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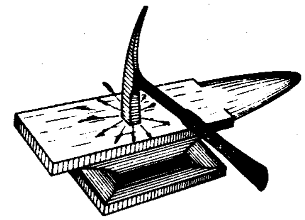

A PRELIMINARY REPORT ON THE COMENDITIC DOME AND ASH FLOW COMPLEX OF SIERRA LA PRIMAVERA, JALISCO; REPLY

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INTRODUCTION

I welcome the opportunity provided by Demant and Vincent's discussion (1978) of Mahood (1977) to correct an error in my original interpretation of the geological evolution of the Sierra La Primavera. The paper was based on observations made during a single field season and on less than a dozen K-Ar dates; I attempted to indicate the preliminary nature of my conclusions in the title of the article. As pointed out by Demant and Vincent, the fundamental error in my interpretation was the assumption that the Tala Tuff was one of the younger eruptive units at Primavera when, in fact, it is one of the older. In this reply, I would like first to present my revised view of the geologic evolution of the Sierra La Primavera and, second, to reply specifically to some of Demant and Vincent's points.

GEOLOGIC HISTORY OF THE SIERRA LA PRIMAVERA

To determine the eruptive history, the Sierra La Primavera was mapped at a scale of 1:25,000. Eruptive units were classified into groups based on stratigraphic relations, although the groups can also be distinguished by K-Ar dates, by microprobe-determined compositions of phenocrysts, or by major- and trace-element bulk compositions (Mahood, 1980a). The following summary of the geologic history of the Sierra La Primavera is a synthesis of field mapping, K-Ar dating, and trace element and mineralogical correlations. The eruptive sequence (Table 1) was calibrated with more than 50 K-Ar determinations performed in the University of California, Berkeley, laboratory. The dates range from 25,000 to 145,000 years and generally agree with relative ages determined in the field. The reader is referred to Mahood (1980a, 1980b) for a full discussion of the geological evolution of the Sierra La Primavera.

Beginning about 145,000 years ago, the pre-caldera lavas (Río Salado, Cañón de Las Flores, and Mesa El León units, and the Arroyo Saucillo group in Figure 1) erupted. They were followed by the eruption, approximately 95,000 years ago, of about 20 km^3 of magma as ash flows that formed the Tala Tuff. Resultant collapse of the roof zone of the magma chamber formed an 11 km-diameter caldera that soon filled with water. Sedimentation began and a "giant pumice horizon", an important stratigraphic marker bed, was deposited. At about the same time, two central domes (the south-central and north-central domes forming the lower portions of Mesa El Nejahuete and Cerro Alto, respectively, in Figure 1) erupted through the middle of the lake. Shortly thereafter, ring domes erupted along two parallel arcs: one along the northeast portion of the ring fracture (consisting of eruptive units here called Pinar de La Venta, Arroyo La Cuartilla, Mesa La Lobera, Cerro El Chapulín, Dos Coyotes, and Arroyo Las Pilas in Figure 1), and the other crossing the middle of the lake (consisting of El Madrón, Cerro El Tule, Cerro Chato, Mesa El Burro, Mesa El Chiquihuitillo, and the upper portions of Mesa El Nejahuete and Cerro Alto in Figure 1). A period of volcanic quiescence was marked by deposition of some 30 m of fine-grained ashy sediments. Approximately 75,000 years ago, a new group of ring domes (Arroyo Las Animas, La Puerta, Cerro el Culebreado, Arroyo Ixtahuatonte, and La Cuesta in Figure 1) erupted at the southern margin of the lake. Ensuing uplift thought to result from renewed insurgence of magma brought an end to the lake. This uplift culminated in the eruption, beginning approximately 60,000 years ago, of aphyric domes and flows along a southern arc (Cerro San Miguel, Llano Grande, Cerros Las Planillas, Arroyo Colorado, Cerro El Tajo, and Cerro El Colli in Figure 1). The youngest of these lavas, Cerro El Colli, erupted approximately 25,000-30,000 years ago.

DISCUSSION OF SPECIFIC POINTS

Stratigraphic position of the Tala Tuff

Although Demant and Vincent are correct in pointing out that the Tala Tuff is not stratigraphically young, it is not true that the Tala Tuff is older than *all* the Primavera domes and flows. For example, the Tala Tuff is banked against the edge of the Cañón de Las Flores flow, contain-

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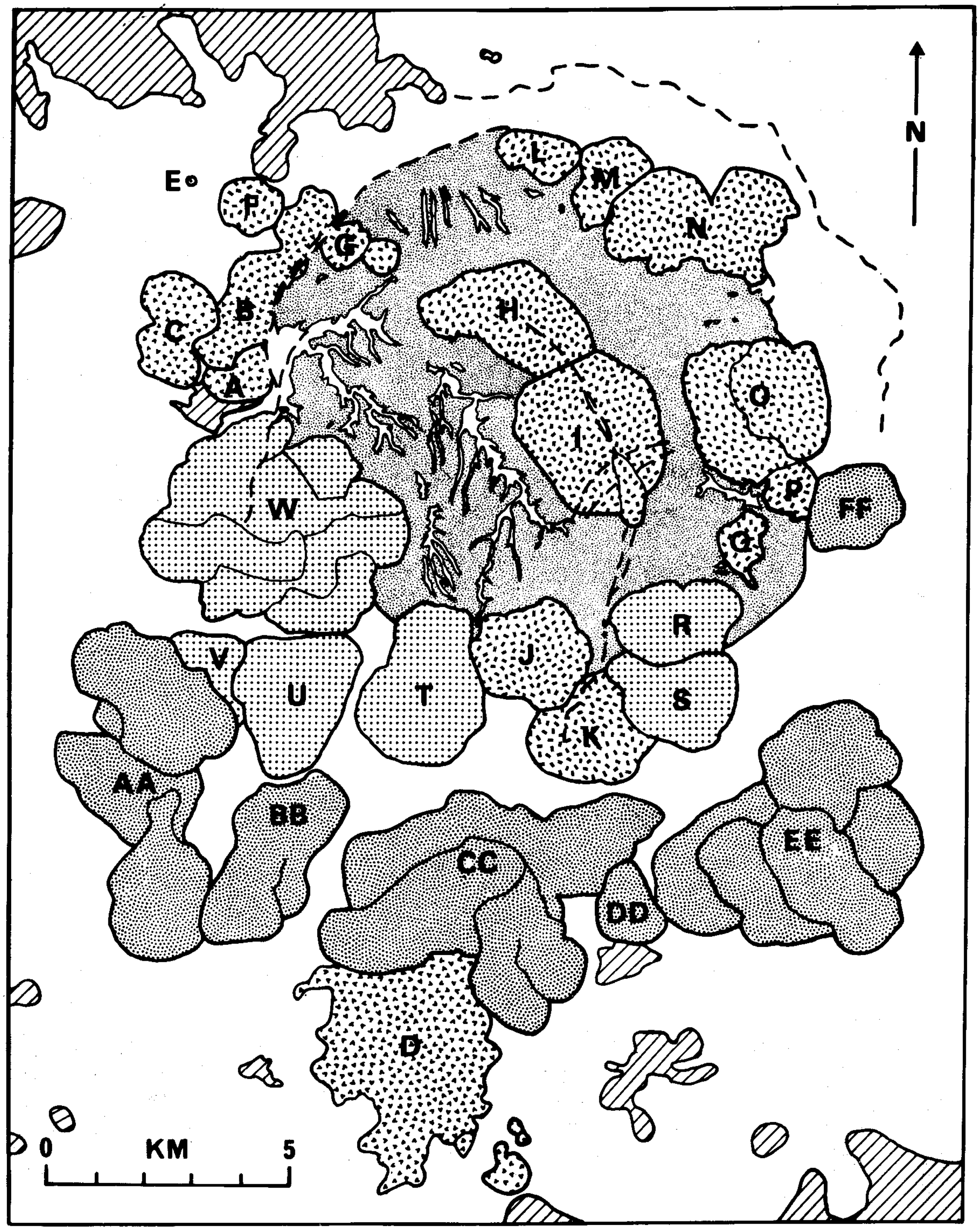

Figure 1.- Sierra La Primavera location map. Solid lines denote contacts; dashed lines: faults; diagonal ruling: pre-Primavera volcanic rocks; V-pattern: pre-caldera lavas; blank: Tala Tuff; light stipple: lake sediments; paired dashes: central domes and older ring domes erupted approximately 95,000 years ago; rectilinear dots: younger ring domes erupted approximately 75,000 years ago; heavy stipple: southern arc lavas. Letters refer to the names of eruptive centers as follows: A: Río Salado dome; B: Cañón de Las Flores flow; C: Mesa El León dome; D: Arroyo Saucillo group; E: Mesa El Chiquihuitillo; F: Mesa El Burro dome; G: Cerro Chato dome; H: Cerro Alto composite dome; I: Mesa El Nejahuete composite dome; J: Cerro El Tule dome; K: El Madron dome; L: Pinar de La Venta dome; M: Arroyo La Cuartilla dome; N: Mesa La Lobera dome; O: Cerro El Chapulín dome; P: Dos Coyotes dome: Q: Arroyo Las Pilas dome; R: Arroyo Ixtahuatonte dome; S: La Cuesta dome; T: Cerro El Culebreado dome; U: La Puerta dome; V: Arroyo Las Animas dome; W: Cerro El Pedernal center; AA: Cerro San Miguel center; BB: Llano Grande flow; CC: Cerros Las Planillas center; DD: Arroyo Colorado dome; EE: Cerro El Tajo center; FF: Cerro El Colli dome.

ing fragments of the aphyric lava near the contact. These relations can be seen approximately 100 m east-southeast of the entrance gate to the Balneario Cañón de Las Flores, and in localities about 100 m south and 150 m northeast of the Balneario Primavera. The Tala Tuff overlies the Río Salado dome along the southern margin of the dome and laps against a lava of the Arroyo Saucillo group just north of Arroyo Saucillo approximately 1.3 km northwest of the village of Los Ocotes. No unequivocal relationships between the Mesa El León dome and the Tala Tuff were found. Where the base of the Mesa El León dome is exposed, west-southwest of Balneario Primavera, it rests upon fluvial pumice and lithic débris. The Mesa El León dome is thought to be older than the Tala Tuff because the top of the dome is at a lower elevation than the surface of the Tala Tuff on the south bank of the Río Salado just south of Mesa El León and because it is similar chemically and mineralogically to the other pre-caldera lavas (Mahood, 1980a).

Cerros Las Planillas

Demant and Vincent correctly point out (p. 221) that there are exceptions to my generalization that the aphyric lavas are younger than the porphyritic lavas, but err in using Cerros Las Planillas as an example. They claim that the southern part of an aphyric dome was destroyed in forming the vent for two porphyritic lava flows. This cannot be the case as all the flows from the Cerros Las Planillas center are aphyric (although locally spherulitic).

Table 1.- Summary of the geologic history of the Sierra La Primavera

Date	Event
145,000-100,000 y.b.p.	Eruption of pre-caldera lavas
95,000 y.b.p.	Eruption of Tala Tuff
–––	Caldera collapse
–––	Eruption of central domes and deposition of the giant pumice horizon
95,000 y.b.p.	Eruption of older ring domes
75,000 y.b.p.	Eruption of younger ring domes
–––	Uplift
60,000-25,000 y.b.p.	Eruption of southern arc lavas

Uplift versus resurgent doming

Demant and Vincent recognized that the topographically high position of caldera-lake sediments requires that they have been uplifted. They attributed this uplift to resurgent doming of the caldera, and, in their figure 2, showed it as occurring prior to the emplacement of post-caldera domes and flows. It is easily demonstrated that this uplift took place after the emplacement of both the 95,000- and 75,000- year ring domes. The autobrecciated bases of domes that erupted at the margins of the lake have horizontal contacts with the underlying lake sediments. The sides of the domes are wedge-shaped, the basal contacts are horizontal and the lake sediments onlap the sloping margins of the domes. The basal contacts were found for most of the older ring domes and about half of the younger ring domes. While the basal contacts of the older ring domes occur up to 10 m above the giant pumice horizon, the basal contacts of the younger ring domes occur higher in the sequence, approximately 50 m above the giant pumice horizon. These relationships are shown diagramatically in Figure 2.

The younger ring domes are lapped by only 10-20 m of sediment. Fine-grained sediments rapidly give way to water-reworked air-fall pumice, and the uppermost part of the section appears to consist of subaerially-deposited tephra units.

At this point, the uplift which produced the topographic Sierra La Primavera brought an end to lacustrine sedimentation. Much of the geomorphic expression of the caldera was destroyed because the hingeline for this uplift nearly coincided with the ring fracture of the caldera. Deformation was concentrated at the margins of the lake, where radial dips of 10-20° and small normal faults in the sediments are common. Toward the center of the lake, dips on the lake sediments rapidly flatten to approximately 2°. Within the central portion of the former lake, the general absence of normal faulting associated with uplift and the notable scarcity of any faults cutting post-giant-pumice-horizon sediments, indicate that the uplift was piston-like; the former caldera block apparently rose as a single unit except at its margins. The uplift was asymmetric to the caldera. It was greatest at the southern margin of the lake; thus a gentle northerly component is superimposed on the radial dips of the lake sediments.

Uplift of this sort should not be confused with resurgence. The term resurgence should be reserved for uplift which immediately follows the collapse of a caldera and is the result of hydrostatic re-equilibration of the system. In classic examples of resurgent cauldrons (*e.g.*, the Valles, (Smith and Bailey, 1968), and Long Valley (Bailey *et al.*, 1976) calderas), resurgence is accompanied by eruptions of lavas in the center of the caldera, so that the earliest lavas are progressively tilted and lapped by younger lavas. At Primavera, emplacement of the 95,000-year central domes and older ring domes, as well as the 75,000-year younger ring domes, was *not* accompanied by doming. The evacuated volume produced on eruption of the Tala Tuff may have been tapped from a sufficiently large area that little or no hydrostatic re-equilibration was needed. The uplift at La Primavera may be akin to the "general uplift" described by Steven and Lipman (1976) for many of the San Juan Mountains calderas.

Phreatomagmatic eruptions

Demant and Vincent attributed a number of features they observed to phreatomagmatic eruptions. I saw little or no evidence for phreatomagmatic activity at La Primavera and believe that the features they describe have different origins.

The "breadcrust bombs" they observed in the Tala Tuff in Arroyo Gallo, southwest of Mesa El Nejahuete, need not have formed by magma encountering the water table; indeed one would have to explain how a phreatomagmatic eruption produced an ash flow. Breadcrust bombs form when the chilled surface of a fragment is cracked due to the expansion on vesiculation of the hot, plastic interior. This chilling can occur during flight through the air; water is not necessary. In Vulcanian eruptions, where breadcrust bombs are common, groundwater does not play a major role. The "bombs" in the Tala Tuff appeared to me to be partially welded tuff rather than new magma. I interpret them as fragments of still-plastic Tala Tuff that were ripped off the conduit walls and then chilled on being entrained in the ash flow at the surface. Similar deposits have been called "co-ignimbrite lag-fall deposits" by Wright and Walker (1977), who have used the distribution of these deposits to determine the source vents for ash-flow eruptions.

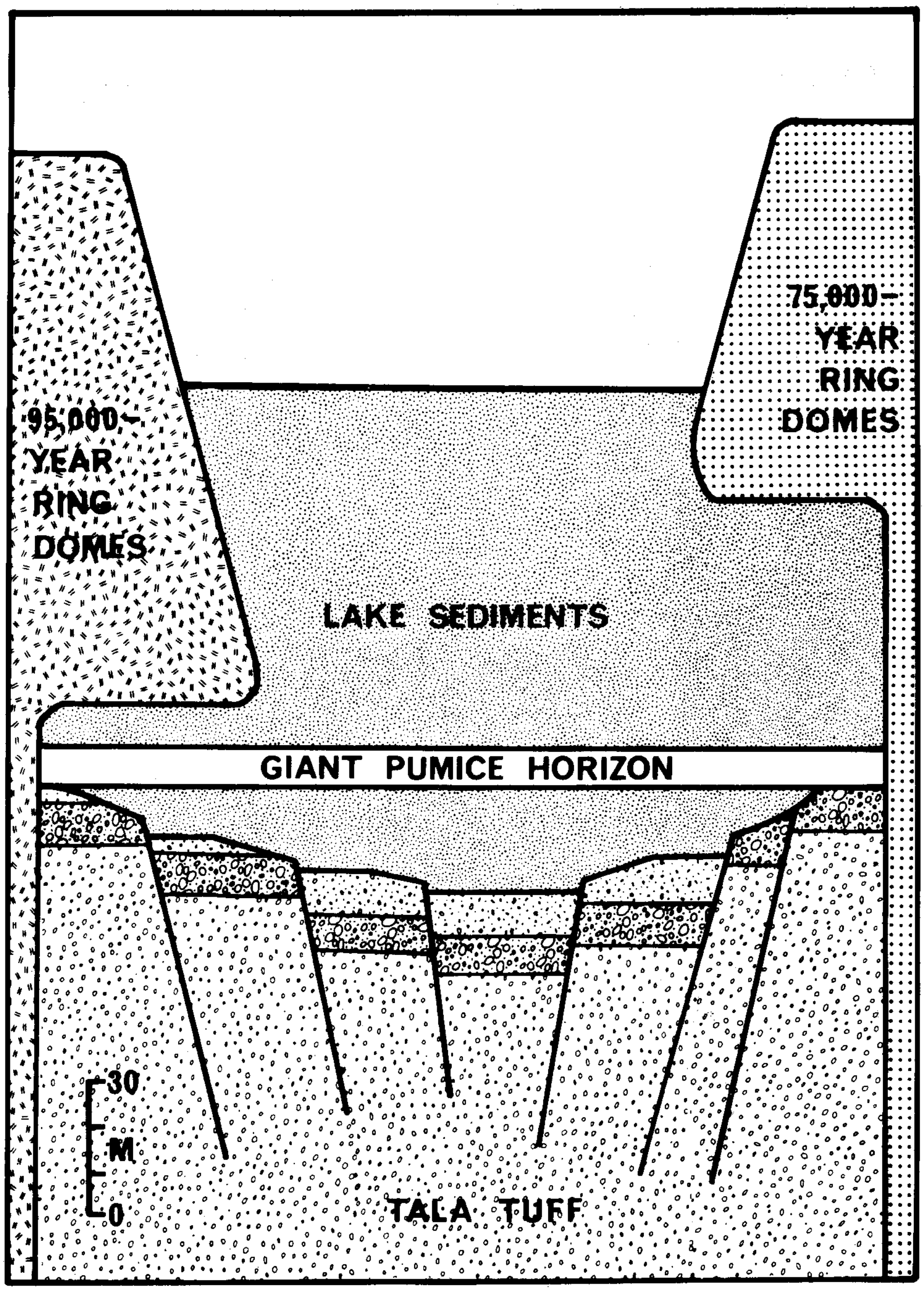

Figure 2.- Schematic stratigraphic section. The basal contacts of the younger ring domes occur higher in the caldera-lake sediment section than those of the older ring domes. The eruption of both groups of domes into the lake indicates that they were emplaced prior to uplift.

Demant and Vincent describe a 2-m-thick lens of coarse débris between two ash flows near Cañón de Las Flores as the deposit of phreatomagmatic explosions. I have seen another example on the south bank of the Río Salado south of Mesa El León as well. In both cases the lenses consist of well-sorted, well-rounded cobbles, at Cañón de Las Flores consisting almost entirely of devitrified rhyolite. They have none of the features characteristic of phreatomagmatic tephra (*e.g.*, poor sorting with an abundance of comminuted fines, angular fragments). I suggest they are lenses of fluvial gravel deposited either by a stream or a slide during a pause in the emplacement of the Tala Tuff.

Finally, Demant and Vincent have attributed "las amplias ondulaciones" of the tephra along the road that penetrates the southern portion of La Primavera to the large-scale cross-bedding characteristic of base surge deposits. However, these deposits lack characteristic features of base surge deposits: fine laminations, poor sorting and a high proportion of fines, pinching and swelling of beds, very low-angle, small-amplitude cross-bedding, and dune structures. I interpret these deposits as air fall that drapes preexisting topography. Alternating periods of eruption and erosion produced a succession of cut-and-fill features that in no way resemble base surge deposits. This pumice has all the features typical of air-fall deposits: crude stratification within units, good sorting, and approximately constant thickness of layers. "Las amplias ondulaciones" are simply air-fall pumice mantling topography.

Fumarolic activity and the final stage of the resurgent cauldron cycle

Demant and Vincent believe that the fumaroles of La Primavera "están relacionados con la cristalización del magma en profundidad bajo la forma de plutones" and cite Smith and Bailey (1968) in support. This implies that the fumaroles represent vapor evolved from a crystallizing magma, an idea that Smith and Bailey (1968) never advocated. All geothermal fluids that have been studied consist dominantly of heated meteoric water. Oxygen isotopic analyses indicate this is true at La Primavera as well (Truesdell and Mahood, in preparation). Smith and Bailey (1968) argued that the length of the fumarolic stage of the resurgent cauldron cycle was related to the long time required for the transfer of *heat* from a crystallizing pluton to the surface.

Fumaroles and hot springs are not restricted to the final stage of Smith and Bailey's resurgent cauldron cycle. They occur during other stages as well; the final stage is just their period of greatest development. I would argue that the eruption of totally aphyric lavas 25,000-30,000 years ago is no the sign of a waning magma chamber, but of a rejuvenated one that has received new input of heat; perhaps in the form of underplating mafic magmas.

Volcanic hazards

Demant and Vincent downplay the volcanic hazards of the Sierra La Primavera because (1) they believe that the most destructive type of eruption, one that produces an ash flow, could not occur again because systems that have produced ash flows on two occasions are unknown, and (2) they believe the effects of emplacement of a new dome would be limited to a fairly innocuous pumice fall. I believe they are wrong on both counts.

Many silicic centers have experienced more than one ash-flow eruption, including the Jemez Mountains, where two major ash-flow eruptions at 1.4 and 1.1 m.y. ago resulted in the formation of the Toledo and Valles calderas, respectively (Doell *et al.*, 1968). This multicyclic behavior of caldera systems is explicitly stated in Smith and Bailey's (1968, p. 651) discussion of resurgent cauldrons:

> "We have not dwelt in any detail in this paper on the multicycle nature of some, perhaps most, cauldron areas, but have mentioned the possibility of recurrence of major ash-flow eruptions (Stage II) during Stage VI to begin a new eruption-collapse cycle."

Yellowstone experienced major ash-flow eruptions at 1.9, 1.2, and 0.6 m.y. ago which resulted in three overlapping calderas. The Timber Mountain and Black Mountain caldera complexes, Nevada, as well as several complexes in the San Juan Mountains, Colorado, have produced two or more ash flow eruptions (Christiansen, 1979). Evidence for the multicyclic nature of silicic systems can also be found in the overlapping ring dikes and central intrusions found commonly in the eroded roots of cauldrons (*e.g.*, the ring complexes of northern Nigeria, Jacobsen, 1977).

Periodicities of major ash-flow eruptions in large silicic systems are on the order of 10^5-10^6 years (Christiansen, 1979). While an ash-flow eruption is remote on the time scale of human affairs, the destruction in the path of an ash flow is complete. It would be well to keep in mind that the suburbs of Guadalajara are built on the Tala Tuff, which resulted from an ash-flow eruption 10^5 years ago, and that the city would almost certainly be in the path of another ash-flow eruption.

The periodicity of dome eruptions in silicic systems is much shorter; such eruptions occurred at La Primavera at 145,000-120,000, 100,000, 75,000, 60,000 and 25,000-30,000 years ago (excluding the domes which erupted 95,000 years ago that were related to caldera collapse). Eruption of a new dome would not be unexpected in terms of La Primavera's eruptive history. Small ash flows and powerful blasts, as well as air-fall pumice, are commonly associated with the emplacement of silicic domes and flows. An ash flow chemically correlated with the 60,000-year southern arc lavas covers about 3.5 km^2 near Tierra Fría and appears to have erupted just prior to emplacement of the Llano Grande flow. Hazards from pumice falls include fatalities due to direct hits by large clasts, collapsing roofs, and inhalation of poisonous gases, as well as longer-term effects on water and air quality, grazing livestock, and agriculture. Directed blasts, a powerful example of which are devasted areas 15 km from the summit of Mount St. Helens just months ago, also commonly accompany emplacement of silicic domes. All these hazards are compounded in the case of La Primavera by the fact that the eastern portion of the Sierra, that closest to Guadalajara, is the most likely location for an eruption, as the southern arc lavas become progressively younger to the east.

Although the eruptive frequency at La Primavera is several orders of magnitude less than that of andesitic stratovolcanoes such as Volcán Colima, the catastrophic effects of an eruption on the outskirts of Guadalajara justify the effort and expense involved in volcanic monitoring.

REFERENCES CITED

Bailey, R.A., Dalrymple, B., and Lanphere, M.A., 1976, Volcanism, structure, and geochronology of Long Valley caldera, Mono County, California: Jour. Geophys. Res., v. 81, p. 725-744.

Christiansen, R.L., 1979, Cooling units and composite sheets in relation to caldera structure: *In*: Chapin, C.E., and Elston, W.E., (Eds.), Ash-flow tuffs. Geol. Soc. America, Spec. Paper 180, p. 29-42.

Demant, Alain, and Vincent, P.M., 1978, A preliminary report on the comenditic dome and ash flow complex of Sierra La Primavera, Jalisco; Discussion: Univ. Nal. Autón. México, Inst. Geología, Revista, v. 2, p. 218-222.

Doell, R.R., Dalrymple, G.B., Smith, R.L., and Bailey, R.A., 1968, Paleomagnetism, potassium-argon ages, and geology of rhyolites and associated rocks of the Valles Caldera, New Mexico: *In*: R.R. Coats, R.L. Hay, and C.A. Anderson (Eds.), Studies in volcanology; a memoir in honor of Howell Williams. Geol. Soc. America, Mem. 116, p. 211-248.

Jacobsen, R.R.E., 1977, Geology of the Liruei, Bante, and adjacent younger granite ring complexes: Geol. Survey Nigeria, Bull. 33, 117 p.

Mahood, G.A., 1977, A preliminary report on the comenditic dome and ash flow complex of Sierra La Primavera, Jalisco: Univ. Nal. Autón. México, Inst. Geología, Revista, v. 1, p. 177-190.

——— 1980a, The geological and chemical evolution of a late Pleistocene rhyolitic center; the Sierra La Primavera, Jalisco, Mexico: Berkeley, Unpub. Ph. D. thesis, California Univ., 245 p.

——— 1980b, Geological evolution of a Pleistocene rhyolitic center; Sierra La Primavera, Mexico: Jour. Volc. Geoth. Res., in press.

Smith, R.L., and Bailey, R.A., 1968, Resurgent cauldrons: *in:* R.R. Coats, R.L. Hay, and C.A. Anderson (Eds.), Studies in volcanology: a memoir in honor of Howell Williams. Geol. Soc. America, Memoir 116, p. 613-662.

Steven, T.A., and Lipman, P.W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado: U.S. Geol. Survey, Prof. Paper 958, 35 p.

Truesdell, A.H., and Mahood, G.A., in preparation, A geochemical and isotopic evaluation of the Sierra La Primavera geothermal system, Jalisco, Mexico.

Wright, J.V., and Walker, G.P.L., 1977, The ignimbrite source problem; significance of a co-ignimbrite lag-fall deposit: Geology, v. 5, p. 729-732.