From Juan Corrin *to Claude AI Sonnet 4.6*, 4th June 2026

You are an expert speleologist, geologist and geomorphologist.
Online resources from the Matienzo Caves website:
https://matienzocaves.org.uk/descrip/2414.htm (now called Cueva Regolfo)
https://matienzocaves.org.uk/descrip/5461.htm (the original exploration showing a fault / crack with a short throw)
Cavers have recently been trying to extend site 2414 (Cueva Regolfo) downwards to link with Cueva del Torno (https://matienzocaves.org.uk/descrip/2366.htm) and / or Cueva de Riaño, part of the near-80km-long Four Valleys System, possibly finding new levels of development en-route.
The entry point is at the base of the depression (altitude 266m) into an 8m high vertical limestone cliff. The depression is entered down the opposite side over a jumble of boulders. A crawl in solid rock reaches a chamber with a further crawl to a 5m pitch which is where the jumbled mess is met (at about 250m altitude), apparently close to the line of the cliff extended downwards
The environment discovered appears to be a fault with solid limestone wall to the southwest (with the cliff above on the surface) and a mixed jumble of rocks (sand or limestone, from transit-van-sized down to gravel and mud). The explorers have had to carefully clear and stabilize rocks as they descended (to about 220m) through the chaos with occasional larger spaces surrounded by the faulted choss.
A shallow valley above feeds water (large volumes in flood) into the mess, appearing as inlet(s) in chamber 1 and cascading down through the choke.
They have also been able to explore a short route heading through the solid wall and another heading northeast into the disturbed area for about 13m. This suggests (to me) that the fault is at least 13m wide, possibly formed on a series of vertical cracks?
The passages in Cueva del Torno below run parallel with the fault SE to NW.
The geology map shows an "unconformity" running parallel to this supposed fault, about 40m to the southwest. This dashed line on the map is drawn starting at the end of a 719m-long West-East "easily distinguished" fault about 200m to the northwest of the 2414 cave. (No other contacts or faults are shown in the immediate area.)
The description for the facies to the southwest of the unconformity is (from Spanish): Bioclastic limestone with orbitolinas, Rhodophyceae, bars with cross bedding. Named: "Fm El Sardinero". Early Cretaceous / Late Albian
The description for the facies to the northeast of the unconformity is (from Spanish): Calcarenites, limestones with corals and rudists Named: "Fm Caliza de Ramales". Early Cretaceous / Early Albian - Late Albian.
Give me your comprehensive understanding of the above scenario, trying to analyse what type of fault has been entered, etc, etc.

Comprehensive Geological & Speleological Analysis: Cueva Regolfo (Site 2414) and the Fault System

1. The Physical Setting and Confirmed Observations

Site 2414 sits at 266m altitude in the Fresnedo area, described as "a prominent depression against a cliff." The cave is confirmed to be "developed on a fault" — the site description for 5461 explicitly notes "the short throw and orbitolina bed is clearly seen at the top of the short climb." This is a crucial datum: the **orbitolina bed** is the key stratigraphic marker horizon. Orbitolinae are conical foraminifera characteristic of the Early Cretaceous (Aptian–Albian), and a visible, displaced bed at the fault throw confirms this is a genuine fault plane — not merely a joint or fracture.

Cueva del Torno (2366) sits at 206m altitude, approximately 314m to the northeast of 2414 (comparing UTM coordinates), with 5,471m of surveyed passage. Critically, in the Canyon Extension description, explorers noted that the positioning of a high chamber "gives a strong indication that this could well be the bottom of the inlet from site 2414, although this is as yet unproven." That geological instinct from 2008 aligns directly with the current digging project.

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2. Fault Type and Structural Interpretation

The Primary Fault

Everything points toward a **normal fault with a downthrow to the northeast**. Here is the reasoning:

a) The orbitolina bed displacement ("short throw") — A visible, measurable offset of a named bed at the very top of the original climb in 5461 tells us unequivocally this is a dip-slip or oblique-slip fault, not a strike-slip (wrench) fault. The throw is described as "short," implying modest vertical displacement at this exposure — perhaps a few metres — but the subsurface geometry may be considerably more complex, with displacement potentially increasing at depth.

b) The cliff geometry — The 8m vertical limestone cliff at the entrance to the depression is itself almost certainly the **surface expression of the fault scarp** or a fault-controlled joint set. In the Cantabrian fold-and-thrust belt, normal faults associated with syn-sedimentary Albian extension, or later tensional reactivation, are common. The cliff forms the southwest wall of the depression.

c) The asymmetric fill — Inside the cave, explorers encounter solid limestone to the southwest (the upthrown block, which also forms the surface cliff) and chaotic, fractured, mixed fill to the northeast (the downthrown block). This asymmetry is the hallmark of a **fault breccia / fault gouge zone** on the hanging wall side, with the footwall remaining as coherent, competent limestone.

d) The depression itself — Elongated depressions aligned along fault traces are classic features of karstified fault zones. Water converges into these structural lows, which is exactly what is observed: a shallow valley above feeding large volumes of flood water directly into the fault zone.

The Fault Zone Width

The fact that explorers can penetrate **~13m horizontally into the disturbed northeastern zone** is highly significant. A 13m+ wide zone of chaotic breccia is not typical of a simple single-plane fault. This suggests one of two interpretations:

1. **A fault damage zone**: Major faults rarely slip on a single plane; they develop a central fault core (gouge/cataclasite, typically centimetres to ~1m wide) flanked by a **damage zone** of fractured, brecciated rock extending several to tens of metres into the wall rocks on both sides. A 13m penetration into disturbed ground is entirely consistent with being within the **hanging-wall damage zone** of a moderately-sized normal fault.
2. **A relay ramp or fault splay zone**: The disturbed material may reflect "a series of vertical cracks" — faults in mechanically layered carbonates rarely propagate as single planes but instead as **en-échelon arrays** of sub-parallel fractures. The 13m-wide chaotic zone could represent the aggregate width of several closely-spaced fault splays with intervening brecciated limestone. The 719m E–W fault to the northwest, ending precisely at the unconformity that runs parallel to the suspected fault, supports a model of **relay structures** — where one fault terminates and strain is transferred to another via a connecting ramp or splay zone.

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3. The Stratigraphic Context: The Unconformity and the Two Formations

This is where the geology becomes particularly revealing.

Fm El Sardinero (SW of unconformity) — Early Cretaceous / Late Albian

Bioclastic limestones with orbitolinas, rhodophyte algae (Rhodophyceae), and cross-bedded bars. This is a **shallow-marine carbonate platform facies** — high-energy shoals and bars, episodically agitated by currents, with red algae indicating well-lit, warm, shallow water. The orbitolinas confirm a Late Albian age at the top of this formation.

Fm Caliza de Ramales (NE of unconformity) — Early to Late Albian

Calcarenites with corals and rudists. This is a classic **Urgonian-type reef and bioherm facies** — the rudists (thick-shelled bivalves) were the reef-builders of the Cretaceous, replacing corals as the dominant carbonate factory. The Fm Caliza de Ramales is one of the major cave-forming limestones in Cantabria: massive, thick-bedded, relatively pure carbonate with good secondary porosity. This is almost certainly the rock mass hosting Cueva del Torno, the Four Valleys System, and the cave passages being dug toward.

The Unconformity — What Does It Mean?

An unconformity between these two formations running **parallel to the suspected fault** ~40m to the southwest is profoundly important:

- In the Cantabrian Basin, the Early–Mid Cretaceous was a period of **syn-rift extensional tectonics**. The Bay of Biscay was opening; normal faults controlled subsidence and differential sedimentation. The Fm Caliza de Ramales reef limestones were deposited in the

deeper, down-faulted basins and platform margins, while the Fm El Sardinero bioclastic facies represent the shallower, more agitated shelf.
- An unconformity between the two formations **running parallel to a fault** strongly suggests that the fault itself is a **syn-sedimentary growth fault** — active during the Albian — with the unconformity representing a stratigraphic hiatus on the upthrown (SW, footwall) block where deposition was intermittent or eroded, while continuous deeper-water deposition occurred on the downthrown (NE) block.
- **The fault predates the karstification.** It is a **structural inheritance** exploited by subsequent dissolutional processes. The fault plane and its associated fracture network created the enhanced permeability pathways that guided speleogenesis — explaining why Cueva del Torno's passages run **parallel to the fault SE–NW**: the cave is a product of preferential dissolution along the same structural grain.

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4. The 719m E–W Fault to the Northwest

The "easily distinguished" E–W fault, 719m long and terminating at the unconformity ~200m NW of site 2414, fits a classic structural model. In the Cantabrian fold belt:

- **NW–SE trending normal faults** (like the suspected fault at 2414) were the dominant syn-rift structures during Albian extension
- **E–W trending faults** are often **transfer faults** or **accommodation zones** that link segments of the main NW–SE fault system

The E–W fault terminating precisely at the unconformity/main fault intersection is consistent with it being a **transfer fault** that dies out as strain is transferred onto the main fault system. Its termination at the unconformity boundary is also consistent with differential movement: the unconformity represents the structural contact between the two fault blocks, and a perpendicular fault cannot propagate across that boundary without losing displacement.

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5. The Boulder Choke: Geological Origin

The "jumbled mess" of transit-van-sized blocks down to gravel and mud, through which explorers are carefully descending, most likely has a **compound origin**:

1. **Primary fault breccia**: The fault plane itself will have generated breccia during repeated seismic slip events over geological time. Angular to sub-angular clasts of both wall rock lithologies would be expected.
2. **Ceiling collapse and void migration**: As the phreatic and vadose cave system evolved below, dissolution of the fault breccia cement and disaggregation of fault gouge would cause progressive upward stoping — blocks falling from roof to floor, the void migrating upward until it reaches the surface depression. The depression itself is the surface expression of this **breakdown column or collapse doline**.
3. **Allogenic sediment input**: The water cascading in from the valley above brings sand, gravel, and mud from outside the system. The mixture of "sand or limestone" material is consistent with both autochthonous (locally-derived limestone) and allochthonous (surface-derived) sediment.
4. **The 5m pitch / ~250m altitude level**: This likely corresponds to a **palaeophreatic level** — a former water table — where dissolution was concentrated horizontally, creating the chamber.

The transition from solid passage to choke at this point may mark the contact zone between the competent footwall limestone and the fractured hanging-wall material.

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6. Hydrogeological Model

The water behaviour confirms a **vadose shaft / inlet system feeding a deeper phreatic network**:

- Surface water sinking in the depression → inlet(s) in Chamber 1 → cascading through the fault choke downward
- The strong draught observed consistently at the dig front (and noted as reversing on some occasions) confirms **connection to a larger, well-ventilated system below**, almost certainly the Four Valleys System
- The altitudinal relationship is telling: the cave entrance is at 266m, the current dig bottom is around 220m, and Cueva del Torno's entrance is at 206m — roughly 14m of altitude remains to be bridged between the current dig bottom and Torno's entrance level, entirely plausible within the chaotic fault zone

The Four Valleys System is well-documented as exhibiting **multiple horizontal development levels**, each reflecting a former valley floor and water table during stepwise Quaternary incision of the surrounding valleys. The altitude span from ~220m (current dig bottom) down to Torno level at 206m, and potentially further to Cueva de Riaño's lower passages, means the diggers could intersect more than one such palaeo-phreatic level as they descend — levels that may host significant undiscovered passage developed along the fault's strike, parallel to the known Torno passages but at different elevations. This inference rests on the known multi-level architecture of the Four Valleys System rather than any specific acoustic or physical evidence from within the 2414 dig itself.

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7. Why Passages in Cueva del Torno Run Parallel to the Fault

The Canyon Extension in Cueva del Torno, running to the northwest, ends only 50m from the "Road to Torno" in Cueva Riaño, and the whole northwestern limb of Torno trends NW–SE. This directional control reflects **speleogenesis along the fault's strike** — the most permeable pathway through the rock mass is the fault plane itself and the parallel fractures in its damage zone. Dissolution preferentially follows bedding planes and fault-parallel joints in the Fm Caliza de Ramales, creating the horizontal to sub-horizontal trunk passages that typify the Four Valleys System at that level.

The current dig is therefore approaching these passages **orthogonally from above** — descending vertically through the fault zone while the target passages run horizontally parallel to it. This is structurally coherent and encouraging for an eventual connection.

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8. Assessment of Fault Type: Summary Classification

Bringing all evidence together:

Feature	Interpretation
Displaced orbitolina bed	Confirms dip-slip fault displacement
SW footwall = solid limestone cliff	Normal fault, SW block upthrown
NE hanging wall = chaotic breccia	Fault damage zone / breccia zone
Surface depression aligned on fault	Collapse doline on fault trace
Parallel unconformity 40m SW	Syn-sedimentary growth fault, Albian age
E–W fault terminating at unconformity	Transfer / accommodation fault
SE–NW trending cave passages below	Speleogenesis along fault strike
Strong, reversing draught	Structural connection to deep phreatic system
13m+ wide disturbed zone	Fault damage zone or en-échelon splay array

The fault is most likely a NW–SE trending, SW [NE?]-dipping normal fault of syn-rift Albian age, reactivated or exploited by karstification during Neogene to Quaternary incision of the valley system. It is not a simple single-plane structure but a fault zone with a significant damage zone hosting the boulder choke. The unconformity to the southwest represents the original basin margin controlled by this fault during Cretaceous deposition.

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9. Prognosis for the Dig

The geology is genuinely encouraging:

- The fault is well-established and connection to Torno's Canyon system is structurally predicted
- The ~14m of altitude remaining between the current dig bottom and Torno's entrance level is well within reach
- The passages in Torno trending NW–SE parallel the fault — the explorers need to find where the fault zone intersects those passages, which could be at the Torno Canyon Extension or in parallel trunk passage not yet discovered
- The general multi-level architecture of the Four Valleys System raises the realistic possibility of intercepting palaeo-phreatic levels at intermediate altitudes between ~220m and ~206m, potentially hosting significant undiscovered passage developed along the fault's strike
- The short route found through the solid SW wall is significant: this suggests the fault plane itself may be locally traversable, offering escape from the chaotic breccia into competent rock where better-formed, potentially decorated passage may exist
- The site was dug on four occasions around Christmas 2025, with a strong outward draught noted on at least two trips — a reversing draught of this strength is one of the most reliable indicators of a substantial connected void system below

The cavers are almost certainly descending through one of the most structurally significant fault zones in the Matienzo karst — the boundary between two Albian reef systems that controlled both the sedimentary history and the subsequent speleological development of this entire sector of the Four Valleys System.