The Origin of Banded Agates

by Robert G. Welch

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Part One

The geological profession has paid little attention to the subject of the origin of agates. This probably is because agates do not have economic importance except to a small band of rock hounds. Dr. Roger Pabian and Dr. Andrejs Zarins of Nebraska are an important exception to this lack of professional geologic attention to agates. Other important contributions have been made by long-time rock hounds from their experience of collecting and cutting agates. As a geologist and rockhound, I hope these articles will add to the understanding of the formation of banded agates.

At the temperatures found in the upper few thousand feet of the earth's crust, silica is only slightly soluble. The maximum concentration is about 13 parts per million of silica to water. The concentration of 12 parts per million is found in waters that flow through basic igneous rocks such as basalt that contain plagioclase feldspar. Water flowing through granitic rocks or even quartz sand will not contain significant silica. The reason for this is when granitic rocks decay, the silica is immediately incorporated into clay minerals. Quartz is insoluble at normal temperatures and pressures.

Twelve parts per million of silica is enough to grow crystalline quartz over a long period of time as molecule by molecule is added to the slowly growing crystal. Agate is not composed of normal euhedral quartz but of fine bands composed of thin crystals perpendicular to the bands. This is commonly referred to as "spherulitic quartz" and is widely thought to be evidence of rapid silica deposition. This rapid form of deposition requires a different kind of silica source.

Large quantities of a relatively insoluble mineral require a different mechanism of transport. This most likely occurs in the form of colloidal suspensions. This could result from the rapid weathering of finely divided volcanic ash, which provides unstable minerals in the form of glass and a very large surface area to weather. If colloidal suspensions have five to ten percent concentrations of silica, they can form gels. If they reached this stage, their viscosity would greatly limit their movement through volcanic ash and pore spaces in rocks. Since openings into lava vesicles are usually small, it seems likely that the colloidal suspension does not reach the gel state.

Dr. Roger Pabian and Dr. Andrejs Zarins in Nebraska Educational Circular No.12 titled "Banded Agates Origins and Inclusions" presents a theory of the formation of banded agates. Briefly summarized, this theory is that gas vesicles in lava fill with silica gel derived from volcanic ash. Dissolved minerals such as sulfo-salts or other metallic ions come into contact with the silica gel initiating a chemical reaction that

separates these components. This reaction proceeds as a concentric wave front. The silica gel reacts by forming spherulitic crystals. The incompatible minerals are expelled by the crystallization and settle out at the ends of the fibrous crystals to create the color banding. The agate has a lower specific gravity than the silica gel from which it formed, which causes the volume to increase. The excess is squeezed outward, forming an escape tube. The under-saturated gel then forms druzy quartz crystals in the remaining void.

I see several problems with this theory. First is the problem of moving a gel through weathering volcanic ash to the lava beds. Because of its viscosity, surface tension would not be overcome within the ash to where it would move. Second, although carefully selected examples will appear to support the theory, most agates do not display critical features. For example, the disrupted banding shown as an illustration of the expelling of fluid from the void is a rare feature. If it was a basic part of the formation of the agates, it should occur in all of them. Also, many agates are filled with bands all the way to the center. In these examples, where is the druzy quartz that supposedly forms from depleted gel? Where is the evidence of fluid being forced out of the remaining void?

One particular kind of agate could not have formed from a gel filling a void, and that is the cave agates. I have two examples of cave agates that form as stalactites in caves. My two examples are Lysite Agate from Wyoming and Cathedral Agate from Mexico. Stalactites have also been observed in nodu1ar agates.

The occurrence of flat banding (called geopedal structure by sedimentary petrographers) inside of concentric banded agate is not explained by the theory. Geopedal structure is a feature recognized by those who study the fabric of sedimentary rocks and the origin of their features as evidence of water standing in the bottom of an open void. The bands form as a response to the level plane of the earth’s gravity, just as in lakes or ponds. Robert Colburn, in his book, “The Formation of Thundereggs,” shows an example (Figure 0.10, page 22) where the flat bands start in one orientation, then a second set of flat bands are deposited at an angle to the first set. The explanation on the photo reads, “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 emplaced. Note the broken shell fragments (breccia) at the bottom of’ the opal layers and the dried mud curls at the top.” Shell fragments in this quote do not refer to organic shells but to shell shaped fragments. Above the flat layers the void was filled by concentric banding. This example illustrates that the silica was emplaced in numerous episodes with drying occurring between each entry of silica. “The Formation of Thundereggs” is only available on CD ROM from the author.

Next month, Part Two of this discussion will concentrate on my view of how banded agates formed and on the so-called “sedimentary agates.”

THE ORIGIN OF BANDED AGATES

Robert G. Welch

Part Two

It is my belief that all banded agates are formed by a process called diagenesis. Diagenesis is a geologic term meaning changed from its original form after deposition. For example, a basaltic lava flow cools after deposition and as it cools, it shrinks. This causes shrinkage cracks, much like the ones formed in drying mud. This is the first stage of diagenesis. Rain falls on the lava dissolving minerals from it and deposits new minerals as cement, coatings or crystals in the cracks and voids, thus altering the composition of the lava. This is diagenesis resulting from sub aerial exposure. If the lava lays exposed for a period of time with nothing being deposited on top of it, the minerals formed will usually be deposits like calcite, aragonite, zeolite, hematite or limonite formed by the weathering of minerals in the lava bed itself. I have in my collection a hematite "plume" from the Woodward Ranch in Brewster County, Texas that was present in an otherwise empty void. If agate had later been deposited around it, it would have been a red plume agate.

Lava flows may be exposed for many years before volcanic ash or another lava flow is deposited on top of it. If another flow is deposited, then this flow will be barren of agate. If the next event is volcanic ash, then the scene is set for the formation of agate. When rain falls on the ash, the minerals are weathered, releasing free silica as colloids. As each rain soaks through the ash it picks up increasing amounts of silica, which drains into the cracks in the lava. When the cracks intersect a vesicle, the fluid slowly spreads into it, held to the walls by surface tension. If too much comes in at one time, it puddles in the bottom of the vesicle, forming flat bands.

Each vesicle in the lava is a separate diagenetic environment. What happens to the vesicle is related to many factors. If the vesicle is not intercepted by a fracture, it may remain empty. The size and orientation of the intersecting fracture can effect the amount and pattern of filling. Vesicles with no exit fractures would be prone to flat banding. Small fractures or fractures not at vertical angle could cause less material to come into the voids. Position in the lava could effect whether small rain events reached the void. Separate voids can have variations in the chemical environment resulting in a different colors in adjoining agates. Variation within the agate can be due to differing rainfall, changing vegetation above, renewed ash falls and other factors.

From the Jurassic to the present extensive volcanism was occurring in what is now the western United States and Mexico. Many of these events culminated in the ejection of huge amounts of volcanic ash that were carried by winds across the entire continent. Ash from the two most recent major events in Wyoming and New Mexico can still be found buried in valleys along some streams. Geochemistry and radiometric dating can identify both the age and source of these ash falls. The White River Formation of South Dakota that preserved a large fauna of Oligocene land animals was formed from a similar event.

The vagaries of wind deposited large amounts of ash in some localities and little or none in other nearby localities.

Agates have been found in limestones across the country from Montana and Wyoming to Kentucky, Tennessee, West Virginia and states in between. They are found in limestones ranging in age from Pennsylvanian to Ordovician. These deposits all have two things in common: (1) They have been weathered and voids formed by solution and (2) the agates only occur in the weathered rocks near the present surface. Pabian and Zarins refer to these agates as sedimentary agates and postulate that they were deposited with or shortly after the limestone from silica gels formed from siliceous fossils or volcanic ash.

A good example of this type of agate are the Teepee Canyon and Fairhills Agates found in place in the Minnelusa Formation of Pennsylvanian age. The Pennsylvanian was a time of many sea level changes, causing the shallow shelf to be alternately inundated and exposed. The Minnelusa Formation was deposited in a shallow shelf environment, which alternated between very shallow sea and "sabka" conditions. A sabka is a relatively flat lying area that is inundated at high tide but is land at low tide. In the nearby Powder River Basin the Minnelusa produces oil from Aeolian sand dunes, which often grade into anhydrite (CaSO4). Interbedded limestones also contain vugs filled with anhydrite. The vugs developed during times of exposure in wet periods with the anhydrite being initially deposited in the vugs as gypsum (CaSO4·H2O) and then converted to anhydrite after burial.

During the Tertiary Period (65 million years to present) the Black Hills were uplifted into a large dome. This folding fractured and exposed the rocks to weathering and erosion. As weathering progressed the fractures in the Minnelusa Formation were enlarged by solution and the anhydrite converted to gypsum and was dissolved out, leaving small to intermediate size cavities. This system differs in important ways to from the volcanic system. The limestones are initially more porous than lava and they can be dissolved by rainfall, allowing infiltration into the host rock itself as well as along the fractures. There is also no base to the infiltration as is the case in individual lava beds. In limestone the water passes on through and is drained to springs and caves. This is the reason that flat (geopedal) banding is absent in agates formed in limestone.

During the time of exposure and erosion, extensive volcanism was occurring nearby in what was to become Yellowstone National Park and to the west. This volcanism periodically dumped thick blankets of volcanic ash on the Black Hills. Many altered ash beds occur in the Tertiary sediments surrounding the Black Hills. As the ash weathered, silica seeped slowly down into the voids. At first it soaked into the limestone walls of the cavities replacing the limestone and altering it to chert. This replacement occurred as convex fronts spreading out from the center to form round to oval nodules. As the walls became less porous the silica began to be deposited as spherulitic crystal bands typical of banded agates. Smaller voids with small openings into them filled completely. Changes in color dominance within the agate are due to changes in the composition of impurities and their concentration. This would occur naturally as weathering progresses in changing climate conditions with wet period and dry periods and their resultant changes in vegetation.

Roger Clark in his excellent book "Fairburn Agate Gem of South Dakota" has many excellent photographs of Fairburn Agate along with Teepee Canyon and Fairhills Agate. Fairburn Agates were eroded from the Minnelusa Formation and re-deposited in Tertiary sediments, particularly the Chadron Formation. Of particular interest are illustrations of slabs of a single Teepee Canyon nodule on pages 47-50. Being a Geologist my first impression of this nodule was that it displays typical karst structure. Karst structure develops by solution and collapse in limestones related to cave formation. It appears that after a long period of low rainfall, which deposited red and orange bands, there was a major rainfall event. This event caused water to surge through the developing agate ripping partially lithofied fragments from the walls and fracturing of some of the remaining wall structure. The jumble of irregular elongate pieces leaves the impression of "floating fragments" when the rock is slabbed. After this disruption a new phase of agate deposition filled the rest of the cavity with white to clear agate.

Why don't I think these agates were formed in the Pennsylvanian Period when the limestone was deposited? To begin with, the different agate colors are due to different minerals as illustrated by Roger Clark on page 62 of his book. If these agates formed from a silica gel deposited with the limestone, all of the bands should be the same basic color. Instead they contain minerals of different compositions. Some were even deposited in varying chemical environments.

There is no evidence of volcanism during the Des Moinesian Epoch of the Pennsylvanian Period in this region. There is therefore no source of silica to form agates. Even creatures using silica in their bodies do not become abundant enough to be the source unless they have a good source of silica in their water. A mechanism for dissolving this organic silica and re-depositing it as silica gel would need to be found before this could be considered as a source

In conclusion, the evidence available fits an interpretation that agates form by a process of diagenesis in pre-existing rocks. They form above the water table where drying can occur between influxes of silica. A silica source that will release large amounts of silica at one time is required. This source can only be finely divided volcanic ash from basic igneous sources.