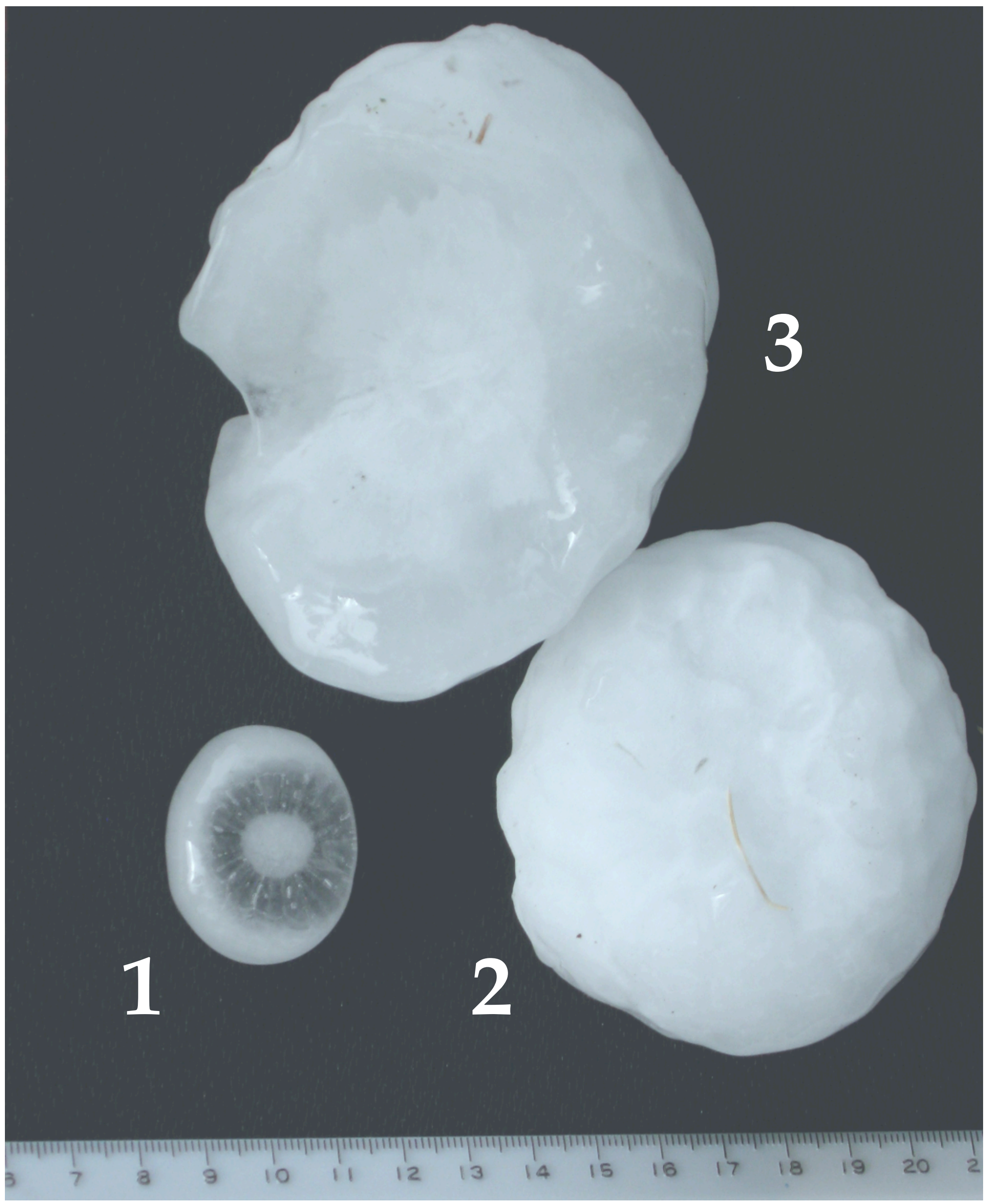
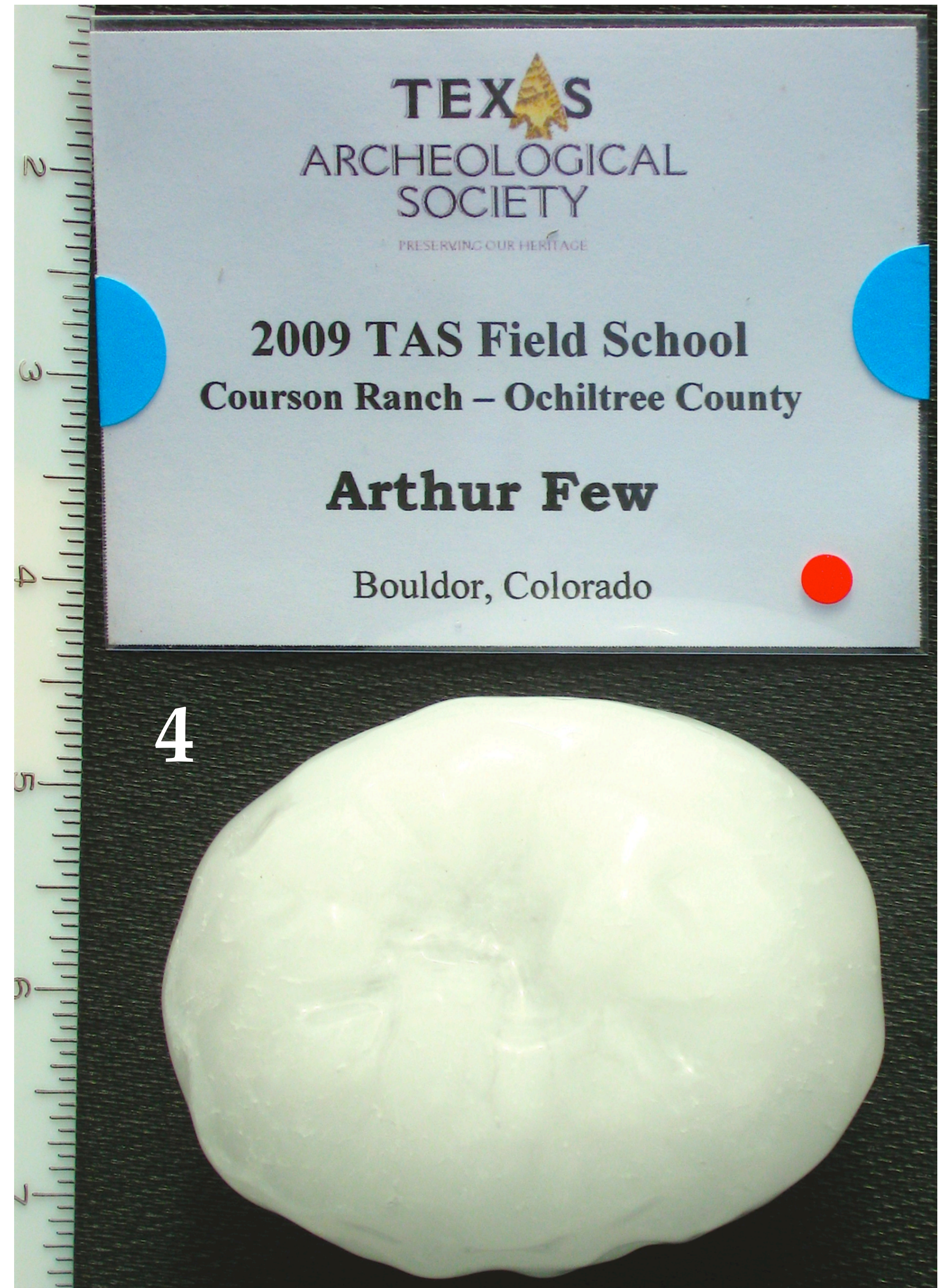
Hailstones - Tracing Their History

The hailstones on this and subsequent pages were collected by Arthur Few ~3 p.m. CDT June 15, 2009, at Wolf Creek County Park, which is ~10 miles south of Perryton Tx in the north east corner of the Texas panhandle. The hailstorm started with pea size hail then progressed through marble, golfball to baseball. As the storm subsided I ran outside and collected 6 hailstones of a variety of sizes and shapes and stored them in the freezer of our RV. A second hailstorm occurred ~5 p.m. that same day with maximum hailstones of quarter size. These photos were taken on the following morning.





1. In general, the larger the hailstone the faster it falls with respect to the air; a very fast updraft can support (levitate) a very large hailstone relative to the ground.

2. The lumpy surface of hailstones is produced by the larger hailstones aggregating smaller hailstones and ice that are moving more slowly in the updraft.

3. When the hailstones fall below the freezing level they will collect water and slowly melt; this melting is accelerated when they land. The melting smooths the surface and gives it shinny appearance.

4. Large hailstones are rarely spherical; as they fall in the updraft, hydrodynamic forces will rotate the hailstone so that its broadest surface is perpendicular to the air velocity and on the bottom. Aggregation will enhance the asymmetry as the larger hailstone will collect smaller hailstones and ice preferentially on the bottom and sides.

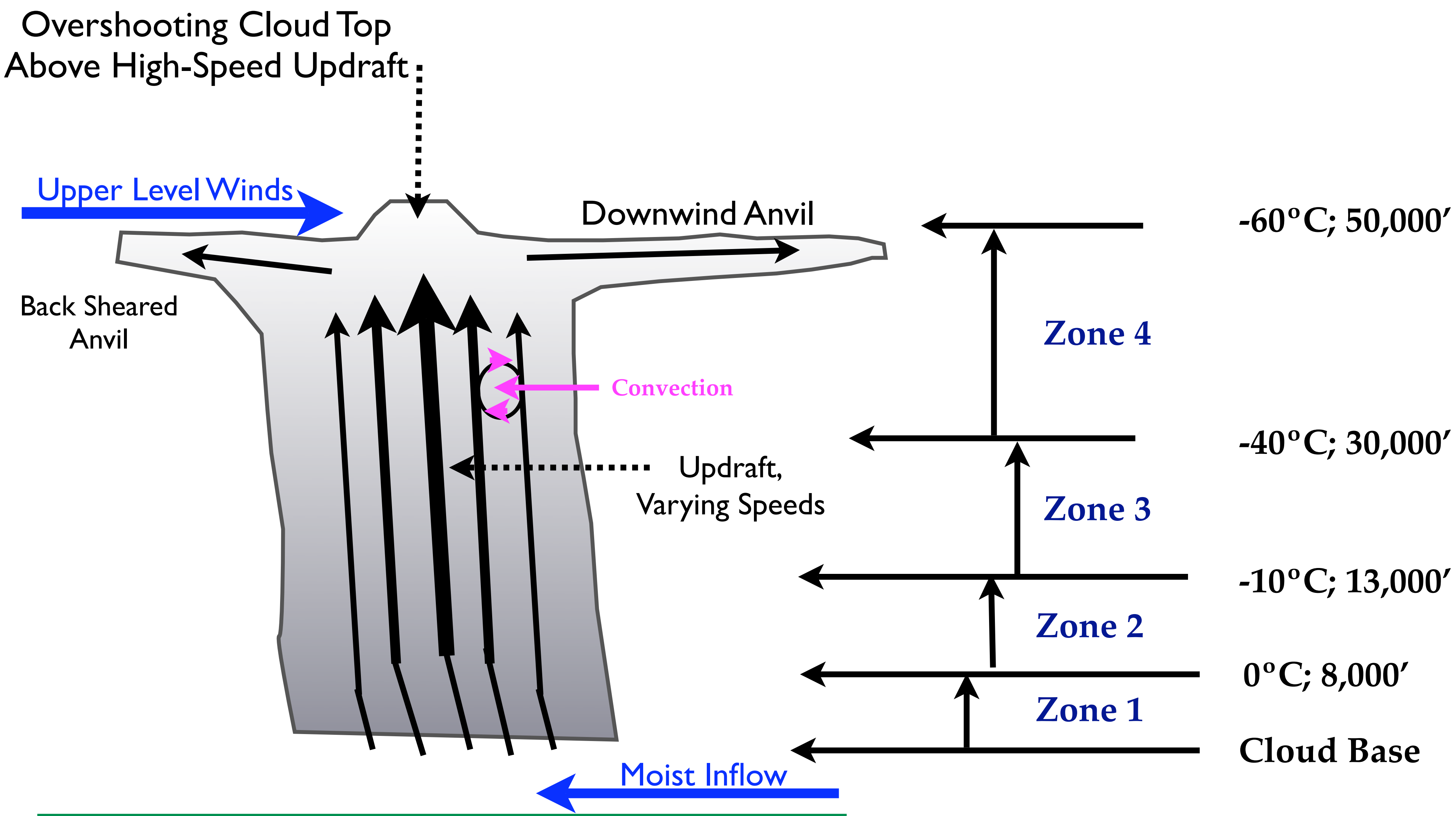
Hailstone #1: The smallest hailstone fell earlier than the others and has experienced considerable melting. Its longest dimension is 3.7 cm; it has a smooth shinny surface. We are able to see inside the hailstone and identify the core (initial hailstone), a clear region of wet growth, and a partial exterior coating of aggregated ice.

Hailstone #2: This moderate size hailstone is the closest one to spherical in shape, but even here the length (8.2 cm) to width (7.5 cm) ratio is 1.1.

Hailstone #3: This hailstone (maximum length 20.8 cm) is somewhat smooth and shinny; it was damaged on impact. I used this hailstone to make a thin section through the center; this will be shown and discussed later.

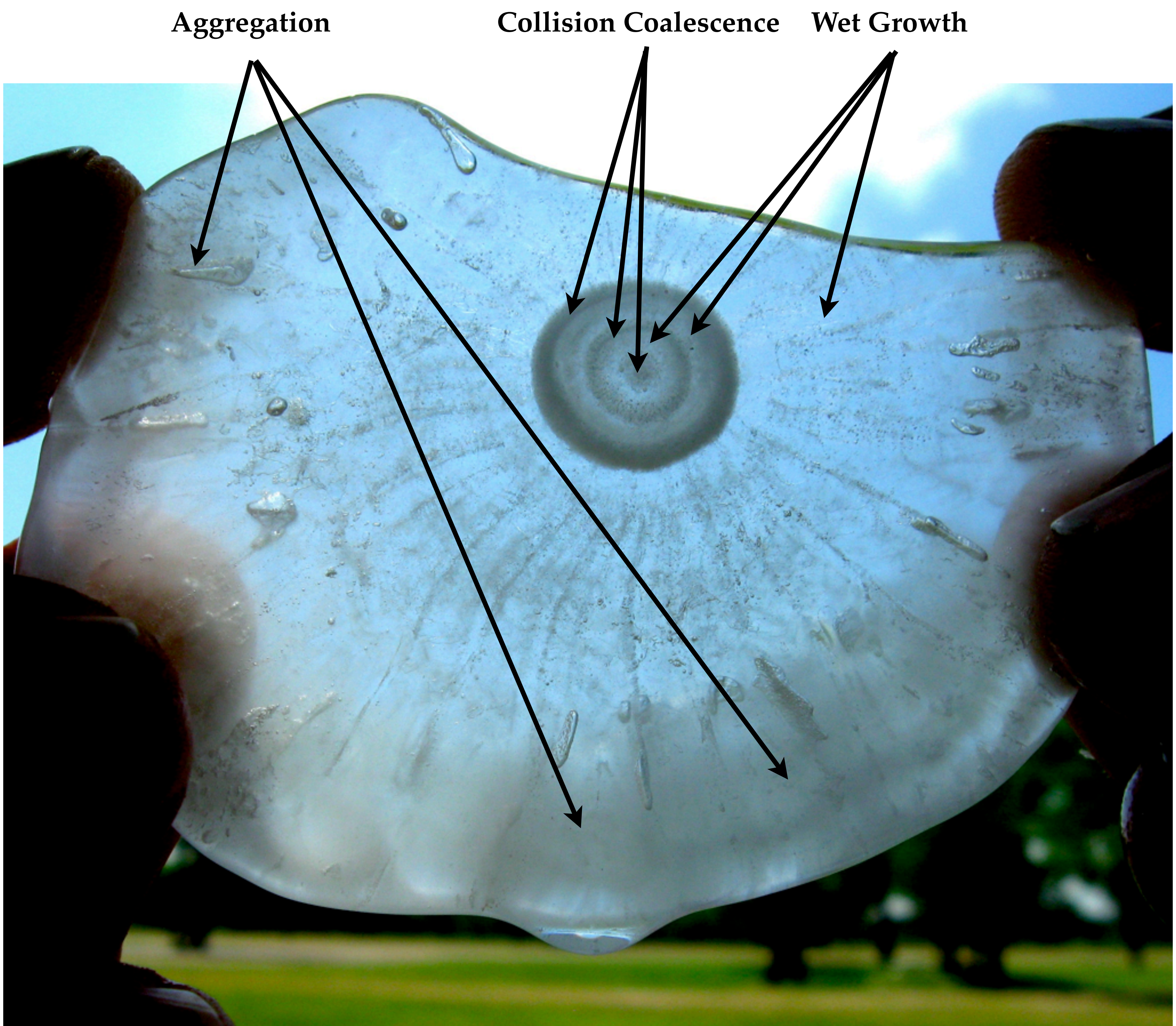
Hailstone #4: This is one of the larger intact hailstone collected (3.5″ by 2.9″ or 8.9 cm by 7.4 cm). The smooth surface indicates melting.

Simplified Hailstorm



Zone 1	[Supersaturated, small cloud droplets]	Very small cloud droplets form on cloud condensation nuclei and grow by condensation of water vapor; this requires supersaturation (humidity greater than 100%). The maximum diameter approaches 20 microns.
Zone 2	[Supersaturated, supercooled, small cloud droplets and ice]	The supercooled (T < 0°C) droplets will freeze upon contact with an ice nuclei; ice growth by vapor deposition proceeds faster than water droplet growth by condensation. Ice can actually steal water from water droplets.
Zone 3	[Supersaturated, supercooled, droplets & ice mixed]	Cloud particle growth is predominately by collision and coalescence; ice contacting water droplets will grow fastest. Electrification occurs in this zone. Near the top of this zone all remaining water droplets will spontaneously freeze.
Zone 4	[Supersaturated, all ice]	Glaciated (all ice); all growth is by collision and coalescence. If during collision an ice particle breaks, then the pieces become independent growing ice particles; this process is ice multiplication, and it produces the fuzzy appearance of the tops of tall clouds.

This is hailstone #3; I have created a thin section (~1 cm) through the center of the hailstone by melting the bottom and top on a hot griddle. In this photo the thin section is backlit by the sky. We can see details of the structure of the hailstone and something of its complex history.



A possible history of hailstone #3

We need to understand two processes before interpreting the hailstone #3 thin section photograph.

Phase-change thermodynamics. **When we freeze water we must extract energy from the water; this energy is called heat of fusion and is equal to 3.34×10^{5} Jkg^{-1}. When a hailstone contacts a supercooled water droplet, the droplet freezes, but the hailstone must extract (accept) the heat of fusion. If the hailstone is passing through a zone of high water content the "freezing" of water droplets will warm the surface of the hailstone eventually reaching 0°C. The liquid water on the external surface of the hailstone will refreeze in the cold cloud air producing a clear ice called wet growth. Another consequence of freezing of any kind is that the release of the heat of fusion warms the air and accelerates the updraft; the more ice the greater the wind speeds and the severity of the storm.**

Convection and lateral motions. **In the presence of updraft shear (faster in the center compared to the edges) convection eddies develop; this allows lateral motions of cloud particles out of and into high speed updraft. From the hailstone's point of view the updraft speed is changing whether by storm dynamic processes or lateral motion; the only relevant parameters are the local updraft speed and the hailstone weight.**

At the very center of the thin section of #3 there is a dark "seed" grown in Zone 2 starting with the freezing of a supercooled water droplet and grown by condensation and collision coalescence. Surrounding the seed is a shell of clear ice also grown in Zone 2 but by wet growth. Next there is a dark shell of ice produced by collision coalescence and aggregation with ice particles; this shell was most likely produced in lower Zone 3. The next shell is clear ice produced by wet growth probably also in Zone 3. Completing the hailstone "kernel" is a final dark shell grown by aggregation in Zone 4.

Now to complete the hailstone growth it must move downward in the cloud; the hailstone is now heavier, the updraft speed near the top of the cloud decreases as the air flow spreads out horizontally, and the decrease in air density with height decreases its ability to support particles. The hailstone starts descending; moving into Zone 3, where an extensive shell of wet growth occurs indicating that the hailstone was in the Zone 3 environment for a relatively long time. (The updraft speed was increasing while the hailstone was growing.) In lower Zone 3 and upper Zone 2 the hailstone encounters numerous developing hailstone kernels, which collide and aggregate with #3 forming the outside lumpy shell. Note that the lumpy structures are approximately the same size as the #3 kernel. Passing through Zone 1 and the air below the cloud the hailstone experiences partial melting of the outer shell.

As noted previously the large hailstones become asymmetric in the final aggregation process because they fall with the bottom always facing into the updraft. They collect cloud particles (hail, ice, droplets) on the bottom and sides with few reaching the center of the top. Examine hailstones #2, #3 and #4 on the first page; they were all photographed from the top. Note that there is a depression in the center where no small hailstones attached. We can use this depression, which is free of the aggregated ice, to look inside the hailstone. The two hailstones below have not appeared previously; they are similar in size to #4.

In these photographs they are backlit by the sky; we are viewing them from the top and the depressions extend inward into the outer wet growth shell. Looking through the depressions we can see the kernel in the center. The aggregation shell on the bottom scatters the light and illuminates the kernel.

Hailstone #5

Hailstone #6