inconsistent with the proximal deposits of a large scoria cone, as proposed by Swanson (1989). Again, we interpret this as post-maar material, deposited on top of the gently inclined slope formed by the underlying surge deposits.

Figure 4 shows several topographic profiles of LB; the outer slope of LB tuff-ring is up to 13°. For comparison, we also show at the same scale profiles of Cerro Pelón and Cerro Cazuela, two typical scoria cones of the DVF. It is clear that the outer slope of LB is gentler than that of the scoria cones.

The age relationship between the scoriae and ash along the maar rims and the surge sequence can be clearly seen in the eastern part of the LBEJVC, where the surge sequence outside of the craters is partially to completely covered by the scoriae and ash. It is possible to follow these deposits continuously around the crater to the western part of the complex, to the area where the remains of the presumed LB scoria cone are located. There can be no doubt that the scoriae and ash lie atop the surge beds, in direct conflict with Swanson's model.

Swanson states in his paper (*op. cit.*, p. 246) that LB scoria cone prevented the westward dispersal of pyroclastic surges.

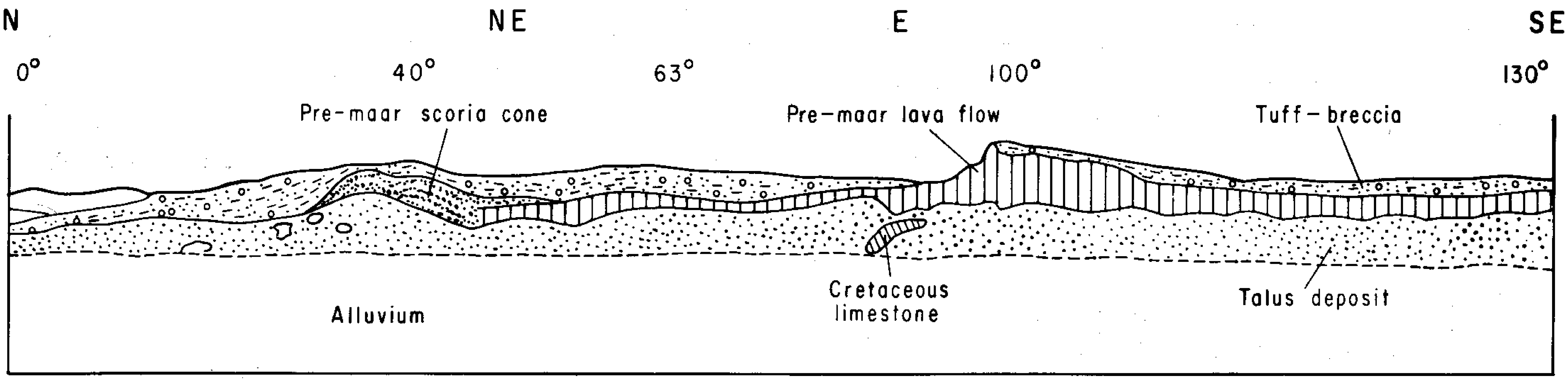

Figure 3.- Geologic sketch of the La Joyuela maar. The cross section of an older scoria cone is exposed in the northeastern portion of the crater (40°). Note the characteristically steep bedding within the primary, near vent scoria deposit. The maar-related tuff-breccia drapes over the older structure (from Aranda-Gómez, 1982).

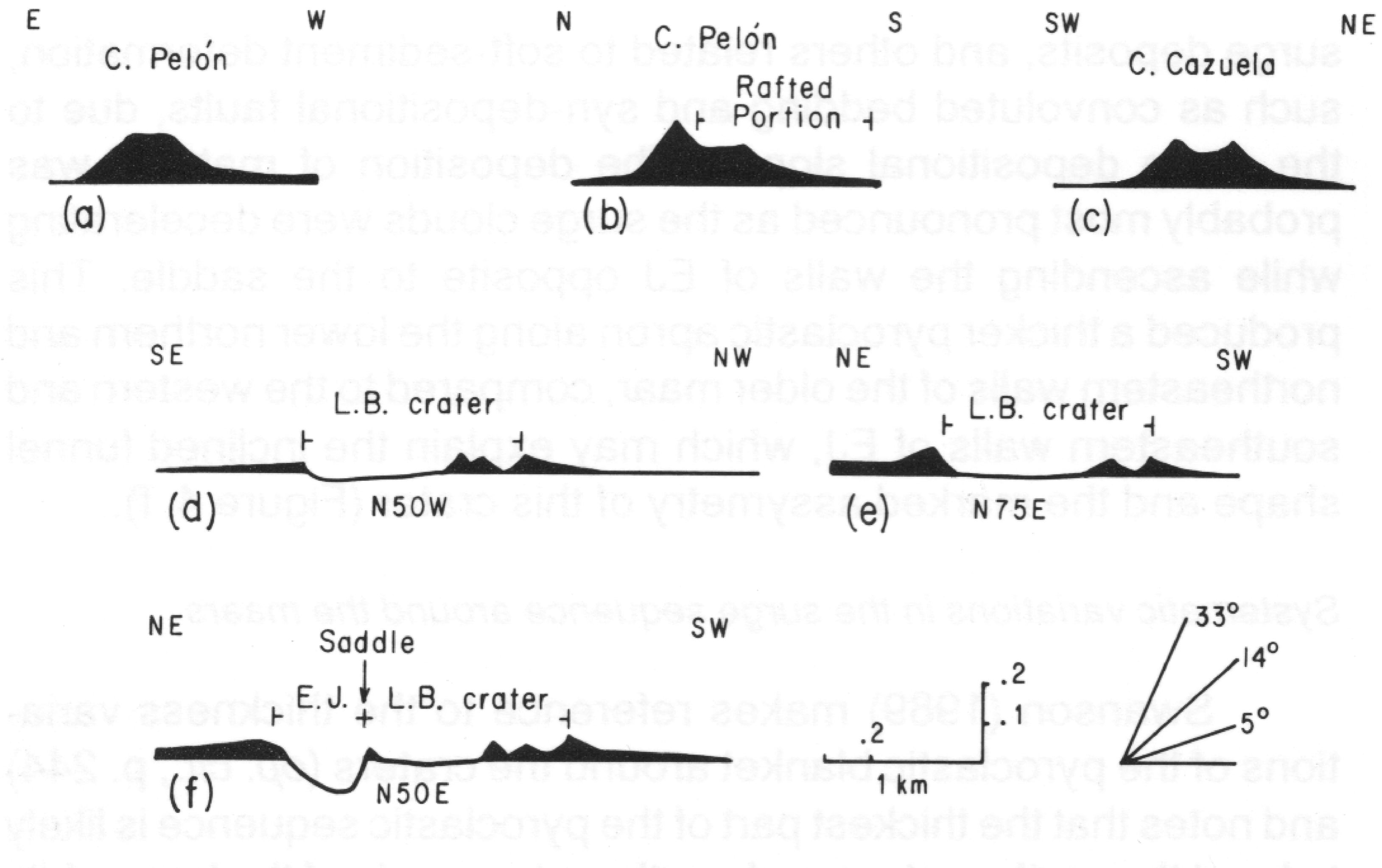

Figure 4.- Comparison between the topographic profiles of LBEJVC and two typical scoria cones from the DVF. All the profiles are at the same scale. Note the difference in the primary slope of the youthful Cerro Pelón scoria cone (A and B) and the slope of the pyroclastic deposit around the maars, particularly in the western part of LB (D, E, F). Diagram F clearly shows the highly asymmetric profile of EJ, with a gentler slope in the wall opposite to the "saddle" between both craters. Vertical exaggeration 2.5.

However, we found several small outcrops of surge beds west of the LBEJVC, exposed in "windows" along vehicle tracks that cut through post-maar scoriae and ash (Figure 1).

SUPPORTIVE EVIDENCE

Size of the proposed LB scoria cone

If it is accepted that LB is a collapse crater that almost completely destroyed an older scoria cone, it is possible, assuming the characteristic primary slope of scoria cones (~ 33°), to use the basal diameter of the remnants of the original volcano (nearly 1,800 m, measured as twice the distance from the break of the slope on the western side of LB to the center of the crater) to calculate the height and volume of the original cone (585 m and 0.5 km^3, respectively). Using geologic maps that cover most of the DVF (DETENAL, 1977a, 1977b, 1977c, 1977d, 1978a, 1978b), we found that the basal diameters of 88 mapped scoria cones in the DVF range from 300 to 1,200 m, with an average of 693 m. Thus, the hypothetical LB scoria cone must have had a diameter nearly three times larger than the average scoria cone in the DVF and 1.5 times larger than any other scoria or cinder cone in the DVF. Figure 5 shows a histogram of the diameter of the 88 cinder cones. The population of the scoria cone diameters in the DVF is best described by a lognormal distribution with a mean of 2.82 and a standard deviation of 0.14. The hypothesized LB cone has a diameter of 3.26 (log of 1,800 m), which is more than three standard deviations removed from the mean. Thus, there is a chance of less than 0.13 % that the LB cone is a member of the scoria cone population.

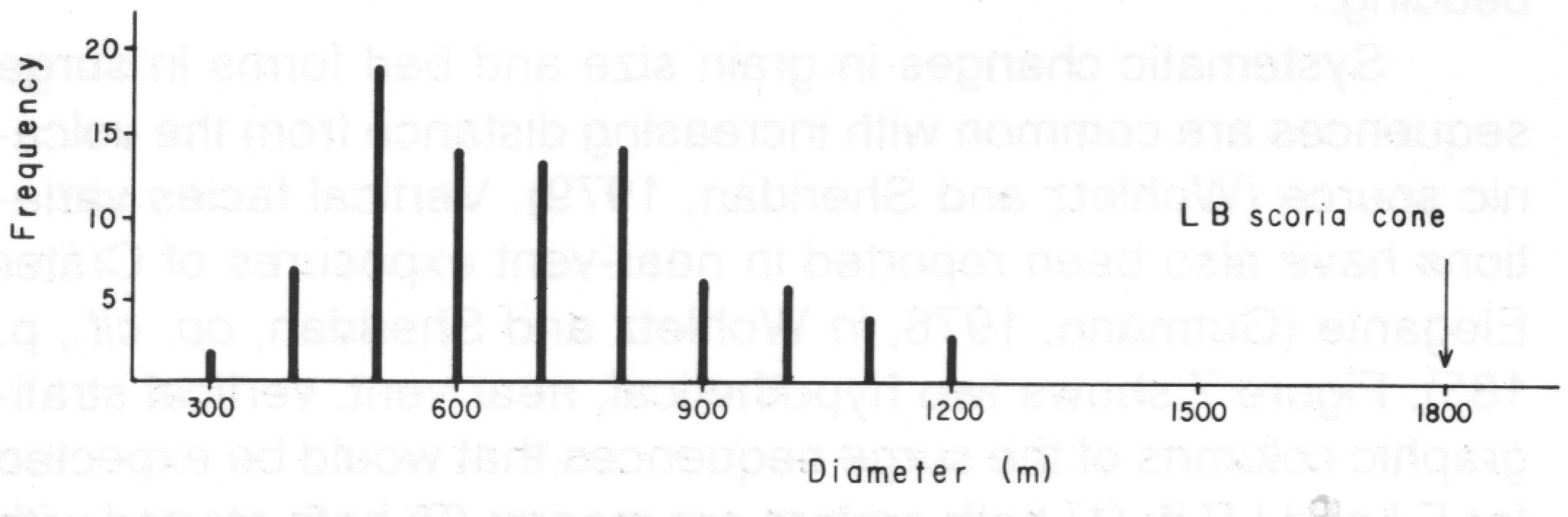

Figure 5.- The histogram shows the basal diameter of 88 scoria cones in the DVF, which range from 300 to 1,200 m. The size of the hypothesized LB scoria cone is also shown.

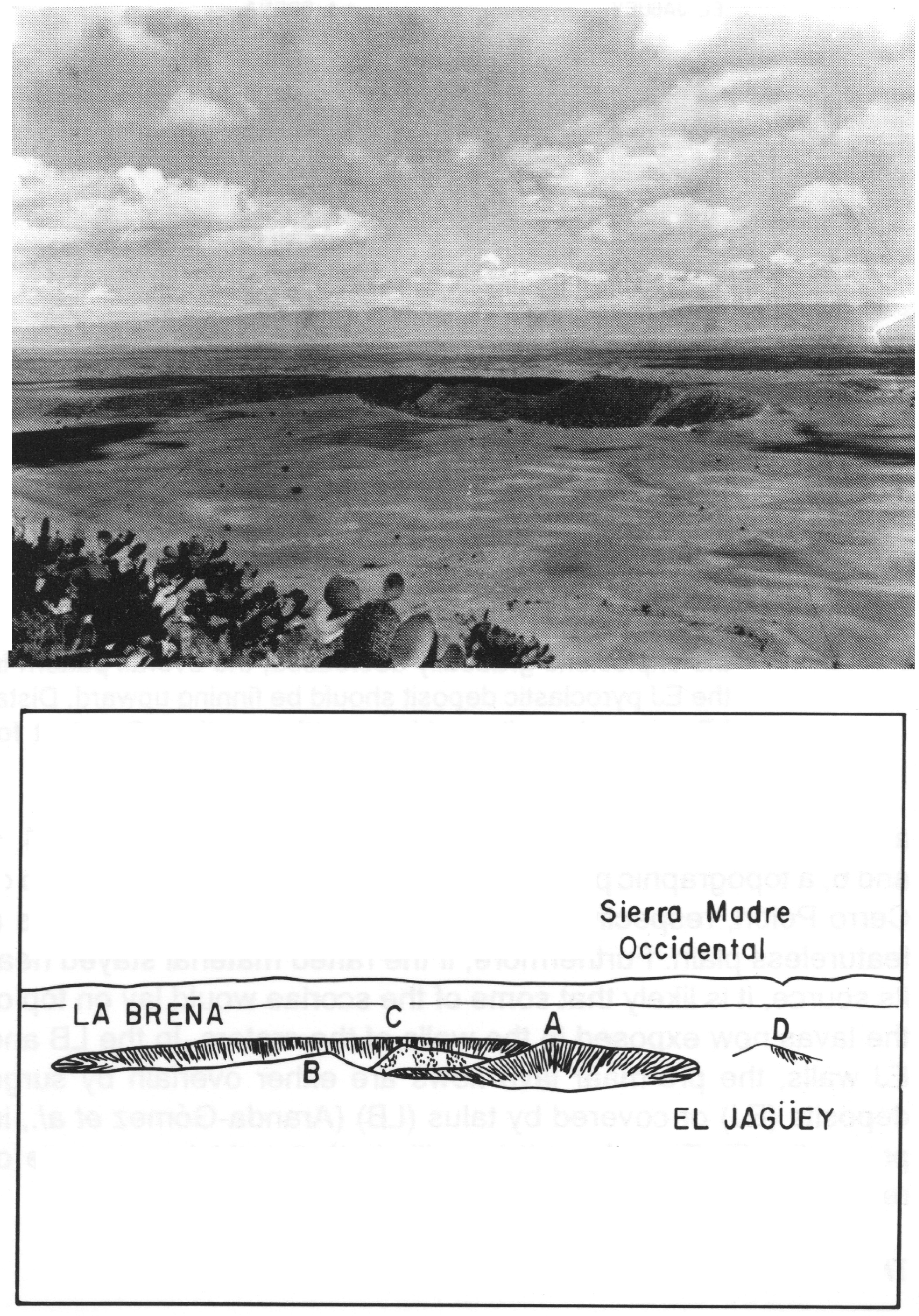

Figure 6.- The LBEJVC seen from the top of Cerro Pelón to the E. Note that the area immediately to the east of LB is a featureless plain, without any signs of agglutinate mounds or hummocky topography. A and B are the highest points at the ends of the saddle that divides the craters. C is the highest post-maar scoria cone in LB.

The rafted portion of LB scoria cone

The Cerro Pelón-Cerro las Tunas complex is located two kilometers to the ENE of LB (Figure 1). This group of volcanoes is composed of two youthful, undissected scoria cones, several lava flows, and a hummocky, reworked scoria deposit, that is the product of partial collapse of the southern part of Cerro Pelón scoria cone (profile b, Figure 4). The reworked scoria deposit formed during rafting of about one-third of the original Cerro Pelón cone by lava flowing southward. This event produced a deposit that is 40–50 m thick and moved only a short distance to the south, to cover an area of nearly 0.3 km^2. Another example of a collapsed scoria cone is Sunset Crater, discussed by Holm (1987), where the rafted materials produced agglutinate mounds, up to 37 m high, along a belt 1.4 km long. Considering the larger size of the proposed scoria cone of LB, it is unlikely that the rafted portion was transported more than one kilometer from its original site. If the model of Swanson (1989) is correct, a large volume of rafted material should be located to the east of LB, and should produce

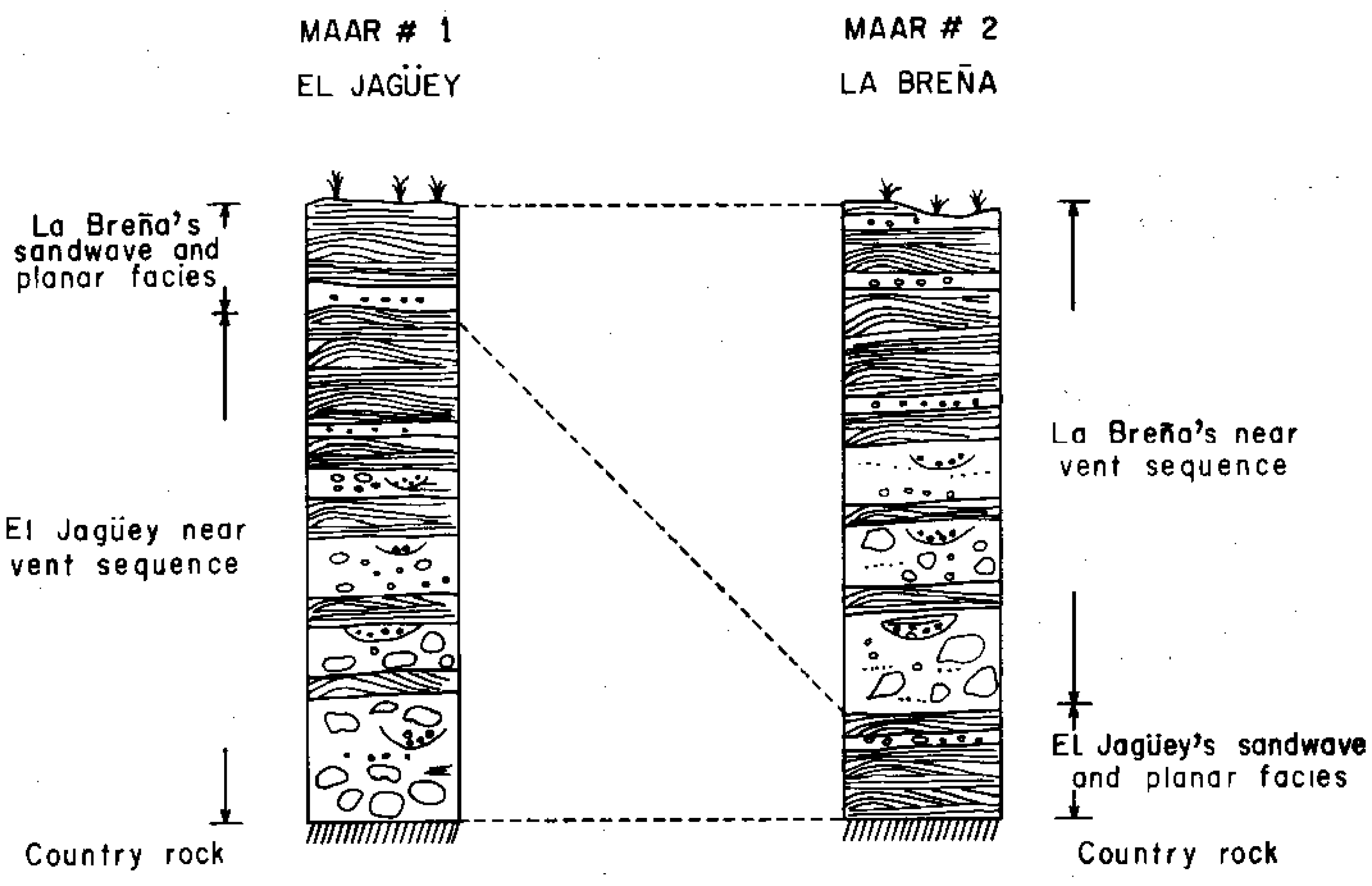

Figure 7.- Hypothetical stratigraphic columns in near-vent exposures around EJ and LB. If EJ is older than LB, and the energy of the explosions gradually decreased, the overall pattern in the EJ pyroclastic deposit should be finning upward. Distal LB surge deposit would cover the section. See text for discussion.

a hummocky, irregular surface. Instead, as seen in Figures 4, e and 6, a topographic profile and a view of LBEJVC from the top of Cerro Pelón, respectively, the eastern area of the complex is a featureless plain. Furthermore, if the rafted material stayed near its source, it is likely that some of the scoriae would lay on top of the lavas now exposed in the walls of the craters. In the LB and EJ walls, the pre-maar lava flows are either overlain by surge deposits (EJ) or covered by talus (LB) (Aranda-Gómez *et al.*, in press, fig. 5). Therefore, it is unlikely that a thick sequence of reworked scoriae exists on top of the lava flows.

The assymetry of the EJ maar

According to our model, sometime during the growth of LB crater the tuff ring around EJ was breached and the subsequent surge clouds that traveled toward the NE crossed the saddle, went down into EJ depression, spread out over the floor, climbed the opposite walls of the crater, and finally reached the surrounding lava plain. During this process, the surge clouds deposited a sequence of steeply dipping beds (22–38°), that lines the older crater (Figure 2, a). These beds show a remarkable array of sedimentary structures, some of them characteristic of base-

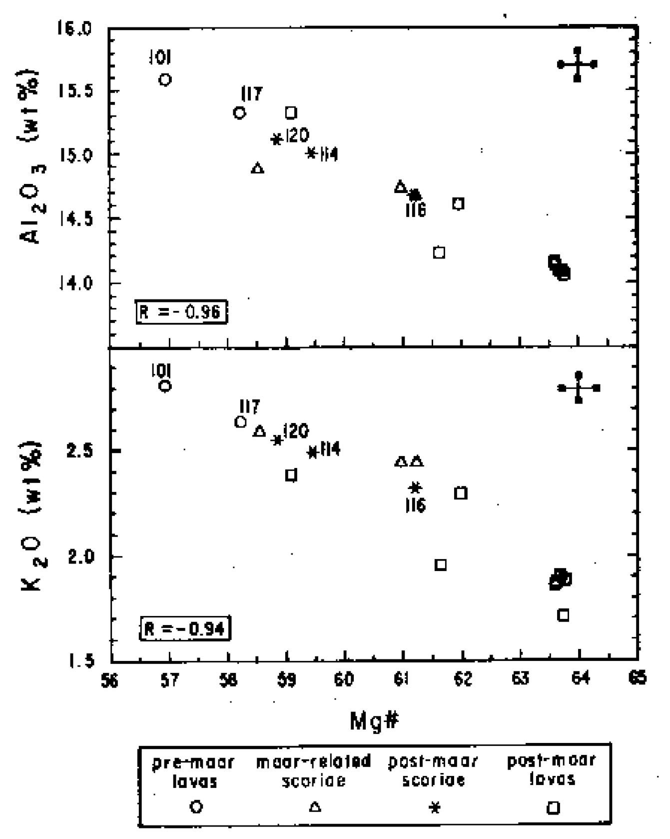

Figure 8.- The chemical compositions of the rock samples collected at LBEJVC show a smooth variation with our inferred position in the eruption sequence. Mg # increased systematically with time during the evolution of LBEJVC from 57.0–58.2 in the pre-maar lavas to 59.1–63.8 in the post maar-lavas. The large crosses in the graphs represent analytical uncertainties.

surge deposits, and others related to soft-sediment deformation, such as convoluted bedding and syn-depositional faults, due to the steep depositional slopes. The deposition of material was probably most pronounced as the surge clouds were decelerating while ascending the walls of EJ opposite to the saddle. This produced a thicker pyroclastic apron along the lower northern and northeastern walls of the older maar, compared to the western and southeastern walls of EJ, which may explain the inclined funnel shape and the marked assymetry of this crater (Figure 4, f).

Systematic variations in the surge sequence around the maars

Swanson (1989) makes reference to the thickness variations of the pyroclastic blanket around the craters (*op. cit.*, p. 244) and notes that the thickest part of the pyroclastic sequence is likely to be at the northwestern and southeastern ends of the low saddle that divides the craters (points A and B in Figure 1, b and in Figure 6). We agree with this inference, but note that it cannot be substantiated in the field. The southeastern wall of EJ is buried by steeply dipping surge deposits that cover the area in the manner of "drape bedding". The northeastern wall of LB is almost completely covered by post-maar scoriae and ash, soils, and talus (reworked scoriae). Therefore, it is not possible to measure the thickness of the surge deposit in either area. We measured and described two sections in the eastern walls of EJ and LB (locations C and D in Figure 1, b). The pyroclastic sequence measured is 12.7 m thick in EJ and 30 m thick in LB. However, this is not the total thickness of the EJ deposit because the base is covered by steeply dipping surge beds. We also measured the total thickness (45 m) of the pyroclastic sequence in the southeastern wall of EJ (location E, Figure 1, b). Thus, if it is accepted that the southern rim of EJ is the thickest part of the deposit (~ 60 m), it must be concluded that the pyroclastic sequence thins out quickly, both to the north and to the south of the point B area (Figure 1, b). Therefore, the thickness variation of the pyroclastic sequence cannot be used to argue for a source within EJ as done by Swanson (1989).

From our detailed descriptions of the stratigraphic sections and study of the pyroclastic surge deposits exposed around the craters, some systematic variations can be deduced. First, it appears that during the initial stages of the formation of the maars, the phreatomagmatic eruptions were more powerful, and deposited near the vents poorly bedded tuff-breccias with abundant large lithic fragments, up to 1.6 m in length. These are analogous to the explosion breccias that characterize the early stages of the formation of tuff rings/cones (Wohletz and Sheridan, 1983). As the development of the maars progressed, the explosions became gradually weaker (due to local depletion in the underlying aquifer) and, consequently, the average grain size of the deposits and the sizes of the ballistic clasts decreased. Parallel to these changes, the sedimentary structures evolved from poorly bedded and sorted tuff breccias and breccias to thinly layered deposits of relatively fine-grained tuffs with common planar and sandwave bedding.

Systematic changes in grain size and bed forms in surge sequences are common with increasing distance from the volcanic source (Wohletz and Sheridan, 1979). Vertical facies variations have also been reported in near-vent exposures of Cráter Elegante (Gutmann, 1976, *in* Wohletz and Sheridan, *op. cit.*, p. 185). Figure 7 shows two hypothetical, near vent, vertical stratigraphic columns of the surge sequences that would be expected for EJ and LB if: (1) both craters are maars; (2) both started with powerful eruptions and the energy of the eruptions gradually decreased with time; and (3) if LB is younger than EJ, as we propose. In general terms, these columns fit well with our measured sections (Aranda-Gómez *et al.*, in press, figs. 4 and 5). However, the measured sections are more complex than the hypothetical columns due to complicating factors listed by Wohletz and Sheridan (1979, p. 191).

The scoria-fall marker bed is 52 cm thick in the southeastern wall of LB (Figure 2, a), is interlayered within a thick sequence of coarse grained tuff-breccias and breccias, and lies 16 m below the crater rim. Along the EJ wall, the same marker bed is thinner (34–2 cm) and is interlayered in a very well-bedded, fine-grained sequence of planar and sandwave beds only 1–5 m from the top of the crater's rim (Figure 2, a). We consider this to be a natural consequence of LB as the source of the overlying surge material around both maars, which should be considerably thicker and coarser grained near the vent (LB), than it is one kilometer away from the source (EJ). Furthermore, prior to the formation of LB, EJ was probably completely surrounded by a tuff ring. Thus, the surge clouds from LB that traveled toward the NE, prior to the breaching of EJ tuff ring, encountered a topographic barrier that caused the accumulation of the coarser material on the slope facing toward LB. It is also probably that not all the surge clouds had enough energy to surmount this barrier, and that only the most powerful blasts sent surge clouds and ballistic clasts above the EJ tuff ring. Thus, the pyroclastic sequence above the marker bed is considerably thinner at EJ. Also consistent with this interpretation, we noticed a systematic decrease both of the abundance and size of the ballistic fragments northwestward along the rim of EJ. In the upper 5 m of the surge sequence, these ballistic blocks decrease from a maximum diameter of 1.6 m along the southeastern rim to ~ 60 cm diameter along the northeastern rim (Figure 2, b).

The water supply for the phreatomagmatic eruptions

As in many other maars around the world (Fisher and Schmincke, 1984), the pyroclastic sequence around the LBEJVC shows compelling evidence for a phreatomagmatic origin. LB and EJ are the only two known maars in the DVF, where nearly 100 Quaternary volcanoes have been identified. The stratigraphic sequence recognized by Albritton (1958) for the DVF includes, at least, two units composed by unconsolidated gravels beneath the "younger basalts" that are potentially good aquifers. It is puzzling that only two maars were formed in the entire volcanic field. Therefore, there must be other factors that lead to the formation of maars, aside from the presence of groundwater and rising magma. We believe that a third factor is the rate of magma ascent. LBEJVC is the place where the largest xenoliths of spinel lherzolite have been found in the DVF. In order to carry on these inclusions from the mantle, the magma had to travel quickly to the surface (Spera, 1987).

Swanson's hypothesis about the role of groundwater in the development of EJ maar is unsatisfactory in several ways. First, if maar formation is a phenomenon associated with the three-month rainy season, and if volcanism occurred randomly throughout the year, the chances of forming maars would be one in four. Therefore, one would expect to find nearly 25 maars in the DVF instead of two. Second, if maar formation is related to the topographic height of the vent and to the proximity to Sierra la Silla, then Cerro Pelón and Cerro las Tunas should also have formed maars because they are higher and closer to Sierra la Silla than the LBEJVC. Furthermore, Cerro Pelón and Cerro las Tunas lie just 2 km northeast of the maar complex (Figure 1). Thus, it is possible that the cones overlie the same aquifer as LB and EJ. Third, the way that Swanson envisions the involvement of water in the development of LBEJVC implies that the aquifer was dry during the formation of the LB scoria cone and then was quickly filled due to seasonal rains in the nearby Sierra la Silla. Aquifers in gravel deposits are dynamic systems that produce seasonal variations in the water table. However, at least a part of the gravels remains saturated with water throughout the year. In support of a relatively large and constant aquifer, is the unchanging character of the lake in the bottom of EJ, whose surface lies ~ 60 m below the lava plain. Therefore, the change from strombolian-type eruptions of the hypothesized LB scoria cone to phreatomagmatic activity centered at EJ maar, due to the sudden influx of groundwater into the volcanic system, cannot be explained in the way Swanson proposed.

Chemical compositions of LBEJVC samples

Swanson (1989) sustains that all volcanic rocks found in the LBEJVC are "nearly identical", both petrographically and chemically. He then uses this interpretation to support his model for the equivalence of the pre-maar lavas and the scoriae and ash found along the northern and western rims of LB. In Pier and coworkers (1991), we present petrographic data, mineral compositions, whole-rock elemental abundances, and Sr-Nd-Pb isotopic ratios for 16 samples from all stages of the LBEJVC evolution. These data not only indicate significant variability for all of these parameters, but also show that the pre-maar lavas are distinct from what we call the post-maar scoriae (Swanson's pre-maar scoria cone) in textures, mineral compositions, and elemental compositions. When the whole-rock chemical data of Pier and coworkers (1991) are interpreted according to our model, a smooth change in Mg# and most element abundances (Figure 8), with eruptive position, is found. When these data are interpreted according to Swanson's model (1989), they appear chaotic.

CONCLUDING REMARKS

A variety of field observations supports our model for the LBEJVC evolution and conflicts with Swanson's (1989) model. Transport directions for the surge deposits in the upper walls of both EJ and LB were deduced from sedimentary bed forms and impact pits of ballistic clasts, and clearly indicate a source at LB. Thickness variations in an interbedded scoria-fall marker bed similarly indicate a source at LB. The absence of base-surge deposits in the western and northern parts of LB is probably the feature that caused Swanson not to interpret LB as a maar. We note, however, that base-surge deposits are also absent in the western part of EJ, which we all agree is a maar. The lack of base-surge deposits in both of these places is a clear result of cover by younger scoria- and ash-fall deposits from the nested scoria cones on the floor of LB. In summary, field relations at the LBEJVC do not require Swanson's (1989) complex model, with the growth of an improbably large scoria cone and its subsequent destruction by rafting and caldera-like collapse.

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Manuscript received: October 22, 1991.