The Formation of Thundereggs

(Lithophysae)

The Mechanisms of Rhyolitic Lava Fractionation and Crystallization of Spherulites and the Formation of Star-Shaped Gas Cavities in Lithophysae.

Preface

Thundereggs were probably first extensively excavated by agate gem enthusiasts and collectors at the original Priday Ranch Deposits, 17 miles north of Madras, Oregon. Indeed, the name "thunderegg" came from the local Warm Springs Indian Tribe who, living on the eastern flanks of the explosive-prone volcanoes such as Mt. Hood, Mt. Jefferson, and Mt. St. Helens, believed that thundereggs were overcast missiles from the thunder-gods in their volcanic quarrels.

I can sympathize well with this myth, for I was in Portland, Oregon that Sunday morning of May 18, 1980 when Mt. St. Helens blew with the force of a five-megaton H-Bomb. Fortunately, the ash and *tephra* drifted eastward on the common west-to-east trade winds, sparing Portland a giant mess of ash to contend with.

Since they were first collected, then later excavated at the Priday Ranch (now Richardson's Rock Ranch, Madras, Oregon), the cutting and lapidary treatment of them has sparked curiosity as to their genesis. While the structure of the whole "eggs" are remarkably similar, their interior agate, opal and quartz cores– along with inclusions of rhyolite shards, moss, and plumes– provide an endless variety, no two being exactly the same.

At first, the Indians' notion of "thunder-god missiles" captured the imagination of early Twentieth Century collectors and a few geologists. At the outcrop of this "original dig," and at subsequently discovered deposits, the eggs are found in an ashy-like material as solid egg-shaped entities. It was easy to speculate that the Indians' "missiles" were volcanic bombs that dropped into volcanic ash. Early on, thundereggs were not of much economic import and theories were first built on fundamental flaws or manufactured by whiskey and forged into a variety of myths. Soon, however, it was realized that thundereggs were not bombs cast into volcanic ash, but rather were ***co-genetic*** (made together) with the material they were found in. At some point, when the “rhyolitic ash” was excavated beyond the erosional zone, a perlite cap-rock with thundereggs in it was encountered, and ultimately found to overlie the entire deposit in sheets four feet thick.

Perlite is a glassy lava rock, and at the Priday Ranch it belongs to what is geologically mapped as the John Day Formation which is composed of rhyolitic ash and welded tuffs during Tertiary Period. The age of this rhyolite-perlite flow has been dated to about twenty million years old. Thus, the perlite would not only be impervious to such bombs, but is far older than the Cascade volcanoes that would have supplied the missiles. By the 1930's, thundereggs were recognized by geologists as being lithophysae, entities of rounded spherulites, often with uneven hollow centers, some filled with chalcedony and/or quartz, found in highly silicic rhyolites and perlites, especially on the contacts between rhyolite and associated perlite.

This laid the bomb myth to rest, but many problems remained to be solved. For example, how does a gas cavity form an irregular or star-shaped hole as it expands or degasses out of a solution? After all, the huge deposits of agate amygdaloid casts from the andesite lavas of Brazil all are rounded or tear-shaped, as would be expected of gas effervescing from a fluid. Even the irregular coalesced, compact gas pockets in scoria zones in basalt and andesite flows as well as in rhyolitic pumice, have smooth interior walls.

Evidently, an entirely different mechanism of gas expansion must be described to explain how an asteriated hole can develop. Also, another problem arises as to how the lithophysae got up into the perlite itself. And finally, great controversy continues to exist on how silica is transported to fill the centers with agate, opal, inclusions and/or typical quartz crystals.

I realize that this will be a difficult task to explain the many phenomena in detail to motivate students and professionals in the Earth sciences to analyze so as to prove or disprove hypotheses offered, and also to include reading understandable and enjoyable to laymen, collectors and rock hounds. It also requires an open mind capable of laying aside favorite pet notions derived from previous theories on thunderegg genesis.

The greater part of this thesis is derived from my experience digging from dozens of deposits in the

Basin Range and Province of the Western United States. I was unaware of such issues, assuming thunderegg genesis was known, until I read a 1979 study of thundereggs by B. M. Shaub in the February-March issues of the *Lapidary Journal*. Since then, and during this work, I have read several publications that seem to be simply getting more complicated. Then, after finishing this first edition, I was given some very old papers by Dr. Peter Woerner, a friend in Germany, that ranged from 1888 through 1954 and found that these old writers were close to solving the formation of lithophysae, indeed, they came closer than any writer has since. But, more importantly, there was one fatal flaw in those old papers that apparently lead later researchers astray and forced me to rewrite my first edition into a model based on a more accountable set of data.

Though being mainly a collector, and having no access to laboratories, I have found a wealth of information in geologic texts and maps from universities and colleges throughout the West. Knowing that thundereggs occur in Tertiary rhyolitic flows (some indicate welded tuffs) the geologic quadrangles and accompanying texts made prospecting far more successful.

In November of 1998, we gave our entire collection to the **Deming-Luna Mimbres Museum** in Deming, New Mexico, a nonprofit public museum operated by the Luna County Historical Society. This was done so as to guarantee that this collection would be maintained in the educational context and order in which each of more than 150 locations are represented, in perpetuity.

Most of the specimens in the photographs in this book are there and I have access to them so any serious investigator may contact me to scrutinize and discuss any specimen or obtain a sample for testing.

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Introduction

This theory on the genesis of thundereggs, or what is called in geology *lithophysae* (singular, *lithophysa*), has been developed from more than 60 years of prospecting, digging, and observation in the field in more than 100 locations in California, Oregon, Nevada, Idaho, Arizona, and New Mexico. At rock and gem shows, I have used my meager "silver pick" to obtain specimens from the state of Colorado, and foreign locations in Mexico, Germany, France, Russia, Turkey, Poland, Ethiopia and Queensland, Australia. In spite of the tonnages of vein and amygdaloidal agates from everywhere else in the world that have flooded the American market for decades, e.g., Brazil, India, Uruguay, and Africa, as well as Montana's glaciated amygdaloids and the famous "coconuts" from Mexico, very few good thundereggs have appeared on the market.

I have been interested in rocks since I was about ten. The first thunderegg I owned was a polished quarter-end piece from the Priday Blue Beds in North Central Oregon that I had traded for a sea shell from a friend. Though I now realized that it was a rock shop "second," its white flat banded center contrasted by an encircling rich blue agate layer, with a star-shaped interior encased in the familiar orangish-brown rhyolite matrix fascinated me. Moreover, the name "thunderegg," guaranteed for me a lifetime obsession.

At about the same time, I joined the East Bay Mineral Society and went on my first field trip to dig the locally popular Berkeley Hills blue agates. These are amygdaloids found in an andesite lave flow exposed near and at the summit of the north-south-trending ridge which rises from about 1500 to 2000 feet forming the main core of the range high above on the east of the San Francisco-Oakland Bay area. These agates have been dug from the exposed edge of this flow about two miles long in a zone only about four feet wide. At places, some exquisite iris agates are found.

I met two fine gentlemen on this and subsequent field trips. They, along with my first thunderegg, were to seal my fate. One was a teacher at the California College of Arts and Crafts. He took an interest in my enthusiasm for rocks. He let me use the diamond lapidary saw in the jewelry classroom after classes all I wanted, in exchange for a small amount that I cut. The other was Calvin Farrar, then in his eighties, a man who had collected thundereggs from a dozen places in Oregon and California: It was from him that I learned that thundereggs came from more places than the Priday Ranch. I also discovered that each location produced a distinctly different textured and colored rhyolite shell, and that the agate interiors were as different as well. I was astonished at the variety of thundereggs Calvin had. He sold rocks and jewelry he made right out of his home. I bought thundereggs from him and he let me cut and polish them, and that is how I started my collection. He showed me how to cut a Priday egg right-side up, so that the flat-layered "waterline" agate and/or quartz crystals would be in the order in which they were deposited.

The Priday Ranch thundereggs are structurally uniform in the several adjacent deposits. They are round to egg-shaped, with raised ridges, two of which encircle the top and bottom like the Tropics of Cancer and Capricorn that encircle the Earth, and four or five longitudinal ridges that intersect these latitudinal lines. If cut perpendicularly through the two latitudinal ridges, the result is a four-pointed star, positioned so that the sequences of agate deposition are in correct chronological order, please see Drawing 1 in Figure 5.10 on page 129. In the rarer five-longitudinally-ridged eggs, I learned that cutting through those lines yielded a five-pointed traditional star. While sacrificing mineralogical sequences, the idealized star enhanced marketability for the tourist as well as the collector.

Calvin advertized in rock and gem magazines to sell his wares, as well as my Berkeley Hills iris agate slabs. As a result of advertising, he had occasional visits from dealers who mined, traveled and sold rough rocks, usually by 100 pound gunny sacks full. Occasionally, one of these "agate miners" would bring in thundereggs from a new location. Calvin was alert to my method of collecting and would chance a purchase in which I would buy, cut, and add the best from each new location to my collection.

By the time I was 15, I had to go to Oregon, which I had envisioned as a mysterious paradise with countless mother-lodes of thundereggs. But I had no car. Previously, I had hitchhiked to rock and mineral locations within 100 miles of my home in Oakland, using a 1948 publication on rock and mineral locations by the California Division of Mines. But to hitchhike to Oregon? Six or seven hundred miles*?!* I had hopped freight trains from San Jose to Oakland after visiting Almaden and Guadelupe Quicksilver Mines of world fame. *But to Oregon?* I had to do it!

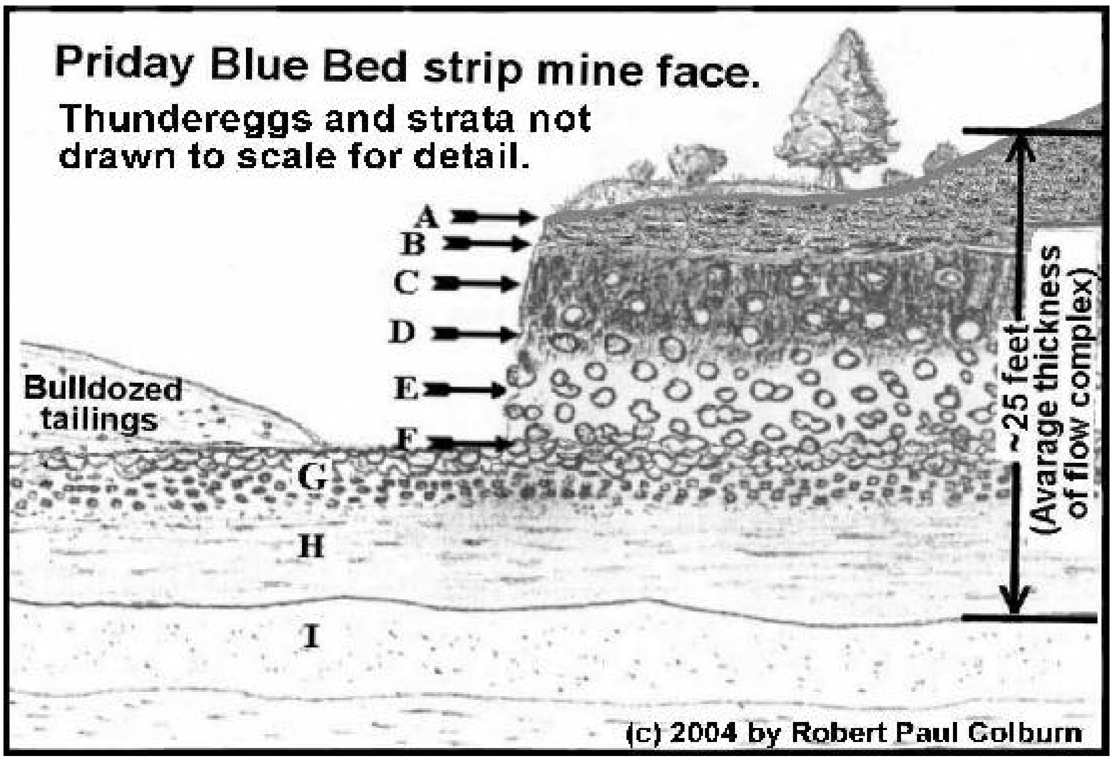
I was 16 in the summer of 1952. I was transfixed while I sat in the open doorway of a box car watching the scenic splendor of the Siskiyou Mountains go by. Whether I got any thundereggs or not, wanderlust from the novelty of seeing strange beautiful new places I had never seen before had me planning new excursions before I even knew what success this first venture would yield.

After leaving the freight train in Bend, Oregon, I hitched a ride to Madras, a small town just 17 miles from my first destination. I went to a rock shop there for information on how to get to the Priday thunderegg beds. The owner was impressed with what he saw, a boy with an obsession: There I stood, with a black leather suitcase, just telling this man that I had traveled on a freight train over 600 miles from Oakland, California ". . . to dig some *thundereggs?!*" After talking awhile, he said he would take me to the diggings the next morning. He let me shower and put me up for the night.

I had always thought Oregon was all a carpet of forests, but once one leaves the Cascade Mountains going east, the state is mostly juniper and sagebrush desert with only islands of forests at some places above 5,000 feet. We arrived at the Priday Blue Beds at opening time. It was, and is still today, a commercial operation where you pay a charge per pound for what you dig. By 1952, a small bulldozer was required to remove tailings that built up behind a four-foot ledge from time to time as digging progressed. The thundereggs were concentrated in a moist, ash-like layer about 18 inches thick, and what surprised me, a 2-to-3 foot thick layer on top of what looked like obsidian.

My new friend, familiar with a little geology, called it a sheet flow of perlite lava. Having read about some speculation that thundereggs were volcanic bombs that dropped into volcanic ash, then filled with agate, piqued my curiosity when I started digging.. I found that the nodules were not only in the "ash" layer, but the top of the underlying rhyolite was composed of a solid mass of thundereggs that seemed to become more sparse as they rose upward into clusters stuck together. More singles occurred as one dug higher into the ashy-clay layer. More astonishing was the fact that some of these "bombs" had managed to get up into the perlite sheet flow and became entirely encased by it.

Figure 0.01



Strata as exposed by strip mining at the Priday Blue Bed, Richardson's Recreational Ranch, Madras, Oregon: A, Top soil; B, Perlite breccia and pumiceous zone (top of flow complex), can run from 4 to 30 feet thick as this top layer has been subject to erosion; C, Black glassy perlite with lithophysae containing fills of about 50/50 "waterline" agate layers over white opal layers; D, Transitional zone gradational downward from black glassy through gray partially altered perlite to the completely altered clay at E, where most of the best thundereggs are found. F, is the rhyolite bedrock composed of a solid mass of egg;. G, The eggs grade downward to empty box-shaped holes to extinction; H,. Solid rhyolite rests conformably on ash layers, I. **Diagram by Robert Paul Colburn**.

Being familiar with how destructive hot lava can be to quartz, as exhibited by California's famous Lake County "Diamonds," I couldn't understand how agate-filled "bombs" could be picked by a hot lava flow and survive completely intact, especially when most of the thundereggs I broke out of the perlite were filled in half with opal. Any seasoned gem maker knows opal can stand far less heat than agate and quartz.

The reason for this is that, though like agate and quartz crystals being a silica (SiO_2) precipitate, opal is a hydrated form, that is, it has water in its molecular structure, hence it must be cut and polished wet. And just as interesting is the "floor" of this thunderegg bed which is composed of a solid mass of eggs cemented to and included within the rhyolite itself!

At the edge of the bed next to the erosional downfall, the dozer had broken off a large chunk of the rhyolite bedrock, exposing the gradation and depth into which the eggs existed. All of the eggs that I later cut that came from the perlite and the underlying "ashy" layer were filled solid, except for three. Those had a small half-inch hollow pocket lined with druzy euhedral quartz crystals. Two had their pockets centered inside half-inch tree ring-like layers of dark blue spherulitically crystalline chalcedony, known popularly as fortification agate. The third had its pocket nearer the upper edge, with the agate bands encircling it trailing off and thinning out at the top ridge that encompasses the egg. This chamber was barely cut into, which was unfortunate because it contained water which dribbled out when shaken. Had I gotten lucky, I would have had an *enhydro*, an agate with a visible bubble moving around when tilted. But such luck is rare.

On the bedrock in contact with the ashy-clay, some eggs could be pried off whole, with more melded into doubles, triples or clusters. Most broke apart revealing a hollow top consisting of a thin layer of chalcedony coating the walls of the egg's interior. Horizontally banded "waterline-opal" is contained within the thin concentric layer and occupying from one quarter to one half of the interior at bottom, with the tops being flat floors, some with chalky surfaces that can be scraped with a fingernail, see Figure 9.07, see also page 437 in the Photo Appendix. And in all, the floors are all horizontal equally with every other egg in the bed, including being horizontal with all the waterline agate and opal found in the two layers above. And all the waterline floors are also horizontal to all the other sheet flows in the extensive Priday rhyolite flows over some fifty plus square miles. Even Pony Butte, which appears to be the only anomaly, rises some 500 feet above all the other sites, is also flat on top as though it broke off as a block and rose vertically straight up as though some cosmic level kept it horizontal with all else below it.

As I was to discover years later, a geologist studying perlite in New Mexico used such floors when considering fault tilting of strata to determine the amount of overburden that would have to be removed if the perlite were to be mined: "The nearly horizontal attitude of the flat upper surface of the white opal in the larger vesicles provides an excellent indicator of the slight degree of tilting that has affected the lower rhyolite in its post-vesicle-filling history" (Robert H. Weber, 1957, *Circular 44*: "Geology and Petrology of the Stendel Perlite Deposit, Socorro County, New Mexico," page 6).

Figure 0.02

Geologic Map of the Stendel Perlite Deposit, Socorro, N.M. (next page following).

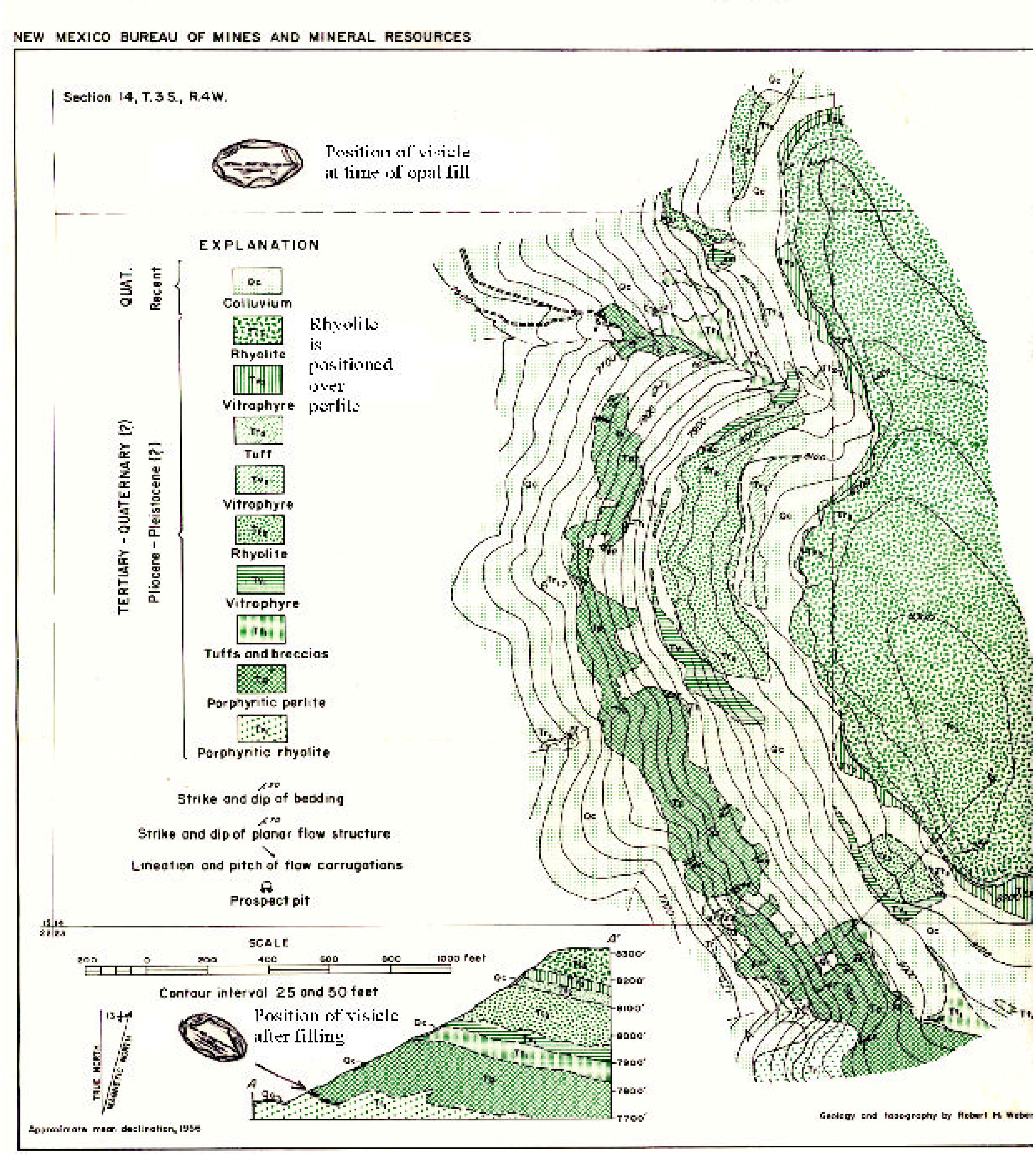
Geology and topography by Robert H. Weber.

Some of these hollow eggs contain worm-like stalactitic growths, many extending into the voids in all directions, in defiance of gravity. Some extend down into the waterline agate layers. The "stalactites" contain a thread of opaque material that must have grown out into the interior first, because they are all contained within the thin, transparent chalcedony that coats the walls of most of the thundereggs in this bed. The vertical, as well as the wandering stalactites appear as eyes and tubes, or as "moss agate" in some of the eggs in the upper layers. Stalactitic growths will be discussed in Chapter 9 on inclusions.

It was getting late, so I decided to go see how deep the eggs existed in a chunk of the rhyolite bedrock kicked up by the dozer. From about several inches to a foot down, the individuality of the thundereggs became lost and less infiltrated with chalcedony, to a point where there was nothing but hundreds of closely packed angular holes in a mass of fine-grained brownish purple rhyolite. In the lengthening sunlight, a broken piece revealed a radial structure from the center of each wall of the cavities. It is as though the silica had not been able to permeate the solid rhyolite to fill the pockets. Moreover, the half filled eggs in the bedrock is a strong indication that the silica had been exhausted at that point.

Figure 0.02

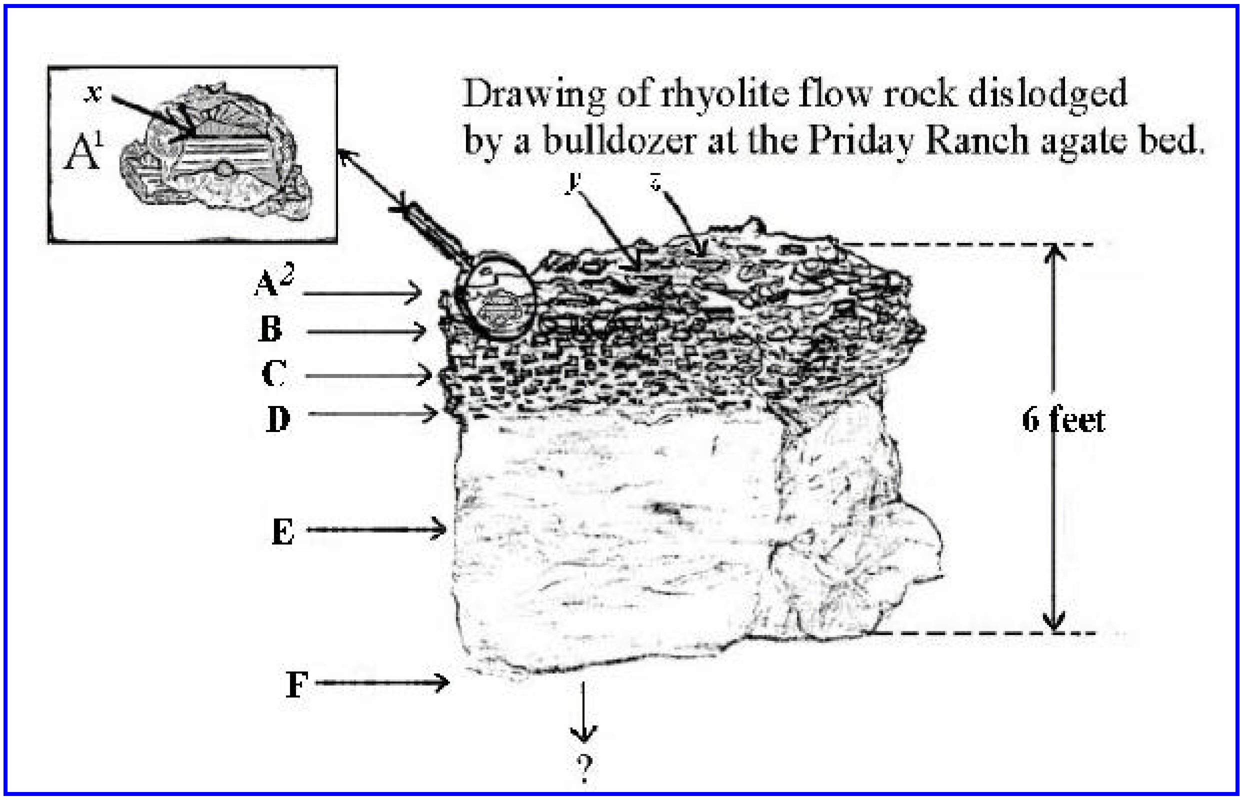
The tilt angle of the before and after tilt angle of the lithophysa drawn in at top and bottom left has been exaggerated to better show the water line angle before and after deformation.



GEOLOGIC MAP OF THE STENDEL PERLITE DEPOSIT, SOCORRO COUNTY, NEW MEXICO

Figure 0.03

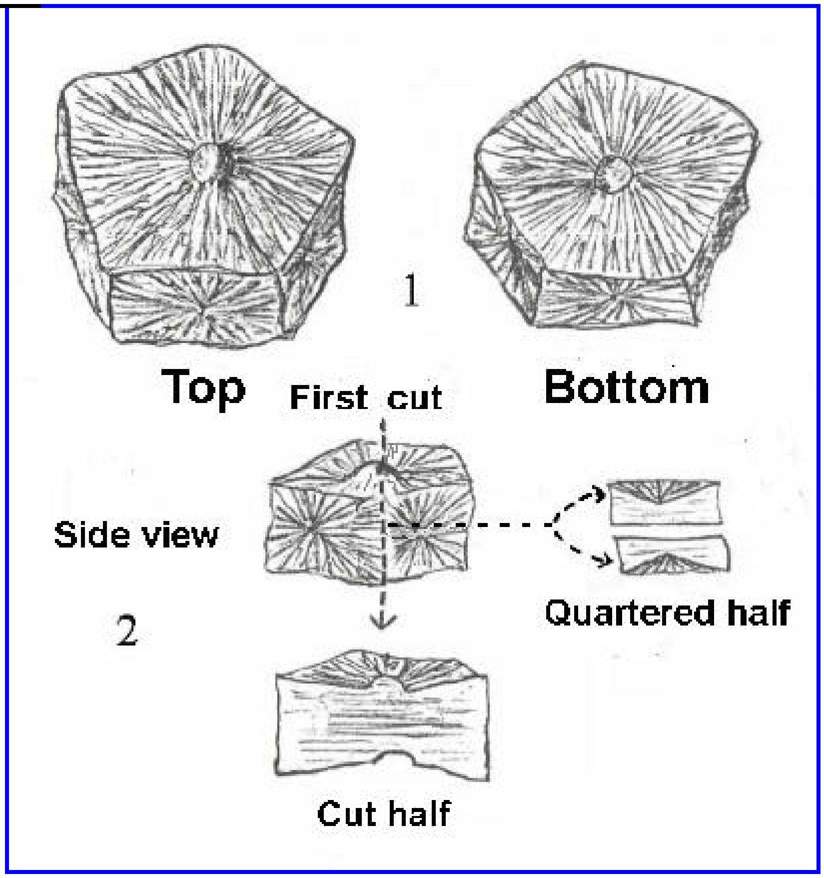
Drawing of rhyolite flow rock dislodged by a bulldozer at Priday Ranch agate bed.



*A^1, Magnified view of lithophysae from "floor"; A^2, of the Priday Blue Bed, Madras, Oregon. Arrows **x**, **y**, and **z** are the opaline, often chalky floors, always horizontal to all bedding in the area, indicating little or no "post-vesicle" filling deformation. B, Transition zone, from the highly silicified lithophysal zone with spherulitic texture and half-filled lithophysae to B, spherulitic texture is limited to almost empty lithophysae, to C, where the spherulitic texture diminishes until the lithophysal identity of the shells is lost. From C to D, the vesicles diminish in size and geometry until extinction into the microcrystalline host rhyolite, E, which rests conformably on the rhyolitic ash and/or ash- flow tuffs of the John Day Formation at F.*

Drawing by Robert Paul Colburn.

The radial, fibrous structures on the pocket walls were familiar to me at that time as existing on the surface of weathered agate cores (Figure 0.04) collected on the slopes below the erosional surface at the edge of this bed. The shapes of these cores are six sided, with a rare seventh face on the side which would account for the rare five-point star when a five-longitudinally-ridged egg is cut to achieve that shape. It is obvious that the edges of the faces correspond to the ridges on the surface of these eggs, and on eggs from other locations as well (which will be discussed later). Each face is depressed inward to the center. A fibrous structure cast on the agate cores radiates from the center of each face toward the edges.



Pencil drawing by the auther in 1965

Figure 0.04 *Dissection of a pentagonal "star" thunderegg. core with its shell weathered off.*

1). The core shows the "button" at center on the top and its corresponding dimple on the bottom.

2). Side view: All the core faces are indented toward the center from which a fibrous radial texture projects. All structures on the core surface have been cast from the original lithophysal cavity. The first cut, bottom, is the core cut in half, the second cut is through the center of one of the halves laid open. Both cuts show that all faces are indented toward their centers.

Drawing by Robert Paul Colburn

The top and bottom faces of the cores have, on one face, a dimple at its center, and the other, a "button" embossed at the center of its face (see Figure 0.04). When whole eggs are cut through those centers, they show the" button" to be a cast of a ***spherule*** in the shell which is porous, unlike the ***silicified*** rhyolite surrounding it, see Figure 0.05. These spherules are light brown to white, often tinged olive green.. Figure 0.06 shows top and bottom of weathered core from the Little Florida Mountains near Deming, New Mexico. On these we see an excellent example of the cast from the spherule seen as a button on the top side and a corresponding dimple on the bottom.

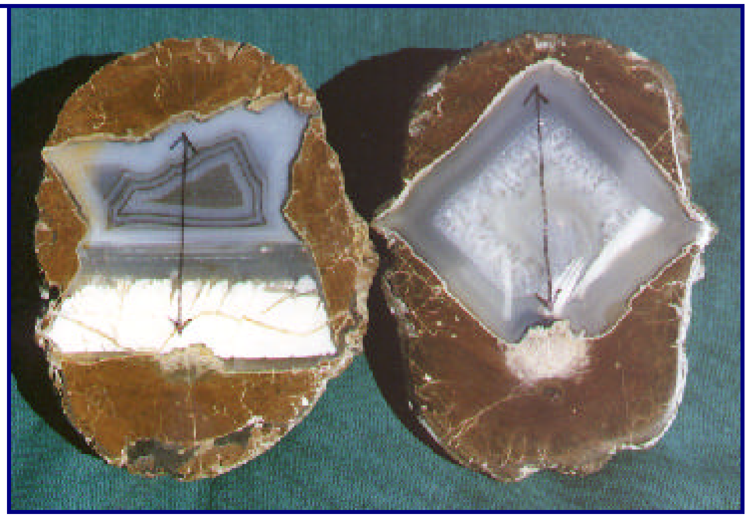


Figure 0.05 *Two specimens cut "right side up" from two different deposits showing the familiar "button" at the center bottom of both, and the corresponding depression at the top, into which the two opposite features fit before expanding gases opened them up.*

The specimen at left is a "box core" thunderegg from the Priday beds, at right is a "biconic core" thunderegg from the Deschutes Canyon 13 miles south of Maupin, Oregon. **Photos by Chris Algar. Actual size each, 9 cm through vertical axis.**

Figure 0.06 *Exterior of the top and bottom of an agate box core from a lithophysa. The shell has been completely weathered off. At left is the "button," cast from spherule on the bottom of the cavity. At right is the opposite side with the "dimple" cast of the spherule on the bottom of the cavity.* **Actual size, 5 cm each, Photo by R. Paul Colburn**

The sizes of these features in the Blue Bed are from one quarter inch to one half inch. Most Priday Blue Bed thundereggs are oval-shaped, ranging from two to four inches in diameter. The button and depression on the top and bottom, respectively, are highly suggestive that these two opposite faces were once common together and had been forced or drawn apart (both of which we will discover later). Another fact is that the positions, the top and bottom, are reversed in some specimens.

I must have seemed like a ten-year-old kid to my rockshop friend, for I had so many questions about thundereggs and what I had seen in the field. He said he had heard of some theory about a rhyolite-mud, in which steam was trapped and when the mud dried, it shrank, pulling apart into a star-like cavity in a process called ***dessication***. This is how the cavities in sedimentary ***septerian*** nodules and geodes form. But, I asked him how the heat from the perlite lave flow didn't destroy those that it came into contact with? This seemed to perplex him, for he tried to divert the line of questions by pointing out other locations to dig at.

I wanted to ask him if the rhyolite flow below where the eggs seemed to come from was a mud flow. And how did they get up into the ash and perlite layers? Did all of these lavas and ash come out at the same time? This last question was to lead to a solution on how thundereggs made of the same rhyolitic composition could be found in three disparate appearing strata, but not until more than thirty years later. And it was from the same geologist quoted above, in the same circular on the Stendel perlite, that the perlite and underlying rhyolite, with its spherulitic (thunderegg) zone on the contact, came from the same melt, extruded concurrently with the two separating almost completely, but still containing a chemical, mineral and textural composition so similar they were mapped as a single ***cogenetic*** unit, i.e., they belonged to the same flow:

"The cogenesis of the perlite and the rhyolite is demonstrated by their nearly identical chemical composition (water-free basis), phenocryst assemblage, and intimate to gradational contact relationships" (Weber, 1957). Cogenesis means "made together" (See Table 0.01). ***Phenocrysts*** are the crystals which define a ***porphyritic*** rhyolite and they are far more viscous, thicker flows than in the lower viscosity thin sheet flows like the rhyolite at the Priday Blue Beds. Porphyritic flows are extruded at lower temperatures than the ***aphanitic*** (microcrystalline) sheet flows at Priday.

Table 0.01

CHEMICAL ANALYSES, NORMS, AND MODES OF LOWER RHYOLITE, PERLITE, AND ALTERED PERLITE. *

	272-P19 Lower Rhyolite (Tr_1)		272-P51d Perlite (Tp)		272-P52a Altered Perlite	
	Natural	Recalculated to Anhydrous	Natural	Recalculated to Anhydrous	Natural	Recalculated to Anhydrous
SiO_2	74.04%	75.79%	73.10%	76.42%	67.65%	75.78%
Al_2O_3	13.35	13.49	12.50	13.07	11.85	13.27
Fe_2O_3	1.01	1.02	0.48	0.50	1.18	1.25
FeO	0.24	0.24	0.42	0.44	0.15	0.17
MnO	0.04	0.04	0.04	0.04	0.04	0.04
MgO	0.18	0.18	0.22	0.23	1.03	1.15
CaO	0.95	0.96	1.03	1.08	2.82	3.16
Na_2O	2.88	2.92	2.99	3.12	0.99	1.11
K_2O	5.15	5.20	4.76	4.98	3.34	3.74
TiO_2	0.12	0.12	0.09	0.09	0.17	0.19
P_2O_5	0.04	0.04	0.03	0.03	0.10	0.11
H_2O^+	0.59	0.00	3.70	0.00	7.13	0.00
H_2O^-	0.14	0.00	0.36	0.00	3.75	0.00
CO_2	N.D.		N.D.		0.00	0.00
S	N.D.		N.D.		0.03	0.00
Total	99.73%	100.00%	99.72%	100.00%	100.23%	100.00%

NORMS			MODES		
Minerals	272-P19	272-P51d	Minerals	272-P19	272-P51d
Quartz	36.51%	36.78%			
Orthoclase	30.90	29.58	Quartz	6.34%	5.43%
Albite	24.80	26.33	Sanadine	1.35	4.05
Anorthite	4.77	5.62	Oligoclase (Ab_{70-81})	8.38	3.66
Corundum	1.24	0.53			
Enstatite	0.51	-	Biotite	1.34	0.53
Forestalled	-	0.27	Hornblende	0.52	0.31
Magnetite	0.47	0.73	Magnetite	0.16	trace
Hematite	0.65	-	Matrix	82.80	86.02
Ilmenite	0.15	0.16			
Total	100.00%	100.00%	**Total**	100.00%	100.00%

*H. B. Wiik, analyst; norms by M. S. Sun.

Table from Robert H. Weber, 1957.

In the thinner flows like those at Priday, the quick cooling did not allow for larger crystals to grow and the crystals from the precursor granite were probably completely melted by the higher temperatures at extrusion. The flow was probably fine textured to microcrystalline to begin with or the flow remained hot enough for the small *crystallites* to form as they are seen in hand specimen where they settled below the spherulitic zone within zone H in Figure 0.01. Unlike the *porphyritic* (grainy) texture of the rhyolite and perlite of the Stendel Deposit in Socorro, New Mexico (porphyritic perlites are often called *vitrophyre*), the rhyolite at Priday Blue Beds is aphanitic (microcrystalline to small visible crystallites) in texture.

The perlite above is amorphous glass so free of crystallites it approaches the clarity of black obsidian, but like perlite, it cannot be napped into tools. The spherulitic zone and lithophysal shells are submicroscopic and silicified to a degree somewhere between opal and jasper with the spherules remaining somewhat porous. The fractures of porphyritic rhyolites and perlites are ragged, the shear-plane interrupted by the larger crystals in the way. At Priday, both rhyolite and perlite show more similar conchoidal fractures. Though I have not seen a chemical ratio analysis of the Priday rhyolite and perlite, I do believe the two to be cogenetic.

The larger problem now is that if the rhyolite and perlite flowed out at the same time, how did the ashy layer get in between the two, and how did the eggs get in all three units? If we recall Weber's observation on the cogenesis of the rhyolite and perlite at the Stendel Deposit, he states, " . . . *Intimate to gradational contact relationships exist.*" The intimate relationship probably means the abrupt end of the rhyolite at contact with the perlite. But first, it is the gradational relationship that may shed light on the "ash layer" problem where it is in contact with the perlite.

In Weber's discussion of the Stendel perlite and its cogenetic rhyolite partner, he describes the alteration of the perlite in fractured zones and along spherulitic and "megaspherulite" zones (the ones containing the opal floors measuring up to five inches). In geology, spherulites containing cavities are also called lithophysae, so Weber's "megaspherulites" are thundereggs. His use of the term megaspherulites shows that this he was not familiar with larger spherulites and that the use of the term spherulites shows that he had never made the connection to lithophysae which is any spherulite that formed a cavity. He did prove, however, the importance of these objects to mining considerations by noting the tilts of the water line opal.

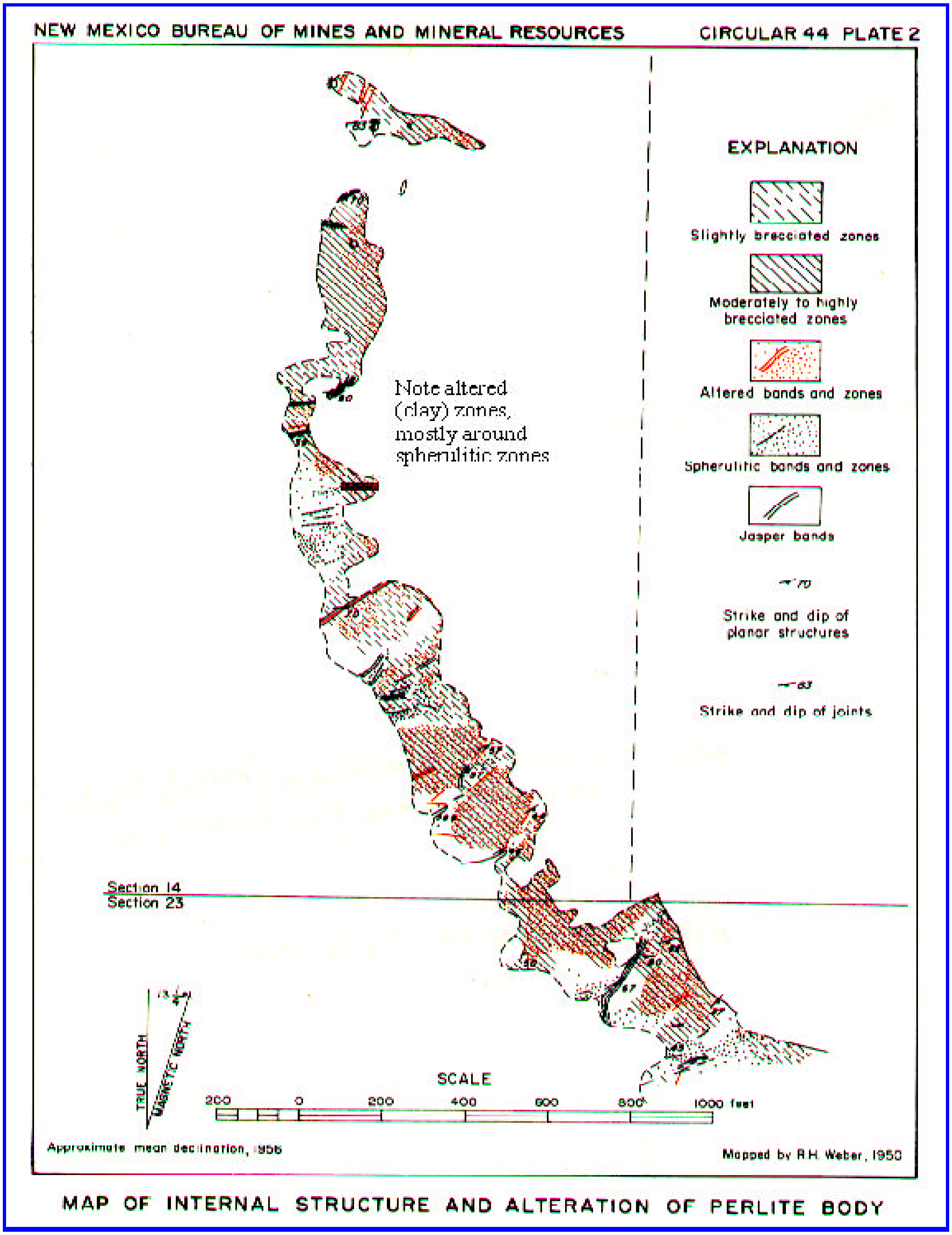
The alteration products of the perlite were found to be montmorillonite, a clay mineral complex of hydrated sodium, potassium, aluminum, and magnesium silicates. The spherulites have a radial, fibrous structure and consist of cristobalite, a high temperature metastable form of silicon dioxide (SiO_2) and perthite, a co-crystalline mineral composed of albite ($NaAlSi_3O_8$ and orthoclase $KAlSi_3O_8$ which forms a weaving pattern called *exsolution lamellae* due to the two different crystal systems they belong to. The chalcedony and opal filling the "megaspherulites" are deposited from aqueous solutions, hydrothermal and surface sources, e.g., lakes, streams, and/or precipitation. As seen in the field and on the geological mapping of the Stendel Deposit, in the S.E. quarter of the S.E. quarter of section 14, and the N.E. quarter of the N.E. quarter of section 23, Township-3-South, Range-4-West, where the "spherulitic zones" are mainly located, the alteration of the perlite is greatest.

Figure 0.07 *Next page following*.

The ashy clay grades up from the rhyolite, through the spherulite and lithophysae zone going from a buff colored material to a less altered gray zone, melding into the perlite above. Though this looks like an ash or a welded tuff where silicified by meteoric solutions, its chemistry was analyzed, and it tracked very closely to the chemistry of the rhyolite and perlite so as to indicate a cogenesis of all three (Weber, 1957, Table 1). This suggests that at the Priday Blue Bed, the ash fall, or "ash-flow tuff" proclaimed by several authors such as Ross and Smith (1961), Shaub (1979), Pabian and Zarins (1994) and others, may not necessarily be an ash or tuff. To date, a petrological chemical analysis of the Priday rhyolite, the perlite, the lithophysal shells and the clay layer between has not been done.

It does seem peculiar that there has been no study of the Priday rhyolite unit in light of the fact that it has been one of the most famous agate deposits in the world, in operation on a commercial bases as a public pay-for-what-you-dig for more than half a century. There has been thousands of tons sold and at ten cents per pound when I dug there in 1952, the value per ton would be $200.00. Richardson's Rock Ranch now gets fifty cents per pound, or $1000.00 per ton which is a respectable sum in any mining operation.

Figure 0.07 *Fracture and spherulite (lithophysae) zones show where alteration of perlite was greatest, shown in red. These areas presented spaces for silica solutions to diffuse into.*



At Priday, a description of hand specimens is suggestive of cogenesis, revealing a gradational continuity through the three components. As noted above, there are the squarish-shaped cavities in the rhyolite below the silica, infused and spherulitically circumscribed similarly shaped cavities which are in contact with the clay above. Immediately below and on this contact, the lithophysal cavities are stuck together on the top of the rhyolite, some of which can be pried off only in clusters, very few can be removed as singles without rupturing the shells. The cavities strictly at this layer are mostly filled about halfway with flat layered chalcedony and opal, the floors of which show little, if any, post -cavity filling deformation, that is, the floors are still parallel to the earth's surface, and also parallel with a sequence of other sheet flows visible on Pony Butte nearby to the north (See Figures 0.08 and 0.09). Above this, and in the clay, the lithophysae (thundereggs) grade upward from clusters to triples, and doubles with singles becoming more numerous near the margin of the overlying perlite.

Figure 0.08

Figure 0.08 is a photo of the Priday Blue Bed thunderegg deposit (taken from Pabian and Zarins, 1994) with Pony Butte in the background. Three strata of rhyolitic lava flows can be seen which lay conformably on ash and/or ash-flow tuffs of the John Day Formation. A first time correct strata profile of the Priday Blue Bed is presented in Figure 3.02.

Little deformation has occurred throughout the history of events affecting the perlite (black rock in the picture) and the filling of the thundereggs contained therein, hence, the "waterline" agate and opal layers conform to the topography of the area. **From Pabian and Zarins, 1994**

Figure 0.09

The egg shown has been broken and shifted by minor faulting as shown by the offset layers and the breccia (broken rock) mixed with decomposed perlite, fell into and filled the hollow top third and the fissure that resulted. Later, more silica was carried by meteoric waters to reseal and "agatize" the wreckage.

The placement of this specimen in the photo is as it was oriented in place in the deposit.

Photo by Chris Algar. Actual size, 3 ½ inches.

The clay-perlite contact is uneven and *not* abrupt. The crumbly, creamy tan clay grades upward near the perlite into increasingly darker shades of light to dark gray, becoming more consolidated and changing to the hard, brittle, black glassy perlite that caps this and other lithologically identical thunderegg beds miles apart in this area.

There are also thundereggs found in the perlite itself, tapering off in number to very few within two feet. All the thundereggs entirely encased in the hard, black perlite have a zone of white colored decomposed (altered) perlite clay around each one. This substance looks like and has a soapy feel like the tanner clay below. There are also a few "duds" in the perlite– spherulites that failed to degas and develop a cavity. There is no clay layer around these. Evidently, there was no cavity for the silica to diffuse into from the perlite when it was saturated with percolating aqueous solutions, hence the perlite about the solid rhyolite spheroids failed to decompose, and the duds remained encased in unaltered perlite. In the cavity developed eggs, the perlite has altered to a clay as though the silica had somewhere to go, or as we will see later, drawn to the cavities. This zone reminded me of the *depletion zones* found around the concretions I once dug out of sandstone in search of fossils.

This phenomenon is well demonstrated elsewhere, especially at two famous public locations: One, the west end of the Dugway Geode Beds in Utah in the northwest quarter of T-11-S, R-12-W, and another above Rockhound State Park near Deming, New Mexico. The Dugway Beds cover a large area and at most places, the perlite is completely decomposed. At the western area of the diggings, much of the perlite is in an original condition, black, glassy, and brittle. Around each geodic (hollow) thunderegg is a white powdery clay. The once-porous rhyolite bodies, stringers, and eggs had absorbed the silica from the surrounding perlite, becoming hard and silicified. The eggs have been partially filled with chalcedony and colloidally suspended white clay particles coating the chalcedony, followed by an overlay of relatively large, clear euhedral quartz crystals yielding a geode of white sparkling beauty called “sugar bowls” by collectors.

At Rockhound State Park, the egg-bearing perlite is at 600 feet above the upper right parking place on a well-defined foot path. The flow structure of this bed is not sheet-like, as it is at Priday, but is mixed with large bodies of rhyolite along with stringers, stretched torpedo-shaped lithophysae, as well as the traditionally round, agate-filled eggs, and duds. It is because the good eggs are surrounded by the yellowish-tan clay, while the duds are within only unaltered black, glassy perlite that allows the experienced digger to determine and throw away the duds and take only the good down the steep, treacherous trail. The perlite at Rockhound Park is quite thick. I have dug downwards more than twelve feet, finding an area rich in eggs and the perlite is mostly decomposed.

Spherulitic buttons are found in these eggs like those at Priday, but sawing through their centers is difficult because they are not as geometrically centered as those at Priday, probably due to the parent lava flowing over an uneven surface. The contorted flow structure is seen in the host rhyolite exposed along and under this bed. Another important phenomenon at this locality is that the deeper one digs, the smaller the agate cores are in relation to the rhyolite shells, to a point where most of the eggs are duds, probably due to greater overburden pressure. The western front of the Little Florida Mountains, on which Rockhound Park sits, appears to be an old fault scarp. A lake and heavy rainfall during the Ice Ages caused chunks of the mountain that contain the thundereggs to break and slide down the newly developed fault scarp before being uplifted about 800 feet to its present elevation. Two sections of a later rhyolite flow, which is horizontal over most of the mountain, can be seen from a short distance away as two strata tilted at about twenty degrees off from the rest of the flow capping the mountain.

This slide-tilting occurred at the time when horizontally layered waterline agate and opal were being implaced in the cavity of these eggs. When I discovered this, I found that by marking them with a black felt marker, from the top down toward the west, for right-side-up orientation before complete removal, that when cut with the mark, some will show this slide event as the upper lines of the agate at about twenty degrees tilted from the lower set of lines (See Figure 0.10). Local rock collectors call these "tiltage eggs."

Figure 0.10

A "tiltage egg" from Rockhound State Park shows an angular unconformity in the "waterline" agate and opal layers caused by an ancient landslide that took place while the layers were implaced. Note the broken shell fragments (breccia) at the bottom of the opal layers and the dried mud curls on top.

Water line opal can only be deposited from fluctuations of copious amounts of silica rich meteoric water, such as that of a stream or lake. This means that these thundereggs were filled *before* *being uplifted to its current elevation.*

Photo by Chris Algar. Actual size, 5 $^{1}/_{4}$ inches.

This would seem to indicate the correctness of Robert Weber's use of the tilting of the opal floors in his "megaspherulites" to determine the amount of deformation, i.e., tilt of the Stendel flows after "vesicle filling" (Weber, 1957) so the amount of overburden could be predicted for mining considerations.

This last point of a thunderegg being *filled* with silica bearing aqueous solutions is important in light of several others attempting to develop various theories on how thundereggs form, specifically by any other means than a gas cavity filled by silica solutions. In a hot molten silica gel accretion theory, it is instructive and necessary to quote a passage from B. M. Shaub's dissertation published in the February (and continued in the March issue) of the *Lapidary Journal* in 1979, page 2348, he says of all other gas-cavity based theories:

> *"All base their theories on the assumption that by some force, mechanism or other culminating processes of nature, large cavities were developed in the acid magmas. The cavities are in reality the only basic starting point for every theory known to the author. The interiors of gas cavities are in general very smooth. Unless deformed after formation, the cavity walls have no distortions or irregular interior surfaces. The writer has never seen rough, irregular inside walls in scoria or other rocks with gas cavities large enough for the examination of their inside cavity walls."*

Then he concludes:

> *"Hence it must be certain that thundereggs are not casts of gas cavities and all theories based on gas cavity filling must be completely defective . . . "*

He goes on to state that,

> *". . .even our renowned petrographers and mineralogists have been led astray on fruitless routes by trying to match the spherical shape of thundereggs with that of the gas cavities . . . "*

He continues to describe his theory on thunderegg genesis which postulates an accretion of silica gel as an immiscible body directly out of molten rock which then spontaneously solidifies to the entities we find today.

I must credit this gentleman with piquing my intuition and inspiring me to reevaluate and write about what I have seen in my specimens and how they occur in the field. My first reaction to this "hot gel" theory was to ask how a calcite crystal could get into such a hot environment to become encased within the bandings of the agate. Calcite crystals cannot form in the 900ºC+ temperatures in the relatively low pressures of a lava flow. Such temperatures would reduce calcite to calcium oxide and carbon dioxide.

I have scores of specimens with calcite crystals well inside the agate, as well as other water-based inclusions such as manganese dendrites, zeolites (sagenite) plumes and stalactitic growths. These growths, which in most cases are the first implacements in thunderegg cavities, have subsequent bandings of chalcedony and/or quartz coating and outlining these as well as every other protuberance on the cavity wall itself. Another theory, antithetical to any hot silica gel, and just as incorrect, is that the radial fibrous structures are seen on weathered agate cores from thundereggs have been misinterpreted as agate casts of fossils or coral. We shall be entertained with this later.

The way the thunderegg shell and cavity develop are totally different from how their contents are implaced. The agate, opal, quartz, jasper, colors, calcite and aragonite, zeolites, dendrites, plumes, bandings, and the inclusion or exclusion of any of the above depending on location, makes for a variety of complex events. So complex that while at the same time Shaub (1979, pages 2352 & 2354 in the same *Lapidary Journal* quoted above) maintains that thundereggs are formed in their entirety in a "closed system," but dismisses the complexities of that process for another, later study:

> *"The development of the complex interiors of the thundereggs is a long and varied story in itself, a story that was directly involved with the different states and composition of a solution and its crystallization in a closed system above the critical temperature as well as at a somewhat lower value. There is probably no experimental data available that would cover such large masses of material and under such varied compositions. Hence, one must exercise some geological and physical-chemical applications in deducing the probable progressive development of the interiors (a field for different ideas)."*

Perhaps we can get closer to understanding thundereggs by approaching them as gas cavities filled with water-based minerals, like those of amygdaloids, an idea fairly well accepted by most geologists. An amygdaloid is a mineral-filled gas cavity found in basalt and andesite lavas such as the well-known huge deposits of Brazilian agates. These nodules have a round to teardrop shape, and the walls of the cavities in these lavas are smooth when amygdaloids are removed or weathered from them, Figures 0.11, 0.12. The lavas that contain these cavities filled or not are called amygdaloidal basalt and/or andesite. These lavas are the largest source of igneous-based agate nodules and geodes in the world. It is infinitely simpler for me to describe a silica-water-based filling for gas cavities in amygdaloids as it is for lithophysae. But it only *seems* counterintuitive that expanding gases can form box like asteriated holes.

Figure 0.11

An amygdaloid from an andesite flow in the Berkeley Hills, California. This specimen was dug from a road cut on Grizzly Peak Blvd about one half mile north of the junction of Fish Ranch Road in the Berkeley Hills above Oakland, California. This specimen was dug by the author after the floods of October 1963. Note the fill-tube at upper left.

Photo by Chris Algar. Actual size, 6 inches.

Figure 0.12

Figure 0.12 is a carnelian agate amygdaloid with a "waterline" agate fill at bottom from a basalt flow in the Oregon Cascades. This specimen was dug from a slide on Thistle Creek above Green Peter Dam, east of Sweet Home, Oregon.

Its original in-situ *position is revealed by the waterline layers which are in agreement with the position that a rising bubble would assume in a fluid like syrup or honey, which is about the range of viscosity in molten basalt or andesite.*

The slightly concave right-side relative to its rounded left discloses the direction and velocity of the flow of its parent which was slowly from left to right when the basalt solidified.

Like that for thundereggs, it rested for a long time before being filled with agate.

Photos by Chris Algar. Actual size, 3 3/4 inches.

Therefore, it will be necessary to find a natural mechanism or set of mechanisms that would produce such a cavity. After doing this, *all* water-based solution fillings of a gas cavity can then be explained. And now, more than fifty years after beginning this lifelong adventure by hopping on a freight-train, I offer for testing and experimentation these hypotheses and explanations of what I have seen and written about and presented below.