El Gordo breakdown

– responses from Claude AI to prompts by Juan Corrin, 3/11/2025

JC: In a very large cave chamber with a sandstone roof (50m above any cavers) in Cantabria, there appears to be a fine "rain" of particles which show up when the space is lit from certain angles. What could the particles be and what mechanism is causing this "precipitation"? Give some deep thought to this: sandstone composition, spalling, drying out, etc, etc.

This is a fascinating speleological phenomenon! Let me think through the possible mechanisms systematically.

Most Likely Explanation: Granular Disaggregation

The "rain" you're observing is almost certainly **slow, continuous detachment of individual sand grains or small grain clusters** from the sandstone ceiling. Here's the detailed mechanism:

Primary Causes:

1. Cement Bond Breakdown

- Sandstone consists of quartz grains held together by cementing materials (silica, calcite, clay minerals, or iron oxides)
- These cements are vulnerable to:
    - **Humidity cycling**: Sandstone absorbs moisture from humid air, then releases it when conditions dry. This expansion-contraction cycle progressively weakens cement bonds
    - **Salt crystallization**: Dissolved salts precipitate in pore spaces, creating mechanical stress that pushes grains apart
    - **Chemical dissolution**: Even weak acids (from CO_2 in cave air) can slowly dissolve carbonate or silicate cements

2. Environmental Changes from Cave Opening If this cave was relatively sealed before human exploration, opening it likely altered:

- Air circulation patterns (increased ventilation)
- Humidity equilibrium (possibly drying out)
- Temperature stability

These changes can trigger accelerated weathering of previously stable surfaces.

3. Stress Relief and Microcracking The 50m of overlying rock was removed by erosion, so the ceiling is in **tension**, not compression. This can cause:

- Microfractures parallel to the ceiling surface
- Gradual propagation of these cracks
- Release of individual grains or thin flakes

Why This Appears as Visible "Rain":

The particles are probably **10-100 micrometers** (fine sand to silt size), which:

- Fall slowly through air (terminal velocity of ~0.01-0.1 m/s)
- Create a **Tyndall effect** when illuminated (scattering light like dust in a sunbeam)
- Are only visible from angles where the light path passes through the falling particle column

The 50m Height Factor:

This is actually crucial to the phenomenon:

- Gives 8-80 minutes of fall time for the finest particles
- Creates a "column" of suspended grains constantly being replenished from above
- Makes the effect much more visible than in lower caves

Additional Contributing Factors:

Bioweathering: Microorganisms (bacteria, fungi, endolithic algae) colonizing the sandstone surface may produce organic acids that attack cements

Cyclic wetting: If there's any percolation from above, water moving through the porous sandstone can carry away fine particles or dissolved cement

Eolian redistribution: Air currents in the chamber may keep the finest particles aloft longer

What the Particles Likely Are:

- Primarily **quartz grains** (the main component of sandstone)
- Some **clay minerals** and cement fragments
- Possibly **silt-sized weathering products**

This phenomenon is actually a form of ongoing cave enlargement - you're witnessing the cave very slowly growing by granular disaggregation rather than the dissolution processes typical of limestone caves. The rate might be just a few grains per square meter per hour, but over millennia, this removes significant material.

Is this a newly explored cave, or has the phenomenon been observed for a long time? Changes in intensity could indicate whether cave opening triggered accelerated weathering.

Continued ...

JC: The chamber has been entered recently, but no enlargement of any entry route was required. The floor of the chamber is a jumble of sandstone blocks (some looking very recent) which have fallen from the roof.

Ah, this **dramatically changes the interpretation** - and raises significant safety concerns! The presence of recent-looking fallen blocks suggests you're witnessing an **active roof failure process**, not just gentle weathering. The fine particle "rain" may be a warning sign.

Revised Assessment: Progressive Roof Failure

The Particle Rain as a Failure Precursor

The fine particles are likely coming from:

1. Fracture Propagation Zones

- As the sandstone develops tensile fractures (the precursors to block detachment), the crack tips experience intense stress concentration
- This grinding action produces **rock flour** - fine powder that falls continuously
- You're essentially seeing the sandstone "failing in slow motion" around developing fracture networks

2. Exfoliation/Spalling

- Sandstone often fails by **thin plate detachment** parallel to the surface
- Before a plate falls, the developing separation plane sheds fine material
- The "rain" could be from multiple zones where plates are gradually separating

3. Stress-Relief Weathering

- The chamber void creates **tensile stress** in the ceiling (it wants to sag/separate)
- This opens grain boundaries and microfractures
- Grain-by-grain loss accelerates dramatically in these high-stress zones

Why Are Blocks Falling?

Several mechanisms likely working together:

Bedding Plane Failure

- Sandstone has horizontal bedding planes (original sediment layers)
- These are natural weakness planes with different cement strength
- Blocks fall when a bedding plane loses cohesion across a sufficient area

Cantilever/Beam Failure

- Large sandstone "beams" can form between fractures
- These fail under their own weight when they reach critical unsupported span
- The chamber's large size (needed for a 50m high ceiling) means potentially large unsupported spans

Undermining/Step-Wise Retreat

- Each block fall creates overhangs and stress concentrations
- The roof may be retreating upward through successive collapses

- The "recent looking" blocks suggest **active, ongoing failure**

The Cantabrian Context Matters:

Northern Spain's climate adds specific factors:

- **High humidity**: Cantabria is very wet (Atlantic climate), promoting:
  - Chemical weathering of cements
  - Clay mineral expansion/contraction
  - Biological activity weakening rock
- **Temperature variation**: Even mild seasonal changes cause:
  - Thermal expansion/contraction cycles
  - Condensation/evaporation affecting cement bonds
- **Percolation water**: If rainwater percolates through the sandstone:
  - It carries away dissolved cements
  - Increases pore pressure within the rock
  - Can "lubricate" bedding planes and fractures

The Critical Question: Is This Accelerating?

The fact that some blocks look "very recent" is concerning. Consider:

1. **Was the chamber naturally stable** until human entry changed air circulation/humidity?
2. **Is the void propagating upward** through progressive collapse? (This can accelerate as undermining increases stress on remaining ceiling)
3. **Is there a triggering event?** (Unusual rainfall, seismic activity, or simply reaching a critical stress threshold)

What the "Rain" Pattern Might Tell You:

- **Concentrated "rain" areas**: Likely zones of active fracture development - blocks may fall soon
- **Diffuse, uniform rain**: More general weathering, perhaps less immediately dangerous
- **Increasing density over time**: Would suggest accelerating failure
- **Variable with humidity/weather**: Indicates water-related weakening

Safety Implications:

This is a **Type 2 rockfall hazard** (progressive failure with precursor signs). The particle rain might provide warning, but:

- Block falls can occur with little immediate warning
- "Recent" blocks suggest the system is actively unstable
- A 50m fall would generate enormous impact forces

Professional cave assessment by someone with rock mechanics expertise would be prudent, especially if this cave sees regular visitor traffic.

Does the particle rain seem concentrated in specific areas, or is it relatively uniform across the chamber? And have you noticed any correlation with weather conditions or time since entry?