Explosion craters and giant gas bubbles on Holocene rhyolite flows at Newberry Crater, Oregon

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ABSTRACT

Forty-seven explosion craters pockmark the surface of the Big Obsidian Flow and Interlake Obsidian Flow within Newberry Crater in central Oregon. The craters range from 12 to 60 m in diameter and from 5 to 14 m in depth. Discontinuous rings of rubble form rims around the craters. At the bottom of four of the craters are parts of spherical cavities or giant gas bubbles that are up to 15 m in diameter and filled to varying degrees with rubble that has collapsed from the crater walls above.

Rhyolite flows are thought to develop layers as gases exsolve from the flow. The surface layer is finely vesicular pumice; beneath this is a layer of obsidian underlain by coarsely vesicular pumice. Giant gas bubbles in the Newberry Crater flows probably form and grow beneath or within the coarsely vesicular pumice and rise upward into the obsidian layer within several meters of the surface, where they burst explosively. The blast creates a steep-walled crater rimmed with blocks of pumice and obsidian. Debris from the explosion falls back into the crater, partially or completely obscuring the giant bubble.

INTRODUCTION

Newberry volcano in central Oregon (Figure 1) has long been known for its diversity of volcanic landforms and rock types (Russell, 1905; Williams, 1935; MacLeod and others, 1982). Newberry Crater at the summit of Newberry volcano (Figure 2) is the centerpiece of the recently (November 1990) established Newberry National Volcanic Monument, which contains some of Oregon's youngest and most intriguing volcanic features. Among the volcanic treasures of Newberry Crater are six rhyolite flows (Figure 3) ranging in age from 6,400 to 1,300 ^{14}C years (Table 1). The surfaces of two of these, the Big Obsidian Flow (1,300 ^{14}C yr B.P.) and the Interlake Obsidian Flow (about 6,300 ^{14}C yr B.P.), remain essentially pristine. The other four flows are mantled by Newberry pumice or vegetation. All flows occurred after the cataclysmic eruption of Mount Mazama (Crater Lake) that blanketed the area with ash about 6,845 ^{14}C yr B.P. (Table 1).

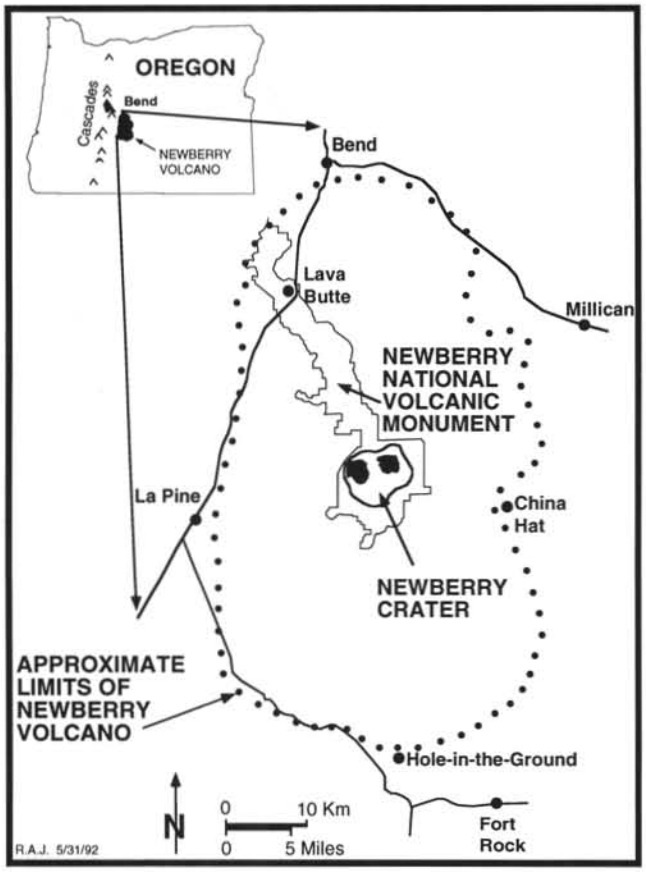

Figure 1. Location of Newberry volcano and Newberry National Volcanic Monument.

Using aerial photographs, I identified 42 small craters on the Big Obsidian Flow and five craters on the Interlake Obsidian Flow. I have visited 40 of these craters and have observed that large spherical cavities occur beneath some of these craters. The craters apparently formed above giant gas bubbles as the bubbles burst explosively near the flow surface.

RHYOLITE FLOWS

All of the post-Mazama rhyolite flows within Newberry Crater have similar chemistry (SiO_2 = 73.3-74.0 percent, MacLeod and Sherrod, 1988). The glassy surface of these flows consists of irregular hills and ridges of rubble. Various forms of pumice and obsidian make up the rubble. Even though these flows are called "obsidian flows," the amount of obsidian exposed on the surface is only 10 percent or less; the other 90 percent comprises various forms of pumice (frothy glass).

Traditionally, a rhyolite lava flow has been

Figure 2. Aerial view of Newberry Crater from northeast across East Lake, showing snow-covered East Lake obsidian flows (left), Big Obsidian Flow (center), and East Lake lobe of Interlake Obsidian Flow (right).

viewed as a body of flow-banded crystalline rock enclosed by a rubble of glassy rock (a in Figure 4). Studies over the last decade have shown that these flows develop distinctive layers as gases exsolve out of their interiors (Fink, 1983; Fink and Manley, 1987; Manley and Fink, 1987a). The flow surface develops a finely vesicular white pumice layer that becomes highly fractured and broken from motion of the flow. This surficial pumice grades downward into a dense glassy zone (obsidian) at a depth of 3 to 5 m. The obsidian is underlain by an irregular, coarsely vesicular pumice layer that in turn grades downward into another glassy zone (b in Figure 4).

Near the margin of larger flows, parts of the least dense coarsely vesicular pumice rise as buoyant diapirs to the surface and distort the layering, while the flow is still in motion. This distortion of the layering exposes the obsidian and coarsely vesicular pumice at the surface. This is particularly evident in the distal areas of the Big Obsidian Flow, where bands of darker coarsely vesicular pumice and obsidian alternate with the lighter colored finely vesicular pumice.

CRATERS ON THE BIG OBSIDIAN FLOW

Forty-two small craters are scattered across the surface of the Big Obsidian Flow (Figures 5 and 6). They are generally circular, 12 to 60 m in diameter, and 5 to 14 m deep, but some are elongate and divided by a low rim. These craters are typically rimmed by discontinuous rings of blocky obsidian and pumice from the flow interior. The rim deposits are generally less than 1 m thick but approach 2 m at some of the larger craters.

In his description of the Big Obsidian Flow, I.C. Russell (1905, p. 108) may have been describing some of these craters when he wrote: "The surface, although generally a plain, is uneven and has hills and hollows resembling those of a glacial moraine but is composed of angular fragments consisting of pumice, scoriae, obsidian, and a few imperfectly shaped bombs. The explanation of this seems to be that mild steam explosions took place in it which threw it into piles, leaving depressions where the explosions occurred. . ."

A majority of the craters occur in groupings of five or more craters, but many remain scattered singly or in pairs. Two areas of the Big Obsidian Flow notably lack craters. One is the central western area where the surface flow banding is highly contorted. The other is the northeast area within the Lost Lake pumice ring.

At the bottom of four of these craters are parts of spherical bubblelike cavities as much as 15 m in diameter (Figures 7 and 8). In all cases the floor of the bubbles has been buried under rubble from the crater walls. The best preserved bubble is beneath a small crater, Crater "Z" (a) in Figure 9, about 12 m in diameter and 5 m

Table 1. *Selected carbon-14 ages from Newberry volcano. From complete listing of carbon-14 ages for Newberry volcano in MacLeod and others (in preparation).*

Geologic event	Carbon-14 age[1] (^{14}C yr B.P.)	Reference	Weighted mean age (^{14}C yr B.P.)	Recalculated age[2] (calendar yr B.P.)
Big Obsidian Flow	No carbon-14 date[3]			
Ash flow from Big Obsidian Flow vent	1,270±60	Pearson and others (1966)		
	1,340±60	Robinson and Trimble (1983)	1,310±40	1,240±50
	1,390±200	Meyer Rubin, *in* Peterson and Groh (1969)		
East Lake obsidian flows	No carbon-14 date[4]			
North Summit flow	6,090±60	Peterson and Groh (1969)	6,090±60	7,000±150
Central Pumice Cone flow	No carbon-14 date[5]			
Game Hut obsidian flow	No carbon-14 date[6]			
Interlake Obsidian Flow	No carbon-14 date[7]			
East Lake tephra	6,220±200	Meyer Rubin and W.E. Scott (unpublished data, 1985)		
	6,500±300	Meyer Rubin, *in* Linneman (1990)	6,400±130	7,300±130
	6,550±300	Meyer Rubin, *in* Linneman (1990)		
Mazama ash, climatic eruption of Mount Mazama (Crater Lake)	6,845±50[8]	Bacon (1983)	6,845±50	7,640±50

[1] Carbon-14 ages based on Libby half-life of 5,568 yr. Years before present (yr B.P.) measured from 1950 A.D.

[2] Generalized from program in Stuiver and Reimer (1986) that computes intercepts and range (one confidence interval). Radiocarbon age curve is not linear and may have multiple possible calendar ages (intercepts) for a given ^{14}C age. Recalculated age as reported here is midpoint between oldest and youngest intercepts, rounded to nearest ten years; reported error is range (one confidence interval as calculated by the program).

[3] Hydration-rind age of 1,400 calendar years in Friedman (1977). Too old, based on stratigraphic position related to carbon-14 dated units; overlies ashflow from Big Obsidian Flow vent.

[4] Hydration-rind age of 3,500 calendar years in Friedman (1977).

[5] Hydration-rind age of 4,500 calendar years in Friedman (1977). Too young, based on stratigraphic position related to carbon-14 dated units; lies between East Lake tephra and North Summit flow.

[6] Hydration-rind age of 6,700 calendar years in Friedman (1977). Too young, based on stratigraphic position related to carbon-14 dated units; lies between East Lake tephra and North Summit flow.

[7] Hydration-rind age of 6,700 calendar years in Friedman (1977). Too young, based on stratigraphic position related to carbon-14 dated units; lies between East Lake tephra and North Summit flow.

[8] Weighted mean age of four charcoal samples (Bacon, 1983): 6,780±100; 6,830±110; 6,880±70; 6,840±100.

deep. A person can enter this bubble through a small hole in the crater floor. Inside, this bubble is approximately 7 m in diameter and nearly complete. The floor is covered by a cone of rubble (blocks of pumice and obsidian) that fell through the hole at the entrance. The interior walls show relatively smooth flow-banded rhyolite. Smaller bubbles up to 0.5 m in diameter occur behind the main bubble wall and form bulbous protrusions into the main bubble. Some walls between the smaller bubbles and the main bubble are ruptured and torn.

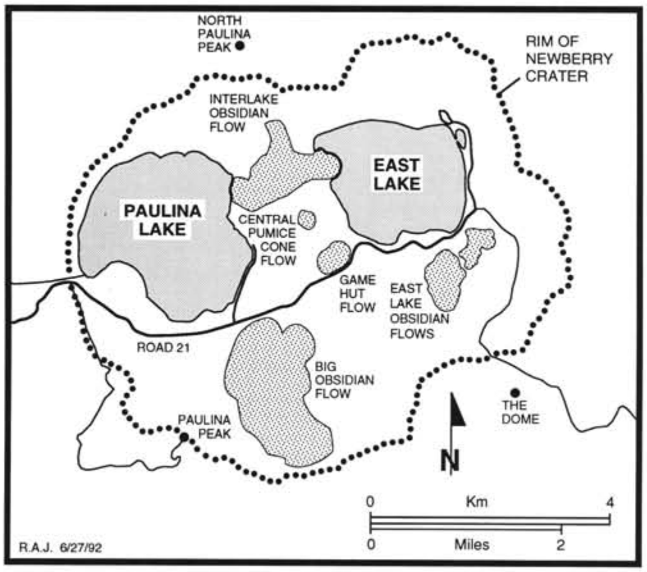

Figure 3. Post-Mazama rhyolite flows in Newberry Crater.

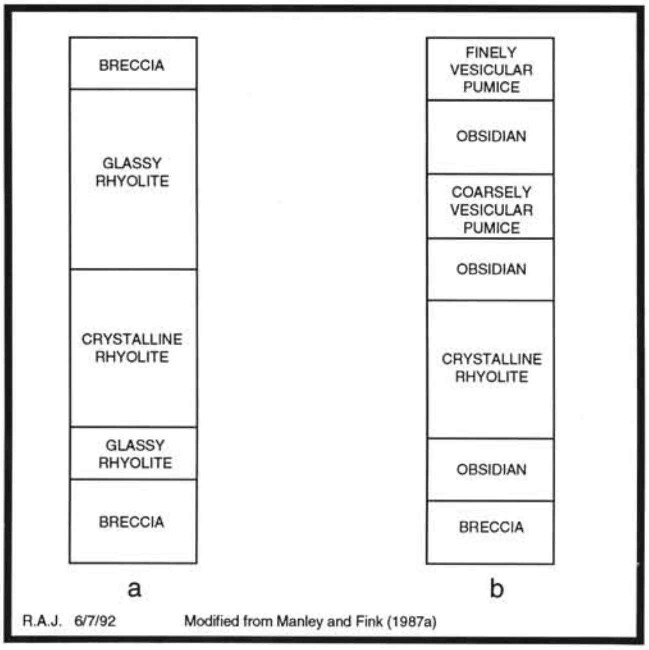

Figure 4. (a) Traditional view of rhyolite flows; (b) new view of rhyolite flows.

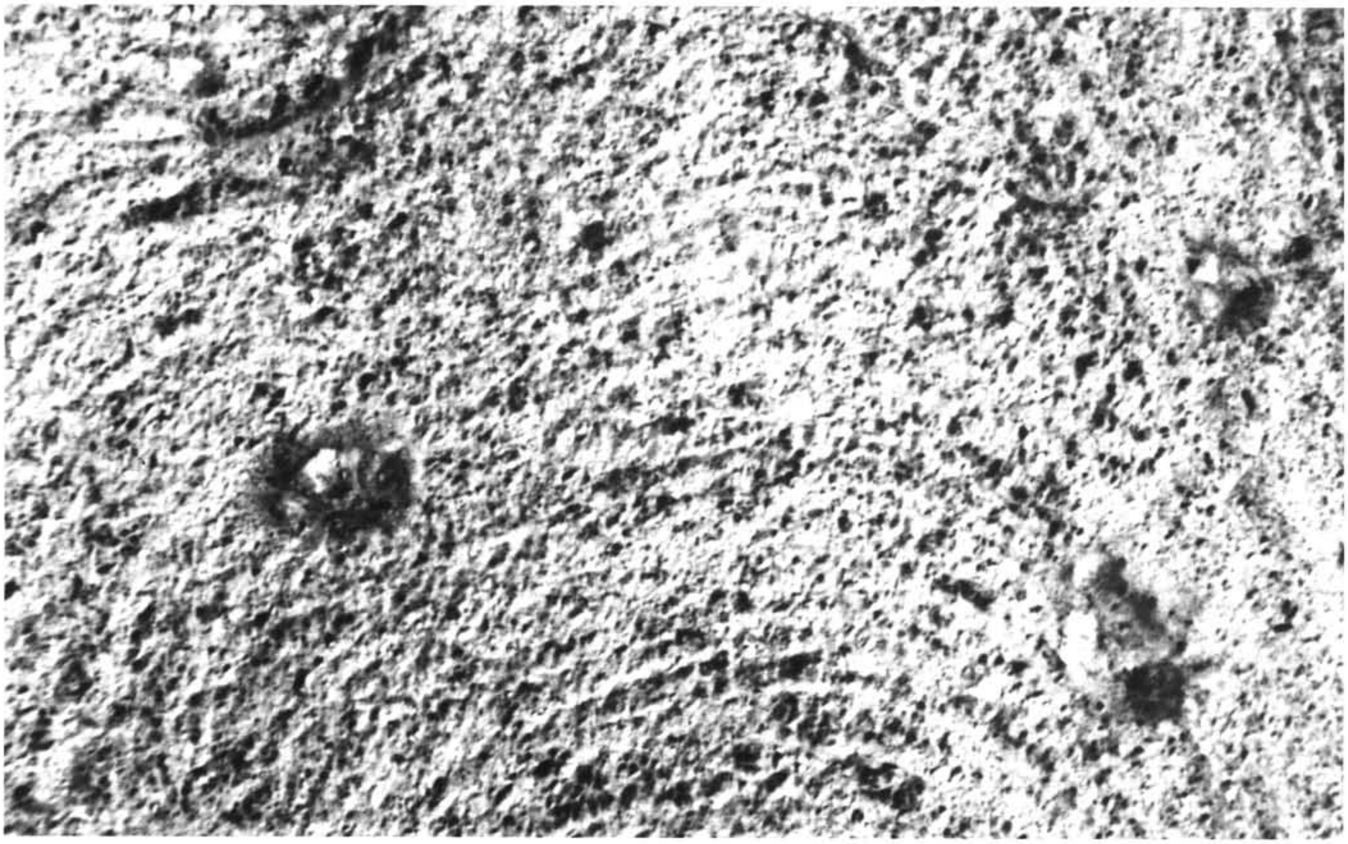

Figure 5. Vertical air photo view of four craters on surface of Big Obsidian Flow. Crater in lower right corner is designated "R"; other craters in view are "S," "Q," and "G," as identified in Figure 6.

The giant bubbles under the other three craters are less completely preserved (b, c, and d in Figure 9). They are generally a bubble-wall segment beneath a thick, massive obsidian overhang with a fan of blocky debris forming a slope to the back wall of the

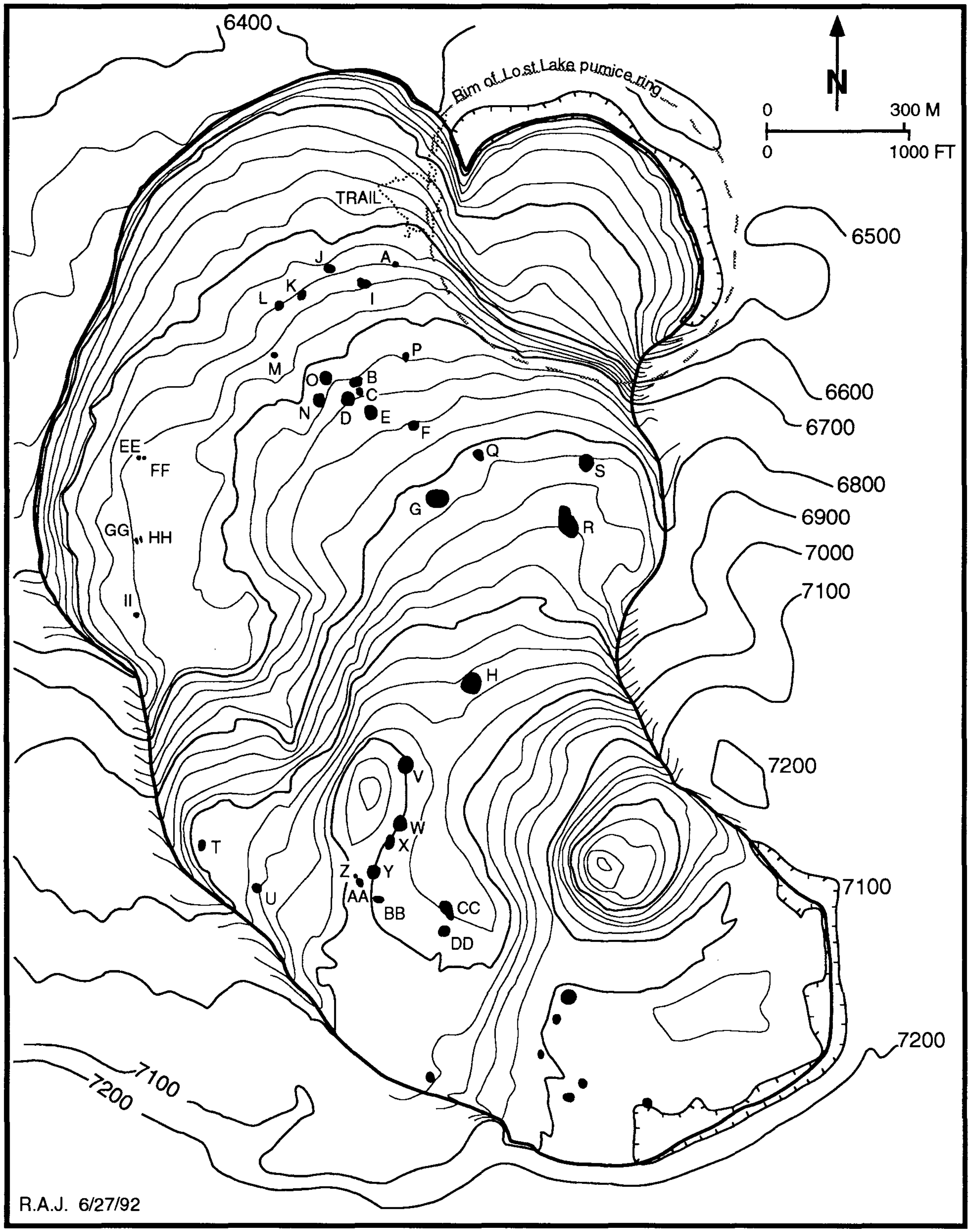

Figure 6. Irregular black dots show size and location of explosion craters on Big Obsidian Flow. Letters are informal names for craters. Route of Big Obsidian Flow Trail is marked.

Figure 7. Entrance to spherical bubblelike cavity below Crater "A" (Figure 6).

bubble. The continuously curving bubble walls suggest that the walls continue well below the rubble in all giant bubbles. Giant bubbles may exist under all craters, but rubble from the crater walls fill them.

Where a bubble wall is exposed in cross section, the flow-banded rhyolite of the bubble wall can be seen to grade outward into massive obsidian. The flow-banded rhyolite of the bubble wall consists of numerous thin layers (1-3 mm each) like the layers of an onion.

CRATERS ON THE INTERLAKE OBSIDIAN FLOW

The Interlake Obsidian Flow possesses five craters (Figure 10). These craters are shallower than those on the Big Obsidian Flow, with gentler crater-wall slopes and no observable spherical cavities. The lack of observable bubblelike cavities may result from the greater age of this flow, about five times older than the Big Obsidian Flow. Over time, the bubbles presumably fill with rubble due to frost wedging and thermal expansion and contraction.

CRATERS ON OTHER RHYOLITE FLOWS

No craters are known to exist on the East Lake obsidian flows. If they exist, they may be hidden under a layer of Newberry pumice from the explosive phase of the Big Obsidian Flow eruption. Heavy vegetation obscures evidence of explosion craters on the flows associated with the Central Pumice Cone.

Six craters have been photo-identified on the Rock Mesa rhyolite flow on the southwest flank of South Sister, but none have been identified on the Devils Hill chain of rhyolite domes and flows on the southeast flank of South Sister.

Craters of similar morphology have been reported on the Glass Mountain rhyolite flow at Medicine Lake Volcano in California (Green and Short, 1971; Fink and Manley, 1989), but no evidence of large spherical cavities has been observed below the floors of craters that have be examined (J.H. Fink, personal communication, 1991).

FORMATION OF GIANT BUBBLES AND CRATERS

The explanation for these craters prior to the work of Fink (1983) involved steam eruptions that resulted when a flow contacted surface waters. For example, Green and Short (1971) included a photo of some of the small craters on the Glass Mountain rhyolite flow at Medicine Lake volcano in California and suggested they were due to explosive activity as the flow moved over wet ground. MacLeod and others (1982) mentioned the scattered small craters on the surface of the Big Obsidian Flow and suggested that they might be of phreatic origin. However, the locations of the craters on the flows suggest an internal origin, not one from steam generated beneath the flow. On the Interlake Obsidian Flow, the five known explosion craters are located near the vent in the final lava erupted from the vent. If the obsidian flow buried surface water or snow, it seems unlikely that explosion craters would have formed after such a considerable amount of lava had passed over the site. Also, the explosion craters are positioned over an original landscape that was probably topographically high and ridgelike, a surface unlikely to host any significant amount of water. On the Big Obsidian Flow, about a third of the craters are located near the vent. Furthermore, the craters penetrate the flow only to a depth of about 15 m, despite a flow thickness of 30 m or more. This suggests that these craters were formed by processes within the flow rather than by interaction of the flow base with surface water, wetlands, or snow.

Manley and Fink (1987b) noted that the locations of small explosion pits on several Holocene rhyolite flows were inconsistent with the flows' overriding snow or standing water. They suggested that the craters were the result of explosive release of vapor from the zone of coarsely vesicular pumice. Fink and Manley (1989) suggested that the surface layers (finely vesicular pumice and obsidian) of rhyolite flows form a cap that is virtually impervious to exsolving gases trapped beneath. This gas-charged zone becomes the frothy, coarsely vesicular pumice layer. They further suggested that diapirs of coarsely vesicular pumice rise to the surface and generate explosions to form the craters. This may be a partial explanation for some craters; on the Big Obsidian Flow, however, fewer than a third of the craters occur in conjunction with distinct surficial evidence (alternating dark and light bands) of such diapirs. Six craters occur in a series of these bands, and part of a bubble wall is preserved in one of them. The remaining craters occur in areas where most of the surface is finely vesicular pumice. The occurrence of obsidian and coarsely vesicular pumice seems to be associated with the craters or with scattered outcrops that form no larger pattern.

Apparently, exsolving gases gradually coalesce to form growing bubbles that slowly rise toward the surface. As these bubbles reach the impervious surface layers, they continue to coalesce to form giant bubbles. When the pressure in these bubbles exceeds the strength of the surface layers, the bubbles vent explosively and form steep-sided craters with rims of rubbly debris. Fallback of roof material and collapse of overly steep crater walls widen the craters, fill the floor with rubble, and obscure evidence of the bubbles in most of the craters, although enough evidence remains to suggest the process of crater formation.

The bubble walls also preserve evidence that smaller gas bubbles were still migrating toward the giant bubble at the time of rupture to the surface. In places where a cross section through the main bubble wall is found, smaller bubbles can be seen behind the main bubble wall. Where the wall material between bubbles was thin enough at the time of rupture of the giant bubble, the walls of the smaller bubbles can be seen to have ruptured into the giant bubble. Where the intervening walls were thicker, the smaller bubbles form bulbous protrusions into the main bubble.

Groups of craters may be located in areas where the dissolved-gas content of the lava was higher. A higher dissolved-gas content would have allowed the formation of more bubbles in these areas. Also, some of the larger craters show evidence of multiple explosions, such as elongated form and low rim deposits crossing the floor of the crater. These multiple craters suggest the contemporaneous explosions of multiple giant bubbles. One preserved bubble wall segment occurs in a crater within a crater: Crater "G" (d) in Figure 9.

The two areas on the Big Obsidian Flow that lack craters can be explained in two ways. The central western area, where the surface flow banding is highly contorted, appears to be the earliest lobe of the flow; the subsequent flow activity produced additional deformation that has probably destroyed most craters in this area. Five small, difficult-to-identify craters occur in this area. The lack of craters within the Lost Lake pumice ring is probably due to the steep slope of the pumice ring down which the flow moved to enter the ring. This probably disrupted the coarsely vesicular pumice layer sufficiently to break up any bubbles that were forming, and insufficient gas remained to reform them.

Figure 8. Interior of spherical bubblelike cavity below Crater "A." Ice-floored pool in center usually remains all summer.

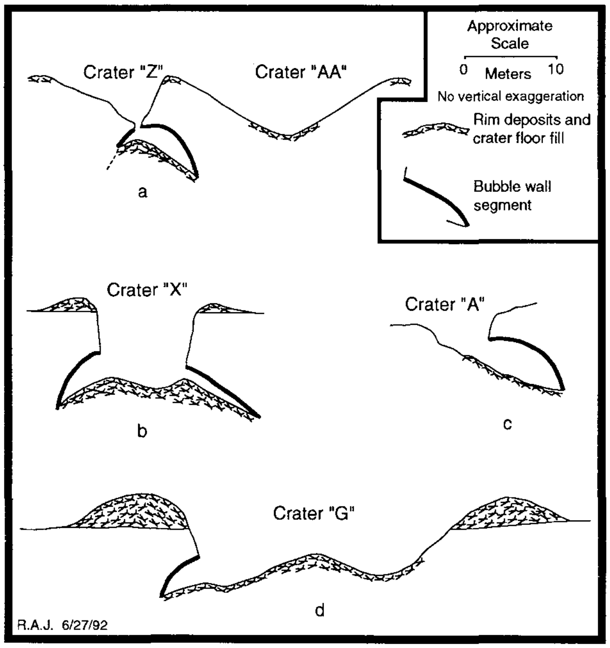

Figure 9. Sketch of cross sections through craters that contain giant bubble wall fragments.

ACKNOWLEDGMENTS

I would like to thank Bruce Nolf, Larry Chitwood, and Dave Sherrod for their encouragement to write this article and their suggestions, comments, and review.

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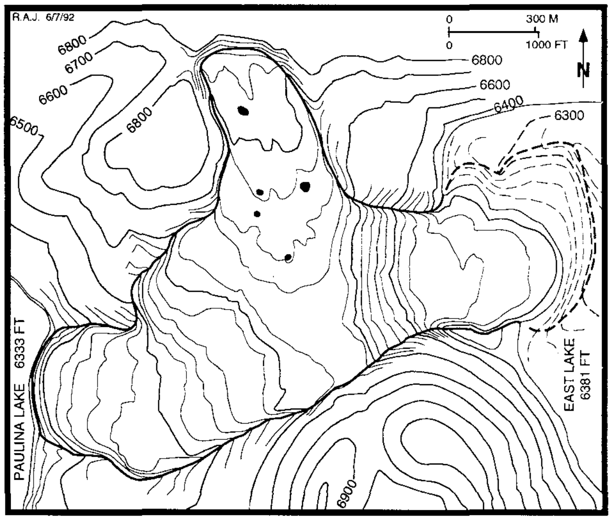

Figure 10. Irregular black dots show size and location of craters on Interlake Obsidian Flow. Dashed lines show contours and flow margin below surface of East Lake. Note that Interlake Obsidian Flow extends into East Lake.

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Letter to the editor

I wish to offer corrections for "A history of geologic study in Oregon," by Orr and Orr, in *Oregon Geology*, v. 54, no. 5, September 1992.

At the time that he enrolled on the Williamson expedition, Dr. John Strong Newberry had no academic appointment. He was actually a well-trained medical doctor who was embarking on his first official expedition as a geologist. It was not until 1866 that he assumed the Chair of Geology and Paleontology in the School of Mines at Columbia College, New York City (cf. *Bulletin of the Geological Society of America*, v. 4, September 1893, p. 396). He retained this position until his death 26 years later.

I also take issue with the Orrs' statement that "Newberry was able to study the geology of the. . . John Day regions in great detail," describing beds as "white, others pink, orange, blue, brown, or green." Newberry did *not* travel to the John Day River region. A careful reading of his description and route shows that he was instead describing the dramatic and colorful strata displayed in the Deschutes Formation in the region of the confluence of the Deschutes and Metolius Rivers near what is now Cove Palisades State Park. Farther downstream he would have passed through some John Day Formation, but less dramatic than the upstream Deschutes Formation.

I consider these minor corrections to an admirable article.

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