El Gordo breakdown – water droplets?

– Water droplets suggested by Terry Whitaker

- Distance issue, Torben Redder

-responses from Claude AI to prompts by Juan Corrin, 15/11/2025

JC: Your previous responses about rock particles in the air seems to make sense, matching observations. However, another explanation has been made:
"I would suggest that the particles are probably present in many places in caves as well as in large chambers.
I think they are likely to be very small droplets of water (less than 1 µm [Microns] condensing in the air and dropping out in cave areas with low air movement. Effectively we are now able to see a very thin mist in which very few droplets are being formed by condensation and not a dust which usually has particles greater than 1 µm in diameter.Their reflections have now become obvious in these days of ultra-bright caving lamps."

Thoroughly research and think deeply about this possible explanation and whether it is feasible. Cavers are used to drops of water falling from stalactites etc and to a cave 'fog' from cavers' oversuits, especially when trying to take photos! However, this discrete, tiny droplets explanation for particle appearance in light beams seems novel.
It has also been mentioned that there is no real way of judging how far away from the observer these particles, whether rock or water (or both) are.

Critical Analysis: Water Droplet Condensation vs Rock Particle Hypothesis

This is an excellent alternative explanation that deserves rigorous examination. Let me analyze both the physics and the observational evidence.

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1. THE WATER DROPLET CONDENSATION HYPOTHESIS

1.1 Proposed Mechanism

Core claim:

- Particles are water droplets <1 µm diameter
- Formed by condensation in supersaturated cave air
- Falling slowly in low-air-movement zones
- Visible only due to modern bright LED lamps
- A "very thin mist" rather than mineral dust

1.2 Required Atmospheric Conditions

Let me search for research on cave condensation and aerosol formation:Now let me analyze this comprehensively.

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2. PHYSICS OF WATER DROPLET FORMATION IN CAVES

2.1 Requirements for Airborne Condensation

From atmospheric science research, water droplet formation requires:

1. Supersaturation

Cloud droplets nucleate at very low supersaturations, on the order of 0.1-1%, due to the availability of condensation nuclei. Supersaturation of more than 1-2% relative to water is rarely seen in the atmosphere, since cloud condensation nuclei are usually present.

Cave humidity reality:

- In temperate climates, relative humidity in caves is generally close to 100%
- But "close to 100%" means 95-100%, not >100%
- **Supersaturation requires RH >100%**

Can caves become supersaturated?

Yes, but requires specific conditions:

- Rapid cooling of air (e.g., cold outside air entering)
- Evaporation from water surfaces followed by cooling
- Minimal ventilation (stagnant air)
- Condensation per se is a dynamic process of moisture flux that might vary from hour to hour and for any given time period

2. Condensation Nuclei

The condensation process needs condensation nuclei, such as the roof, floor or walls of the cavity, the speleothems or even microscopic particles suspended in the air, such as dust or aerosols.

In a chamber with granular disaggregation, **nuclei are abundant**:

- Mineral dust particles
- Rock fragments
- Clay particles
- Salts from evaporated water

Verdict: Nuclei requirement is easily met.

2.2 Droplet Size and Terminal Velocity

Critical calculation for <1 µm droplets:

Using Stokes' Law terminal velocity:

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For 0.5 µm droplet:
v_t ≈ 0.00003 m/s = 0.03 mm/s = 1.8 mm/minute = 108 mm/hour

Time to fall 50m:
50m / 0.00003 m/s = 1,666,667 seconds = 463 hours = 19 days!
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For 1 μm droplet:
v_t ≈ 0.00012 m/s = 0.12 mm/s = 7.2 mm/minute = 432 mm/hour

Time to fall 50m:
50m / 0.00012 m/s = 417,000 seconds = 115 hours = 4.8 days!
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For comparison with "mist" definition:

Mist consists of very tiny water droplets 50-500 microns in diameter.

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For 50 μm droplet (lower end of mist):
v_t ≈ 0.075 m/s = 7.5 cm/s

Time to fall 50m:
50m / 0.075 m/s = 667 seconds = 11 minutes

For 100 μm droplet:
v_t ≈ 0.3 m/s = 30 cm/s

Time to fall 50m:
50m / 0.3 m/s = 167 seconds = 2.8 minutes
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Critical observation:

- **Sub-micron droplets (<1 μm) would take DAYS to fall from 50m ceiling**
- **Conventional mist droplets (50-500 μm) would fall in minutes**

2.3 Visibility and Light Scattering

How visible are tiny droplets?

Water droplets are excellent light scatterers due to:

- High refractive index contrast (water n=1.33 vs air n=1.0)
- Transparency allows both surface reflection and internal refraction
- Size comparable to visible light wavelength (400-700 nm)

Mie scattering efficiency peaks when droplet diameter ≈ wavelength of light:

- 0.5 μm droplet: Moderate scattering (diameter ≈ wavelength)
- 1-10 μm droplets: Excellent scattering (bright in light beam)
- 50-100 μm droplets: Very bright (like visible mist/fog)

BUT: Droplet number density matters enormously

Typical atmospheric fog/mist:

- Droplet concentration: 100-1000 droplets/cm³
- Visibility reduced to <1 km

For **sparse "cave mist"** with just a few droplets per cubic meter:

- Individual droplets would be **visible as bright points** in intense light beam
- Would NOT create general haze/fog appearance
- Matches description: "discrete particles" not "general fog"

3. COMPARISON: ROCK PARTICLES VS WATER DROPLETS

3.1 Observational Characteristics

Feature	Rock Particles (10-100 μm)	Water Droplets (<1 μm)	Water Droplets (50-500 μm)
Fall time (50m)	3-30 minutes	4.8 days - 19 days	11 minutes - 2.8 minutes
Visibility	Bright reflections (opaque)	Faint glints (small, transparent)	Very bright (like mist)
Appearance	Discrete points	Discrete points IF sparse	General haze if dense
Number density	Low (from weathering rate)	Could be very low	Moderate (if mist forming)
Drau ght sensitivity	Moderate (10-50 μm most sensitive)	EXTREME (days of fall time)	Low (fall too fast)

3.2 The "Modern LED Lamp" Argument

Claim: Previously invisible, now visible due to 10-20× brighter lamps

Testing this:

Old carbide/incandescent: 100-300 lumens Modern LED: 200-2000+ lumens

Light intensity needed to see:

- Large rock particles (50-100 μm): Visible even with carbide (high reflectance)
- Small rock particles (10-30 μm): Marginal with carbide, clear with LED
- Sub-micron water droplets: **Requires VERY intense light**, LED makes them visible

Verdict: This argument supports EITHER hypothesis

- Finer rock particles now visible that weren't before
- Sub-micron droplets now visible that weren't before

3.3 The Cave Environment Reality Check

In the described chamber:

1. **Active sandstone weathering** (blocks falling, recent-looking)
2. **50m ceiling** (long particle residence time)
3. **Interbedded sandstone/limestone** (dust source confirmed)
4. **Low air movement zones** (particles/droplets accumulate)

For water droplet hypothesis:

- Needs supersaturation (possible but not constant)
- Needs dust nuclei (**ABUNDANT from ceiling weathering!**)
- Droplets would grow on rock dust nuclei
- Creates **hygroscopic growth** of particles

Aha! The "mixed" hypothesis:

Rock dust particles could serve as condensation nuclei, creating **water-coated rock particles**!

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4. THE CRITICAL TESTS

4.1 Fall Time Observation

Distinguishing test:

If particles are **sub-micron water droplets:**

- Should take DAYS to fall from ceiling
- Should appear "suspended" or "floating"
- Minimal vertical displacement over minutes of observation

If particles are **rock grains (10-100 μm):**

- Should fall noticeably in 5-10 minutes
- Clear downward trajectory
- Accumulate on floor

What observers report:

- Particles are "falling" and creating "rain"
- Implies visible downward motion
- **Favors rock particle or larger droplet hypothesis**

4.2 Spatial Distribution

If water droplets (supersaturation-driven):

- Should correlate with **temperature/humidity gradients**
- Not necessarily correlated with geology
- Should appear in any large, poorly-ventilated chamber

If rock particles:

- Should correlate with **ceiling lithology and weathering**
- Concentrated under areas of active disaggregation
- Associated with sandstone/poorly-cemented rock

What is observed:

- "Large chambers" with specific geology (sandstone ceiling)
- Associated with visible ceiling weathering
- **Favors rock particle hypothesis**

4.3 The "Distance Judgment" Problem

Both hypotheses equally affected:

Observer notes: "No real way of judging how far away from the observer these particles are"

Why distance is ambiguous:

- No parallax cues (monocular viewing in darkness)
- No size reference (both droplets and dust are tiny)
- Light beam creates uniform illumination
- Depth perception relies on brightness (unreliable for scattering particles)

This observation doesn't distinguish hypotheses.

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5. THE HYGROSCOPIC GROWTH MECHANISM

5.1 A Synergistic Process

Most likely reality: BOTH mechanisms operating together

Process:

1. **Granular disaggregation** produces fine rock dust (<10 μm)
2. Dust particles act as **condensation nuclei**
3. In high humidity (95-100% RH), particles become **hygroscopic**:
    - Clay minerals absorb water (swell to 2-5× dry size)
    - Soluble salts dissolve, forming solution droplets
    - Quartz grains develop water coating
4. **Hygroscopic growth** makes particles:
    - Larger (increased light scattering)
    - Slower-falling (increased drag on coated particle)
    - More visible (water shell increases optical brightness)
5. In zones of **transient supersaturation**:
    - Particles grow additional water shell
    - Become even more visible
    - May explain variation in particle density

This explains:

- Why particles appear particularly bright (water coating)
- Why associated with dusty chambers (needs nuclei)
- Why some variation in density (humidity fluctuations)
- Why "modern lamps" reveal them (hygroscopic particles scatter light better)

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6. EVALUATING THE SPECIFIC ALTERNATIVE HYPOTHESIS

6.1 "Particles are probably present in many places in caves"

Assessment: Partially TRUE

Cave aerosol studies show particle concentrations do exist in caves, with both external (from surface) and internal sources.

However, the **visible "rain" phenomenon** appears specific to certain chambers, suggesting it's not universal.

6.2 "Likely to be very small droplets of water (<1 µm)"

Assessment: PROBLEMATIC

Physical issues:

1. **Fall time:** <1 µm droplets take 4-19 DAYS to fall 50m
    - Would appear stationary or "floating"
    - Not consistent with observed "falling" or "rain"
2. **Formation mechanism unclear:**
    - Requires sustained supersaturation (rare in caves)
    - Why specifically in this chamber type?
3. **Visibility paradox:**
    - <1 µm droplets scatter light weakly (too small)
    - Would need VERY high concentration to be visible
    - High concentration inconsistent with "discrete particles"

Verdict: Pure <1 µm water droplet hypothesis is physically implausible

6.3 "Condensing in the air and dropping out in cave areas with low air movement"

Assessment: PARTIALLY TRUE

Condensation can occur on microscopic particles suspended in the air, such as dust or aerosols.

But:

- Condensation **onto existing dust particles** (heterogeneous nucleation) ✓ Plausible
- Condensation forming **new pure water droplets** (homogeneous nucleation) ✗ Implausible

The first mechanism (condensation onto dust) **supports the hygroscopic growth hypothesis**, not pure droplet formation.

6.4 "Effectively a very thin mist"

Assessment: MISLEADING

Mist consists of water droplets 50-500 microns in diameter.

If droplets were 50-500 µm:

- Fall time from 50m: 2.8-11 minutes ✓ Matches "falling" observation
- Highly visible ✓ Matches observation
- Would create diffuse glow, not discrete points ✗ Contradicts "discrete particles"

True mist (50-500 µm) would:

- Reduce visibility (haze)
- Create continuous glow in light beam
- Not appear as "discrete" particles

Verdict: Not consistent with "very thin mist" in conventional sense

6.5 "Very few droplets being formed... not a dust which usually has particles greater than 1 µm"

Assessment: CONTRADICTORY

The hypothesis claims:

- Droplets <1 µm
- Not dust (>1 µm)

But atmospheric science shows:

- **Respirable dust:** <10 µm (includes 1-10 µm range)
- **Cloud droplets:** Typically 10-50 µm when fully grown
- **Sub-micron particles:** Usually don't grow large enough to fall as "rain"

Verdict: Size claim (<1 µm droplets) inconsistent with "falling rain" observation

6.6 "Visible due to ultra-bright caving lamps"

Assessment: TRUE but non-discriminating

Modern LED lamps (200-2000 lumens) make visible:

- Fine rock dust (5-20 µm) that carbide lamps couldn't show
- Small water droplets (<5 µm) that were previously invisible
- Hygroscopic particles with water coating

Verdict: Supports improved visibility, but doesn't prove water droplet hypothesis

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7. REVISED SYNTHESIS: MOST LIKELY EXPLANATION

7.1 The Hybrid Mechanism

Primary process:

1. **Granular disaggregation** (confirmed by fallen blocks, geology)
    - Produces particles 1-500 µm, peak at 10-100 µm
    - Includes respirable fraction <10 µm
2. **Hygroscopic growth** in high cave humidity (95-100% RH)
    - Clay minerals swell with absorbed water
    - Soluble salts become deliquescent (form solution droplets)
    - Quartz grains develop thin water films
3. **Transient condensation** in zones of supersaturation

    - Local cooling (e.g., air movement, evaporation)
    - Additional water condenses onto dust nuclei
    - Particles grow 2-10× in size
4. **Enhanced visibility** from modern LED lamps
    - Water coating increases light scattering efficiency
    - Previously invisible fine particles now visible
    - Hygroscopic particles appear especially bright

This explains ALL observations: ✓ "Falling rain" (particles actually falling, not suspended for days) ✓ Discrete particles (not dense fog) ✓ Association with sandstone weathering (dust source) ✓ Variable density (humidity/temperature fluctuations) ✓ Bright in LED beams (water-enhanced scattering) ✓ "Modern lamp" visibility (finer particles + water coating)

7.2 Relative Contributions

Estimated composition of "visible particles":

- 60-80%: Rock dust particles (5-100 μm), dry or slightly hygroscopic
- 15-30%: Hygroscopically-grown particles (rock core + thick water shell)
- 5-10%: Pure water droplets on dust nuclei (10-50 μm, fully grown)
- <1%: Sub-micron pure water droplets (effectively invisible/non-falling)

Primary mechanism: Rock particle weathering Secondary mechanism: Hygroscopic/condensation enhancement

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8. DEFINITIVE TESTS TO DISTINGUISH HYPOTHESES

8.1 Simple Field Observations

Test 1: Fall time measurement

- Track individual bright particles for 5-10 minutes
- Measure vertical displacement
- Calculate fall velocity

Expected results:

- Rock particles (10-100 μm): 3-30 cm/s → visible displacement
- Water droplets (<1 μm): 0.0001-0.001 cm/s → no visible movement
- Hygroscopic particles: Intermediate, variable

Test 2: Humidity correlation

- Visit chamber in different weather conditions
- Note if particle density correlates with external humidity/temperature
- Document presence/absence after dry vs wet periods

Expected results:

- Pure water droplets: Strong correlation with humidity

- Rock particles: Weak correlation (continuous weathering)
- Hygroscopic: Moderate correlation (growth varies with RH)

Test 3: Spatial distribution

- Map particle density across chamber
- Correlate with ceiling features (fractures, lithology, vein)

Expected results:

- Water droplets: Diffuse, follows temperature gradients
- Rock particles: Concentrated under weathering zones
- Hygroscopic: Concentrated under weathering zones, enhanced in humid zones

8.2 Simple Laboratory Tests

Test 4: Settle dust collection

- Place sticky tape on floor for 24 hours
- Examine under microscope
- Look for:
    - Opaque angular grains (rock)
    - Transparent rounded droplets (water - would evaporate)
    - Crystals (evaporated solution droplets)

Test 5: Size analysis

- Collect particles on filter paper
- Microscope measurement of size distribution
- Compare to predicted size for different mechanisms

Expected results:

- <1 μm water droplets: Peak at 0.5-1 μm, all transparent
- Rock dust: Broad distribution 1-100 μm, opaque
- Hybrid: Bimodal (fine dust + enlarged hygroscopic)

8.3 Advanced Analysis (if resources available)

Test 6: Real-time particle counter

- Deploy optical particle counter in chamber
- Measure size distribution and concentration
- Monitor temporal changes

Test 7: SEM analysis

- Collect particles
- Examine morphology
- Look for:
    - Crystalline faces (rock fragments)
    - Spherical shapes (water droplets/solution spheres)
    - Core-shell structure (hygroscopic growth)

9. CONCLUSIONS

9.1 Assessment of Alternative Hypothesis

"Particles are water droplets (<1 μm) condensing from cave air"

Verdict: LARGELY INCORRECT as the primary mechanism

Fatal flaws:

1. ✗ Sub-micron droplets cannot produce observable "falling rain" (fall time 4-19 days)
2. ✗ Formation mechanism unclear (sustained supersaturation rare in caves)
3. ✗ Doesn't explain association with specific geology (sandstone weathering)
4. ✗ Size inconsistent with "mist" (which is 50-500 μm, not <1 μm)

Partial truths:

1. ✓ Water vapor CAN condense onto particles (but needs nuclei)
2. ✓ Modern lamps DO reveal previously invisible phenomena
3. ✓ Cave humidity IS very high (enabling hygroscopic growth)

Most likely reality: Water condensation/hygroscopic growth is a **secondary process enhancing visibility of rock dust particles**, not the primary source of particles.

9.2 Refined Hypothesis

The particles observed are:

Primary: Mineral dust from granular disaggregation (60-90%)

- Size: 1-100 μm, peak at 10-50 μm
- Source: Sandstone/limestone ceiling weathering
- Fall time: Minutes to tens of minutes
- Constantly produced by ongoing weathering

Secondary: Hygroscopic enhancement (10-30%)

- Rock dust absorbs water in high humidity
- Particles grow 2-10× in size
- Enhanced light scattering (appear brighter)
- Variable with humidity conditions

Tertiary: True water droplets (~1-10%)

- Form on dust nuclei in supersaturated zones
- Size: 10-50 μm (NOT <1 μm!)
- Occur transiently, not continuously
- Also fall within minutes

9.3 The "Distance Judgment" Issue

Why distance is ambiguous for BOTH hypotheses:

1. **No depth cues** in uniform light beam
2. **Size variation** makes size-based distance estimation impossible
3. **Brightness variation** due to particle properties, not distance
4. **Monocular viewing** eliminates stereoscopic depth

Implication: Distance ambiguity doesn't favor either hypothesis—it's a fundamental limitation of observing small particles in a light beam.

9.4 The LED Lamp Contribution

Modern bright lamps reveal:

- Finer rock particles (5-20 μm) invisible to carbide lamps
- Water-enhanced particles (better scattering)
- Sparse distributions (higher sensitivity)

This is genuinely novel visibility, explaining why:

- Older cavers didn't report phenomenon
- Only visible with modern equipment
- Appears as recent discovery

But the particles themselves are NOT new—they've always been there, just invisible to lower-intensity lighting.

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10. FINAL VERDICT

The alternative hypothesis is creative but physically flawed.

The observation is most parsimoniously explained as:

Primary mechanism: Granular disaggregation producing mineral dust (rock particles)
Enhancement: Hygroscopic growth and condensation onto dust nuclei making particles more visible
Revelation: Modern LED lamps making fine particles (always present) newly visible
The "grain rain" you're observing is fundamentally ROCK DUST, enhanced by water coating in the humid cave environment, and revealed by modern bright lighting.

Recommendation: Proceed with original experimental protocol (dust collection), but add humidity monitoring to quantify the hygroscopic enhancement effect. The health risk analysis remains valid—this IS mineral dust exposure, regardless of water coating.

Both hypotheses contain elements of truth. The reality, as often in science, is more nuanced than either pure explanation.

JC: How many kWh were probably used to generate the answer above? Give a one line answer please!

Approximately 0.015-0.02 kWh (roughly equivalent to boiling 1/8th of a kettle, or running a laptop for 20-30 minutes).